Engineering materials

Introduction

What is engineering materials?

- Engineering materials is a branch of science which deals with the study of existing materials, their properties, functions, uses and effects over different compositions and mixtures. It provides the reader a broad knowledge of materials over a wide range.

Types of materials

- Materials are classified as:

1. Metals
2. Non-metallic materials

Metals may be Ferrous or non ferrous however non-metallic materials may be synthetic or natural.

Metals

Metals are the materials which show the properties like hardness, opaque, shiny and has good electrical and thermal conductivity.

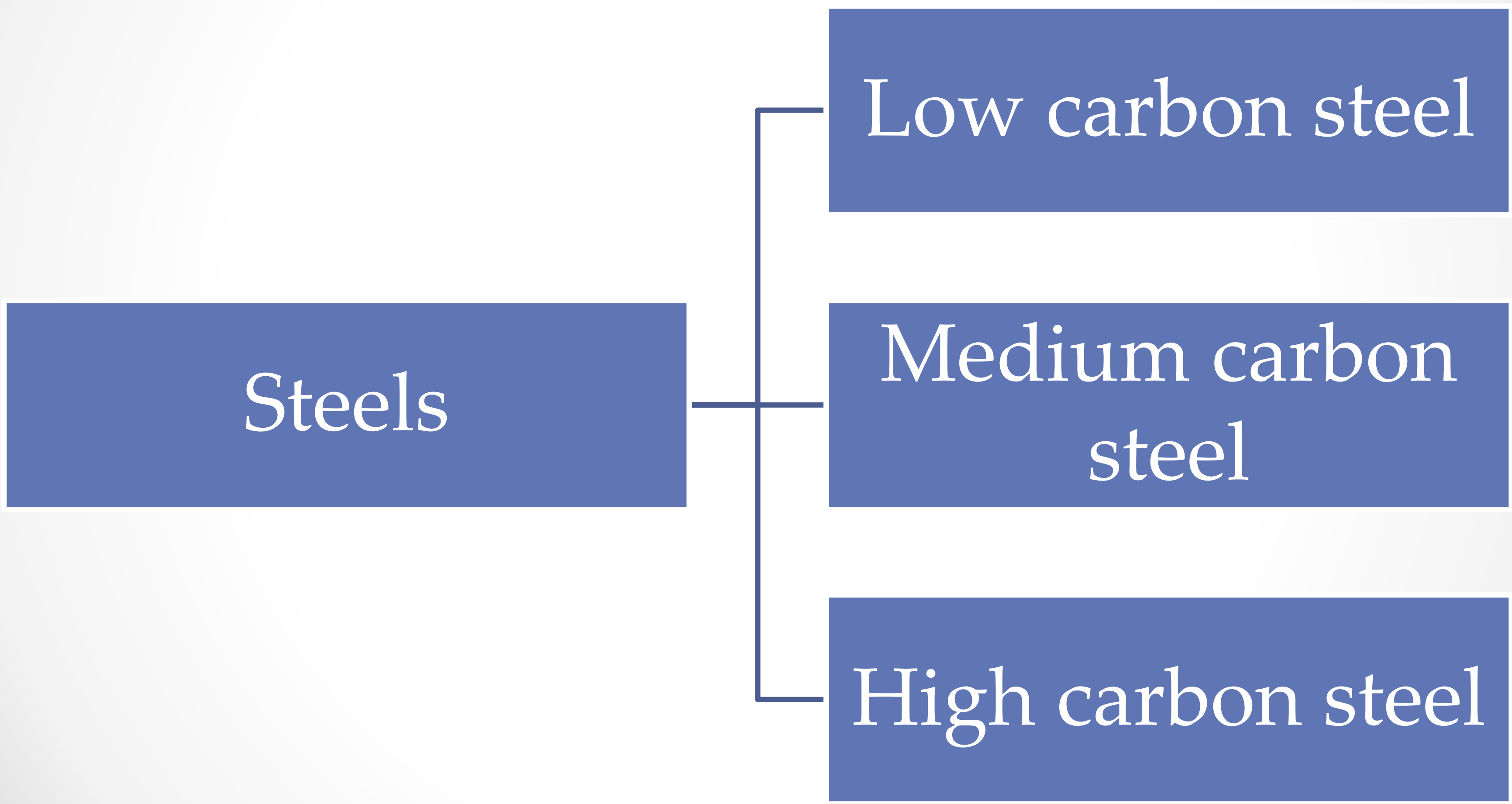
Metals

Ferrous materials

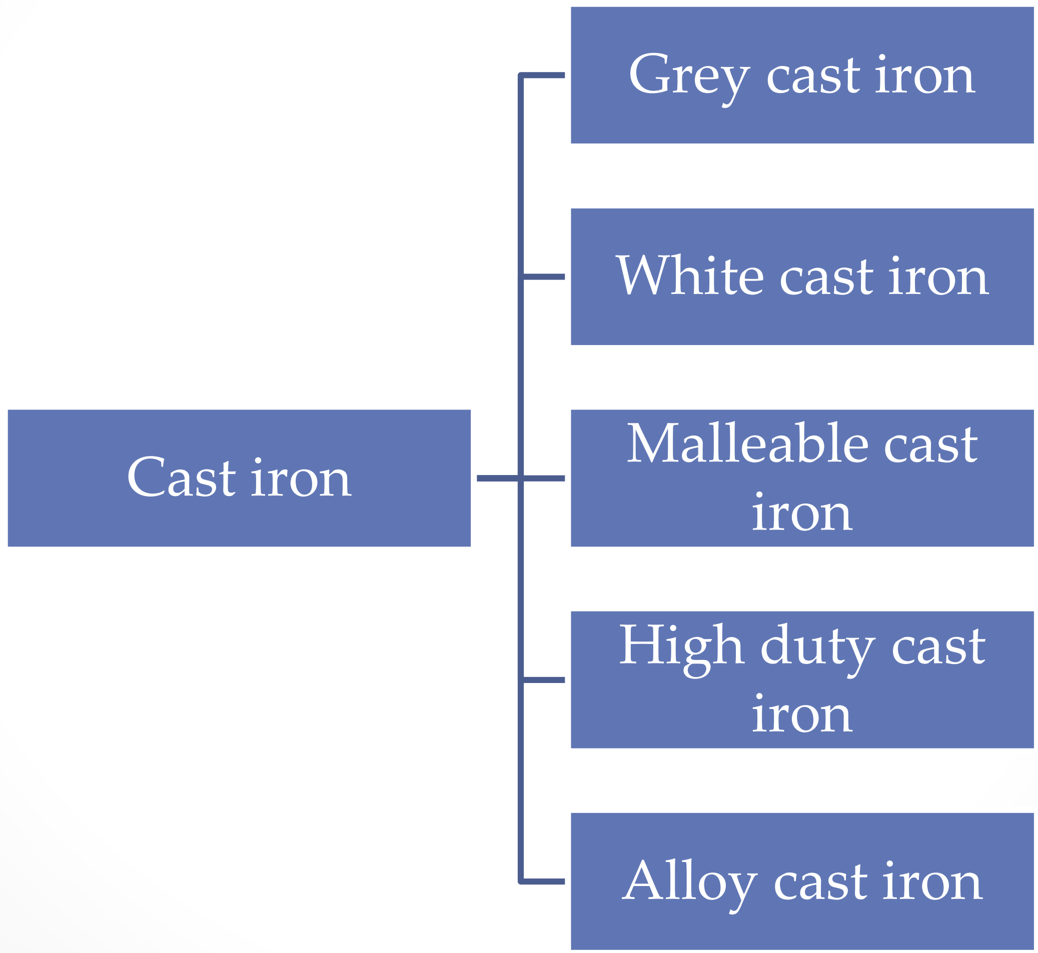
- Metals or alloys having high percentage of iron.
- These materials are used where high strength is required at relatively low cost.
- These materials are basically obtained from pig iron ore which after treatment gives three types of ferrous materials.

1. Steel
2. Cast iron
3. Wrought iron

Classification of steel



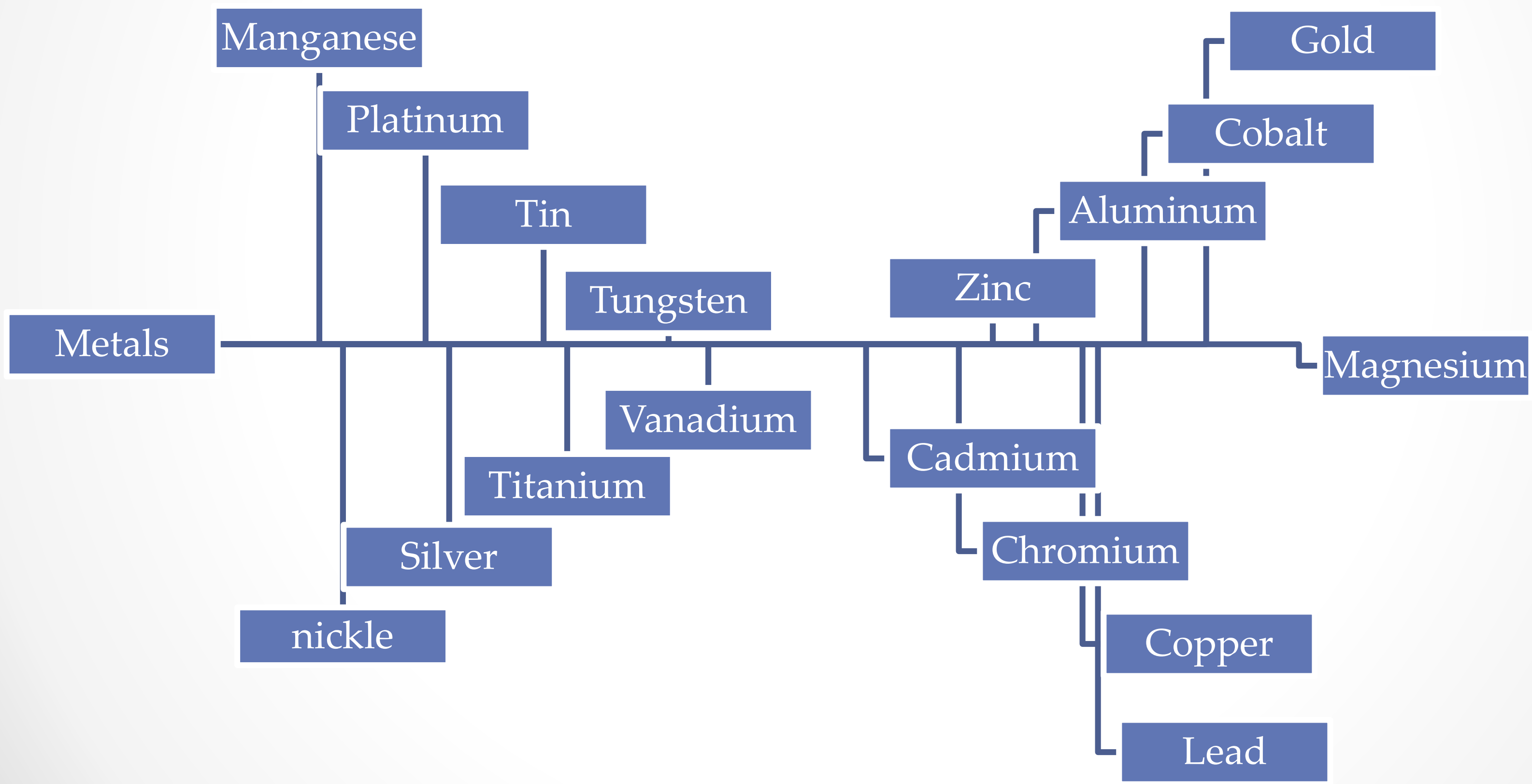
Classification of cast iron



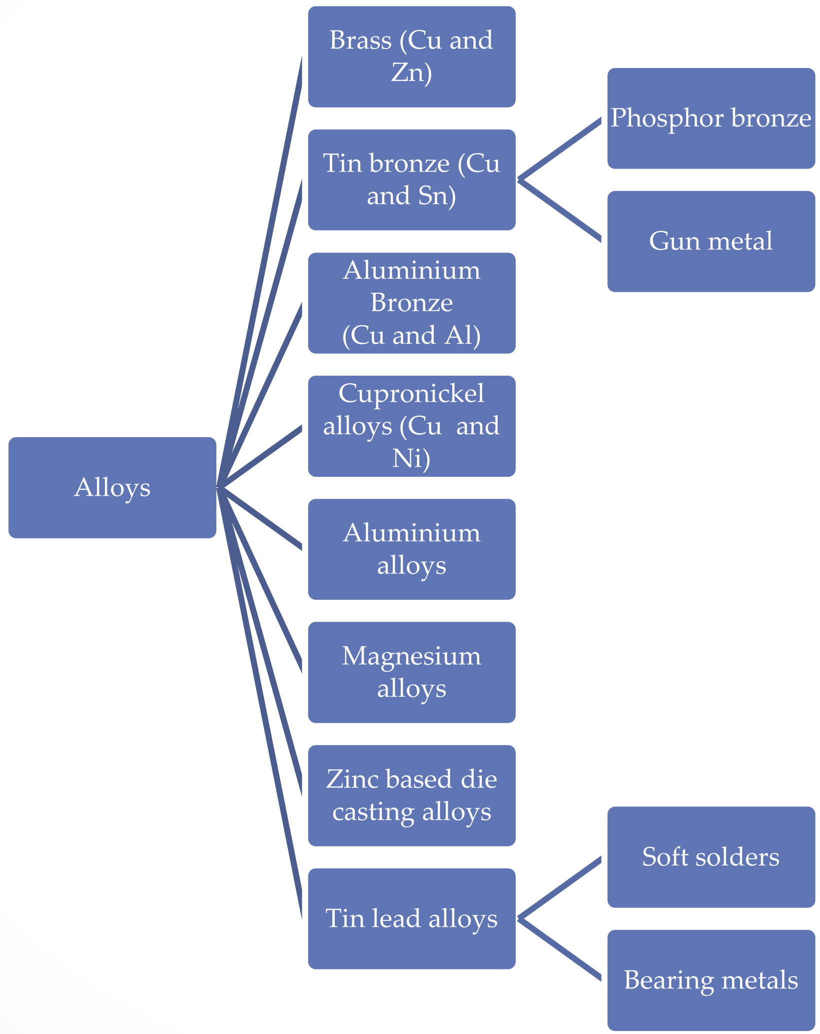
Non-ferrous materials

- Metals other than iron
- They are basically used in alloy form. In pure form, they are used with other materials in order to obtain a certain property like corrosion resistance, ductility, hardness etc.
- They are used with other metals in order to improve their strength.
- Non-ferrous materials may be metals other than iron or alloys.

Classification of non-ferrous metals



Classification of non-ferrous alloys



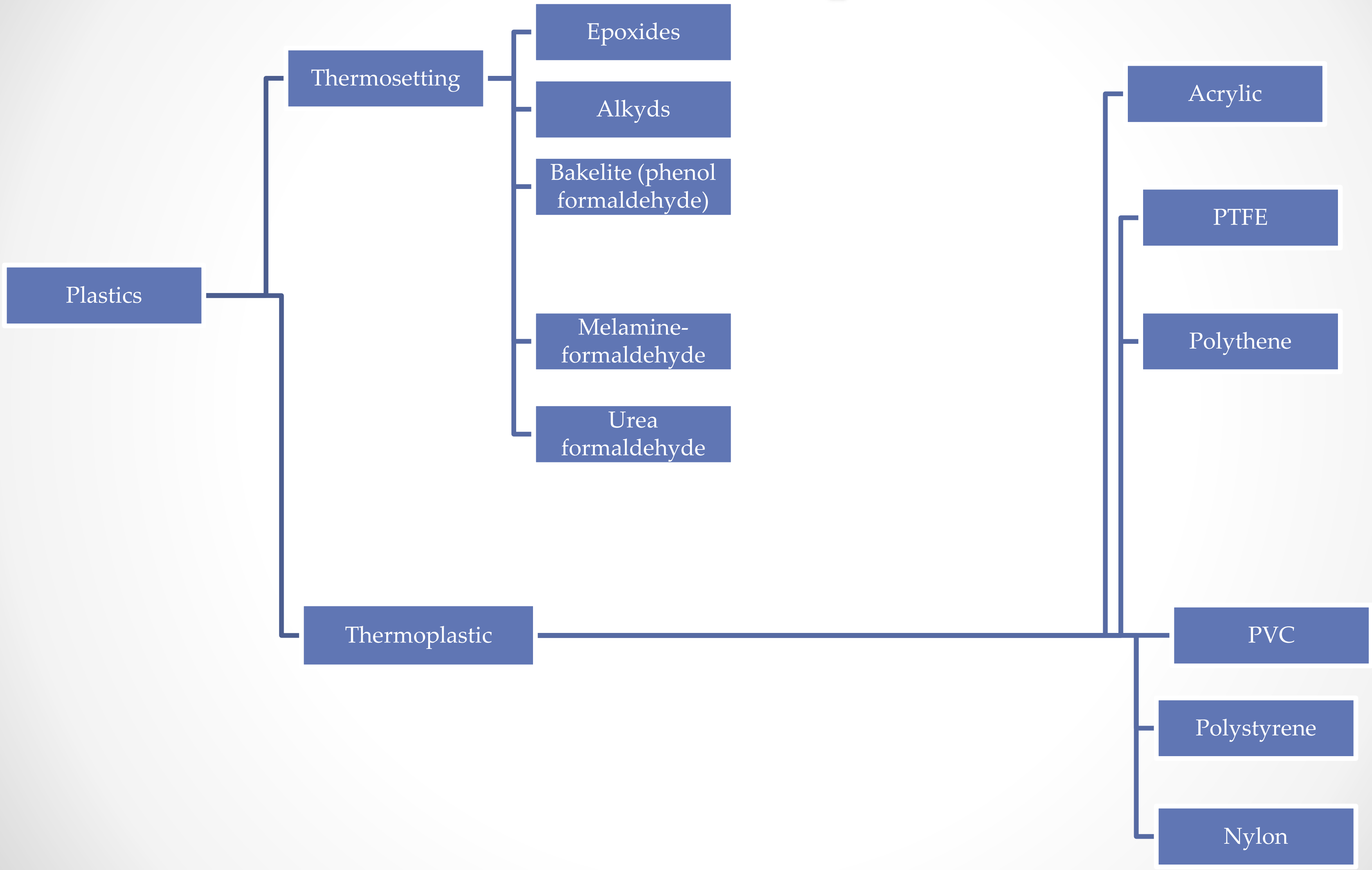
Non-metallic materials

Synthetic materials

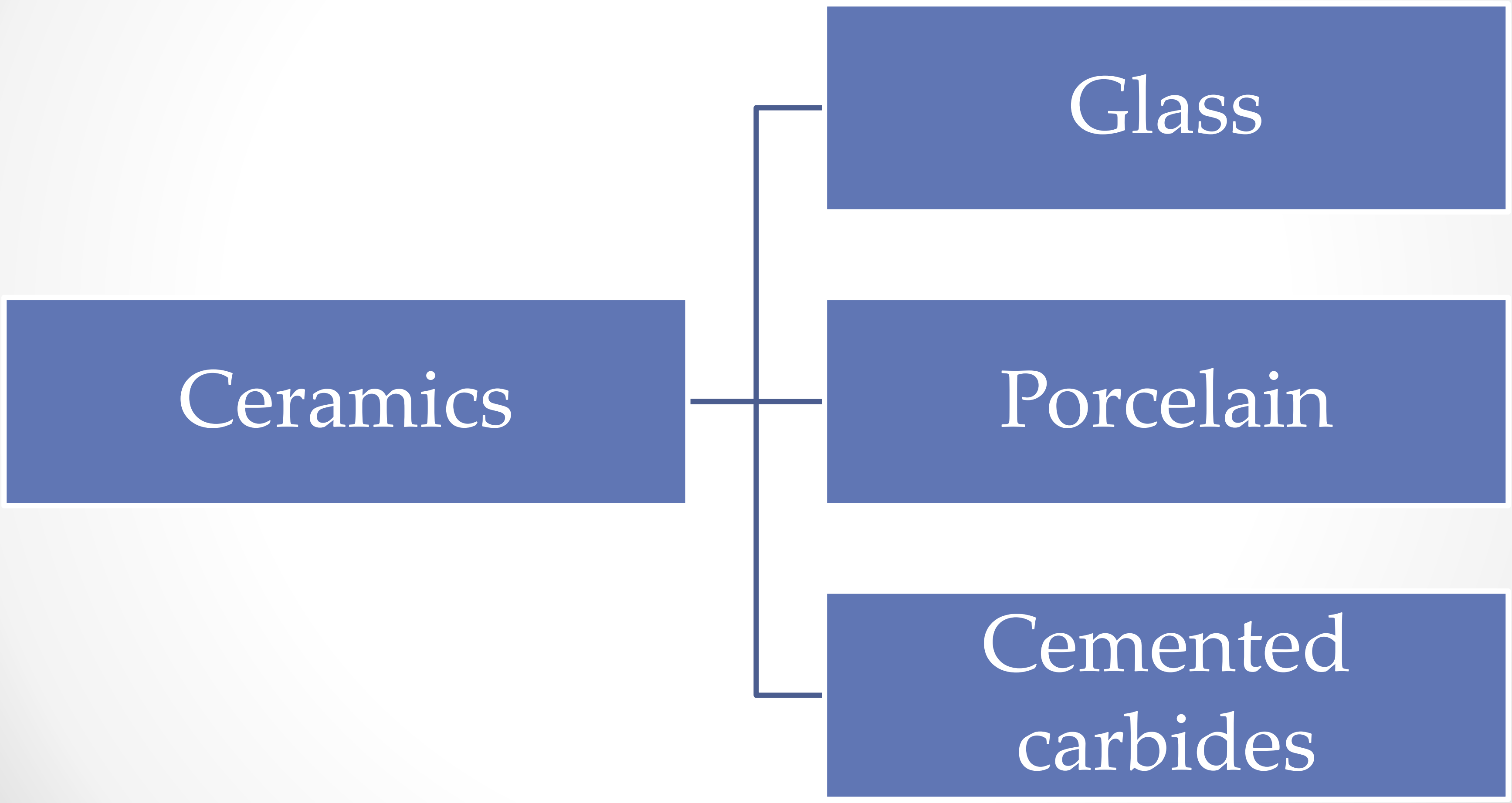
- These are non-metallic materials that do not exist in nature, although they are manufactured from nature substances like oils, coal etc. They may be in one of the following type:

1. Plastics
2. Ceramics
3. Composites

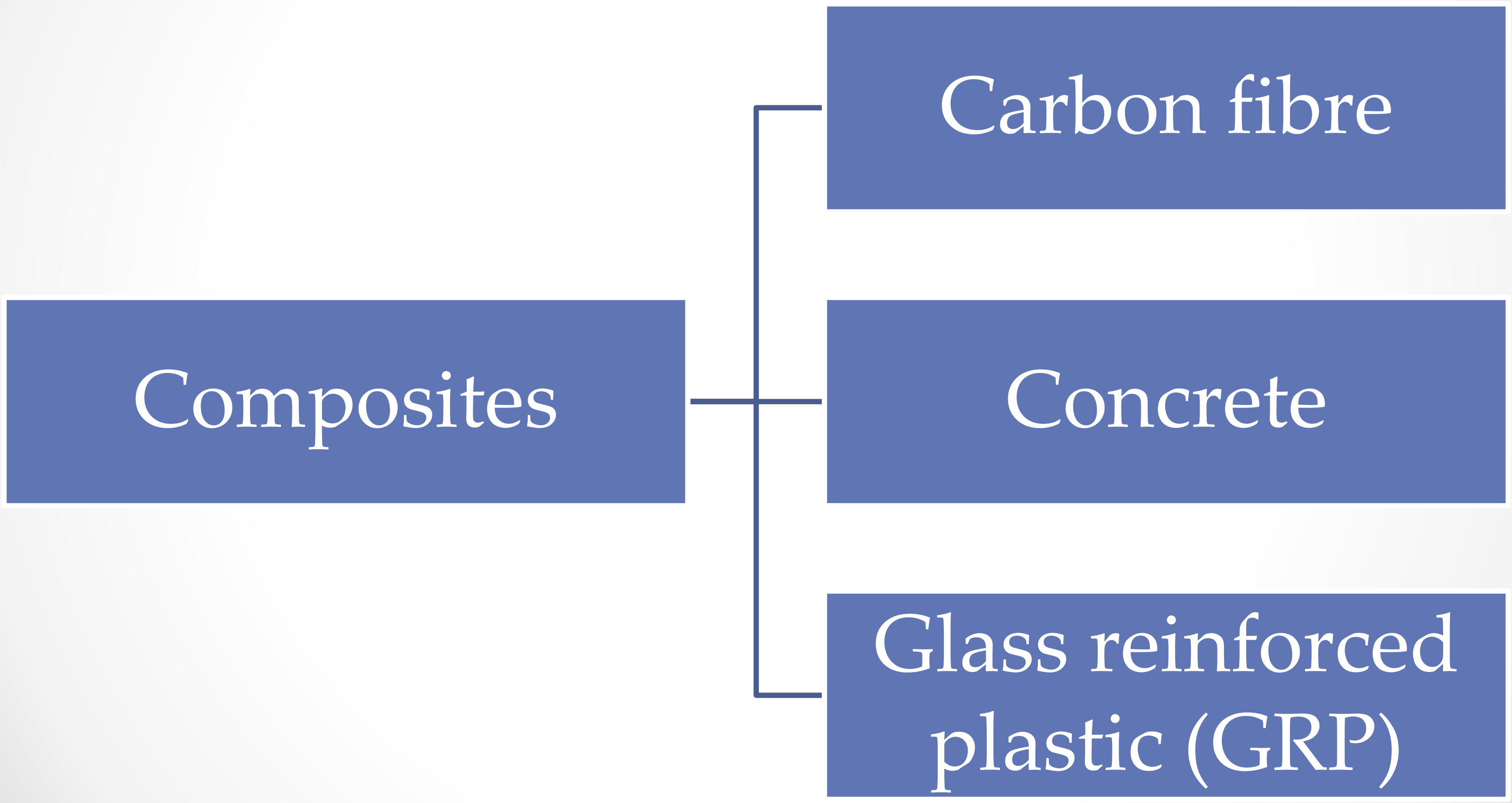
Classification of plastics



Classification of ceramics



Classification of composites



Natural non-metallic materials

- These occur naturally. Some of the natural materials are :

1. Wood
2. Rubber
3. Glass
4. Emery (naturally occurring aluminum oxide)
5. Ceramic
6. Diamonds
7. Oils
8. Silicon

Cement:

Cement is the mixture of calcareous, siliceous, argillaceous and other substances. Cement is used as a binding material in mortar, concrete, etc.

Chemical Composition of cement is:

Lime	63%
Silica	22%
Alumina	06%
Iron oxide	03%
Gypsum	01 to 04%

Suchismita Sahu, Asst. Professor
KIIT University

Bogue's Compounds

C3S & C2S PRVIDE STRENTH & OFFERS RESISTANCE TOWARDS THE

Name of Compound	Formula	Abbreviated Formula
Tricalcium silicate	3 CaO.SiO2	C3S –hydrates rapidly; provides early & ultimate strength
Dicalcium silicate	2 CaO.SiO2	C2S-hydraes slowly& provides strength after a duration of 7 days
Tricalcium aluminate	3 CaO.Al2O3	C3A-hydrates rapidly; provides early strength & less ultimate strength
Tetracalcium aluminoferrite	4 CaO.Al2O3.Fe2O3	C4AF-doesn't provide strength but is stable than C3A

TYPES OF CEMENT:

1. Ordinary Portland Cement
2. Rapid Hardening Cement (or) High Early Strength cement
3. Extra Rapid Hardening Cement
4. Sulphate Resisting Cement
5. Quick Setting Cement
6. Low Heat Cement
7. Portland Pozzolana Cement
8. Portland Slag Cement
9. High Alumina Cement
10. Air Entraining Cement
11. Supersulphated Cement
12. Masonry Cement
13. Expansive Cement
14. Colored Cement
15. White Cement

(1) ORDINARY PORTLAND CEMENT:

- It is called Portland cement because on hardening (setting) its colour resembles to rocks near Portland in England. It was first of all introduced in 1824 by Joseph Asp din, England.

- Most important type

- Classified into three grades, namely 33 grade, 43 grade and 53 grade.

Chemical Composition of O.P.Cement:

O.P.C has the following approximate chemical composition:

The major constituents are:

1. Lime	(CaO)	60- 63%
2. Silica	(SiO2)	17- 25%
3. Alumina	(Al2O3)	03- 08%

Chemical Composition of O.P.Cement: Continued-------

The auxiliary constituents are:

1. Iron oxide (Fe2O3) 0.5- 06%
2. Magnesia (MgO) 1.5- 03%
3. Sulphur Tri Oxide (SO3) 01- 02%
4. Gypsum 01 to 04%

Functions of Cement Manufacturing Constituents

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(i) Lime (CaO):

1. Lime forms nearly two-third (2/3) of the cement. Therefore sufficient quantity of the lime must be in the raw materials for the manufacturing of cement.
2. Its proportion has an important effect on the cement. Sufficient quantity of lime forms di-calcium silicate and tri-calcium silicate in the manufacturing of cement.
3. Lime in excess, causes the cement to expand and disintegrate.

(ii) **Silica (SiO_2):**

1. The quantity of silica should be enough to form di-calcium silicate and tri-calcium silicate in the manufacturing of cement.

2. Silica gives strength to the cement.

3. Silica in excess causes the cement to set slowly.

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(iii) Alumina (Al_2O_3):

1. Alumina supports to set quickly to the cement.

2. Lowers the clinkering temperature.

3. Alumina in excess, reduces the strength of the cement.

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(iv) **Iron Oxide (Fe_2O_3):**

Iron oxide gives colour to the cement.

(v) **Magnesia (MgO):**

1. It also helps in giving colour to the cement.
2. Magnesium in excess makes the cement unsound.

(vi) <u>Calcium Sulphate (or) Gypsum (Ca SO4) :</u>

At the final stage of manufacturing, gypsum is added to increase the setting of cement.

(2) RAPID HARDENING CEMENT:

- Also known as early gain in strength of cement. This cement contains more %age of C3S and less %age of C2S, high proportion of C3S will impart quicker hydration
- The high strength at early stage is due to finer grinding, as fineness of cement will expose greater surface area for the action of water.
- The strength obtained by this cement in 03 days is same as obtained by O.P.C in 7 days.
- Initial and final setting times are same as OPC.ie. 30mins and 10 hrs.And soundness test by Le-Chatielier is 10mm and Autoclave is 0.8%.
- Greater lime content than OPC

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(3) EXTRA RAPID HARDENING CEMENT:

- It is obtained by intergrinding Cacl2 with rapid hardening cement.
- Addition of Cacl2 should not exceed 2% by weight of the rapid hardening cement.
- Concrete made by using this cement should be transported, placed, compacted & finished within about 20 minutes.
- Strength is higher than 25% than that of rapid hardening cement at 1 or 2 days.

(4) SULPHATE RESISTING CEMENT:

- It is modified form of O.P.C and is specially manufactured to resist the sulphates.
- This cement contains a low %age of C_3A and high %age of C_3S
- This cement requires longer period of curing.
- It develops strength slowly, but ultimately it is as strong as O.P.C.

(5) QUICK SETTING CEMENT:

- This cement is manufactured by adding small %age of aluminum sulphate (Al2SO4) which accelerates the setting action.
- Gypsum content is reduced.
- Sets faster than OPC.
- Initial setting time is 5 minutes. Final setting time is 30 minutes.

(6) LOW HEAT CEMENT:

- Low percentage of tri-calcium aluminates (C3A) and silicate (C3S) and high %age of di-calcium silicate (C2S) to keep heat generation low.
- Very slow rate of developing strength as rate of C3S Content is low.
- Heat evolved @ 7 days-66 cal/g and 28 days-75 cal/g
- initial set time-1 hr, final set time-10 hrs
- Better resistance to chemical attack than OPC.

(7) Portland Pozzolana Cement:

- OPC clinker and Pozzolana (Calcined Clay, Surkhi and Fly ash) ground together.

Produces less heat of hydration and offers great resistance to attacks of Sulphates.

- Used in marine works and mass concreting.
- Ultimate strength is more than OPC.
- Low shrinkage on drying
- Water tightness.

(8) Portland Slag Cement:

- Produced by mixing Portland cement clinker, gypsum and granulated blast furnace slag which shall not exceed 65%
- blackish grey in color.
- Lesser heat of hydration.
- Suitable for marine works, mass concreting.
- Offers good resistance to the attack of sulphate.

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(9) HIGH ALUMINA CEMENT:

Different from OPC

Characterised by its dark colour, high heat of hydration and resistance to chemical attack.

Initial setting time of 4 hrs and final setting time of 5 hrs.

Raw materials used are limestone and bauxite

(10) AIR ENTRAINING CEMENT:

- OPC with small quantity of air entraining materials (oils, fats, fatty acids) ground together.
- Air is entrained in the form of tiny air bubbles which enhances workability and reduces seggregation and bleeding.
- It increases sulphate water resistance of concrete.

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(11) **Supersulphated Cement:**

- Ground blast furnace slag + OPC +CASO4.

Heat of hydration which is considerably lower.

- It is also resistant to Sulphate attack.
- Used in a) Marine Structures, b) Mass concrete works

(12) **Masonry Cement:**

- Unlike ordinary cement, it is more plastic.
- Made by mixing hydrated lime, crushed stone, granulated slag or highly colloidal clays are mixed with it.
- Addition of above mentioned materials reduces the strength of cement.

(13) Expansive Cement:

- The main difference in this cement is the increase in volume that occurs when it settles.
- Used to neutralize shrinkage of concrete made from ordinary cement so as to eliminate cracks. A small percentage of this cement with concrete will not let it crack. It is specially desirable for hydraulic structures.
- In repair work, it is essential that the new concrete should be tight fitting in the old concrete. This can be done by using this cement

(14) Colored Cement:

- Suitable pigments used to impart desired color.
- Pigments used should be durable under light, sun or weather.

(15) WHITE CEMENT:

- OPC with pure white color produced with white chalk or clay free from iron oxide.
- As iron oxide gives the grey colour to cement, it is therefore necessary for white cement to keep the content of iron oxide as low as possible.
- Instead of coal, oil fuel is used for burning.

AGGREGATES

Aggregates are inert materials which are mixed with binding material such as cement or lime for manufacturing of mortar or concrete. Aggregates are used as filler in mortar and concrete and also to reduce their cost.

CLASSIFICATION OF AGGREGATES

Depending upon the size of their particles aggregates are classified as:

(1) Fine aggregates

(2) Coarse aggregates

(1) Fine Aggregates:

Aggregates whose particles pass through 4.75 mm IS sieve are termed as fine aggregates. Most commonly used fine aggregates are sand (pit or quarry sand, river sand and sea sand) and crushed stone in powdered form, how ever some times sukhi and ash or cinder are also used.

(a) Sand:

It consists of small angular or rounded grains of silica depending upon the source from which it is obtained. It is classified as:

(i) Pit or quarry sand:

It is found as deposited in soil and is to be excavated out. Its grains are generally sharp or angular. It should be free from organic matter and clay. It is usually considered to be the best fine aggregate for use in mortar and concrete.

(ii) River Sand:

It is obtained from the banks and beds of rivers. It may be fine or coarse. Fine sand obtained from beds and banks of rivers is often found mixed with silt and clay so it should be washed before use. But coarse sand is generally clean and excellent for use especially for plastering.

(iii) **Sea Sand**:

It consists of fine rounded grains of brown colour and it is collected from sea shores or sea beaches. Sea sand usually contains salts and while using that in mortar, etc, causes disintegration of the work in which it is used. In R.C.C work these salts will attack reinforcement if salt content is high. These salts may cause efflorescence. It should be used locally after thorough washing.

(b) **Crushed stone**:

It is obtained by crushing the waste stones of quarries to the particular size of sand. Sand obtained from by crushing a good quality stone is excellent fine aggregate.

Mortar made with this sand is usually used in ashlar work (good quality of work).

(2) Coarse Aggregates:

Aggregates whose particles do not pass through 4.75 mm IS are termed as coarse aggregates. Most commonly used coarse aggregates are crushed stone, gravel; broken pieces of burnt bricks,etc.

(a) Crushed stone:

It is an excellent coarse aggregate and is obtained by crushing granite, sand stone or grained lime stone and all types of stones. Crushed stones are used for the construction of roads and railway tracks, etc.

(b) Gravel:

It is an other very good coarse aggregate. It is obtained from river beds, quarries and sea shores. The gravel obtained from sea shores should be well washed with fresh water before use in order to remove the impurities which may be clay, salts ,silt,etc. It is commonly used in the preparation of concrete.

(c) **Broken pieces of bricks**:

It is also a good artificial source of coarse aggregates. It is obtained by breaking well burnt bricks. It is generally used in lime concrete at places where aggregates from natural sources are either not available or are expensive. It can be used at places where low strength is required. It should be watered well before using it in the preparation of concrete. It is commonly used for mass concrete in foundations and under floors.

GOOD QUALITYIES OF AN IDEAL AGGREGATE:

An ideal aggregate used for the manufacturing of concrete and mortar, should meet the following requirements.

- (1) It should consist of natural stones, gravels and sand or in various combinations of these materials.
- (2) It should be hard, strong and durable.

- (3) It should be dense, clear and free from any coating.
- (4) It should be free from injurious vegetable matters.
- (5) It should not contain flaky (angular) and elongated pieces.
- (6) It should not contain any material liable to attack steel reinforcement in case of reinforced concrete.

CHARACTERISTICS OF AGGREGATES:

Important characteristics of aggregates which influence the properties of resulting concrete mix are discussed as under:

1.Composition:

- Aggregate containing the constituents which generally react with alkalies in cement cause excessive expansion, cracking of concrete mix, should never be used. Suitability of aggregates should be judged either by studying its service history or by laboratory tests.

2. Size and shape:

The size and shape of the aggregate particles mainly influence the quantity of cement required in a concrete mix and ultimately economy of the concrete. For the preparation of economical concrete, one should use largest coarse aggregates feasible for the structure.

Type of structure	Max. size of aggregate
1. Mass concrete work i.e. dams, retaining walls, piers and abutments, etc.	40 mm
2. R.C.C work i.e. beams, columns, etc	20 mm
3. Flooring	10 mm

It may be clearly noted that the size and shape of the aggregate particles influence the properties of freshly mixed concrete more as compared to those of hardened concrete.

QUALITY TESTS OF AGGREGATES:

There are so many tests which are to be performed to check the quality of aggregates but some important tests are discussed below.

1. Crushing Test of Aggregate:

The aggregate crushing value gives a relative measure of resistance of an aggregate to crushing under a gradually applied compressive load. The aggregate crushing strength value is useful factor to know the behaviour of aggregates when subjected to wear.

2. Impact Value Test:

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact. The impact value is some times used as an alternative to its crushing value.

3. Abrasion Value:

The aggregate abrasion value gives a relative measure of resistance of an aggregate to wear when it is rotated in a cylinder along with some abrasive charge.

SIEVE ANALYSIS:

In determination of the proportions of the particles with in certain ranges in an aggregate by separation on various sieves of different size openings, may be defined as sieve analysis.

<u>FINENESS MODULUS (F.M):</u>

The sum of cumulative percentage of residues retained on each of the Indian standard sieves (80mm,40mm,20mm,10mm,4.75mm,2.36mm,1.18mm,600 microns,300microns and 150 microns each succeeding sieve has half the aperture of the previous one), divided by the 100,is known as "***Fineness modulus***" of the aggregates. The fineness modulus of an aggregate is roughly proportional to the average size of particles of the aggregates.

(OR)

Index Number expressing the relative sizes of both coarse and fine aggregates is called “Fineness Modulus”.

Sand	Fineness Modulus
Fine	2.2 to 2.6
Medium	2.6 to 2.9
Coarse	2.9 to 3.2

Note:

It is recommended that the fineness modulus of sand should not be less than 2.5 and should not be more than 3.0

INTRODUCTION

- **CONCRETE**

  Concrete is a composite material in which a binding material mixed in water on solidification binds the inert particles of well graded fine and coarse aggregates.

  Cement and lime are generally used as binding materials, whereas sand cinder is used as fine aggregates and crushed stones, gravel, broken bricks, clinkers are used as coarse aggregates.

CONCRETE

Freshly prepared concrete till it has not yet set is called *wet or green concrete.* After it has thoroughly set and fully hardened it is called *set concrete* or just concrete.

TYPES OF CONCRETE AND ITS USES

Concrete are classified into different types:

1. According to binding material used in concrete.
2. According to design of concrete.
3. According to purpose of concrete.

TYPES OF CONCRETE AND ITS USES

CLASSIFICATION ACCORDING TO BINDING MATERIAL:

According to binding material used concrete are classified into two types.

(1) Cement concrete (2) lime concrete.

CEMENT CONCRETE

The concrete consisting of cement, sand and coarse aggregates mixed in a suitable proportions in addition to water is called cement concrete. In this type of concrete cement is used as a binding material, sand as fine aggregates and gravel, crushed stones as coarse aggregates.

In cement concrete useful proportions of its ingredients are

1 part cement:1-8 part sand:2-16 parts coarse aggregates.

USES

cement concrete is commonly used in buildings and other important engineering works where strength and durability is of prime importance.

LIME CONCRETE

The concrete consisting of lime, fine aggregates, and coarse aggregates mixed in a suitable proportions with water is called lime concrete.

In this type of concrete hydraulic lime is generally used as a binding material, sand and cinder are used as fine aggregates and broken bricks, gravel can be used as coarse aggregates.

PLACING OF LIME CONCRETE :

Placing of concrete shall be completed within three hours of adding water in case of concrete is prepared with hydraulic lime.

Concrete should be well cured for a period of atleast 10 days.

USES:

Lime concrete is generally used for the sake of economy in foundation works, under floors, over roof and where cement is not cheaply and easily available in required quantity.

TYPES OF CONCRETE AND ITS USES

CLASSIFICATION ACCORDING TO DESIGN OF CONCRETE

(1) Plain cement concrete.

(2) Reinforced cement concrete(RCC).

(3) Pre-stressed cement concrete(PCC).

PLAIN CEMENT CONCRETE

The cement concrete in which no reinforcement is provided is called plain cement concrete or mass cement concrete.

This type of concrete is strong in taking compressive stresses but weak in taking tensile stresses.

USES:

Plain cement concrete is commonly used in for foundation work and flooring of buildings.

REINFORCED CEMENT CONCRETE(RCC)

The cement concrete in which reinforcement is embedded for taking tensile stress is called reinforced cement concrete.

In this type of concrete the steel reinforcement is to be used generally in the form of round bars,6mm to 32mm dia. This concrete is equally strong in taking tensile, compressive and shear stresses. Usual proportions of ingredients in a reinforced concrete are 1part of cement:1-2parts of sand:2-4parts of crushed stones or gravel.

USES: RCC is commonly used for construction of slabs, beams, columns, foundation, precast concrete.

REINFORCED CEMENT CONCRETE(RCC)

REINFORCED CEMENT CONCRETE(RCC)

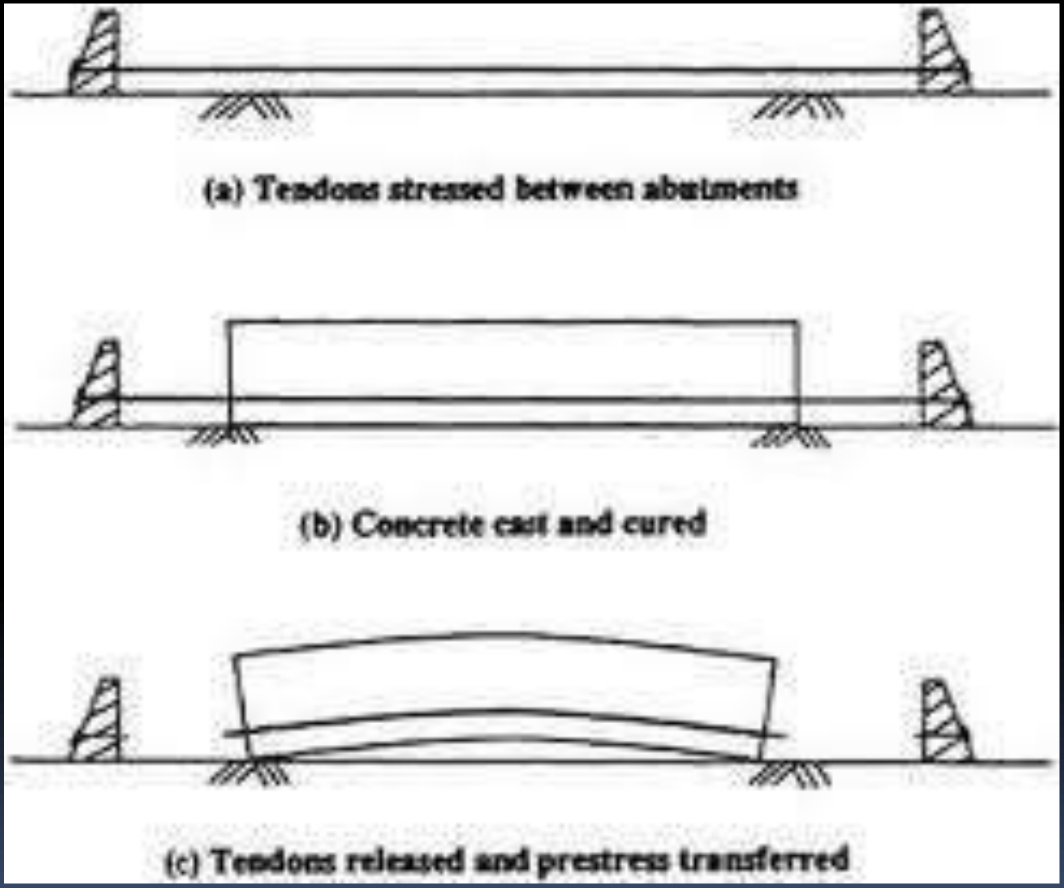
PRE-STRESSED CEMENT CONCRETE (PCC)

The cement concrete in which high compressive stresses are artificially induced before their actual use is called pre-stresses cement concrete.

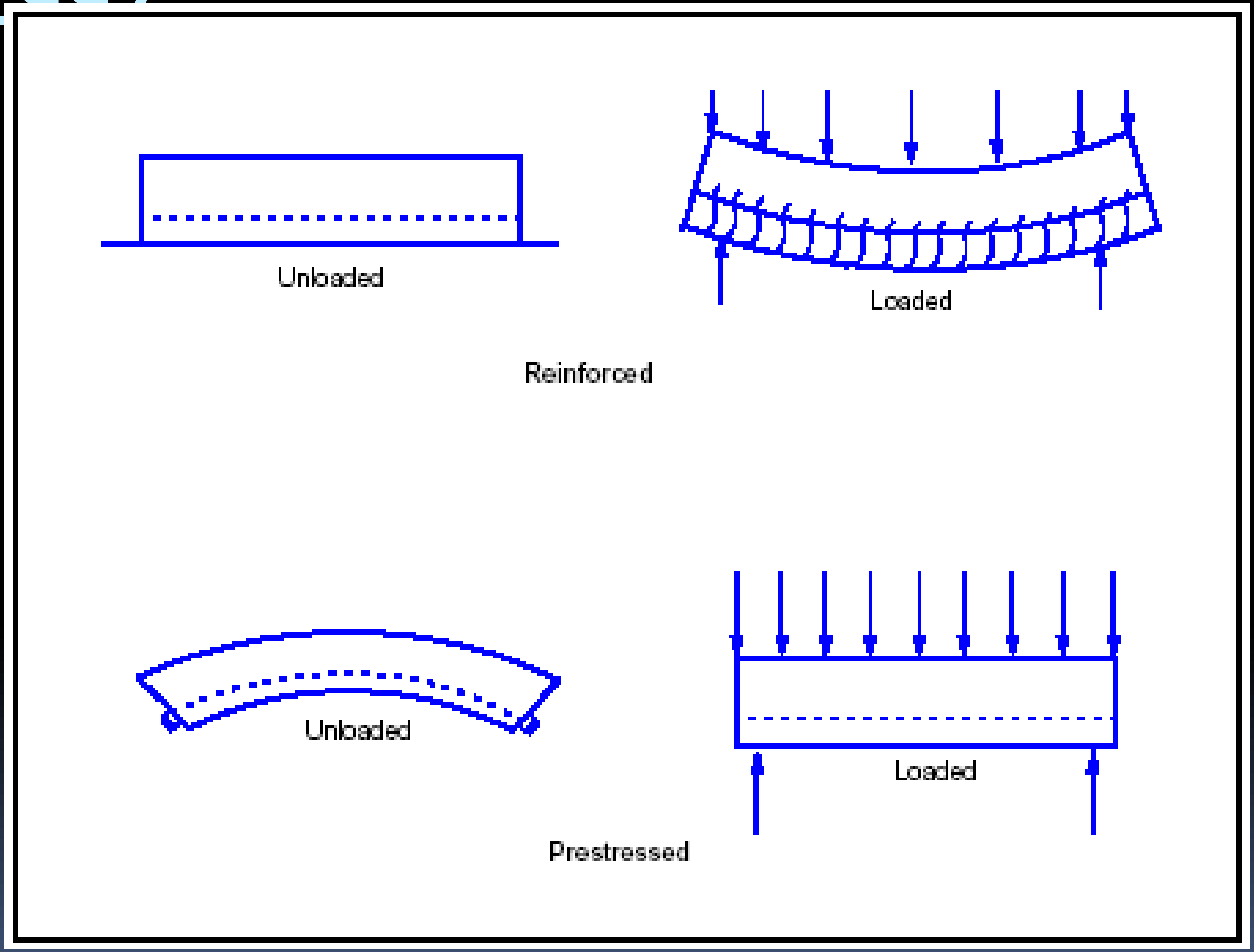
in this type of cement concrete, the high compressive stresses are induced by pre-tensioning the reinforcement before placing the concrete, and the reinforcement is released when final setting of the concrete take place.

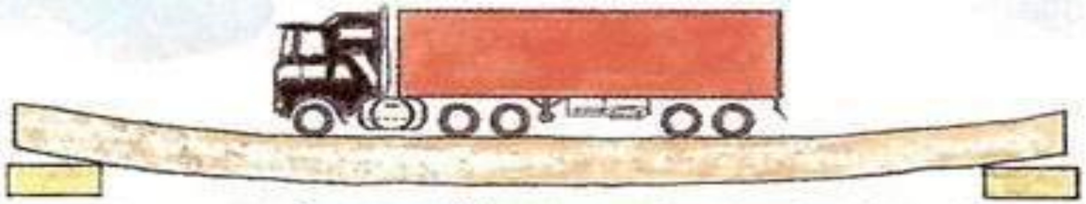
Uses : This concrete can take up high tensile and compressive stresses without development of cracks. The quantity of reinforcement can be considerably reduced by using this concrete.

PRE-STRESSED CEMENT CONCRETE (PCC)

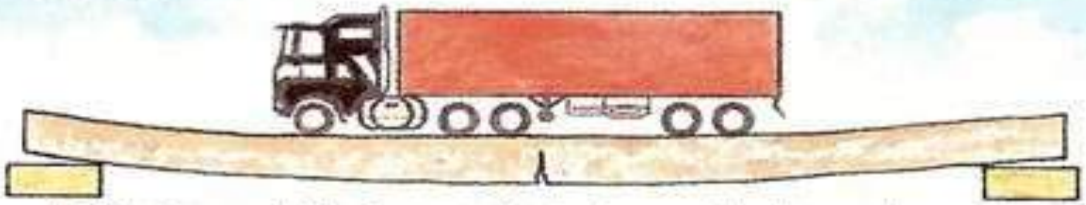


PRE-STRESSED CEMENT CONCRETE (PCC)

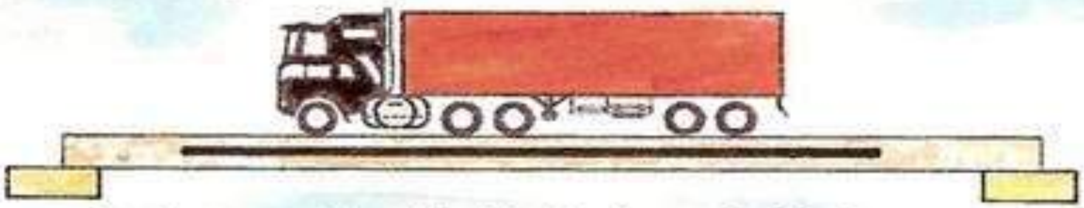




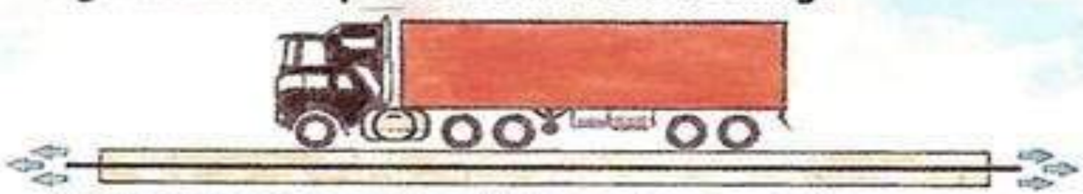
▲ A concrete beam will begin to bend when heavily loaded.



▲ The base of the beam starts to crack where the concrete is pulled apart.



▲ Placing a steel rod inside the beam holds the concrete together and stops the beam from cracking.



▲ Stretching the rod and then releasing it to squeeze the concrete makes the beam very strong.

TYPES OF CONCRETE AND ITS USES

CLASSIFICATION ACCORDING TO PURPOSE

According to purpose concrete is classified into following types.

a. Vacuum concrete:

The cement concrete from which entrained air and excess water is removed after placing it, by suction with the help of vacuum pump is called vacuum concrete.

In this concrete the excess water which is added to increase workability but not required for the hydration of cement of concrete is removed by forming vacuum chamber

VACCUM CONCRETE

b. Air entrained concrete

The concrete prepared by mixing aluminum in it is called air entrained ,cellular or aerated concrete. In this concrete bubbles of hydrogen gas are liberated which forms cell and make the concrete cellular.

USES: This concrete is used for lining walls and roofs for heat and sound insulation purpose.

c. Light weight concrete

The concrete prepared by using coke breeze, cinder or slag as coarse aggregate is called light weight concrete. The concrete is light in weight and posses heat insulating properties.

USES

This concrete is used in making precast structural units for partition and wall lining.

DESCRIPTION OF WORK CONCRETE	GRADE OF
Concrete in columns, beams	1:1:2
Water retaining structures, Piles, precast work or dense Concrete.	1:1.5:3
RCC beams, slabs, columns	1:2:4
Foundations for buildings, Mass reinforced works.	1:3:6
For mass concrete work.	1:4:8

WATER CEMENT RATIO

- In the preparation of concrete the water cement ratio is very important
- For normal construction the water cement ratio is usually 0.5
- Adding to much water will reduce the strength of concrete and can cause seggregation.

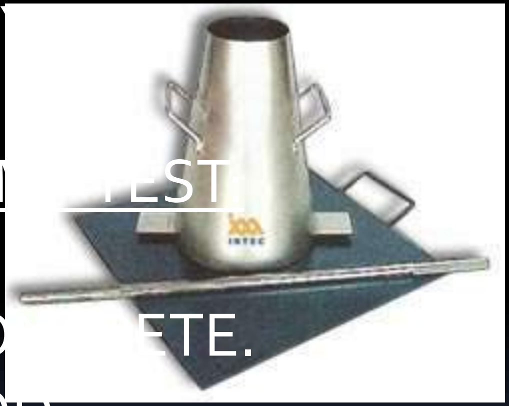
WATER CEMENT RATIO

- For different ratio of concrete the amount of water for 50kg of cement is

Concrete ratio quantity	Water
1:3:6	34 liter
1:2:4	30 liter
1:1.5:3	27 liter
1:1:2	25 liter

SLUMP TEST

SLUMP TEST IS A TEST CONDUCTING BEFORE CONCRETE TO BE USED FOR CASTING. THE PURPOSE OF SLUMP TEST IS TO DETERMINE THE WATER CONTENT IN CONCRETE AND ITS WORKABILITY.



EQUIPMENT FOR SLUMP TEST

1. BASE PLATE.
2. TROWEL TO MIX CONCRETE.
3. STEEL TAMPING ROD.
4. SLUMP CONE.
5. RULER.

SLUMP TEST

STEP 1:

Fill cone 1/3 full by volume and rod 25 times with 5/8-inch diameter x 24-inch-long hemispherical tip steel tamping rod. (This is a specification requirement which will produce nonstandard results unless followed exactly.) Distribute rodding evenly over the entire cross section of the sample.

SLUMP TEST

STEP 2:

Fill cone 2/3 full by volume. Rod this layer 25 times with rod penetrating into, but not through first layer. Distribute rodding evenly over the entire cross section of the layer.

SLUMP TEST

STEP 3:

Remove the excess concrete from the top of the cone, using tamping rod as a screed. Clean overflow from base of cone.7 Immediately lift cone vertically with slow, even motion. Do not jar the concrete or tilt the cone during this process. Invert the withdrawn cone, and place next to, but not touching the slumped concrete. (Perform in 5-10 seconds with no lateral or torsional motion.)

SLUMP TEST

STEP 4:

Lay a straight edge across the top of the slump cone. Measure the amount of slump in inches from the bottom of the straight edge to the top of the slumped concrete at a point over the original center of the base. The slump operation shall be completed in a maximum elapsed time of 21/2 minutes. Discard concrete. DO NOT use in any other tests.

Slump value for different concrete

- Mass concrete and road work 2.5 to 5cm
- Ordinary beams and slabs 5 to 10cm
- Columns and retaining walls 7.5 to 12.5cm

WORKABILITY OF CONCRETE

- It is the amount of work required to place concrete and to compact it thoroughly.
- Workability of concrete increases with the addition of water but it reduces the strength that's why it is not a desirable way of increasing the workability.
- Use of aggregates which are round and have smooth surfaces increases the workability.

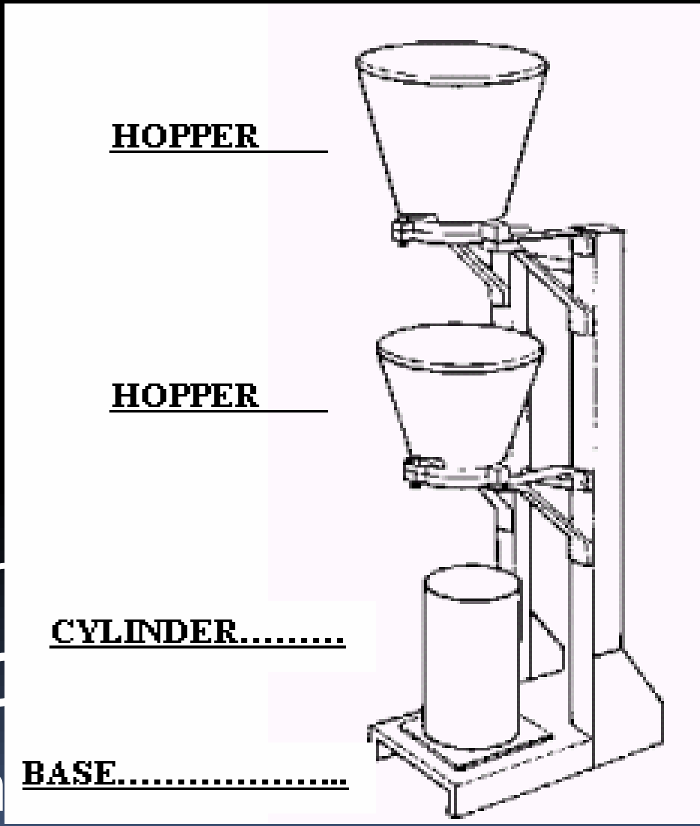
WORKABILITY OF CONCRETE

- Workability could also be improved by adding air entraining agent such as vinsol resin or Darex.
- Use of *Lisapole* liquid at 30 cubic centimeter per bag of cement improves not only the workability but also the water tightness of concrete.
- Workability of concrete is better determine by compaction factor test.

COMPACTION FACTOR TEST

COMPACTION FACTOR TEST

- The apparatus use for compaction factor test consist of two hoppers ***A*** and ***B*** and a cylinder ***C.***
- The hoppers are provided with hinged bottom. There is a clear distance between hopper ***A*** and ***B*** and cylinder ***C.*** the diameter of cylinder ***C*** is 15cm and is of 30cm heigh



COMPACTION FACTOR TEST

- Cement concrete to be tested is placed in the hopper ***A*** and its bottom released. The concrete falling in hopper ***B*** achieves some compaction.
- The bottom of hopper ***B*** is now released so that concrete now falls in cylinder ***C.*** surplus concrete is removed from the top of cylinder. Concrete in the cylinder is now weighed. Let this weight be W_1.
- After cleaning the cylinder it is refilled with concrete in layers of 5cm each. Every layer of concrete is thoroughly compacted with an iron rod. Concrete in the cylinder is weighted again. Let this weight be W_2 .

COMPACTION FACTOR TEST

- The ratio of the two weights is known as compaction factor.

  Compaction Factor= W_1/W_2

- A compaction factor of 0.85 represents a mix of poor workability, 0.92 represents medium and 0.95 represents good workability.

PLACING OF CONCRETE

- After mixing of concrete it should be placed within 30min of adding of water.
- It should be quickly transported to the place of lying by means of iron pans manually, in wheel barrows, by pumping or by cranes.
- In placing, concrete should be laid in thin layers. Each layer being thoroughly consolidated, before the next one is laid.

PLACING OF CONCRETE

- Concrete should not be dropped from a height as it would cause segregation of aggregates.
- In case concrete has more of water or it has been laid in thick layers then on compaction water and fine particles of cement comes at the top forming a layer of weak substance known as ***laintance***

COMPACTION OF CONCRETE

- Compaction of concrete is very important in developing qualities like strength, durability, imperviousness by making the concrete dense and free from voids.
- In case of RCC compaction is done by pinning with an iron rod or even with trowel blade.
- Excess temping should be avoided as otherwise water, cement and finer particles would come to the surface and results in non uniform concreting.

COMPACTION OF CONCRETE

- In case of important and big works, compaction of concrete is done with vibrator.
- Use of vibrator is best and the most efficient way of compacting concrete. It gives very dense concrete.
- Care should be taken not to make excessive use of vibrators otherwise the concrete becomes non homogeneous

CURING OF CONCRETE

- The process of keeping concrete wet to enable it to attain full strength is known as ***curing.***
- The objective of curing is to prevent loss of moisture from concrete due to evaporation or because of any other reasons.
- Curing should be done for a period of three weeks but not less then 10 days.

CURING OF CONCRETE

- To do curing, any one of the following method can be used.

i. The surface of concrete is coated with a layer of bitumen or similar other waterproofing compound which gets into the pores of concrete and prevent loss of water from concrete.

ii. Concrete surface is covered with waterproof paper or with a layer of wet sand. It could also be covered with gunny bags.

CURING OF CONCRETE

CURING OF CONCRETE

CURING OF CONCRETE

CURING OF CONCRETE

QUALITIES OF GOOD CONCRETE

- ***STRENGTH:*** The concrete should be able to withstand the stresses that it is subjected to. It is quite strong in compression but weak in tension.
- ***DURABILITY:*** It should be durable enough to resist the effect of weathering agents.
- ***DENSITY:*** the concrete should be well compacted so that there are no voids or hollows left. It should weigh 3000 kg/cu.m

QUALITIES OF GOOD CONCRETE

- ***WATERTIGHTNESS:*** when used for construction of water retaining structures such as dams, elevated tanks and water reservoirs then this property of concrete becomes very important. Otherwise the moisture inside the RCC would corrode steel and leakage would start resulting in the ultimate failure of the structure.

QUALITIES OF GOOD CONCRETE

- ***WORKABILITY:*** It should be easily workable.
- ***RESISTANCE TO WEAR AND TEAR:*** when used in floors and in the construction of roads the concrete should be able to withstand abrasive forces.

TIMBER:

The wood which is suitable or fit for engineering construction or engineering purpose is called timber.

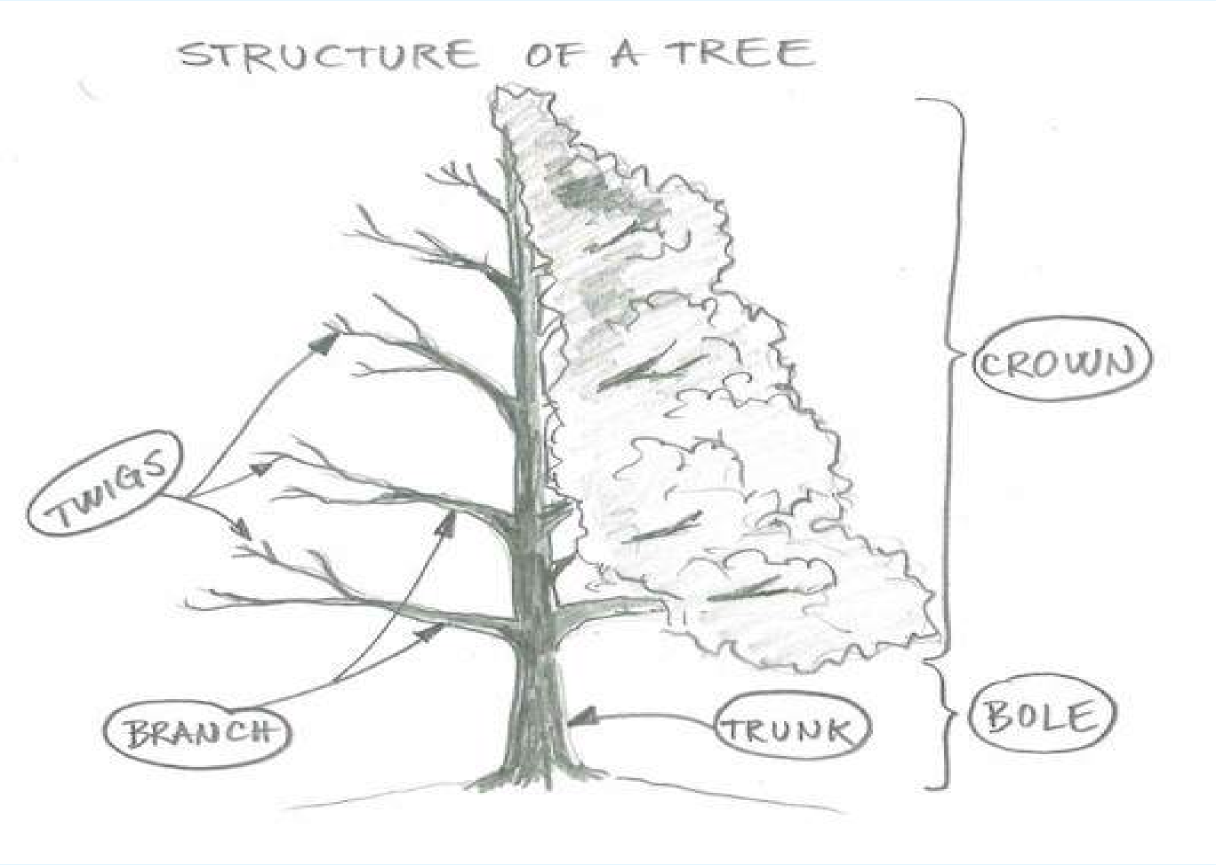
WOOD:

The organic matter obtained from trees is called wood.

LUMBER:

The sawed wood meant for construction in the form of boards is called lumber.

Structure of a Tree



TYPES OF TREES:

Trees are classified into two groups depending upon growth pattern.

(1) Endogenous trees:

The trees which grow inwards in longitudinal fibrous mass are called endogenous trees.

(2) <u>Exogenous tress</u> :

The trees which grow in out wards across horizontal section of stem are called exogenous trees.

These trees are only fit for engineering construction.

Exogenous trees are again subdivided in to two types.

- **Conifers or Evergreen:**
  - They give soft wood.
  - They have pointed leaves.

Examples:

- Deodar
- Pine
- Chir
- Kail,etc

- **Deciduous:**
  - These have hard wood.
  - These have broad leaves.

Examples:

- Teak
- Sal
- Shisham, etc.

SEASONING OF TIMBER:

As fresh timber which is obtained from trees contains about 30 to 40 % sap or moisture. This sap is very harmful for the life of a timber. Therefore, it is necessary to remove that sap by applying some special methods. All those methods which are used for removing the sap from timber are collectively termed as seasoning of timber.

Advantages of seasoned timber:

- It has reduced weight,
- It is strong and durable,
- It has resistance to decay or rot,
- It takes high polish,
- It is easier to work,
- Its life is more.

Types of Timber Seasoning:

The main types of timber seasoning are as under.

(1)Natural Seasoning,

(2)Artificial Seasoning,

(a) Kiln Seasoning,

(b) Chemical Seasoning,

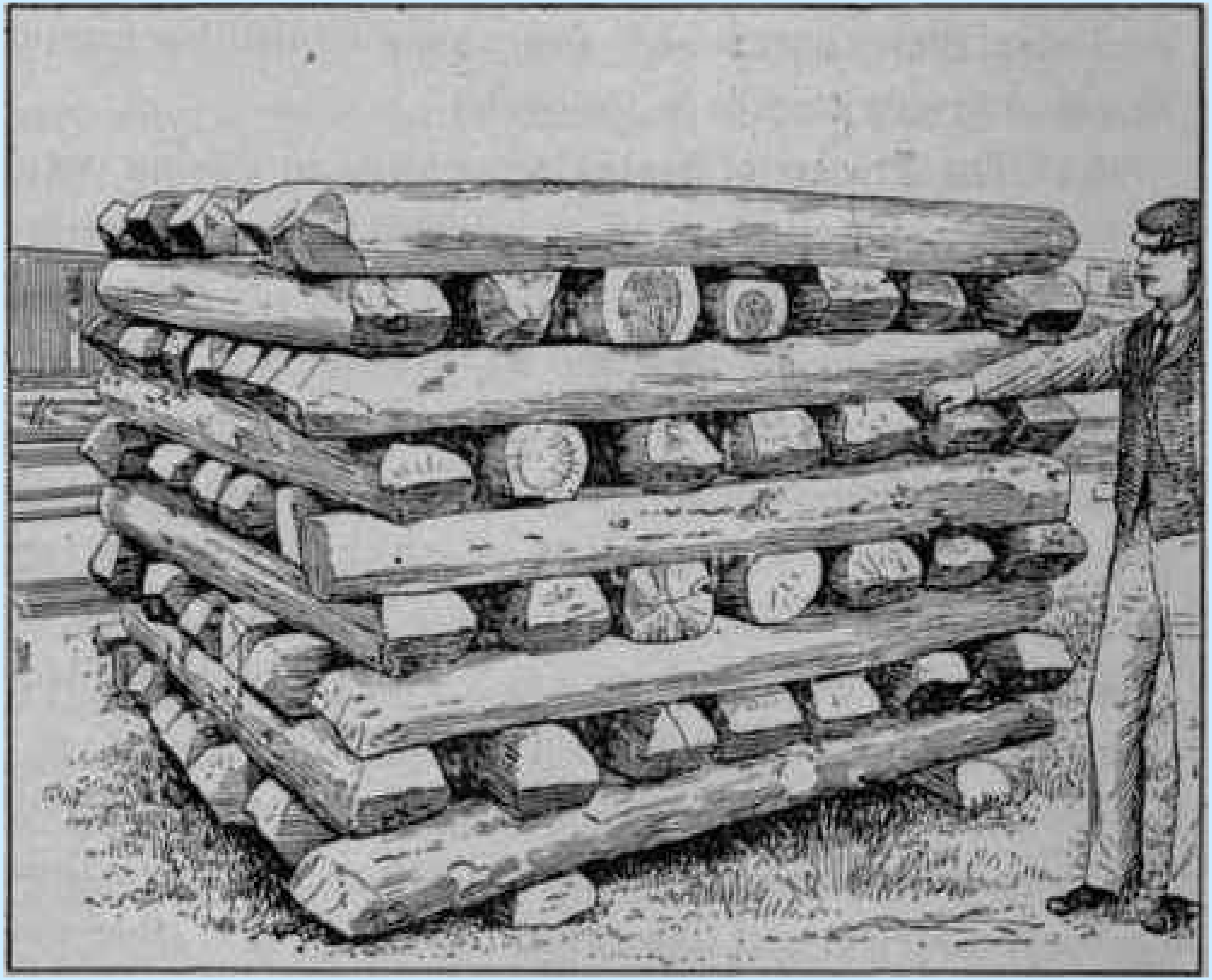
(c) Electric Seasoning,

(3) Water Seasoning,

(1) <u>Natural Seasoning:</u>

In the air seasoning or natural seasoning or natural drying, seasoning of timber, timber is dried by direct action of air, wind and sun. In this method, the timber logs are arranged one over the other, keeping some space or distance between them for air circulation of fresh air.

Generally this type of seasoning requires few months to over a year, this is very slow process.



(2) ARTIFICIAL SEASONING

(a) Kiln Seasoning,

(b) Chemical Seasoning,

(c) Electric Seasoning,

(a) <u>Kiln Seasoning</u>:

In kiln seasoning timber is placed in a chamber with some special heating arrangement.

In this process one thing should be kept in mind that heating system should be under control, other wise timber will be crack or wrap. The time required for this seasoning is 3 to 12 days. This is quick process.

Kiln Seasoning

(b) Chemical Seasoning:

In chemical seasoning carbon dioxide, ammonium carbonate or urea are used as agents for seasoning, those are applied in dry state, the inter surface of timber dries first than outer side.

This ensures uniform seasoning. The time required for this seasoning is 30 to 40 days.

(c) Electric Seasoning:

In this method electric current is passed through the timber logs. The time required for this seasoning is 05 to 08 hours.

Electric Seasoning

(3) <u>Water Seasoning:</u>

In water seasoning, timber logs are kept immersed whole in the flowing water. The sap present in timber is washed away. After that logs are taken out from water and are kept in open air, so water present in timber would be dried by air. The time required for this type of seasoning is 2 to 4 weeks.

USES OF TIMEBR:

Timber is used in:

1. Building construction,
2. Construction of house posts,
3. Construction of beams,
4. Construction of rafters,
5. Construction of bridges,
6. Construction of piles, poles and railway sleepers,

Continued--------

Prepared by:G.S.Solangi

7. For furniture making,
8. For light packing cases,
9. For high packing cases (for machinery and similar stores),
10. For manufacturing of agricultural implements,
11. For making toys, etc,
12. For manufacturing of veneers and ply woods.

- **<u>VENEER</u>:**

Thin sheet of uniform thickness of wood is called veneer.

- **<u>PLYWOOD</u>:**

Veneers used for making plywood are known as plies and ply wood is made by gluing together plies in odd numbers. Gluing is done under pressure.

ACOUSTICAL MATERIALS

PRESENTED BY –

SHAHZEB RAHMAN
SHOVNA PATHAK
ZEB FATIMA ZAIDI
ABDUL AHAD QAVI
SEERAT FATIMA
ZEHRA ABIDI
INTEGRAL UNIVERSITY

ACOUSTICS

- **Acoustics** is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration,sound, ultrasound and infrasound. A scientist who works in the field of acoustics is an **acoustician** while someone working in the field of acoustics technology may be called an acoustical engineer. The application of acoustics is present in almost all aspects of modern society with the most obvious being the audio and noise control industries.

•The word "acoustic" is derived from the Greek word ἀκουστικός (*akoustikos*), meaning "of or for hearing, ready to hear" and that from ἀκουστός (*akoustos*), "heard, audible",which in turn derives from the verb ἀκούω (*akouo*), "I hear".

The study of acoustics revolves around the generation, propagation and reception of mechanical waves and vibrations.

TYPES OF MATERIALS

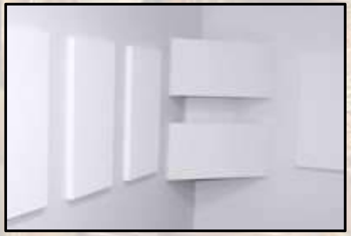
- SOUND ABSORBERS
- SOUND DIFFUSERS
- NOISE BARRIERS
- SOUND REFLECTORS

SOUND ABSORBERS

- These sound absorbing acoustical panels and soundproofing materials are used to eliminate sound reflections to improve speech intelligibility, reduce standing waves and prevent comb filtering.
- Typical materials are open cell polyurethane foam, cellular melamine, fiberglass, fluffy fabrics and other porous materials. A wide variety of materials can be applied to walls and ceilings depending on your application and environment.
- These materials vary in thickness and in shape to achieve different absorption ratings depending on the specific sound requirements.







TYPES –

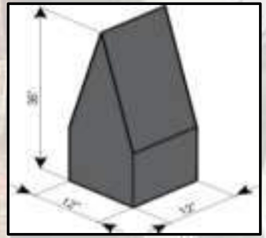
- ❑ **Acoustical foam panels**
- ❑ **White paintable acoustical wall panels**
- ❑ **Fabric wrapped panels**
- ❑ **Acoustical wall coverings**
- ❑ **Ceiling tiles**
- ❑ **Baffles and banners for ceiling**
- ❑ **Fibre glass blankets and roll**

❑ACOUSTICAL FOAM PANELS

- These acoustical foam sound absorbers are used in a wide variety of applications ranging from Recording and Broadcast Studios to Commercial and Industrial Facilities. Available in Polyurethane or in a Class 1 Fire Rated foam. These products can be applied directly to walls, hung as baffles or used as freestanding absorbers.

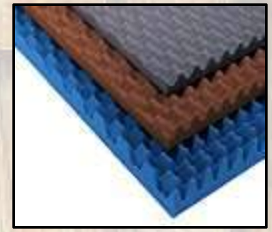
STACKABLE FOAM

Design enables you to increase thickness quickly by nesting layers



ANECHOIC WEDGE

Anechoic wedges are ideal for controlling low frequency sound to create a room that is perceptually devoid of sound.

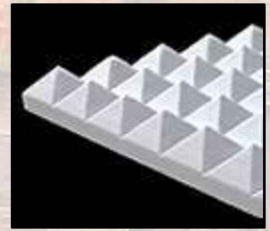


STANDARD POLYURETHANE FOAM PATTERNS

Standard patterns include wedge, pyramid, max wedge for low frequency absorption, ceiling baffles, bermuda triangle traps for corners, sounds cylinders free standing absorbers

CUTTING WEDGE

Installs to create seamless absorptive walls, and enhance imaging by reducing unwanted reflections. Available in 1'x1' or 2'x4' sheets.



FIRE RATED FOAM

Absorbers are lightweight open cell foams used when a Class 1 fire rated foam is required. Standard patterns include Wedge, Pyramid, Max Wedge, Ceiling Baffles and more. These can easily mount to walls or ceilings.

❑WHITE PAINTABLE PANELS

- It is a white acoustical wall panel with a soft textured appearance. The two foot by one foot dimension provides installers flexibility to mount acoustical panels around existing objects. In addition to reducing echo and reverberation, these acoustical panels are used to create unique designs and patterns. The glass fiber core is faced with a paintable covering. This allows you to match or complement existing wall colors by applying a light coat of flat or matte spray paint. To customize the look even further, many local printing companies now have the capability to produce an image directly to the face of these panels.
  ∞ Quick & Easy acoustical solution
  ∞ Soft drywall texture appearance
  ∞ Create unique patterns
  ∞ Panel size allows for flexible mounting options
  ∞ Paintable & Printable finish

Construction: 1 " Fiberglass 6 PCF acoustical core + molded fiberboard + paintable facing. Resin hardened square edges. Paintable finish covers face and exposed edges.
Class A rating per ASTM E 84
Panel Size: 2' x 1' (24 inches by 12 inches)
Thickness: 1-1/8"
Quantity per box: 10 panels

Sustainability

This product bears the Green Cross label for recycled content. The acoustical substrate is certified on average to contain at least 35% recycled glass, with 9% post-consumer and 26% pre-consumer content.

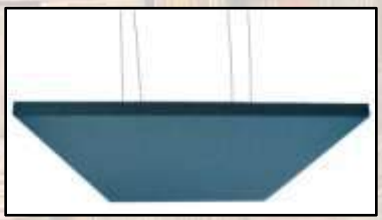
Mounting

Installs using standard impaling clip method. (adhesive by others) Other mounting options shown below.
❑MOUNT IN CORNERS USING CORNER CLIPS.
❑MOUNT ON TWO INCH STAND OFF CLIPS

❑FABRIC WRAPPED PANELS

- Acoustical sound panels utilize 6-7 PCF glass fiber material for maximum absorption. Available as wall panels, ceiling tiles, hanging baffles, acoustical clouds and bass traps, with more than 50 standard colors to choose from, these materials will look as good as they sound. The standard sizes and configurations best maximize raw materials, however, many of these products can be customized to meet specific requirements should you need material sized to fit or other finishes or coverings.

WALL PANELS



CEILING CLOUDS

•Ceiling clouds reduce reflected sound in areas such as theaters, restaurants, arenas, shopping malls, convention centers, recording and broadcast rooms, or anywhere absorption is required.

• Used to reduce echo and reverberation in applications, small and large. These panels are manufactured from a rigid high density (6-7 PCF) glass fiber acoustical board and covered with an acoustically transparent fabric.

CEILING TILES

• Ceiling Tiles are an excellent choice for many ceiling grid applications requiring high absorption.

CEILING BAFFLES

•All surface faces and edges of the glass fiber core are wrapped in fabric to match or accentuate room décor . Ceiling Baffles absorb sound on all sides and edges.

BROADBAND ABSORBER

•Sculptured sound absorbing modular units used for walls, as corner traps, bass traps and ceiling applications. Available in half-rounds or quarter-rounds.

❑WALL COVERINGS

- Acoustical wall fabric is a dimensional fabric that offers excellent acoustical properties, unmatched fade resistance, and a fire/smoke retardant class A rating. Sound channels is resistant to moisture, mildew, rot, bacteria, and is non-allergenic. Produced with no voc's (volatile organic compounds), ods's (ozone depleting substances), heavy metals or formaldehyde, it's the perfect acoustic fabric for offices, classrooms, conference centers or any area where speech intelligibility is a critical factor.

Features:

•Lightweight Acoustic Fabric
•Easy to install
•Class A
•Passes Corner Burn Test
•Available in Many Colors
•Durable / Abuse Resistant
•Improves Speech Intelligibility

Applications:

•Conference Rooms
•Theaters
•Hospitals
•Municipal
•Office Partitions
•Schools
•Hallways
•and more...

Installation:

•This material is not factory trimmed. It is necessary for the installer to cut a straight vertical edge
•Following the ribbed pattern. All edges must be butt joined. Do not overcut edges. Cut material to
•Desired lengths, allowing for top and bottom trimming. Wall carpet should be hung
•Straight up. Do not alternately reverse strips.
•Apply a premixed heavy duty adhesive directly to the wall, allowing it to dry to its maximum tackability
•Without it being overly dry. (Important!!! Adhesives are ready mixed. Do not dilute)
•Adhesive and do not apply adhesive to the back of the wall covering).
•Please be sure to follow instructions as provided by the adhesive manufacturer.

⅛"

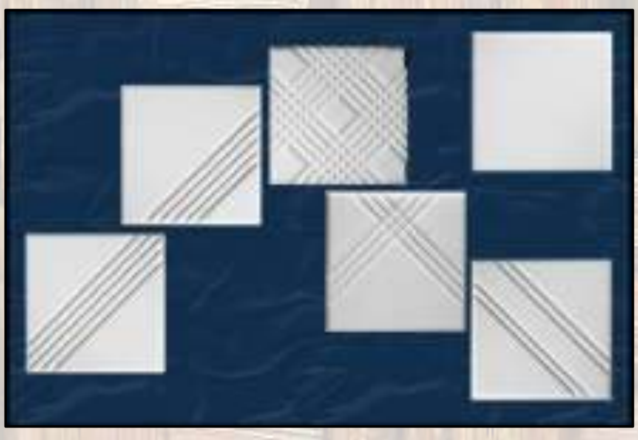
❑CEILING TILES

- Cloudscape® Ceiling Tiles absorb noise and block sound transmission. These ceiling tiles are designed to fit into existing 2' x 2' suspended drop tile ceiling grid systems. They may also retrofit in a 2' x 4' ceiling grid by installing cross tees. Cloudscape® ceiling tiles may also be ordered as a full 24" x 24" size, un-backed for adhesive mounting directly to walls or ceilings.
- Ordinary ceilings take on new levels of visual excitement with these sculptured tiles. They are available in five different patterns plus a non-patterned look to enable you to "mix and match" for your own designs.

Available Sizes:

24" x 24" (nominal)

Specify grid when ordering: 9/16 or 15/16



❑BAFFLES AND BANNERS

- Baffles and Banners are designed to solve acoustical problems economically in any large cubic volume space such as arenas, gymnasiums, theaters, restaurants, and auditoriums. Reverberation times that range from 4 to 9 seconds can be reduced to 1/2 to 2 seconds. Speech intelligibility is greatly improved and sound intensity levels are reduced simultaneously by 3 to 12 decibels.

BAFFLES:

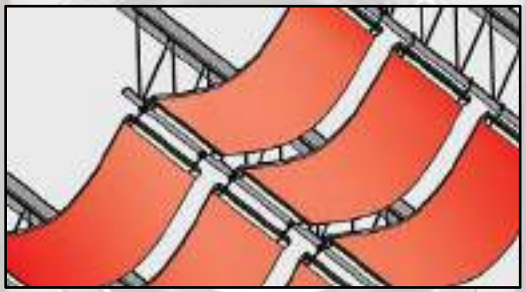
• Baffles are an economical way to reduce sound pressure levels and lower reverberation times in large spaces such as gymnasiums, theaters, restaurants, health and fitness clubs, etc. Reverberation times can be lowered from a RT60 of 4 - 9 seconds down to a RT60 of 0.5 - 2 seconds. Speech intelligibility is greatly improved and sound intensity levels can be simultaneously reduced by 3 to 12 decibels.

•These baffles are easily suspended from existing open truss and pre-engineered suspension systems. They are designed to hang in a vertical fashion, allowing free flow of air and integrate exceptionally well with existing sprinklers, lighting and HVAC systems.

BANNERS:

•Speech intelligibility is greatly improved and sound intensity levels can be simultaneously reduced by 3 to 12 decibels.

•Banners are suspended from ceilings, bar joists or pre-engineered suspension systems. They are designed to hang in a horizontal or in a catenary fashion using edge stiffeners or deck mounted flat with washer plates



❑SOUND DIFFUSERS

- These devices reduce the intensity of sound by scattering it over an expanded area, rather than eliminating the sound reflections as an absorber would. Traditional spatial diffusers, such as the polycylindrical (barrel) shapes also double as low frequency traps. Temporal diffusers, such as binary arrays and quadratics, scatter sound in a manner similar to diffraction of light, where the timing of reflections from an uneven surface of varying depths causes interference which spreads the sound.

QUADRA PYRAMID DIFFUSER

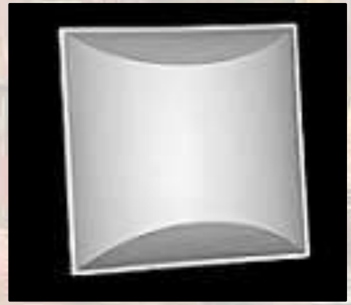
•This diffuser generates a uniform polar response over a broad frequency range using a pre-rotated pyramidal pattern to create 16 angles of reflection.

PYRAMIDAL DIFFUSER

•This traditional industry workhorse disperses sound uniformly over a broad frequency range. A quick solution to reduce flutter echo.

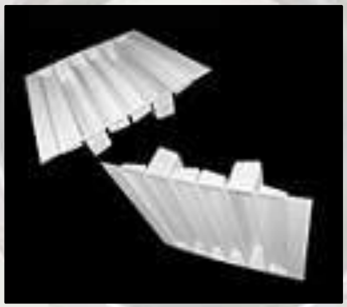
DOUBLE DUTY DIFFUSER

•These Polycylindrical Diffusers do twice the work. They scatter sound and function as a bass trap.



QUADRATIC DIFFUSER

A true quadratic residue diffuser designed for uniform broadband scattering and reducing High-Q reflections.



❑NOISE BARRIERS

These materials range from dense materials to block the transmission of airborne sound to devices and compounds used to isolate structures from one another and reduce impact noise.

BARRIERS

•Sound barrier materials are used to reduce the transmission of airborne sound. The BlockAid® series of products include the standard one pound per square foot non reinforced barrier, transparent material when observation or supervision is required, reinforced vinyl to create a hanging barrier partition.

COMPOSITES

•Composite materials are manufactured from combinations of various materials from open and closed celled foams to quilted fiberglass and barrier. These products are used to block and absorb sound for machine enclosures as well as blocking airborne sound and impact noise. Some of these products include Composite Foams, StratiQuilt Blankets and Floor Underlayment.

VIBRATION CONTROL

•Vibration control products are used to absorb vibration energy and prevent structural noise transmission. These include vibration damping compounds and vibration pads, isolation hangers, and resilient clips. They improve sound transmission loss.

❑FABRICS

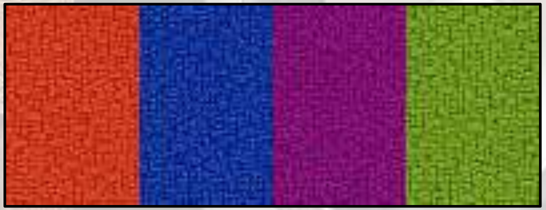
- Acoustical fabrics are typically used to either absorb sound or as a cover for acoustical panels. Some fabrics can also be used as a speaker grill cloth or as a finish on other types of materials.

SOUND CHANNELS WALL FABRICS

•Acoustical wall fabric is a dimensional fabric that offers excellent acoustical properties, unmatched fade resistance, and a fire/smoke retardant class A rating. Sound channels® is resistant to moisture, mildew, rot, bacteria, and is non-allergenic. Produced with no voc’s (volatile organic compounds), ods’s (ozone depleting substances), heavy metals or formaldehyde, it's the perfect acoustic fabric for offices, classrooms, conference centers or any area where speech intelligibility is a critical factor.

GUILFORD OF MAINE

•Guilford of Maine® Fabric is and acoustically transparent fabric used to cover many of our products including acoustical wall panels, diffusers, and corner traps. Fabric is also sold separately as speaker grill cloth, wall covering and for other field applications.



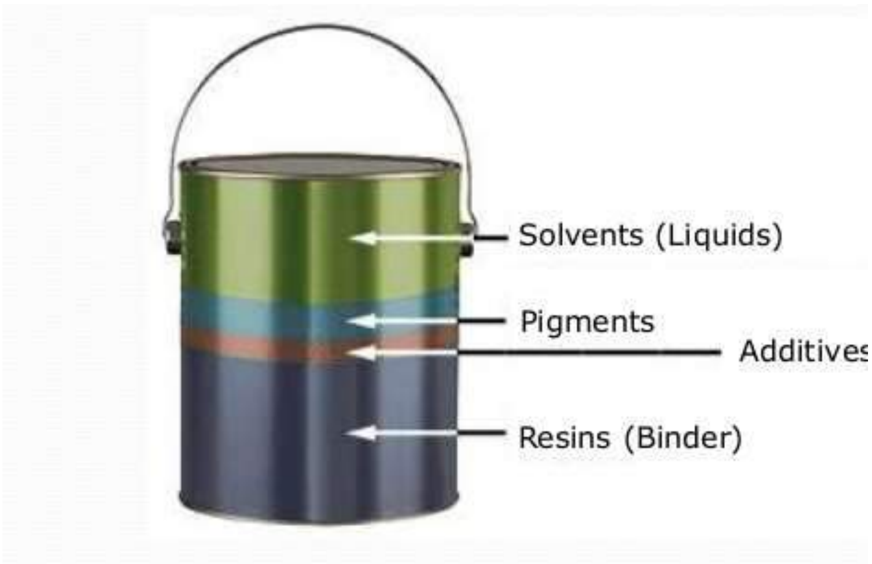
What Is Paint?

To most people, paint is the colour on the walls of their home, the colour of their car, bike or any object which a person can relate to in his Daily Life but,

Paint is more than just the colour though, it is a colored substance which is spread over a surface and is left to dry to leave a thin decorative, colored & protective coating film. Higher the Paint Quality Higher the Preparation Of Base.

What is Paint Made Of:-

1. **Pigment** - to provide colour, hiding and control gloss.
2. **Resin** – the binder to hold the pigment particles together and provide adhesion to the surface painted.
3. **Solvent** – to act as a carrier for the pigments and resin – the solvent may be organic Or Inorganic (such as Mineral, Chemicals or water).
4. **Additives** – to enhance certain properties such as ease of brushing, mould resistance, scuff resistance, drying and sag resistance.



What is Paint Made Of:-

Pigment

Solvent

Additive

Resin

We apply paint for:-

1. Decoration
2. Protection
3. Identification
4. Sanitation

Classification of Paints:-

- Paints
  - Water Based
  - Oil Based

Classification of Water Based Paints:-

It is a Mixer of Pigments, Binder, Drier and mainly Water.

The majority of wall paint sold today is water-based.

Water Based Paints comes in the Range of Cheap to Highly Expensive Luxury Qualities.

Many Categories of Water Based Paints Are Easily washable when Set and Dried.

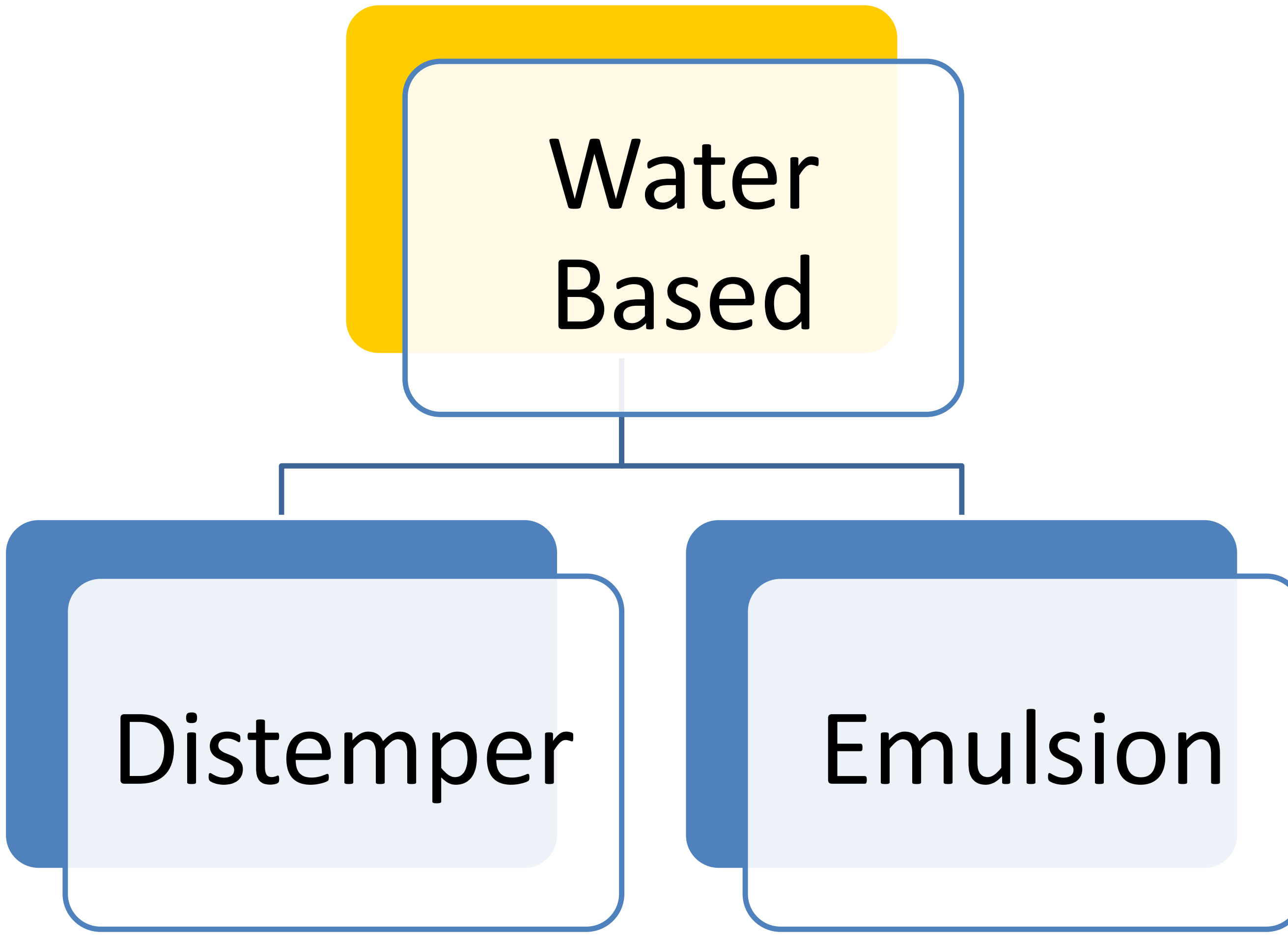
It is suitable for Interior as well as exterior walls.

Only Water is added before its application Process.

Requires Lesser time than Oil Paints to Dry.

Maintains its Original Colour For longer period of time.

Classification of Water Based Paints:-



Types of Water Based Paints:-

Distemper:-

Distemper paint is an ancient type of paint made of water, chalk and pigment, bound with either an animal glue or the adhesive.

Distemper paint is thin and not durable, but can be made inexpensively and can achieve nearly any color.

- It is used as a cost effective Painting Solution.
- Used For Painting Interior Walls,

Distemper

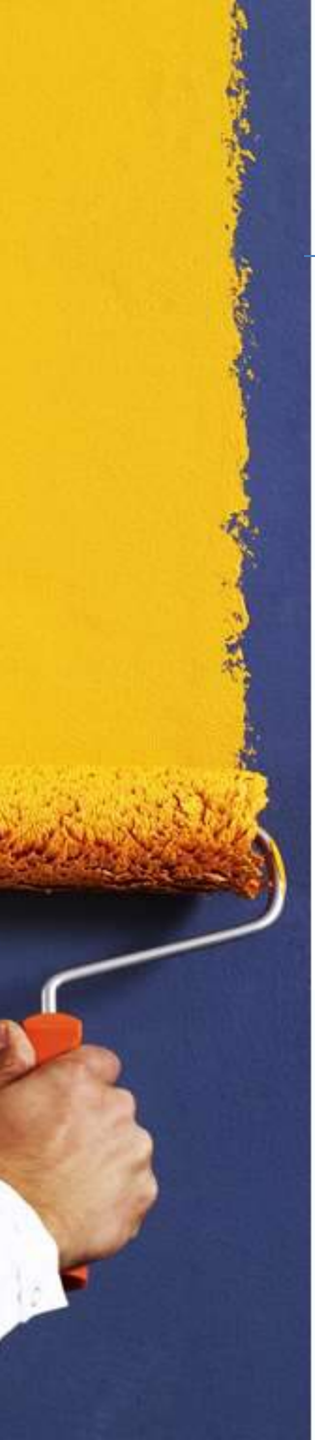
Acrylic

Synthetic

Distemper Paint :

Acrylic Distemper:- It is acrylic distemper of the highest quality and gives the wall a delightful smooth matte finish. High Finish in Distemper.
Brands:-Asian Paints, Berger, Dulux, Nerolac, British Paint, Nippon etc.
Sizes:-1kg,2kg,5kg,10kg,20kg
Area covered:- 1kg= 150-180 sq.ftx2 Coats
Price= 1100 Rs per 20kg

Synthetic Distemper:- Synthetic Distemper is water-based finished value for Money Distemper. Low Finish in Distemper.
Brands:- Asian Paints, Berger, Dulux, Nerolac, British Paint, Nippon etc.
Sizes:- 1kg,2kg,5kg,10kg,20kg
Area covered:- 1kg= 100-120 sq.ftx2 Coats
Price= 800 Rs per kg.



Properties of Distemper Paint:-

1. On drying, the film of distemper shrinks. Hence, it leads to crackling and flaking, if the surface to receive distemper is weak,
2. The coating of distemper are usually thick and more brittle than other types of water paints.
3. The film developed by the distemper is porous in character and it allows water vapor to pass through it.
4. They are generally light in colour and they provide a good reflective coating.
5. They are less durable than oil paints or Emulsion Paints.
6. They can be applied on brickwork, cement plastered surface, lime plastered surface etc.
7. They exhibit poor workability.
8. They prove to be unsatisfactory in damp locations such as kitchen, bathroom, etc.

Types of Water Based Paints:-

Emulsion:-
These are superior Quality of paints formed by mixing oil/water
And an emulsifying agent to prevent the separation of the
Combination.
They have much better ease of application, are washable.
Have greater overall Decorative appeal.
They provide a higher coverage than a distemper or Enamel.

Emulsion

- Interior
- Exterior

Interior Emulsions:-

1. **Vinyl matt** emulsion gives a matt, non-shiny finish that is good for not showing small imperfections on the wall or ceiling. (The shinier finishes reflect back more light and highlight any imperfections.

2. **Vinyl satin** emulsion gives a subtle soft-sheen finish and is a more durable surface than vinyl matt. It is suitable for areas that might need to be occasionally lightly washed or sponged.

3**. Vinyl silk** emulsion gives a high sheen finish and is the most durable of all the emulsion paints. It is good for rooms that are subject to a lot of moisture i.e. condensation.

Variables of Interior Emulsions Matt Finish found In India:-

400RS/LTR

200RS/LTR

250RS/LTR

180RS/LTR

150RS/LTR

420RS/LTR

220RS/LTR

200RS/LTR

220RS/LTR

200RS/LTR

150RS/LTR

400RS/LTR

Etc.

Variables of Interior Emulsions Satin Finish found In India:-

350RS/LTR

450RS/LTR

450RS/LTR

520RS/LTR

390RS/LTR

450RS/LTR

400RS/LTR

420RS/LTR

480RS/LTR

280RS/LTR

450RS/LTR

450RS/LTR

Etc.

Variables of Interior Emulsions Premium Silk Shine Finish found In India:-

500RS/LTR

750RS/LTR

520RS/LTR

480RS/LTR

400RS/LTR

510RS/LTR

480RS/LTR

550RS/LTR

Etc.

Though Rates Decreases as per Increased Quantity

Exterior Emulsions:-

1. It is a smooth water-based, modified acrylic, exterior wall finish with silicon additives.

2. These are the Paints that are used in Exterior Potion of a building that is exposed to direct sunlight, air and water.

3. They have additional qualities to with stand the weather condition comes with keeps on changing as per the seasons.

4. These types of paints are oftenly used in painting Building from Exterior as well as used in interior portion of stairs.

Variables of Exterior Emulsions found In India:-

9500RS/20LTR

9500RS/20LTR

9800RS/20LTR

6000RS/20LTR

4000RS/20LTR

8000RS/20LTR

4500RS/20LTR

250RS/LTR

3000RS/20LTR

3500RS/20LTR

350/ltr

270RS/LTR

Etc.

Variables of Exterior Emulsions found In India:-

4200RS/20LTR

4800RS/20LTR

520RS/20LTR

3800RS/20LTR

3800RS/20LTR

3000RS/20LTR

4200RS/20LTR

4500RS/20LTR

250RS/LTR

5000RS/20LTR

6200RS/20LTR

5800RS/20LTR

Etc.

Oil Based Paints:-

Oil-based paint is more durable, but it takes longer to dry, and cleanup requires turpentine oil or paint thinner for its application.

Oil-based paints are made with either alkyd (synthetic) or linseed (natural) oils.

Generally termed as Enamel Paints which comes under Different varied colours.

Oil based paints are durable but it changes its original colour after the year passes.

Oil Based paints Comes In three Finishes i.e High gloss, satin and matt.

It can be used on walls, ceilings, doors, windows, mosquitoes mesh, Iron frames/Furniture, Wooden frames/Furniture's, Art craft Items etc.

Usually when paint on iron a red oxide coat is applied first to protect iron from getting rotten.

Uses of Oil Based Paints:-

Uses of Oil Based Paints:-

Variables of Oil Paints found In India:-

220RS/LTR

290RS/LTR

320RS/LTR

340RS/LTR

420RS/LTR

400RS/LTR

250RS/LTR

280RS/LTR

200RS/LTR

250RS/LTR

3000RS/LTR

350RS/LTR

Etc.

Cement Paint:-

1. **Cement paint** is water based **paint** and is applied to either exterior or interior walls including brick work and concrete.
2. It is used for **painting** exterior wall surface mainly for preventing water penetration and reductions of dirt collection.
3. There are limited shades of the colors offered.
4. It requires ample of water so that the cement paint can keep going.
5. It has to be used within two hours, else it can dry up and harden up like a rock.
6. Durable and water resistant.
7. It is extensively used for patios, garages, driveways, sidewalks, and concrete furniture.
8. It prevents growth of fungus and bacteria on exterior surfaces.
9. Comes in powder form.

Cement Paint:-

Process of Painting a new wall:-

Pre- Painting

Check the surface for incidence of dampness or water seepage.

Rectify the water seepage problem at source. This could mean repairing leaking pipes or cracks in the exterior walls.

Any loose plaster should be removed from the wall. Check for loose plaster by tapping on the walls. A hollow sound indicates loose plaster.

Process of Painting a new wall:-

Pre- Painting

Allow newly plastered surfaces to mature for a period of at least 6 months after the application of a coat, to ensure thorough drying of plaster .

Scrape with sandpaper to ensure that the surface is dry and free from dust, dirt or grease.

Cracked or flakes should be sealed Properly with sealant.

Process of Painting a new wall:-

Painting

Wall surface is to be Prepared using POP Or Wall Putty With Specialized Equipments and let it dry for 24 hours.

Sanding Of walls is done with sandpaper to make the base even and balanced.

Coats Of primer is applied on the surface using Brushes and Roller.

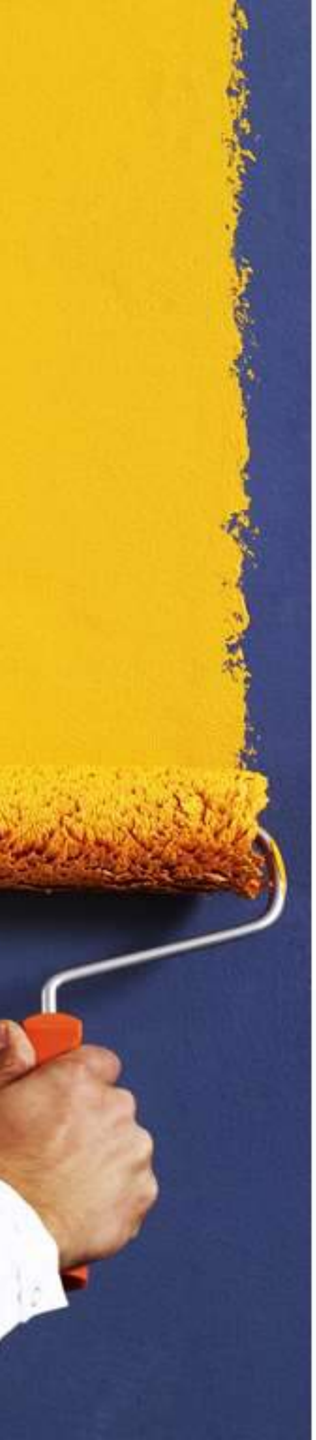
Process of Painting a new wall:-

Painting

A base of chalk powder mixed White enamel paint is applied on the walls to make it more smoother.

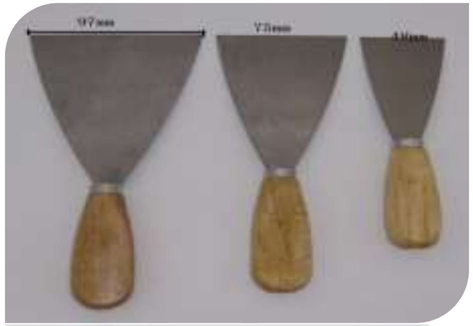
Sanding of walls is done with sandpaper to make the base even and balanced.

Second layer Of the same putty is applied to make it feel and look more smooth and balanced.



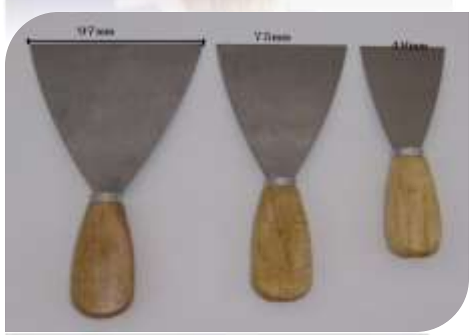
Process of Painting a new wall:-

Painting



Error are checked and repaired using the same chalk powder putty using Patti or Putty Knife followed by sanding of walls.

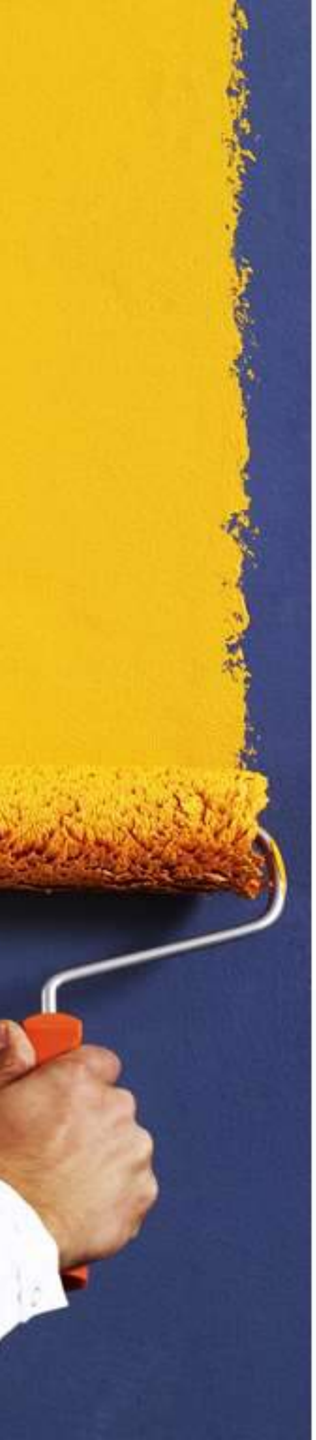
First Coat is applied on the walls in “W” formation with Roller and Brushes.



Error are checked and repaired with the same chalk powder putty using Patti or Putty Knife.

Process of Painting a new wall:-

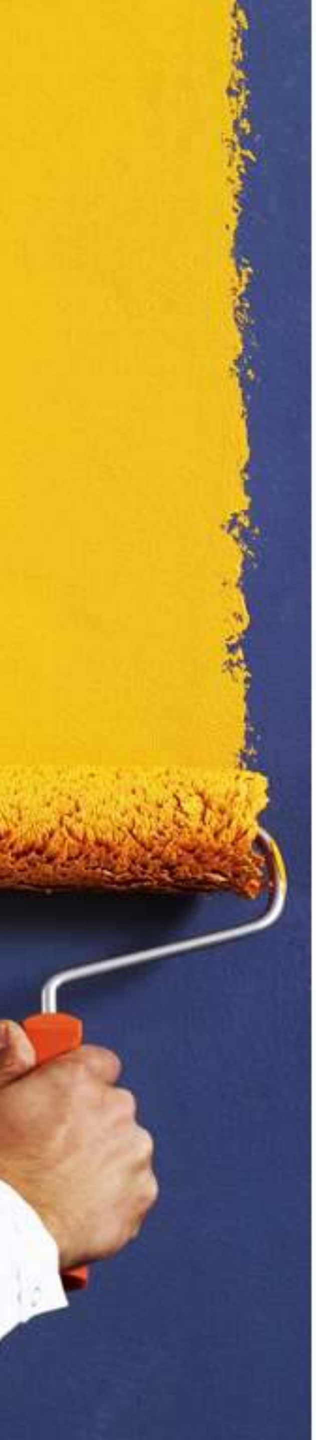
Painting



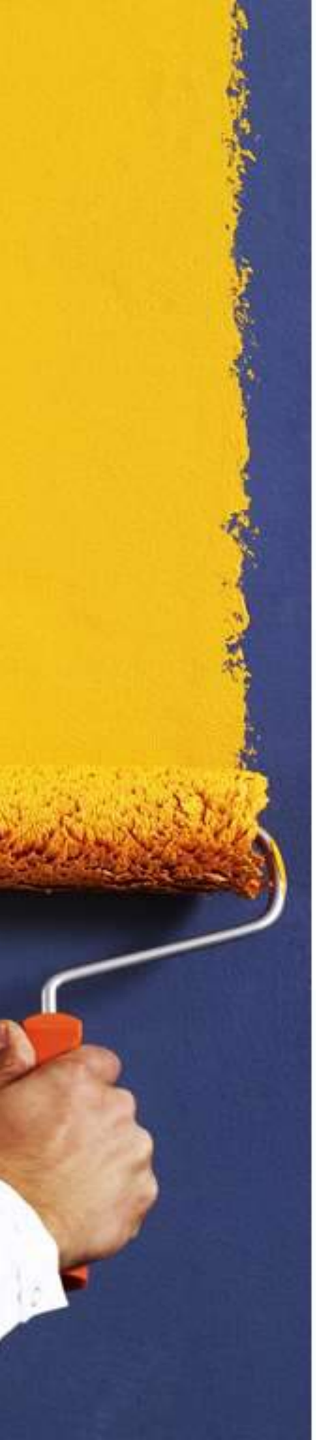
Second layer Of Paint is applied in the same W pattern.

Final Repairs are examined if any.

Final 3rd Coat is applied on the walls. To make the wall look Beautiful .



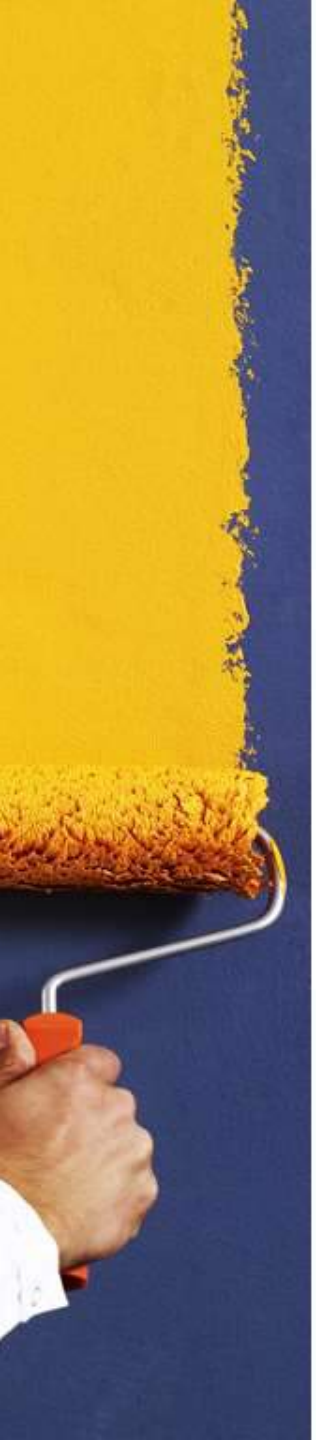
Final Presentation of walls after Painting Service:-



Characteristics of an ideal Paint:-

1. When applied to the surface, paint should form a thin film of uniform nature.
2. The colour of the paint should withstand the adverse environmental conditions for a long time.
3. It should be easily applicable with a brush or spraying devices.
4. It should have an attractive and pleasuring appearance.
5. The surface of the paint should not show cracks after drying.
6. It should be elastic. i.e. must be able to withstand change in temperature.
7. It should have ideal resistance to corrosion and protect the material over which it is used.
8. It should possess good spreading or covering power, as it determines the cost.
9. No marks of roller or brush should be visible in the form of bubbles or stripes.
10. Paint must not allow moulds and algae to grow on it.
11. It should not have any joints visible in between.

Defects found in Painting:-



Blistering

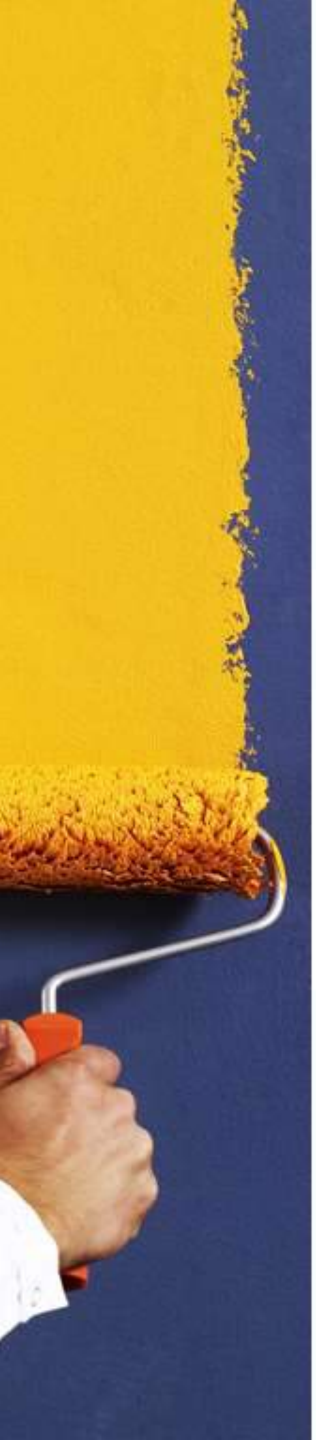
Fungus

Bittiness

Bleeding

Brush Marks

Chalking



Defects found in Painting:-

Cracking

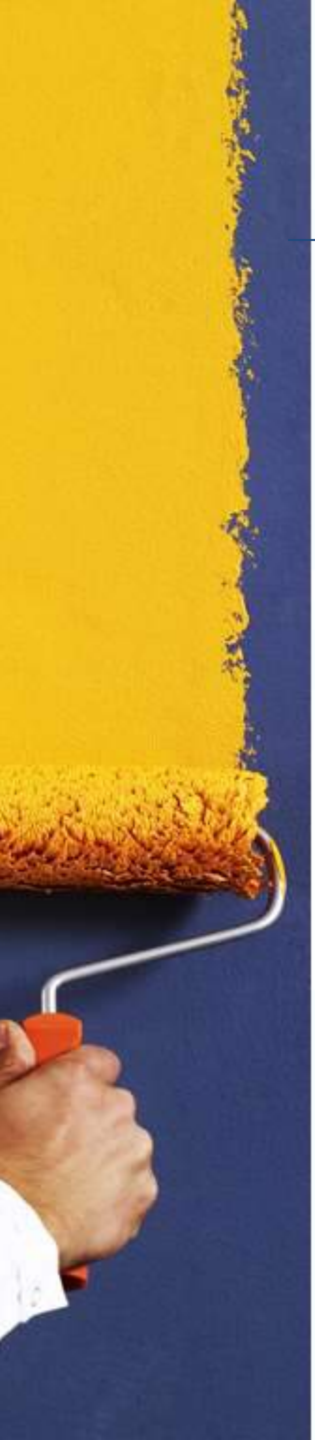
Efflorescence

Flaking

Patchiness

Peeling

Sagging



Causes of Failure in Painting:-

1. BAD WORKMANSHIP
2. CONDITIONS FOR PAINING
3. MOISTURE
4. SALTS AND ALKALIES
5. UNSUITABLE SURFACES
6. WRONG CHOICE OF PAINT
7. TOOLS OF PAINTING

Brands Offering Paints in India:-

asianpaints

Dulux

Since 1760
Lewis Berger
Paint your imagination

British Paints

SHALIMAR PAINTS

KANSAI NEROLAC PAINTS LIMITED

J&N PAINTS Jenson & Nicholson

NIPPON PAINT

Wood Finishes :-

Often, the **wood's** color is changed by staining, bleaching. Once the **wood** surface is prepared and stained, the **finish** is applied and this finish is termed as Wood Finish.

It usually consists of several coats of stainer, Sealer, drying oil, Filler, lacquer, varnish, or paint, and each coat is typically followed by Fine sanding.

There are different types of finishes available in the market from low range to high end collection as per customers requirement and budget and purpose of use such as:-

1. Lacquer Finish(Medium)
2. P.U Finish (High)
3. Polyester Finish (Premium High end)
4. Melamyne Finish (Medium)
5. Touch Wood Finish (Economical)
6. Enamel Finish (Economical)

Brands:- Sirca, Asian Paints, ICA, MRF, Berger, Dulux, Jeevan Jor , Duco, Wembley Etc.

Wood Finishes :-

Prices:

1. Lacquer Finish(Medium)
   Stainer= 200-350 rs per ltr, Sealer= 200-280rs per ltr
   Thinner= 100rs-180rs per ltr, Lacquer= 250-200rs per ltr.
2. P.U Finish (High)
   Stainer= 200-450rs per ltr, Sealer= 550-750 rs per ltr
   Thinner= 250rs per ltr, Top Coat= 1500 rs per ltr.
3. Polyester Finish (Premium High end)
   Stainer= 200-450rs per ltr, Sealer= 750-800 rs per ltr
   Thinner= 350rs per ltr, Top Coat= 2000 rs per ltr.
4. Melamyne Finish (Medium)
   Stainer= 200-350rs per ltr, Sealer= 250-350rs per ltr
   Thinner= 220rs per ltr, Top Coat= 310-350 rs per ltr.
5. Touch Wood Finish (Economical)
   Stainer= 25rs per 250gm, Sealer= 250-300rs per ltr
   Tarpetine Oil= 75-90 rs per ltr, Top Coat= 250 rs per ltr.
6. Enamel Finish (Economical)
   Enamel= 250rs per ltr, Tarpetine Oil= 75-90rs per ltr.

Wood Finishes :-

Process of Varnishing

Sand down the wood.

Repeat the sanding process with a progressively finer grain.

Inspect the wood to determine whether or not you're satisfied with the surface.

Wood Finishes :-

Process of Varnishing

Wipe down your wood and remove any dust.

Test the color before proceeding with a stain.

Apply the stain using a rag or a brush.

Wood Finishes :-

Process of Varnishing

Start by applying the stain in a small area, like a leg or a drawer front.

Continue applying the stain, and then wipe away the excess before it dries.

Pick a finish for your wood
Lacquer, touchwood, Melamine, PU, Polyester

Wood Finishes :-

Process of Varnishing

Apply one coat of base coat (Usually termed as Sealer) using a Compressor machine or a rag.

Sand it once again and match the Colours that is mismatched .

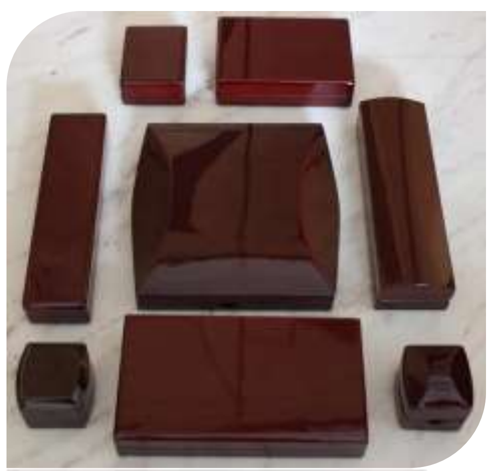
Apply 2nd coat of base coats using A Compressor machine or a rag.

Wood Finishes :-

Process of Varnishing

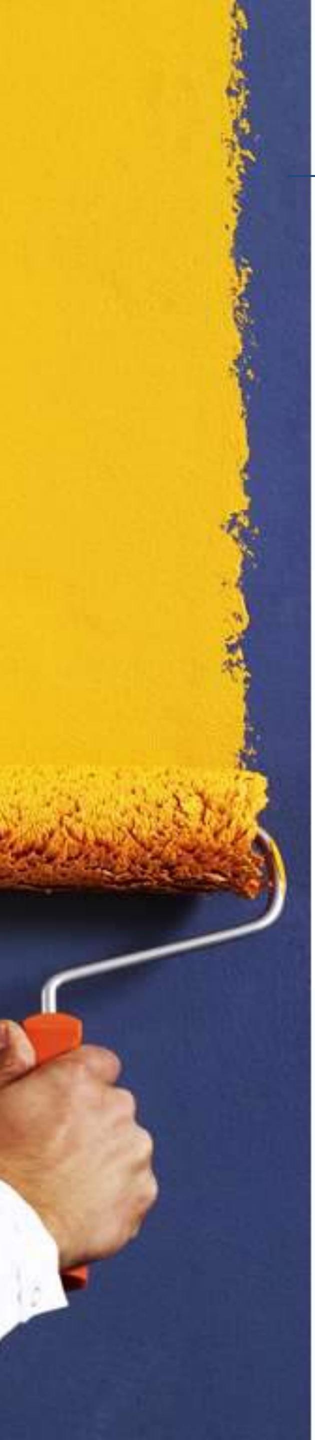
Sand it Once again for the last time
And match the colours using strainer.

Apply the final top Coat termed
As gloss, matt or satin matt or
Semi gloss



Final Product.

For Old wood work first Old paint or
polish is removed using paint
Remover and gloves then same
process is followed.



Characteristics of an ideal Varnish:-

1. When applied to the surface, it should form a thin film of uniform nature.
2. The colour of the stainer should withstand for a long time.
3. It should be easily Cleaned later on.
4. It should have an attractive and pleasuring appearance.
5. The surface of the Varnish should not show cracks or blurry whiteness after drying.
6. Must be able to withstand change in temperature.
7. It should possess good spreading or covering power, as it determines the cost.
8. No marks Should be Visible
9. It should not have any joints visible in between.
10. Grains should be visible to give it a natural look f done on wooden surface.
11. It should have a smooth surface after drying up
12. No dust particles should be there and no drop off of final coat should ne visible.

Brands Offering Wood finishes in India

Sirca
THE WOOD COATINGS

DUCO

asianpaints

Dulux

NIPPON PAINT

ICA

jivanjor
NAYA YUG. NAYA JOD

Berger
Paint your imagination

Paints

- Interiors
  - Walls
    - Distemper
    - Luster
    - Enamel
    - Emulsion
  - Metals
    - Enamel
  - Wood
    - Wood Finish
- Exteriors
  - Emulsion
  - Textured
  - Cement

Some Imp. Tools Required For Painting

Brush

Crack Seal

Roller

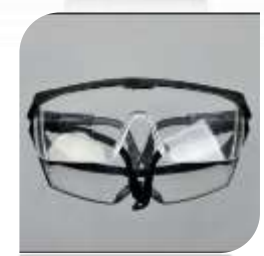
Sand Paper

Thinner

Turpentine Oil

Patti

Masking Tape



Glasses

Some Imp. Tools Required For Painting

Ladder

Cling Wrap

Wall Putty

Spray Gun

Compressor

Water

Some Imp. Tools Required For Painting:-

Tray

Dhoti

Primer

Chalk Powder

Plaster of Paris

Cleaner

Wallpapers:-

Wallpaper is a kind of material used to cover and decorate the interior walls of homes, offices, cafes, government buildings, museums, post offices, and other buildings.

It has Transformed the Practice of Wall paint job.

It is very easy to paste and save a lot of time and money.

Does not require much of maintenance.

It is usually sold in rolls and is put onto a wall using wallpaper paste.

In practice from 18^{th} century to today's world. Established in Europe.

Usually Made up of vinyl coated paper .

Kinds of Wallpapers:-

1. Painted wallpaper
2. Printed block wood wallpaper
3. Hand-printed stencil wallpaper
4. Machine-printed wallpaper
5. Flock wallpaper (Classy,Royal)
6. Custom wallpaper
7. High-tech wallpaper
8. Seismic wallpaper
9. Artistic wallpaper
10. Water proof
11. Scratch proof

Application of Wallpapers:-

Like paint, wallpaper requires proper surface preparation before application. Additionally wallpaper is not suitable for all areas.

For a better finish , Thinner papers on poorer quality walls can be cross-lined with lining paper first .

Wallpaper is pasted using Wallpaper adhesives.

Removal of wallpaper:

1. **Water**
2. **Chemical wallpaper stripper**
3. **Steam**

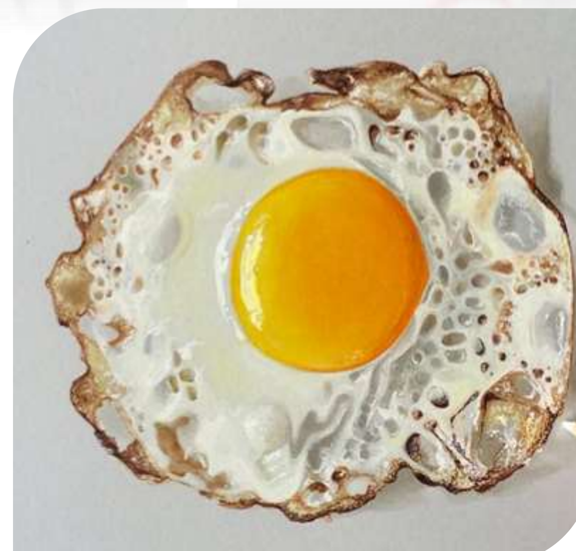
Sizes Available :

27 inches by 27 feet

21.5 inches by 33 feet

Designs of Wallpapers:-

Designs of Wallpapers:-



Sushant S Rane

PRESENTATION ON

PAINTS,VARNISHES AND DISTEMPERS

PAINT

A Paint is a Solution or suspension (emulsion) of pigment, binder, and mineral solvent (or water) that on drying forms an adhering film on the surface it is applied for protection and/or decoration.

CONSTITUENTS OF AN OIL

An oil paint is generally made up of six main constituents given below:

a. A base

b. An inert filler or extender

c. Colouring pigment

d. A vehicle

e. A solvent or thinner

f. A drier

CHARACTERISTICS OF A GOOD PAINT

A good paint should have the following characteristics:

1. It should stick well to the surface and should be able to seal the porous substrata.
2. Its consistency should provide easy workability .
3. The thickness of the paint film should be adequate for good protection and decoration of the surface.
4. The paint film should dry rapidly.
5. The dried paint film should be able to withstand the adverse weather effect for a long time without losig gloss.
6. It should offer resistance to failure by checking ,cracking and flaking.
7. It should posses good moisture resistance.
8. Its colour should not fade with the passage of time.

BASES

The pigments commonly used as the principal constituents for forming the body of various types of paints are given below:

1. White lead
2. Red lead
3. Lead
4. Zinc white or zinc oxide
5. Iron oxide
6. Titanium white or titanium dioxide
7. lithopone

VEHICLE

The vehicles commonly used in an oil paint are briefly described below:

1. Linseed oil
2. Raw linseed oil
3. Boiled linseed oil
4. Double boiled linseed oil
5. Poppy oil
6. Tury oil
7. Nut oil

COLOURING PIGMENTS

Colouring pigments are used to give the desired colour to the paint. The colouring pigments generally used are given below:

a. Black pigments : lamp black, vegetable black, graphite.
b. Brown pigments :Raw umber, burnt umber.
c. Blue pigments: Prussian blue, ultramarine blue.
d. Yellow pigments: chrome yellow, yellow ochre.
e. Red pigments: Indian red, red lead.
f. Green pigments: Green earth, chrome green.

TYPES OF PAINTS

1. Aluminium paints
2. Anti-corrosive paints
3. Asbestos paints
4. Bituminous paints
5. Bronze paints
6. Cellulose paints
7. Casein paints
8. Cement based paints
9. Enamel paints
10. Oil paints
11. Rubber base paints

ALUMINIUM PAINTS

ANTI-CORROSIVE PAINTS

ASBESTOS PAINTS

CEMENT BASED PAINT

OIL PAINTS

PROCESS OF PAINTING DIFFERENT SURFACES:

The process of painting on new wood work can be divided into the following stages:

01. Preparation of surface

02. Knotting

03. Priming

04. Stopping

05. Surface coats or under coatings

06. Finishing coat

PAINTING WITH BRUSHES

Prior to painting ,the loose bristles should be removed by taping the brush gently against the palm of hand ,twirling it rapidly between the palms of hand and finally putting the loose bristles out .The brush should not be dipped too deeply in the paint, and the excess paint should be removed by gently rubbing the brush against the inside surface of the paint pot.

SPRAY PAINTING

Painting with the spray gun is considered to be a highly developed and efficient method of applying all types of protective coatings. There is also economy in labour and the consumption of material as only two coats of spray are considered sufficient to obtain the desired finish .The process of painting with spray machine may be summarized as below.

VARNISH

Varnish is a clear, pale solution of a resinous substance (like amber, common resin, copal, lac or shellac) dissolved in either oil, turpentine or alcohol. Varnish plays an important role in finishing wooden surfaces of doors, window, floors etc.

TYPES OF VARNISH

1. Oil varnish
2. Spar varnish
3. Flat varnish
4. Asphalt varnish
5. Spirit varnish

OIL VARNISH

SPAR VARNISH

FLAT VARNISH

ASPHALT VARNISH

SPIRIT VARNISH

FURNITURE POLISH

The following mixture will be made an excellent furniture polish:

MATERIAL	QTY REQUIRED
01.Linseed oil	16 litre
02.Methylated spirit	2 litre
03.Vinegar	1litre
04.Turpentine	1litre
05.Copal varnish	1litre
06.Muriatic (hydrochloric acid)	0.75litre

DISTEMPERS

Distempers may be defined as water paints consisting of whiting (powdered chalk), some colouring pigment (if desired) and glue size mixed in water.

Distemper may give either a washable or non-washable surface according to the medium used.

They are cheaper than paints and varnishes and are easier to work.

DISTEMPERING WITH DRY DISTEMPER

The new plaster is allowed to dry for at least two months before applying distemper. However, incase of old surfaces ,all dust ,dirt, scales and greasy marks should be removed and all the holes and cracks should be filled with plaster of Paris mixed with dry distemper of the colour to be used. A coat of whiting is then applied over the prepared dry-clean surface which acts as the priming coat for the distemper. The dry distemper is then converted into a liquid by mixing it with water and stirring it well .As a rule 0.6 litre of water should be used per kg. of distemper.

OIL BOUND DISTEMPER

A distemper or water based paint that contains some drying oils to enhance its spreading and drying characteristics .It is form of distemper in which the drying oil is rendered mixable with water. The distemper in pasty form is available in different shades in sealed tins.

CASEIN PAINTS

Casein is a protein substance derived from milk curds. Casein paint is made by working a mixture of finely ground casein (which acts as a binder) with a base of white pigment which is usually slaked lime, and is sold in powdered or paste form in sealed tins. Casein paints , on account of their high opacity , give pleasing results in one coat. They are applied on new plaster without any danger of blistering, scaling or any adverse effect of free alkali.

INTRODUCTION

Bitumen is an oil based substance. It is a semi-solid hydrocarbon product produced by removing the lighter fractions (such as liquid petroleum gas, petrol and diesel) from heavy crude oil during the refining process.

CHEMICAL COMPOSTION OF BITUMEN-

- Bitumen is a mixture of about 300 - 2000 chemical components, with an average of around 500 - 700. Elementally, it is around 87 to 92% carbon and 6 to 8%hydrogen , and up to 5% sulphur, 1% nitrogen, 1% oxygen.

PROPERTIES OF BITUMEN

- Adhesion
- Water Resistance
- Hardness
- Viscousity

TYPES OF BITUMEN AND ITS USE

TYPE-

- Penetration Grade
  Bitumen 80/100
  Bitumen 60/70
  Bitumen 30/40
- Industrial grade bitumen
- Cutback
- Bitumen Emulsion
- Modified Bitumen
- Viscosity grade Bitumen

USE-

- In construction of roads , runways & platforms .
- In water proofing.
- In canal lining to prevent erosion.
- Damp proof courses for masonry.
- Mastic flooring for factories & godowns .
- In tank foundation.


BITUMEN ROAD

TEST OF BITUMEN

- Penetration Test
- Softening Point Test

PENETRATION TEST

Peneration is conducted
with the help of
PENETROMETER
Apparatus.

SOFTENING POINT TEST

- Sofnening point test is conducted with the help of Rings & Ball Test Appratus.

Ceramics

- One of the largest groups of materials with the properties of nonmetals and all are made by firing or burning, often including silicates and metal oxides.
- Greek term *Keramos*, meaning "a potter" or "pottery”.

Ceramic materials are attractive for several reasons :

- Cheap in terms of its starting materials.
- Compared to metals, lightweight and retain their strength up to 1000˚C where metals tends to fail.
- They have electrical, optical, and magnetic properties of value in the computer and electronic industries.

History

- The art of making pottery by forming and burning clay has been practiced from the earliest civilizations.
- Burnt clayware has been found dating from about 15,000 B.C. and as well developed as an industrial product in Egypt by about 5000 B.C.
- Formed glass dates from the period 7000-5000 B.C. and was a stable industry in Egypt by about 1500 B.C.

Ceramics Industry

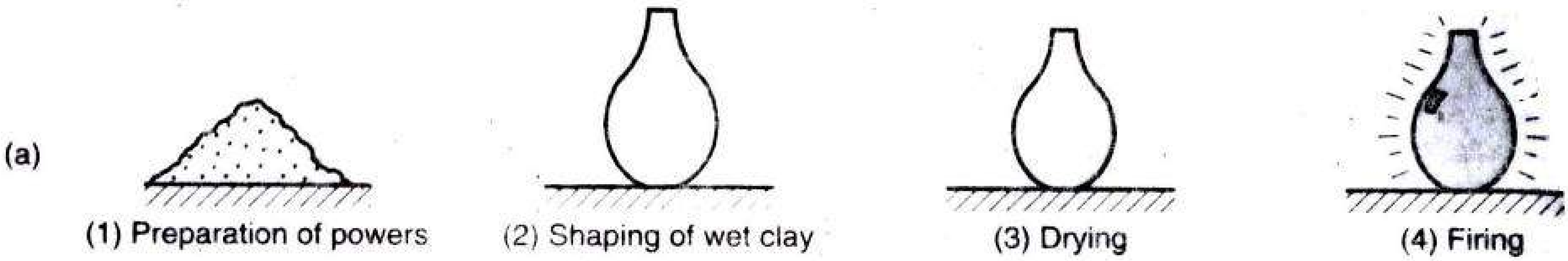
- ❖An important characteristic of the ceramics industry is that it is basic to the successful operation of many other industries.
- ❖In the Philippines, smuggled ceramics has cause severe effect on the ceramic industry locally. But exporting of ceramic materials is significantly increasing.

Uses of Ceramics

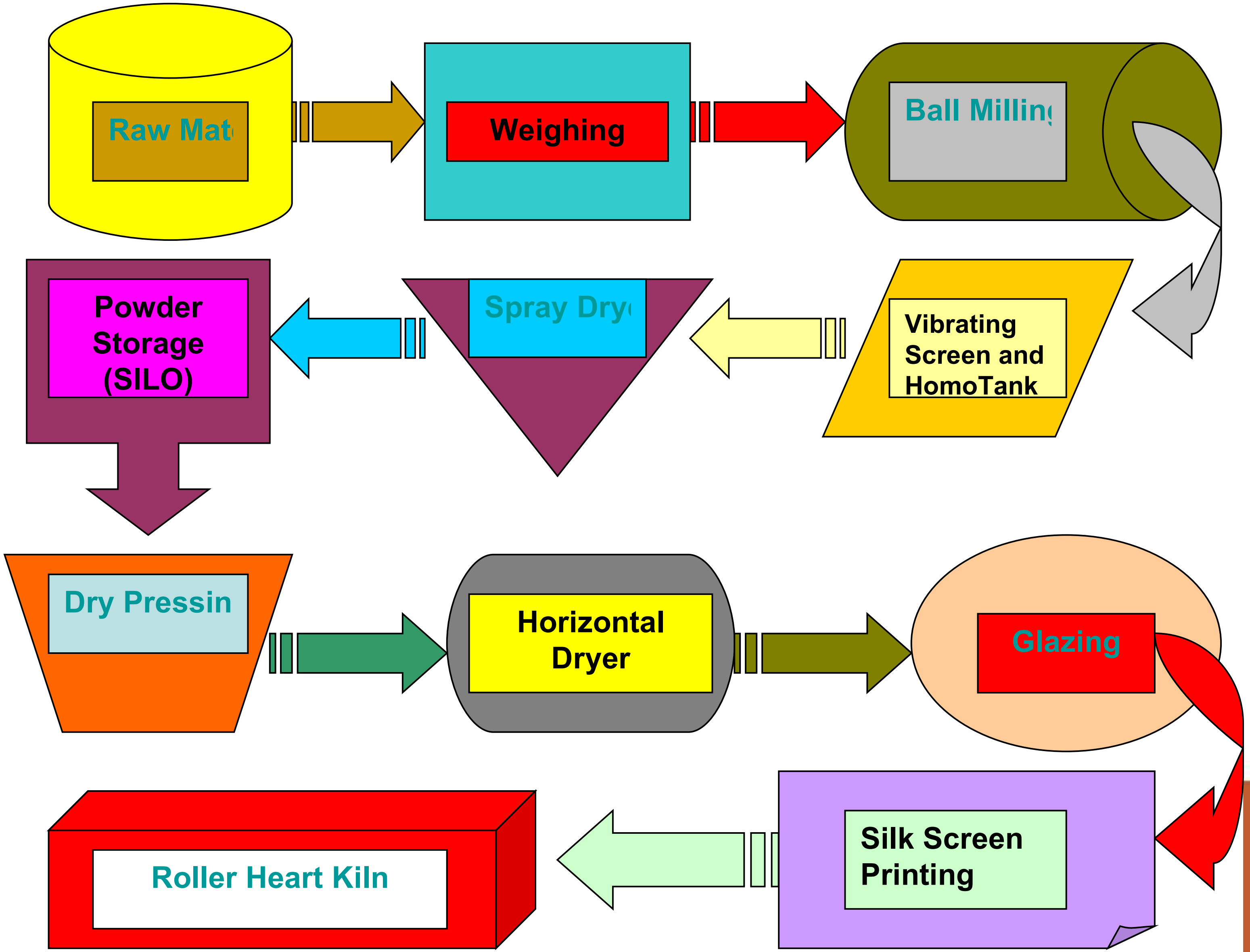
- The ceramics industry is divided in the manufacture of the ff. products:
  - Structural Clay Products
  - Whitewares
  - Refractories
  - Glasses
  - Abrasives
  - Cements
  - Advance Ceramics
    - -Structural
    - -Electrical
    - -Coating

Classifications of the Ceramics

- Traditional Ceramics
- New Ceramics



Ceramic Tile Processes



Raw Materials

- The traditional ceramics industry is largely based on various combinations of clay minerals, feldspar and silica.
- The mineral raw materials used in the ceramic industry are mainly inorganic, nonmetallic, crystalline solids formed by complex geologic processes.

Raw Materials

- Oxygen, silicon, and aluminum together account for 90% of the elements in the earth’s crust , These, together with other minerals compounds of oxygen, constitute the greatest bulk of naturally occurring ceramic raw materials.

Raw Materials

- Clay Minerals
- Talc and Related Minerals
- Silica and Silicate Minerals
- Feldspars and related minerals.
- Refractory Raw Materials

Talc

Silica

Clay

Common Types of Clay

- ❖ Kaolin or China Clay
- ❖ Ball Clays
- ❖ Fire Clays
- ❖ Flint Clays
- ❖ Pottery Clay
- ❖ Shale
- ❖ Vitrifying Clays
- ❖ Brick Clays
- ❖ Slip Clays

Important Characteristics of Clays in Ceramic Bodies

- Clays have the ability to form clay-water composition and to maintain their shape and strength during drying and firing
- They fuse over a temperature range depending on their composition in such a way as to become dense and strong without losing their shape

Talc and Related Minerals

- Talc is a hydrous magnesium silicate which has a layer structure similar to that of the clay minerals.
- It is an important ceramic raw material for the manufacture of electrical and electronic components

Talc and Related Minerals

- Pyrophyllite
- Block talc
- Asbestos

Silica and Silicate Minerals

- Silica is a major ingredient in glass, glazes, enamels, refractories, abrasives, and whiteware compositions.
- It is widely used because it is inexpensive, hard, chemically stable

Silica and Silicate Minerals

- The major source of silica for the ceramic industry is sandstone, consisting of lightly bonded quartz grains.
- The sand is frequently mined by loosening the quarts grains with a stream of high-pressure water.

Feldspars and Related Minerals

- Feldspar are anhydrous aluminosilicates containing K+, Na+, and Ca2.; they are present in virtually all igneous rocks.
- Most production comes from pegmatites which are coarsely crystalline rock formed in the later stages of crystallization of a magma

Feldspars and Related Minerals

- Nepheline syenite
- Wollastonite
- Sillimanite

Sillimanite

Nepheline syenite

Wollastonite

Refractory Raw Materials

- Alumina
- Magnesia
- Dolomite
- Chrome Ore

Alumina

Magnesia

Dolomite

Chrome Ore

Other Raw Materials

- Soda ash
- Borate minerals
- Fluorspar
- Phosphate minerals
- Abrasive raw materials

Soda Ash

Flourspar

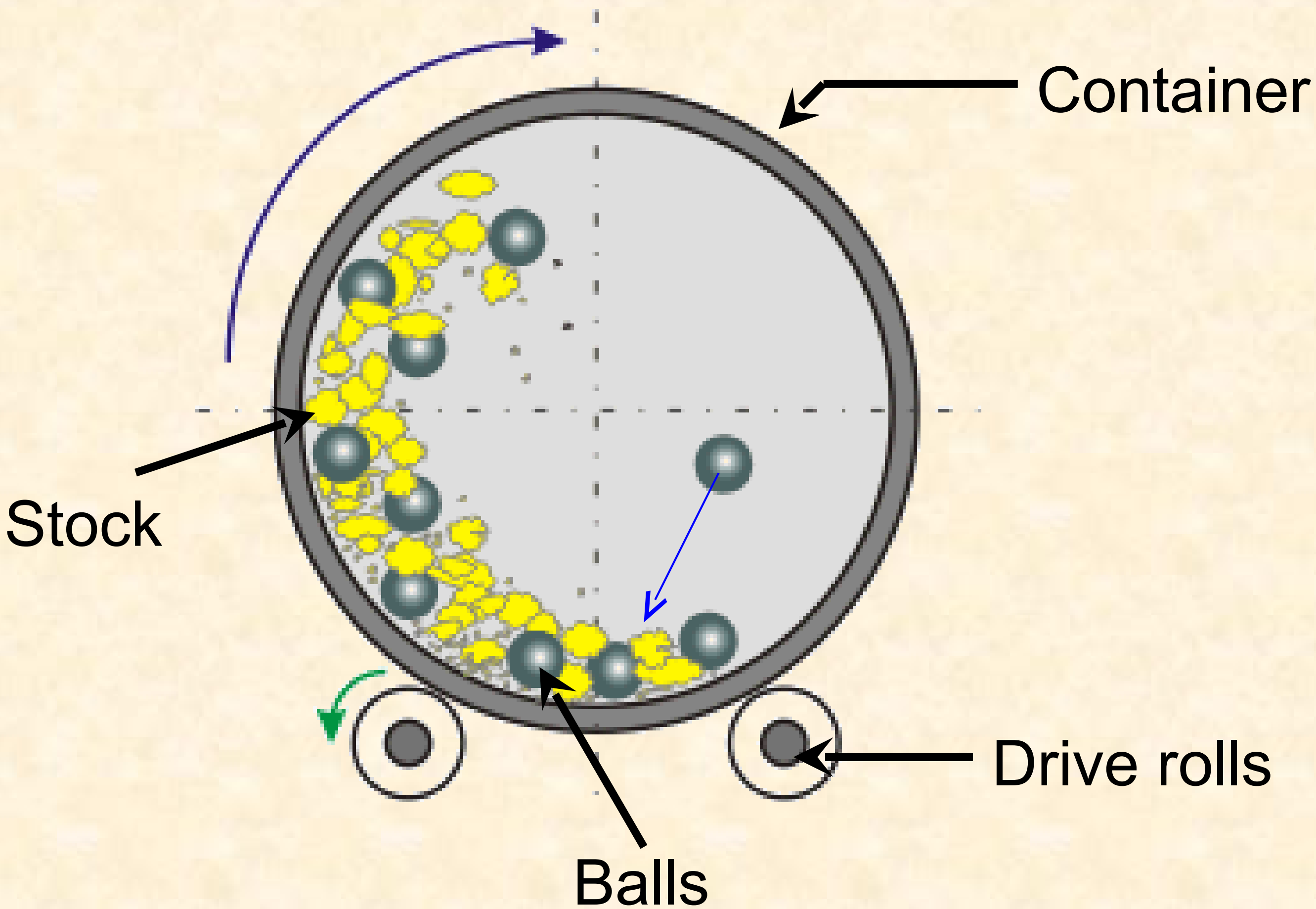
Borate Minerals

Ball Milling

- Spheres mixed with the stock to be comminuted are rotated inside a large cylindrical container.

- These operations are often carried out with water

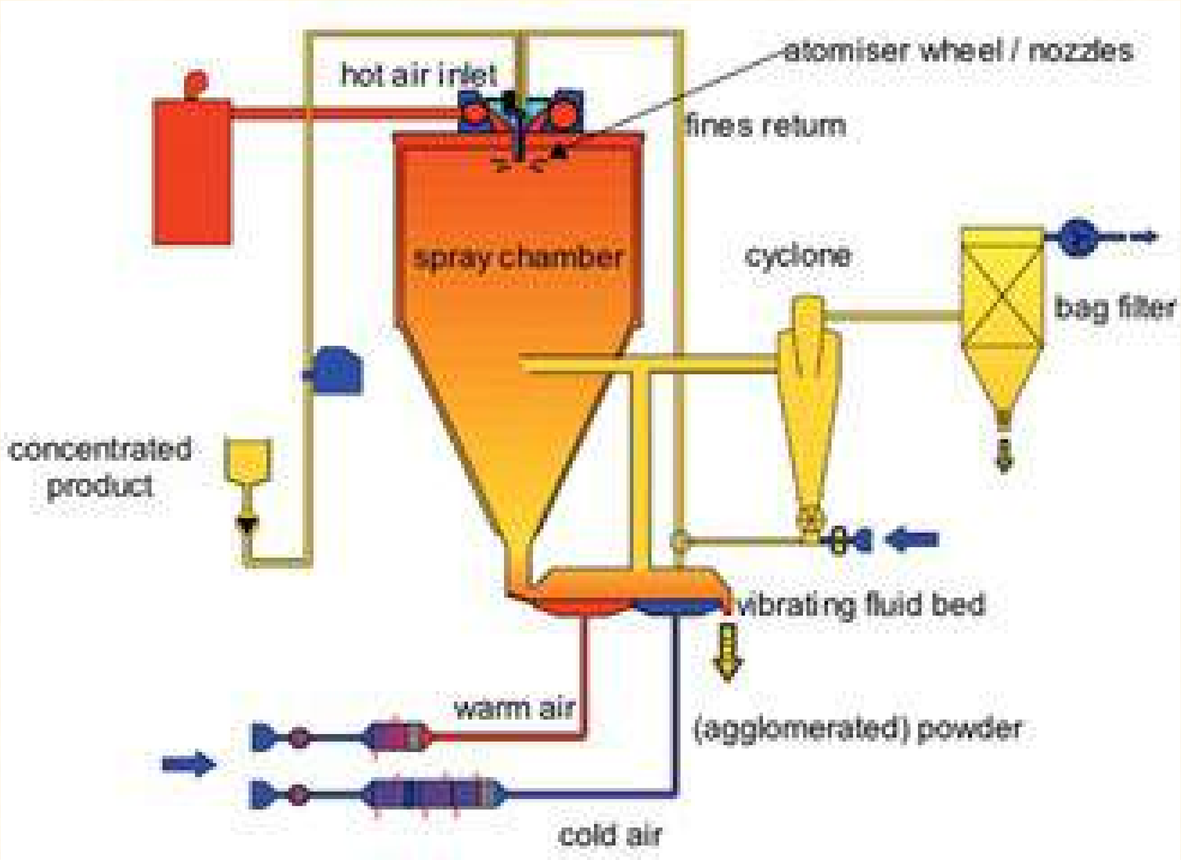
Ball Milling



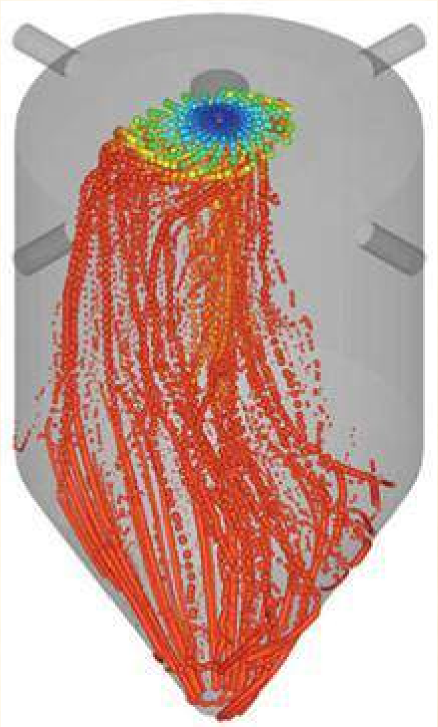
Spray Dryer

- Characterized by atominization of a solution or suspension into droplets, followed by drying.

Spray Dryer



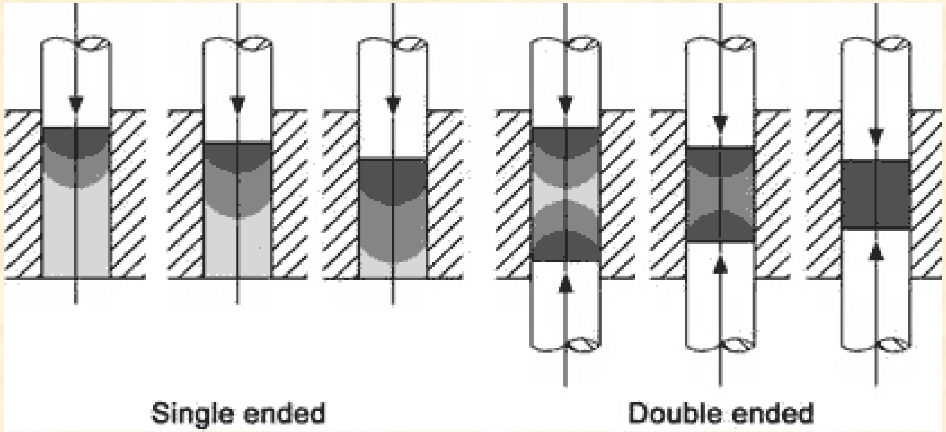
Schematic Diagram of Spray Dryer



Particle Trajectory

Dry Pressing

- Forming of the "greenware" tile body.
- Non-clumping granulates are compressed in steel dies designed appropriately for the part to be manufactured.

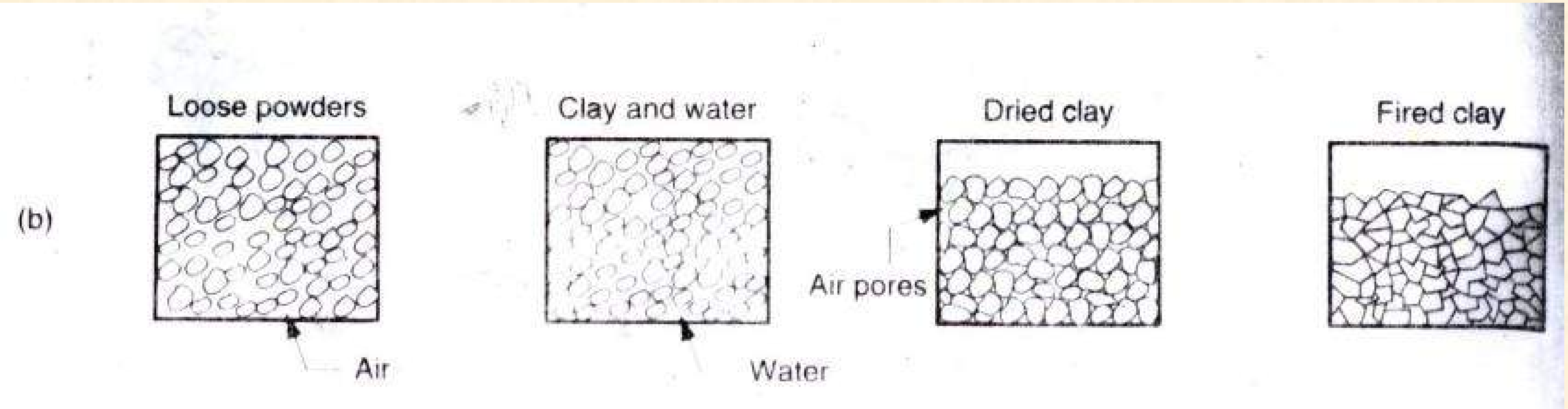


Glazing

- The application of glassy coatings on ceramic wares to give them decorative finishes and to make them impervious to moisture

Roller Hearth Kiln

- A roller tunnel kiln for firing a drying refractory material advanced along the refractory rotatable rollers includes an upper section comprising a prefiring zone, a firing zone, a first forced cooling zone, a natural cooling zone and a second forced cooling zone.



Roller Hearth Kiln

Firing zone

Gear system

Entrance

Traditional Ceramic Processes

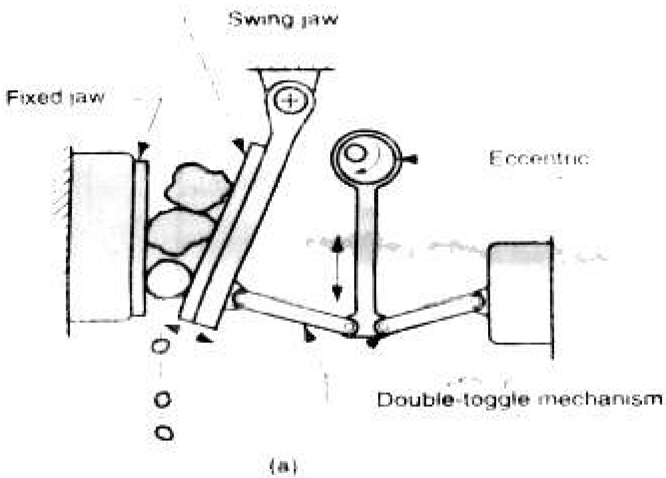
A. Preparation of Raw Materials

- Crushing

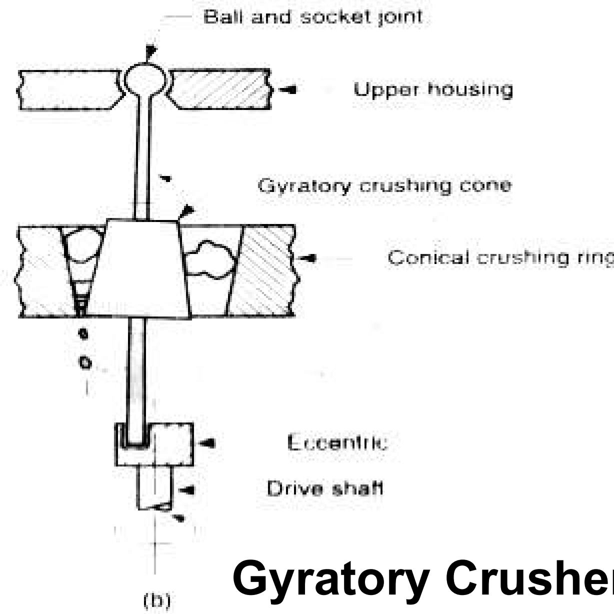
  Types of Equipments Used

  a) Jaw Crushers
  b) Gyratory Crushers
  c) Roll Crushers
  d) Hammer Mills

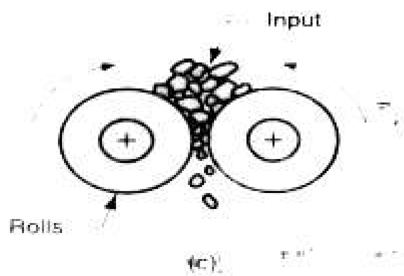
Crushing



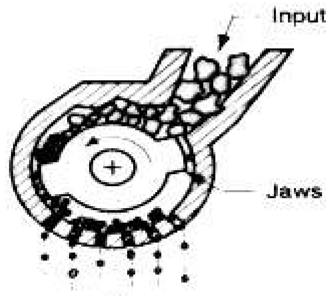
Jaw Crusher



Gyratory Crusher



Roll Crusher



Hammer Mill

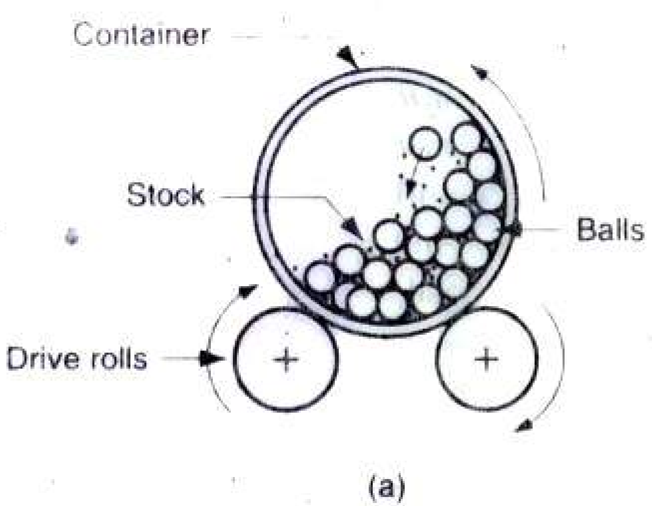
Traditional Ceramic Processes

- Grinding

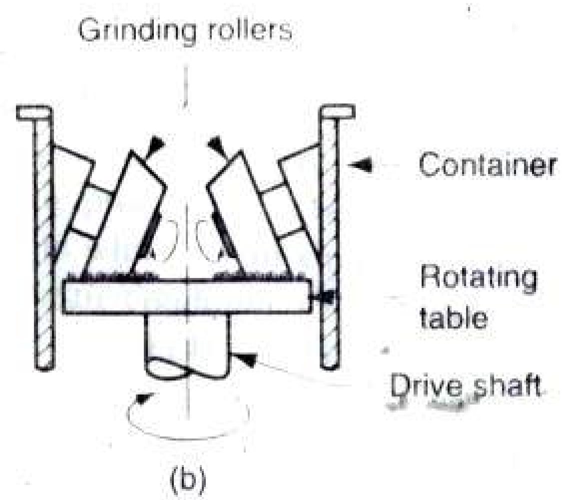
  Types of Equipments Used

  a) Ball mill
  b) Roller mill
  c) Impact grinding

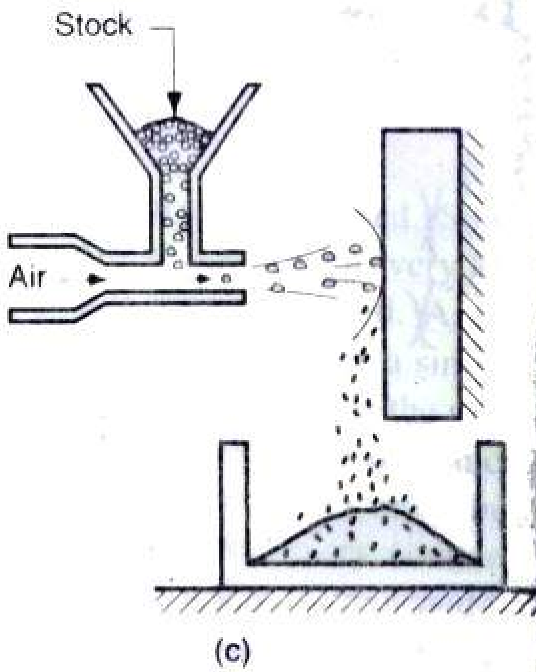
Grinding



Ball Mill



Roller Mill



Impact Grinding

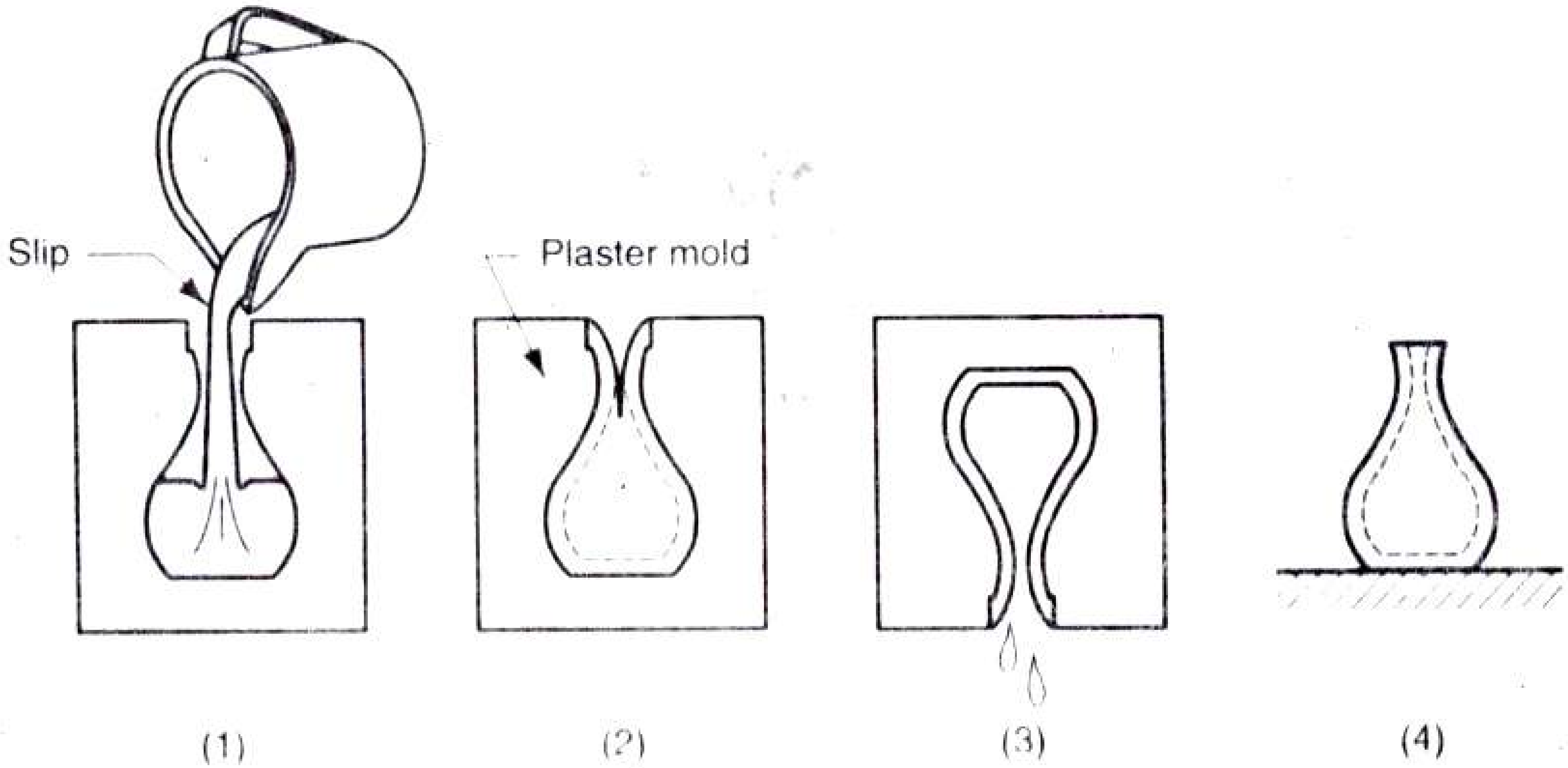
Traditional Ceramic Processes

B. Shaping Processes

a) Slip Casting
   1. Drain Casting
   2. Solid Casting

b) Plastic Forming
   1. Manual Forming
   - Hand modeling
   - Hand molding
   - Hand throwing

Drain Casting



Traditional Ceramic Processes

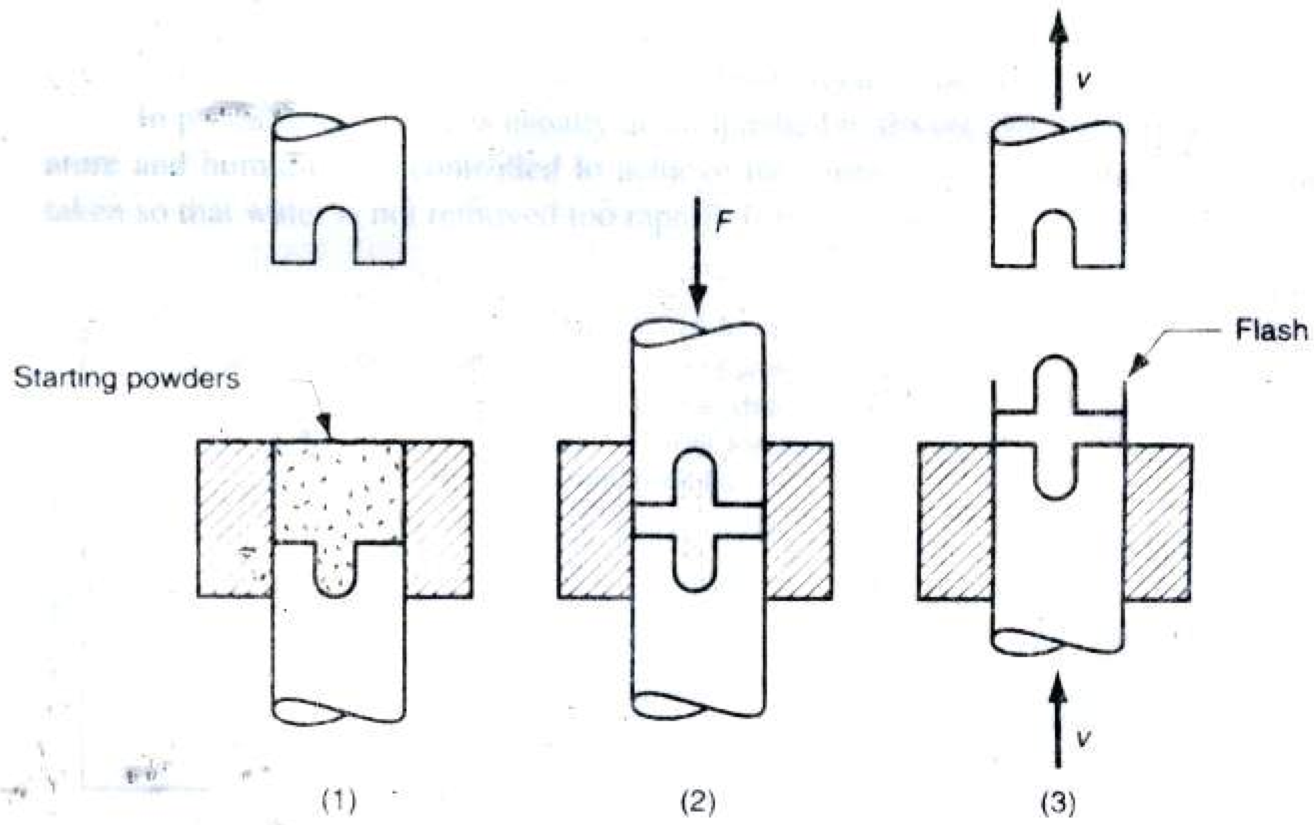
1. Mechanized

- Jiggering
- Plastic pressing
- Extrusion

a) Semi-dry Pressing

c) Dry Pressing

Semidry Pressing



Traditional Ceramic Processes

A. Drying

C. Firing

E. Glazing

New Ceramic Processes

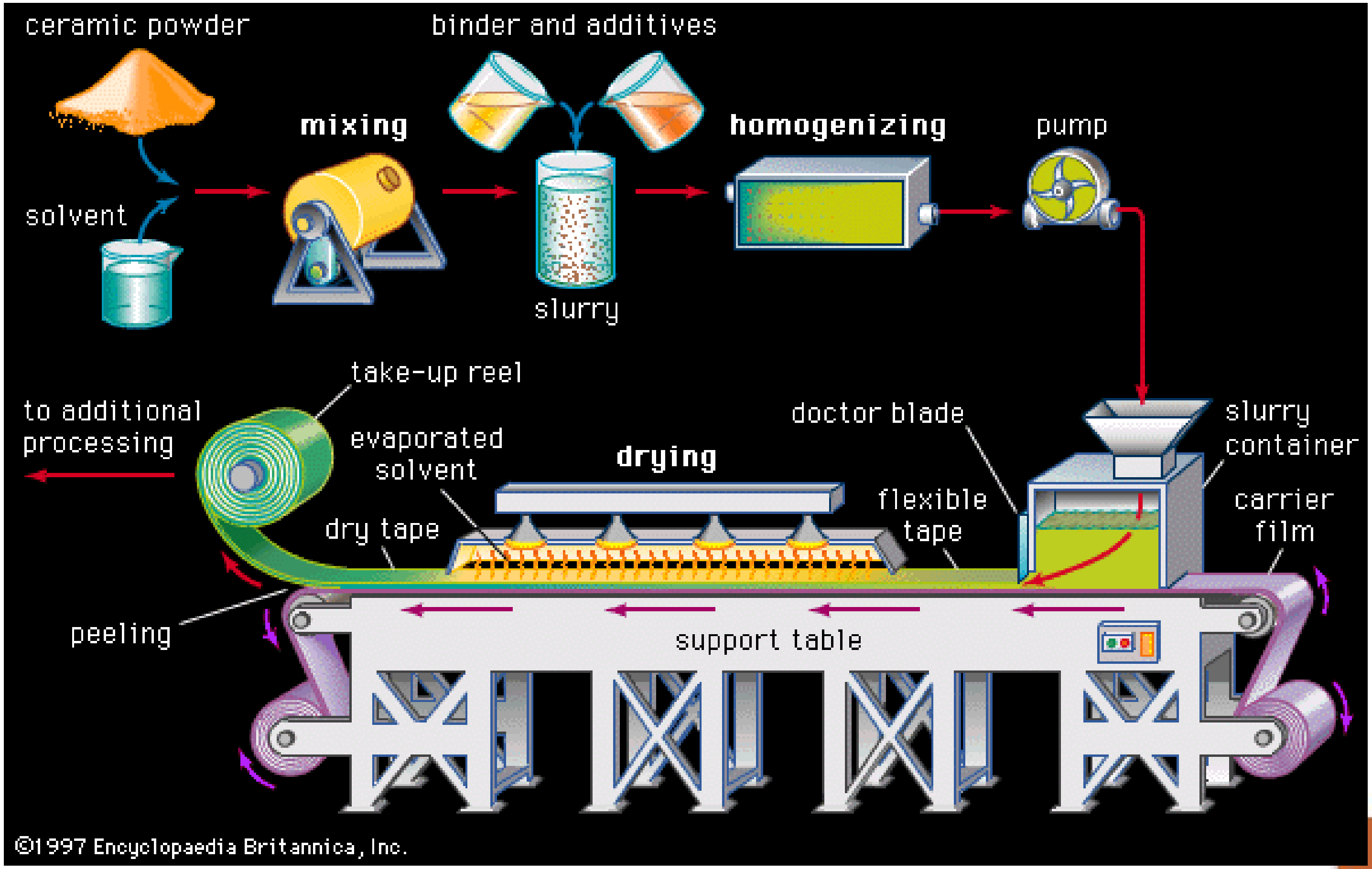
A. Preparation of Raw Materials
   1. Freeze Drying
   2. Precipitation from solution

B. Shaping
   1. Hot pressing
   2. Isostatic pressing
   3. Doctor-blade process
   4. Injection molding

New Ceramic Processes

A. Sintering
   1. To bond individual grains into a solid mass
   2. To increase density
   3. To reduce or eliminate porosity
B. Finishing
   1. To increase dimensional accuracy
   2. To improve surface finish
   3. To make minor changes in part geometry

New Ceramic Processes



Doctor blade Process

Factors Affecting Ceramic Process

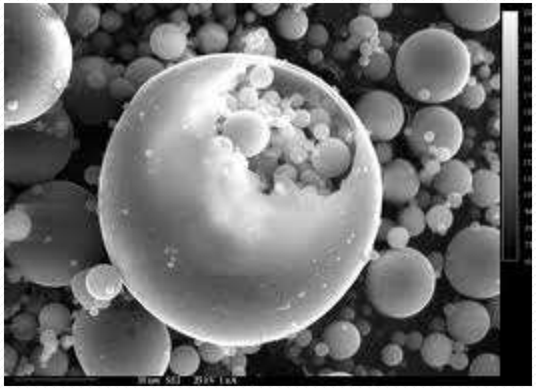
- Oxidation
- Decomposition Reactions
- Phase Transformations
- Trapped Gases
- Non uniform Mixing
- Over firing
- Hot Pressing

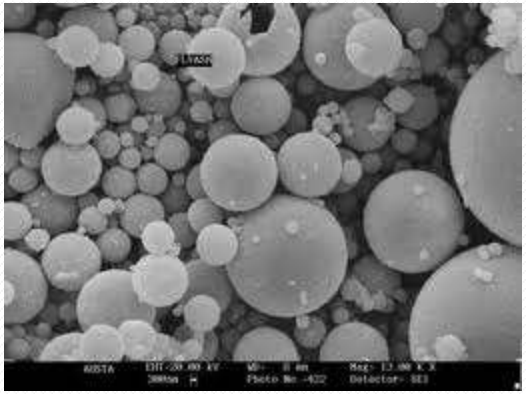
Common Errors in Ceramic Process

- ❖Firing Shrinkage
- ❖Warping

FLY ASH-INTRODUCTION

- Fly ash is a fine powder produced as a product from industrial plants using pulverized coal or lignite as fuel.
- It is the most widely used pozzolan siliceous or aluminosiliceous in nature in a finely divided form.
- They are spherical shaped “balls” finer than cement particles.





FLY ASH AS A SUPPLEMENTARY:

Apart from technical advantages it attributes to the concrete properties, fly ash has its own benefits

- **Problem of disposal:**

  In India alone, we produce 75 million tons of fly ash every year, the disposal of which has become a serious environmental problem. The effective use of fly ash in concrete making is therefore attracting serious considerations of concrete technologists and government departments.

Global CO_2 emissions:

- Global cement production is about 1.3 billion tons in 1996 and production of every 1 ton of cement emits 0.87 ton of carbon dioxide.

- In broader terms, 7% of global CO_2 emissions can be attributed to Portland cement industry.

FLY ASH IN CONCRETE:

- **Fly ash could be an expensive replacement for Portland cement in concrete and using it, improves strength, segregation and ease of pumping concrete.**

The rate of substitution typically specified is a minimum of 1 to 1 ½ pounds of fly ash to 1 pound of cement

- **Fly Ash particles provide a greater workability of the powder portion of the concrete mixture which results in greater workability of the concrete and a lowering of water requirement for the same concrete consistency**.

CHEMICAL COMPOSITION

MATERIALS	PORTLAND CEMENT%	FLY ASH%
SiO_2	21.82	53.39
Al_2O_3	6.49	16.07
Fe_2O_3	1.93	13.05
CaO	60.74	6.33
MgO	1.08	5.48
SO_3	2.62	1.06
Na_2O	0.14	1.59
Free Cao	0.84	0.11

1. fly ash are amorphous (glassy) due to rapid cooling; those of cement are crystalline, formed by slower cooling.
2. Portland cement is rich in lime (CaO) while fly ash is low. Fly ash is high in reactive silicates while Portland cement has smaller amounts

COMPARISON BETWEEN CLASSES OF FLY ASH

CHEMICAL COMPOUND	POZZOLAN TYPE			CEMENT
	CLASS F	CLASS C	CLASS N	
SiO	54.90	39.90	58.20	22.60
Al_2O_3	25.80	16.70	18.40	4.30
Fe_2O_3	6.90	5.80	9.30	2.40
CaO	8.70	24.30	3.30	64.40
MgO	1.80	4.60	3.90	2.10
SO_3	0.60	3.30	1.10	2.30
Na_2O & K_2O	0.60	1.30	1.10	0.60

- **Class F is fly ash produced from burning anthracite or bituminous coal, and Class C is produced from the burning of sub-bituminous coal and lignite.**
- **Class F is low in lime, under 15 percent, and contains a greater combination of silica, alumina and iron (greater than 70 percent) than Class C fly ash.**
- **Class C fly ash comes from coals which may produce an ash with higher lime content — generally more than 15 percent often as high as 30 percent. Elevated CaO may give Class C unique self-hardening characteristics.**

PHYSICAL ASPECTS:

The fly ash from boilers where mechanical collectors are used is coarser than fly ash from electrostatic precipitators.

- The color varies from light to dark grey depending upon its carbon contents.
- The quality of fly ash varies from source to source.
- fly ash particles are small, they effectively fill voids

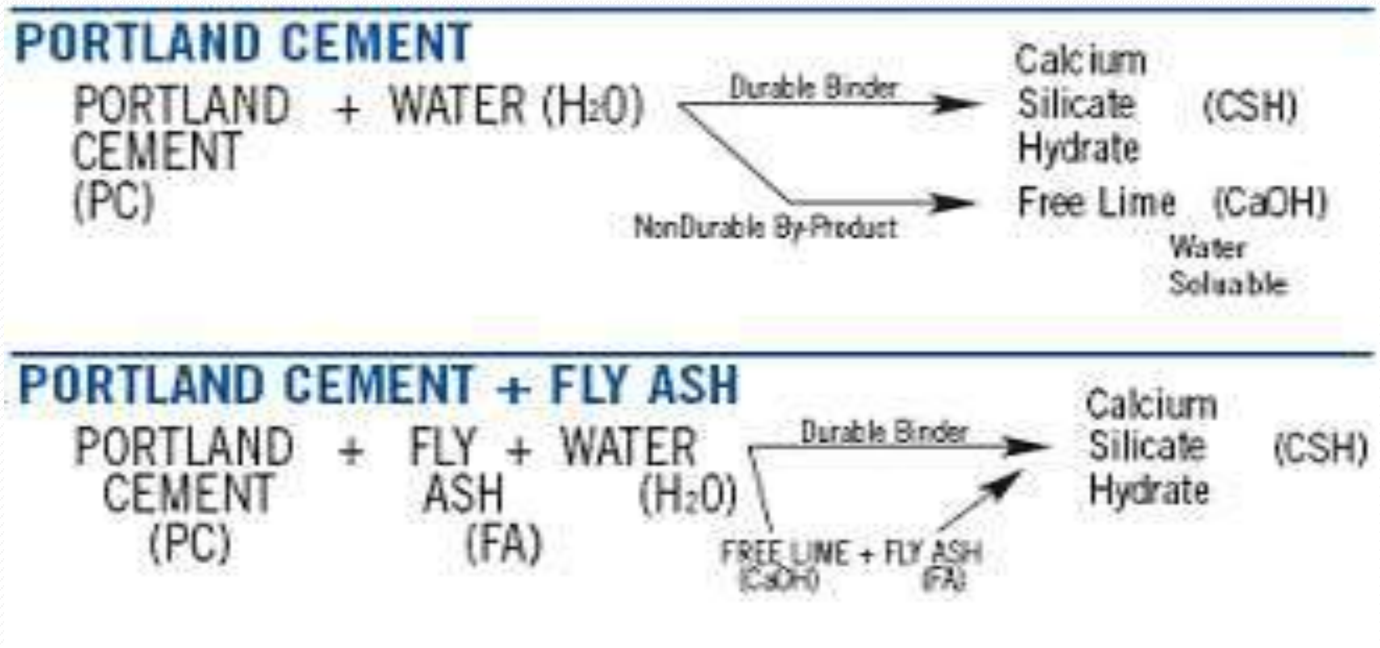
Though fly ash offers environmental advantages it also improves the:

- performance and quality of concrete.
- Fly ash affects the plastic properties of concrete by improving workability
- Reduces water demand
- Reduces segregation and bleeding.
- Lowers heat of hydration.
- Fly ash increases strength
- Reduces permeability

MECHANICAL ATTRIBUTES:

REACTION WITH MOISTURE:

The main benefit of fly ash in concrete is that it not only reduces the amount of non durable calcium hydroxide (lime), but in the process converts it into calcium silicate hydrate (CSH), which is the strongest and most durable portion of the paste in concrete.



HEAT OF HYDRATION:

- Fly Ash has a lower heat of hydration.

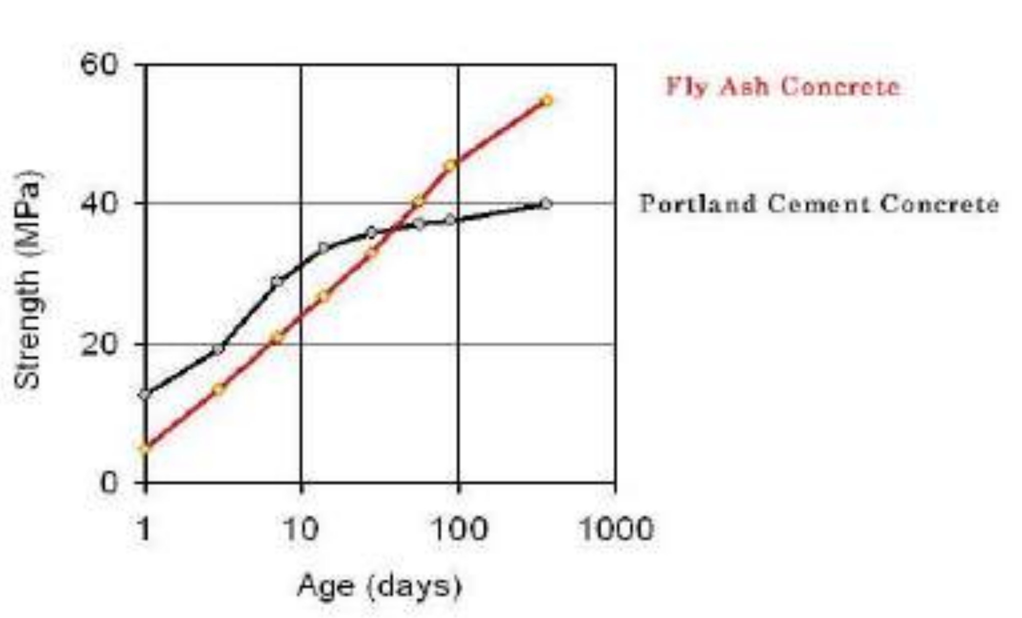
- Portland Cement produces considerable heat upon hydration.

- In mass concrete placements the excess internal heat may contribute to cracking.

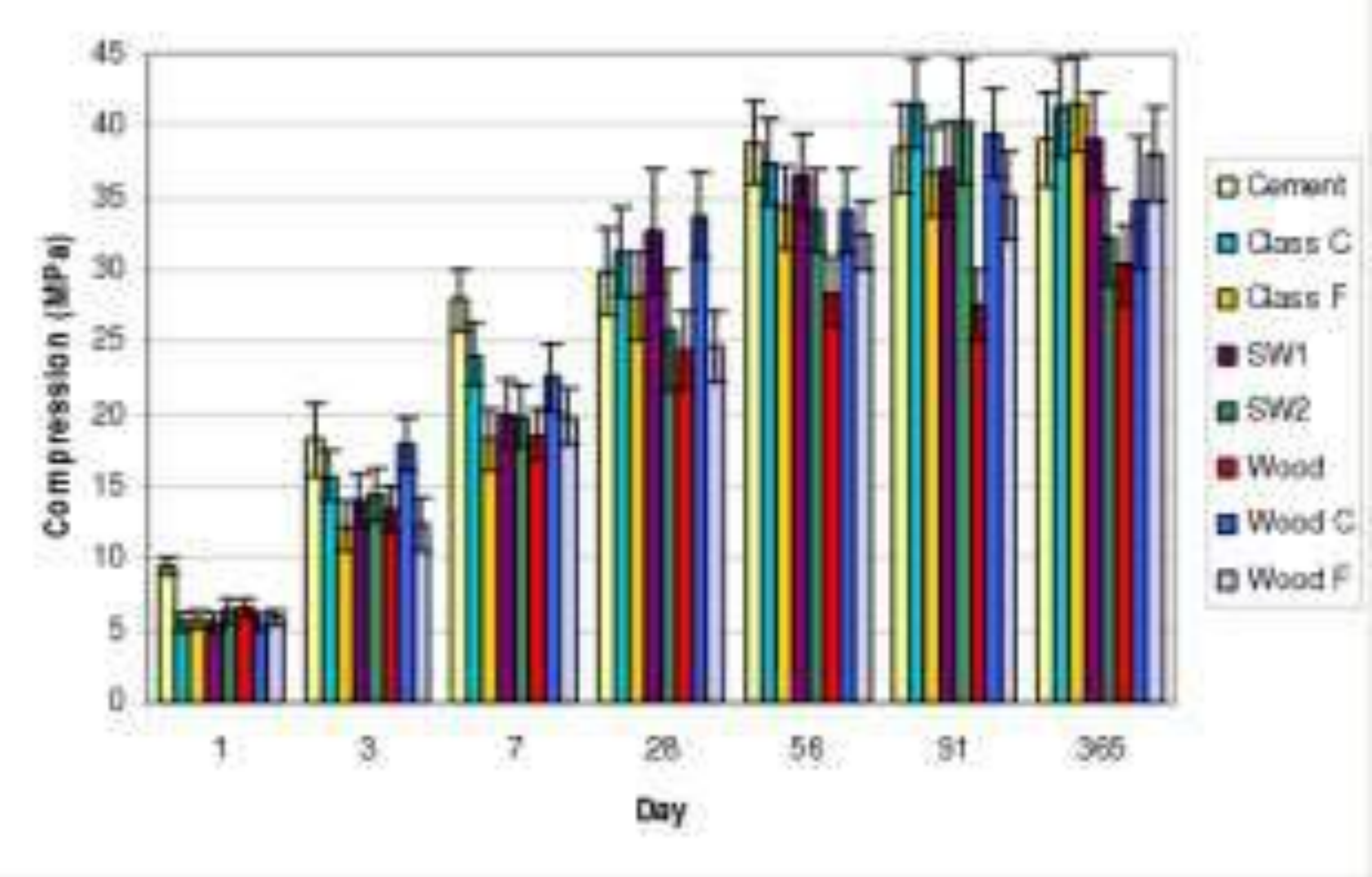
- The use of Fly Ash may greatly reduce this heat build up and reduce external cracking.

COMPRESSIVE STRENGTH:

- Typically, concrete made with fly ash will be slightly lower in strength than straight cement concrete up to 28 days, equal strength at 28 days, and substantially higher strength within a year's time.
- Thus, fly ash concrete achieves significantly higher ultimate strength than can be achieved with conventional concrete.



COMPRESSIVE STRENGTH TEST:



FLY ASH CONCRETE:

NEED FOR EXTENDING STRENGTH SPECIFICATIONS BEYOND 28 DAYS

- Developing sustainable concrete to last more than 100 years requires extending the 28-day specifications.

- Extended age parameters can assure more durable concrete.

- Proper mix designs can be developed to optimize the projects timeline.

PROJECTS AND THEIR AGE ACCEPTANCE:

project	Fly ash%	Age strength acceptance
Naval facilities engineering	25-40%	28-56 day acceptance
Olivenhain dam San Diego	65%	365 day acceptance
Washbum airport	35%	28-,56-and 90-day acceptance
Caltrans	25-35%	42 days

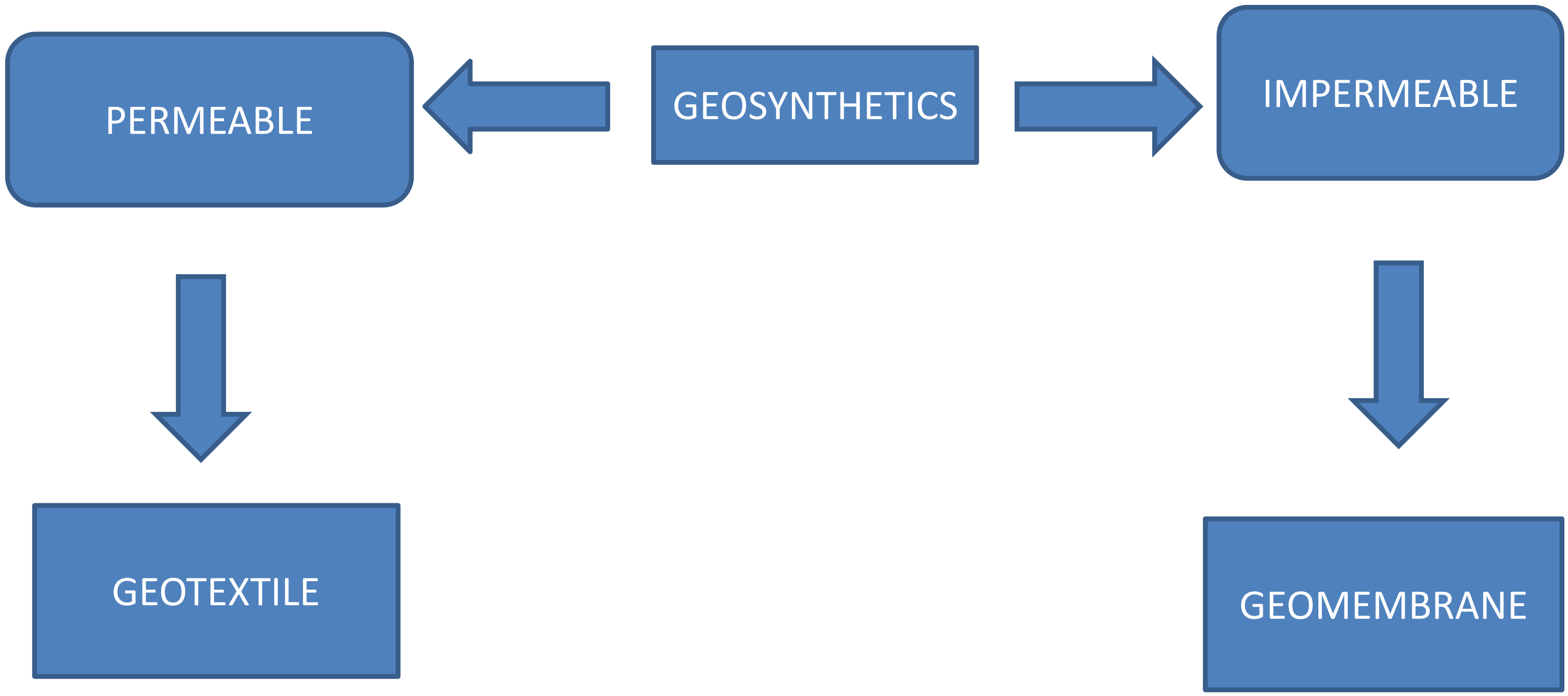
CONCLUSION:

Fly ash thus holds a vast potential for improving the modern day concrete when it comes to quality in the long term. In spite of being an industrial waste, it can improve durability and reduce heat of hydration.

The prospects of fly ash are still being underused even today. Thus keeping in mind about environmental concerns and its indispensability as a mineral admixture, the values of fly ash should be effectively garnered .

What Are Geosynthetics?

- A planar, polymeric (synthetic or natural) material used in contact with soil/rock and/or any other geotechnical material, for Filtration, Drainage, Separation, Reinforcement, Protection, Sealing and Packing



GEOTEXTILES :

Any permeable textile natural or synthetic, used with foundation soil, rock, earth, or any other geotechnical engineering related material

History of Geotextiles in India

- Used commercially since early ’80s
- However, during ’80 – ’90 the use was restricted to separation, filtration and drainage application for both non-woven and woven type
- Indian manufacturer like Hitkari, Tata Mills etc. participated in production of non-woven type for civil engineering application
- Application in river Training works and erosion control also started
- National Highways saw the application in drainage, embankment protection, base course stabilization and separation below highway embankments, also protection against erosion.
- Growing usage for environmental projects such as landfills, waste storage etc.
- Now there are non-woven as well as woven Geotextile manufacturer besides several unorganized participations

Types of Geotextile

1.Non-woven

2.Woven

3.knitted fabrics :

(rarely used as geotextiles.)

WOVEN	NON WOVEN
Separation	Separation
Reinforcement	Filtration
Impermeable	Permeable
Referred by strength	Referred by weight
ex:furniture fabrics	ex :medical garmnets,hazmat clothing

Areas of application of Geotextiles :

Flexible paved road construction

Drainage applications

Pavement overlays

Function of geotextiles:

service life of roads

load carrying capacity

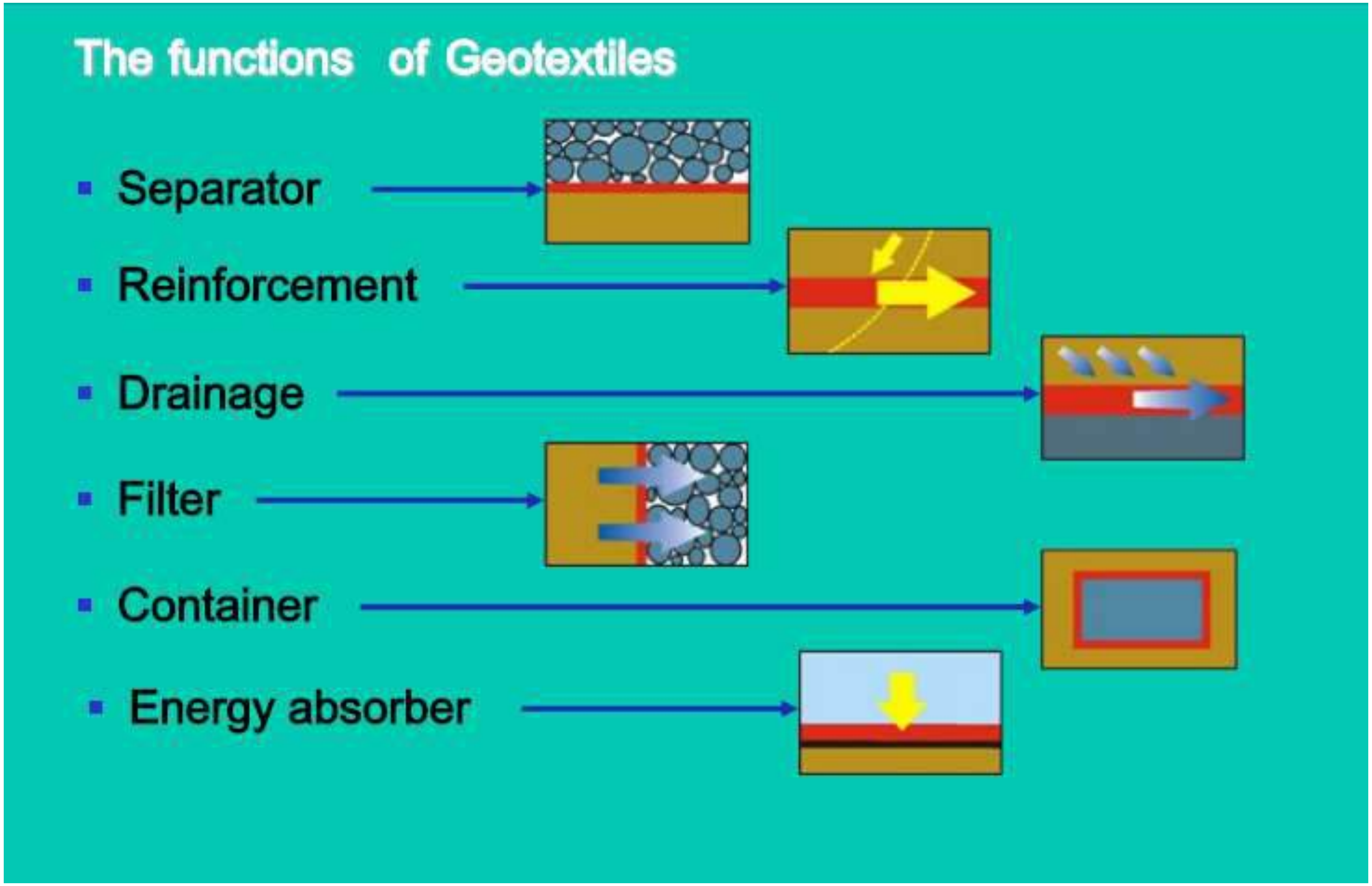
rutting overlays

Physical Properties

Property	Value range
Specific gravity	0.9 – 1.7
Mass per unit area	135 – 1000 g/m^3
Thickness	0.25 – 7.5 mm
Stiffness	Nil – 25,000 mg-cm

• Mechanical properties of geotextiles

Property	Value Range
Compressibility	Nil to high
Tensile strength (grab)	0.45-4.5 kN
Tensile strength (wide width)	9-180 kN/m
Confined tensile strength	18-180 kN/m
Seam strength	50-100% of tensile
Cycle fatigue strength	50-100% of tensile
Burst strength	350-5200 k Pa
Tear strength	90-1300 N
Impact strength	14-200 J
Puncture strength	45-450 N
Friction behavior	60-100% of soil friction
Pullout behavior	50-100% of geotextile strength



The functions of Geotextiles
Separator
Reinforcement
Drainage
Filter
Container
Energy absorber

Distribution of Geotextile Use in South Asia

	Nonwovens	Wovens	Knitted	Extruded
Percentage distribution of Geotextile type in the South Asia				
	45%	35%	5%	15%

	Percentage distribution of Geotextile type per application			
	Nonwovens	Wovens	Knitted	Extruded
Roads	55	35	10	35
Rail	5	8	~	10
Structures	2	25	15	20
Drainage	10	2	15	5
Erosion	3	2	5	2
Dams	1	~	~	~
Canals	1	1	~	~
Tunnels	2	~	~	~
Solid Waste	6	2	5	5
Liquid Waste	6	2	5	5
Embankments	4	10	45	15

GEOMEMBRANE

- Geomembranes are thin 2D sheet of materials with a very low permeability.
- These are subjected to very small amount of seepage ass a result of permeation.
- Geomembranes are made up of materials like PVC,CPE etc.
- Geomembrane width is not more than 2mm and thickness of 0.5-2.55mm
- Membranes are reinforced with bitumen may be of 4-5M wide with thickness of 1.5-6mm.

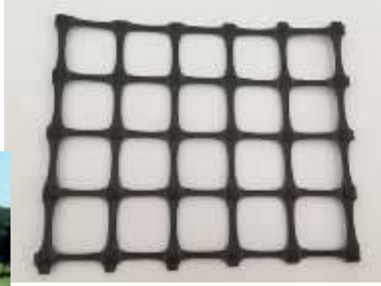
Geosynthetics are classified as follows :

- Geotextiles
- Geogrids
- Geonets
- Geomembrane
- Geocells
- Geofoam
- Geocomposites

Market size including imports (Rs Crore)	
Synthetic Geotextile products	241
Woven Geotextiles	85
Nonwoven Geotextiles	67
Geogrids/Others	35
Geomembranes/Geocomposites (PVD, etc)	54
Agro-based Geotextiles	31
Total	272

Geogrids

- A planar, polymeric structure consisting of a regular open network of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents, used in contact with soil/rock and/or any other geotechnical material in civil engineering applications.

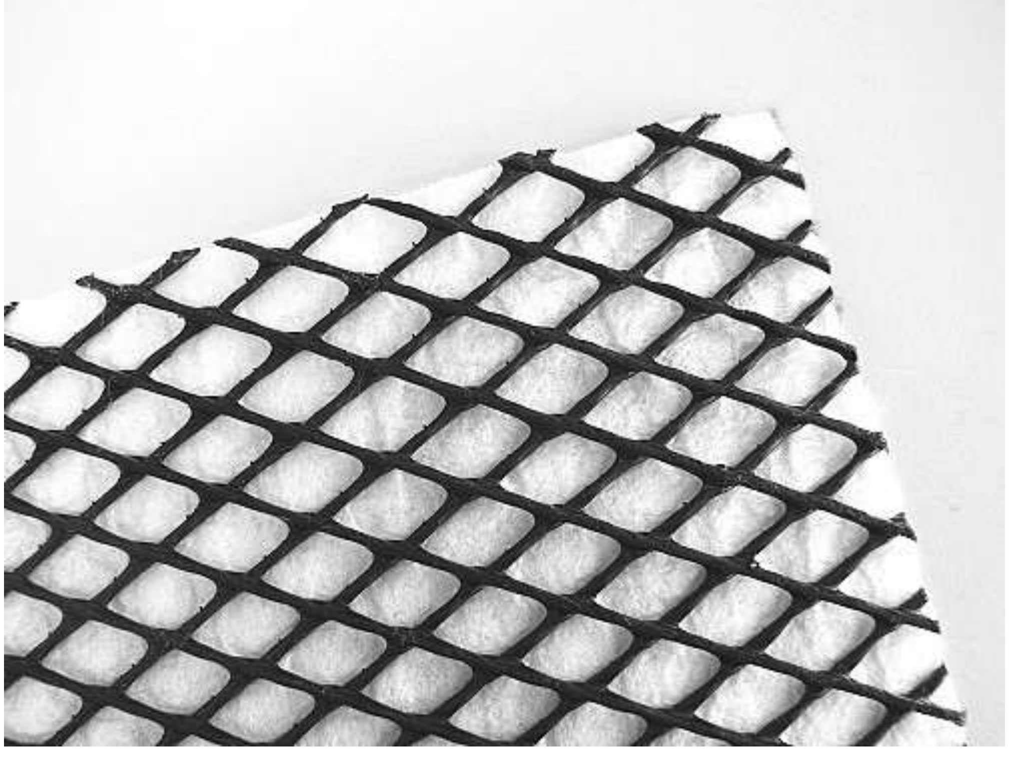


Use of grogrid for soil reinforcement

Use of grogrid in grass lanes

Geonet

- A planar, polymeric structure consisting of a regular DENSE network, whose constituent elements are linked by knots or extrusions and whose openings are much larger than the constituents, used in contact with soil rock and /or any other geotechnical material in civil engineering applications



GEOCELLS:

Geocells are 3-dimensional honeycomb-like structures, made of strips of polymer sheet.

Similar to geotextiles or geogrids but have depth

It is used in erosion control

Geosynthetics – the functions

- Separation
- Drainage
- Filtration
- Reinforcement
- Moisture barrier
- Cushion

Materials used for Geosynthetics

- Polyamide
- Polyester
- Polyethylene
- Polypropylene
- Polyvinylchloride
- Chlorinated polyethylene

BENEFITS OF GEOSYNTHETIC REINFORCEMENT

1 PAVEMENT SYSTEMS

1.1 BASE/SUBGRADE

2 EMBANKMENTS OVER SOFT SOILS

3 SLOPES AND WALLS

1.Pavement systems :

c

new roads

maintenance of existing roads

1.1 BASE AND SUB-BASE REINFORCEMENT

The use of a geosynthetic placed as a tensile element at the bottom or within a flexible pavement base or sub-base to :

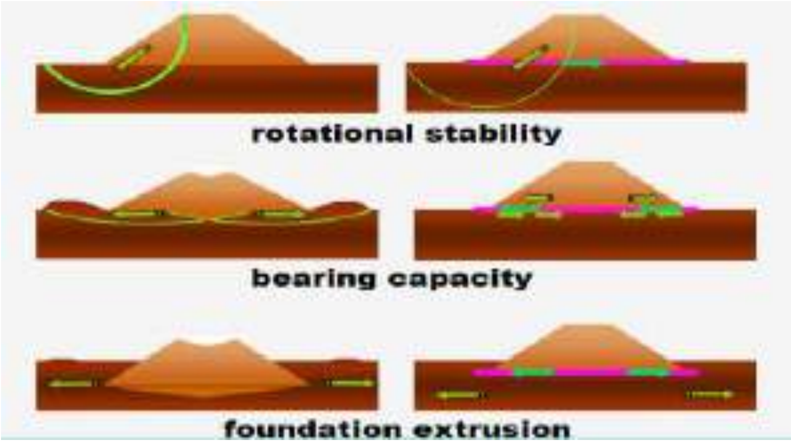
- increase the service life
- obtain equivalent performance with a reduced structural section
- avoid subsidence problems (sinkholes)

Applications:

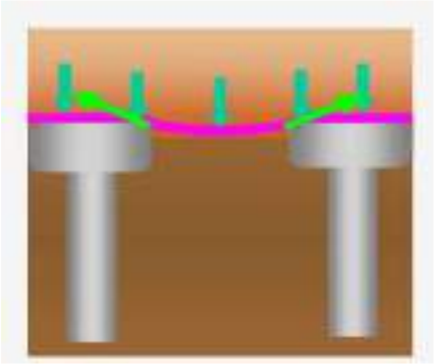
- Permanents ways
- Parking lots
- Airport taxiways
- Container loading facilities
- Railway tracks

2 EMBANKMENTS OVER SOFT SOILS

Basal reinforcement



Piled embankments with basal reinforcement

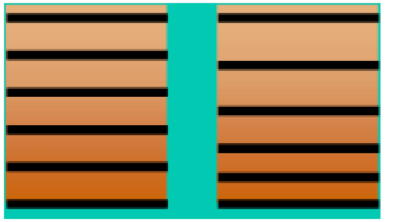


3. SLOPES AND WALLS

TYPES (angel of inclination larger than 80degrees)

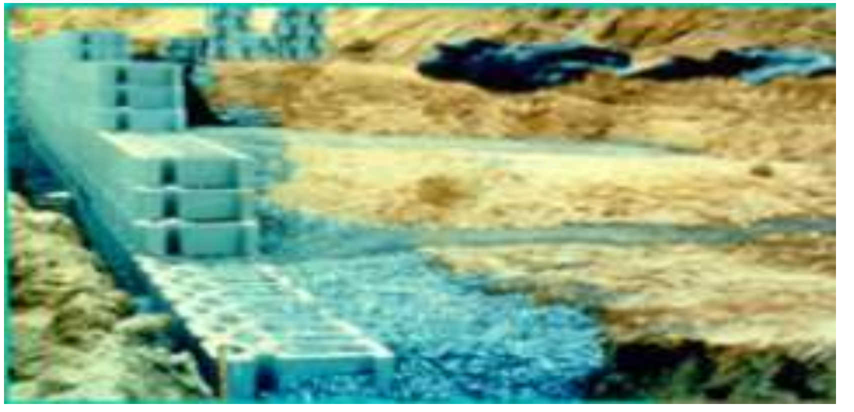
i. STEEP SLOPES

ii. BLOCK WALLS



Reinforcement spacing

Steep slopes



Block walls

benefits

Economical solutions

Rapid and simple construction method

Allows construction in difficult terrain

Allows use of cheaper fill material

Satisfactory appearance structures

Environmental:

reduce damaged areas and

reduce natural material extracting

Applications of geosynthetics

- Unpaved roads
- Separation
- Reinforcement
- Filtration
- Drainage
- Moisture barrier (when impregnated)
- Hydropower construction
- Environmental engineering
- Railway construction
- Road construction
- At seaports and
- airports Mine construction In urban construction

WORLD MARKET FOR GEOSYNTHETICS

- World Geosynthetics to 2013 – Global demand for geosynthetics is projected to increase 5.3 percent annually through 2013. China will account for the largest share of new global demand as it continues to develop large-scale infrastructure and erosion control projects. North America will remain the second largest regional market. Geogrids will achieve the fastest gains

CONCLUSION

It is expected that the use of geosynthetics will become increasingly routine, and that geosynthetics will be the standard material of choice for several applications. Use of geosynthetics in pavement structures (to perform the functions of separation, filtration, drainage, and reinforcement) should increase significantly in the new millennium as the benefits of these materials are quantified. In addition, the versatility and usage of geosynthetics will be enhanced with the development and adoption of in situ and rapid soil testing procedures

GLASS

Introduction

- Glass: it is an amorphous, hard, brittle, transparent, or translucent, super cooled liquid of infinite viscosity, obtained by fusing a mixture of metallic silicates, most commonly of Na,K,Ca. and Pb
- It has no sharp melting point and definite structural formula

- It may be represented as $xR_2O.yMO.6SiO_2$,

where

R is an atom of an monovalent alkali metal like Na,K,, etc,

M is an atom of a bivalent metal like Ca,Pb,,Zn, etc.,x and y are whole numbers

- In some glasses, $SiO_2$is replaced by $Al_2O_3.B_2O_3.P_2O_5$, etc.

- General formula of ordinary glass or soda-lime glass is $Na_2O.CaO.SiO_2$

Properties of Glass:

- It is amorphous and it has no definite melting point
- It can absorb and reflect light
- It is a good insulator of electricity
- It is effected by Alkalis

- It is not affected by Air, Water and acid however it reacts with HF to form SiF_4

Types of Glass

- Glasses are classified into two types:
  1. Soft Glass (soda-lime glass)
  2. Hard Glass(potash-lime glass)

Soft Glass (soda-lime glass):

- Structural formula of soft glass is $Na_2O.CaO.6SiO_2$
- Sodium carbonate, calcium carbonate, silica are raw materials for the preparation of soft glass
- They are resistant to water and melt easily
- However they are easily attacked by acids

Uses

- They are widely used as window glasses, electric bulbs, plate-glasses, bottles, jars, building blocks, and cheaper table wares where high temperature-resistance and chemical stability are not required.

Hard Glass (Potash-Lime Glass)

- Composition of Hard-Lime glass is $K_2O.CaO.6SiO_2$
- Silica, Potassium carbonate and sodium carbonate are raw materials for preparation of hard glass.
- They have high melting points and less acted by alkalis, acids.

USES

- These glasses (costlier than soda-lime glasses) are used for chemical apparatus, combustion tubes, etc., which are to be used for heating purposes

Manufacturing Steps:

- 1.Melting
- 2.Forming and Shaping
- 3.Annealing
- 4.Finishing

Melting

- : Raw marerials, in proper proportions(e.g sand, soda, ash and limetone for common glass) are mixed with refinely added cullets called as “batch” are heated in open hearth furnace in which heat is produced by burning of producer gas.At high temperatures like 1800^{o}C glass starts melting

Reaction involved in manufacturing of soft glass:

- $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$
- $Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2$

  When all the carbon dioxide has escaped out of the molten mass , decolorizes (such as MnO_2 or nitre) are added to do away with ferrous compounds and carbon , if present. If a coloured glass is desired , the colouring salts are added at this stage. Heating is continued, till the molten mass is free from bubbles and glass- balls and then cooled to about 800^0C.

Colors-coloring salts

- Yellow- ferric salt
- Green- ferrous and chromium salts
- Blue- cobalt salts
- Purple-manganesedioxide
- Red- nickel salts or Cu_2O
- Fluorescent greenish- yellow- uranium oxide
- Opaque milky white- Cryolite(Na_3AlF_3) or calcium phosphate.

Forming:

- molten glass is then worked into articles of desired shapes by either blowing or moulding or pressing between rollers.

Glass blowing

Annealing:

- Glass, being insulator cannot be cooled rapidly because if it is cooled rapidly the superficial layer cools down and the inner layer remains in expanded state which may cause breakage of glass.
- Due to this reason glass is passed through different zones of decreasing temperature and this process is known as annealing.

Finishing

- All glass articles, after annealing, are subjected to finishing processes such as cleaning, grinding, polishing, cutting, sand-blasting, etc.

Concrete Hollow Blocks

Introduction

What is Concrete Hollow Blocks?

- A Concrete masonry unit (CMU) – also called Concrete block, cement block, and foundation block – is a large rectangular brick used in construction. Concrete blocks are made from cast concrete, example: Portland cement and aggregate, usually sand and fine gravel for high-density blocks. Lower density blocks may use industrial wastes as an aggregate.

What is Masonry?

- Any building material made of stone.
- Used for walls.

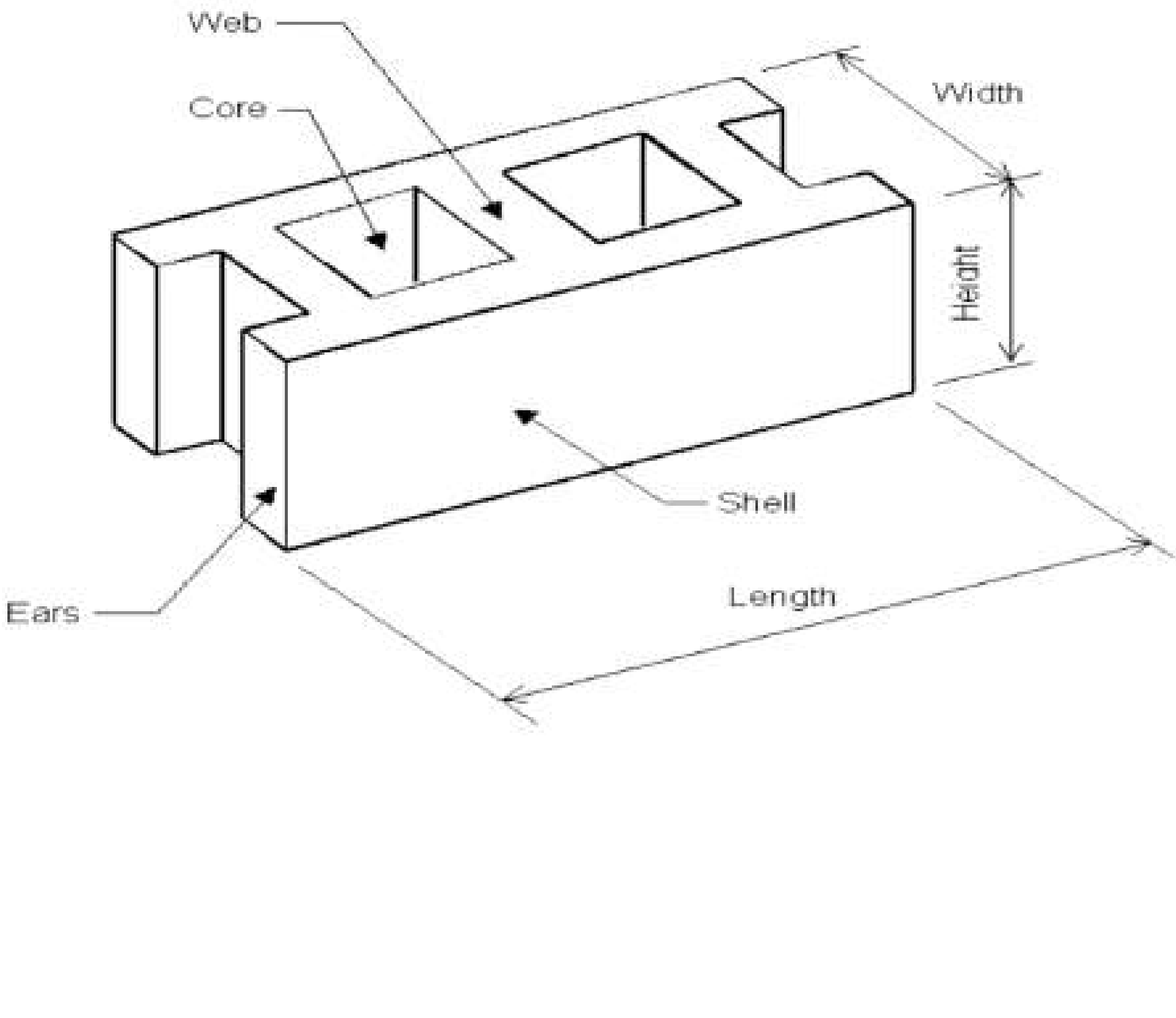
Two types of Masonry

- Structured/load-bearing – this is used for exterior walls.

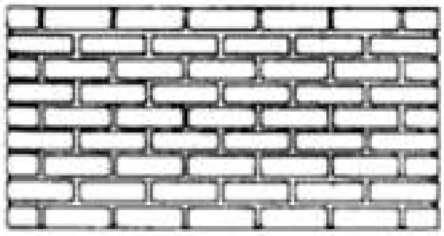
- Non structured/non load-bearing – this is used for interior walls.

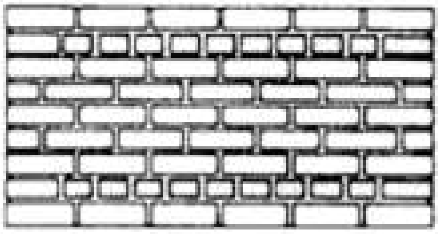
Parts of a masonry unit

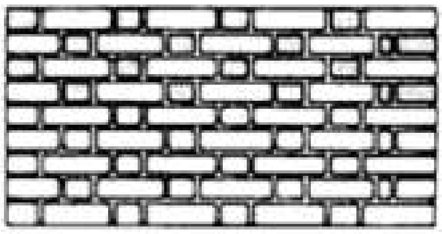
- Core
- Stretcher or Face Shell
- Header
- Web

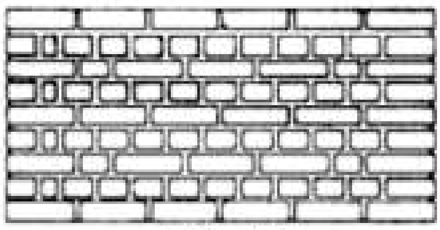


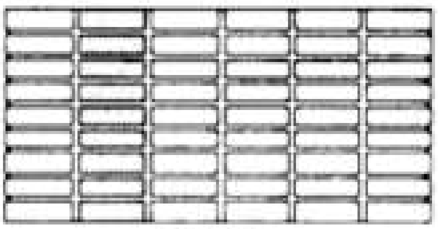
Arrangements of Masonry Unit

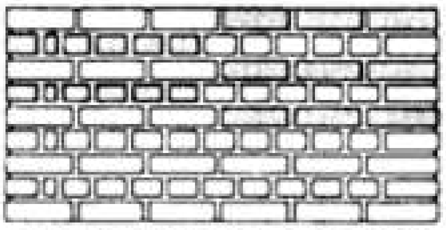

RUNNING


COMMON OR AMERICAN


FLEMISH


ENGLISH


STACK


ENGLISH CROSS OR DUTCH

Two types of load-Bearing Blocks

- **Type N** - Blocks rated N are rated for use as exterior walls both above and below grade

- **Type S** - concrete blocks rated S are not rated for moisture penetration and are used instead as interior walls or as above grade exterior walls with a weather protective coating.

5 Main types of Concrete hollow blocks:

Hollow load-bearing concrete block

Load bearing concrete hollow block are block that can or intended to carry load aside from its own weight. Easier handling and facility for conducting or steel reinforcement through the hollows.

Solid load-bearing Concrete Block

Solid masonry, without steel reinforcement, tends to have very limited applications in modern wall construction. Such walls can, however, be quite economical and suitable in some applications; solid unreinforced masonry walls tend to be low and thick as a consequence of their lack of tensile strength.

Hollow non load-bearing concrete block

- Non-load bearing concrete hollow block are used for fences, wall partition or divider and this is not intended to carry load.

Concrete building tile

- Concrete tiles are made from sand, water, cement and pigments, and are not fired like clay tiles, but cured at temperatures of approximately 60 degrees Celsius. The curing process makes them sturdy enough to be transported and laid within a few days of manufacture, and they get stronger over time.

Concrete Brick

- Concrete brick is made from solid concrete. These bricks are used to cover the facade of a home, build fences, and enhance the overall beauty of a home's exterior.
- Concrete bricks are quickly becoming a popular alternative to other home facade materials.

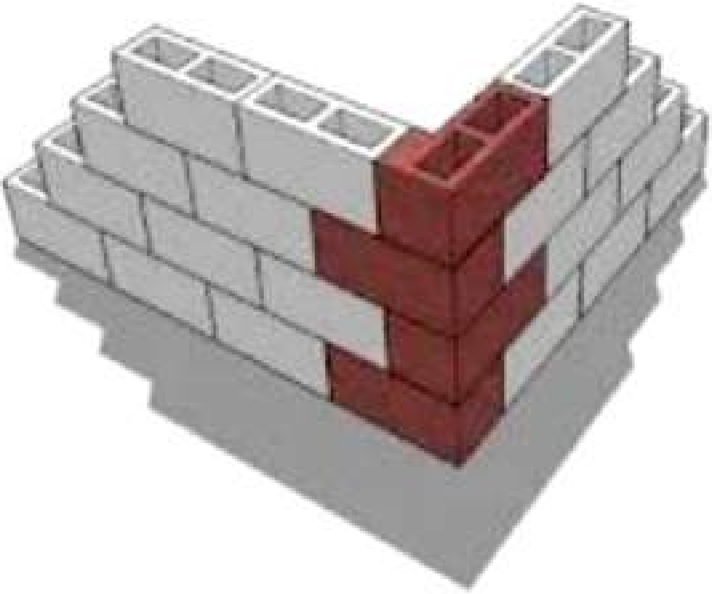
Other types of Concrete Hollow Blocks

Stretcher

- A stretcher block is the most commonly used block in construction. It is laid with its length parallel to the face of the wall.

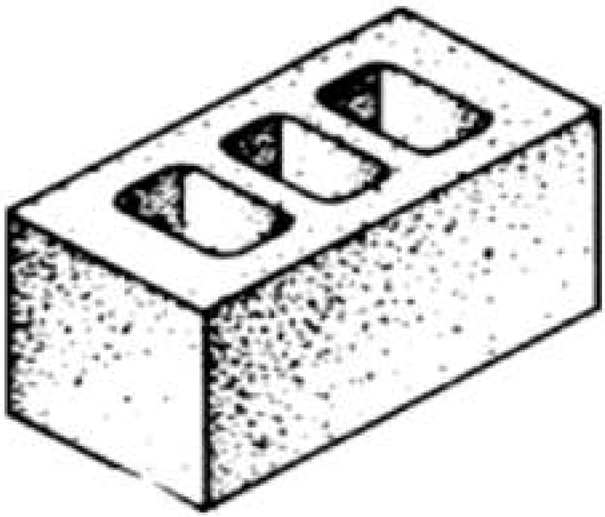
Corner

- Corner. A corner block is used for corners at simple window and door openings.



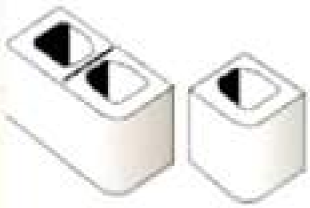
Double Corner or Pier

- A double-corner or pier block is used for constructing piers pilasters or for any other purpose where both ends of the block would be visible.



Bull Nose

- A bull-nose block serves the same purpose as a corner block, but it is used **<u>where round corners are desired</u>**.



Jamb

- A wood-sash jamb block is used with a stretcher and a corner block around elaborate window openings. The recess in the block allows room for the various casing members, as in a double-hung window.

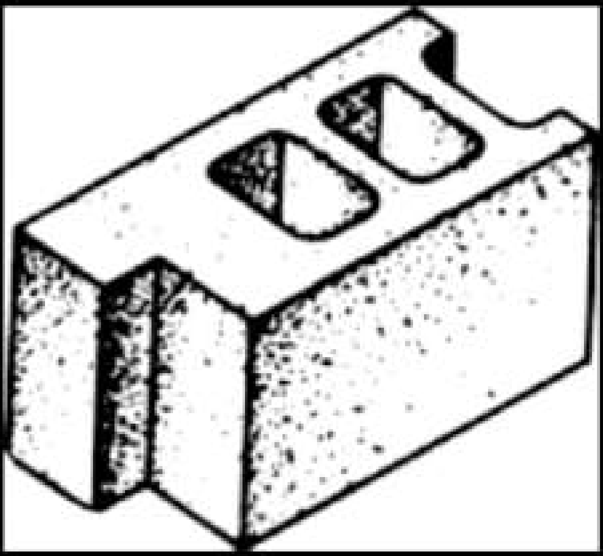
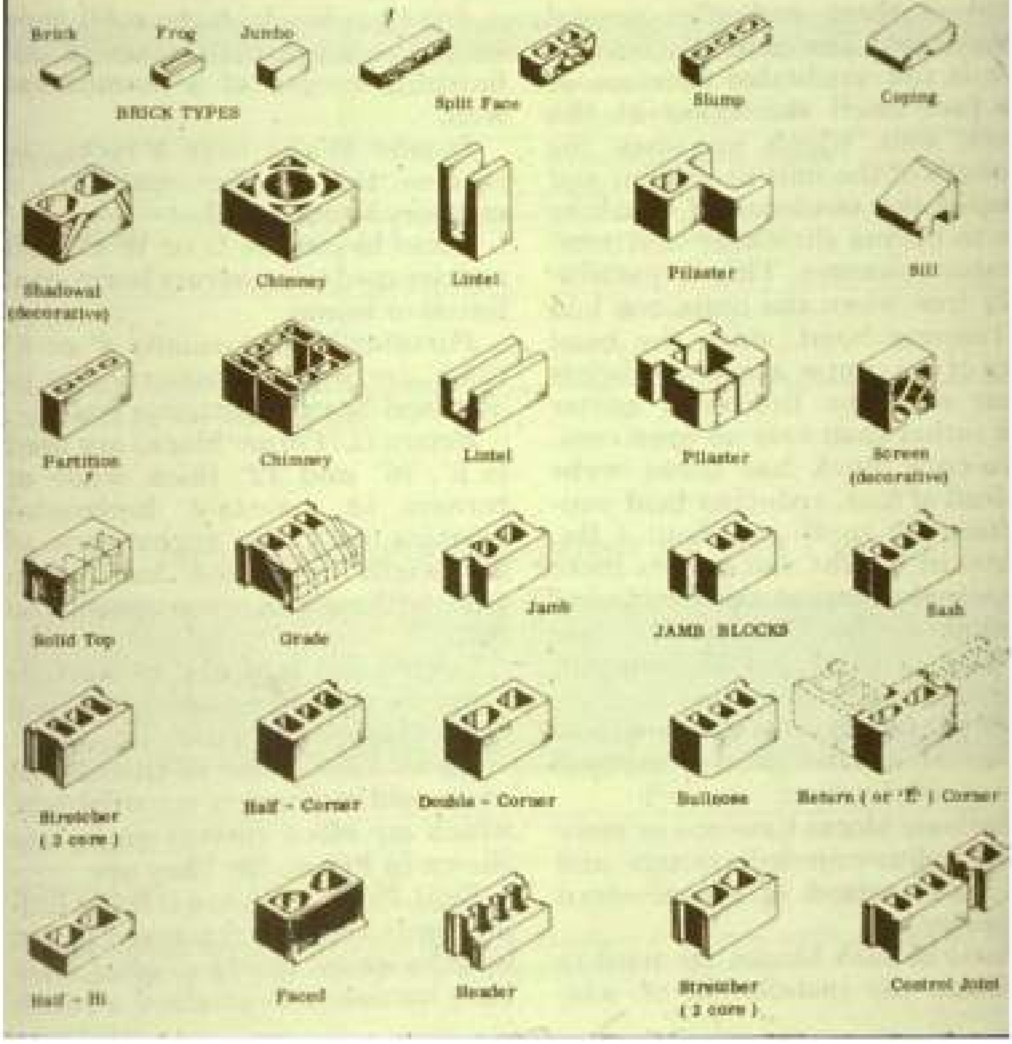
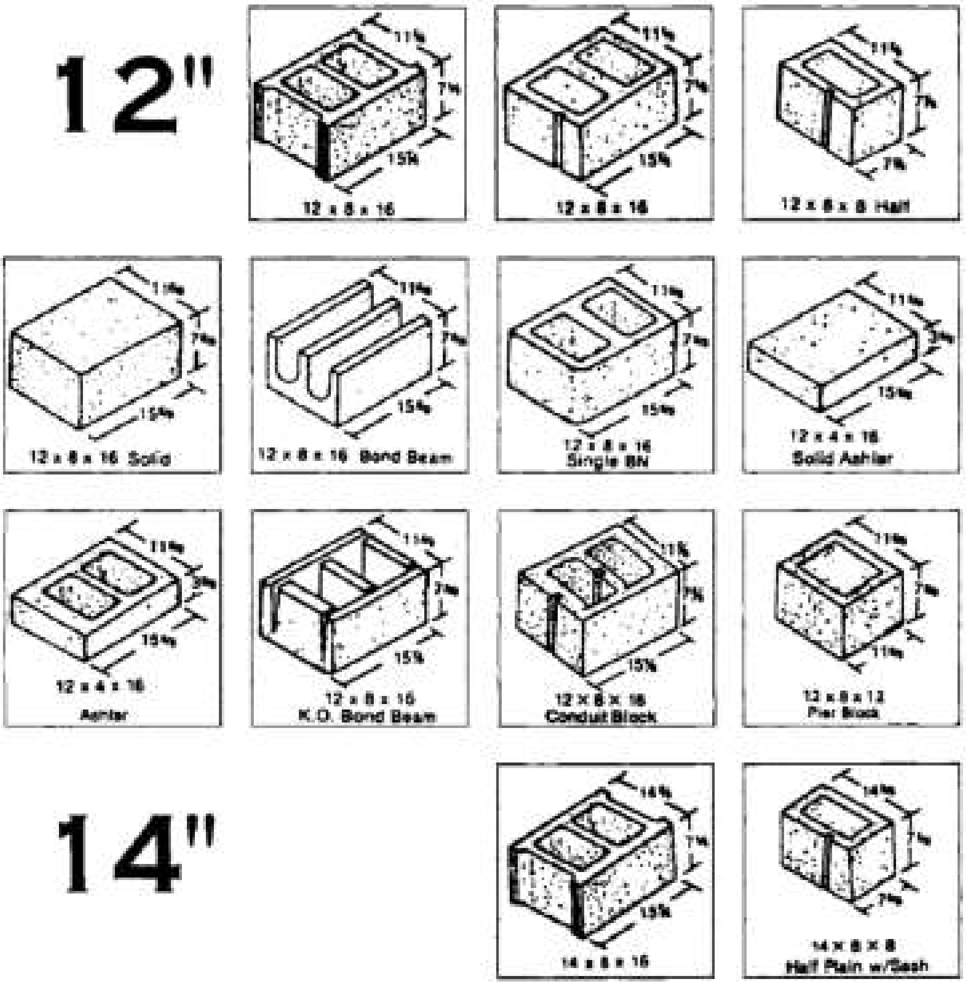


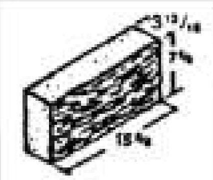
FIG. 38 TYPICAL SHAPES OF CONCRETE BLOCK





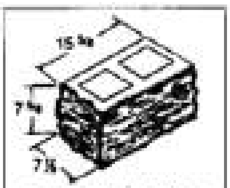
12"
12 x 8 x 16
12 x 8 x 16
12 x 8 x 8 Half
12 x 8 x 16 Solid
12 x 8 x 16 Bond Beam
12 x 8 x 16
Single BN
12 x 4 x 16
Solid Ashlar
12 x 4 x 16
Ashlar
12 x 8 x 16
K.O. Bond Beam
12 X 8 X 16
Conduit Block
12 x 8 x 12
Pier Block
14"
14 x 8 x 16
14 X 8 X 8
Half Plain w/Sash

SPLIT FACE BLOCK

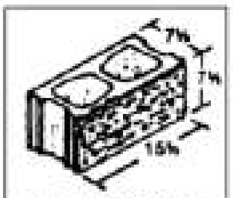


4 x 8 x 16 Split Face

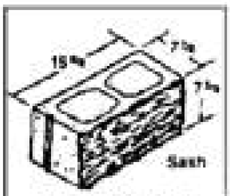
4 x 8 x 12
Split Face Corner



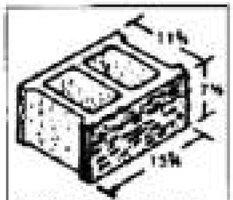
8 x 8 x 16 Split Face
Corner



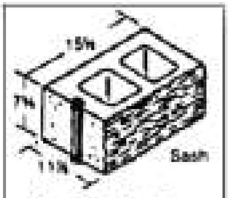
8 x 8 x 16 Split Face



8 x 8 x 16 Split Face



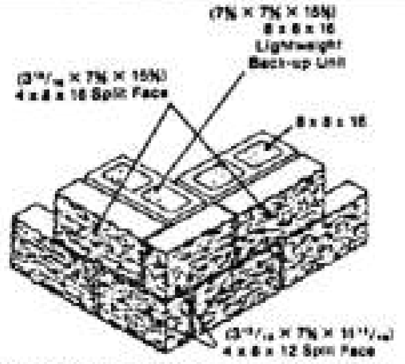
12 x 8 x 16 Split Face



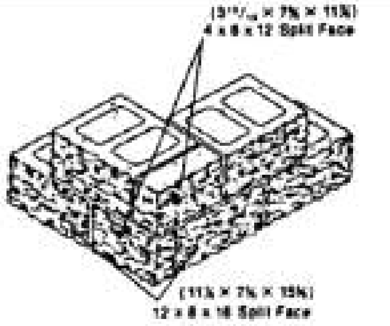
12 x 8 x 16 Split Face

SPLIT FACE BLOCK

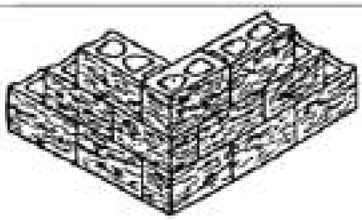
WITH CORNER DETAILS



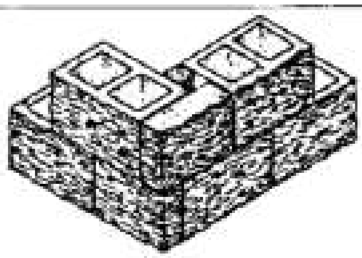
4 X 8 X 12 SPLIT FACE CORNER DETAIL
FOR 4" WALL



4 X 8 X 12 SPLIT FACE CORNER DETAIL
FOR 12" WALL

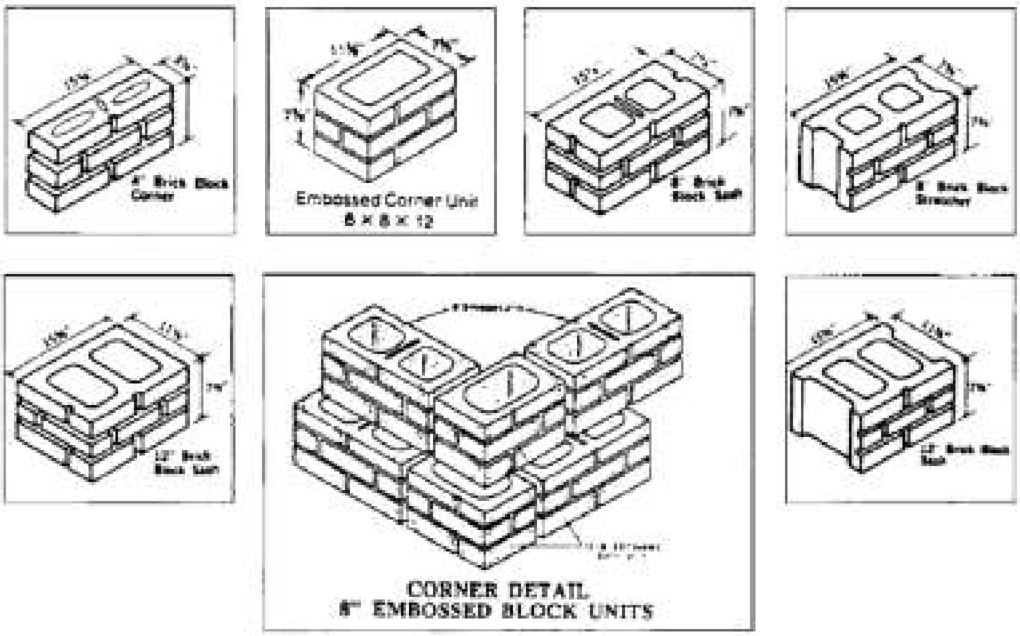


CORNER DETAIL
USING 8 X 8 X 16 S.F. CORNER UNIT



12"SPLIT FACE CORNER DETAIL
USING 4 X 8 X 12 S.F. CORNER UNIT

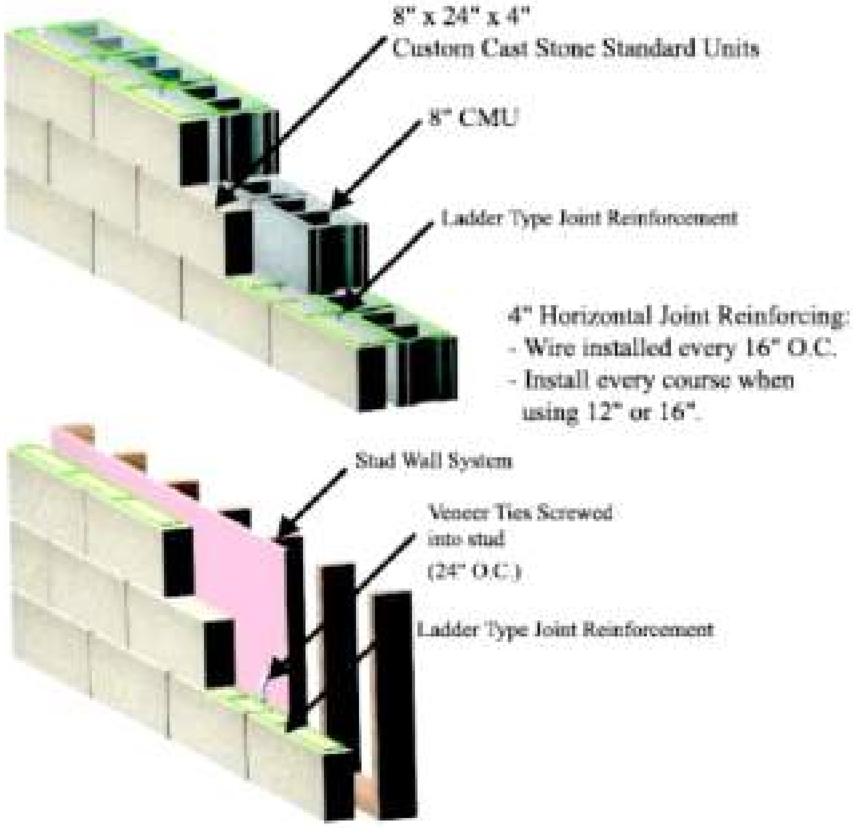
EMBOSSED BRICK-FACED BLOCK



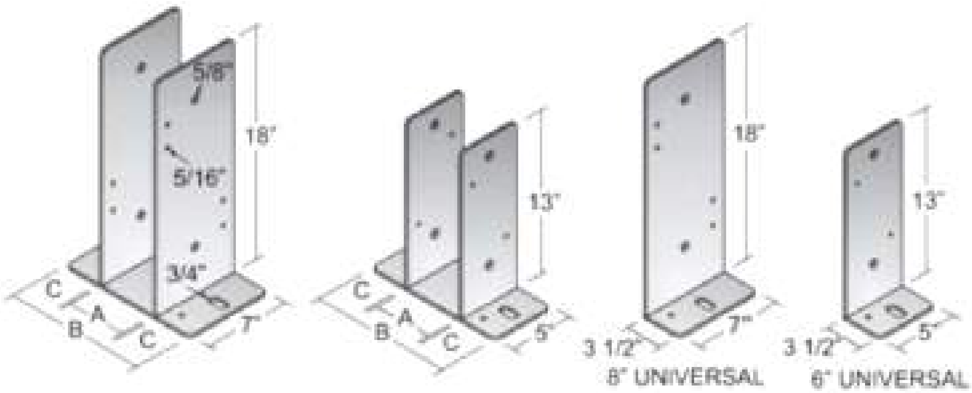
12 & 8" Embossed Block are available embossed on both sides.
Note: Embossed Brick-Face Block should be laid on 1/4 bond.

Examples of Masonry Units

- **Veneer masonry**
- A masonry veneer wall consists of masonry units, usually clay-based bricks, installed on one or both sides of a structurally independent wall usually constructed of wood or masonry. In this context the brick masonry is primarily decorative, not structural. The brick veneer is generally connected to the structural wall by brick ties (metal strips that are attached to the structural wall, as well as the mortar joints of the brick veneer). There is typically an air gap between the brick veneer and the structural wall. As clay-based brick is usually not completely waterproof, the structural wall will often have a water-resistant surface (usually tar paper) and weep holes can be left at the base of the brick veneer to drain moisture that accumulates inside the air gap. Concrete blocks, real and cultured stones, and veneer adobe are sometimes used in a very similar veneer fashion.


8" x 24" x 4"
Custom Cast Stone Standard Units
8" CMU
Ladder Type Joint Reinforcement
4" Horizontal Joint Reinforcing:
- Wire installed every 16" O.C.
- Install every course when
using 12" or 16".
Stud Wall System
Veneer Ties Screwed
into stud
(24" O.C.)
Ladder Type Joint Reinforcement

- **Dry set masonry**
- The strength of a masonry wall is not entirely dependent on the bond between the building material and the mortar; the friction between the interlocking blocks of masonry is often strong enough to provide a great deal of strength on its own. The blocks sometimes have grooves or other surface features added to enhance this interlocking, and some *dry set* masonry structures forgo mortar altogether.

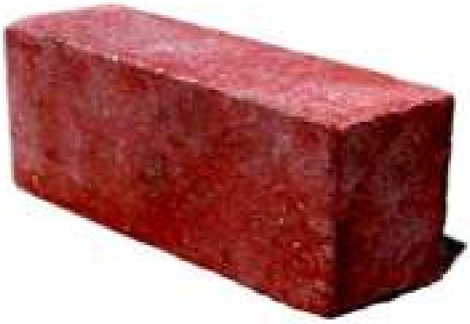


- **Solid masonry**
- Solid masonry, without steel reinforcement, tends to have very limited applications in modern wall construction. While such walls can be quite economical and suitable in some applications, susceptibility to earthquakes and collapse is a major issue. Solid unreinforced masonry walls tend to be low and thick as a consequence.

- **Brick**
- Solid brickwork is made of two or more layers of bricks with the units running horizontally (called *stretcher* bricks) bound together with bricks running transverse to the wall (called "header" bricks). Each row of bricks is known as a course. The pattern of headers and stretchers employed gives rise to different **bonds** such as the common bond (with every sixth course composed of headers), the English bond, and the **Flemish bond** (with alternating stretcher and header bricks present on every course). Bonds can differ in strength and in insulating ability. Vertically staggered bonds tend to be somewhat stronger and less prone to major cracking than a non-staggered bond.

Uses

- Bricks are used for building and **pavement.** In the USA, brick pavement was found incapable of withstanding heavy traffic, but it is coming back into use as a method of **traffic calming** or as a decorative surface in **pedestrian precincts**. For example, in the early 1900s, most of the streets in the city of **Grand Rapids**, **Michigan** were paved with brick. Today, there are only about 20 blocks of brick paved streets remaining (totalling less than 0.5 percent of all the streets in the city limits).



BRICKS

PAVER BLOCKS (PAVEMENTS, SIDEWALKS)

- **Stones** - a concretion of earthy or mineral matter: **a :** such a concretion of indeterminate size or shape **:ROCK b :** a piece of rock for a specified function: as (1) **:** a building block **:** a paving block **:** a precious stone **: GEM :GRAVESTONE : GRINDSTONE : WHETSTONE:** a surface upon which a drawing, text, or design to be lithographed is drawn or transferred.

Sustainable Modern Concrete Products

Fly ash concrete (a sustainable, environment-friendly material)

- Fly ash is an inexpensive replacement for portland cement used in concrete, while it actually improves strength, segregation, and ease of pumping of the concrete.
- Fly ash is also used as an ingredient in brick, block, paving, and structural fills. Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation.

Two Classifications of Fly ash

- Class F fly ash - with particles covered in a kind of melted glass, greatly reduces the risk of expansion due to sulfate attack, as may occur in fertilized soils or near coastal areas.

- Class C fly ash - is also resistant to expansion from chemical attack, has a higher percentage of calcium oxide, and is more commonly used for structural concrete.

Light-transmitting concrete

- LiTraCon is a trademark for a translucent concrete building material. The name is short for "light-transmitting concrete". The technical data sheet from the manufacturer[1]says the material is made of 96% concrete and 4% by weight of optical fibers,[2][3] it was developed in 2001 by Hungarian architect Áron Losonczi working with scientists at the Technical University of Budapest.

- known also as translucent concrete

Laminating Adhesives

- Can be classified by application type:
  - Solvent borne
  - Solventless (100% solids)
  - Waterborne
  - Radiation Curable (100% solids)
  - Combination radiation curable

- Can be classified by performance level or chemistry

Polyether Urethane

–water, solvent, and solventless

Polyester

–solvent based

Polyester Urethane

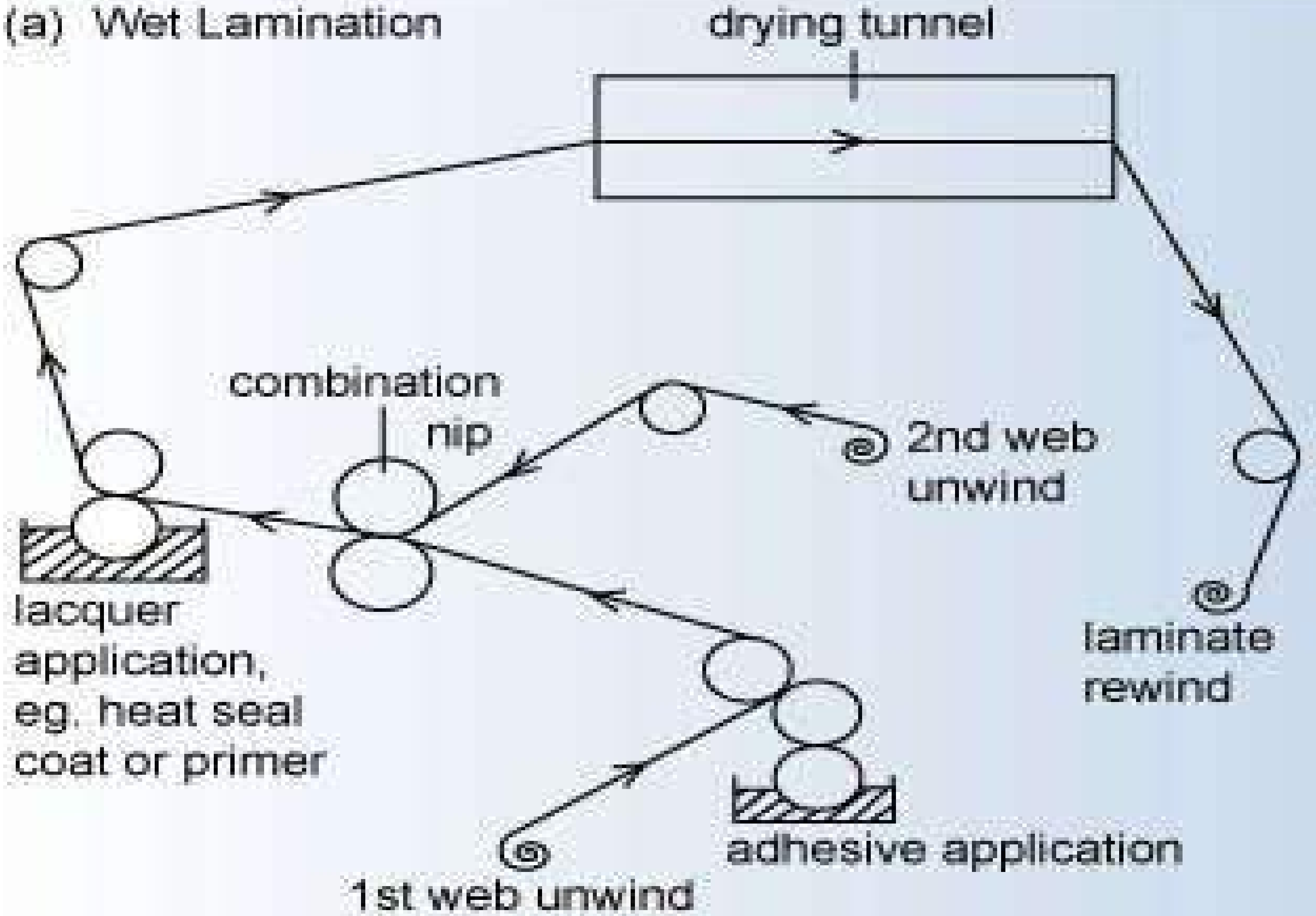
–water, solvent, and solventless

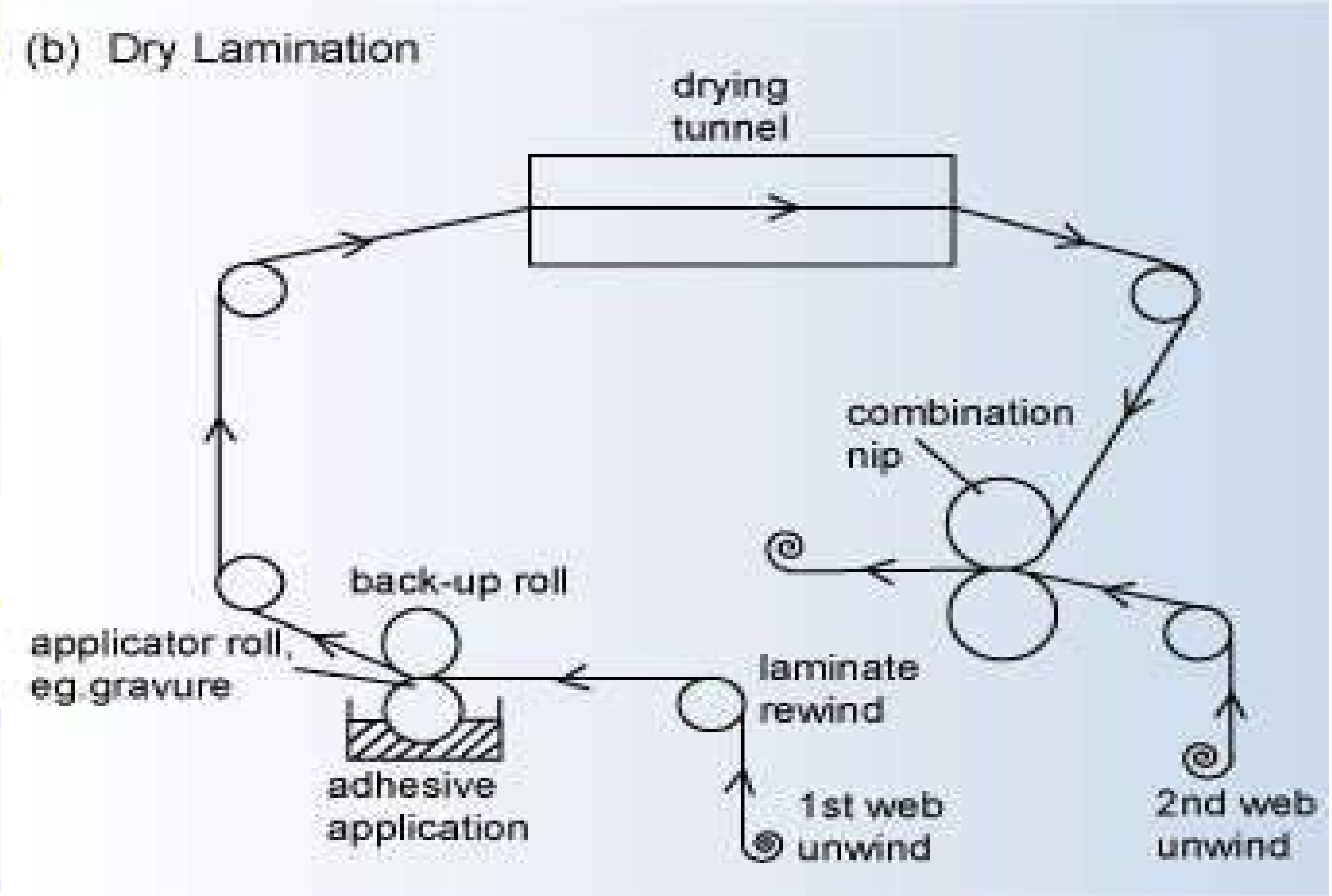
Acrylic

-usually water based but could be solvent

Wet and Dry Lamination

The manufacture of film laminates is a relatively simple continuous process of coating and bonding. Specific processes differ primarily by how the adhesive is applied and converted from a liquid to a solid. There are several laminating processes that can be easily adapted to production. These are generally classified as either wet or dry laminating processes and they are described in Table 1.


(a) Wet Lamination
drying tunnel
combination
nip
2nd web
unwind
laminate
rewind
lacquer
application,
eg. heat seal
coat or primer
adhesive application
1st web unwind


(b) Dry Lamination
drying
tunnel
combination
nip
back-up roll
applicator roll,
eg.gravure
laminate
rewind
adhesive
application
1st web
unwind
2nd web
unwind

Process	Description	Typical Application Equipment	Typical Adhesives
Dry Processes			
Dry bond laminating	A liquid adhesive is coated on a substrate, dried with heat and air flow, and then laminated to a second substrate via a heated compression nip.	Gravure application cylinder	Polyurethane dispersions, acrylic, emulsions, acrylic solvent, water-based polyvinyl alcohol, ethylene vinyl acetate copolymers, silicone solvent
Hot melt seal coating	Low viscosity hot melt adhesives are applied to substrate and then later	Heated roto-gravure cylinder, extruder	Ethylene vinyl acetate, modified polyolefins, polyesters
Cold seal	A liquid adhesive is applied, dried with heat and air, and then bonded only with slight pressure (formulated so that tack to non-cold seal surfaces is minimized)	Same are dry bonding	Synthetic rubber, acrylic / natural rubber

Wet Processes			
Wet bond laminating	Liquid adhesive is applied to a substrate, then immediately laminated to a second substrate via a nip followed by drying with heat and air flow (one substrate must be porous to allow evaporation of water or solvent)	Gravure cylinder or smooth roll	Polyurethane dispersions, acrylic, emulsions, water-based polyvinyl alcohol, ethylene vinyl acetate copolymers
Solventless laminating	The adhesive is metered onto the substrata in liquid form. It is then mated to a second substrate via a heated nip	Multiple application roll configurations	Polyurethanes, polyesters

The main items in a lamination line are the film un winders and winders, adhesive coater, and laminator.

There are a number of coating methods that can be used depending on the nature of the adhesive.

Specific applications may require varying degrees of adhesive coating thickness.

Table 2 shows a summary of some of the capabilities and limitations of common coating methods that are used in producing laminates.

Coating Method	Viscosity, cps	Coating Weight, gm/ m^2	Coating Accuracy, +/- %	Coating Speed, m/min	Type of Adhesives Commonly Used
Wire rod	100-1,000	15-100	10	100-200	Solution, emulsion
Knife over roll	4,000-50,000	25-750	10	100-150	Solution, emulsion, 100% solids
Reverse roll	300-50,000	25-250	5	100-400	Solution, emulsion
Gravure	15-1500	2-50	2	100-700	Solution, emulsion
Extrusion die	400-500,000	15-750	5	300-700	Emulsion, hot melt, 100% solids
Slot die	400-200,000	20-700	2	100-300	Emulsion, hot melt, 100% solids
Curtain	50,000-125,000	20-500	2	100-500	Emulsion, hot melt

Wet Laminating

With wet laminations, the adhesive is applied to one substrate, usually by roller coating or air knife. The coated substrate is then nipped with another substrate, and the resulting laminate may then be left to air dry or passed through a heated oven to remove solvent and build bond strength. The types of adhesive used for wet lamination are:

- waterborne natural products, such as starch and dextrin or
- waterborne synthetic latex products, such as polyvinyl acetate, acrylic, etc.
- 100% reactive liquids, such as polyurethanes or polyesters.

Wet lamination via waterborne or solvent based adhesives is confined to applications where at least one substrate is porous (e.g., paper, cardboard, textiles) to facilitate drying. Once cured, bond strength is generally high enough to cause failure or tearing of the porous substrate.

Most often, waterborne synthetic latex adhesives are utilized for wet bonding because of their high initial strength and fast drying characteristics when applied to porous substrates.

Dry Lamination

Dry laminations are those in which the liquid adhesive is first dried before lamination. The adhesive can be either applied to one substrate and dried or it can be applied as a hot melt type of film (essentially another film layer). The adhesive is then in the dry solid or slightly tacky stage when joined with the other substrate. The bonding is generally achieved during a high temperature, high pressure nip. The temperature and pressure are sufficient to cause the adhesive to flow and create an instantaneous bond when it cools and gels.

Dry lamination can be applied to a broader range of products such as film-to-film and film-to-foil.

Dry laminating adhesives are generally solvent based although considerable development has taken place to reduce or replace the solvent to meet environmental regulations.

This has produced several strong competitors to conventional solvent-based adhesives such as:

- hot melts (e.g., ethylene vinyl acetate copolymers),
- 100% reactive solids (e.g., two-part polyurethanes,
- one part moisture curing polyurethanes and UV/EB curable acrylates),
- high solids solvent based (e.g., silicone), and
- waterborne adhesives (e.g., acrylic emulsions).

A significant advantage of reactive 100% solids adhesive in addition to the reduction in possible VOCs is the possible elimination of drying ovens and resulting energy cost.

Hot melt adhesives are applied by heating the hot melt formulation to a closely controlled temperature and applying via extrusion or die coaters. With hot melt adhesives, a pre-made film of hot melt material may also be interleaved between two substrates at a high temperature nip to achieve lamination.

Another method of making a laminate, which is outside the scope of this article, is coextrusion. Coextrusion allows the production of a laminate in a single process. In this process two or more thermoplastic materials are extruded separately and combined either internally in the die or immediately after leaving the die. A separate adhesive is often not required; however, certain film laminates may require the application of a "tie-coat" to maximize adhesion of one film to the other. The coextrusion process is generally used for very high volume laminate production.

Adhesive lamination is the preferred joining process when a specific film composition cannot be effectively run in a coextrusion system due to equipment limitations or when the high temperatures required in coextrusion would be harmful to the film. Adhesive lamination is also preferred when the adhesive itself can provide additional functionality to the final product.

The Laminating Adhesive

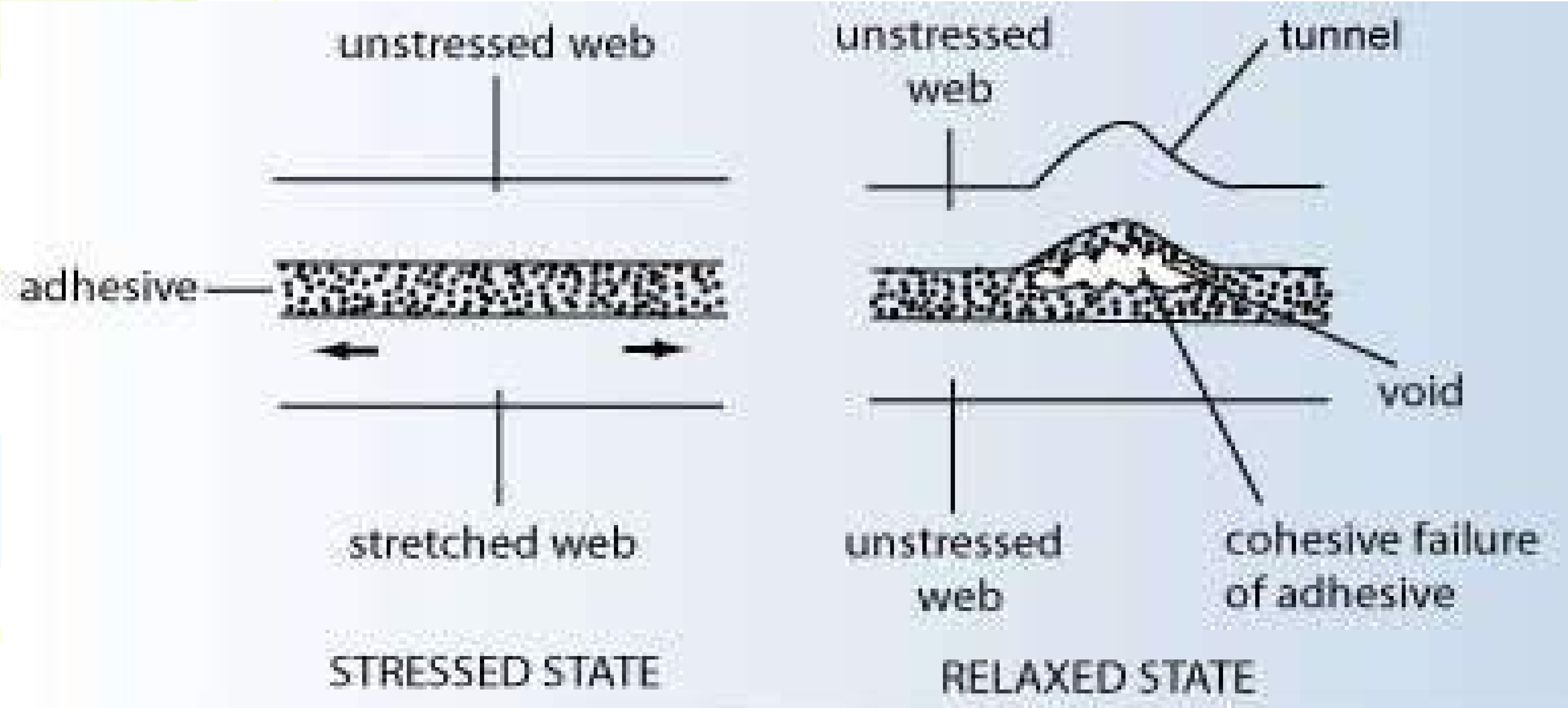
Selection of a particular adhesive system depends on a number of factors, all of which can lead to problems unless they are properly understood or controlled. Common chemical, physical, and performance factors are shown in Table 4.

Chemical	• Mixing ratio of components • Shelf-life of resins • Pot-life after mixing • Curing time and energy required
Physical	• Molecular weight • Solids content • Solution viscosity, melt viscosity • Wetting behavior and coating ability • Drying speed
Performance	• Initial bond strength (green tack) • Ultimate bond strength • Resistance to service environments • Adaptability to laminating processes • Laminating conditions (nip pressure, temperature, speed, etc.)

It should be noted that the adhesive in a laminate is often chosen for more than only its bonding ability. In addition to holding the substrates together for the life of the laminate, the adhesive might have to perform certain other functions that are necessary to the success of the final product.

These additional functions could include:
increased or decreased gas permeability,
flame resistance,
thermoforming capability,
optical clarity,
electrical insulation or conductivity,
chemical and heat resistance, etc.

The laminating adhesive must also be resistant to an effect called "tunneling". As illustrated in Figure 2, tunneling is the localized separating or delamination of the substrates caused by two films of different extensibility that stretch or relax at different rates.
The localized stresses that are produced can have a detrimental effect on the laminate's appearance and performance.


unstressed web
adhesive
stretched web
STRESSED STATE
unstressed web
tunnel
void
unstressed web
cohesive failure of adhesive
RELAXED STATE

Lamination Adhesives

for General Purpose applications

- **Can be single or two component solvent based, solventless or water based**

- **Typical uses:**
  - **Salty snacks**
  - **Confectionery**
  - **Bottle labels**
  - **Bakery**

Lamination Adhesives

for General Purpose
examples

- **Performance of adhesives goes from fairly low performance to very demanding**
- **Here we have a bottle label – low bond strength, some water resistance, and high line speeds**
- **Can be waterborne or 100% solids**

Lamination Adhesives

Medium Performance

- Can be two component solvent based, solventless or water based
- Typical applications:
  - –Spice pouches
  - –Flavors
  - –Chemical
  - –Soap
  - –Industrial
  - –Medical/ pharmacuetical
  - –Hot fill (juices, etc.)

Lamination Adhesives

Medium Performance examples

- Must have product resistance
- Must have high heat resistance for zipper installation

Lamination Adhesives

High Performance

- Specialty applications where high heat and or chemical resistance is needed (solvent based or solventless)

- Typical applications:
  - specialty pouches
  - specialty lidding
  - Concentrated chemical storage
  - Outdoor exposure / agricultural bags

Lamination Adhesives

Highest
Performance

- Adhesive must survive retort process
  (up to 120ºC 30 minutes).
- Adhesive must have product resistance.
- Usually solvent borne;
  some uses of solventless in high performance

Advances In Laminating Adhesives

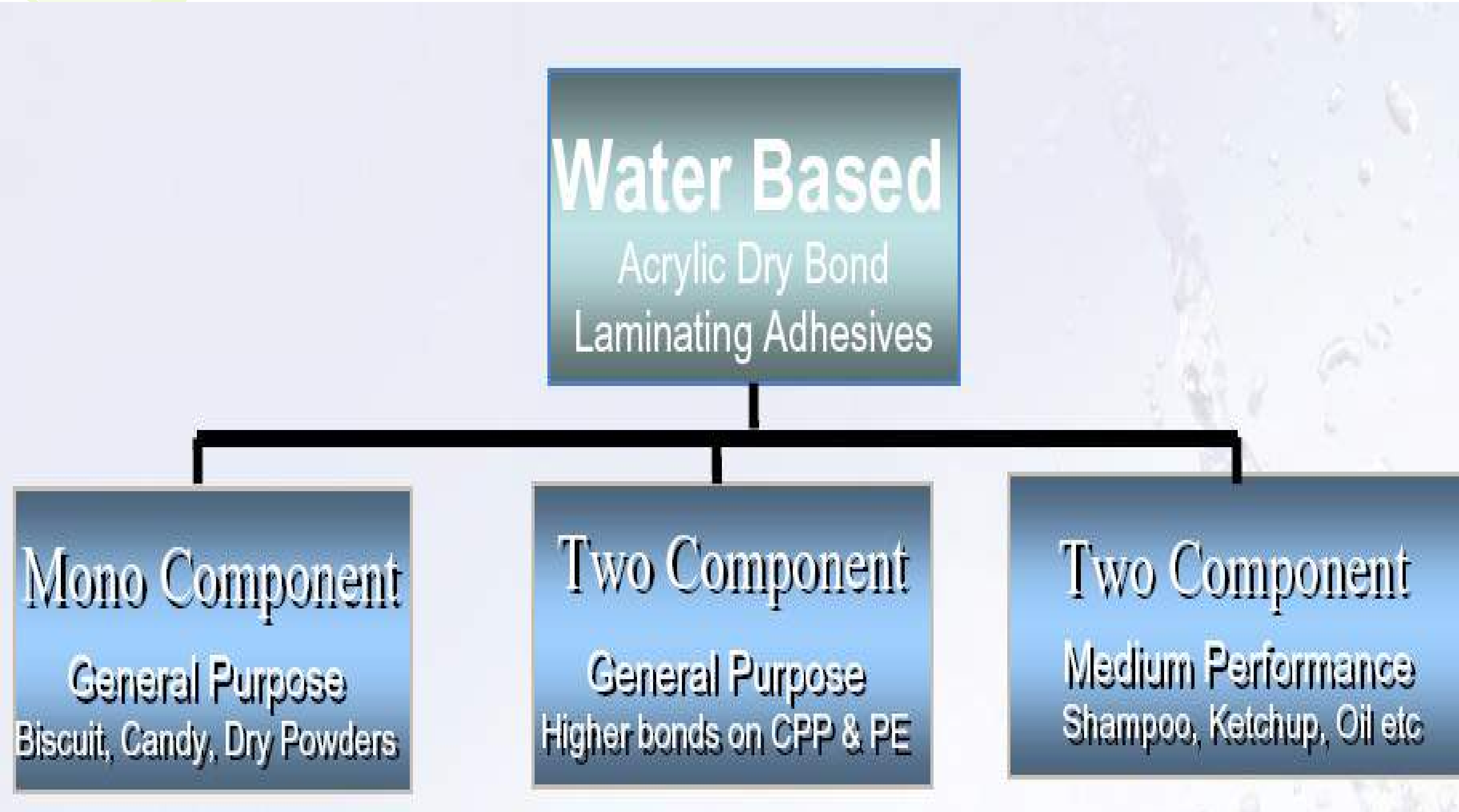
- **New high performance adhesives that give improved application characteristics (higher solids at lower viscosities)**
- **New waterborne adhesives that have bond values more equivalent to solvent based adhesives**

Water Based Dry Lamination Adhesives

- An emulsion polymer made by free radical polymerisation of monomers in water.
- High MW polymer particles finely suspended in water.
- Appearance : translucent to opaque white (as supplied, converts to a transparent film on drying)
- Particle Size : < 1.0 micron
- pH neutral –no corrosion.
- Forms a flexible film on drying.

Advantages

- Very Stable Adhesive System –No viscosity adjustment required on the machine.
- Low viscosity : Easier to apply & transfer
- Particle Nature –Faster / Easier Drying c.f. WB PU systems •Water Based : No retained solvent issues
- High Molecular Weight : Immediate Slitting



Water Based
Acrylic Dry Bond
Laminating Adhesives
Mono Component
General Purpose
Biscuit, Candy, Dry Powders
Two Component
General Purpose
Higher bonds on CPP & PE
Two Component
Medium Performance
Shampoo, Ketchup, Oil etc

Why Move to Water Based technology?
The Value Proposition

- Economics
- Performance & Ease of Use
- Supply Chain Benefits
- EHS Benefits

Economics

•Lower Coating Weight / Lower Applied Cost as compared to Solvent Based adhesives

•Low Capital Expenditure & Savings in Working Capital –Run on existing Dry Laminators with minor modifications–Lower inventory carrying cost due to immediate slitting advantage

•Lower Waste Costs (1 K)

–No mixed adhesive wastage during roll changes & at the end of the day.

–No waste through wrong mixes

–Reduced waste disposal costs as product is non-hazardous

Performance & Ease of Use

- Supplied ready to use (1 K)
- Excellent wet out and adhesion to metallizedfilms(1K)
- Bonds to a wide variety of films & Paper , most cost effective solution for Film / Paper lamination
- Excellent green shear and comparable bond and seal strengths to SB / SL adhesives
- Comparable Heat and Chemical Resistance to SB / SL adhesives
- Excellent gloss & clarity of laminate
- Water wash up

Supply Chain Benefits

- Laminates can be slit immediately resulting in shorter lead time to customer
- Lower rework / rejection of laminate due to solvent retention / odour issues
- Reduced requirement of warehousing area for finished laminate
- Most economical and suitable for short job runs due to better pot life (especially 1 K)

Environment / Health & Safety Benefits

- Safer work place (solvents have extremely low flash points and are a potential fire hazard)
- Reduced staff exposure to solvents
- No Primary Aromatic Amine issues (Liquid food packaging)
- Compliance with all major Food Safety regulations such as FDA 175.105, 177.1395 and EU FC/P
- No solvent vented to the atmosphere –no air pollution during lamination

Water Based Dry lamination –The Value P

Advantages over Solvent-Based Adhesives

•More cost effective

–Lower dry adhesive cost.

–Lower coat weights can be applied.

–No need for dilution for machine runs.

–Avoids viscosity control requirement during production.

–Lowers inventory costs for laminated stock –instant slitting & cure.

•Odor free laminate –no solvents from the adhesive.

Laminating Adhesives : How they Stack Up?

	Economics	Safety, Odor Risk	Cure Time*	Processing
SL	Good	Low	High	Fair
WB	Fair	Low	Low	Easy
SB	Low	High	Fair	Easy

Water Based Dry lamination - The Misunderstood Technology

"I can not run water based adhesives because…"

- It will not work for film to film lamination…
- My machine can not dry water…
- I will need to run my machine slower…
- My ovens will rust…
- I will not get the performance necessary for my packaging requirement…

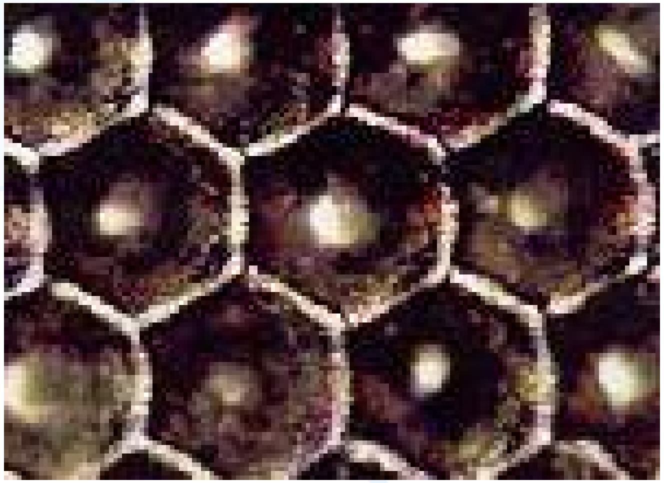
What does one need to run Water Based Adhesives ? The Key requirements on an existing Dry Laminator

- Suitable Gravure Cylinder
- Suitable Drying Tunnel
- Corona Treater (between primary unwind and gravure cylinder)
- Laminating Nip Wrap angle / Temperature & Nip Pressure
- Recirculation tank for adhesive circulation
- Smoothing bar

The recommended Laser engraved cell pattern for thin film coatings is the 60° HEXAGON cell pattern.

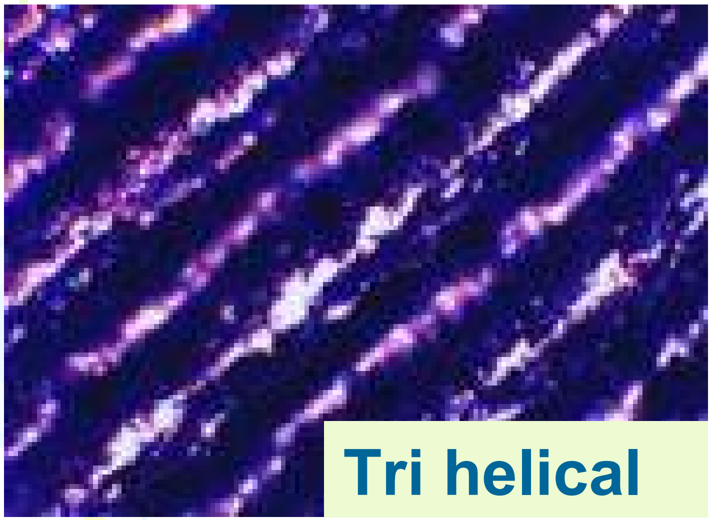
Thin film coatings require engraving screen counts from 120 to 800 cells to the linear inch.

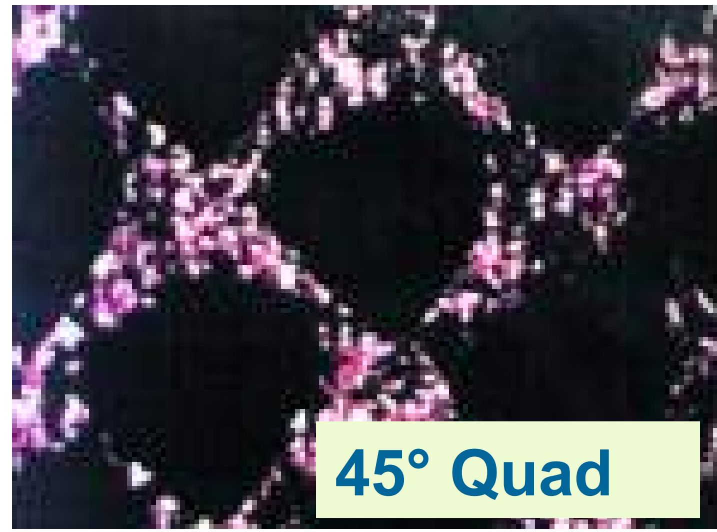
When compared with chrome, the 60° hexagon Laser engraved roll offers thinner cell walls, wider cell openings and bowl-shaped cells.



The recommended Laser engraved cell patterns for thick film coatings are TRIHELICAL and 45° QUAD shaped engravings.

Thick film coatings require engraving screen counts from 30 to 200 cells per linear inch.





These coarse screen rolls are re polished after engraving, to smooth out inherently rough cell walls caused by extremely deep cell engraving recast. The higher the cell volume, the greater the need to remove excessive recast. The degree of post-finishing or post-polishing is accomplished under highly controlled volume measurement conditions.

While manufacturing coarse screen engravings, the primary quality parameters are:

- Precise cell volumes to deliver exact coating weight or thickness; and
- Smooth cell walls to offer minimum blade wear conditions to optimize production time.

Drying Tunnel

- Long Tunnels with zones systems are better
- Good Air volumes and Air Velocity
- Positive Air exhaust volumes
- No Recirculation of exhausted air between zones
- Simple retained moisture test can be done to determine efficiency of the drying tunnel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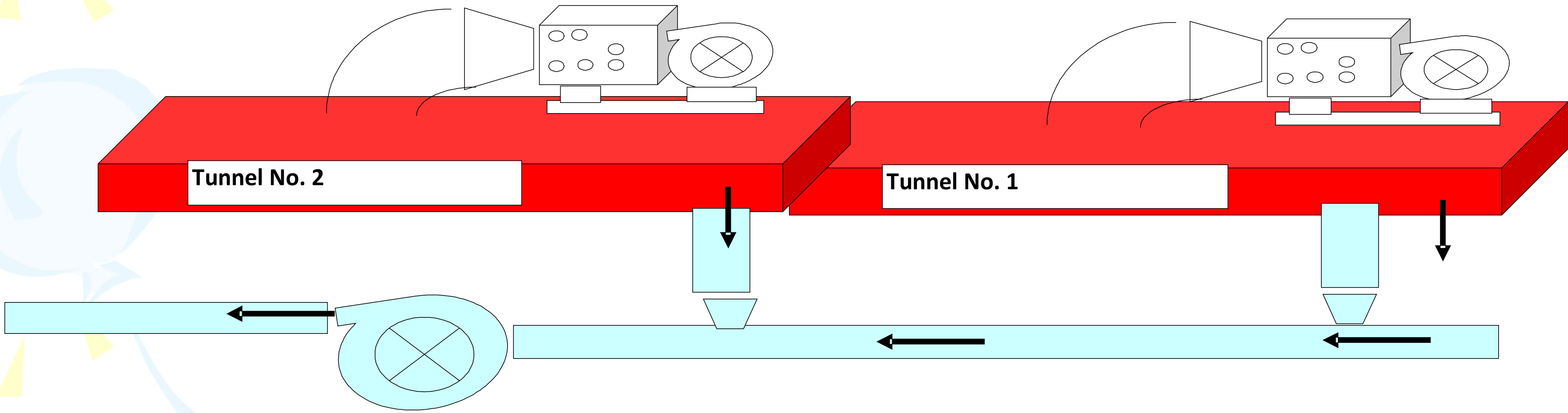


Tunnel No. 2
Tunnel No. 1

Corona treater

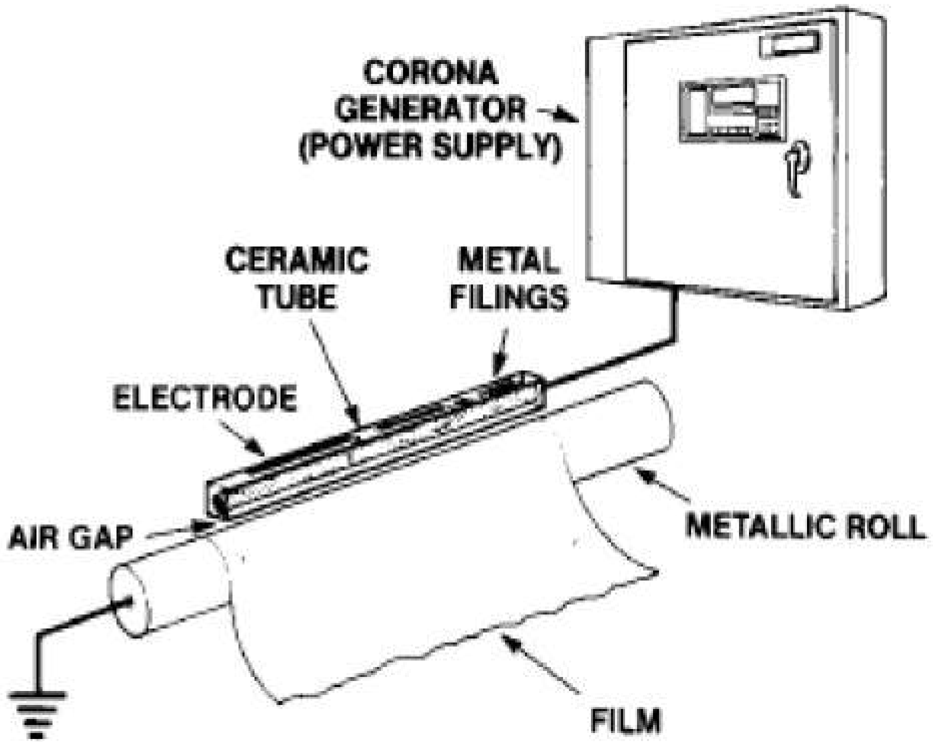


Figure 18. Ceramic Electrode/Bare-Roll.

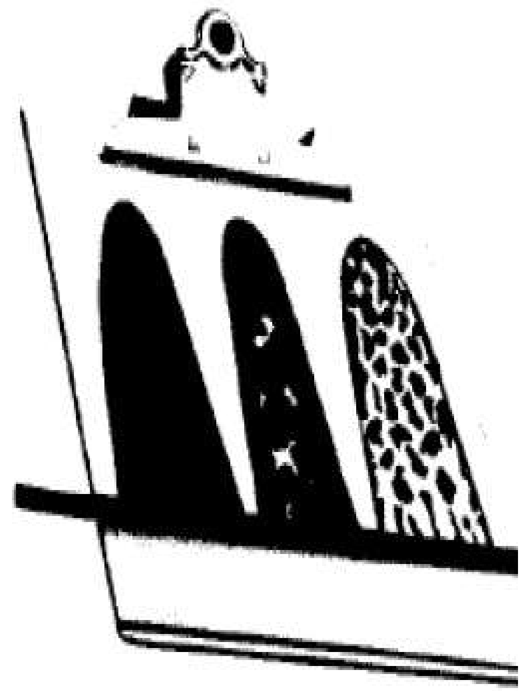


Figure 8. Drawdown of Three Dyne Solutions.

Water Based Adhesive Technology

- Runs on existing dry laminators with minor modifications
- User Friendly – Easy Mixing / No Viscosity Adjustment
- Excellent clarity and improved gloss of laminate
- No VOC or DG Issues. Safer , improved Regulatory Compliance.
- Superior economics as compared to Solvent based adhesives
- Faster Processing – No WIP , superior speed to market
- Most suitable for short lamination runs , lamination of metallised structures and film / paper applications.
- Most suitable for liquid food packaging
- Odour free laminates
- General to Medium Performance (liquid packing) adhesives available

Lamination is also possible

With

Heat Seal

Or

Cold seal adhesives

What Is A Heat Seal?

- Thermoplastic material applied as a liquid coating, dried, tack, and block free.

- Heat activated by to become soft and tacky.

- Pressed to second substrate to make bond.

- Cooled to room temperature to form bond between layers of substrates.

Components of Heat Seals

- Defining resin or resins.
- Tackifier resins or additives
- Lubricants, waxes, and slip modifiers.
- Antioxidants and stabilizers.
- Anti-blocking and heat stabilizing fillers.
- Solvents and diluents.
- Water, dispersants, pH control, and surfactants.

Classes Of Chemistry

Solid Resin

- Ethylene Vinyl acetate (EVA).
- Modified EVA.
- Modified Polyolefin Copolymers.
- Modified Polyolefin Terpolymers.
- Polyester (PET).
- Modified PET.

Water Based

- EVA and Modified EVA
- Ethylene acrylic acid (EAA)
- Ethylene methacrylate (EMA)
- Ethylene methyl methacryalte (EMMA)
- Polyvinyl alcohol (PVOH)
- Acrylic
- PVdC

SolventBased

- EVAIonomer
- Vinyl
- PET
- PVOH
- Polypropylene (PP)
- Acrylic
- Polyamide

Markets Served

- Food Pouches
- Medical
- Pharmaceutical
- Peelable Lidding
- Portion Packaging
- Industrial
- Instant Photograph
- Agricultural Containers
- Paper and Graphics
- Frozen Food Cartons
- In Mold Label

Heat Seals:

New Developments

- **Waterborne high porosity heat seal coating – platform technology for varying porosities and seal activation temperatures.**

- **Higher solids EVA waterborne heat seal coatings**

- **Heat seal coatings for shrink label applications**

Cold Seals

- Adhesives (cohesives) that bond when exposed to pressure only
- Formulated so that tack to non cold seal surfaces is minimized
- Release lacquers or films are still required due to pressure in roll stock

Synthetic Cohesive Coating

Cohesive (cold seals) are products used for applications where the bond between two substrates is formed without any heat, only pressure.

Synthetic cold seals are based on synthetic rubber as opposed to natural rubber based cold seals.
Natural rubber based products have been associated with allergic reactions in persons sensitive to these types of compounds.

Used primarily for medical bandage packaging, our synthetic cold seals perform well on a wide variety of film and paper substrates offering high bond strength and excellent economics.

Product Applications for Cold Seal Adhesives

- Heat sensitive products such as chocolate and ice cream
- Very high speed packaging machines
- Combination of both: high speed packing for heat sensitive products
- Medical packaging materials
- Industrial applications

How Cold Seals Work

- When cold seal is applied and dried, adhesive portion orients toward the film, while the cohesive orients toward the surface
- Pressure is applied and the long rubber polymer chains intertwine giving cohesive bonding

Synthetic Cold Seals

- Composed of cohesive and adhesive components
- Cohesive components are synthetic elastomers
- Synthetic elastomers eliminate variation due to natural product
- Synthetics also eliminate allergy issues

Cold Seals: New Developments

- Acrylic / natural rubber based cold seals formulated to decrease end seal deadening

- 100% synthetic cold seal using proprietary technology

New Solvent less adhesive from Dow Chemicals

Product : Mor-Free™ L75-173/C-145

This is solvent free , 100% solids , two component , low cost adhesive for Lamination of Flexible laminates.

The distinct advantages of this adhesive are

- Processing/ coating at room temp
- Fast curing
- still very good pot life
- useful for laminating all known substrates
- the laminates could be processed further just after 4 hrs. of coating, in the same shift.

New Development

Compared to many conventional two-part systems, one-part epoxy adhesives enable manufacturing companies to improve productivity, increase product quality and decrease hazards to the workforce.

Replacing two-part systems with one-part products can deliver several advantages and improvements.

ONE-PART EPOXY ADHESIVES WILL ELIMINATE:

- Eliminate the dispensing and metering equipment (required for two-part adhesives)
- Eliminate waste resulting from unused mixed adhesive and subsequent waste disposal costs.
- Eliminate mix ratio tolerance concerns .
- Eliminate concerns about pot-life and subsequent processing downtime resulting from product viscosity exceeding process tolerances.

ONE-PART EPOXY ADHESIVES WILL REDUCE:

- Reduce operator labor needed to maintain meter mix equipment and components or to manually weigh and mix product.
- Reduce labor required to oversee and maintain cleaning of pumps, vats, scales and other associated manufacturing equipment.
- Reduce manufacturing process equipment capital cost by elimination of expensive meter mix equipment and associated expense with maintenance, spare parts and cleaning.
- Reduce energy use with cure temperatures that can go as low as 80°C while maintaining shelf life at 25°C for over 2 months.

ONE-PART EPOXY ADHESIVES WILL IMPROVE:

- Improve raw material procurement and flow by replacing two containers required for two-part systems to only one container for one-part systems.
- Improve final product consistency and quality as a result of more consistent adhesive or coating.
- Improve worker safety and decrease hazardous communication requirements with the elimination of volatile corrosive curing agent components from raw material inventory and limiting exposure of hazardous chemicals to operators.
- Improve adhesive performance where specific sacrifices may have been made with a two-part system in order to maximize pot life, meet required viscosities, and/or mix ratio requirements.

New Development

Solventless lamination Adhesives

universally applicable solventfree reactive polyurethane adhesives. In finished laminates, retained solvents left behind by adhesives are no longer an odor problem
– because no solvents are used.

The Advantages

> Fast migration compliance for food safety
> High productivity
> No solvents
> High machine speed
> Cost efficient
> Low energy requirements

> Processing at 40-50°C
> Long pot life
> Easy cleaning
> Conventional mix ratios
➢ Broad application range, from standard to high performance

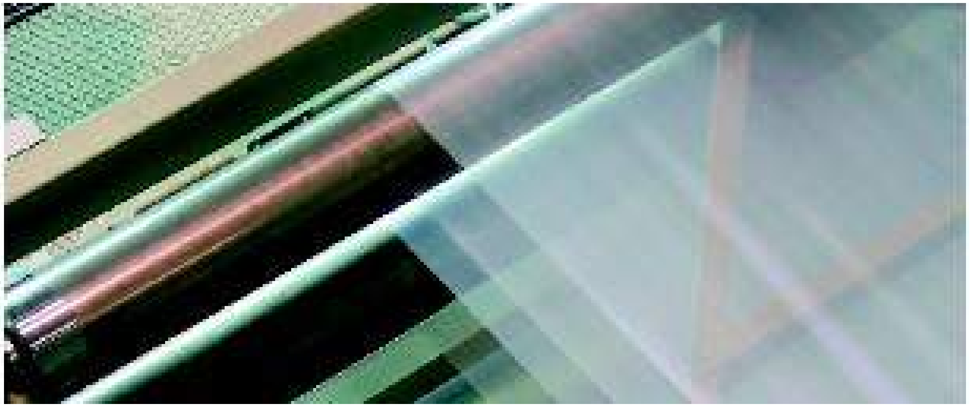
Extrusion Coating Lamination

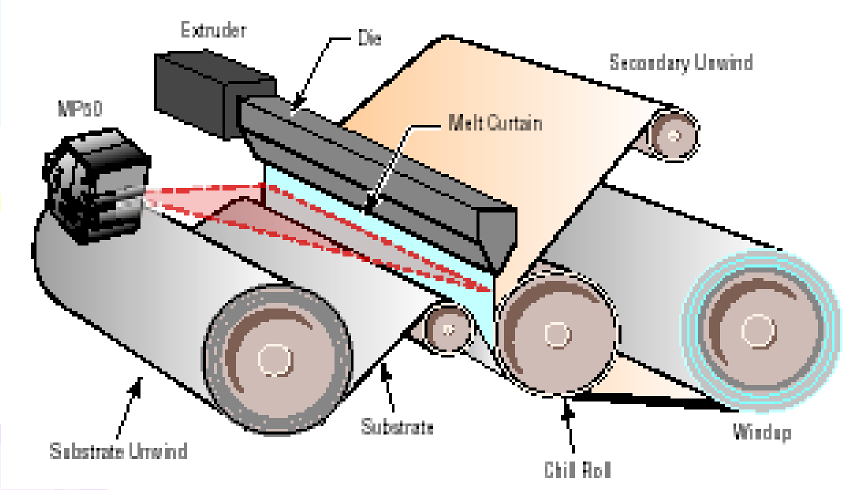
Extrusion lamination is a process that is used to combine two different substrates using molten polymers. The process of **extrusion lamination metal, paper and mainly plastic films**. It can provide lamination of different thicknesses with level of quality. includes both the characteristics of extrusion and lamination.

process to coat an additional layer on existing roll stock of paper, cotton cloth, woven fabrics, jute fabric, aluminum foil, Bopp film or polyester film. This process can be used to improve the characteristics of paper by coating on it with polyethylene to make it more resistant to water. The extruded layer can also be used as an adhesive to bring two other materials together.

- It can be used on various substrates as paper, cotton cloth, woven fabrics, jute fabric, aluminium foil, Bopp film or even a polyester film.
- Can perform either extrusion coating or extrusion lamination.
- Highly efficient and durable lamination.

Film Extrusion, Extrusion Coating, and Lamination Processes





Extrusion laminating (also known as sandwich laminating) is a process related to extrusion coating, but the extrusion-coated layer is used as an adhesive layer between two or more substrates. A secondary layer is applied to the extrusion coating while it is still hot. The MP50 monitors the melt curtain before the chill roll before the sandwich is formed. The sandwich is then pressed together by pressure rolls. In addition to providing adhesion, the extrusion-coated layer may also serve as a moisture barrier.

Flexible laminates
Some applications

Refractory materials

INTRODUCTION

- What are are refractory materials?

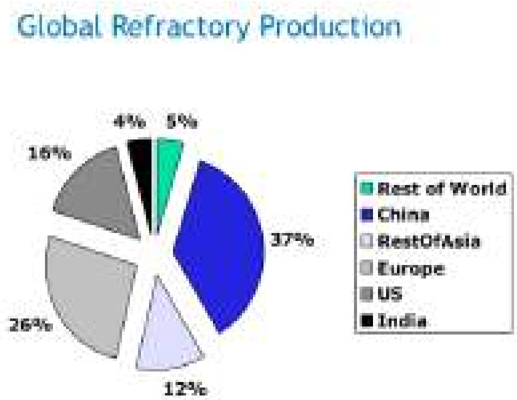
Materials that

- Withstand high temperatures and sudden changes
- Withstand action of molten slag, glass, hot gases etc
- Withstand load at service conditions
- Withstand abrasive forces
- Conserve heat
- Have low coefficient of thermal expansion
- Will not contaminate the load

Deffination

- Refractory Is a class of materials which are produced from non metallic materials.The are primary materials used inerlinning of industrial; furness and process capability to withstand heat and pressure and are used in steel,aluminium,glass,cement,petrochemicals,non-ferrous metals,thermal power plants and ceramic industries.they are produced in Special shapes and are custom made to suit the requirements of the various industries.
- Refractories are classified on the basis of therir chemical composition.end use and manufacturing method.They can be classified acidic basic and nutral refractories.A small range of high melting point material like magnetia,bauxite ,fireclay and silica are used to produce refractories.

Our position in global market



Industrial uses

- **Refractories**

Refractory lining of a furnace arc

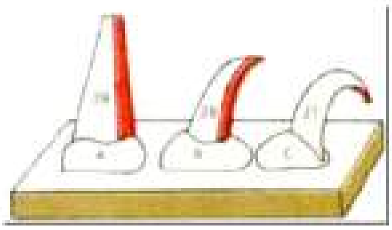
Refractory walls of a furnace interior with burner blocks

Properties of Refractories

- Melting point
  - Temperature at which a 'test pyramid' (cone) fails to support its own weight
- Size
  - Affects stability of furnace structure
- Bulk density
  - Amount of refractory material within a volume (kg/m3)
  - High bulk density = high volume stability, heat capacity and resistance
- Porosity
  - Volume of open pores as % of total refractory volume
  - Low porosity = less penetration of molten material

Properties

- Cold crushing strength
  - Resistance of refractory to crushing
- Creep at high temperature
  - Deformation of refractory material under stress at given time and temperature
- Pyrometric cones
  - Used in ceramic industries to test 'refractoriness' of refractory bricks
  - Each cone is mix of oxides that melt at specific temperatures



Properties

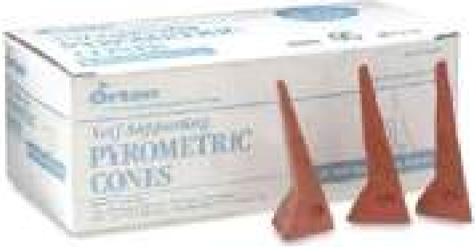
- Volume stability, expansion & shrinkage
  - Permanent changes during refractory service life
  - Occurs at high temperatures
- Reversible thermal expansion
  - Phase transformations during heating and cooling
- **Size and dimensional stability**
  - The size and shape of the refractories is an important feature in design since it affects the stability of any structure. Dimensional accuracy and size is extremely important to enable proper fitting of the refractory shape and to minimize the thickness and joints in construction.

Properties

- **Abrasion resistance**
  - The mechanical stress of refractory bricks is not caused by pressure alone, but also the abrasive attack of the solid raw materials as it slowly pass over the brickwork and by the impingement of the fast moving gases with fine dust particles. Therefore the cold crushing strength is not alone sufficient to characterize the wear of the refractories. There is no approved method for testing abrasion resistance but there are some methods available to give reference values such as Bohme grinding machine method and sand blast method etc.
- **Specific heat**
  - The specific heat is a material and temperature related energy factor and is determined with the help of calorimeters. The factor indicates the amount of energy (calories) needed to raise the temperature of one gram of material by 1 deg C. Compared to water, the specific heats of refractory materials are very low. These values are less than one fourth of value of specific heat of water.

Pyrometric cones

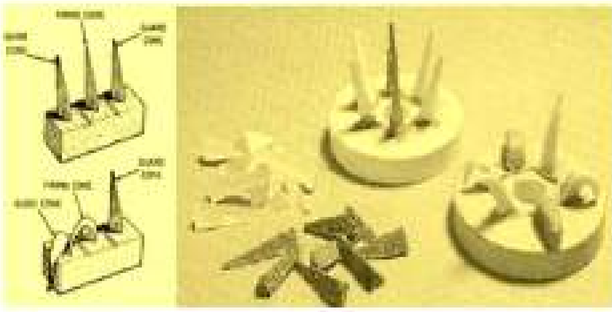
Pyrometric cones are pyrometric devices that are used to gauge heatwork during the firing of ceramic materials. The pyrometric cone is "A pyramid with a triangular base and of a defined shape and size; the "cone" is shaped from a carefully proportioned and uniformly mixed batch of ceramic materials so that when it is heated under stated conditions, it will bend due to softening, the tip of the cone becoming level with the base at a definitive temperature. Pyrometric cones are made in series, the temperature interval between the successive cones usually being 20 degrees Celsius. The best known series are Seger Cones (Germany), Orton Cones (USA) and Staffordshire Cones (UK).



Self supporting pyrometric cones

Pyrometric cones Equivalent (pce)

These cones are pyramidal in shape and have a height of 38 mm of a triangular base and 19 mm long sides. They are allowed to heat under 10˚C per min as a result of they undergo fusion as a definite temperature.This temperature at which they fusion or softening of the test cones is shown by its apex touching the base.The PCE of the given refractory may be regurded as the no of test cones,which also fuse with the test cone.

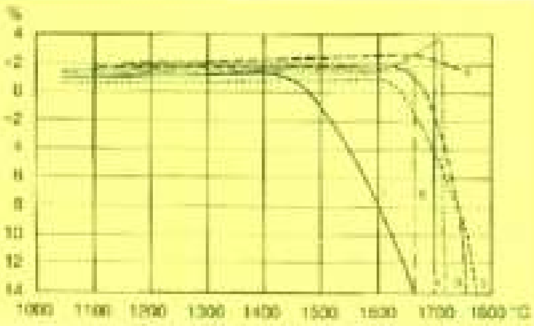


PCE cones before and after firing

Refractory Under Load(RUL)

- **Refractoriness under load:**
  - Refractoriness under load (RUL) evaluates the softening behaviour of fired refractory bricks at rising temperature and constant load conditions. RUL gives an indication of the temperature at which the brick will collapse in service condition with similar load. However, under actual service conditions the bricks are heated only on one face and most of the load is carried by the relatively cooler rigid portion of the refractory bricks. Hence, the RUL test gives only an index of refractory quality, rather than a figure which can be used in a refractory design. Under service conditions, where the refractory used is heating from all sides such as checkers, partition walls etc. the RUL test data is quite significant. For RUL, samples in cylindrical shape of 50 mm height and 50 mm diameter are heated at a constant rate under a load of 0.2 N/Sqmm and the change in height includes the thermal expansion and also the expansion of test equipment. The test results are taken from the recording. The initial temperature is taken at 0.6 % compression while the final temperature is taken at 20 % compression or when the specimen has collapsed.

"ROL" curves for different refractory bricks



Refractoriness under load curves of refractory bricks
1. Fireclay, 2. Sillimanite, 3. Chrome magnesia, 4. Silica (crown), 5. Silica (Coke oven), 6. Magnesia chrome

Types of refractories

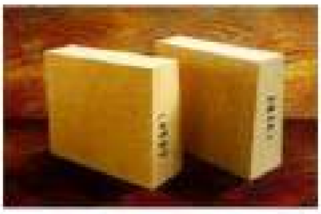
- 3 types-
- 1)Acid refractories(e.g silica bricks)
- 2)Basic refractories(e.g magnetia bricks)
- 3)Nutral refractories(e.g karborundum bricks)

Types

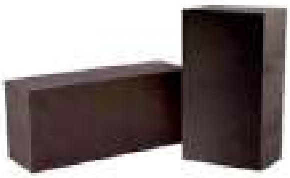
- There are three types of refractory material that we discussed in the previous slide-
  - 1)**Acid Refractory:** This refractories are made up of acidic material like zircon,fire clay and silica.
  - 2)**Basic Refractories:** This type is made up of basic material like dolomite,magnetia.
  - 3)**Nutral Refractory:** Thus type is made up of alumina ,chromite,silicon carbide and mulite.we can not use acidic refractory directly in the basic environment and vice versa because they will be corroded.

Classification on basis of temparature range

- **Refractory**:when temperature is between 1580-1780 e.g. fire clay
- **High Refractory**:when temperature is between 1780-2000 E.g. chromites
- **Super refractory**:when temperature is between >2000 E.g. zircons



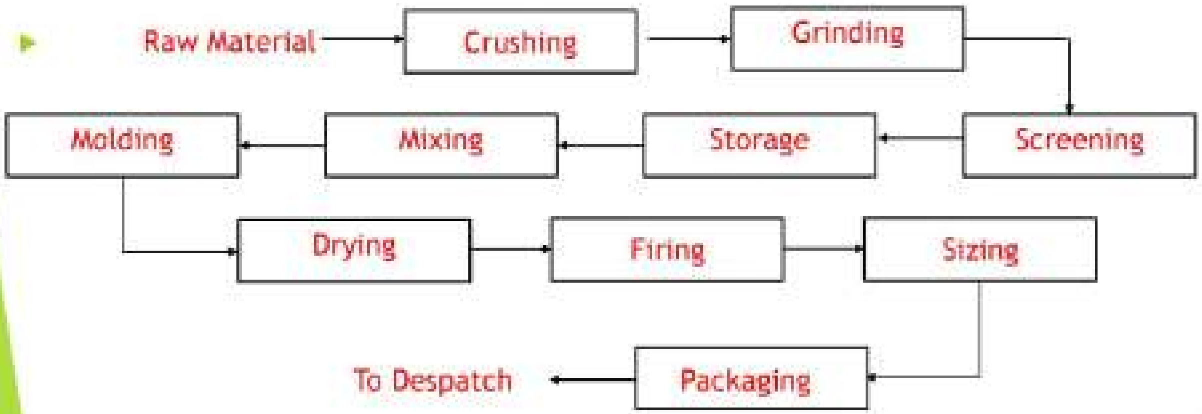
Fire Clay Brics



Chromite Bricks

Zirconia Brics

Block Diagram of manufacturing refractory



s0me common refractory bricks used in industry

- Sillica bricks
  - It contains 90-95 of silica and 2 of cao
  - Cao is added to furnish the bond.
  - Raw material is used quartz ,quartzite,and sand stone
  - Crushed and groud with lime water..and this thik paste is then made into brick bye hand moulding or machine pressing.
  - then the bricks are dried into the drier and burnt into kilns
  - The temperature is properly maintained
    - First it is slowly raised in about 24 hours to about 1500°C and it is maintained for 12 hours so as to allow quaqrtzite to be converted into crystobellite

s0me common refractory bricks used in industry

Quartzite (Crystalline) $\xleftrightarrow{870^\circ C}$ Tridymite (α form of silica) $\xleftrightarrow{1117^\circ C}$ Crystobellite (β form of sillica)

- After it is cooled for one or 2 weeks so thtcrystallobite slowly changes into trydemite.
- Sio as we get a mixture of trydemite ande crystallibite in the final brick

Properties and Uses of Silica Bricks

- **Properties:**
  - i)Yellow in colour,25% porous.They have sp. Gr. Of about 2.3-2.4
  - ii)They do not contract in use vbut they gtave 50% of permanent expansion when reheated.and it is reversible and it returns to its original size when cooled.this expansion happens due to allotropic transformation.thuys if quartzite is not fully converted into trydemite and crytallobite it give 17.2% of permanent expansion.so for this the refractory structure may fall.So the heating is necessary.
  - iii)They have homogenious texture and their refractory under load is 3.5 Kg/sq. cm. upto 1500˚C.
- **Uses:**
  - Used for making the roof of open hearth furness,coke oven walls,roof of electric furness.They also used as the linning of blast furnest because of their high conductivity.

Magnesia bricks

There are two types of Magnesite bricks:

Burned Magnesite brick:

- · Material and Technique: magnesia as raw material
- · Property: good high-temperature performance, strong slag resistance
- · Application: used in permanent linings of EAF and steel Convertors, lime kilns, glass tank regenerators, torpedo cars and non-ferrous furnaces

Magnesia bricks

- **Fused Magnesite brick:**
  - Material and Technique: fused magnesia, shaped under high pressure, fired under ultra high temperature and finished with post technical treatment
  - Property: high bulk density, good high-temperature performance and strong hydration resistance
  - Application: used in the tapping hole of the convertor with severe slag corrosion and wear, the slag line of non-ferrous furnaces, the tapping hole of metal mixer furnaces, and chimney block of glass tank regenerator
- Refractory Under Load 3.5 Kg/Sq. cm. upto 1500˚C.But it can withstand upto 2000˚C without any load.
- They are used as the basis lnning in the basic converter and open hearth furness.

Zirconia brics

They are obtained by heating zirconite mineral and colloidal zirconia(prepared by drying zirconium nitratesolution and making residue into solution and again drying).Here alumina is used as binding agent.Temparature required is 1700˚C.Since zirconite undergoes volume changes of heating and cooling.So it is stabilized by adding magnesium oxide.

Zirconia bricks

Properties:

i)They are nutral refractory but they are not quite resistance to acidic slag.Hence they are at the border line of nutral and basic refractory.
ii)Used upto 2000˚C.Their rul is 3.5Kg/sq cm upto 1900˚C.They are also resistnce to thermal shock.

Uses

- They are very costly,so they are used only where the high temperature is used such as electric furness.
- Zircon silicate bricks are used as an inert intermediate layer between high alumina bricks and silica crowns. In addition, they serve as a safety layer in the bottom of the melting tank, as they provide high resistance to metal drop drilling

Beryllia brick

- They are made by firing mouled articles from pure beryllia at 1900˚C-2000˚C.
- Properties:
  - i) Beryllia bricks possesses high fussion point(2550˚C)
  - ii) Low electrical conductivity ,high thermal conductivity ,good resistance to thermal shock and inertness to CO and CO_2 upto 2000˚C.They also have considerably hot strength.
- Uses:
  - i) Having considerable hot strength it is used in jet propulasion fields.
  - ii) They are used in making crucible for melting uranium and thorium in nuclear engineering.Due to its low nuhtron absorption capacity it is used as moderator in nuclear reactors and also in radiation shields in carbon resistance furnace.

- **Drawback:**
  - Its only drawback is beryllia is capable of volatizing at 1000˚C in presence of water vapour.Beryllia dust if inhale in small quantity can cause serious health hazard.Since great precaution should be taken.

Carbon brick

- Two types of carbon brick:
  - i) CARBON BRICKS PHENOL IMPREGENATED - (AF) QUALITY.
    - The impervious carbon bricks are especially developed for Highly Corrosion Resistance, Excellent Resistance to Thermal Shocks, High Crushing Strength, High Thermal Conductivity & it withstand a temperature upto 180°c. Very minimum Porosity i.e. 2-3 % & Maximum Carbon content i.e.98 % and Low Ash.
  - ii) NON-IMPRENGNATED CARBON BRICKS (STANDARD BRICKS "A" QUALITY).
    - The non-impervious carbon bricks especially designed for Highly Corrosion Resistance including all major Acids and Alkalies. More than 750°C temperature absorbing capacity. Carbon Content is 99% minimum & very low ash i.e. less than 1.0 %

Carbon brick

CARBON BRICKS PHENOL IMPREGENATED

Specifications	Results
Size As per standard; & thickness 10 To 100 mm Tol. (+/-)1mm .	
Density	1.6 gms./cc Avg.
Comp. Strength	600 kg/cm2 Avg.
Flexural Strength	300 kg/cm2 Avg.
Tensile Strength	125 kg/cm2 Avg.
Porosity	4 % Max.
Water Absorption	2 % Max.
Abradability Index	140 on Morgan Scale
Carbon Content	98 - 99 % Min.
Thermal Conductivity	4 - 6 w/mk.
Ash Content	1.5 % Max.
Temp. Resistivity	Upto 180°c
Chemical Duty	Suitable for Phosphoric Acid / HF / Flurosilicic Acid / H_2SO_4 & HCL Upto temp. 180°c
	Suitable for HNO_3, max. Con. 30%, Temp. upto 90°c

NON – IMPRENGNATED CARBON BRICKS

Specifications	Results
Size As per standard ; & thickness 10 To 100 mm Tol. (+/-)1mm .	
Density	1.5 gms/cc Avg.
Comp. Strength	350 kg/cm2 Avg.
Flexural Strength	100 - 150 Kg/cm2 Avg.
Tensile Strength	60 kg/cm2
Porosity	18 - 24 %
Water Absorption	12-18 %
Carbon Content	99 % Appox.
Ash Content	1 % Max.
Thermal Conductivity	4 - 6 w/mk.
Abradability Index	100 -110 on Morgan Scale
Temp. Resistivity	Upto 750°C
Chemical Duty	Suitable for Phosphoric Acid /H2SO4/ HF / Flurosilicic Acid / HCL Upto temp. 750°C.
	Suitable for HNO3 & all Alkalis max. Con. 30%, Temp. upto 120°c

INTRODUCTION

- A plastic material is any of a wide range of synthetic or semi-synthetic organic solids that are mouldable.
- Plastics are typically organic polymers of high molecular mass, but they often contain other substances.
- They are usually synthetic, most commonly derived from petrochemicals, but many are partially natural.
- Synthetic resigns may be phenol, formaldehyde, cellulose vinyl, alkyl, etc. The moulding compounds are catalysts, fillers, hardeners, lubricants, pigments, plasticizers, solvents, etc.

- **POLYMERIZATION:** The simplest substances consisting of one primary chemical are known as the monomers or monoliths. They are to be combined or synthesized to form polymers by the process known as the **polymerization**.

- **POLYMER** : The word polymer literally means “ many parts “. A polymeric solid material may be considered as to be one that contains many chemically bonded parts or units which themselves are bonded together to form a solid.

- Two industrially important polymeric materials are:

  1. Plastics
  2. Elastomers

- Plastics are a large and varied group of synthetic materials which are processed by forming or molding into shape. Just as we have many types of metals such as aluminium and copper, we have many types of plastics such as polyethylene and nylon.

- Plastics can be divided into two classes.
  1. **Thermo plastics**
  2. **Thermo setting plastics**,

  depending on how they are structurally and chemically bonded.

THERMO PLASTICS

- **Thermo plastics**: These plastics can be softened by heating and hardened by cooling any number of times without changing the properties of the material.
- It is thus possible to shape and reshape these plastics by means of heat and pressure.
- One important advantage of this variety of plastics is that scrap obtained from old and warnout articles can be effectively used again.
- **Properties** :
  1. Softens and liquefies on heating and hardens up to cooling.
  2. Retains shape after manufacture.
  3. Suitable for recycling.
  4. Can be reshaped by heat.
  5. It may melt before passing to a gaseous state.
  6. Allow plastic deformation when it is heated.
  7. They are soluble in certain solvents.
  8. Swell in the presence of certain solvents.

- Examples and applications of thermoplastic plastic materials:
  1. High pressure polyethylene as applied to rigid material covered with electrical machines, tubes, etc...
  2. Low pressure polyethylene elastic material used for insulation of electrical cables, etc...
  3. Polystyrene applied for electrical insulation, handles of tools...
  4. Polyamide used for making ropes, belts, etc...
  5. PVC or polyvinyl chloride for the manufacture of insulation materials, pipes, containers, etc.

- Examples of thermoplastic adhesives:
  1. Acrylates
  2. Cyanoacrylates
  3. Epoxy cured by ultraviolet radiation
  4. Acrylates cured by ultraviolet radiation

- **THERMO PLASTIC MATERIALS :**

1. Polyvinyl chloride (P V C)

PROPERTIES : Rigid , tough , elastic to feel.

Uses : Plumbing pipes and sanitary fittings are manufactured out of this material. Shower curtains , window frames, flooring , corrugated roofing sheets , plastic coating to steel sheets tanks, water cisterns, etc.

2. Acrylic :

PROPERTIES: Glass clear , some what brittle sound when tapped.

Uses : Glazing , bath rooms and sinks.

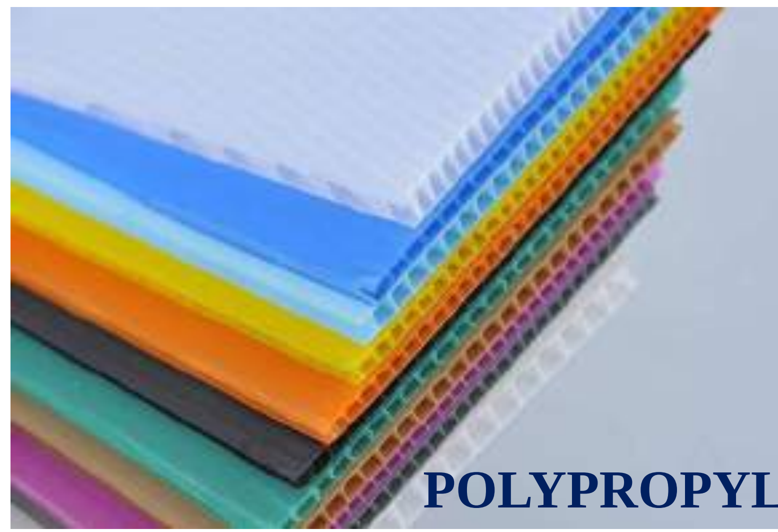
3. Polyethylene (or polythene) – low density:

PROPERTIES: Flexible, feels like paraffin wax.

Uses ; bottles, buckets, sheeting water tanks.

4. Polyethylene (or polythene)- high density :

PROPERTIES: stiff and hard, coarser than the polythylene of low density used as large storage bottles, water tank.



5. Polypropylene :

PROPERTIES : smooth, rigid, lightest of all plastics – it floats in water. Uses : wc cisterns, sink traps, washing machine bids, food containers, appliances , car fender.

6. Polystyrene : Solid (glassy) state at room temperature, but flows if heated above its glass transition temperature and becoming solid again when cooling off. Pure solid polystryrene is a colourless, hard plastic with limited flexibility. Polysterene can be transparent or can be made to take on various colours.

Uses : Refrigerator containers , food trays, packaging, food containers, disposable cups, plates, cutlery, CD and cassette boxes.

7. Nylon : PROPERTIES : High density polythene but smoother to feel.

Uses : Textiles , brush bristles, carpeting , surgical trays , bearings , pressure tubing.

THERMOSETTING PLASTICS

- These plastics are either originally soft or liquid or they soften once upon heating, they harden permanently.
- When they are heated in the temperature of 127 degree centigrade to 177 degree centigrade , they set permanently and further application of heat does not alter their form of soften them.
- But at temperature of about 343 degree centigrade, the charring occurs. The thermo setting plastics are durable, strong and hard.
- They are available in a variety of beautiful colours.
- They are mainly used in engineering applications of plastics.

- Properties :

1. Permanently hard on heating above a certain temperature.
2. Undergoes chemical changes during manufacture.
3. Cannot be melted and reshaped.
4. Little potential for recycling.

- Examples and uses:

1. Polyester fibreglass systems: sheet molding compounds and bulk molding compounds)
2. Polyurethanes: insulating foams, mattresses, coatings, adhesives, car parts, print rollers, shoe soles, flooring, synthetic fibers, etc. Polyurethane polymers are formed by combining two bi- or higher functional monomers/oligomers.
3. Vulcanized rubber
4. Bakelite, a phenol-formaldehyde resin used in electrical insulators and plasticware
5. Urea-formaldehyde foam used in plywood, particleboard and medium-density fiberboard
6. Melamine resin used on worktop surfaces.
7. Epoxy resin used as the matrix component in many fiber reinforced plastics such as glass-reinforced plastic and graphite-reinforced plastic)

- **THERMOSETTING PLASTIC MATERIALS**

1. Melamine formaldehyde (formica):

PROPERTIES : Hardest of common plastics , heat resistant.

BAKELITE

2. Phenolics (bakelite) :

PROPERTIES : The cheapest. Heavy solid plastic material, fishy smell when burnt dark in color. Heat resistant.

Uses : Bottle caps, plastic automobile parts, bonding plywood and chip board, glues, laminates with other materials.

3. Urea formaldehyde :

PROPERTIES : Similar to phenolic but can be produced in lighter colours.

Uses : Door furniture, light switches, and electrical fittings, glues, bottoms, radio cabinets, etc.

UF

EPOXY

4. Epoxies:

PROPERTIES: Resin and hardener.

Uses: Used as adhesives.

5. Polyesters :

PROPERTIES: produced as fibres and films.

Uses ; Used for reinforced plastics.

CLASSIFICATION ACCORDING TO STRUCTURE OF ATOMS

According to this classification , the plastics are divided into 2 groups.

- **HOMOGENEOUS PLASTICS** : This variety of plastic contains carbon chain ie, the plastics of this group are composed of carbon atoms only and they exhibit homogeneous structure.

- **HETEROGENEOUS PLASTICS** : This variety of plastic is composed of the chain containing carbon and oxygen, the nitrogen and other elements and they exhibit heterogeneous structure.

Physical and mechanical properties

- According to this classification, plastics are divided into four groups.
  1. Rigid plastics
  2. Semi –rigid plastics
  3. Soft plastics
  4. Elastomers.

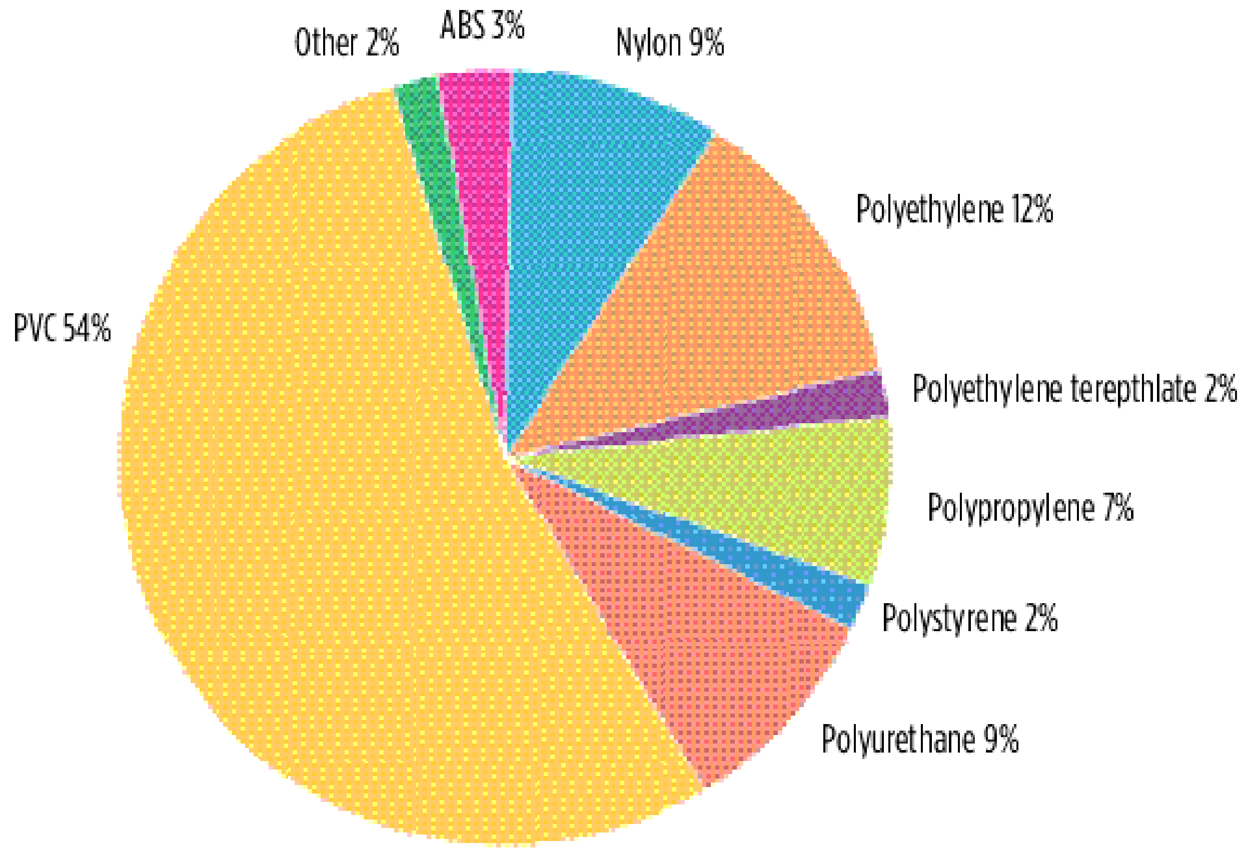
- RIGID PLASTICS : These plastics have high modulus of elasticity and they retain their shape under exterior stresses applied at normal or moderately increased temperatures.
- SEMI- RIGID PLASTICS: These plastics have a medium modulus of elasticity and the elongation under pressure completely disappears, when pressure is removed.
- SOFT PLASTICS: These plastics have a low modulus of elasticity and the elongation under disappears slowly, when pressure is removed.
- ELASTOMERS : These plastics are soft and elastic materials with a low modulous of elasticity. They deform considerably under load at room temperature and return to their original shape, when the load is released. The extension can range up to ten times their original dimensions.

PROPERTIES OF PLASTICS

The following properties are common with most of the plastics.

1. They are light in weight.
2. They have good resistance to most of the chemical.
3. They have high electrical strength.
4. They have good corrossive resistance.
5. Plastics can be moulded to any desired shape and size.
6. They can be made transperent or color.
7. They are cheap compared to metals.
8. All operations like drilling ,sawing, punching can be done on plastics.
9. Painting and polishing is not necessary.
10. The plastics posses excellent electric insulating properties.
11. The plastics, have low specific gravity, the average being 1.3 to 1.40.

Plastics used in construction



source: Principia Partners

PVC

- **Polyvinyl chloride**, commonly abbreviated **PVC**, is the third-most widely produced plastic, after polyethylene and polypropylene.
- PVC is used in construction because it is more effective than traditional materials such as copper, iron or wood in pipe and profile applications.
- It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates.
- In this form, it is also used in clothing and upholstery, electrical cable insulation, inflatable products and many applications in which it replaces rubber.

- APPLICATIONS:

PVC's relatively low cost, biological and chemical resistance and workability have resulted in it being used for a wide variety of applications.

1. It is used for sewerage pipes and other pipe applications where cost or vulnerability to corrosion limit the use of metal.
2. With the addition of impact modifiers and stabilizers, it has become a popular material for window and door frames.
3. By adding plasticizers, it can become flexible enough to be used in cabling applications as a wire insulator.
4. The material comes in a range of colors and finishes, including a photo-effect wood finish, and is used as a substitute for painted wood, mostly for window frames and sills when installing double glazing in new buildings, or to replace older single-glazed windows.
5. Other uses include fascia, and siding or weatherboarding.
6. This material has almost entirely replaced the use of cast iron for plumbing and drainage, being used for waste pipes, drainpipes, gutters and downspouts.
7. uPVC does not contain phthalates, since those are only added to flexible PVC, nor does it contain BPA. uPVC is known as having strong resistance against chemicals, sunlight, and oxidation from water.

ACRYLIC

- In the plastics industry most acrylics are polymers of methyl methacrylate (PMMA).
- Acrylics may be in the form of molding powders or casting syrups, and are noted for their exceptional clarity and optical properties.
- Acrylics are widely used in lighting fixtures because they are slow-burning or even self-extinguishing, and they do not produce harmful smoke or gases in the presence of flame.
- The most important properties for acrylic (PMMA) are its optical clarity, low UV sensitivity, and overall weather resistance. Acrylic is often used as a glass substitute.

- APPLICATIONS:

1. Transparent glass substitute.
2. Acrylic paint essentially consists of PMMA suspended in water; however since PMMA is hydrophobic, a substance with both hydrophobic and hydrophilic groups needs to be added to facilitate the suspension.

3. Laser cut acrylic panels have been used to redirect sunlight into a light pipe or tubular skylight and, from there, to spread it into a room.

4. panels have been commercialized for purposes of day lighting, to be used as a window or a canopy such that sunlight descending from the sky is directed to the ceiling or into the room rather than to the floor. This can lead to a higher illumination of the back part of a room, in particular when combined with a white ceiling, while having a slight impact on the view to the outside compared to normal glazing

POLYMER FILM

- **Plastic film/Polymer film** is a thin continuous polymeric material. Thicker plastic material is often called a “sheet”.
- These thin plastic membranes are used to separate areas or volumes, to hold items, to act as barriers, or as printable surfaces.
- Plastic films are used in a wide variety of applications.
- These include: packaging, plastic bags, labels, building construction, landscaping, electrical fabrication, photographic film, film stock for movies, video tape, etc.

FIBRE REINFORCED PLASTIC

- **Fibre-reinforced plastic** (**FRP**) (also *fibre-reinforced polymer*) is a composite material made of a polymer matrix reinforced with fibres.
- The fibres are usually glass, carbon, basalt or agamid, although other fibres such as paper or wood or asbestos have been sometimes used.
- The polymer is usually an epoxy, vinylester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use.
- FRPs are commonly used in the aerospace, automotive, marine, and construction industries.
- FRPs have been used widely in the design of new construction. Structures such as bridges and columns built completely out of FRP composites have demonstrated exceptional durability, and effective resistance to effects of environmental exposure.

- Pre-stressing tendons, reinforcing bars, grid reinforcement , and dowels are all examples of the many diverse applications of FRP in new structures.

- One of the most common uses for FRP involves the repair and rehabilitation of damaged or deteriorating structures.

- Several companies across the world are beginning to wrap damaged bridge piers to prevent collapse and steel-reinforced columns to improve the structural integrity and to prevent buckling of the reinforcement.

- Architects have also discovered the many applications for which FRP can be used. These include structures such as siding/cladding, roofing, flooring and partitions.

SYNTHETIC RUBBER

- **Synthetic rubber**, invariably a polymer, is any type of artificial elastomer mainly synthesised from petroleum byproducts.
- Synthetic rubber, like natural rubber, has uses in the automotive industry for door and window profiles, hoses, belts, matting, flooring and dampeners (antivibration mounts).
- Synthetic rubber displays the capacity of elasticity, synonymous in colloquial terms to bounciness, flexibility or pliability.
- Water-repellent materials are those that do not allow water molecules to penetrate or pass through. Thus, synthetic rubber absorbs little to no water.

- Another property that makes it possible for synthetic rubber products to be used in the electrical industry is electrical resistance.

- Synthetic rubbers exhibit high resistance to heat, meaning the material poorly conducts heat energy transference.

- Certain synthetic rubbers display properties of chemical resistance, which in this instance means the chemical composition of the material cannot be readily changed through contact with other materials.

ASBESTOS CEMENT PRODUCTS

- Asbestos Cement is primarily a cement-based product where about 10% to 15% w/w asbestos fibres are added to reinforce the cement.
- Asbestos cement is weatherproof in that although it will absorb moisture, the water does not pass through the product.
- It was used for corrugated sheets, slates, moulded fittings, soffits and undercloak, water cisterns, rainwater gutters, down pipes, pressure pipes, underground drainage and sewer pipes, sills, copings, chalkboards, fascias, infill panels, etc.
- It is sometimes difficult to tell the difference between an asbestos cement product and a low-density insulation board.
- Where the product has been used as a roofing or cladding product, open to the weather, you can be confident that the product is asbestos cement.

- **ADVANTAGES OF PLASTICS OVER OTHER MATERIALS:**

1. It can be moulded into finished products at a relatively low cost, compared to the machining and fabricating costs for wood and metal.
2. It resists chemicals.
3. It poses a high strength to weight ratio.
4. It does not rust like iron.
5. It is non conductor of electricity.
6. It is light in weight.
7. It is easy to fabricate.

- **DISADVANTAGE OF PLASTICS:**

1. It has low modulus of elasticity.
2. It is not reliable with respect to weathering

Metals.

Two main groups,

1.Ferrous.

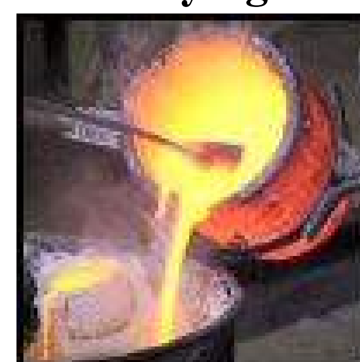
2.Non-Ferrous.

- Metals
  - Ferrous
    - Pure Ferrous Metals
      - Iron
    - Ferrous Alloys
      - Steel
        - High Speed Steel
  - Non Ferrous
    - Pure Non Ferrous Metals
      - Copper
      - Alum.
      - Zinc
      - Tin
      - Lead
      - Silver
      - Gold
      - Mercury
    - Non Ferrous Alloys
      - Brass
        - Copper + Zinc
      - Bronze
        - Copper + Tin
      - Solder
        - Lead + Tin

High Speed Steel Cutting Tools

Mercury is the only non ferrous metal that is liquid at room temperature.

Alloying.



Ferrous Metals.

<u>Ferrous metals</u>:
Ferrous metals are metals that consist mostly of iron and small amounts of other elements. Ferrous metals are prone to rusting if exposed to moisture. Ferrous metals can also be picked up by a magnet. The rusting and magnetic properties in ferrous metals are both down due to the iron. Typical ferrous metals include mild steel, cast iron and steel.

<u>Examples</u>:
1.Mild Steel.
2.Cast Iron.
3.High Carbon Steel.
4.High Speed Steel.
5.Stainless Steel.

Rusting.

Magnetism.

Ferrous Metals.

Metal Type.	Metal Uses.	Melting Point.
Mild Steel. A ductile and malleable metal. Mild steel will rust quickly if it is in frequent contact with water.	Used as Nuts and bolts, Building girders, car bodies, gates, etc.	1600°C

Ferrous Metals.

<u>Metal Type.</u>

<u>Cast Iron.</u>
Is a very strong metal when it is in compression and is also very brittle. It consists of 93% iron and 4% carbon plus other elements.

<u>Metal Uses.</u>

Used as car Brake discs, car cylinders, metalwork vices, manhole covers, machinery bases eg: The pillar drill.

<u>Melting Point.</u>

1200°C

Ferrous Metals.

Metal Type.

High Carbon Steel .

It is a very strong and very hard steel that has a high resistance to abrasion. Properties – Up to 1.5% carbon content. Very tough.

Metal Uses.

Used for hand tools such as screwdrivers, hammers, chisels, saws, springs and garden tools.

Melting Point.

1800°C

Ferrous Metals.

Metal Type.

High Speed Steel.

HSS is a metal containing a high content of tungsten, chromium and vanadium. However it is very brittle but is also very resistant to wear.

Metal Uses.

Used for drill bits and lathe cutting tools. It is used where high speeds and high temperatures are created.

Melting Point.

1400°C

Ferrous Metals.

Metal Type.

Stainless Steel.
Stainless steel is very resistant to wear and water corrosion and rust.
Properties – It is an alloy of iron with a typical 18% chromium 8% nickel and 8% magnesium content.

Metal Uses.

Used for kitchen sinks, cutlery, teapots, cookware and surgical instruments.

Melting Point.

1400°C

Non – Ferrous Metal.

<u>Non-Ferrous Metals</u>:

Non-ferrous metals are metals that do not have any iron in them at all. This means that Non-ferrous metals are not attracted to a magnet and they also do not rust in the same way when exposed to moisture. Typical Non-ferrous metals include copper, aluminium (coke cans), tin and zinc.

<u>Examples</u>:

1. **Aluminium.**
2. **Copper.**
3. **Zinc.**
4. **Tin.**
5. **Lead.**
6. **Silver.**
7. **Gold.**
8. **Magnesium.**

Non – Ferrous Metal.

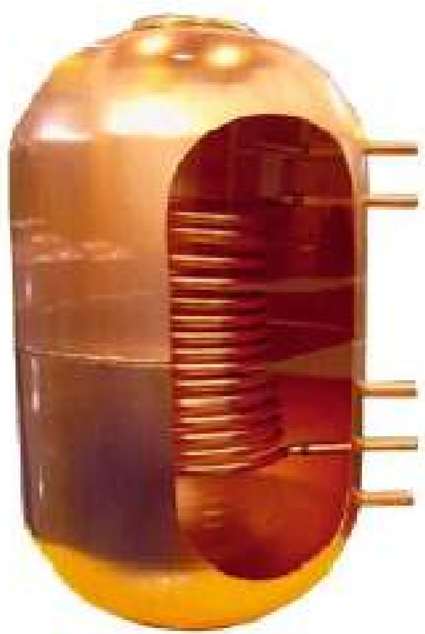
Metal Type.	Metal Uses.	Melting Point.
Aluminium. It tends to be light in colour although it can be polished to a mirror like appearance. It is very light in weight.	Used for saucepans, cooking foil, window frames, ladders, expensive bicycles.	660°C

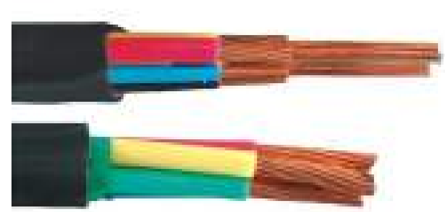




Non – Ferrous Metal.

Metal Type.	Metal Uses.	Melting Point.
Copper. It is a ductile and malleable metal. It is often red / brown in colour. It is a very good conductor of heat and electricity.	Used for plumbing, electric components, cookware and roof coverings.	1084°C





Non – Ferrous Metal.

Metal Type.	Metal Uses.	Melting Point.
Zinc. It is very resistant to corrosion from moisture. However zinc is a very weak metal and is used mainly for coating steel.	Used as a coating on screws, steel buckets etc It is also used to galvanize steel.	419°C

Non – Ferrous Metal.

Metal Type.

Tin.

It is a very ductile and very malleable metal. It is resistant to corrosion from moisture. It is bright silver in appearance. Tinplate is steel with a tin coating.

Metal Uses.

Used as a coating on food cans, beer cans. Used as whistles, tin foil and soldering.

Melting Point.

231°C

Non – Ferrous Metal.

Metal Type.

Lead.

It is a soft, malleable metal. It is also counted as one of the heavy metals. Lead has a bluish-white color after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air.

Metal Uses.

Used for roof flashing. Also used for batteries and for X-ray protection. Lead is used for its weight in many ways.

Melting Point.

327°C

Non – Ferrous Metal.

Metal Type.

Silver.

A soft, white, lustrous transition metal, it has the highest electrical conductivity of any element and the highest thermal conductivity of any metal. The metal occurs naturally in its pure, free form.

Metal Uses.

Used for jewelry and high quality cutlery. Also used for currency coins and sports trophies. Used in mirrors as a reflective metal.

Melting Point.

961°C





Non – Ferrous Metal.

Metal Type.

Gold.

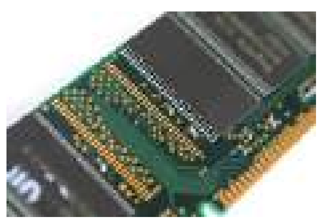
Gold is a dense, soft, shiny, malleable and ductile metal. Pure gold has a bright yellow color and luster traditionally considered attractive, which it maintains without oxidizing in air or water. Gold resists attacks by individual acids It won't tarnish, discolor, crumble, or be affected by most solvents.

Metal Uses.

Used mainly for jewelry. Also used in computers as a conductor. Used for its reflective powers to protect satellites.

Melting Point.

1337°C



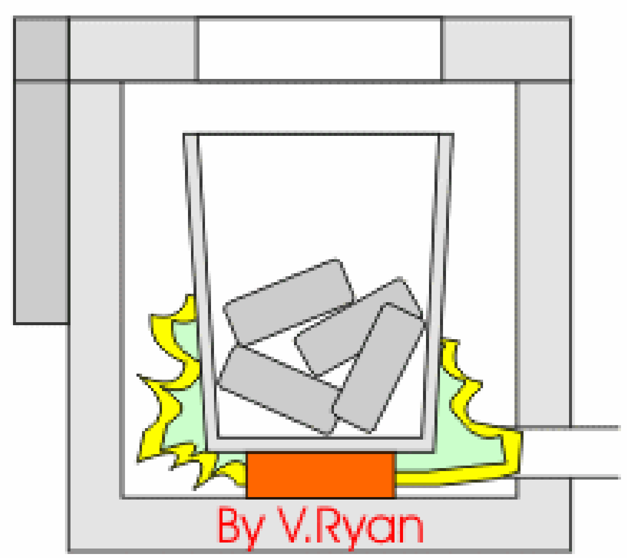
Non – Ferrous Metal.

Metal Type.	Metal Uses.	Melting Point.
Magnesium. Magnesium is a fairly strong, silvery-white, light-weight metal (one third lighter than aluminum) that slightly tarnishes when exposed to air. In a powder, this metal heats and ignites when exposed to moisture and burns with a white flame.	Magnesium is used in pyrotechnic (i.e. fireworks). It is alloyed with other metals to make them lighter and more easily welded.	648°C

Non – Ferrous Metal Alloys.

<u>Non-Ferrous Metal Alloys:</u>
Non-ferrous metal alloys are metals that are a mixture of two or more metals. The main ones in everyday use are,

Brass.
Bronze.
Solder.



Heating metals in a furnace to form an alloy.

Non – Ferrous Metal Alloys.

Metal Type.

Brass.

Brass is a mixture of copper and zinc. Copper is the main component, and brass is usually classified as a copper alloy. The color of brass varies from a dark reddish brown to a light silvery yellow. Brass is stronger and harder than copper, but not as strong or hard as steel. It is easy to form into various shapes, a good conductor of heat, and generally resistant to corrosion from salt water.

Metal Uses.

Brass is used to make water fittings, screws, radiators, musical instruments, and cartridge casings for firearms.

Melting Point.

940°C

Non – Ferrous Metal Alloys.

Metal Type.	Metal Uses.	Melting Point.
Bronze. Bronze is a metal alloy consisting primarily of copper, usually with tin as the main additive. It is a hard and brittle metal. It has a very high resistance to corrosion.	Used for ship propellers and underwater fittings. Also used for statues and medals. -	950°C

Non – Ferrous Metal Alloys.

Metal Type.	Metal Uses.	Melting Point.
Solder. Solder is a fusible metal alloy used to join together metal work pieces and having a melting point below that of the work pieces. It is an alloy of Lead and Tin.	Solder is used for electronics, plumbing, jewelry making and repair processes where metal parts cannot be effectively or safely welded.	200°C

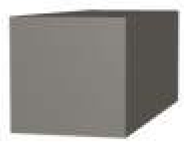
Metal pieces after mining and separation from their ores.
(Note: Carbon and Phosphorous are non metals, while Silicon is a semi-metal)

Metal Shapes.

Metal can be provided in various shapes and sizes. Some examples of these are shown below.

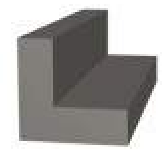
Round Solid.

Square Solid.



Hexagonal Solid.

Angle Iron Solid.



Round Hollow. (Tube)

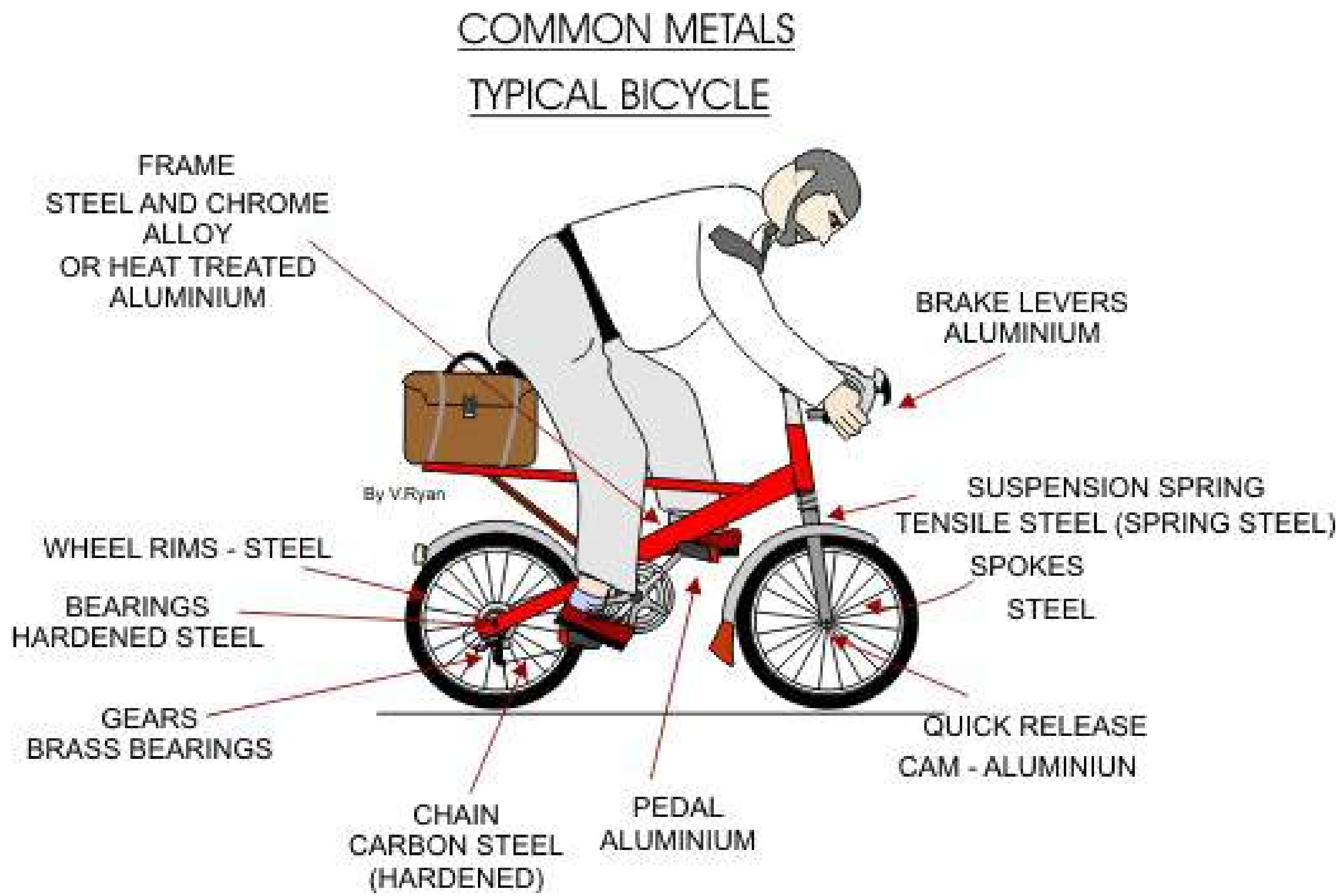
Square Hollow. (Box Iron)

Hexagonal Hollow.

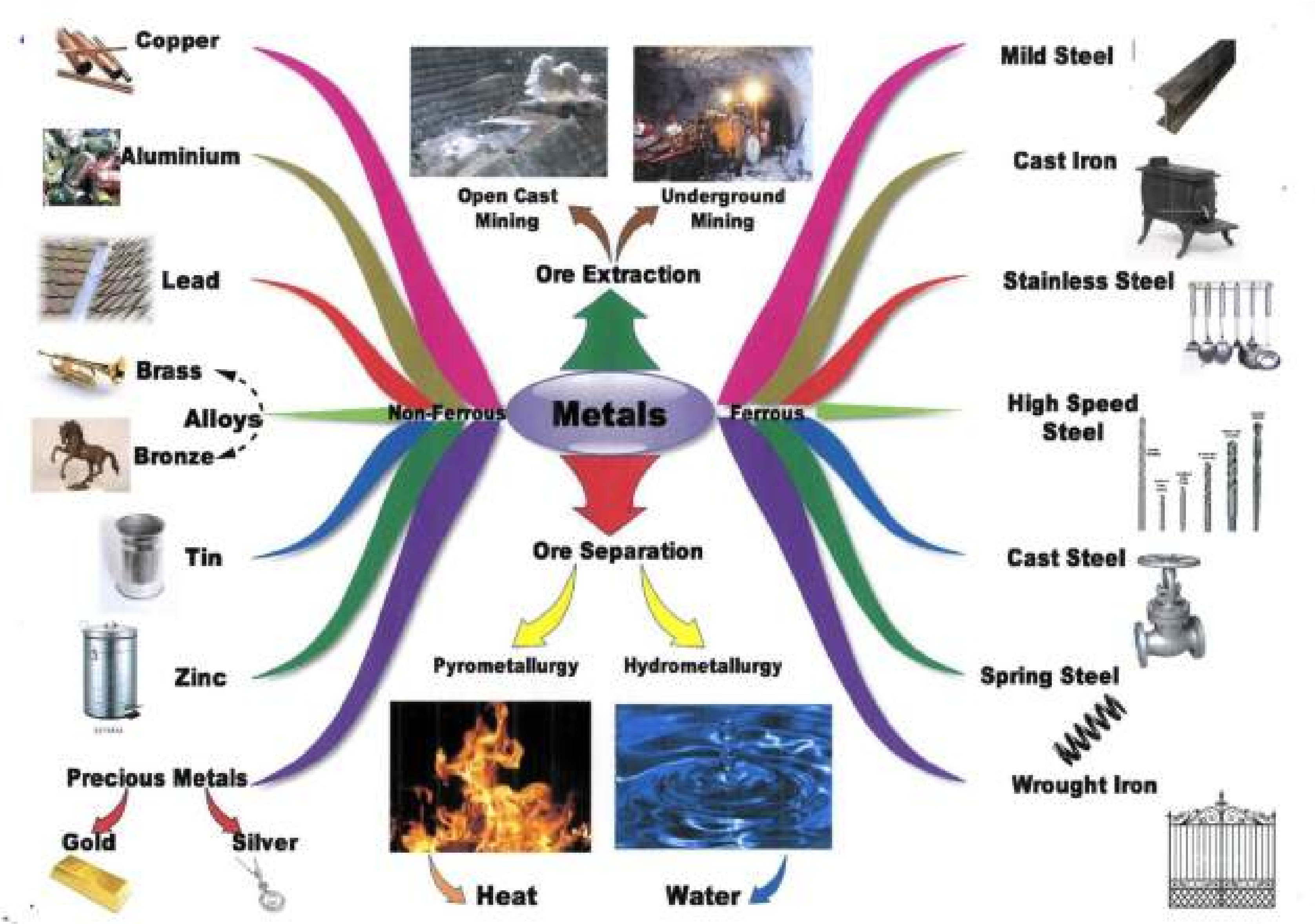
Angle Iron Hollow.

Metals in Everyday Use.

Below is a list of metals that would be used in the manufacturing of a bicycle.



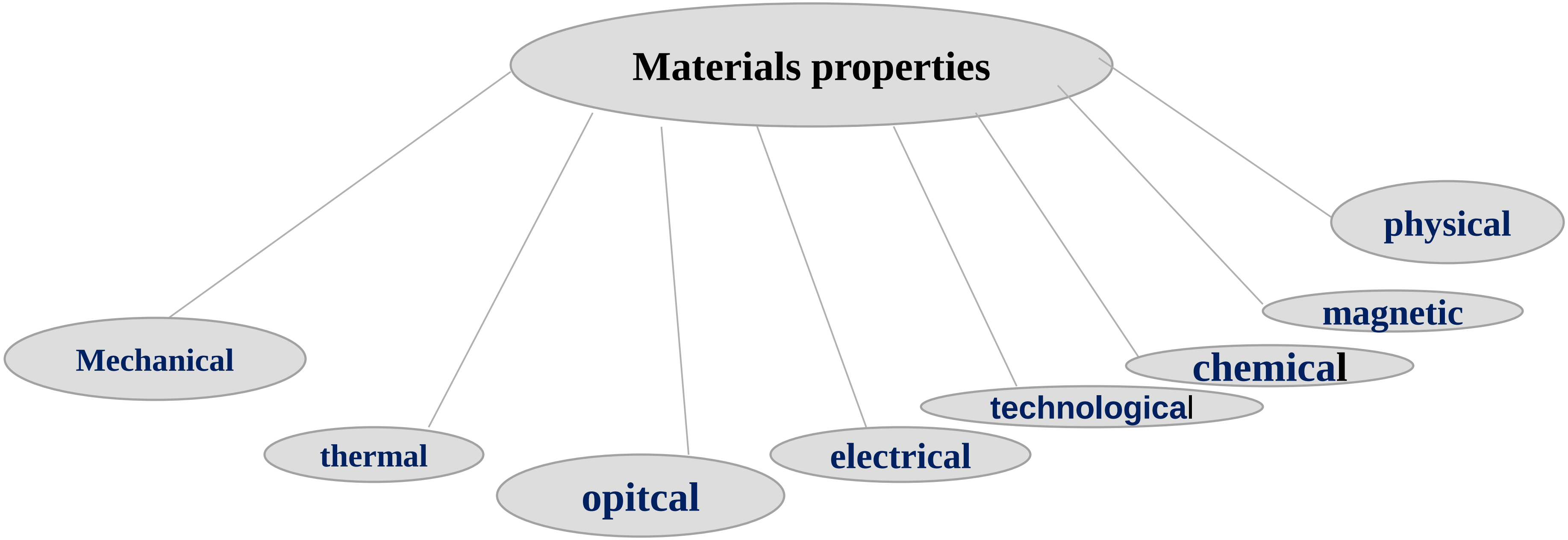
Revision Work/Metals.



INTRODUCTION

- The practical application of engineering materials in manufacturing engineering depends upon through knowledge of their particular properties under wide range of conditions.
- The term "**property**" is a qualitative or quantitative measure of response of materials to externally imposed conditions like forces and temperature.
- However, the range of properties found in different classes of materials is very large.

CLASSIFICATION OF MATERIAL PROPERTY:



MECHANICAL PROPERTIES:

- The properties of materials that determines its behaviour under applied forces are called ***mechanical properties.***
- They are usually related to the elastic and plastic behaviour of the material.
- These properties are expressed as the function of stress-strain.etc
- A sound knowledge of mechanical properties of materials provides the basis for predicting behaviour of materials under different load conditions and designing the components out of them.

CLASSIFICATION OF MECHANICAL PROPERTIES:

1). ELASTICITY
2). PLASTICITY
3). TOUGHNESS
4). RESILIENCE
5). TENSILE STRENGTH
6). YIELD STRENGTH
7). IMPACT STRENGTH
8). DUCTILITY
9). HARDNESS
10). FATIGUE
11). CREEP
12). WEAR RESISTANCE

STRESS -STRAIN

- Experience shows that any materials subjected to a load may either deform , yield or break , depending upon-

  The magnitude of load

  Nature of the material

  Cross sectional dimension

- The engineering stress and strain are based on the original sample dimension which changes during test.
- True stress and strain on other hand based on actual or instantaneous dimensions and are better representation of deformation behaviour of the material.

True strain, $\varepsilon = \sum \frac{L_1 - L_o}{L_o} + \frac{L_2 - L_1}{L_1} + \frac{L_3 - L_2}{L_2} \ldots\ldots$

$$\varepsilon = \int_{L_o}^{L} \frac{dL}{L} = \ln \frac{L}{L_o} = \ln (e + 1)$$

Engineering stress, $s = P/A_o$

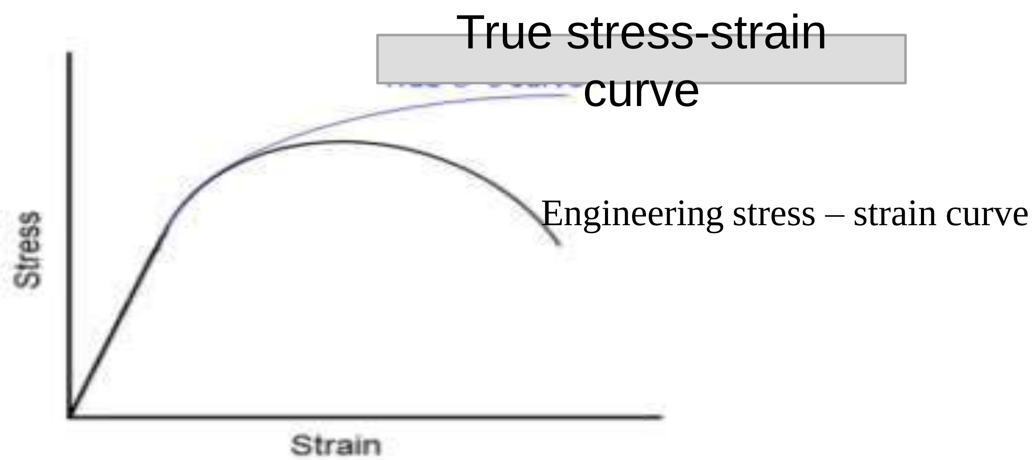
True stress, $\sigma = P/A = (P/A_o)(A_o/A) = s\,(A_o/A)$

Volume, AL, remains constant, $A_oL_o = AL \rightarrow A_o/A = L/L_o = (e+1)$

$\sigma = s\,(e+1)$

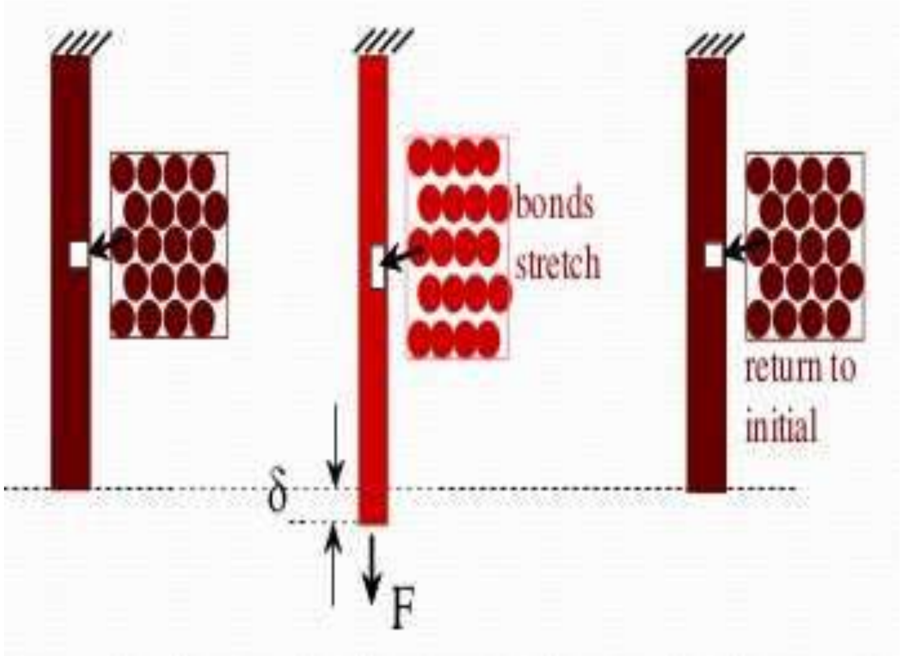
Engineering stress and strain curve is based on original area ,it descends after maximum load as the load bearing capacity of sample decrease due to reduction in area.

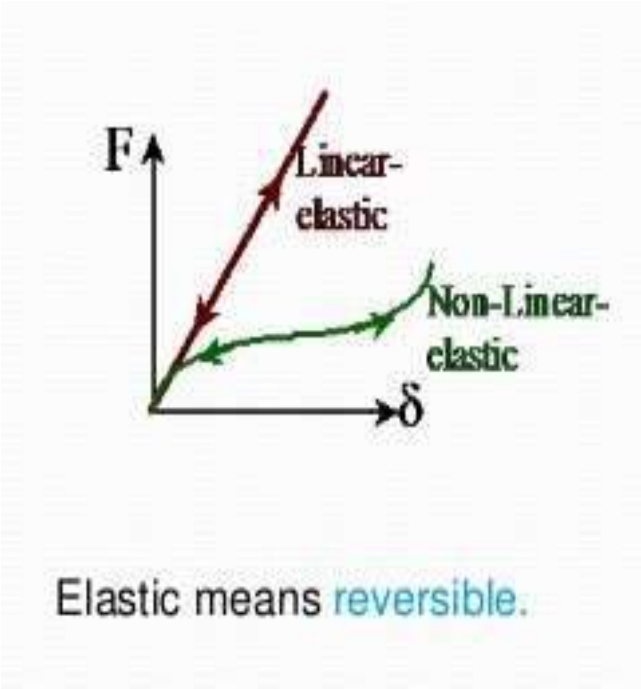
True stress-strain curve, continue to go up till fracture as it is based on actual area



ELASTICITY

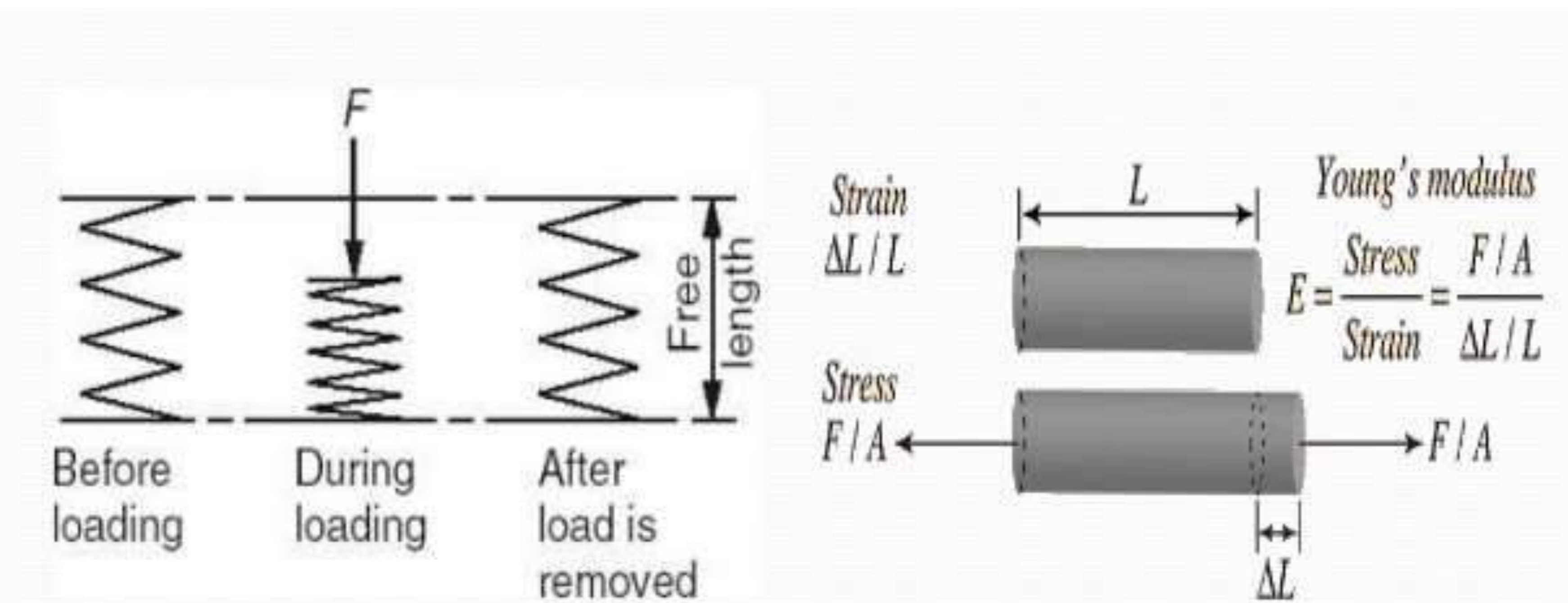
- The property of material by virtue of which deformation caused by applied loads disappears upon removal of load.
- Elasticity of the material is the power of coming back to its original position after deformation when the stress or load is removed.





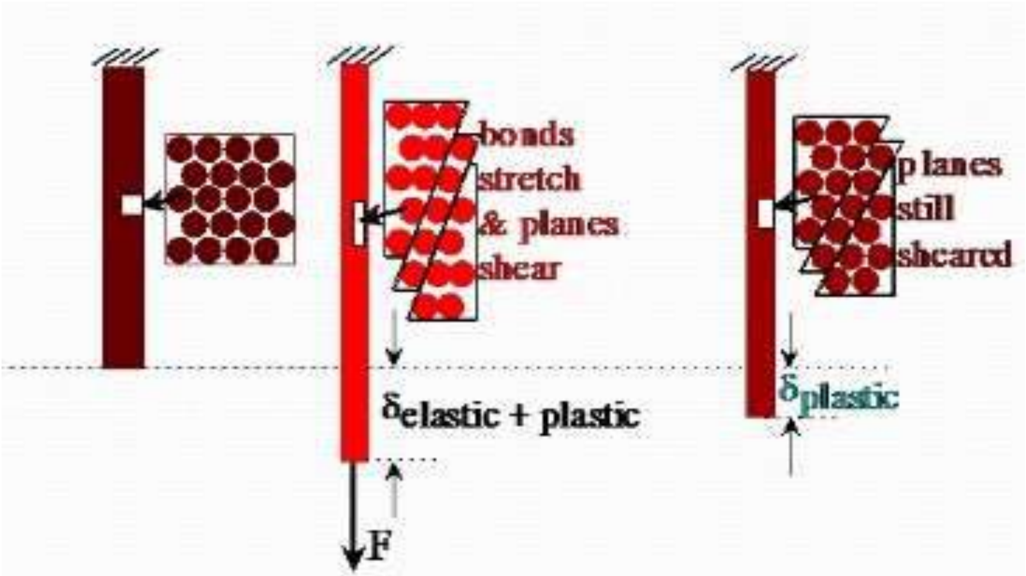
- The physical reasons for elastic behavior can be quite different for different materials. In metals, the atomic lattice changes size and shape when forces are applied (energy is added to the system). When forces are removed, the lattice goes back to the original lower energy state.
- In engineering, the amount of elasticity of a material is determined by two types of material parameter.
- The first type of material parameter is called a ***modulus***, which measures the amount of force per unit area (stress) needed to achieve a given amount of deformation. The units of modulus are ***pascals*** (Pa).
- A higher modulus typically indicates that the material is harder to deform.

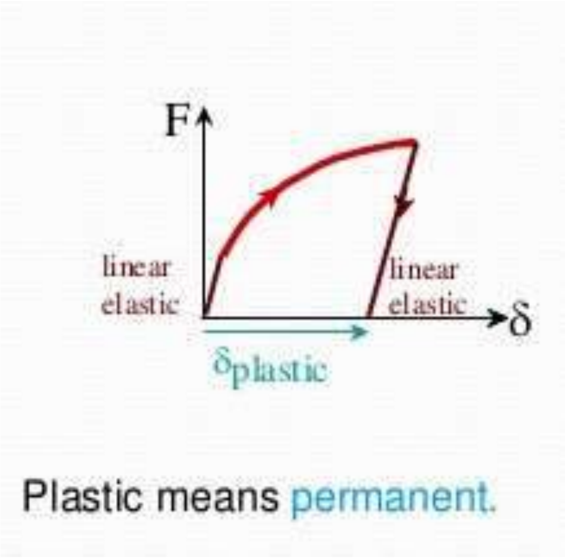
- The second type of parameter measures the **elastic limit**. The limit can be a stress beyond which the material no longer behaves elastic and deformation of the material will take place.
- If the stress is released, the material will elastically return to a permanent deformed shape instead of the original shape.



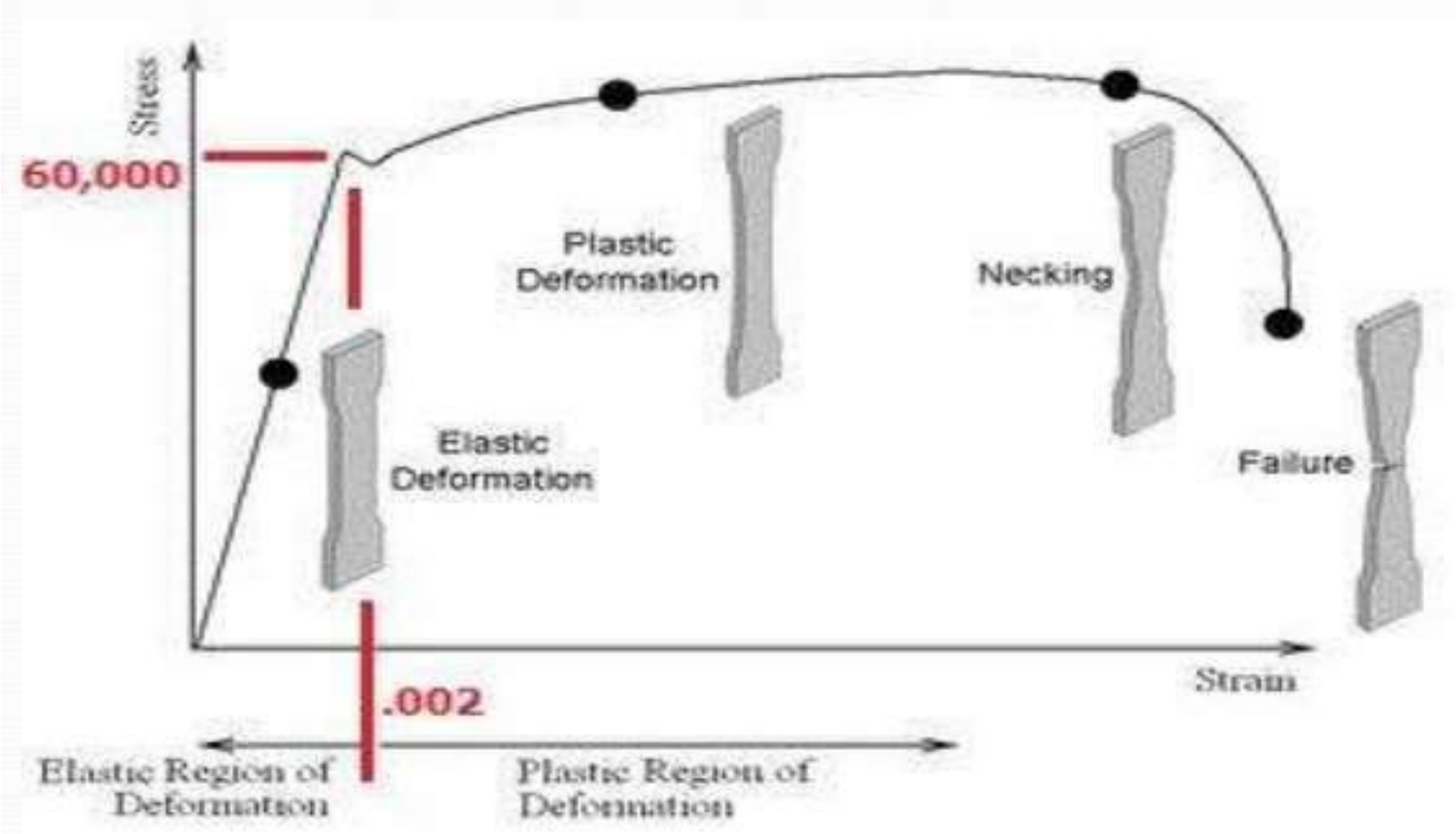
PLASTICITY:

- The plasticity of a material is its ability to undergo some degree of permanent deformation without rupture or failure.
- Plastic deformation will take only after the elastic limit is exceeded.
- It increases with increase in temperature.





STRESS-STRAIN CURVE FOR SHOWS ELASTICITY AND PLASTICITY FOR MATERIALS:



DUCTILITY:

- It is the ability of a material to undergo plastic deformation without fracture.
- Ex:- Mild steel is ductile material.

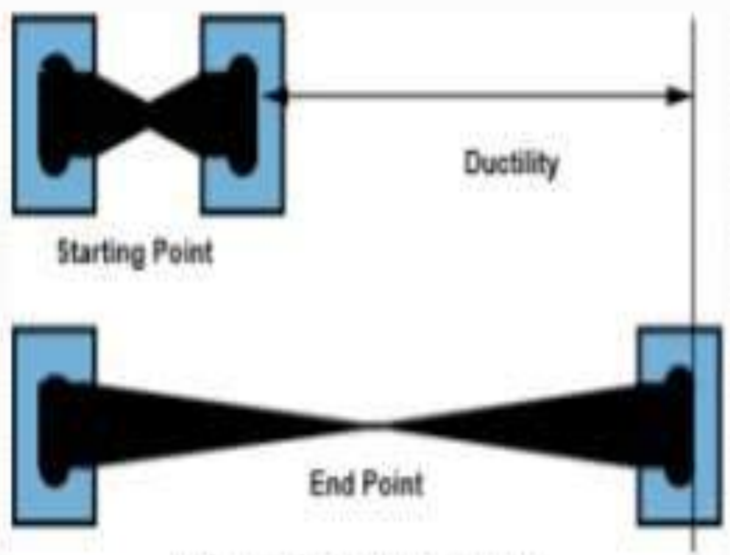
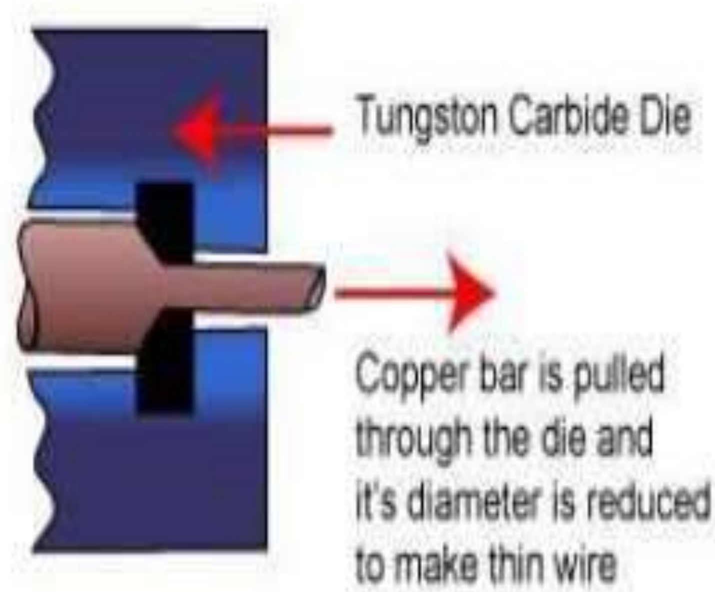


Figure 23:2: Ductility Test



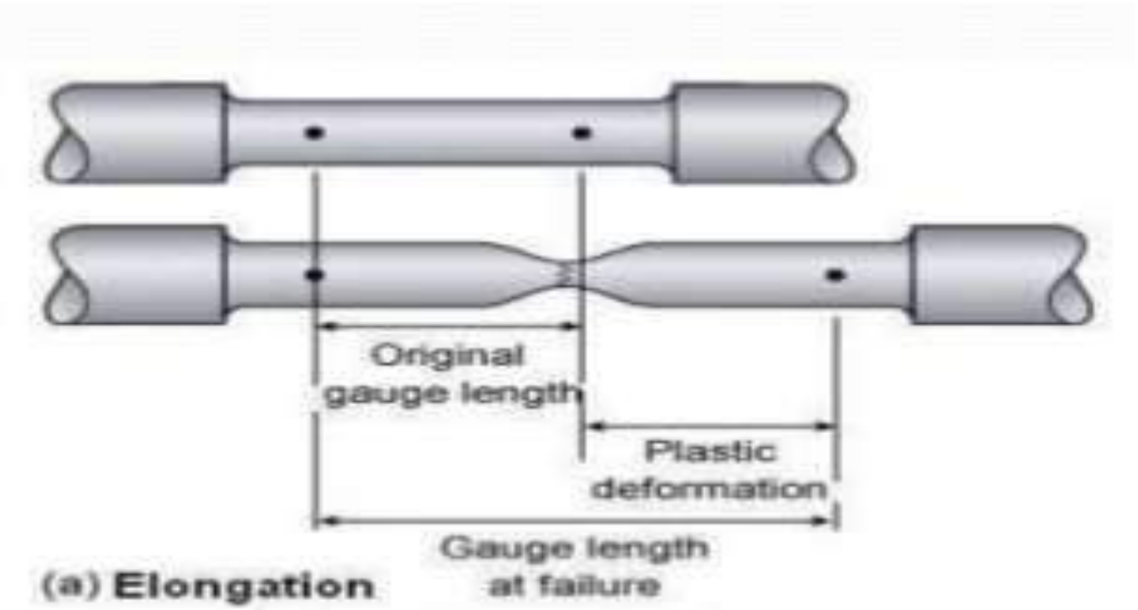
- There are two common measure of ductility:-

1). **Percentage elongation**:-% elongation describes the extent to which specimen structure before repture.

% elongation=Lf-Lo/Lo*100

where, Lf= final gauge length

Lo = initial gauge length



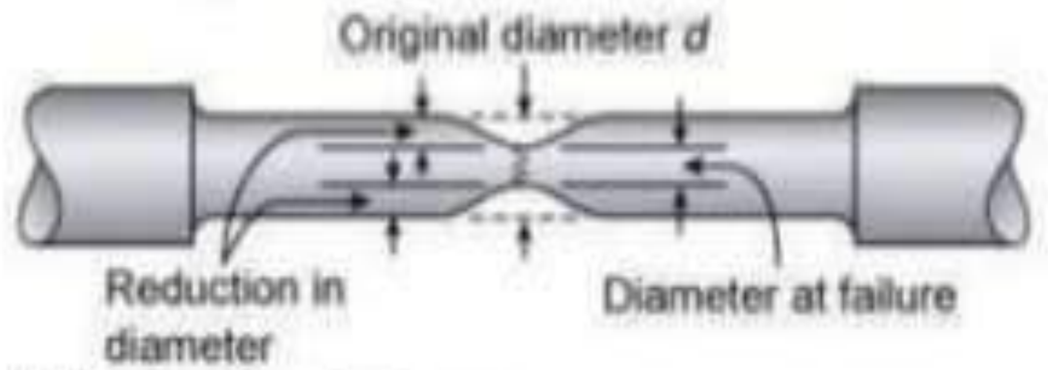
2). **Percentage reduction:-** % reduction is a measure % change in cross sectional area at point of fracture before and after the test.

% reduction=Af-Ao/Ao*100

where,

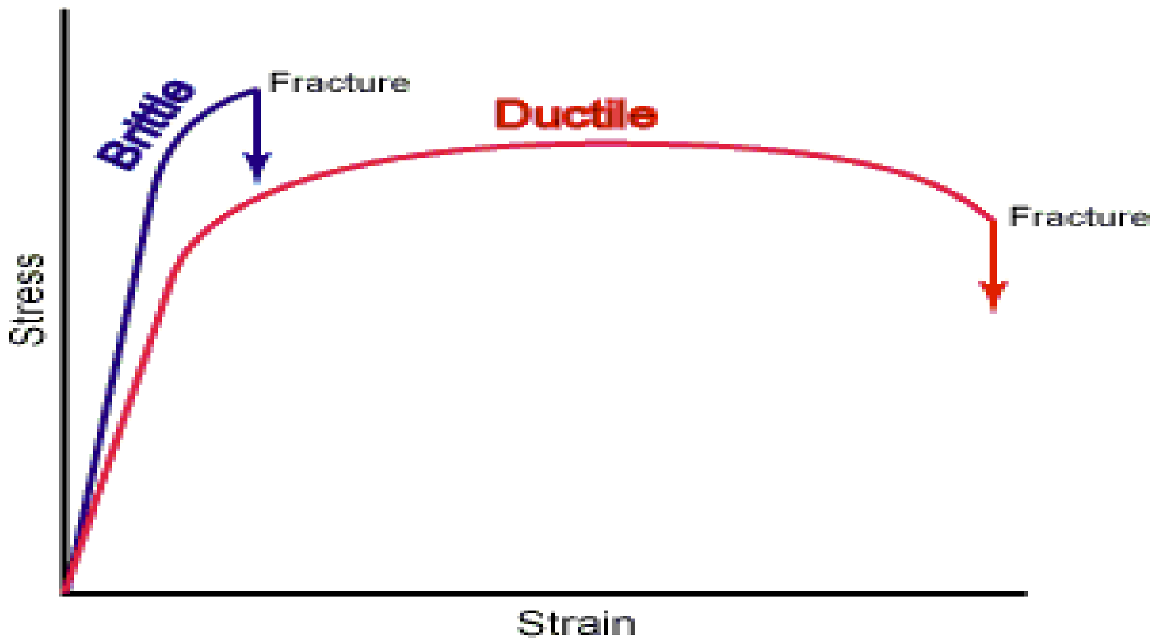
Af= final cross sectional area

Ao= initial cross sectional area



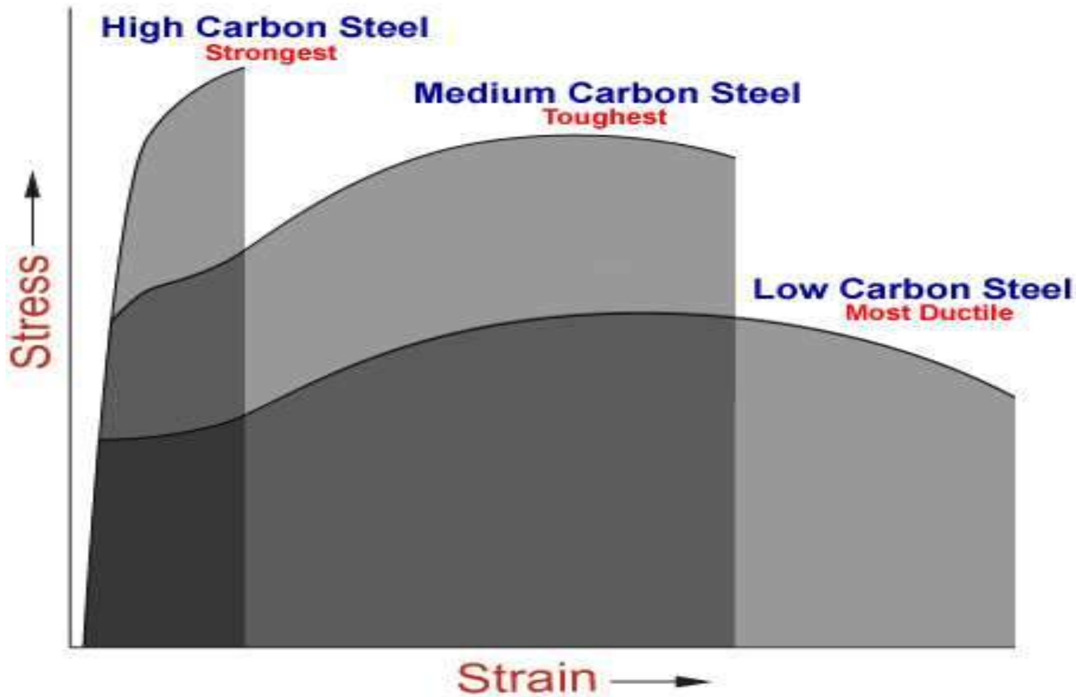
(b) Reduction in Area

- The amount of ductility is an important factor when considering forming operations such as rolling and extrusion. Ductility is also used a quality control measure to assess the level of impurities and proper processing of a material.
- For ductile material, breaking strength is less than UTS ,and necking precedes fracture.
- For brittle material, fracture usually occur before necking and possibly before the onset of plastic flow.



TOUGHNESS

- Toughness is the ability of the material to absorb energy during plastic deformation upto fracture.
- .A material with high strength and high ductility will have more toughness than a material with low strength and high ductility.
- Toughness is a good combination of strength and ductility.
- one way to measure toughness is by calculating the area under the stress strain curve from a tensile test. This value is simply called “material toughness” and it has units of energy per volume.
- Material toughness equates to a slow absorption of energy by the material.



several variables that have a profound influence on the toughness of a material:-

1). **Strain rate** - metal may possess satisfactory toughness under static loads but may fail under dynamic loads or impact. toughness decrease as the rate of loading increases.

2). **Temperature:-** Temperature is the second variable to have a major influence on its toughness. As temperature is lowered, the ductility and toughness also decrease.

3). **Notch effect:-** The third variable is termed notch effect, has to due with the distribution of stress. A material might display good toughness when the applied stress is uniaxial.

- ***Two of the toughness properties that will be discussed in more detail are:-***

1).**Impact toughness-** The impact toughness of a material can be determined with a Charpy test.

- Impact tests continue to be used as a quality control method to assess notch sensitivity and for comparing the relative toughness of engineering materials.

- Toughness is greatly affected by temperature, a Charpy test is often repeated numerous times with each specimen tested at a different temperature.

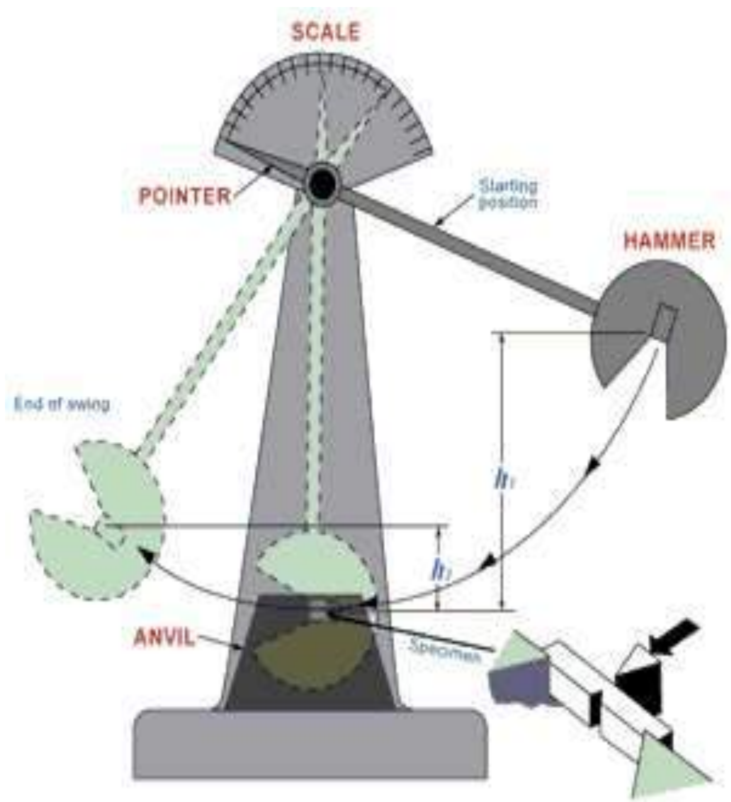
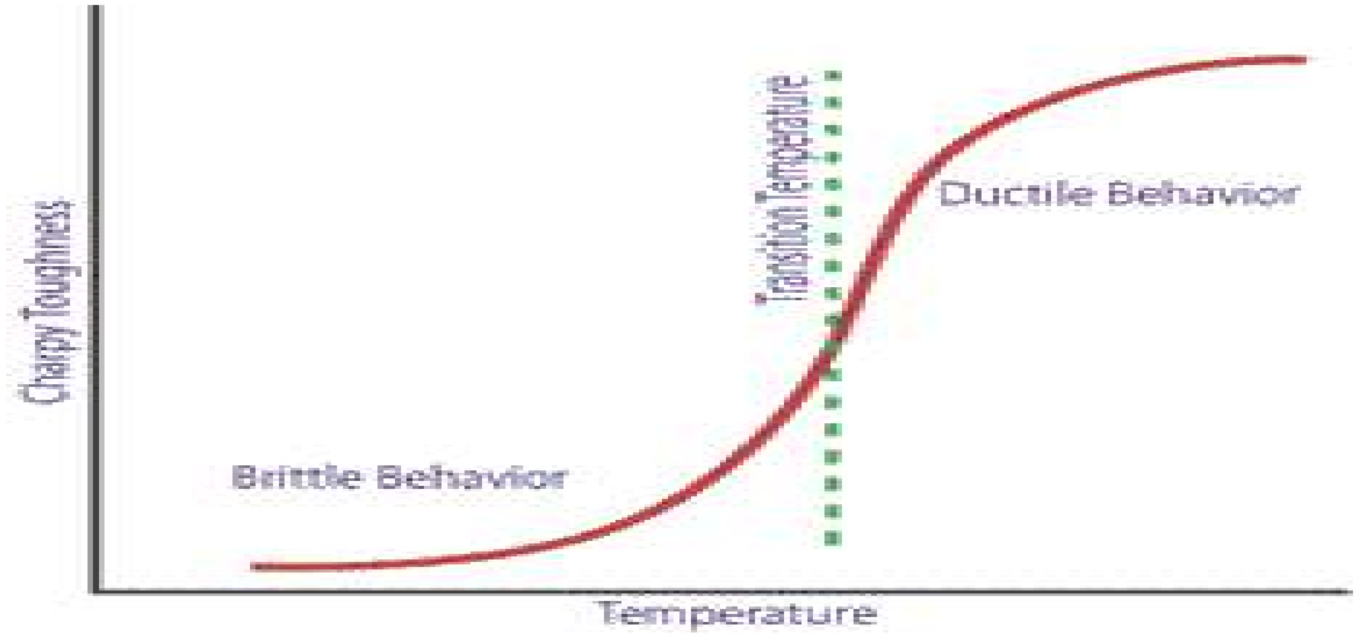


FIG-CHARPY TESTER

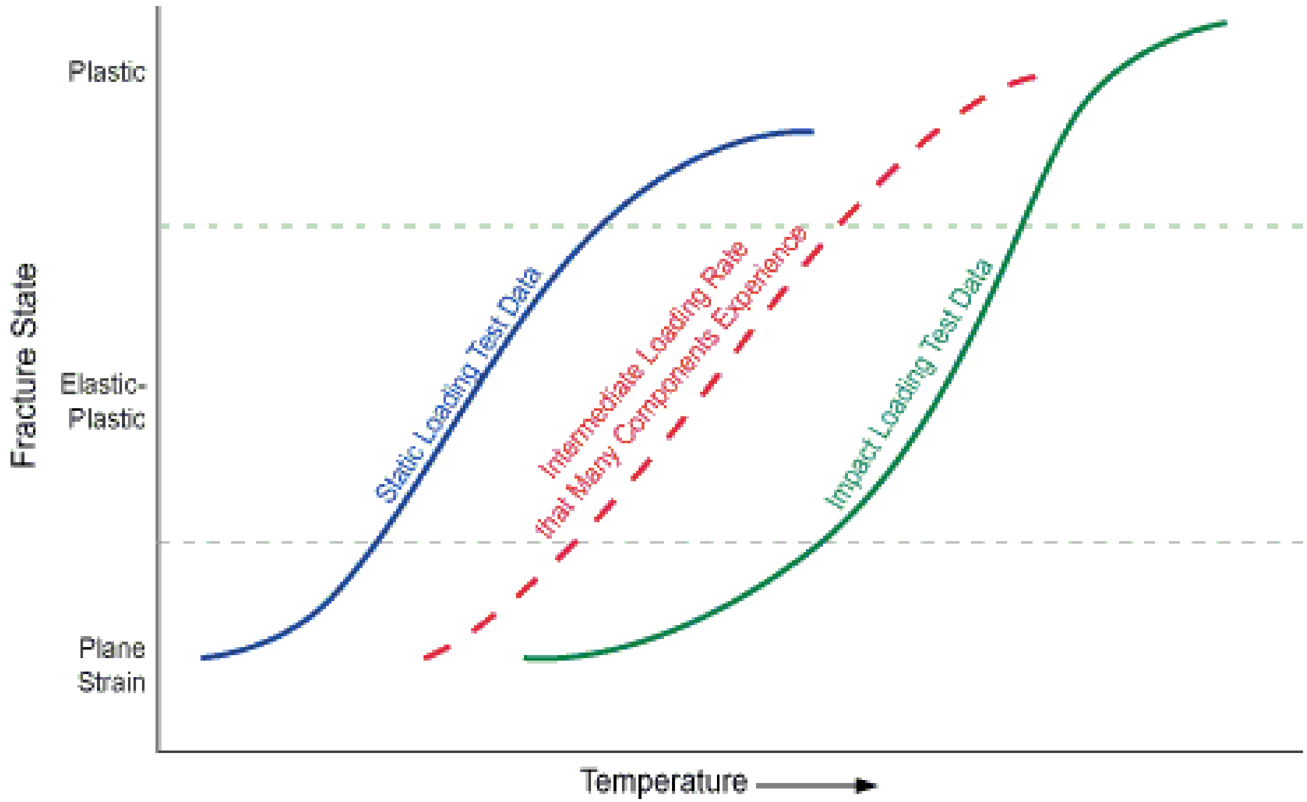
- This produces a graph of impact toughness for the material as a function of temperature.
- It can be seen that at low temperatures the material is more brittle and impact toughness is low. At high temperatures the material is more ductile and impact toughness is higher.
- The transition temperature is the boundary between brittle and ductile behavior and this temperature is often an extremely important consideration in the selection of a material.



2). **Notch-Toughness:**

- Notch toughness is the ability that a material possesses to absorb energy in the presence of a flaw.
- Notch-toughness is measured with a variety of specimens such as the Charpy V-notch impact specimen or the dynamic tear test specimen.
- impact testing the tests are often repeated numerous times with specimens tested at a different temperature.
- With these specimens and by varying the loading speed and the temperature, it is possible to generate curves such as those shown in the graph.
- The material develops plastic strains as the yield stress is exceeded in the region near the crack tip.

- The amount of plastic deformation is restricted by the surrounding material, which remains elastic.When a material is prevented from deforming plastically, it fails in a brittle manner.



HARDNESS

It is the property of a metal, which gives it the ability to resist being permanently deformed when a load is applied.

The greater the hardness of the metal, the greater resistance against the deformation.

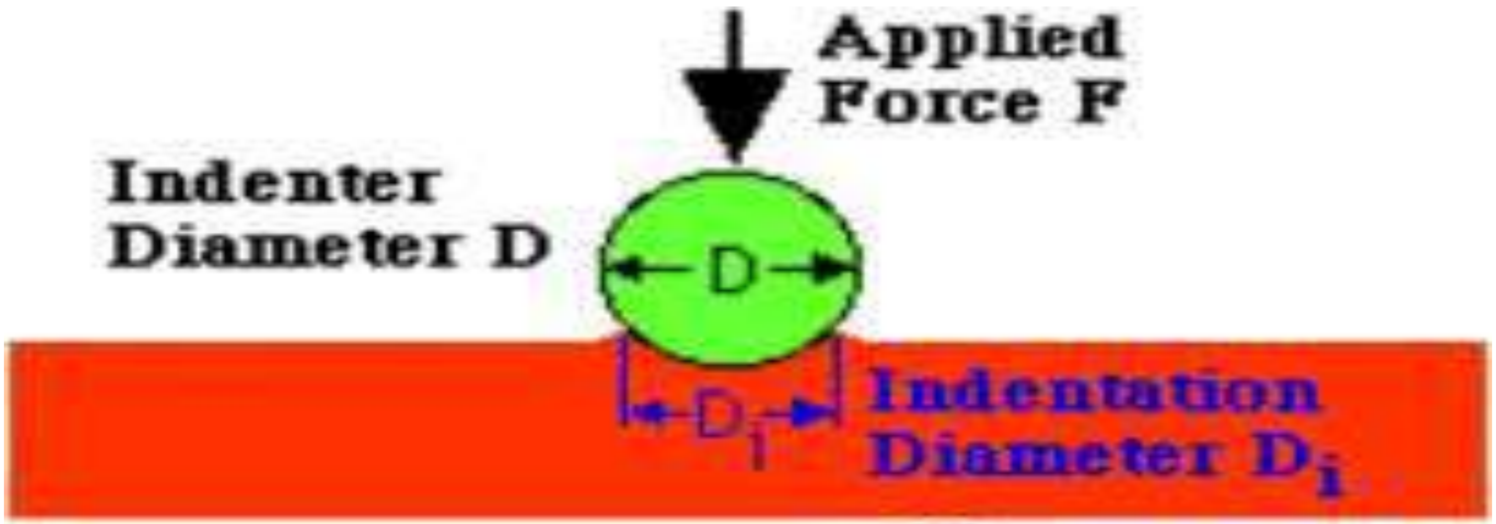
Various hardening process

- Hall- Petch strengthening (Grain boundary)
- Work hardening
- Solid solution strengthening
- Precipitation hardening
- Martensitic transformation

MEASUREMENT METHODS

- Rockwell hardness test
- Brinell hardness test
- Vickers hardness test
- Knoop hardness
- Shore
- Mohs test
- Barcol hardness test

BRINELL HARDNESS TEST



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$

HARDNESS DEPENDS ON

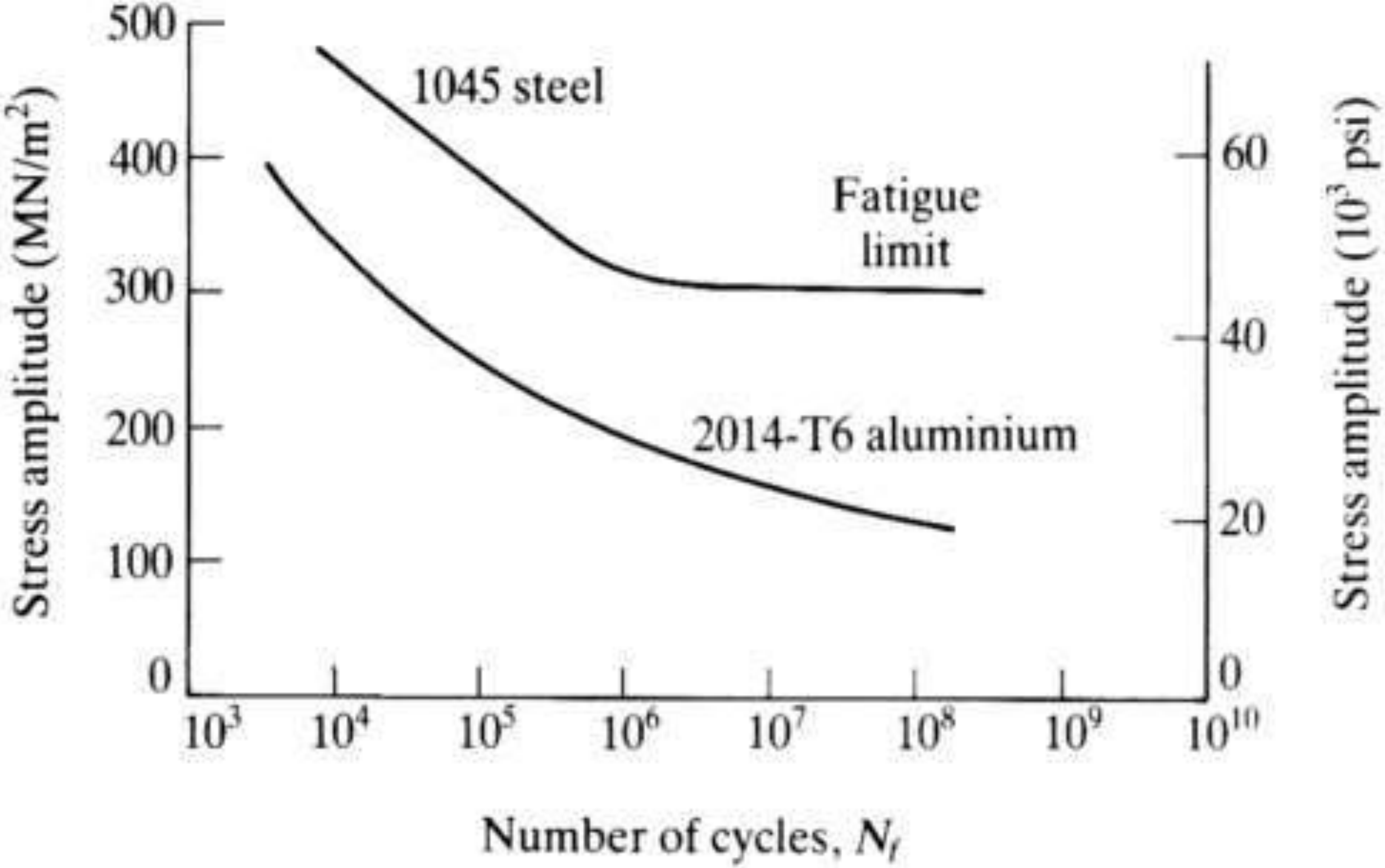
- Ductility
- Elastic stiffness
- Plasticity
- Strain
- Toughness
- Viscosity

FATIGUE

Metal fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loadings.

The highest stress that a material can withstand for an infinite number of cycles without breaking called also **endurance limit**

The greater the applied stress range, the shorter the life.

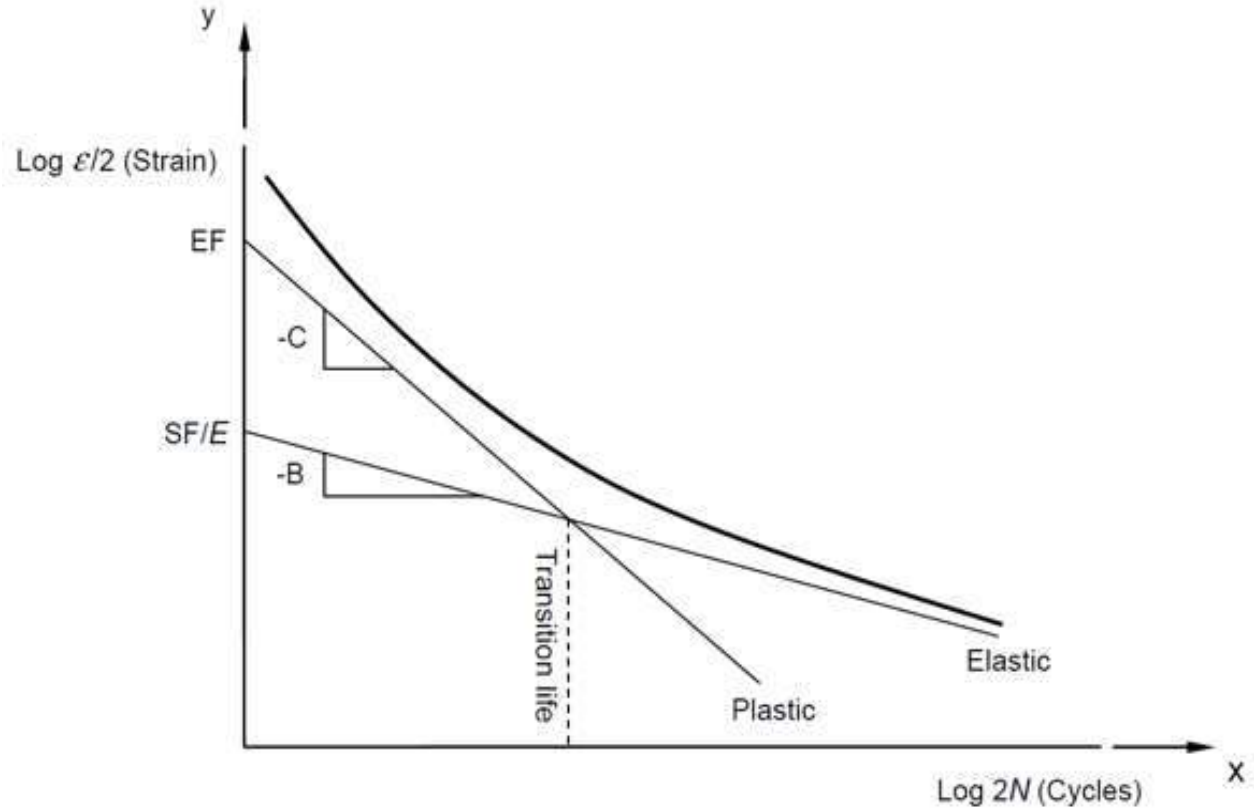


Stress amplitude (MN/m²)
500
400
300
200
100
0
1045 steel
Fatigue
limit
2014-T6 aluminium
Stress amplitude (10³ psi)
60
40
20
0
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
10¹⁰
Number of cycles, N_f

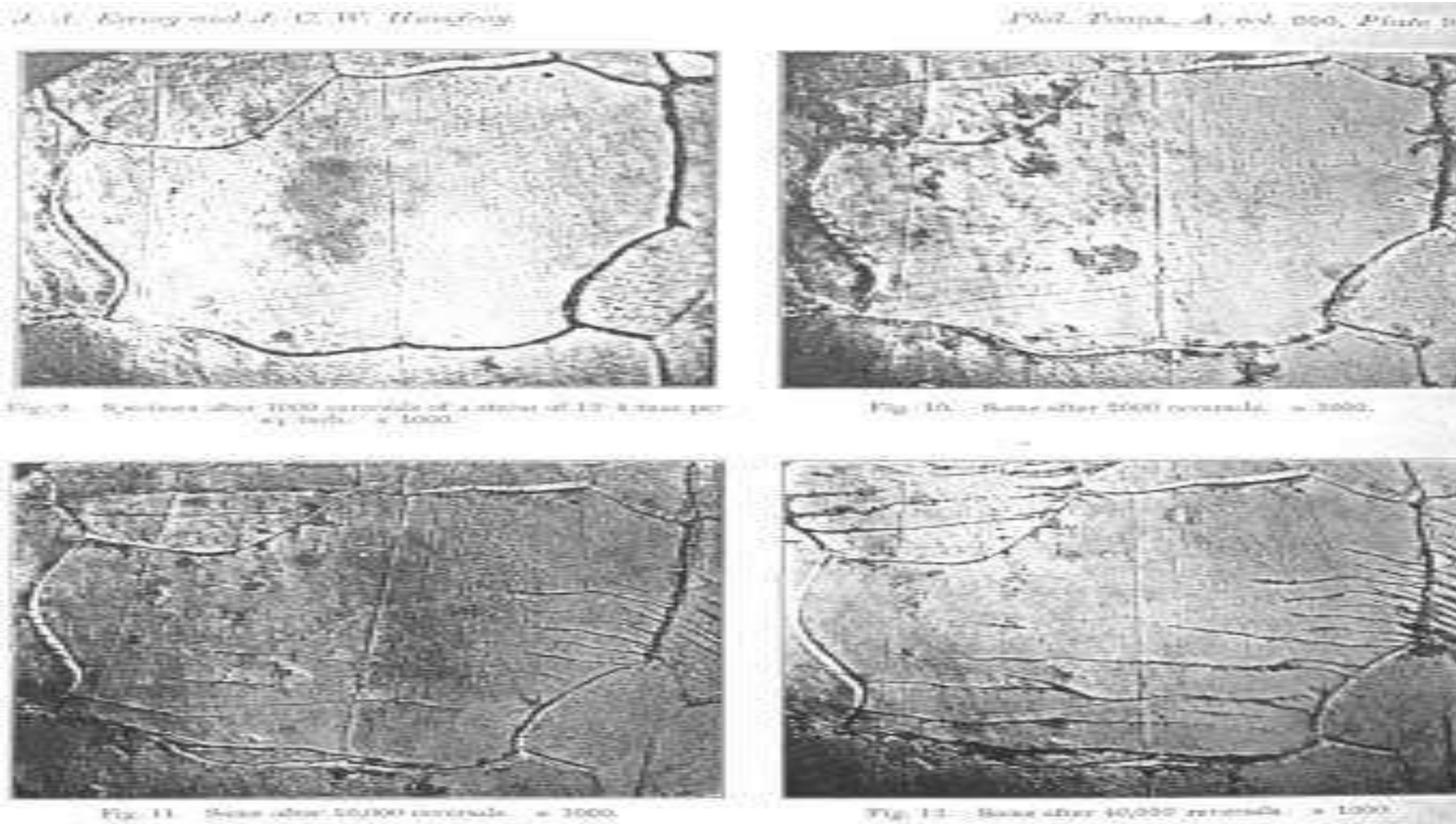
Prediction of fatigue

- 1)S-N Curve
- 2)Strain life relationship
- 3)Fracture mechanics approach
- 4) Goodman life equation

Strain-life relationship



Fatigue in steel



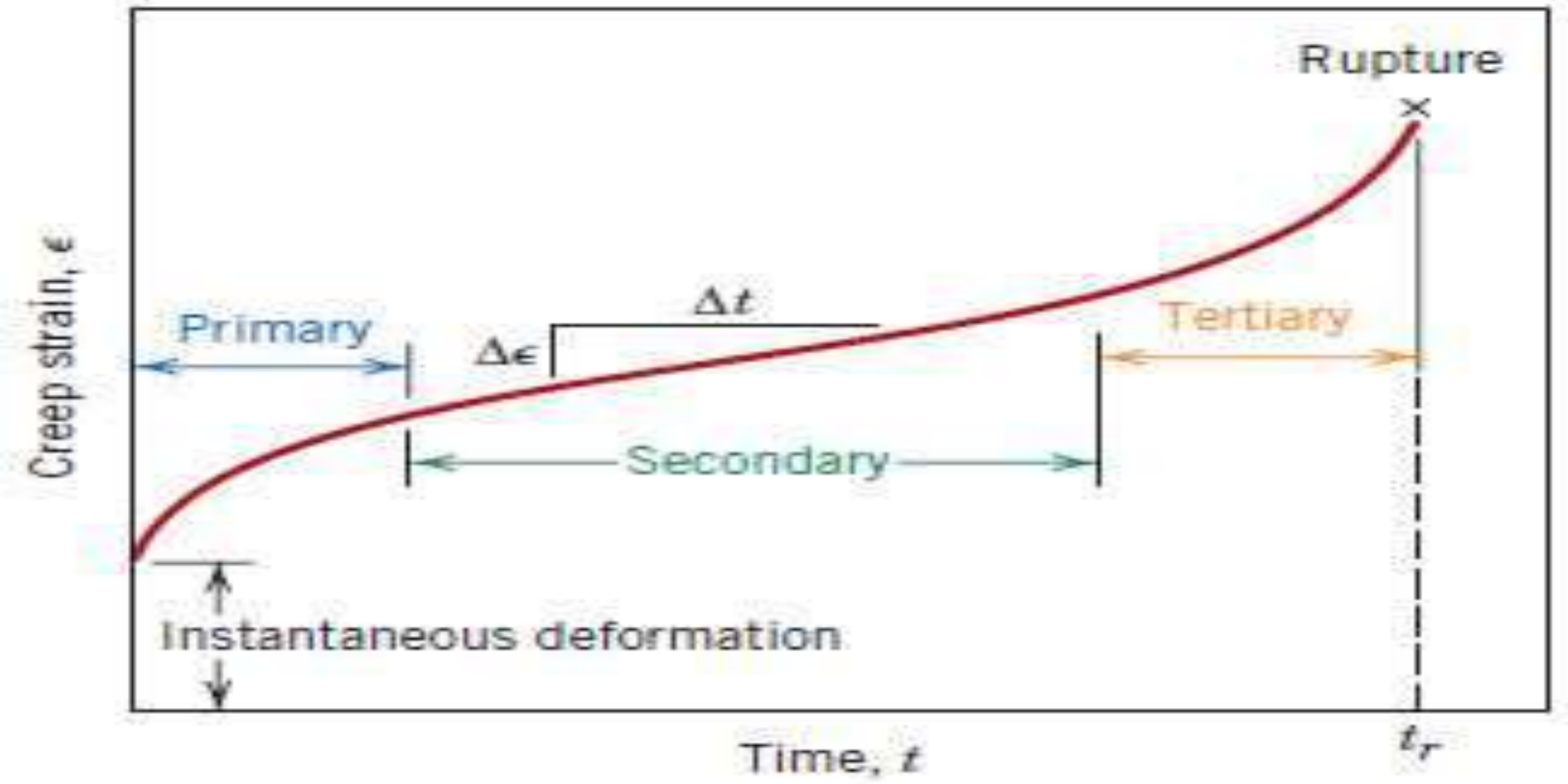
CREEP

The tendency of a solid material to deform permanently under the influence of mechanical stresses.

It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material.

Creep is more severe in materials that are subjected to heat for long periods, and generally increases as they near their melting point.

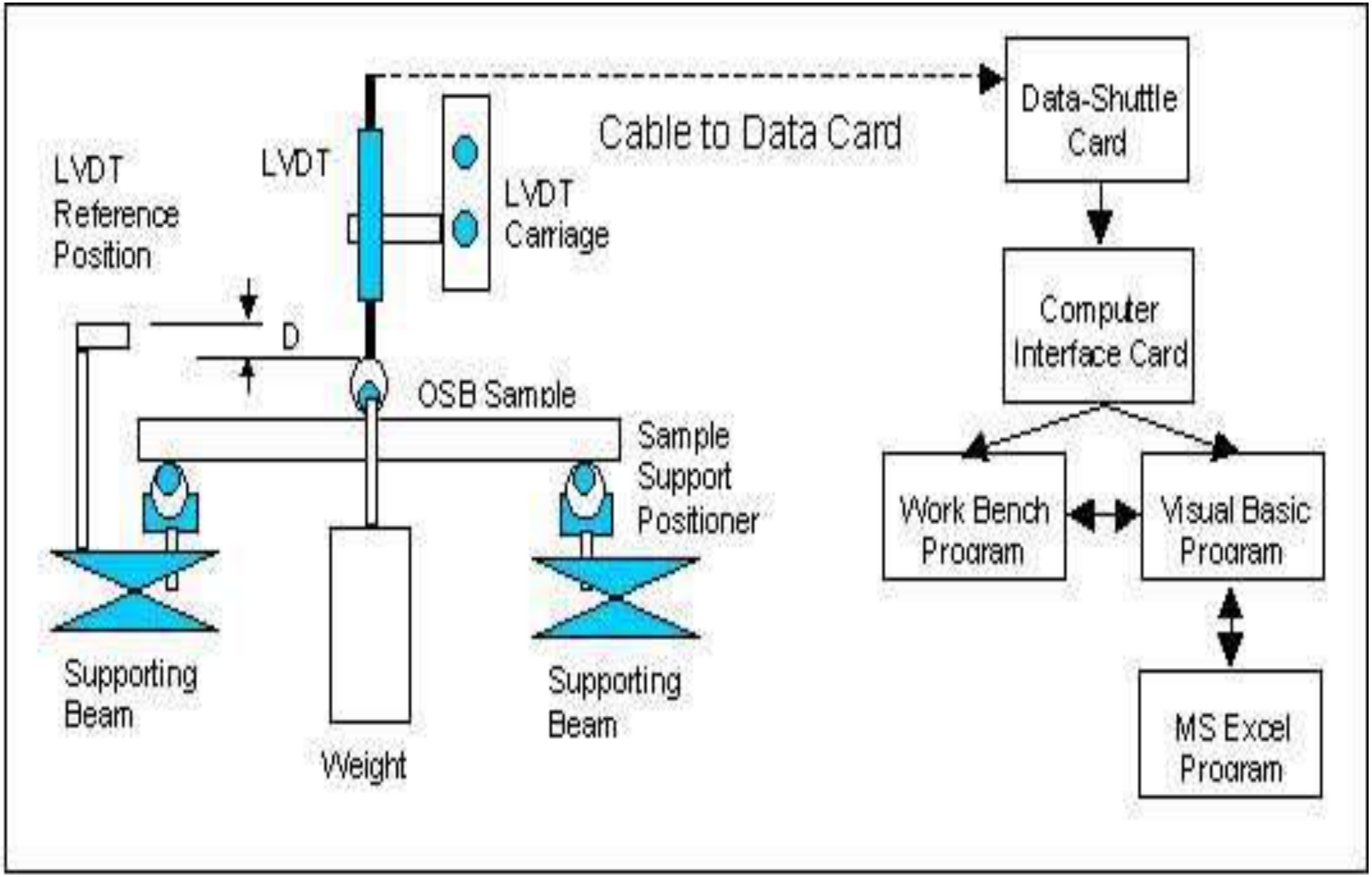
Creep development



INFLUENCING FACTORS

- Diffusion
- Dislocation
- Temperature
- Stress

Schematic of the test setup for creep measurements.



WEAR

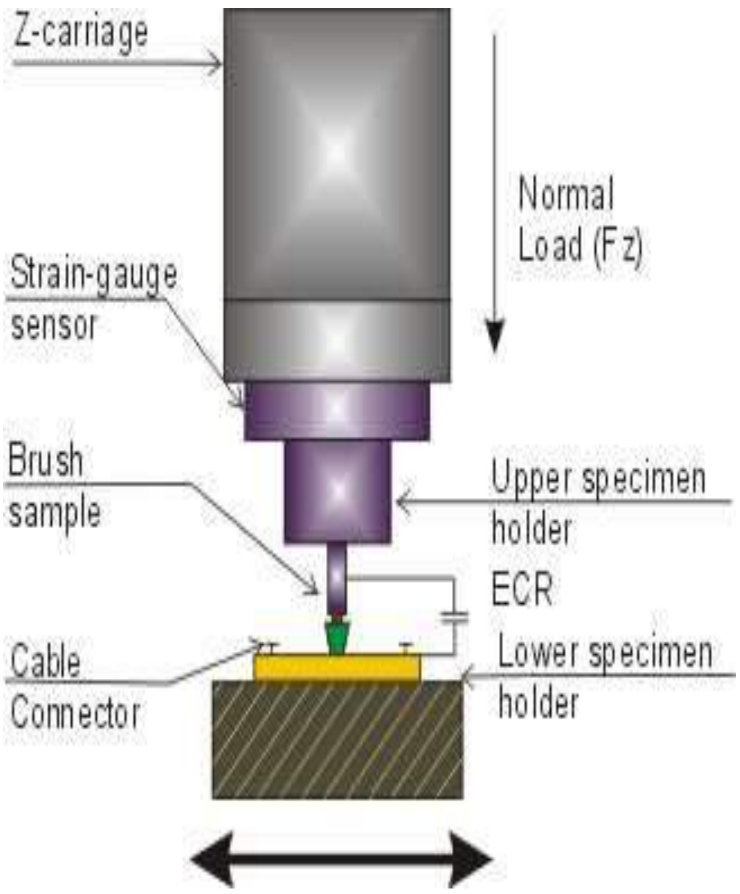
Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface.

CLASSIFICATION

- 1)Adhesive wear
- 2) Abrasive wear
- 3)Surface fatigue
- 4)Fretting wear
- 5)Erosive wear
- 6)Corrosive and oxidation wear

Measurement of wear

- Tribometer



- Archard equation

- Q=KWL/H
- where
- *Q* is the total volume of wear debris produced
- *K* is a dimensionless constant
- *W* is the total normal load
- *L* is the sliding distance
- *H* is the hardness of the softest contacting surfaces
- Note that is proportional to the work done by the friction forces as described by Reye's hypothesis.

Introduction

The quality and utility of monitoring, evaluation and research in our projects and programmes fundamentally relies on our ability to collect and analyse quantitative and qualitative data. Monitoring and evaluation plans, needs assessments, baseline surveys and situational analyses are all located within a project cycle and require high-quality data to inform evidence-based decision-making and programmatic learning. To achieve this it is useful to reflect on research practices, which in a monitoring, evaluation, accountability and learning context refers to the systematic investigation of programmes. Although this session targets monitoring and evaluation specialists, it is framed by the research agenda and will build on your existing knowledge of using different data collection methods in your project work.

More specifically, we will discuss the process of identifying research questions and selecting appropriate methodologies, understanding the difference between quantitative and qualitative data, and associated benefits and limitations. We will give an overview of common methods and data analysis techniques for both quantitative and qualitative research and finally discuss the interpretation of findings using multiple data sources. The scope of this module is limited to concepts that will enable learners to gain a broad understanding of the subject area. However, we will include links to useful resources should learners wish to increase their knowledge on a particular topic.

Learning Outcomes for this Session

When you have studied this session, you should be able to:

1. Develop research questions and link them to study designs
2. Understand differences between quantitative and qualitative research and their application
3. Be familiar with different methods for collecting and analysing qualitative data
4. Be familiar with different methods for collecting quantitative data and basic concepts of probability sampling
5. Understand simple descriptive analyses for quantitative data
6. Interpret multiple sources of data and develop evidence-based conclusions and recommendations

These learning outcomes will equip you to better understand the data collection methods and tools that are used within the overall MEAL system. For example, you will learn how to report on the mandatory global outcome indicators. Each of the mandatory global outcome indicators, as explained later in the module, have specific tools and methods for data collection – some qualitative, some quantitative.

1 Developing research questions and linking them to study designs

We have all had questions and experienced a desire to know more about the impact and local impressions of our programmes as well as how people and culture influence our activities. This curiosity to question and learn is integral to our delivery of quality programmes. But how do we move from having an interest to knowing more about a particular area, through to developing a research question(s) and determining the right study design? The aim of this section is to guide you through the process of developing research questions, studying objectives and linking them to an appropriate study design.

1.1 Case study: Working Street Children in Karachi, Pakistan

To assist with demonstrating the aim of this section, as well as exemplifying, illustrating and linking the different topics described in this module, we will give examples referring back to a simulated case study.

Case study: Working Street Children in Karachi, Pakistan

Picture by Olivia Arthur/Magnum Photos for Save the Children

Poverty is forcing more and more children to seek work on the streets of Karachi, enabling them to take an active role in sustaining themselves and their families. Whilst most children live with family or relatives, some children live on the street with no adult supervision and care.

Children are typically employed as street vendors, car washers, shoe-shiners and as beggars and scavengers. Furthermore, large numbers of children are picked up on the street to do ad hoc domestic work, particularly girls, often performing physically-demanding tasks in situations where they face risk of abuse and exploitation behind the walls of private homes.

Regardless of the type of labour, working street children often miss out on regular schooling and on opportunities that would enable them to pursue their right to a 'normal' childhood and a dream to escape poverty. They are often required to engage in risky, heavy and age-inappropriate forms of labour, which, among other issues, can have serious consequences for their physical and emotional health.

In this session you will learn how to develop a 'situation analysis' study to understand the struggles and coping strategies of working street children in Karachi.

1.2 Developing research questions and study objectives

A key step in the planning of research is to be clear about its purpose and scope. The purpose of this study in part is to reflect gaps in existing knowledge and in part to inform future programmes. The scope of a research project is usually determined by time, resources and staff constraints, so keep that in mind when you develop your research question.

A research question is meant to help you focus on the study purpose. A research question should therefore define the investigation, set boundaries and provide some level of direction.

In the process of developing a research question, you are likely to think of a number of different research questions. It is useful to continually evaluate these questions, as this will help you refine and decide on your final research question. You could, for example, ask:

- Is there a good fit between the study purpose and the research question?
- Is the research question focused, clear and well-articulated?
- Can the research question be answered? Is it feasible – given time, resource and staff constraints?

Activity 1 (SAQ)

Here are examples of research questions relating to the case study. Which research question do you think is the most appropriate?

1. What is life like for working street children?
2. What are the struggles and coping strategies of working street children in Karachi, and what are the implications of these observations to development programmes?
3. How can Save the Children best support working street children in Karachi?

The answer can be found at the end of this session.

To further help you define your investigation it is useful to develop a few study objectives. These objectives should be specific statements that reflect the steps you will take to answer your research question. For the above case study, I would include the following objectives:

- Map out the struggles and coping strategies of working street children in Karachi
- Determine how socio-economic status impacts on children's struggles and coping strategies
- Identify differences between boys and girls as well as the cause of these differences
- Discuss the implications of these findings to development programmes.

By addressing these four study objectives, you will automatically begin to 'paint a picture' that answers your overarching research question.

Depending on the nature of your research question and study objectives, you may begin to think about the direction you think the answers will take. For example, in what ways do you think socio-economic status may determine the struggles of working street children and their ability to cope with hardship?

Figure 1 summarises key steps for you to establish a study focus.

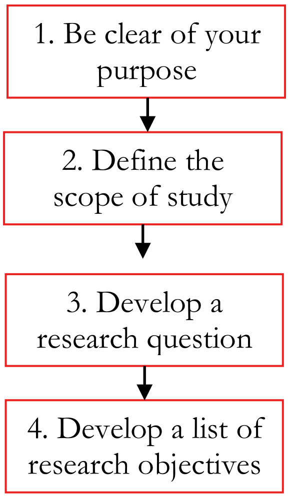


Figure 1: 'Steps' to establish a study focus

1.3 Deciding on a study design

Once you are happy with your research question and study objectives you can begin to determine which study design is most appropriate to answer your question. There are many different kinds of study designs for monitoring, evaluation and research. They can either be exploratory and observational, meaning they try to explore and observe what is happening in a given context, or they can be experimental, which means they are aiming to test the impact of an intervention.

Activity 2 (SAQ)

Let's say we are going to use the second research question: What are the struggles and coping strategies of working street children in Karachi, and what are the implications of these observations to development programmes?

To answer this question, do you need to develop a study design that is exploratory or experimental?

To help you answer this question, you can consider the following questions:

- Do you need to develop an experiment and test different possibilities? Or is your study more about exploring and developing an impression about local experiences?
- Will you need to compare and contrast populations with different outcomes? Will you need to follow a group of participants over a period of time (i.e. follow a cohort)? Or will you be exploring their perspectives at a specific point in time?

The answer can be found at the end of this session.

As your study seeks to describe some features (struggles and coping strategies) of a group of working street children at one specific point in time, you are in the process of developing an exploratory study. Exploratory studies are useful for conducting situation analyses and benefit from drawing on both qualitative and quantitative methods. If you were developing a study to assess the impact of an intervention supporting working street children in Karachi, you would likely benefit from developing a study with a more experimental design with a before and after intervention focus. For more detail on experimental evaluation designs, please consult Session 7.

1.4 Promoting ethical and participatory research

After having determined the design of your study, it is time to think about how you might best engage with the respondents of the study, many of whom will be children. You will, for example, need to consider the following questions:

What might be the social and ethical implications of the respondent's engagement with you and the study? How can you best protect and safeguard their well-being and interests? What are ethical and safe ways to involve children in research?

These questions are important to consider and resonate with Save the Children's child safeguarding policy. Broadly said, ethical research is about 'doing good and avoiding harm' to those participating in the research. This is achieved primarily by consulting communities of your areas of study and attaining answers and practical responses to the above questions. Make sure you follow up on their recommendations. You also need to familiarise yourself with existing toolkits and universal guidelines for conducting ethical research (see resources below) and use this information to develop informed consent forms, which include:

i. An **information sheet** in the local language, explaining: who you and Save the Children are, including your contact details; the purpose of the interview or exercise; whether they have to take part; what will happen if they do not want to participate; what will happen if they agree to participate; how long it will take; how confidentiality will be assured; what they will get out of it; risks associated with their participation; approximate data of completion and anticipation how the information gathered will be used. If you will be involving non-literate groups you need to think about how to communicate this information to them, for example in a group discussion and/ or with visual materials.

ii. A **consent form** that includes statements that the participant has understood what they will be involved in (e.g.,' I understand that if I decide at any time that I don't want to participate in this study, I can tell the researchers and will be withdrawn from it immediately. This will not affect me in any way'. Or, to take another instance: 'I understand that reports from the findings of this study, using information from all participants combined together, will be published. Confidentiality and anonymity will be maintained and it will not be possible to identify me from any publications'.

You need to prepare separate information consent forms for both children and adults. If children under the age of 18 are participating in your study, you also need to obtain informed consent from their guardians. Different data collection methods require different informed consent forms. So it is important you tailor your information sheets and consent forms to your specific study. More and more organisations, including Save the Children UK, are setting up internal ethics committees in place to support and guide staff to conduct ethical research. At the end of this session we have included some resources providing you with additional information.

How can you promote children's participation in a study?

As Session 8 Children's participation in MEAL demonstrates, Save the Children has a longstanding history of recognising children as social actors with a unique perspective and insight into their own reality. This recognition is borne out of an acknowledgement of the benefits of involving community members and children in research processes. In the spirit of promoting children's participation, researchers can explore ways to use methods that bring forward children's voices as well as identifying ways in which children can act as co-researchers (see resources below). This may include using drawings or disposable cameras (click http://resourcecentre.savethechildren.se/sites/default/files/documents/3738.pdf for an example) or participatory action and learning tools (click http://www.aidsalliance.org/includes/Publication/Tools_Together_Now_2009.pdf for an example) to promote children's participation.

1.5 Differences between quantitative and qualitative research and their application

Research is a systematic investigation that aims to generate knowledge about a particular phenomenon. However, the nature of this knowledge varies and reflects your study objectives. Some study objectives seek to make standardised and systematic comparisons, others seek to study a phenomenon or situation in detail. These different intentions require different approaches and methods, which are typically categorised as either quantitative or qualitative. You have probably already made decisions about using qualitative or quantitative data for monitoring and evaluation. Perhaps you have had to choose between using a questionnaire or conducting a focus group discussion in order to gather data for a particular indicator.

1.6 Quantitative research

Quantitative research typically explores specific and clearly defined questions that examine the relationship between two events, or occurrences, where the second event is a consequence of the first event. Such a question might be: 'what impact did the programme have on children's school performance?' To test the causality or link between the programme and children's school performance, quantitative researchers will seek to maintain a level of control of the different variables that may influence the relationship between events and recruit respondents randomly. Quantitative data is often gathered through surveys and questionnaires that are carefully developed and structured to provide you with numerical data that can be explored statistically and yield a result that can be generalised to some larger population.

1.7 Qualitative research

Research following a qualitative approach is exploratory and seeks to explain 'how' and 'why' a particular phenomenon, or programme, operates as it does in a particular context. As such, qualitative research often investigates i) local knowledge and understanding of a given issue or programme; ii) people's experiences, meanings and relationships and iii) social processes and contextual factors (e.g., social norms and cultural practices) that marginalise a group of people or impact a programme. Qualitative data is non-numerical, covering images, videos, text and people's written or spoken words. Qualitative data is often gathered through individual interviews and focus group discussions using semi-structured or unstructured topic guides.

1.8 Summary of differences

	Qualitative research	**Quantitative research**
Type of knowledge	Subjective	Objective
Aim	Exploratory and observational	Generalisable and testing
Characteristics	Flexible	Fixed and controlled
	Contextual portrayal	Independent and dependent variables
	Dynamic, continuous view of change	Pre- and post-measurement of change
Sampling	Purposeful	Random
Data collection	Semi-structured or unstructured	Structured
Nature of data	Narratives, quotations, descriptions	Numbers, statistics
	Value uniqueness, particularity	Replication
Analysis	Thematic	Statistical

Table 1: Key differences between qualitative and quantitative research

Although the table above illustrates qualitative and quantitative research as distinct and opposite, in practice they are often combined or draw on elements from each other. For example, quantitative surveys can include open ended questions. Similarly, qualitative responses can be quantified. Qualitative and quantitative methods can also support each other, both through a triangulation of findings and by building on each other (e.g., findings from a qualitative study can be used to guide the questions in a survey).

2 Methods for collecting and analysing qualitative data

This section starts off by introducing you to four commonly used qualitative data collection methods. These collection methods and many others are also described in the Save the Children Evaluation Handbook, which also explain how to use them in evaluation. It then explains how you may go about involving participants: this is also known as sampling. The section ends with a discussion of a couple of approaches to qualitative data analysis. You may have used some of these methods as part of your routine project monitoring activities, in a needs assessment or baseline or as part of an evaluation exercise.

2.1 Individual interview

An individual interview is a conversation between two people that has a structure and a purpose. It is designed to elicit the interviewee's knowledge or perspective on a topic. Individual interviews, which can include key informant interviews, are useful for exploring an individual's beliefs, values, understandings, feelings, experiences and perspectives of an issue. Individual interviews also allow the researcher to ask into a complex issue, learning more about the contextual factors that govern individual experiences.

2.2 Focus group discussions

A focus group discussion is an organised discussion between 6 to 8 people. Focus group discussions provide participants with a space to discuss a particular topic, in a context where people are allowed to agree or disagree with each other. Focus group discussions allow you to explore how a group thinks about an issue, the range of opinions and ideas, and the inconsistencies and variations that exist in a particular community in terms of beliefs and their experiences and practices. You should therefore purposefully (the adjective is 'purposive') recruit participants for whom the issue is relevant. Be clear about the benefits and limitations of recruiting participants that represent either one population (e.g. school going girls) or a mix (e.g. school going boys and girls), and whether or not they know each other.

2.3 Photovoice

Photovoice is a participatory method that enables people to identify, represent and enhance their community, life circumstances or engagement with a programme through photography and accompanying written captions. Photovoice involves giving a group of participant's cameras, enabling them to capture, discuss and share stories they find significant. For more detail, click here [http://www.photovoice.org/PV_Manual.pdf].

2.4 Picture story

The picture story method enables children, in a fun and participatory way, to communicate their perspectives on particular issues through a series of drawings (story telling) they have made. The story telling can either be done in writing, depending on the child's level of literacy, or verbally with a researcher. The picture story method is relatively quick and inexpensive, particularly if the draw-and-write technique is adopted. The picture story method provides a non-threatening way to explore children's views on a particular issue (e.g. barriers to girl's education) and to begin to identify what can be done to address any struggles faced by children.

2.5 Identifying participants

Qualitative research often focuses on a limited number of respondents who have been purposefully selected to participate because you believe they have in-depth knowledge of an issue you know little about, such as:

- They have experienced first-hand you topic of study, e.g. working street children
- They show variation in how they respond to hardship, e.g. children who draw on different protective mechanisms to cope with hardship on the street and in the work place
- They have particular knowledge or expertise regarding the group under study, e.g. social workers supporting working street children.

You can select a sample of individuals with a particular 'purpose' in mind in different ways, including:

- Extreme or typical case sampling – learning from unusual or typical cases, e.g. children who expectedly struggle with hardship (typical) or those who do well despite extreme hardship (unusual)
- Snowball sampling – asking others to identify people who will interview well, because they are open and because they have an in-depth understanding about the issue under study. For example, you may ask street children to identify other street children you can talk to.
- Random purposeful sampling – if your purposeful sample size is large you can randomly recruit respondents from it.

Whilst purposeful sampling enables you to recruit individuals based on your study objectives, this limits your ability to produce findings that represent your population as a whole. It is therefore good practice for triangulation purposes to recruit a variety of respondents (e.g., children, adults, service users and providers)

Click here [http://goo.gl/y8Jz9d] for more detail on qualitative sampling techniques.

Activity 3 (SAQ)

Imagine that you have arrived in Karachi to conduct the study detailed in the case study on working street children (see above). A local social worker introduces you to two former street working children and you learn that they still have lots of friends still working on the street. As a way to identify participants for your study, you ask the two former street working children if they can recommend and invite some of their friends on the street to participate in the study. You also ask them to spread word of the study in anticipation that their friends will also help you to identify potential participants.

How would classify this kind of sampling?

1. Extreme or typical case sampling?
2. Snowball sampling?
3. Random purposeful sampling?

The correct answer can be found at the end of this session.

3 Qualitative data analysis

Qualitative data analysis is a process that seeks to reduce and make sense of vast amounts of information, often from different sources, so that impressions that shed light on a research question can emerge. It is a process where you take descriptive information and offer an explanation or interpretation. The information can consist of interview transcripts, documents, blogs, surveys, pictures, videos etc. You may have been in the situation where you have carried out 6 focus group discussions but then are not quite sure what to do with the 30 pages of notes you collected during the process. Do you just highlight what seems most relevant or is there a more systematic way of analysing it?

Qualitative data analysis typically revolves around the impressions and interpretations of key researchers. However, through facilitation, study participants can also take an active role in identifying key themes emerging from the data. Because qualitative analysis relies on researchers' impressions, it is vital that qualitative analysis is systematic and that researchers report on their impression in a structured and transparent form. This is particularly important considering the common perception that qualitative research is not as reliable and sound as quantitative research.

Qualitative data analysis ought to pay attention to the 'spoken word', context, consistency and contradictions of views, frequency and intensity of comments, their specificity as well as emerging themes and trends. We now explain three key components of qualitative data analysis.

3.1 The process of reducing your data

There are two ways of analysing qualitative data. One approach is to examine your findings with a pre-defined framework, which reflects your aims, objectives and interests. This approach is relatively easy and is closely aligned with policy and programmatic research which has pre-determined interests. This approach allows you to focus on particular answers and abandon the rest. We refer to this approach as 'framework analysis' (Pope et al 2000). The second approach takes a more exploratory perspective, encouraging you to consider and code all your data, allowing for new impressions to shape your interpretation in different and unexpected directions. We refer to this approach as thematic network analysis (Attride-Stirling, 2001). More often than not, qualitative analysis draws on a mix of both approaches.

Whichever approach guides you, the first thing you need to do is to familiarise yourself with your data. This involves reading and re-reading your material (data) in its entirety. Makes notes of thoughts that spring to mind and write summaries of each transcript or piece of data that you will analyse. As your aim is to condense all of this information to key themes and topics that can shed light on your research question, you need to start coding the material. A code is a word or a short phrase that descriptively captures the essence of elements of your material (e.g. a quotation) and is the first step in your data reduction and interpretation.

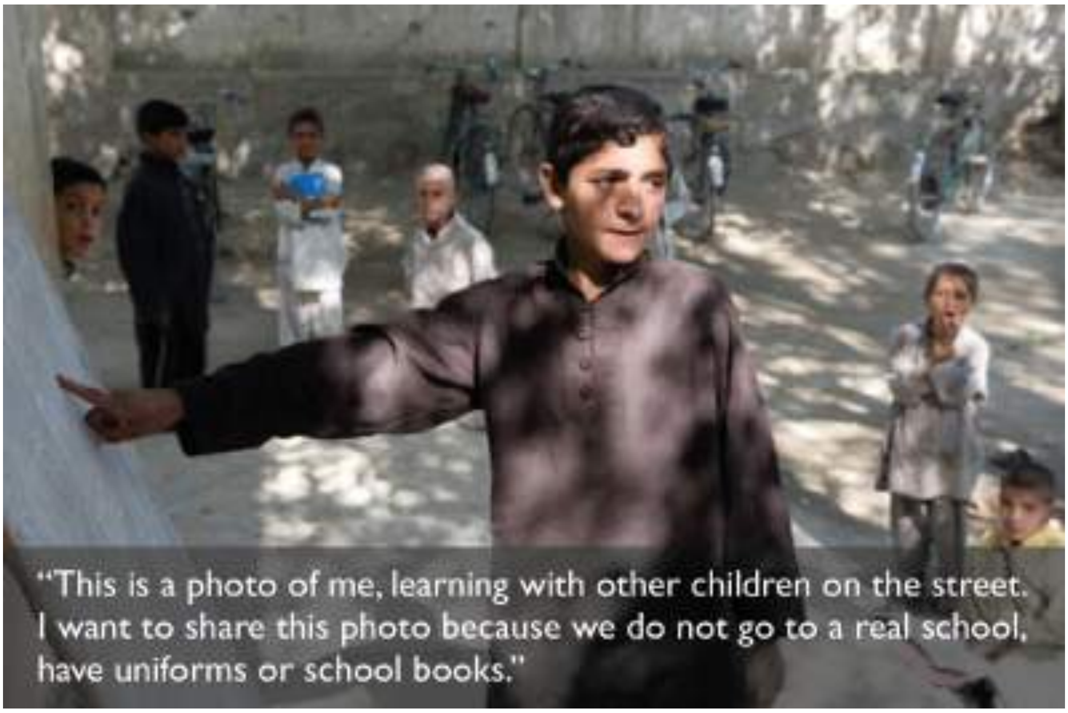


Figure 2: Example qualitative data © Olivia Arthur/Magnum Photos for Save the Children

How would you code the (fictitious) qualitative data in Figure 2? One appropriate phrase to descriptively summarise the text segment and the accompanying photo could be 'Torn uniform'.

To help speed up your coding you can, after having read through all of your data, develop a coding framework, which consists of a list of codes that you anticipate will be used to index and divide your material into descriptive topics. If you are approaching your data following the deductive framework approach, your coding will be guided by a fixed framework (and you index your material according to these pre-defined codes). If, however, you are following the more inductive thematic network approach, you are likely to add new codes to your list as you progress with the coding, continually developing your coding framework. Coding is a long, slow and repetitive process, and you are encouraged to merge, split up or rename codes as you progress. There is no fixed rule on how many codes you should aim for, but if you have more than 100-120 codes, it is advisable that you begin to merge some of your codes.

Once you have coded all of your material you need to start abstracting themes from the codes. Go through your codes and group them together to represent common, salient and significant themes. A useful way of doing this is to write your code headings on small pieces of paper and spread them out on a table: this process will give you an overview of the various codes and will also allow you to move them around and cluster them together into themes. Look for underlying patterns and structures – including differences between types of respondents (e.g., adults versus children, men versus women) if analysed together. Label these clusters of codes (and perhaps even single codes), with a more interpretative and 'basic theme'. Take a new piece of paper, write the 'basic theme' label, and place it next to your cluster of codes. If, for example, the codes 'Torn uniform' and 'No school books' appear in your interview transcripts with working street children, they can be clustered together as 'Working street children lack school materials' (see Figure 3).

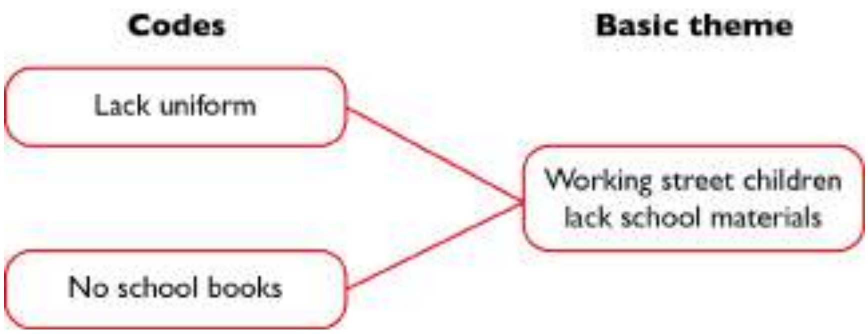


Figure 3: From codes to basic themes

You may find that not all of your codes are of interest and relevance to your research question and that you choose to only cluster 60 of your codes into 'basic themes' that help shed light on your question. Let us say, for arguments sake, that through this process you identify 20 'basic themes'. Repeat this process with your basic themes. Examine your 'basic themes' and cluster them together into higher order and more interpretative 'organising themes'. Let us say, again for arguments sake, that this process reduces your 20 'basic themes' to four 'organising themes', two of which represent struggles faced by working street children (as exemplified by Figure 4) and two which give detail to their coping strategies. Figure 4 also illustrates how you can transparently show how you went from having descriptive codes to focusing on a few distinct, interpretative and networked themes that you can use to begin answering parts of your research question.

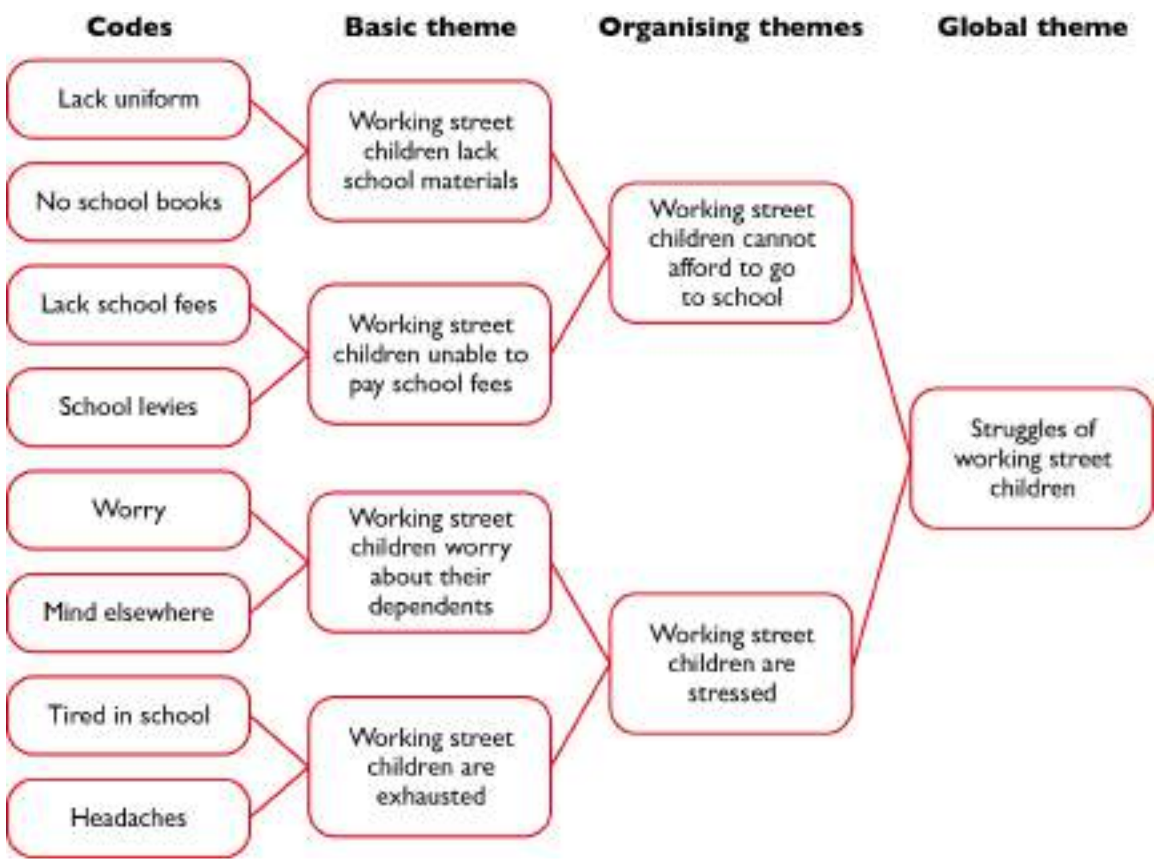


Figure 4: From codes to organising and global themes

The method of cutting out codes and moving them around on a table is often referred to as the 'table method'. The 'table method' works particularly well for smaller studies. If you have vast amounts of data (e.g. more than 20 interview transcripts), you may find it helpful to use qualitative data analysis software, such as Nvivo or Atlas.Ti. These software packages are, however, not free and you will require a license.

You are now half way through the session and this would be a good time to take a break before you continue.

4 Quantitative data and methods

Quantitative data is numerical and can be collected in a number of forms. The most common forms of quantitative data used in Save the Children are shown below.

- **Units:** number of staff that have been trained; number of children enrolled in school for the first time
- **Prices:** amount of money spent on a building, or the additional revenue of farmers following a seed distribution programme
- **Proportions/percentages:** proportion of the community that has access to a service
- **Rates of change:** percentage change in average household income over a reporting period
- **Ratios:** ratio of midwives or traditional birth attendants to families in a region
- **Scoring and ranking**: scores given out of ten by project participants to rate the quality of service they have received.

Statistical analysis is used to summarise and describe quantitative data and graphs or tables can be used to visualise present raw data. This section will review the commonly used methods/sources of quantitative data and the techniques used for recruiting participants.

4.1 Quantitative methods

Quantitative data can be collected using a number of different methods and from a variety of sources.

1. **Surveys and questionnaires** use carefully constructed questions, often ranking or scoring options or using closed-ended questions. A closed-ended question limits respondents to a specified number of answers. For example, this is the case in multiple-choice questions. Good quality design is particularly important for quantitative surveys and questionnaires.
2. **Biophysical measurements** can include height and weight of a child
3. **Project records** are a useful source of data. For example, the number of training events held and the number of participants attending
4. **Service provider or facility data** includes school attendance or health care provider vaccination records
5. **Service provider or facility assessments** are often carried out during the monitoring and evaluation of our projects. Save the Children examples include our quality of learning environment and quality of child protection service global indicators [*see sessions 15 and 16*]

4.2 Sampling for quantitative methods

Commonly in our research or programmatic data collection, it is not possible or even desirable, to collect data from a whole target group or population. This could be extremely difficult and expensive. Through accurate *sampling* of a subset of the population we can reduce costs and gain a good representation from which we can infer or generalise about the total population.

Accurate sampling requires a *sample frame* or list of all the units in our target population. A unit is the individual, household or school (for example) from which we are interested in collecting data. A sample frame for a household survey would include all the households in the population identified by location or, in the case of our case study, all of the working street children in Karachi.

4.3 Bias

The process of recruiting participants for quantitative research is quite different from that of qualitative research. In order to ensure that our sample accurately represents the population and enables us to make generalisations from our sample we must fulfil a number of requirements.

Sampling bias can occur if decisions are made about sample selection that mean that some individuals have a greater chance of being selected for the sample than others. Sample bias is a major failing in our research design and can lead to inconclusive, unreliable results. There are a many different types of bias. For example, tarmac bias relates to our tendency to survey those villages that are easily accessible by road. We may be limited in our ability to travel to many places due to lack of roads, weather conditions etc. which can create a bias in our sample.

Self-selection or non-response bias is one of the most common forms of bias and is difficult to manage. Participation in questionnaire/surveys must be on a voluntary basis. If only those people with strong views about the topic being researched volunteer then the results of the study may not reflect the opinions of the wider population creating a bias.

Activity 4 (SAQ)

From the three examples below, select which sample selection is **not biased**.

A. A government official with good knowledge of the area identifies schools to be included in the sample

B. You wait at the market on a Monday morning and interview every third person that comes through the gates

C. From an accurate list of children enrolled in a school you pick children's names out of a hat.

The answer can be found at the back of the session.

4.4 Simple random sampling

A simple random sample is the simplest way to select participants from a population. Pulling names out of a hat or using an online random number generator such as www.random.org can create a random sample. Using these methods means that each individual in the population has the same chance of being selected for the sample.

4.5 How many? Sample size calculation

Calculating the most appropriate sample size is an important step in the research process. A larger sample provides a more precise estimate of the 'real' situation but the benefits of increased sample size get smaller as you near the total population. Therefore, there is a trade-off between sample precision and considerations of optimal resource use.

There are no 'rules of thumb' when determining sample size for quantitative research. It is not possible to say whether 10% of the population, for instance, would provide an adequate sample, as this will be affected by a number of factors. You should be wary of sample plans in research or evaluations that suggest sample size can be calculated using a percentage of the population without further clarification or rationale for this.

Statisticians will calculate sample size using a range of different equations, each of which are appropriate for different research situations and contexts. It is important to discuss the objectives of your research, expected results, data types, resources and context with a statistician or technical advisor at the design stage of your research in order to calculate an appropriate sample.

It is also useful to understand the two main statistics, which will be used to calculate the sample size. These are the **confidence interval** or **margin of error** and the **confidence level**.

The **confidence interval** is the acceptable range in which your estimate can lie. For example, if you were using a sample to collect data estimating the percentage of street children in Karachi who are engaged in harmful work you might set your margin of error at 10%. This would mean that if, following the collection of your data you found that 75% of children in your sample are engaged in harmful work, you would know that the real number for the population would be plus or minus 10% i.e. anywhere between 65% and 85%.

If you are carrying out before and after intervention analysis to determine whether your work has contributed to a change you will need to consider what *size of effect* you anticipate occurring before you calculate your sample size. For example, if you are carrying out a project which expects to reduce the number of children working on the street from 75% to 70% you would not want to use a confidence interval of 10% as your estimate would not be precise enough to detect this change.

The **level of confidence** determines how sure you want to be that actual percentage (of children engaged in harmful work for example) falls within your selected confidence interval. As we are using a sample and not asking every single child individually we are always making an estimate of the real value and we can never be 100% confident. A level of confidence of 95% is commonly used, which means that there is a 5% chance that the actual percentage will *not* lie between the confidence interval selected.

When deciding on what confidence interval to use in your sample size calculation it is important to remember that whilst a larger range gives you a smaller sample size, a smaller range gives you greater precision in your results. Selecting a lower level of confidence will also give a smaller sample size but also decrease the reliability of the data. Unfortunately there is no simple answer and you need to review the values used on a case-by-case basis. Remember, however, that if the sample is too small then this will lead to inconclusive results, which cannot provide us with the information that we need. If the sample is too large, however, it may be impossible to collect and resources will be wasted.

4.6 Sampling methods

Stratified sampling: Stratified sampling is used when individuals in a population can be split into distinct, non-overlapping groups. These groups are called ‘strata’. Common strata are village, district, urban/rural etc.

In stratified sampling, the number of participants sampled from each strata is calculated proportionally to the total population. For example, a population of 100 people live in two villages, with 30% in village A and 70% in village B. We have a required sample size of 60. In order to stratify our sample we need to calculate 30% of 60.

Number of people from village A in sample = 60 * 0.3 = 18 people

Number of people from village B in sample = 60 * 0.7 = 42 people

Stratified sampling is beneficial when there are big differences between the strata, as they can give a more accurate representation of the population and, if the sample size is large enough, allow for further sub-set analysis.

5 Quantitative analysis

The methods we have described above help us to collect quantitative data, but is the collection of data our end goal?

No, of course not! A large set of data sitting in a spreadsheet does not help us to understand the characteristics of the population we are working with or describe the changes brought about by our projects. We need to use the data to create information.

In our case study example, we may have interviewed children working on the street in Karachi and collected all the data together in a spreadsheet; however, we need to analyse and summarise the data to answer our research questions. We need to understand what percentage of children are involved in different work types. For instance, we may want to understand if girls and boys carry out similar tasks or are exposed to similar risks.

Statistics help us turn quantitative data into useful information to help with decision-making. We can use statistics to summarise our data, describing patterns, relationships and connections. Statistics can be *descriptive* or *inferential*. Descriptive statistics help us to summarise our data whereas inferential statistics are used to identify statistically significant differences between groups of data (such as intervention and control groups in a randomised control study). During this module our focus will be on descriptive rather than inferential statistics: this will also help to give a short introduction to the most common descriptive statistics.

5.1 Data structure

We generally collect data from a number of individuals or '**units**'. These units are most often the children or adults that we are working with. However, our units could also be hospitals or schools, for example. The different measurements, questions or pieces of information that we collect from these individuals are the **variables.**

5.2 Variables

There are two types of variables, numerical and categorical. It is important to distinguish between these two types of variables, as the analysis that you do for each type is slightly different.

Categorical variables are made up of a group of categories. Sex (male/female) is a categorical variable, as is quality of training (good; bad; average).

Numerical variables are numbers. They can be counts (e.g. number of participants at a training) or measures (e.g. height of a child) or durations (e.g., age, time spent)

5.3 Analysis of categorical variables

Categorical data groups all units into distinct categories which can be summarised by determining how many times a category occurs. For example, the number of females in a group of participants. We describe this as the frequency of females in the group.

This information is presented using a *frequency table*. The frequency table shows us how many participants fall into each category. We can also then represent this as a percentage or proportion of the total. Figure 5 shows an example frequency table for the different types of work carried out by children working on the street in Karachi.

Type of work	Number of children
Street vendor	87
Car washing	92
Shoe-shiner	67
Scavenging	98
Begging	110
Domestic work	45
Other	28
TOTAL	527

Figure 5. Type of work for street children in Karachi

Frequency tables can be used to present findings in a report or can be converted into a graph for a more visual presentation.

A **proportion** describes the *relative frequency* of each category and is calculated by dividing each frequency by the total number.

Percentages are calculated by multiplying the proportion by 100. Proportions and percentages can be easier to understand and interpret than examining raw frequency data and are often added into a frequency table (see figure 6).

Type of work	Number of children	Percentage of children
Street vendor	87	16.51
Car washing	92	17.46
Shoe-shiner	67	12.71
Scavenging	98	18.60
Begging	110	20.87
Domestic work	45	8.54
Other	28	5.21
TOTAL	**527**	**100**

Figure 6. Types of work for street children in Karachi

5.4 Analysis of numerical variables

Two statistics – the centre and the spread – commonly describe numerical data.

The centre describes a typical value and the spread describes distance of data from the centre.

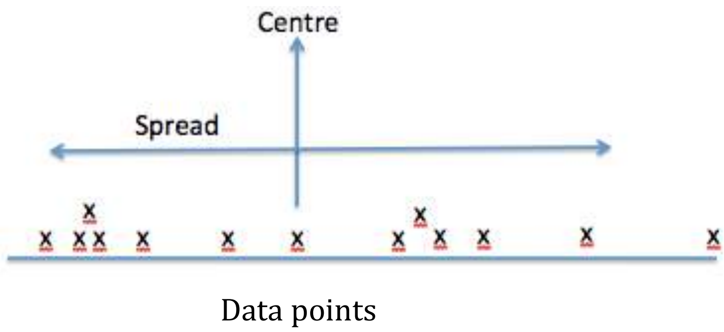


Figure 7 Diagram showing centre and spread for a set of data points

The most common statistics used to describe the centre are the **mean** (commonly known as the average) and the **median**. The median is the middle value in a data set, half the data are greater than the median and half are less. The mean is calculated by adding up all the values and then dividing by the total number of values.

Using our case study example – if you were to interview 23 street children and record their age you might get a set of data as below. Each number is the age of an individual child and the ages have been arranged in order.

3	3	4	4	5	7	7	8	9	10	10	11	12	12	12	13	13	14	14	15	15	15	16

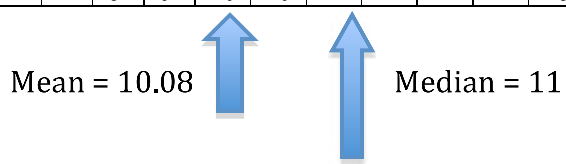


Figure 8 Mean and median age of children

The mean and the median would be different for this dataset. To calculate the median you need to arrange the children in order of age and then find the mid-way point. In this example, 11 children are below the age of 11 and 11 children are above the age of 11.

To calculate the mean you need to add up all the ages and then divide by the number of children (23 in this example).

So

3+3+4+4+5+7+7+8+9+10+10+11+12+12+12+13+13+14+14+15+15+16 = 232

232/23 = 10.08 = mean age of the children interviewed.

Spread is most easily described using the **range** of the data. This is the difference between the minimum and maximum. The range of the example data above would be 13 years (minimum = 3, maximum = 16).

Other statistics describing spread are the **interquartile range** and **standard deviation**.

The interquartile range is the difference between the upper quartile and lower quartile. A quarter (or 25%) of the data lie above the upper quartile and a quarter of the data lie below the lower quartile.

The standard deviation shows the average difference between each individual data point (or age of child in our example) and the mean age. If all data points are close to the mean then the standard deviation is low, showing that there is little difference between values. A large standard deviation shows that there is a larger spread of data. Calculating the standard deviation yourself is a little complex but this can also be done easily in Microsoft Excel (see *Computer Assisted Statistics Textbook* for details on how to calculate standard deviation).

Activity 5 (SAQ)

Examine the frequency table and answer the following true/false and multiple-choice questions

Age Group	Frequency	Proportion
0-5 years	56	0.24
6-10 years	93	0.39
10 + years	87	
TOTAL	236	

Figure 9. Frequency table showing the ages of children working on the street in Karachi

1. Age group is a numerical variable
2. Which value is the proportion of 10+ year old children in the sample
   A. 0.4
   B. 37
   C. 0.37
3. Which of the below statements is correct
   A. Centre is estimated by the interquartile range
   B. Standard deviation and interquartile range give an indication of spread
   C. Median is an indicator of centre and mean is an indicator of spread
   D. Mean is an estimate of the most common frequency

Answers can be found at the back of the session.

6 Discussing results and drawing conclusions

The final stage of the research process is to interpret the findings, making conclusions and recommendations. When drawing conclusions you should review and summarise your findings looking for explanatory patterns or relationships that help answer your research questions.

Questions to consider when interpreting your findings:

- Did the research methodology and data collected answer the research question? Do the findings support our hypotheses (quantitative)?
- How do the different findings interact? Do they explain each other or are there contradictions?
- Can we triangulate the data from a number of different sources (different stakeholders, different methodologies, external sources of information)?
- What were the limitations of the study and how do they affect the results?
- Are there any areas that require further research or follow up?

6.1 Mixed methods and triangulation

If you have collected both quantitative and qualitative data you should compare and contrast these findings when interpreting your work. The integration of quantitative and qualitative research can give us a broader understanding of our research subject. Quantitative research can describe magnitude and distribution of change, for instance, whereas qualitative research gives an in-depth understanding of the social, political and cultural context. Mixed methods research allows us to triangulate findings, which can strengthen validity and increase the utility of our work.

Triangulation is when we compare a number of different data sources and methods to confirm our findings. For example, we could compare the perspectives of teachers, students and parents on the quality of schooling. Triangulation can bring strength to our conclusions or identify areas for further work.

You should also reflect on your findings in comparison to other research or evaluation work in the area and consider whether findings were similar.

6.2 Limitations

When drawing conclusions and making recommendations it is important to recognise the limitations of our data. In quantitative research, the level to which we can generalise our findings to the wider population will depend upon the quality of the sampling strategy used. You should be careful not to over-generalise results: for example, suggesting a result is applicable for the whole country when only two out of eight regions were sampled.

Findings from qualitative research should not be used to make inferences about a wider population but can be used to provide examples of how or why in specific contexts.

It is also important that conclusions and recommendations are based on the data collected rather than personal opinions. When reporting quantitative or qualitative data, you can only make valid conclusions on the topics researched and for which you have supporting evidence.

6.3 Displaying and reporting on your qualitative and quantitative data

Any research report must be guided by the transparency of the process through which conclusions have been drawn. A report must therefore include:

- An **'Introduction'** that argues for the importance of exploring a particular research question, highlighting the gaps in, and limitations of, existing evidence.
- A **'Methodology'** section that justifies your sampling strategy and the research methods to be used to answer your research question: this gives detail to the process through which data was collected and analysed.
- A **'Findings'** section that presents key findings emerging from the analysis that answers the research question. If, for example, your qualitative data analysis generated two 'global themes', they could each represent a findings chapter, with 'organising themes' representing sub-headings, under which the 'basic themes' are discussed and supported by plenty of quotations, which are extracted from your codes. For quantitative data you may present frequency tables or graphs of variables of interest. When presenting qualitative findings, it is important that you do not only discuss and present a single and dominant view, but also acknowledge contradictions and disagreements within the data. Please note that when presenting qualitative data, you cannot claim causality and association. You are presenting people's perceptions and experiences of a phenomenon. As such, you have to be careful about how you present a finding. You can for example say 'some respondents felt …', 'a common opinion was …', 'The perception of some adults was …', 'this suggests a possible relationship between …' and so forth.

A **'Discussion'** section that highlights how the findings emerging from the study either corroborate, contradict or build on existing evidence as well as giving detail to the limitations of the study.

Summary of this Session

This session has taken you through the process of identifying research questions and selecting appropriate methodologies. You now hopefully have a better understanding of the difference between quantitative and qualitative data collection methods and associated benefits and limitations. We also introduced you to some common methods and techniques of data analysis for both quantitative and qualitative research.

We hope you found this session useful and will draw on it to develop systematic investigations that can be used to improve the quality, impact and accountability of our programmes. Best of luck!

Useful resources

Ethical research with children

UNICEFs Technical note on Ethical Research with Children
[http://www.unicef.org/evaluation/files/TechNote1_Ethics.pdf]

The Ethics of Social Research with Children and Families in Young Lives: Practical Experiences
[http://resourcecentre.savethechildren.se/sites/default/files/documents/6312.pdf]

Ethical Principles, Dilemmas and Risks in Collecting Data on Violence against Children. A review of available literature
[http://resourcecentre.savethechildren.se/sites/default/files/documents/6777.pdf]

Children's participation in research guides:

Children in focus: A manual for participatory research with children
[http://resourcecentre.savethechildren.se/sites/default/files/documents/5412.pdf]

So you want to involve children in research? A toolkit supporting children's meaningful and ethical participation in research relating to violence against children
[http://resourcecentre.savethechildren.se/sites/default/files/documents/2437.pdf]

Guide on Participatory Monitoring and Evaluation Methodologies for Working with Children and Youth
[http://resourcecentre.savethechildren.se/sites/default/files/documents/7191.pdf]

A guide for young people to learn how to do research and create positive change
[http://resourcecentre.savethechildren.se/sites/default/files/documents/5901.pdf]

Quantitative Data Analysis

Computer Assisted Statistics Textbooks (CAST)
[http://cast.massey.ac.nz/collection_public.html]

Statistical Services Centre, University of Reading (2006) Writing up research, a statistical perspective.
[http://www.reading.ac.uk/ssc/n/resources/Docs/Writing up research - a statistical perspective.pdf]

Sampling

Statistical Services Centre, University of Reading 'Some basic ideas of sampling' (2000)
[http://www.reading.ac.uk/ssc/n/resources/Docs/Some_Basic_Ideas_of_Sampling.pdf]

Wilson, I. Some practical sampling procedures for development research.
[http://www.reading.ac.uk/ssc/n/resources/Docs/Some_practical_sampling_procedures.pdf]

References

Attride-Stirling J. (2001). 'Thematic networks: an analytic tool for qualitative research'. *Qualitative Research*, vol. 1, no. 3: pp. 385–405 [Online]. Available at http://goo.gl/VpQeQJ (retrieved on 2 January 2014).

Pope, C., Ziebland, S., and Mays, N. (2000). 'Analysing qualitative data'. *British Medical Journal*, 320 : pp. 114–116 [Online]. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1117368/pdf/114.pdf (retrieved on 2 January 2014).

Self-Assessment Questions (SAQ) answers

Activity 1

The second question is probably the most appropriate research question. It is clear, focused and gives an indication of what the study sets out to do. The first question is too simple and can incorporate anything. The third question is unclear. It does not give any indication of what you will be studying and assumes children need support.

Activity 2

To answer your research question, you will need to develop an exploratory study design.

Activity 3

The answer is: 2. Snowball sampling

You may think that in qualitative research, any sampling technique is acceptable. In a way it is, as long as your sampling technique reflects your research question and that you declare what sampling technique you adopted.

Activity 4

The correct answer is C. This is why:

- Answer A: In this answer we do not know what criteria the government official is using to select the schools for the sample. S/he may be selecting the well-organised schools to reflect positively on the government or in fact selecting poorly run schools to bring more money into the area. The decision to include the schools is *subjective* rather than *objective*.
- Answer B: You are not giving all members of the population an equal chance to be selected for the sample. Perhaps some people arrive late to the market or visit on a different day.
- Answer C: This method should give a random sample, as long as the list of children is accurate.

Activity 5

1. FALSE. The data here show that age has been grouped into distinct categories: 0-5 years, 6 – 10 years, and 10+. This means the variable is categorical. Age can also be represented as a numerical variable if the specific age of each child was recorded rather than a group description.
2. C. Answer a. is an incorrect calculation. Answer b. is the percentage.
3. B. Centre and spread
4. B. Standard deviation and interquartile range give an indication of spread.

Glossary items

Research – To study (something) systematically, gathering and reporting on detailed and accurate information.

Randomisation – A method based on chance alone, by which study participants are assigned to a study.

Sampling – A process through which study participants, or locations, are recruited to take part in a study.

Triangulation – Is when we compare a number of different data sources and methods to confirm our findings. For example, we could compare the perspectives of teachers, students and parents on the quality of schooling. Triangulation can bring strength to our conclusions or identify areas for further work.

Findings – Summaries, impressions or conclusions reached after an examination or investigation of data.

Bias – A tendency to yield one outcome more frequently than others, often as a result of having or showing an unfair tendency to select some people or locations over others.

Infer – Deduce or conclude (information) from evidence and reasoning rather than from explicit statements.

Generalise – The ability to make statements and draw conclusions that can have a general application.

- Identification of soil types in the field, is limited to defining the colour, texture and plasticity
- Done without the benefit of major equipment
- It is necessary to do general assessment of sites during field reconnaissance and during the initial phases of work
- Sometimes these tests may be sufficient for ordinary works, but in most cases it will serve as an aid.Detailed and precise identification requires laboratory testing.

VISUAL EXAMINATION (TEXTURE)

By looking at the soil, we can make distinction between gravel, sand, and fines (silt and clay combined) components.

- However silt and clay particles cannot be separated without further magnification.

- The examination is done by drying a sample, spreading it on a flat surface, and then simply segregating it into its various components

SEDIMENTATION/DISPERSION TEST

- This test is done by shaking a portion of the sample into a glass container of water and allowing the material to settle.
- The gravel and coarse sand will settle almost immediately
- The fine sand will take 30 seconds to less than 5 minutes
- The silt may require as much as about an hour
- Clay shall remain in suspension for several hours
- The material will settle in layers.
- The percentage of each component is estimated by comparing the relative thickness of each of the layers in the bottom of the jar

Toughness (Plasticity) Test

In this test, a roll of soil moist enough to have workability, is pressed between the thumb and index finger into a thread of 3mm dia(or a ribbon)

a)If soil can be rolled into a thread of 3mm dia with no cracks in the sample it is clayey

b)If soil can be rolled into a thread of 3mm dia but cracks develop on the surface of the sample it is Silt or silt with clay.

c) If soil can not be rolled into a thread of 3mm then it is (Non-Plastic) sandy soil

Dry Strength/Breaking Test

- The dry strength/breaking test is normally made on a pat of soil which is allowed to completely dry in air.
- Attempts are made to break the dried pat between the thumb and fingers
- If it doesn't break it is Very highly plastic clays
- If it breaks with great effort it is plastic clay
- If it can be broken and powdered with ease, then it is silt or silt with clay
- if crumbling or powdering will occur while being picked up by the hands then it is siltey sand

- **SHAKING/DILATENCY TEST**
- Soil is moistened to a putty state and a pat is formed out of it & placed on the palm of hand.
- The hand is then shaken vigorously and in between it is stricken against hand.
- If the surface becomes glossy by rising of moisture to surface and on squeezing between fingers gloss disappears quickly it is silt
- If the process of appearance & disappearance of moisture(which is called Reaction) is slow then it is silty clay
- When Reaction does not occur, the soil is clayey.

WET TEST

- Place a pint of soil on a palm ,add a little water & rub between thumb and finger.

- If soil gives soapy touch and sticks to fingers ,it is clay

- If it doesn't give a soapy touch and doesn't stick to fingers and dries quickly it is silt

- If it gives rough feeling and no sign of wetting appears it is fine sand

SOAKING TEST

- Put a small lump of soil in glass container containing pure water

- Observe lump disintegrating in water

- If the soaking & disintegration takes place quickly ,it is silt or clay of low plasticity

- If the soaking & disintegration takes place very slowly ,it is clay of high plasticity

"QUALITY IS NOT AN ACCIDENT; BUT IT IS THE RESULT OF INTELLIGENT EFFORTS"

WHAT IS QUALITY?

- "Quality is fitness for use. "
- "The totality of features and characteristics of a product or service that bear on its ability to satisfy a given need."
- "Quality involves meeting customers need, preferences and exceeding it."
- "Quality also encompasses people, process and environment."

WHY QUALITY CONTROL?

- Manufacturing process is a repetitive process depending on both controllable and non-controllable factors.
- This produces deviation in the quality of the product.
- QC is the process of verification , or correction of the quality of the product when deviations are found to be more than expected.

WHAT IS QUALITY CONTROL?

"Those planned and systematic actions which provides a mean to control and measure the characteristics of a product, process or a service to established requirements."

QUALITY CONTROL AS PER ISO:

- "The operational techniques and activities that are used to satisfy quality requirements."
- The quality control system verifies and maintains desired level of quality in an existing product or service by careful planning, use of proper equipments and continued inspection and corrective action as required.

WHAT IS QC INSPECTION

- The ISO standard defines inspection as "activity of measuring, examining, testing one or more characteristics of a product or service and comparing the results with specified requirements in order to establish whether conformity is achieved for each characteristic."

QC AND INSPECTION

INSPECTION LOOP

IDENTIFICATION OF DEFECTS

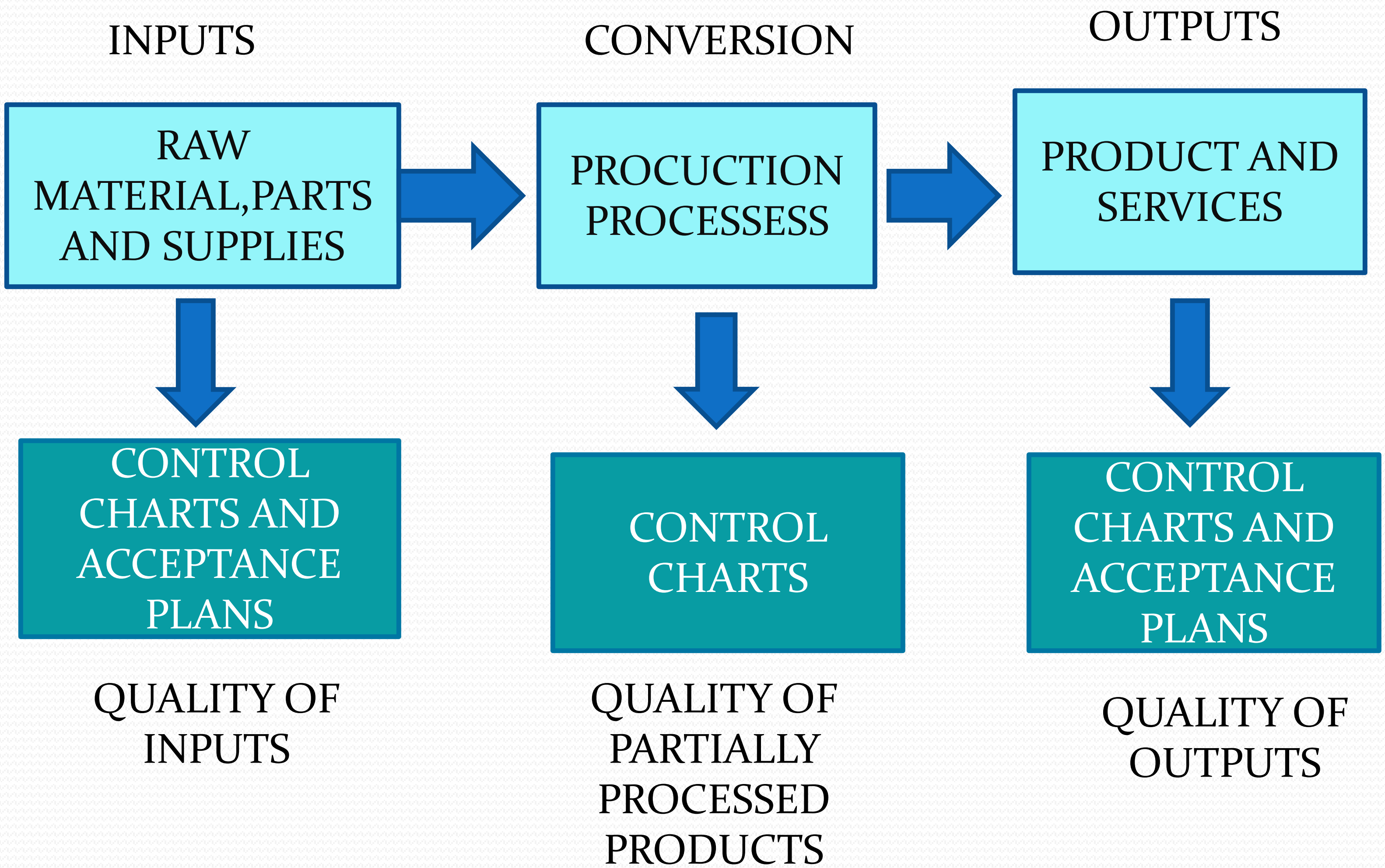
CORRECTION OF DEFECT

QUALITY

FEEDBACK OF THIS DEFECT TO APPROPRIATE PERSON

DETERMINATION OF CAUSE OF DEFECT

QC THROUGHOUT PRODUCTION SYSTEM



PRE-PRODUCTION QC INSPECTION

- The safety and efficacy of the finished dosage form is largely dependent on the purity and quality of the bulk active drug substance.
- Physical tests such as particle size for raw materials flow properties etc. are essential tests to assure consistent operation of the production and control system and to assure quality and efficacy

PRE-PRODUCTION QC INSPECTION

- To decrease quality risk, the inputs can be inspected prior to production.
- Samples are randomly taken and checked.
- An experienced inspector examines the sample/prototype to make sure that

✓ the raw materials meet the specified standards

✓ Whether development team has clearly communicated the requirements to the manufacturing team.

✓ Whether equipments for mass production is similar to that for making prototypes.

IN PROCESS INSPECTION

- The first products that got out of the line are inspected for conformity.
- If issues are raised at this stage, the factory can immediately take actions and avoid delays.
- In-process products are rarely checked as it takes technician to reliably detect errors on unfinished products.

CLASSIFICATION OF IN-PROCESS INSPECTION

1. Trial run inspection: Tools and machines are checked before operation.
2. First-off inspection: The items produced in the first production run are inspected and examined with respect to specifications.
3. Inspection by self control: Done by operators, controlling operations at different levels of production process.
4. Decentralised inspection: Semi finished goods are inspected either on machines or in the production line.

5. Centralised inspection:

- There can be single inspection unit for whole plant
- Or each section can have inspection unit to inspect the items
- The inspection staff is more experienced and skilled in this case
- Sophisticated and reliable instruments and techniques are use to measure the quality
- Hence centralised inspection is reliable and accurate.

QC INSPECTION IN PRODUCTION

1) Component dominant: Incoming material must be checked for required specifications.
2) Set-up dominant: An operation once set at a level, remains at that level for long. Hence products produced initially if found free from defects and conforming to specifications, then the operation can be cleared for continuous operation.
3) Machine dominant: Operation drift away from initial set-up level as operation proceeds. Hence needs periodic inspection for correcting set up.

4. Operator dominant: A certain portion of job is entirely influenced by operator's skill.

5.Information dominant: All the information including the SOP's, nature of job is given to concerned person.

6.Record dominant: The written records and documentation of every process and test conducted should be maintained.

QC INSPECTION IN ANALYTICAL

In general, these inspections include:

- The specific methodology which will be used to test a new drug product
- A complete assessment of laboratories conformance with GMP'S
- A specific aspect of laboratory operations

- Laboratory records and logs represent a vital source of information that allows a complete overview of the technical ability of the staff and of overall quality control procedures.
- SOPs should be complete and adequate and the operations of the laboratories should conform to the written procedures.
- Specifications and analytical procedures should be suitable and, as applicable, in conformance with application commitments and compendial requirements

- Documents relating to the formulation of the product, synthesis of the bulk drug substance, product specifications, analysis of the product, and others are examined during the review process in headquarter
- Inspections are designed to determine if the data submitted in an application are authentic and accurate and if the procedures listed in the application were actually used to produce the data contained in the application.
- Additionally, they are designed to confirm that plants (including QC laboratory) are in compliance with CGMP regulations.

FDA INSPECTION

- Based on team inspection approach.

- Highly technical and specialised testing equipments, procedures, data manipulations as well scientific laboratory operations will be evaluated.

- The inspection of a laboratory requires the use of observations of the laboratory in operation and of the raw laboratory data to evaluate compliance with CGMP's.

FDA INSPECTION- 4M's

1. MACHINE:

- ✓ Inspection should confirm that preventive maintenance, cleaning, adjustment etc are performed
- ✓ Machine usage, maintenance, calibration logs, repair records should be examined
- ✓ Verify that the equipments were in good working order at the time the batches were analysed.

2. <u>METHOD/PROCESS:</u>

- ✓ Information regarding validation of methods should be carefully evaluated
- ✓ All processes that may cause deviation to a device's specification and all validated process must be monitored and controlled
- ✓ If the process is software controlled, confirm that the software was validated
- ✓ Review the software documents, software validation activities, software change controls and software validation results to confirm that software will meet user need

3. MATERIALS:

- Raw material testing is of utmost importance as it directly affects the quality of final product
- Hence inspection should examine the analysis of materials including purity test, quality, charts etc
- Inspect if the methods for analysing the purity were validated
- The manufacturer must have complete knowledge of manufacturing process and the potential impurities that may appear in materials.
- These impurities cannot be evaluated by without a suitable method and one that has been validated

4. MAN:

- Verify that personnel have been qualified to implement validated processes or
- appropriately trained to implement processes which yield results that can be fully verified
- Confirm that the employees have complete knowledge of the devices, processes
- Confirm that employees are aware of the device defects that may occur as a result of improper performances
- Confirm that the employees conducting QC tests are aware of the defects and errors that may be encountered while performing their responsibilities

FINAL INSPECTION

- It is also known pre-shipment inspection.
- This is the most popular type of QC inspection for importers.
- It takes place once all the products are finished and ready for shipment.
- The samples are drawn in a random manner and thus can be representative of the whole batch.

STATISTICAL QUALITY CONTROL

- It is a technique for controlling quality of product using a set of statistical tools

- It involves two elements:

  - Statistical process control: This summarizes collection of data , makes use of control charts.

  - Acceptance sampling

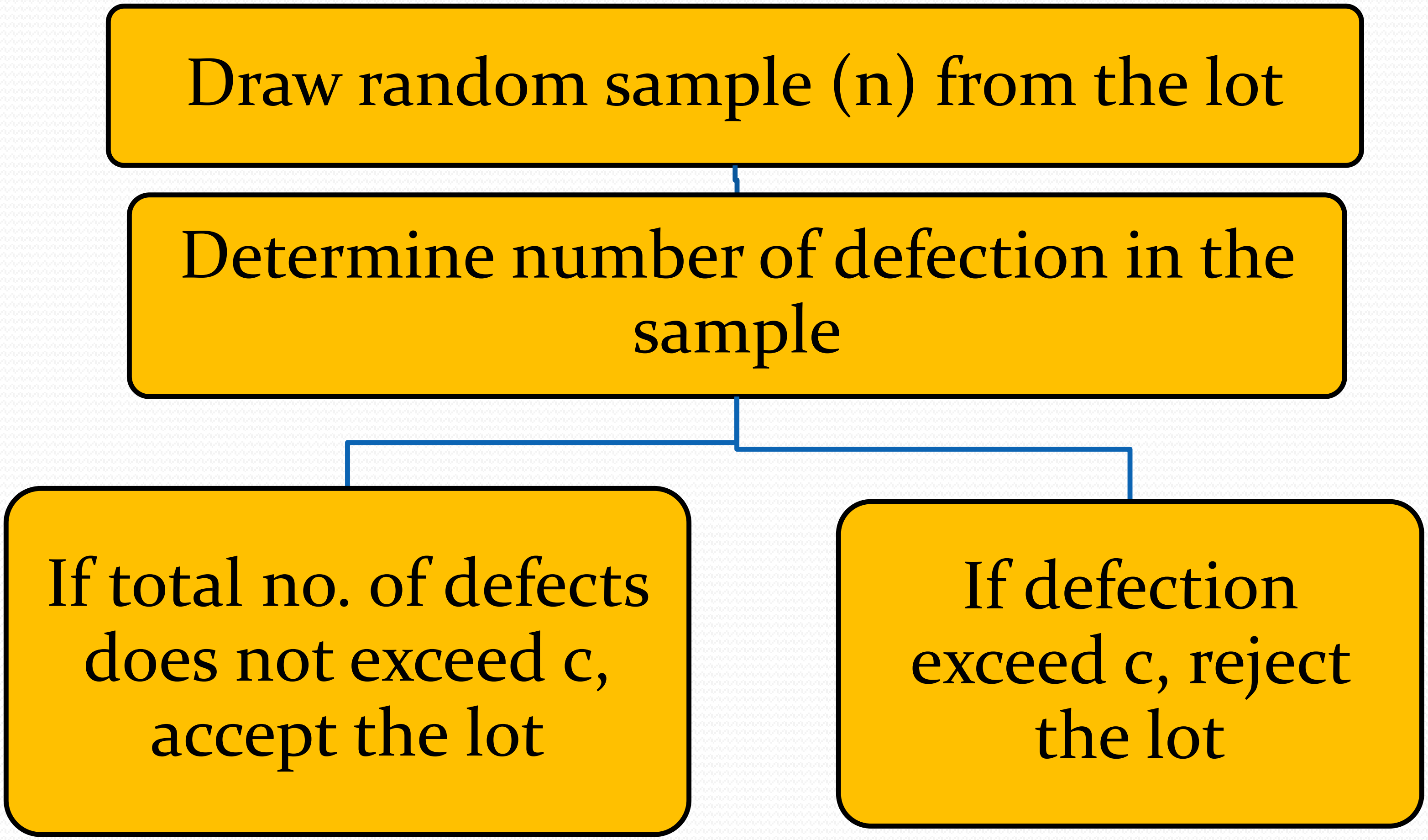
CONTROL CHARTS

- Primary purpose of control charts is to indicate when production processes might have changed sufficiently to affect product quality.
- If the indication is that product quality has deteriorated, corrective is taken.
- Compare attributes (No. of defectives in a sample)or variables (characteristics that can be measured on a continuous scale (weight, length, etc.) of the sample with that of the standard

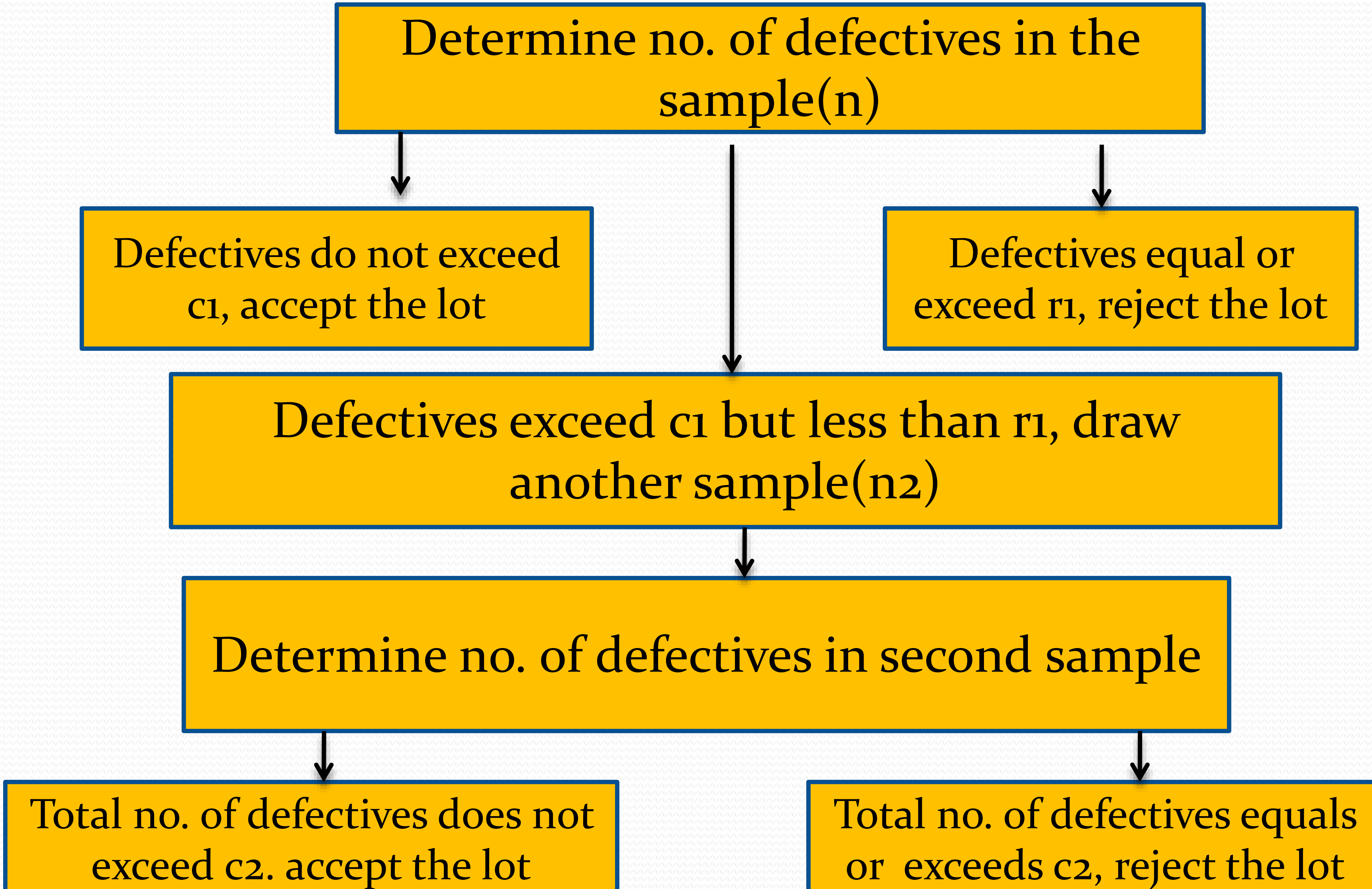
ACCEPTANCE SAMPLING OR SAMPLING INSPECTION

- It is the process of evaluating portion of the product material in a lot for the purpose of accepting or rejecting the lot as either conforming or not conforming to quality specifications.
- The acceptance plan identifies the:
  - Size of samples, n
  - Type of samples
  - Decision criterion, c, used to either accept or reject the lot
- Samples may be either single, double, or sequential.

SINGLE SAMPLING PLAN



DOUBLE SAMPLING PLAN



SEQUENTIAL/MULTIPLE SAMPLING

- This is extension of double sampling plan
- At each stage of sampling the cumulated results are analysed to take decision of accepting/rejecting the lot
- If no final decision can be taken at anyy stage, then another sample is drawn to take further decision.

QUALITY AUDIT

- ISO defines audit as systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these are implemented effectively and are suitable to achieve objectives.
- It checks if quality system and procedures are

✓ Free from congenital defects

✓ Are capable of achieving and maintaining standards of quality chosen by enterprise or costumers

✓ being adhered to and compiled with, in day to day work.

QUALITY AUDIT AND FOLLOW UP

- Prior to writing auditing report, auditor explains the observations to auditee
- Corrective actions to be taken are proposed
- Audit report are written in standard format which contain area audited, dates of audit, persons contacted, commendable features and recommendations.
- The report must contain status of implementation of pending corrective measures as per previous audit.

QC INSPECTION IN DISTRIBUTION AND STORAGE

GMP summarises following principles with respect to distribution:

- Only authorised products are distributed
- Premises are suitable for their intended use and kept on good sanitary condition
- All products are received, stored and handled carefully
- All operations are performed according to written procedure, supervised and documented
- Adequate provision exist to handle complaints, recalls and return goods

- Storage: Warehouse should be clean, inaccessible for unauthorised persons, temperature and humidity control, adequate shelving, free from insects and vermin.

- Special storage:

✓ Availability of cold room/refrigerator for vaccines and biological products

✓ Special storage areas for controlled drugs and other prescription drugs

✓ Suitable and secure storage facility for controlled drugs and poisons

INSPECTION OF ESTABLISHMENT INSPECTION OF THE DRUG DISTRIBUTION CHAIN

- Objectives: To ensure-

✓ Protection of patients and members of the public from malpractice by distributors and supplier of drugs

✓ Adherence to the drug laws and regulations governing compounding, distribution, importation, export and storage of drugs.

✓ High ethical and professional standards of pharmaceutical practice.

INSPECTION AND NARCOTIC SECTION

Functions of Narcotic Drug Unit:

- Controls the use of narcotic and pyschotropic drug substances
- Issue importation and trade license for narcotic drugs
- Prepare registry book and template necessary to control use of narcotic substances and distribute them among the concerned authority
- Prepare annual statistic on narcotic and pyschotropic drug substances.

- Production area of narcotic drugs should be isolated from other production area
- The areas should be such that they preclude the drugs falling into hands of unauthorized persons
- The rooms should be equipped with security alarms
- Room should have metal door and be lockable and non passsable
- The room shall be without windows and separated from surrounding rooms by partitions
- Separate record of all activities related to these drugs must be maintained.

PENICILLIN DRUGS

- Dedicated, self contained premises, facilities and equipments must be used
- Dust generating operations should maintain relatively negative pressure
- The exhaust air should be decontaminated as required
- Production area should be ventilated and temperature, humidity and filtration should be controlled
- Separate storage area should be maintained and the area must be clearly marked
- Its access is restricted to authorised persons
- QC labs should be designed to suit intended use and avoid mix-ups
- There should be adequate space for sample handling, storage of retention and stability samples and storage of records.

HORMONAL PRODUCTS

- The premise should be designed to facilitate cleaning and decontamination
- Various rooms should have interlock mechanism or other system to prevent opening of more than one door at a time
- Supply of safe breathing air should be provided to prevent the operate from inhaling air from the facility
- This can be done by central air supply system or self contained breathing apparatus
- Alarm system for: main air supply failure, temperature out of specification(oos), humidity oos, CO_2 oos, CO oos and SO_2 oos.

CONCLUSION

- Quality is a never ending prospect…..
- Increase in quality, increases production, decreases cost and increases profits
- Thus quality control and inspection form an integral part of a company's management.

IS : 2386 (Part IV) - 1963

(Reaffirmed 1990)

Indian Standard

METHODS OF TEST FOR AGGREGATES FOR CONCRETE

PART IV MECHANICAL PROPERTIES

Tenth Reprint MARCH 1997

(Incorporating Amendment No. 1)

UDC 691.322 : 620.17

BUREAU OF INDIAN STANDARDS

MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG

NEW DELHI 110002

Gr 7

March 1964

Indian Standard

METHODS OF TEST FOR AGGREGATES FOR CONCRETE

PART IV MECHANICAL PROPERTIES

(*Continued on page 2*)

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(*Continued from page 1*)

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Shri K. K. Nambiar	The Concrete Association of India, Bombay
Shri C. L. N. Iyengar (*Alternate*)	
Dr M. L. Puri	Central Road Research Institute (CSIR), New Delhi
Prof G. S. Ramaswamy	Central Building Research Institute (CSIR), Roorkee
Shri K. Siva Prasad (*Alternate*)	
Shri T. N. S. Rao	Gammon India Ltd, Bombay
Shri S. R. Pinheiro (*Alternate*)	
Superintending Engineer, 2nd Circle	Central Public Works Department
Shri O. P. Goel (*Alternate*)	
Shri J. M. Trehan	Roads Wing, Ministry of Transport & Communications
Shri R. P. Sikka (*Alternate*)	
Shri H. T. Yan	Braithwaite Burn & Jessop Construction Co Ltd, Calcutta

Indian Standard

METHODS OF TEST FOR AGGREGATES FOR CONCRETE

PART IV MECHANICAL PROPERTIES

0. FOREWORD

0.1 This Indian Standard (Part IV) was adopted by the Indian Standards Institution on 24 September 1963, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Building Division Council.

0.2 One of the major contributing factors to the quality of concrete is the quality of aggregates used therein. The test methods given in this standard are intended to assist in assessing the quality of aggregates. In a given situation, for a particular aggregate, it may not be necessary to assess all the qualities and therefore it is necessary to determine beforehand the purpose for which a concrete is being used and the qualities of the aggregate which require to be assessed. Accordingly, the relevant test methods may be chosen from amongst the various tests covered in this standard. For the convenience of the users, the test methods are grouped into the following eight parts of Indian Standard Methods of Test for Aggregates for Concrete (IS : 2386-1963):

Part I	Particle Size and Shape
Part II	Estimation of Deleterious Materials and Organic Impurities
Part III	Specific Gravity, Density, Voids, Absorption and Bulking
Part IV	Mechanical Properties
Part V	Soundness
Part VI	Measuring Mortar Making Properties of Fine Aggregate
Part VII	Alkali Aggregate Reactivity
Part VIII	Petrographic Examination

0.3 The Sectional Committee responsible for the preparation of this standard has taken into consideration the views of concrete specialists, testing authorities, consumers and technologists and has related the standard to the practices followed in this country. Further, the need for international co-ordination among standards prevailing in different countries of the world has also been recognized. These considerations led the Sectional Committee to derive assistance from the published standards and publications of the following organizations:

British Standards Institution

American Society for Testing and Materials

0.4 Wherever a reference to any Indian Standard appears in these methods, it shall be taken as a reference to its latest version.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960 Rules for Rounding Off Numerical Values (*Revised*). The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

0.6 This standard is intended chiefly to cover the technical provisions relating to testing of aggregates for concrete, and it does not include all the necessary provisions of a contract.

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1. SCOPE

1.1 This standard (Part IV) covers the following tests for aggregates for concrete:

a) Determination of Aggregate Crushing Value,

b) Determination of the 10 percent Fines Value,

c) Determination of Aggregate Impact Value,

d) Determination of Aggregate Abrasion Value,

e) Determination of the Polished Stone Value, and

f) Determination of Crushing Strength.

2. DETERMINATION OF AGGREGATE CRUSHING VALUE

2.1 Object — This method of test covers the procedure for determining the aggregate crushing value of coarse aggregate.

NOTE 1 — The 'aggregate crushing value' gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. With aggregate of 'aggregate crushing value' 30 or higher, the result may be anomalous and in such cases the 'ten percent fines value' should be determined instead.

NOTE 2 — The standard aggregate crushing test shall be made on aggregate passing a 12·5-mm IS Sieve and retained on a 10-mm IS Sieve. If required, or if the standard size is not available, other sizes up to 25 mm may be tested but owing to the non-homogeneity of aggregates the results will not be comparable with those obtained in the standard (*see* Note 1 under **2.6**). Smaller sizes may also be tested (*see* Note 2 under **2.6**).

2.2 Apparatus — The apparatus for the standard test shall consist of the following:

a) A 15-cm diameter open-ended steel cylinder, with plunger and base-plate, of the general form and dimensions shown in Fig. 1. The surfaces in contact with the aggregate shall be machined and case-hardened or otherwise treated so as to have a diamond (VH) pyramid hardness number of not less than 650 VH.

b) A straight metal tamping rod of circular cross-section 16 mm in diameter and 45 to 60 cm long, rounded at one end.

c) A balance of capacity 3 kg, readable and accurate to one gram.

d) IS Sieves of sizes 12·5, 10 and 2·36 mm.

e) A compression testing machine capable of applying a load of 40 tonnes and which can be operated to give a uniform rate of loading so that the maximum load is reached in 10 minutes. The machine may be used with or without a spherical seating.

f) For measuring the sample, cylindrical metal measure of sufficient rigidity to retain its form under rough usage and of the following internal dimensions:

Diameter	11·5 cm
Height	18·0 cm

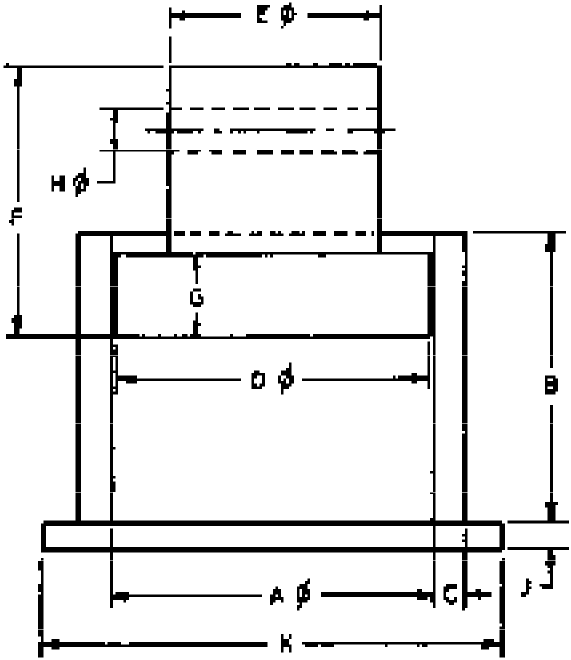
2.3 Preparation of Test Sample — The material for the standard test shall consist of aggregate passing a 12·5-mm IS Sieve and retained on a 10-mm IS Sieve, and shall be thoroughly separated on these sieves before testing. For other sizes, the material shall be separated on the appropriate sieves given in Table 1.

TABLE 1 DETAILS OF AGGREGATE CRUSHING TEST FOR NON-STANDARD SIZES OF AGGREGATE

(*Clauses* 2.3 *and* 2.4.2)

Nominal Sizes (IS Sieves)		Diameter of Cylinder to be Used	Size of IS Sieve for Separating Fines
Passing through	Retained on		
mm	mm	cm	
25	20	15·0	4·75 mm
20	12·5	15·0	3·35 mm
10	6·3	15·0 or 7·5	1·70 mm
6·3	4·75	15·0 or 7·5	1·18 mm
4·75	3·35	15·0 or 7·5	850 microns
3·35	2·36	15·0 or 7·5	600 microns

NOTE — About 6·5 kg of natural aggregate is required to provide the two test samples for the 15-cm cylinder, or about 1 kg for the 7·5-cm cylinder.



KEY TO DIMENSIONS			
Letter	Dimension for	150-mm Cylinder	75-mm Cylinder
	Cylinder	mm	mm
A	Internal diameter	152.0 ± 0.5	77.0 ± 0.5
B	Height	130 to 140	70 to 80
C	Wall thickness	≮ 16	≮ 8
	Plunger		
D	Diameter of piston	150 ± 0.5	75.0 ± 0.5
E	Diameter of stem	100 to 150	50 to 75
F	Height	100 to 115	65 to 75
G	Depth of piston	≮ 25	≮ 20
H	Diameter of hole (nominal)	20	10
	Base-Plate		
J	Thickness (nominal)	6.3	6.3
K	Side length of square	200 to 250	110 to 115

FIG. 1 PRINCIPAL DIMENSIONS OF APPARATUS FOR AGGREGATE CRUSHING TEST

2.3.1 The aggregate shall be tested in a surface-dry condition. If dried by heating, the period of drying shall not exceed four hours, the temperature shall be 100° to 110°C and the aggregate shall be cooled to room temperature before testing.

2.3.2 The quantity of aggregate shall be such that the depth of material in the cylinder, after tamping as described in **2.3.3**, shall be 10 cm.

2.3.3 The appropriate quantity may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth, each layer being tamped 25 times with the rounded end of the tamping rod and finally levelled off, using the tamping rod as a straight-edge.

2.3.4 The weight of material comprising the test sample shall be determined (Weight *A*) and the same weight of sample shall be taken for the repeat test.

2.4 Test Procedure — The cylinder of the test apparatus shall be put in position on the base-plate and the test sample added in thirds, each third being subjected to 25 strokes from the tamping rod. The surface of the aggregate shall be carefully levelled and the plunger inserted so that it rests horizontally on this surface, care being taken to ensure that the plunger does not jam in the cylinder.

2.4.1 The apparatus, with the test sample and plunger in position, shall then be placed between the platens of the testing machine and loaded at as uniform a rate as possible so that the total load is reached in 10 minutes. The total load shall be 40 tonnes.

2.4.2 The load shall be released and the whole of the material removed from the cylinder and sieved on a 2·36-mm IS Sieve for the standard test, or the appropriate sieve given in Table I. The fraction passing the sieve shall be weighed (Weight *B*).

In all of these operations, care shall be taken to avoid loss of the fines. Two tests shall be made.

2.5 Calculation — The ratio of the weight of fines formed to the total sample weight in each test shall be expressed as a percentage, the result being recorded to the first decimal place:

$$\text{Aggregate crushing value} = \frac{B}{A} \times 100$$

where

B = weight of fraction passing the appropriate sieve, and

A = weight of surface-dry sample.

2.6 Reporting of Results — The mean of the two results shall be reported to the nearest whole number as the 'aggregate crushing value' of the size of material tested, which shall be stated.

NOTE 1 — *Aggregate larger than 12.5 mm* — In general, the larger sizes of aggregate will give a higher aggregate crushing value, but the relationship between the values obtained with different sizes will vary from one aggregate to another. Particular care shall be taken with larger sizes of aggregate to ensure that the plunger does not jam in the cylinder. However, for such aggregate, a 7.5-cm diameter cylinder may be used, and this has been found to give slightly higher results than the standard cylinder, so that the errors are compensating.

NOTE 2 — *Aggregate smaller than 10 mm* — In general, the smaller sizes of aggregate will give a lower aggregate crushing value, but the relationship between the values obtained with different sizes will vary from one aggregate to another.

For testing aggregate smaller than 10 mm:

a) The form and dimensions of the 7·5-cm cylinder shall be as shown in Fig. 1 and the surfaces shall be as for the standard cylinder.

b) The tamping rod shall be 8 mm in diameter and 30 cm long, rounded at one end.

c) The balance shall be of capacity 500 g, readable and accurate to 0·2 g.

d) The IS Sieves shall be as given in Table I.

e) The compression testing machine shall be capable of applying a load of 10 tonnes uniformly in 10 minutes.

f) The metal measure shall be 6 cm in diameter and 9 cm in height.

g) The depth of material in the 7·5-cm cylinder shall be 5 cm after tamping.

h) The total load applied in 10 minutes shall be 10 tonnes.

Otherwise, the provisions of the standard test, as set out in **2.2** to **2.6** shall apply.

3. DETERMINATION OF TEN PERCENT FINES VALUE

3.1 Object — This method of test covers the procedure for determining the 'ten percent fines' value of coarse aggregates.

NOTE — The 'ten percent fines' value gives a measure of the resistance of an aggregate to crushing, that is, applicable to all aggregates.

3.2 Apparatus — The apparatus for the standard test shall consist of the following:

a) A 15-cm diameter open-ended steel cylinder, with plunger and base-plate, of the general form and dimensions shown in Fig. 1. The surfaces in contact with the aggregate shall be machined and case-hardened or otherwise treated so as to have a diamond (VH) pyramid hardness number of not less than 650 VH.

b) A straight metal tamping rod of circular cross-section 16 mm in diameter and 45 to 60 cm long, rounded at one end.

c) A balance of capacity 3 kg, readable and accurate to one gram.

d) The IS Sieves of sizes 12·5, 10 and 2·36 mm.

e) A compression testing machine capable of applying a load of 50 tonnes and which can be operated to give a uniform rate of loading so that the maximum load in any test is reached in 10 minutes. This load may vary from 0·5 to 50 tonnes.

f) For measuring the sample, a cylindrical metal measure of sufficient rigidity to retain its form under rough usage and of the following internal dimensions:

Diameter 11·5 cm

Height 18·0 cm

g) Means of measuring the reduction in the distance between the platens of the testing machine to the nearest one millimetre during the test (for example, a dial gauge).

3.3 Preparation of Test Sample — The material for the test shall consist of aggregate passing a 12·5-mm IS Sieve and retained on a 10-mm IS Sieve and shall be thoroughly separated on these sieves before testing.

3.3.1 The aggregate shall be tested in a surface-dry condition. If dried by heating, the period of drying shall not exceed four hours, the temperature shall be 100 to 110°C and the aggregate shall be cooled to room temperature before testing.

3.3.2 The quantity of aggregate shall be such that the depth of material in the cylinder, after tamping as described in **3.3.2.1**, shall be 10 cm.

3.3.2.1 The appropriate quantity may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth, each layer being tamped 25 times with the tamping rod and finally levelled off, using the tamping rod as a straight-edge, care being taken in the case of weaker materials not to break the particles.

3.3.3 The weight of material comprising the test sample shall be determined (Weight *A*) and the same weight of sample shall be taken for the repeat test.

NOTE — About 6·5 kg of natural aggregate is required to provide the two test samples. Less of light-weight aggregate is required.

3.4 Test Procedure — The cylinder of the test apparatus shall be put in position on the base-plate and the test sample added in thirds, each third being subjected to 25 strokes from the tamping rod, care being taken in the case of weak materials not to break the particles. The surface of the aggregate shall be carefully levelled and the plunger inserted so that it rests horizontally on this surface, care being taken to ensure that the plunger does not jam in the cylinder.

3.4.1 The apparatus, with the test sample and plunger in position, shall then be placed in the compression testing machine. The load shall be applied at a uniform rate so as to cause a total penetration of the plunger in 10 minutes of about:

15·0 mm for rounded or partially rounded aggregates (for example, uncrushed gravels),

20·0 mm for normal crushed aggregates, and

24·0 mm for honeycombed aggregates (for example, expanded shales and slags).

These figures may be varied according to the extent of the rounding or honeycombing.

3.4.2 After reaching the required maximum penetration, the load shall be released and the whole of the material removed from the cylinder and sieved on a 2·36-mm IS Sieve. The fines passing the sieve shall be weighed, and this weight expressed as a percentage of the weight of the test sample. Normally, this percentage will fall within the range 7·5 to 12·5, but if it does not, a further test shall be made at a load adjusted as seems appropriate to bring the percentage fines within the range of 7·5 to 12·5.

NOTE — The formula given in **3.5** may be used for calculating the load required.

3.4.3 A repeat test shall be made at the load that gives a percentage fines within the range 7·5 to 12·5.

3.5 Calculations — The mean percentage fines from the two tests at this load shall be used in the following formula to calculate the load required to give 10 percent fines:

$$\text{Load required for 10 percent fines} = \frac{14 \times x}{y + 4}$$

where

x — load in tonnes, and

y — mean percentage fines from two tests at x tonnes load.

3.6 Reporting of Results — The load required to produce 10 percent fines shall be reported to the nearest whole number for loads of 10 tonnes or more, the nearest 0·5 tonne for loads of less than 10 tonnes.

4. DETERMINATION OF AGGREGATE IMPACT VALUE

4.1 Object — This method of test covers the procedure for determining the aggregate impact value of coarse aggregate.

NOTE — The 'aggregate impact value' gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from its resistance to a slow compressive load.

4.2 Apparatus — The apparatus shall consist of the following:

a) An impact testing machine of the general form shown in Fig. 2 and complying with the following:

1) Total weight not more than 60 kg nor less than 45 kg.

2) The machine shall have a metal base weighing between 22 and 30 kg with a plane lower surface of not less than 30 cm diameter, and shall be supported on a level and plane concrete or stone block or floor at least 45 cm thick. The machine shall be prevented from rocking either by fixing it to the block or floor or by supporting it on a level and plane metal plate cast into the surface of the block or floor.

3) A cylindrical steel cup of internal dimensions:

Diameter	102 mm
Depth	50 mm

and not less than 6·3 mm thick with its inner surface case-hardened, that can be rigidly fastened at the centre of the base and easily removed for emptying.

4) A metal tup or hammer weighing 13·5 to 14·0 kg, the lower end of which shall be cylindrical in shape, 100·0 mm in diameter and 5 cm long, with a 2-mm chamfer at the lower edge, and case-hardened. The hammer shall slide freely between vertical guides so arranged that the lower (cylindrical) part of the hammer is above and concentric with the cup.

5) Means for raising the hammer and allowing it to fall freely between the vertical guides from a height of 380 ± 5·0 mm on to the test sample in the cup, and means for adjusting the height of fall within 5 mm.

6) Means for supporting the hammer whilst fastening or removing the cup.

NOTE — Some means for automatically recording the number of blows is desirable.

b) *Sieves* — The IS Sieves of sizes 12·5, 10 and 2·36 mm.

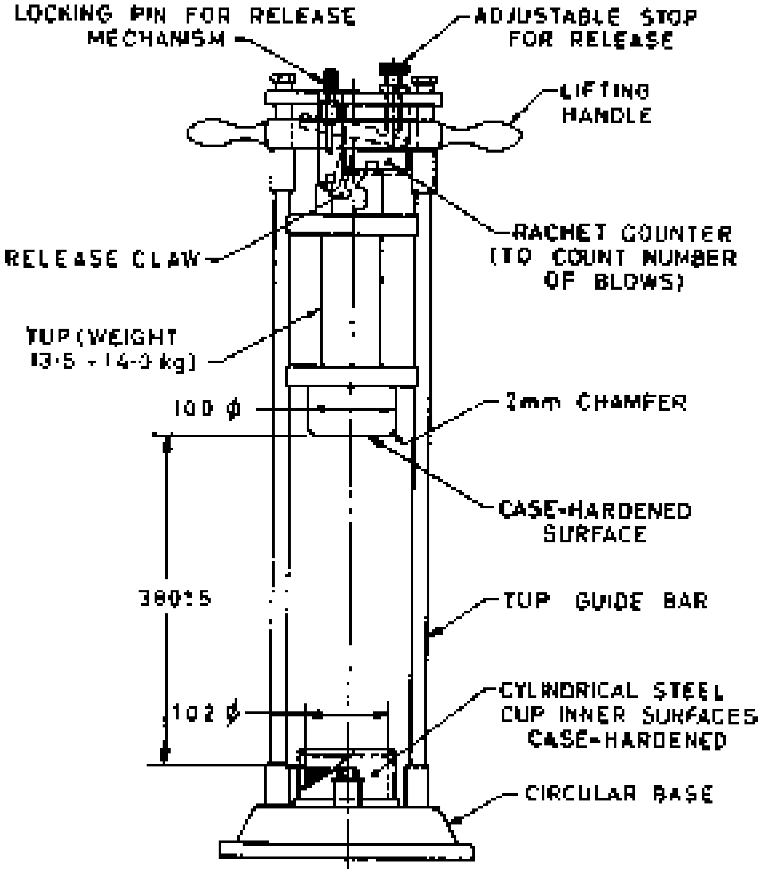
c) *Measure* — A cylindrical metal measure, tared to the nearest gram, of sufficient rigidity to retain its form under rough usage, and of the following internal dimensions:

Diameter	75 mm
Depth	50 mm

d) *Tamping Rod* — A straight metal tamping rod of circular cross-section 10 mm in diameter and 230 mm long, rounded at one end.

e) *Balance* — A balance of capacity not less than 500 g, readable and accurate to 0·1 g.

f) *Oven* — A well-ventilated oven, thermostatically controlled to maintain a temperature of 100° to 110°C.



All dimensions in millimetres.

FIG. 7 AGGREGATE IMPACT TEST MACHINE

4.3 Preparation of the Test Sample

4.3.1 The test sample shall consist of aggregate the whole of which passes a 12·5-mm IS Sieve and is retained on a 10-mm IS Sieve. The aggregate comprising the test sample shall be dried in an oven for a period of four hours at a temperature of 100° to 110°C and cooled.

4.3.2 The measure shall be filled about one-third full with the aggregate and tamped with 25 strokes of the rounded end of the tamping rod.

further similar quantity of aggregate shall be added and a further tamping of 25 strokes given. The measure shall finally be filled to overflowing, tamped 25 times and the surplus aggregate struck off, using the tamping rod as a straight-edge. The net weight of aggregate in the measure shall be determined to the nearest gram (Weight A) and this weight of aggregate shall be used for the duplicate test on the same material.

4.4 Test Procedure

4.4.1 The impact machine shall rest without wedging or packing upon the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical.

4.4.2 The cup shall be fixed firmly in position on the base of the machine and the whole of the test sample placed in it and compacted by a single tamping of 25 strokes of the tamping rod.

4.4.3 The hammer shall be raised until its lower face is 380 mm above the upper surface of the aggregate in the cup, and allowed to fall freely on to the aggregate. The test sample shall be subjected to a total of 15 such blows each being delivered at an interval of not less than one second.

4.4.4 The crushed aggregate shall then be removed from the cup and the whole of it sieved on the 2·36-mm IS Sieve until no further significant amount passes in one minute. The fraction passing the sieve shall be weighed to an accuracy of 0·1 g (Weight B). The fraction retained on the sieve shall also be weighed (Weight C) and, if the total weight ($B + C$) is less than the initial weight (Weight A) by more than one gram, the result shall be discarded and a fresh test made. Two tests shall be made.

4.5 Calculations — The ratio of the weight of fines formed to the total sample weight in each test shall be expressed as a percentage, the result being recorded to the first decimal place:

$$\text{Aggregate impact value} = \frac{B}{A} \times 100$$

where

B = weight of fraction passing 2·36-mm IS Sieve, and

A = weight of oven-dried sample.

4.6 Reporting of Results — The mean of the two results shall be reported to the nearest whole number as the aggregate impact value of the tested material.

5. DETERMINATION OF AGGREGATE ABRASION VALUE

5.1 Object — This test covers the following two methods of determining the abrasion value of coarse aggregate:

a) By the use of Deval machine (*see* **5.2**), and

b) By the use of Los Angeles machine (*see* **5.3**).

NOTE — Wherever possible, method (b) should be preferred to method (a).

5.2 Test for Abrasion of Coarse Aggregates by the Use of Deval Machine

5.2.1 *Apparatus* — The apparatus shall consist of the following:

a) *Deval machine* — The Deval abrasion testing machine shall consist of one or more hollow cast iron cylinders closed at one end and furnished with a tightly fitting iron cover at the other. The inside diameter of the cylinders shall be 20 cm and depth 34 cm. The cylinders shall be mounted on a shaft at an angle of 30 degrees with the axis of rotation of the shaft.

b) *Sieve* — The 1·70-mm IS Sieve having square holes.

5.2.2 *Abrasive Charge* — The abrasive charge shall consist of 6 cast iron spheres or steel spheres approximately 48 mm in diameter, each weighing between 390 and 445 g.

5.2.2.1 An abrasive charge of 6 spheres weighing 2 500 ± 10 g shall be used with each test sample.

5.2.3 *Grading* — The coarse aggregate shall be separated by sieving in accordance with the sieve analysis specified in Part I of this standard into the various sizes required for grading the test sample according to one of the gradings specified in **5.2.4**. The material thus separated into various sizes shall be washed and dried.

5.2.4 *Test Sample* — The test sample shall consist of dry coarse aggregate made up of percentages of the various sizes conforming to one of the gradings shown below. The grading used shall be that most nearly representing the coarse aggregate furnished for the work.

Grading	*Passing IS Sieve*	*Retained on IS Sieve*	*Percentage of Sample*
A	20-mm	12·5-mm	25
	25-mm	20-mm	25
	40-mm	25-mm	25
	50-mm	40-mm	25
B	20-mm	12·5-mm	25
	25-mm	20-mm	25
	40-mm	25-mm	50
C	20-mm	12·5-mm	50
	25-mm	20-mm	50
D	12·5-mm	4·75-mm	50
	20-mm	12·5-mm	50
E	10-mm	4·75-mm	50
	12·5-mm	10-mm	50

5.2.4.1 The weight of the test sample shall depend upon its average specific gravity and shall be as follows:

Range in Specific Gravity	*Weight of Sample* g
Over 2·8	5 500
2·4 to 2·8	5 000
2·2 to 2·39	4 500
Less than 2·2	4 000

5.2.4.2 When the coarse aggregate furnished for the work contains as much as 25 percent of material finer than 12·5 mm but is of such size that either grading A, B or C would be used for the abrasion test, a second abrasion test shall be made, using grading D, if in the opinion of the engineer, the particles less than 12·5 mm in size are not at least equal in hardness to those particles 12·5 mm or over in size.

5.2.4.3 *Crushed gravel* — In the case of crushed gravel, the test sample shall contain crushed fragments so as to be representative of the gravel furnished for the work and shall be prepared in accordance with **5.2.3**, **5.2.4.1** and **5.2.4.2**.

NOTE — For the purpose of this test, a crushed gravel fragment may be considered as a fragment of gravel having at least one fractured face.

5.2.5 *Procedure* — The test sample and the abrasive charge shall be placed in the Deval abrasion testing machine and the machine rotated for 10 000 revolutions at a speed of 30 to 33 rev/min. At the completion of the test, the material shall be removed from the machine and sieved on a 1·70-mm IS Sieve. The material retained on the sieve shall be washed, dried, and accurately weighed to the nearest gram.

5.2.6 *Calculation*

5.2.6.1 *Percentage of wear* — The loss by abrasion shall be considered as the difference between the original weight of the test sample and the weight of the material retained on the 1·70-mm IS Sieve, expressed as percentage of the original weight of the test sample.

5.2.6.2 *Crushed gravel* — In the case of crushed gravel, the percentage by weight of crushed fragments shall be determined, and the permissible percentage of wear which shall be calculated as follows:

$$W = \frac{AL + (100 - A)L'}{100}$$

where

W = permissible percentage of wear,

A = percentage of uncrushed fragments,

L = maximum percentage of wear permitted by the specifications for gravel consisting entirely of uncrushed fragments,

$100 - A$ = percentage of crushed fragments, and

L' = maximum percentage of wear permitted by the specifications for gravel consisting entirely of crushed fragments.

5.2.7 *Reporting of Results* — The report shall include the following:

a) Percentage of wear,

b) Percentage of crushed fragments in the test sample, and

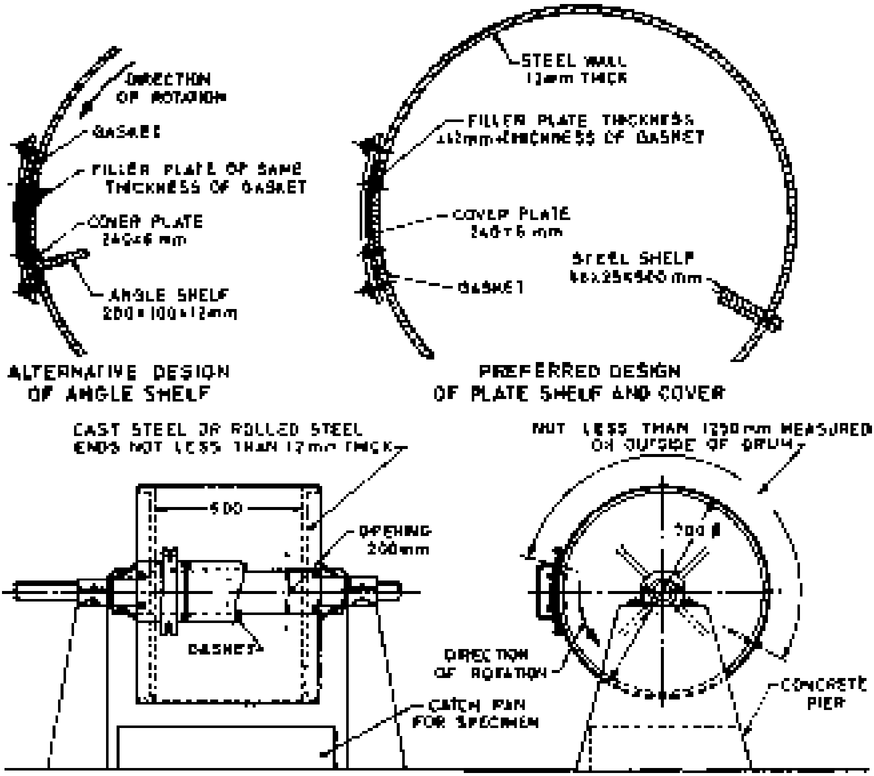
c) Weight and grading of the test sample.

5.3 Test for Abrasion of Coarse Aggregates by the Use of Los Angeles Machine

5.3.1 *Apparatus* — The apparatus shall consist of the following:

a) *Los Angeles machine* — The Los Angeles abrasion testing machine, conforming in all its essential characteristics to the design shown in Fig. 3, shall be used. The machine shall consist of a hollow steel cylinder, closed at both ends, having an inside diameter of 700 mm and an inside length of 500 mm. The cylinder shall be mounted on stub shafts attached to the ends of the cylinders but not entering it, and shall be mounted in such a manner that it may be rotated about its axis in a horizontal position. An opening in the cylinder shall be provided for the introduction of the test sample. The opening shall be closed dust-tight with a removable cover bolted in place. The cover shall be so designed as to maintain the cylindrical contour of the interior surface unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test. A removable steel shelf, projecting radially 88 mm into the cylinder and extending its full length, shall be mounted along one element of the interior surface of the cylinder. The shelf shall be of such thickness and so mounted, by bolts or other approved means, as to be firm and rigid. The position of the shelf shall be such that the distance from the shelf to the opening, measured along the circumference of the cylinder in the direction of rotation, shall be not less than 1 250 mm.

NOTE — The use of the shelf of wear-resistant steel, rectangular in cross-section and mounted independently of the cover, is preferred. However, a shelf consisting of a section of rolled angle, properly mounted on the inside of the cover plate, may be used, provided the direction of rotation is such that the charge will be caught on the outside face of the angle.



NOTE 1 — Shaft bearing will be mounted on concrete piers or other rigid supports.

NOTE 2 — Suggested horse power for motor is not less than one.

All dimensions in millimetres.

FIG. 3 LOS ANGELES ABRASION TESTING MACHINE

b) *Sieves* — The 1·70-mm IS Sieve.

5.3.2 *Abrasive Charge* — The abrasive charge shall consist of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 and 445 g.

5.3.2.1 The abrasive charge, depending upon the grading of the test sample as described in 5.3.3 shall be as follows:

Grading	*Number of Spheres*	*Weight of Charge* g
A	12	5 000 ± 25
B	11	4 584 ± 25
C	8	3 330 ± 20
D	6	2 500 ± 15
E	12	5 000 ± 25
F	12	5 000 ± 25
G	12	5 000 ± 25

5.3.3 *Test Sample* — The test sample shall consist of clean aggregate which has been dried in an oven at 105° to 110°C to substantially constant weight and shall conform to one of the gradings shown in Table II. The grading or gradings used shall be those most nearly representing the aggregate furnished for the work.

NOTE — It is recognized that different specification limits may be required for gradings E, F and G than for A, B, C and D. It is urged that investigations be conducted to determine the relationship, if any, which exists between results for these coarse gradings using the 10 000 g samples and the finer ones using the 5 000 g samples.

TABLE II GRADINGS OF TEST SAMPLES

(*Clause* 5.3.3)

Sieve Size (Square Hole)		Weight in g of Test Sample for Grade						
Passing	Retained on	A	B	C	D	E	F	G
mm	mm							
80	63	—	—	—	—	2 500*	—	—
63	50	—	—	—	—	2 500*	—	—
50	40	—	—	—	—	5 000*	5 000*	—
40	25	1 250	—	—	—	—	5 000*	5 000*
25	20	1 250	—	—	—	—	—	5 000*
20	12·5	1 250	2 500	—	—	—	—	—
12·5	10	1 250	2 500	—	—	—	—	—
10	6·3	—	—	2 500	—	—	—	—
6·3	4·75	—	—	2 500	—	—	—	—
4·75	2·36	—	—	—	5 000	—	—	—

*Tolerance of ±2 percent permitted.

5.3.4 *Procedure*

5.3.4.1 The test sample and the abrasive charge shall be placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of 20 to 33 rev/min. For gradings A, B, C and D, the machine shall be rotated for 500 revolutions; for gradings E, F and G, it shall be rotated for 1 000 revolutions. The machine shall be so driven and so counter-balanced as to maintain a substantially uniform peripheral speed. If an angle is used as the shelf, the machine shall be rotated in such a direction that the charge is caught on the outside surface of the angle. At the completion of the test, the material shall be discharged from the machine and a preliminary separation of the sample made on a sieve coarser than the 1·70-mm IS Sieve. The finer portion shall then be sieved on a 1·70-mm IS Sieve in the manner described in **2.3** of Part I of this standard.

5.3.4.2 The material coarser than the 1·70-mm IS Sieve shall be washed dried in an oven at 105 to 110°C to a substantially constant weight, and accurately weighed to the nearest gram.

NOTE — Attention is called to the fact that valuable information concerning the uniformity of the sample under test may be obtained by determining the loss after 100 revolutions. When this determination is made, care should be taken to avoid loss of any part of the sample; the entire sample, including the dust of abrasion, shall be returned to the testing machine for the completion of the test.

5.3.5 *Reporting of Results* — The difference between the original weight and the final weight of the test sample shall be expressed as a percentage of the original weight of the test sample. This value shall be reported as the percentage of wear.

6. DETERMINATION OF THE POLISHED-STONE VALUE

6.1 General — The object of this test is to determine the polished-stone value which gives a relative measure of the extent to which different types of roadstone in the wearing surface will polish under traffic. The results of this test are used for comparative purposes only; limits cannot, at present, be specified for the polished-stone value in any particular set of circumstances. Where the wearing surface of a road consists largely of stone, the state of polish of the stone will be the dominant factor but other factors also affect the resistance of the surface to skidding.

The test is in two parts:

a) Samples of stone are subjected to an accelerated polishing action in a special machine.

b) The state of polish reached by each sample is measured by means of a suitable friction test and is expressed as the 'polished-stone value'.

6.2 Apparatus — The apparatus shall consist of the following:

a) An accelerated polishing machine (*see* Fig. 4) which shall be rigidly mounted on a firm, level and non-resilient base of stone or concrete and shall include:

1) A road wheel having a flat periphery, and of such a size and shape as to permit fourteen of the specimens to be clamped on the periphery so as to form a continuous surface of stone particles 45 mm wide and 405 mm in diameter.

2) Means for rotating the road wheel about its own axis at a speed of 320 to 325 rev/min.

3) Means for bringing the surface of a rubber-tyred wheel of 20 cm diameter and 5 cm breadth to bear on the stone surface of the road wheel with a total load of 40 kg. The tyre shall be an industrial 8 × 2 pneumatic 4-ply rating smooth hand-truck tyre with a hardness of 55 ± 5* and shall be inflated to a pressure of 3·15 ± 0·15 kg/cm^2. It shall be free to rotate on its own axis, which shall be parallel with the axis of the road wheel; the plane of rotation of the tyre shall be accurately in line with that of the road wheel. Before a new tyre is used on an actual test, it shall be given a preliminary run of 3 hours with sand and 3 hours with emery flour, as in an actual test, but using spare specimens. The tyre shall be discarded after 30 test runs have been made with it, or sooner if it shows signs of irregular wear.

4) Means to feed the sand specified in 6.3 and water at a uniform rate and in such a way that the sand and water are continuously and uniformly spread over the surfaces of the tyre and the specimens where they are in contact. This requires about 12 g/min of sand and 20 g/min of water.

5) Means to feed the emery powder specified in 6.3 and water at a uniform rate and in such a way that the emery powder and water are continuously and uniformly spread over the surface of the tyre and the specimens where they are in contact. This requires about 2 g/min of emery powder and 5 g/min of water.

b) A friction tester complying with the requirements set out in 6.6 and 6.7.

c) The IS Sieves shall be of the following sizes:

10 mm, 8·0 mm (both perforated plate), 425 microns, 300 microns, 212 microns and 150 microns (fine mesh).

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*Appendix C of IS : 809-1957 Specification for Rubber Flooring Materials for General Purposes (Since revised) gives the method of determining the Hardness.

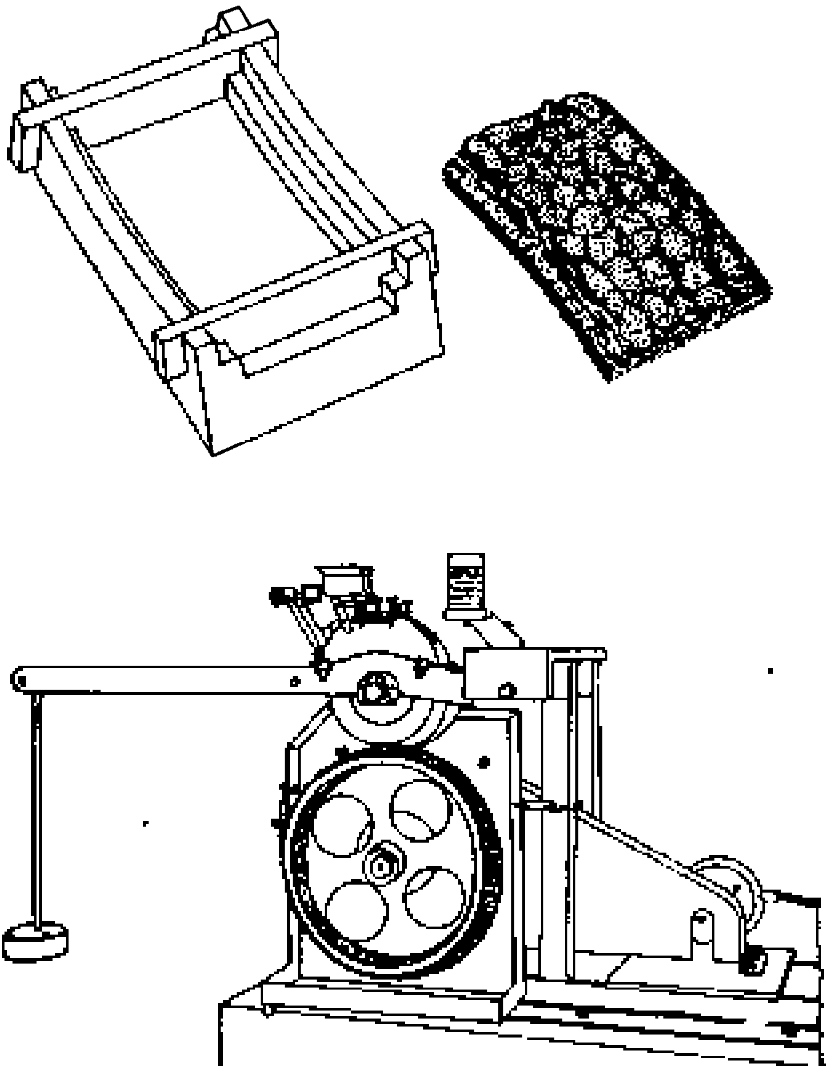

FIG. 4 SPECIMEN AND APPARATUS FOR ACCELERATED POLISHING

6.3 Materials — A supply of clean, hard siliceous sand, graded within the following limits; about 2·5 kg will be required for each test run:

Passing IS Sieve	*Percentage by Weight*
425-micron	100
300-micron	85-100
212-micron	20-50
150-micron	0-5

A supply of air-floated emery powder, 100 percent finer than 0·06 mm and not less than 70 percent finer than 0·002 mm; about 550 g will be required for each test run.

6.4 Preparation of Specimens — At least 3 kg of 10-mm particles shall be available for each sample to be tested. The particles actually used in the preparation of the test specimens shall all pass the 10-mm IS Sieve and be retained on the 8·0-mm IS Sieve and shall be neither flaky nor elongated. These shall be clean and free from dust.

6.4.1 When it is desired to test materials larger than 10 mm which may have characteristics differing from particles of the test size, the particles for the specimen should be obtained by crushing the larger particles.

6.4.2 Each specimen shall consist of a single layer of 40 to 50 of the particles spaced as closely as possible and covering an area of 90·5 × 44·5 mm, set in a sand-cement mortar* with their exposed surfaces proud of the mortar. The surface of the specimen shall be flat across the shorter dimension but shall be curved in the arc of a circle of 400 mm diameter along the longer dimension. The individual particles shall be mounted in such a way that the surfaces exposed to wear are as nearly flat as possible, and in any case present no sharp edges to the polishing tyre. The specimens shall be not less than 12·5 mm thick, and shall be of such a shape as to permit their being clamped round the flat periphery of the road wheel of the accelerated polishing machine so as to form a continuous outer surface of particles with an outer diameter of 405 mm. At least two specimens shall be made from each material to be tested.

6.5 Accelerated Polishing of Specimens — The specimens shall be rigidly clamped round the periphery of the road wheel of the accelerated polishing machine; the wheel will accommodate 14 specimens, and it has been found useful when mounting the specimens on the wheel to insert strips of polythene† about 0·25 mm thick between and beneath them. The pneumatic-tyred wheel shall be brought to bear on the surface of the

*The mortar shall consist of a mixture of equal portions by weight of the sand specified in 6.3 and high-alumina cement. It is desirable to reinforce each specimen with 3 pieces of 1·2 mm iron wire laid along the longer dimension.

†It should be noted that the name 'polythene' is equivalent to the name 'polyethylene'.

specimens with a total load of 40 kg and the road wheel started up and brought to a speed of 320 to 325 rev/min. Water and the sand specified in **6.3** shall be fed continuously at the rates specified in **6.2** (a) on the road wheel while it rotates at 320 to 325 rev/min for a period of 3 hours ±5 min.

6.5.1 The machine and specimens shall then be thoroughly cleaned by washing so that all traces of sand are removed and the machine operated for a further three hours as described in **6.5**, except that in place of the sand and water the air-floated emery powder specified in **6.3** and water shall be fed continuously at the rates specified in **6.2** (a). After 3 hours ±5 min running with the emery powder, the machine shall be stopped and the machine and specimens cleaned. The specimens after polishing are extremely sensitive to handling, and fingering of the polished surfaces shall be avoided. The specimens shall then be tested on the friction tester as described in **6.6**.

6.6 Friction Tester — The friction test shall be made with a tester (*see* Fig. 5) constructed to drawings supplied by the Road Research Laboratory, UK. The tester shall provide:

a) a spring-loaded rubber slider of the weight, size and shape specified below, mounted on the end of a pendulum arm so that the sliding edge is 50 cm from the axis of suspension.

b) means for setting the column of the instrument vertical.

c) means for rigidly locating one of the curved specimens from the accelerated polishing machine with its longer dimension in the track of the pendulum, centrally with respect to the rubber slider and to the axis of suspension of the pendulum.

d) means for raising and lowering the axis of suspension of the pendulum so that the slider can (1) swing clear of the surface of the specimen or (2) be set to slide over a fixed length of surface of 75±1·5 mm.

e) means for holding and releasing the pendulum arm so that it falls freely from a horizontal position.

f) a pointer balanced about the axis of suspension indicating the position of the pendulum arm throughout its forward swing, and moving over a circular scale drawn up as specified in **6.6.1** to **6.6.3**. The weight of the pointer shall be not more than 85 g and the friction in the pointer mechanism shall be adjustable so that, with the pendulum arm swinging freely from a horizontal position, the outward tip of a 30-cm long pointer may be brought to rest on the forward swing of the arm at a point 10 mm below the horizontal.

6.6.1 The weight of the swinging arm including the slider shall be 1·500 ± 0·025 kg, the centre of gravity lying on the axis of the arm at a distance of 405±5 mm from the centre of suspension.

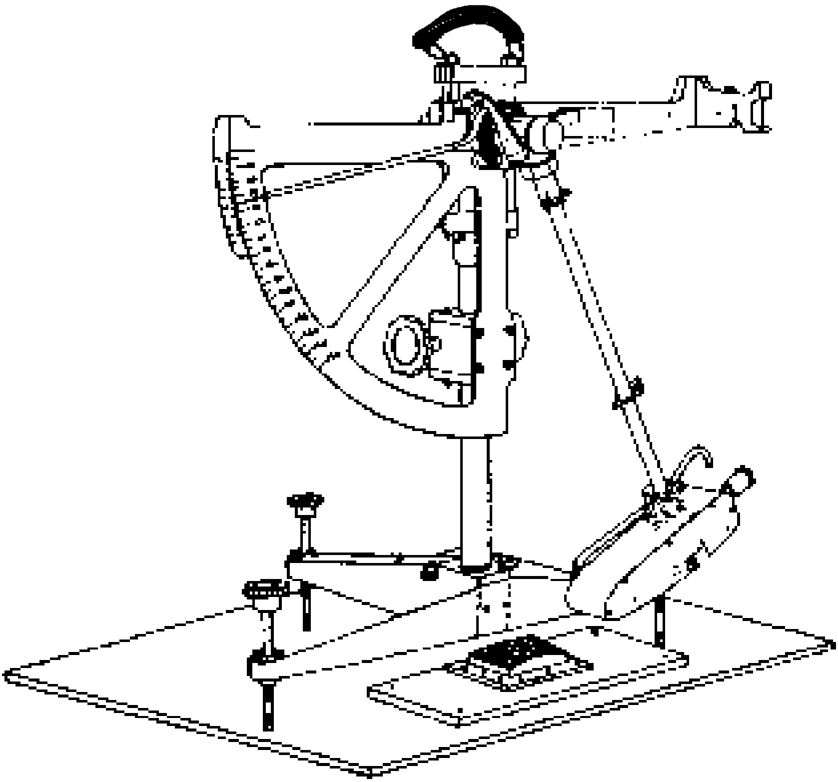

FIG. 5 APPARATUS USED TO MEASURE THE COEFFICIENT OF FRICTION OF THE SPECIMEN

6.6.2 The slider shall consist of a rubber pad 32 mm wide and 6·5 mm thick held on a rigid base with a total weight of 25 ± 2 g which is mounted on an axis set at an angle of 20 degrees with the horizontal when the pendulum is at the lowest point of its swing, so that (a) only the rear edge of the slider contacts the test surface, and (b) the slider can turn about its axis without obstruction to follow unevenness of the surface perpendicular to the plane of the pendulum swing. The slider shall be spring loaded against the test surface and the load on the slider shall be 2·25 ± 0·05 kg in its mean position; the change in load on the slider shall be not greater than 190 g/cm deflection of the slider.

6.6.3 The slider shall be made from rubber tested and specially selected for the purpose. Before use, each working end of a new slider shall be roughened by swinging it at least 10 times over a dry, unpolished specimen, which shall not be one of the specimens to be tested. Each slider shall be used for not more than 500 swings with each of the two usable ends, and shall, in any case, be discarded not more than one year after the date it is supplied.

NOTE — Recent research has thrown new light on the properties of rubber that govern its frictional resistance. Until the results of this research can be applied on a commercial scale, it is essential that the rubber for use in the slider be carefully tested and selected. When so selected, it should last without any ageing effect for at least a year; full instructions on this and other points relating to the use of the portable tester are issued with each instrument.

6.6.4 All bearings and working parts of the instruments shall be enclosed as far as possible, and all materials used shall be suitably treated to prevent corrosion under wet conditions.

6.7 Calibration of the Tester — The scale of the instrument when used for this test shall give the coefficient of friction, expressed as a percentage, and shall be drawn up by means of the following equation:

$$\mu = \frac{W X Z}{P D p} \times 100$$

where

μ = effective coefficient of friction, expressed as a percentage;

W = weight in kg of the swinging arm;

X = distance in cm of the effective centre of gravity of the arm from the centre of oscillation;

Z = vertical distance of the edge of the scale below the zero of the scale, which shall be 10 mm below the horizontal when the arm is released to swing freely from the horizontal;

P = normal load in kg on the slider;

D = sliding distance in cm; and

p = length in cm of the pointer.

The instrument shall be cross-checked with the Road Research Laboratory standard machine on the following wetted surfaces:

a) A glass plate.

b) Five smooth-looking surfaces having a texture depth less than 0·25 mm and covering a range of coefficients of friction, expressed as a percentage, of at least 25 to 75 percent.

c) Five rough-looking surfaces having a texture depth greater than 0·51 mm and covering a range of coefficients of friction, expressed as a percentage, of at least 35 to 70 percent.

On these tests no pairs of results on any surface shall differ by more than ±3 percent and the mean results for the 11 samples shall not differ by more than ±1·5 percent.

6.8 Friction Test Procedure — The test shall be made at a temperature of 20 ± 2°C.

6.8.1 The tester shall rest upon a firm level surface and the levelling screws shall be adjusted so that the column is vertical. The axis of suspension of the pendulum shall then be raised so that the arm swings freely, and the friction in the pointer mechanism shall be adjusted so that when the pendulum arm and pointer are released from the right-hand horizontal position the pointer comes to rest at the zero position on the scale.

6.8.2 The specimen shall then be rigidly located with its longer dimension lying in the track of the pendulum, and centrally with respect to the rubber slider and to the axis of suspension of the pendulum. The height of the axis of suspension of the pendulum shall then be adjusted so that in traversing the specimen the rubber slider is in contact with it over the whole width of the slider and over a length of 75±1·5 mm of the specimen under a normal load of 2·25±0·05 kg. The surfaces of the specimen and the rubber slider shall then be wetted with a copious supply of clean water, care being taken not to disturb the slider from its set position. The pendulum and pointer shall then be released from the horizontal position and the reading of the pointer recorded to the nearest whole number.

6.8.3 The procedure shall then be repeated with a second specimen of the same material.

6.8.4 If the values obtained from the two specimens differ by more than 3 percent, a further specimen or specimens shall be tested until two values agree within this limit.

NOTE — If the tester has not been used for eight hours previously, five swings shall be made on a spare specimen before an actual test is made.

6.9 Reporting of Results — The mean of the two values of the coefficient of friction, expressed as a percentage, shall be reported to the nearest whole number as follows:

Laboratory determined polished-stone value* ......

7. DETERMINATION OF CRUSHING STRENGTH

7.1 General — When aggregates are not available, this test may be used to give a direct measure of the stress in kg/cm² at ultimate failure of a rock under a slowly increasing compressive load.

*This is not, and should not be confused with, the 'Sideway force coefficient' or the 'Skid-resistance value' determined on a road.

7.2 Apparatus — The apparatus shall consist of the following:

a) A compression testing machine of suitable capacity and at least one platen having a spherical seating of not more than 2·5 cm radius.

b) A well-ventilated oven, thermostatically controlled to maintain a temperature of 100° to 110°C.

7.3 Test Specimens — The test specimens shall be cylinders of 25 ± 0·5 mm mean diameter and of 25 ± 0·5 mm mean height. In any one specimen, the diameter shall not vary by more than 0·25 mm and the height by not more than 0·15 mm. The end faces shall be at right angles to the cylindrical axis and shall be lapped plane to an accuracy of 0·025 mm.

7.3.1 The samples from which the test specimens are prepared shall be taken from freshly quarried material and only from pieces which show no evidence of incipient fracture. When planes of structural weakness are discernible, the sample shall be so selected as to furnish some test specimens with the planes of structural weakness at right angles to the cylindrical axis of the specimen.

7.3.2 The size of the samples shall be approximately 8 × 4 × 4 cm if the test specimens are to be prepared by grinding only and 15 × 15 × 10 cm of the test specimens are to be prepared by drilling, sawing and grinding.

7.3.3 In the preparation of the test specimens, the rock shall not be subjected to any treatment (such as chipping with a hammer) liable to induce incipient fracture. A copious flow of cold water shall be used throughout all grinding, drilling and sawing operations, to ensure that the aggregate is not damaged by overheating.

7.3.4 The test specimens shall be dried for four hours in the oven at a temperature of 100° to 110°C and cooled before test.

7.3.5 If no planes of structural weakness are apparent, three specimens shall be tested. If planes of structural weakness are apparent, four specimens shall be tested, of which two shall have the planes at right angles to the axis of the cylinder.

7.4 Procedure — The diameter and height of each specimen shall be measured to an accuracy of 0·025 mm. The specimen shall be placed centrally between the steel platens without packing.

7.4.1 Each test shall be a direct compression test in which the load is applied to the ends of the cylindrical test specimen at a rate of about 5 tonnes per minute. In making each test, the final load necessary to produce crushing of the specimen shall be observed.

7.5 Calculations — The stress shall be calculated in kg/cm² from the cross-sectional area of the specimen.

7.6 Reporting of Results The value of the crushing stress for each individual specimen, and the average crushing stress shall be reported to the nearest 5 kg/cm². Any peculiar condition of a test specimen which might affect the result of the test, such as the presence of seams, fissures, etc, shall be noted in the report.

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002
Telephones: 323 0131, 323 3375, 323 9402
Fax: 91 11 3234062, 91 11 3239399, 91 11 3239382

Telegrams: Manaksanstha
(Common to all Offices)

Central Laboratory:	Telephone
Plot No. 20/9, Site IV, Sahibabad Industrial Area, SAHIBABAD 201010	8-77 00 32
Regional Offices:	
Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	323 76 17
*Eastern : 1/14 CIT Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	337 86 62
Northern : SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 38 43
Southern : C.I.T. Campus, IV Cross Road, CHENNAI 600113	235 23 15
†Western : Manakalaya, E9 Behind Marol Telephone Exchange, Andheri (East), MUMBAI 400093	832 92 95
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*Sales Office is at 5 Chowringhee Approach, P. O. Princep Street, CALCUTTA 700072	27 10 85
†Sales Office is at Novelty Chambers, Grant Road, MUMBAI 400007	309 65 28
‡Sales Office is at 'F' Block, Unity Building, Narashimaraja Square, BANGALORE 560002	222 39 71

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AMENDMENT NO. 2 SEPTEMBER 1981

TO

IS:2386(Part IV)-1963 METHODS OF TEST FOR AGGREGATES FOR CONCRETE

PART IV MECHANICAL PROPERTIES

Alterations

(*Page 8, Note 1 under clause 2.6, last sentence*) - Delete.

(*Page 13, clause 5.1*) - Substitute the following for the existing clause:

'5.1 Object - This test covers the method of determining the abrasion value of coarse aggregate by the use of Los Angeles machine (see 5.2).'

(*Pages 14 to 16, clauses 5.2 to 5.2.7*) - Delete and renumber the subsequent clauses accordingly.

(BDC 2)

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AMENDMENT NO. 3 OCTOBER 1983
TO
IS : 2386 (Part IV) - 1963 METHODS OF TEST FOR AGGREGATES FOR CONCRETE

PART IV MECHANICAL PROPERTIES

Alterations

(*Page* 5, *clause* 2.2) — Substitute the following for the existing clause:

' **2.2 Apparatus** — The apparatus for the standard test shall consist of the following:

a) An open-ended 150 mm cylindrical cell with appropriate base plate and plunger, metal measure and tamping rod conforming to IS : 9376-1979 Specification for apparatus for measuring aggregate crushing value and ten percent fines value;

b) A balance of capacity 3 kg readable and accurate to one gram;

c) IS sieve of sizes 12·5 mm, 10 mm and 2·36 mm; and

d) A compression testing machine capable of applying a load of 40 tonnes in not more than 10 minutes at a uniform rate of loading. The machine may be used with or without a spherical seating.

(*Page* 5, *Table* 1, *Note*) — Substitute the following Note for the existing:

' Note — About 6·5 kg of natural aggregates is required to provide two test samples for 15 cm cylinder and about 1 kg for 7·5 cm cylinder. For lightweight aggregates, the quantity will vary depending on the density of the aggregate.'

(*Page* 6, *Fig.* 1) — Delete.

(*Page* 7, *clause* 2.3.2) — Substitute the following for the existing clause:

' **2.3.2** The quantity of aggregate shall be such that the depth of material in the cylinder, after tamping as described in 2.3.3, shall be about 10 cm.'

(*Page* 8, *clause* 2.6 *Note* 1, *last sentence*) — Delete.

(*Page* 8, *clause* 2.6 *Note* 2) — Substitute the following Note for the existing:

'NOTE 2 — *Aggregates smaller than 10 mm* — In general the smaller sizes of aggregates will give a lower aggregate crushing value, but the relationship between the values obtained with different sizes will vary from one aggregate to another. The tests on smaller aggregates may be made either using the standard apparatus described in 2.2 or a smaller apparatus consisting of a 75 mm cylindrical cell with appropriate accessories conforming to IS : 9376-1979 Specification for apparatus for measuring aggregate crushing value and ten percent fines value. In case a smaller apparatus is used, the errors for the smaller sizes of aggregate tested in the smaller apparatus are compensated since the results obtained with the smaller apparatus have been found to be slightly higher than those with the standard apparatus.

The accessories for the smaller apparatus shall be a balance of capacity 500 g, readable and accurate to 0·2 g; IS sieves of appropriate sizes as given in Table 1; and a compression testing machine capable of applying a load of 10 tonnes in not more than 10 min at a uniform rate of loading. Further, in the test using the smaller apparatus, the depth of material in the 75 mm cylinder shall be about 50 mm and the total load applied in 10 min shall be 10 tonnes.'

(*Pages* 8 and 9, *clause* 3.2) — Substitute the following for the existing clause:

'**3.2 Apparatus** — The apparatus shall consist of the following:

a) A 150 mm cylindrical cell with appropriate plunger and base plate, tamping rod and metal measure conforming to IS : 9376-1979 Specification for apparatus for measuring aggregate crushing value and ten percent fines value;

b) A balance of capacity 3 kg, readable and accurate to one gram;

c) IS sieves of sizes 12·5 mm, 10 mm and 2·36 mm;

d) A compression testing machine capable of applying a load of 50 tonnes in not more than 10 minutes at a uniform rate of loading. The load may vary from 0·5 to 50 tonnes; and

e) A means of measuring the reduction in the distance between the platens of the testing machine to the nearest one mm during the test (for example, a dial gauge).'

(*Page* 9, *clause* 3.3.2) — Substitute the following for the existing clause:

'3.3.2 The quantity of aggregate shall be such that the depth of material in the cylinder, after tamping as described in 3.3.2.1, shall be about 10 cm.'

[*Page* 19, *clause* 5.3.4.1 (*see also* Amendment No. 2), *third line*] — Substitute '30 to 33 rev/min' *for* '20 to 33 rev/min'.

[*Page* 19, *clause* 5.3.5 (*see also* Amendment No. 2)] — Substitute the following for the existing clause:

'5.3.5 *Reporting of Results* — The difference between the original weight and the final weight of the test sample shall be expressed as a percentage of the original weight of the test sample. The mean of two results shall be reported as the percentage of wear.'

(*Pages* 26, 27 *and* 28, *clauses* 7 *to* 7.6) — Delete.

Addendum

(*Page* 7, *clause* 2.3.3) — Add the following at the end of the clause:

'(*see* Note given in Table 1)'

(BDC 2)

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भारतीय मानक

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(पहला पुनरीक्षण)

Indian Standard

ORDINARY PORTLAND CEMENT, 53 GRADE — SPECIFICATION

(First Revision)

ICS 91.100.10

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

March 2013 **Price Group 5**

Cement and Concrete Sectional Committee, CED 2

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was published in 1987. This revision incorporates the experience gained with the use of this standard and brings the standard in line with the latest developments in this field.

Since the publication of this standard, a large number of amendments were issued from time-to-time in order to modify various requirements based on experience gained with the use of the standard and the requirements of the users, and also keeping in view the raw materials available in the country and found suitable for the manufacture of cement. The important amendments included: use of performance improvers for addition during clinker grinding stage, incorporation of requirement of chloride content for the cement used in structures other than prestressed concrete, permitting use of 25 kg, 10 kg, 5 kg, 2 kg and 1 kg bags for packing of cement, and requirement of packing cement for export. In view of the large number of amendments, the Sectional Committee decided to bring out this first revision of the standard incorporating all these amendments so as to make it more convenient for the users. Further, following are the other significant modifications incorporated in this revision:

a) Requirement for insoluble residue has been specified as 5.0 percent, maximum irrespective of addition of performance improver(s) or otherwise.
b) SO_3 content requirement has been revised to 3.5 percent maximum irrespective of C_3A content, primarily to accommodate use of coal/pet coke as fuel which may have higher sulphur content; subject to the cement conforming to all the requirements of the standard.
c) A clause has been introduced requiring manufacturer to furnish a certificate indicating alkali content if required by the purchaser.
d) Requirement of marking of type and amount of performance improver(s) on the bag has been incorporated.
e) Requirement of testing the cement samples at the earliest but not later than 3 months since the receipt of samples for testing, has been included.

With the increase in SO_3 content limit in this revision, suitable caution needs to be exercised for limiting the sulphates in concrete in accordance with the provision of IS 456 : 2000 ‘Code of practice for plain and reinforced concrete (*fourth revision*)’.

Quantity of cement packed in bags and the tolerance requirements for the quantity of cement packed in bags shall be in accordance with the relevant provisions of the *Standards of Weights and Measures (Packaged Commodities) Rules*, 1977 and **B-1.2** (*see* Annex B). Any modification in these rules in respect of tolerance on quantity of cement would apply automatically to this standard.

This standard contains Sl No. (viii) of Table 2 and **12.2.1** which give option to the purchaser and Sl No. (v) of Table 3 and **9.2**, **9.3**, **9.4** and **9.4.3**, which call for agreement between the purchaser and the supplier.

Specific requirements of ordinary Portland cement for manufacture of railway sleepers to be designated as 53-S grade are given in **5.2**, Table 3 and **10.1**. To differentiate it with normal grade, ‘53-S grade’ shall be marked on the bags/packages for such cement in place of ‘53 grade’.

The composition of the technical Committee responsible for the formulation of this standard is given in Annex C.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

ORDINARY PORTLAND CEMENT, 53 GRADE — SPECIFICATION

(First Revision)

1 SCOPE

This standard covers the manufacture and chemical and physical requirements of 53 grade ordinary Portland cement.

2 REFERENCES

The standards given in Annex A contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 4845 shall apply.

4 MANUFACTURE

4.1 Ordinary Portland cement, 53 grade shall be manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker so as to produce a cement capable of complying with this standard. No material shall be added after burning, other than gypsum (natural mineral or chemical, *see* Note), water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including colouring agents, which have proved not to be harmful.

NOTE — Chemical gypsum shall be added provided that the performance requirements of the final product as specified in this standard are met with.

4.1.1 Limit of addition of performance improver shall be as given in Table 1 and shall be inclusive of 1 percent additives as mentioned above.

If a combination of above performance improvers is added, the maximum limit of total addition shall be 5 percent.

5 CHEMICAL REQUIREMENTS

5.1 When tested in accordance with the methods given in IS 4032, ordinary Portland cement, 53 grade shall comply with the chemical requirements given in Table 2.

Table 1 Performance Improvers
(*Clause* 4.1.1)

Sl No. (1)	Performance Improver (2)	Percentage Addition by Mass, *Max* (3)	Requirement (4)
i)	Fly ash	5	Conforming to IS 3812 (Part 1)
ii)	Granulated slag	5	Conforming to IS 12089
iii)	Silica fume	5	Conforming to IS 15388
iv)	Limestone	5	$CaCO_3$ content calculated from CaO content shall not be less than 75 percent when tested in accordance with IS 1760 (Part 3)
v)	Rice husk ash	5	a) Reactive silica shall not be less than 80 percent when tested as per IS 3812 (Part 1) b) Pozzolanic activity index shall not be less than 90 percent when tested as per **10** of 1S 1727 c) Loss on ignition shall not be more than 5.0 percent when tested as per IS 1727
vi)	Metakaolin	5	a) Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) in percent by mass shall not be less than 94.0 percent when tested as per IS 1727 b) Loss on ignition shall not be more than 2.0 percent when tested as per IS 1727 c) Total alkalis as sodium oxide (as Na_2O equivalent) in percent by mass shall not be more than 1.5 percent when tested as per IS 4032 d) Particles retained on 45 micron IS sieve (wet sieving) shall not be more than 1.5 percent when tested as per 1S 1727

Table 2 Chemical Requirements for Ordinary Portland Cement, 53 Grade

(*Foreword* and *Clauses* 5.1 *and* 5.2)

Sl No. (1)	Characteristic (2)	Requirement (3)
i)	Ratio of percentage of lime to percentages of silica, alumina and iron oxide, when calculated by the formula: $\frac{CaO - 0.7\ SO_3}{2.8\ SiO_2 + 1.2\ Al_2O_3 + 0.65\ Fe_2O_3}$	0.80-1.02
ii)	Ratio of percentage of alumina to that of iron oxide, *Min*	0.66
iii)	Insoluble residue, percent by mass, *Max*	4.0
iv)	Magnesia, percent by mass, *Max*	6.0
v)	Total sulphur content calculated at sulphuric anhydride (SO_3), percent by mass, *Max*	3.5
vi)	Loss on ignition, percent by mass, *Max*	4.0
vii)	Chloride content, percent by mass, *Max*	0.1
viii)	Alkali content	0.05 (for prestressed structures, *see* Note)

NOTE — Alkali aggregates reactions have been noticed in aggregates in some parts of the country. On large and important jobs where the concrete is likely to be exposed to humid atmosphere or wetting action, it is advisable that the aggregate be tested for alkali aggregate reaction. In the case of reactive aggregates, the use of cement with alkali content below 0.6 percent expressed at sodium oxide (Na_2O), is recommended. Where, however, such cements are not available, use of alternative means may be resorted to for which a reference may be made to **8.2.5.4** of IS 456. If so desired by the purchaser, the manufacturer shall carry out test for alkali content.

5.2 Cement used for railway sleepers shall additionally satisfy the following chemical/mineralogical requirements and shall be designated as 53-S grade:

a) Magnesia, percent by mass, *Max* — 5.0

b) Tricalcium aluminate content, percent by mass, *Max* — 10.0

c) Tricalcium silicate, percent by mass, *Min* — 45.0

NOTE — The tricalcium aluminate content (C_3A) and tricalcium silicate content (C_3S) are calculated by the formula:

C_3A = 2.65 (Al_2O_3) – 1.69 (Fe_2O_3)

C_3S = 4.07 (CaO) – 7.60 (SiO_2) – 6.72 (Al_2O_3) – 1.43 (Fe_2O_3) – 2.85 (SO_3)

where each symbol in brackets refers to the percent (by mass of total cement) of the oxide, excluding any contained in insoluble residue referred to at Sl No. (iii) of Table 2.

6 PHYSICAL REQUIREMENTS

Ordinary Portland cement, 53 grade shall comply with the physical requirements given in Table 3.

7 STORAGE

The cement shall be stored in such a manner as to permit easy access for proper inspection and identification, and in a suitable weather-tight building to protect the cement from dampness and to minimize warehouse deterioration (*see also* IS 4082).

8 MANUFACTURER'S CERTIFICATE

8.1 The manufacturer shall satisfy himself that the cement conforms to the requirements of this standard and, if requested, shall furnish a certificate to this effect to the purchaser or his representative, within ten days of testing of the cement (except for 28 days compressive strength test results, which shall be furnished after completion of the test).

8.2 The manufacturer shall furnish a certificate indicating the alkali content, if requested.

9 PACKING

9.1 The cement shall be packed in any of the following bags:

a) jute sacking bag conforming to IS 2580;
b) multi-wall paper sacks conforming to IS 11761;
c) light weight jute conforming to IS 12154;
d) HDPE/PP woven sacks conforming to IS 11652;
e) jute synthetic union bags conforming to IS 12174; or
f) any other approved composite bag.

Bags shall be in good condition at the time of inspection.

9.1.1 The net quantity of cement per bag shall be 50 kg subject to provisions and tolerance given in Annex B.

9.2 The net quantity of cement per bag may also be 25 kg, 10 kg, 5 kg, 2 kg or 1 kg subject to tolerances as given in **9.2.1** and packed in suitable bags as agreed to between the purchaser and the manufacturer.

9.2.1 The number of bags in a sample taken for

Table 3 Physical Requirements for Ordinary Portland Cement, 53 Grade
(*Foreword* and *Clause* 6)

Sl No. (1)	Characteristic (2)	Requirement (3)	Method of Test, Ref to (4)
i)	Fineness, m^2/kg, *Min*	225 370 for 53-S grade	IS 4031 (Part 2)
ii)	Soundness:		
	a) By Le Chatelier method, mm, *Max*	10 } See Note 1	IS 4031 (Part 3)
	b) By autoclave test method, percent, *Max*	0.8 } See Note 1	
iii)	Setting time:		
	a) Initial, min, *Min*	30 60 for 53-S grade } See Note 2	IS 4031 (Part 5)
	b) Final, min, *Max*	600 } See Note 2	
iv)	Compressive strength, MPa (*see* Note 4):		IS 4031 (Part 6)
	a) 72 ± 1 h, *Min*	27	
	b) 168 ± 2 h, *Min*	37 37.5 for 53-S grade	
	c) 672 ± 4 h, *Min*	53	
v)	Transverse strength (optional)	See Notes 3 and 4	IS 4031 (Part 8)

NOTES

1 In the event of cements failing to comply with any one or both the requirements of soundness specified in this table, further tests in respect of each failure shall be made as described in IS 4031 (Part 3), from another portion of the same sample after aeration. The aeration shall be done by spreading out the sample to a depth of 75 mm at a relative humidity of 50 to 80 percent for a total period of 7 days. The expansion of cements so aerated shall be not more than 5 mm and 0.6 percent when tested by Le Chatelier method and autoclave test respectively. For 53-S grade cement, the requirement of soundness of unaerated cement shall be maximum expansion of 5 mm when tested by the Le-Chatelier method.

2 If cement exhibits false set, the ratio of final penetration measured after 5 min of completion of mixing period to the initial penetration measured exactly after 20 s of completion of mixing period, expressed as percent, shall be not less than 50. In the event of cement exhibiting false set, the initial and final setting time of cement when tested by the method described in IS 4031 (Part 5) after breaking the false set, shall conform to the value given in this table.

3 By agreement between the purchaser and the manufacturer, transverse strength test of plastic mortar in accordance with the method described in IS 4031 (Part 8) may be specified. The permissible values of the transverse strength shall be mutually agreed to between the purchaser and the supplier at the time of placing the order.

4 Notwithstanding the compressive and transverse strength requirements specified as per this table, the cement shall show a progressive increase in strength from the strength at 72 h.

weighment showing a minus error greater than 2 percent of the specified net quantity shall be not more than 5 percent of the bags in the sample. Also the minus error in none of such bags in the sample shall exceed 4 percent of the specified net quantity of cement in the bag. However, the average of net quantity of cement in a sample shall be equal to or more than 25 kg, 10 kg, 5 kg, 2 kg or 1 kg, as the case may be.

9.3 Supplies of cement in bulk may be made by arrangement between the purchaser and the supplier (manufacturer or stockist).

NOTE — A single bag or container containing 1 000 kg and more, net quantity of cement shall be considered as the bulk supply of cement. Supplies of cement may also be made in intermediate bags/containers, for example, drums of 200 kg, by agreement between the purchaser and the manufacturer.

9.4 When cement is intended for export and if the purchaser so requires, packing of cement may be done in bags or in drums with net quantity of cement per bag or drum as agreed to between the purchaser and the manufacturer.

9.4.1 For this purpose, the permission of the certifying authority shall be obtained in advance for each export order.

9.4.2 The words 'FOR EXPORT' and the net quantity of cement per bag/drum shall be clearly marked in indelible ink on each bag/drum.

9.4.3 The packing material shall be as agreed to between the manufacturer and the purchaser.

9.4.4 The tolerance requirements for the quantity of cement packed in bags/drum shall be as given in **9.2.1** except the net quantity which shall be equal to or more than the quantity in **9.4**.

10 MARKING

10.1 Each bag of cement shall be legibly and indelibly marked with the following:

a) Manufacturer's name and his registered trade-mark;
b) The words 'Ordinary Portland Cement, 53 Grade' or 'Ordinary Portland Cement, 53-S Grade', whichever is applicable;

c) Net quantity, in kg;
d) The words 'Use no Hooks';
e) Batch/control unit number in terms of week, month and year of packing;
f) Address of the manufacturer; and
g) Type and percentage of performance improver(s) added, in case of addition of performance improvers.

10.2 Similar information shall be provided in the delivery advices accompanying the shipment of packed or bulk cement and cement drums (*see* **9.3**).

10.3 BIS Certification Marking

The cement may also be marked with the Standard Mark.

10.3.1 The use of the Standard Mark is governed by the provisions of *the Bureau of Indian Standards Act*, 1986 and the Rules and Regulations made thereunder. The details of conditions under which a license for the use of the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

11 SAMPLING

11.1 A sample or samples for testing may be taken by the purchaser or his representative, or by any person appointed to superintend the work for the purpose of which the cement is required or by the latter's representative.

11.1.1 The samples shall be taken within three weeks of the delivery and all the tests shall be commenced within one week of sampling.

11.1.2 When it is not possible to test the samples within one week, the samples shall be packed and stored in air-tight containers and tested at the earliest but not later than 3 months since the receipt of samples for testing.

11.2 In addition to the requirements of **11.1**, the methods and procedure of sampling shall be in accordance with IS 3535.

11.3 The manufacturer or the supplier shall afford every facility, and shall provide all labour and materials for taking and packing the samples for testing the cement and for subsequent identification of cement sampled.

12 TESTS

12.1 The sample or samples of cement for test shall be taken as described in **11** and shall be tested in the manner described in the relevant clauses.

12.2 Independent Testing

12.2.1 If the purchaser or his representative requires independent tests, the samples shall be taken before or immediately after delivery at the option of the purchaser or his representative, and the tests shall be carried out in accordance with this standard on the written instructions of the purchaser or his representative.

12.2.2 The manufacturer/supplier shall supply, free of charge, the cement required for testing. Unless otherwise specified in the enquiry and order, the cost of the tests shall be borne as follows:

a) By the manufacturer/supplier, if the results show that the cement does not comply with the requirements of this standard, and
b) By the purchaser, if the results show that the cement complies with the requirement of this standard.

12.2.3 After a representative sample has been drawn, tests on the sample shall be carried out as expeditiously as possible (*see* **11.1.1** and **11.1.2**).

13 REJECTION

13.1 Cement may be rejected if it does not comply with any of the requirements of this standard.

13.2 Cement remaining in bulk storage at the factory, prior to shipment, for more than six months, or cement in bags, in local storage such as, in the hands of a vendor for more than 3 months after completion of tests, shall be retested before use and shall be rejected if it fails to conform to any of the requirements of this standard.

ANNEX A
(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
456 : 2000	Code of practice plain and reinforced concrete (*fourth revision*)
650 : 1991	Specification for standard sand for testing of cement (*second revision*)
1727 : 1967	Methods of test for pozzolanic materials (*first revision*)
1760 (Part 3) : 1992	Methods of chemical analysis of limestone, dolomite and allied materials: Part 3 Determination of iron oxide, alumina, calcium oxide and magnesia (*first revision*)
2580 : 1995	Textiles — Jute sacking bags for packing cement — Specification (*third revision*)
3535 : 1986	Methods of sampling hydraulic cements (*first revision*)
3812 (Part 1) : 2013	Specification for pulverized fuel ash: Part 1 For use as pozzolana in cement, cement mortar and concrete (*third revision*)
4031	Methods of physical tests for hydraulic cement
(Part 2) : 1999	Determination of fineness by specific surface by Blaine air permeability method (*second revision*)
(Part 3) : 1988	Determination of soundness (*first revision*)
(Part 5) : 1988	Determination of initial and final setting times (*first revision*)
(Part 6) : 1988	Determination of compressive strength of hydraulic cement (other than masonry cement) (*first revision*)
(Part 8) : 1988	Determination of transverse and compressive strength of plastic mortar using prism (*first revision*)
4032 : 1985	Methods of chemical analysis of hydraulic cement (*first revision*)
4082 : 1996	Recommendations on stacking and storage of construction materials and components at site (*second revision*)
4845 : 1968	Definitions and terminology relating to hydraulic cement
4905 : 1968	Methods for random sampling
11652 : 1986	Specification for high density polyethylene (HDPE)/polypropylene (PP) woven sacks for packing cement (*second revision*)
11761 : 1986	Specification for multi-wall paper sacks for cement (*first revision*)
12089 : 1987	Specification for granulated slag for manufacture of Portland slag cement
12154 : 1987	Light weight jute bags for packing cement
12174 : 1987	Jute synthetic union bags for packing cement
15388 : 2003	Specification for silica fume

ANNEX B
(*Foreword* and *Clause* 9.1.1)

TOLERANCE REQUIREMENTS FOR THE QUANTITY OF CEMENT PACKED IN BAGS

B-1 The average of the net quantity of cement packed in bags at the plant in a sample shall be equal to or more than 50 kg. The number of bags in a sample shall be as given below:

Batch Size	*Sample Size*
100-150	20
151-280	32
281-500	50
501-1 200	80
1 201-3 200	125
3 201 and over	200

The bags in a sample shall be selected at random. For methods of random sampling, IS 4905 may be referred to.

B-1.1 The number of bags in a sample showing a minus error greater than 2 percent of the specified net quantity (50 kg) shall be not more than 5 percent of the bags in the sample. Also the minus error in none of such bags in a sample shall exceed 4 percent of the specified net quantity of cement in the bag.

NOTE — The matter given in **B-1** and **B-1.1** are extracts based on the *Standards of Weights and Measures (Packaged Commodities) Rules*, 1977 to which reference shall be made for full details. Any modification made in these Rules and other related Acts and Rules would apply automatically.

B-1.2 In case of a wagon/truck load of up to 25 tonne, the overall tolerance on net quantity of cement shall be 0 to 0.5 percent.

NOTE — The mass of a jute sacking bag to hold 50 kg of cement is 531 g, the mass of a 6-ply paper bag to hold 50 kg of cement is approximately 400 g, the mass of a light weight jute bag to hold 50 kg of cement is approximately 450 g, the mass of a HDPE/PP woven sack to hold 50 kg of cement is approximately 70 g/71 g respectively, and the mass of a jute synthetic union bag to hold 50 kg of cement is approximately 420 g.

ANNEX C
(*Foreword*)

COMMITTEE COMPOSITION

Cement and Concrete Sectional Committee, CED 2

Organization	*Representative(s)*
Delhi Tourism and Transportation Development Corporation Ltd, New Delhi	Shri Jose Kurian (***Chairman***)
ACC Ltd, Mumbai	Shri S. A. Khadilkar Shri Sharad Kumar Shrivastava (*Alternate*)
Ambuja Cements Limited, Mumbai	Shri C. M. Dordi Dr A. N. Vyasa Rao (*Alternate*)
Association of Consulting Civil Engineers (India), Bangalore	Shri Avinash D. Shirode Shri K. K. Meghashyam (*Alternate*)
Atomic Energy Regulatory Board, Mumbai	Shri L. R. Bishnoi Shri Saurav Acharya (*Alternate*)
Builders' Association of India, Mumbai	Dr Narendra D. Patel
Building Materials and Technology Promotion Council, New Delhi	Shri J. K. Prasad Shri C. N. Jha (*Alternate*)
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Cement Manufacturers' Association, Noida	Shri N. A. Viswanathan Dr S. K. Handoo (*Alternate*)
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Central Public Works Department, New Delhi	Shri A. K. Garg Shri Manu Amitabh (*Alternate*)
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Delhi Development Authority, New Delhi	Chief Engineer (QAC) Director (Material Management) (*Alternate*)
Engineers India Limited, New Delhi	Shri Vinay Kumar Shri A. K. Mishra (*Alternate*)

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Indian Roads Congress, New Delhi	Secretary General Director (*Alternate*)
Institute for Solid Waste Research & Ecological Balance, Visakhapatnam	Dr N. Bhanumathidas Shri N. Kalidas (*Alternate*)
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Ministry of Road Transport & Highways, New Delhi	Shri A. N. Dhodapkar Shri S. K. Puri (*Alternate*)
National Council for Cement and Building Materials, Ballabgarh	Shri V. V. Arora Dr M. M. Ali (*Alternate*)
National Test House, Kolkata	Shri B. R. Meena Shrimati S. A. Kaushil (*Alternate*)
Nuclear Power Corporation of India Ltd, Mumbai	Shri U. S. P. Verma Shri Arvind Shrivastava (*Alternate*)
OCL India Limited, New Delhi	Dr S. C. Ahluwalia
Public Works Department, Government of Tamil Nadu, Chennai	Superintending Engineer Executive Engineer (*Alternate*)
Research, Design & Standards Organization (Ministry of Railways), Lucknow	Shri R. M. Sharma Shri V. K. Yadava (*Alternate*)
Sanghi Industries Limited, Sanghi Nagar	Shri D. B. N. Rao Dr H. K. Patnaik (*Alternate*)
Structural Engineering Research Centre (CSIR), Chennai	Dr K. Ramanjaneyulu Shri P. Srinivasan (*Alternate*)
The India Cements Limited, Chennai	Dr D. Venkateswaran Shri S. Gopinath (*Alternate*)
The Indian Hume Pipe Company Limited, Mumbai	Shri P. R. Bhat Shri S. J. Shah (*Alternate*)

Organization	*Representative(s)*
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The National Institute of Engineering, Mysore	Dr N. Suresh Shri H. N. Ramathirtha (*Alternate*)
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Voluntary Organization in Interest of Consumer Education, New Delhi	Shri M. A. U. Khan Shri H. Wadhwa (*Alternate*)
In personal capacity (*36, Old Sneh Nagar, Wardha Road, Nagpur)*	Shri L. K. Jain
In personal capacity (*EA-92, Maya Enclave, Hari Nagar, New Delhi*)	Shri R. C. Wason
In personal capacity (*E-1, 402, White House Apartments, R.T. Nagar, Bangalore*)	Shri S. A. Reddi
BIS Directorate General	Shri A. K. Saini, Scientist 'G' and Head (Civ Engg) [Representing Director General (*Ex-officio*)]

Member Secretaries
Shri Sanjay Pant
Scientist 'E' & Director (Civ Engg), BIS

Shri S. Arun Kumar
Scientist 'C' (Civ Engg), BIS

Cement, Pozzolana and Cement Additives Subcommittee, CED 2 : 1

In personal capacity (*E-1, 402, White House Apartments, R.T. Nagar, Bangalore*)	Shri S. A. Reddi (***Convener***)
ACC Ltd, Mumbai	Shri S. A. Khadilkar Shri Sharad Kumar Shrivastava (*Alternate*)
AIMIL Ltd, New Delhi	Dr V. M. Sharma Shri Aman Khullar (*Alternate*)
All India Mini Cement Manufacturers' Association, Hyderabad	Shri S. R .B. Ramesh Chandra Shri S. Srikanth Reddy (*Alternate*)
Ambuja Cements Ltd, Ahmedabad	Shri C. M. Dordi Dr A. N. Vyasa Rao (*Alternate*)
Atomic Energy Regulatory Board, Mumbai	Shri L. R. Bishnoi Shri Saurav Acharya (*Alternate*)
Building Materials and Technology Promotion Council, New Delhi	Shri J. K. Prasad Shri C. N. Jha (*Alternate*)
Cement Corporation of India Ltd, New Delhi	Shri M. K. Agarwal Shrimati Saraswathi Devi (*Alternate*)
Cement Manufactuters' Association, Noida	Shri Subrato Chowdhury Dr K. C. Narang (*Alternate*)
Central Building Research Institute (CSIR), Roorkee	Dr B. K. Rao Dr S. K. Agarwal (*Alternate*)
Central Electricity Authority, New Delhi	Shri Y. K. Sharma Shri Mohan Kumar (*Alternate*)
Central Pollution Control Board, Delhi	Shri J. S. Kamyotra Shri P. K. Gupta (*Alternate*)
Central Public Works Department, New Delhi	Shri A. K. Garg Shri Manu Amitabh (*Alternate*)
Central Road Research Institute (CSIR), New Delhi	Dr A. K. Misra Shri J. B. Sengupta (*Alternate*)
Central Soil and Materials Research Station, New Delhi	Shri Murari Ratnam Shri N. Sivakumar (*Alternate*)
Central Water Commission, New Delhi	Director, CMDD (N&W) Deputy Director, CMDD (NW&S) (*Alternate*)

Organization	*Representative(s)*
Dalmia Cement (Bharat) Limited, New Delhi	Dr K. C. Narang Shri C. S. Sharma (*Alternate*)
Fly Ash Unit, Ministry of Science and Technology, New Delhi	Dr Vimal Kumar
Gammon India Limited, Mumbai	Shri Avinash Y. Mahendrakar Shri Manish Mokal (*Alternate*)
Grasim Industries Limited, Mumbai	Shri A. K. Jain Dr S. P. Pande (*Alternate*)
Gujarat Engineering Research Institute, Vadodara	Shri B. M. Rao Shri K. L. Dave (*Alternate*)
Hindustan Construction Company Limited, Mumbai	Shri S. K. Dharmadhikari Shri K. R. Viswanath (*Alternate*)
Indian Concrete Institute, Chennai	Dr Anant M. Pande Secretary General (*Alternate*)
Indorama Cement Limited, Mumbai	Shri Sanjeev Parasrampuria Brig R. V. Seetaramaiah (*Alternate*)
Institute for Solid Waste Research & Ecological Balance (INSWAREB), Visakhapatnam	Dr N. Bhanumathidas Shri N. Kalidas (*Alternate*)
Lafarge India Limited, Mumbai	Shri M. K. Chaudhary Shri Anil Parashar (*Alternate*)
Madras Cements Ltd, Chennai	Shri Balaji K. Moorthy Shri Anil Kumar Pillai (*Alternate*)
Maharashtra Engineering Research Institute, Nasik	Scientific Research Officer Assistant Research Officer (*Alternate*)
Military Engineer Services, Engineer-in-Chief Branch, Army Headquarter, New Delhi	Brig Rajesh Tyagi Col Mukesh Chopra (*Alternate*)
Ministry of Commerce & Industry, New Delhi	Shri P. K. Jain Shri Shaish Kumar (*Alternate*)
Ministry of Shipping, Road Transport & Highways, New Delhi	Shri A. K. Sharma Shri Harichand Arora (*Alternate*)
National Council of Cement and Building Materials, Ballabgarh	Dr M. M. Ali Dr S. Harsh (*Alternate*)
National Hydrolectric Power Corporation Limited, Faridabad	Shri A. K. Jain
National Test House, Kolkata	Shri D. V. S. Prasad Dr Moitrayee Devi (*Alternate*)
NTPC Ltd, New Delhi	Shri A. Vijayaraman Shri Masoom Ali (*Alternate*)
OCL India Limited, New Delhi	Dr S. C. Ahluwalia
Orkla India Pvt Ltd, Navi Mumbai	Shri Kshmendranath P. Shri Prashant Jha (*Alternate*)
Public Works Department, Government of Tamil Nadu, Chennai	Joint Chief Engineer (Irrigation) Executive Engineer (*Alternate*)
Ready Mixed Concrete Manufacturers' Association, Mumbai	Shri Vijaykumar R. Kulkarni
Research, Design and Standards Organization (Ministry of Railways), Lucknow	Deputy Director (B&F) Asstt Design Engineer (B&F) (*Alternate*)
Tamil Nadu Minerals Limited, Chennai	Shri K. Sumanth Babu
Tata Steel Ltd, Jamshedpur	Shri Indranil Chakrabarti
Ultra Tech Cement Ltd, Mumbai	Shri Subrato Chowdhury Shri Biswajit Dhar (*Alternate*)
In personal capacity (*II/69, President's Estate, New Delhi*)	Shri K. H. Babu

Panel for Revision of Cement Standards, CED 2 : 1/P1

Organization	*Representative(s)*
In personal capacity (*II/69, President's Estate, New Delhi*)	SHRI K. H. BABU (***Convener***)
AIMIL Ltd, New Delhi	DR V. M. SHARMA SHRI AMAN KHULLAR (*Alternate*)
Cement Manufacturers' Association, Noida	DR D. GHOSH SHRI SANJAY JAIN (*Alternate*)
Central Building Research Institute (CSIR), Roorkee	DR S. K. AGARWAL SHRI NEERAJ JAIN (*Alternate*)
Central Public Works Department, New Delhi	SHRI A. K. GARG SHRI MANU AMITABH (*Alternate*)
Military Engineer Services, Engineer-in-Chief's Branch, Army Headquarter, New Delhi	SHRI P. K. JAIN LT-COL PRADEEP TIWARI (*Alternate*)
National Council for Cement and Building Materials, Ballabgarh	DR S. HARSH DR U. K. MANDAL (*Alternate*)
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BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.org.in

Regional Offices:		*Telephones*
Central :	Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern :	1/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern :	SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 3843 60 9285
Southern :	C.I.T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western :	Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

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(पाँचवां पुनरीक्षण)

Indian Standard

ORDINARY PORTLAND CEMENT, 33 GRADE — SPECIFICATION

(Fifth Revision)

ICS 91.100.10

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

March 2013 **Price Group 5**

Cement and Concrete Sectional Committee, CED 2

FOREWORD

This Indian Standard (Fifth Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was first published in 1951 and subsequently revised in 1958, 1967, 1976 and 1989. This revision incorporates the experience gained with the use of this standard and brings the standard in line with the latest developments in this field.

Since the fourth revision of this standard, a large number of amendments were issued from time-to-time in order to modify various requirements based on experience gained with the use of the standard and the requirements of the users, and also keeping in view the raw materials available in the country and found suitable for the manufacture of cement. The important amendments included: use of performance improvers for addition during clinker grinding stage, incorporation of requirement of chloride content for the cement used in structures other than prestressed concrete, permitting use of 25 kg, 10 kg, 5 kg, 2 kg and 1 kg bags for packing of cement, and requirements of packing cement for export. In view of the large number of amendments, the Sectional Committee decided to bring out this fifth revision of the standard incorporating all these amendments so as to make it more convenient for the users. Further, following are the significant modifications incorporated in this revision:

a) Requirement for insoluble residue has been specified as 5.0 percent, maximum irrespective of addition of performance improver(s) or otherwise.
b) An upper limit of compressive strength at 28 days, equal to the minimum requirement plus 15 MPa, has been incorporated.
c) SO_3 content requirement has been revised to 3.5 percent maximum irrespective of C_3A content, primarily to accommodate use of coal/pet coke as fuel which may have higher sulphur content; subject to the cement conforming to all the requirements of the standard.
d) A clause has been introduced requiring manufacturer to furnish a certificate indicating alkali content if required by the purchaser.
e) Requirement of marking of type and amount of performance improver(s) on the bag has been incorporated.
f) Requirement of testing the cement samples at the earliest but not later than 3 months since the receipt of samples for testing, has been included.

With the increase in SO_3 content limit in this revision, suitable caution needs to be exercized for limiting the sulphates in concrete in accordance with the provision of IS 456 : 2000 'Code of practice for plain and reinforced concrete (*fourth revision*)'.

Quantity of cement packed in bags and the tolerance requirements for the quantity of cement packed in bags shall be in accordance with the relevant provisions of the *Standards of Weights and Measures (Packaged Commodities) Rules*, 1977 and **B-1.2** (*see* Annex B). Any modification in these rules in respect of tolerance on quantity of cement would apply automatically to this standard.

This standard contains Sl No. (viii) of Table 2 and **12.2.1** which give option to the purchaser and Sl No. (v) of Table 3 and **9.2**, **9.3**, **9.4** and **9.4.3**, which call for agreement between the purchaser and the supplier.

The composition of the technical Committee responsible for the formulation of this standard is given in Annex C.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

ORDINARY PORTLAND CEMENT, 33 GRADE — SPECIFICATION

(Fifth Revision)

1 SCOPE

This standard covers the manufacture and chemical and physical requirements of 33 grade ordinary Portland cement.

2 REFERENCES

The standards given in Annex A contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 4845 shall apply.

4 MANUFACTURE

4.1 Ordinary Portland cement, 33 grade shall be manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker so as to produce a cement capable of complying with this standard. No material shall be added after burning, other than gypsum (natural mineral or chemical, *see* Note), water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including colouring agents, which have proved not to be harmful.

NOTE — Chemical gypsum shall be added provided that the performance requirements of the final product as specified in this standard are met with.

4.1.1 Limit of addition of performance improver shall be as given in Table 1 and shall be inclusive of 1 percent additives as mentioned above.

If a combination of above performance improvers is added, the maximum limit of total addition shall be 5 percent.

5 CHEMICAL REQUIREMENTS

When tested in accordance with the methods given in

Table 1 Performance Improvers
(*Clause* 4.1.1)

Sl No.	Performance Improver	Percentage Addition by Mass, *Max*	Requirement
(1)	(2)	(3)	(4)
i)	Fly ash	5	Conforming to IS 3812 (Part 1)
ii)	Granulated slag	5	Conforming to IS 12089
iii)	Silica fume	5	Conforming to IS 15388
iv)	Limestone	5	$CaCO_3$ content calculated from CaO content shall not be less than 75 percent when tested in accordance with IS 1760 (Part 3)
v)	Rice husk ash	5	a) Reactive silica shall not be less than 80 percent when tested as per IS 3812 (Part 1) b) Pozzolanic activity index shall not be less than 90 percent when tested as per **10** of 1S 1727 c) Loss on ignition shall not be more than 5.0 percent when tested as per IS 1727
vi)	Metakaolin	5	a) Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) in percent by mass shall not be less than 94.0 percent when tested as per IS 1727 b) Loss on ignition shall not be more than 2.0 percent when tested as per IS 1727 c) Total alkalis as sodium oxide (as Na_2O equivalent) in percent by mass shall not be more than 1.5 percent when tested as per IS 4032 d) Particles retained on 45 micron IS sieve (wet sieving) shall not be more than 1.5 percent when tested as per 1S 1727

IS 4032, ordinary Portland cement, 33 grade shall comply with the chemical requirements given in Table 2.

6 PHYSICAL REQUIREMENTS

Ordinary Portland cement, 33 grade shall comply with the physical requirements given in Table 3.

Table 2 Chemical Requirements for Ordinary Portland Cement, 33 Grade

(*Foreword* and *Clause* 5)

Sl No. (1)	Characteristic (2)	Requirement (3)
i)	Ratio of percentage of lime to percentages of silica, alumina and iron oxide, when calculated by the formula: $\frac{CaO - 0.7\ SO_3}{2.8\ SiO_2 + 1.2\ Al_2O_3 + 0.65\ Fe_2O_3}$	0.66-1.02
ii)	Ratio of percentage of alumina to that of iron oxide, *Min*	0.66
iii)	Insoluble residue, percent by mass, *Max*	5.0
iv)	Magnesia, percent by mass, *Max*	6.0
v)	Total sulphur content calculated as sulphuric anhydride (SO_3), percent by mass, *Max*	3.5
vi)	Loss on ignition, percent by mass, *Max*	5.0
vii)	Chloride content, percent by mass, *Max*	0.1
viii)	Alkali content	0.05 (for prestressed structures, *see* Note)

NOTE — Alkali aggregates reactions have been noticed in aggregates in some parts of the country. On large and important jobs where the concrete is likely to be exposed to humid atmosphere or wetting action, it is advisable that the aggregate be tested for alkali aggregate reaction. In the case of reactive aggregates, the use of cement with alkali content below 0.6 percent expressed as sodium oxide (Na_2O), is recommended. Where, however, such cements are not available, use of alternative means may be resorted to for which a reference may be made to **8.2.5.4** of IS 456. If so desired by the purchaser, the manufacturer shall carry out test for alkali content.

Table 3 Physical Requirements for Ordinary Portland Cement, 33 Grade

(*Foreword* and *Clause* 6)

Sl No. (1)	Characteristic (2)	Requirement (3)	Method of Test, Ref to (4)
i)	Fineness, m^2/kg, *Min*	225	IS 4031 (Part 2)
ii)	Soundness:		IS 4031 (Part 3)
	a) By Le Chatelier method, mm, *Max*	10 (See Note 1)	
	b) By autoclave test method, percent, *Max*	0.8 (See Note 1)	
iii)	Setting time:		IS 4031 (Part 5)
	a) Initial, min, *Min*	30 (See Note 2)	
	b) Final, min, *Max*	600 (See Note 2)	
iv)	Compressive strength, MPa (*see* Note 4):		IS 4031 (Part 6)
	a) 72 ± 1 h, *Min*	16	
	b) 168 ± 2 h, *Min*	22	
	c) 672 ± 4 h, *Min*	33	
	Max	48	
v)	Transverse strength (optional)	See Notes 3 and 4	IS 4031 (Part 8)

NOTES

1 In the event of cements failing to comply with any one or both the requirements of soundness specified in this table, further tests in respect of each failure shall be made as described in IS 4031 (Part 3), from another portion of the same sample after aeration. The aeration shall be done by spreading out the sample to a depth of 75 mm at a relative humidity of 50 to 80 percent for a total period of 7 days. The expansion of cements so aerated shall be not more than 5 mm and 0.6 percent when tested by Le Chatelier method and autoclave test respectively.

2 If cement exhibits false set, the ratio of final penetration measured after 5 min of completion of mixing period to the initial penetration measured exactly after 20 s of completion of mixing period, expressed as percent, shall be not less than 50. In the event of cement exhibiting false set, the initial and final setting time of cement when tested by the method described in IS 4031 (Part 5) after breaking the false set, shall conform to the value given in this table.

3 By agreement between the purchaser and the manufacturer, transverse strength test of plastic mortar in accordance with the method described in IS 4031 (Part 8) may be specified. The permissible values of the transverse strength shall be mutually agreed to between the purchaser and the supplier at the time of placing the order.

4 Notwithstanding the compressive and transverse strength requirements specified as per this table, the cement shall show a progressive increase in strength from the strength at 72 h.

7 STORAGE

The cement shall be stored in such a manner as to permit easy access for proper inspection and identification, and in a suitable weather-tight building to protect the cement from dampness and to minimize warehouse deterioration (*see also* IS 4082).

8 MANUFACTURER'S CERTIFICATE

8.1 The manufacturer shall satisfy himself that the cement conforms to the requirements of this standard and, if requested, shall furnish a test certificate to this effect to the purchaser or his representative, within ten days of testing of the cement (except for 28 days compressive strength test results, which shall be furnished after completion of the test). The type and percentage addition of performance improver(s) shall also be indicated in the certificate.

8.2 The manufacturer shall furnish a certificate indicating the alkali content, if requested.

9 PACKING

9.1 The cement shall be packed in any of the following bags:

a) jute sacking bag conforming to IS 2580;
b) multi-wall paper sacks conforming to IS 11761;
c) light weight jute conforming to IS 12154;
d) HDPE/PP woven sacks conforming to IS 11652;
e) jute synthetic union bags conforming to IS 12174; or
f) any other approved composite bag.

Bags shall be in good condition at the time of inspection.

9.1.1 The net quantity of cement per bag shall be 50 kg subject to provisions and tolerance given in Annex B.

9.2 The net quantity of cement per bag may also be 25 kg, 10 kg, 5 kg, 2 kg or 1 kg subject to tolerances as given in **9.2.1** and packed in suitable bags as agreed to between the purchaser and the manufacturer.

9.2.1 The number of bags in a sample taken for weighment showing a minus error greater than 2 percent of the specified net quantity shall be not more than 5 percent of the bags in the sample. Also the minus error in none of such bags in the sample shall exceed 4 percent of the specified net quantity of cement in the bag. However, the average of net quantity of cement in a sample shall be equal to or more than 25 kg, 10 kg, 5 kg, 2 kg or 1 kg, as the case may be.

9.3 Supplies of cement in bulk may be made by arrangement between the purchaser and the supplier (manufacturer or stockist).

NOTE — A single bag or container containing 1 000 kg and more, net quantity of cement shall be considered as the bulk supply of cement. Supplies of cement may also be made in intermediate bags/containers, for example, drums of 200 kg, by agreement between the purchaser and the manufacturer.

9.4 When cement is intended for export and if the purchaser so requires, packing of cement may be done in bags or in drums with net quantity of cement per bag or drum as agreed to between the purchaser and the manufacturer.

9.4.1 For this purpose, the permission of the certifying authority shall be obtained in advance for each export order.

9.4.2 The words 'FOR EXPORT' and the net quantity of cement per bag/drum shall be clearly marked in indelible ink on each bag/drum.

9.4.3 The packing material shall be as agreed to between the manufacturer and the purchaser.

9.4.4 The tolerance requirements for the quantity of cement packed in bags/drum shall be as given in **9.2.1** except the net quantity which shall be equal to or more than the quantity in **9.4**.

10 MARKING

10.1 Each bag of cement shall be legibly and indelibly marked with the following:

a) Manufacturer's name and his registered trade-mark;
b) The words 'Ordinary Portland Cement, 33 Grade';
c) Net quantity, in kg;
d) The words 'Use no hooks';
e) Batch/Control unit number in terms of week, month and year of packing;
f) Address of the manufacturer; and
g) Type and percentage of performance improver(s) added, in case of addition of performance improvers.

10.2 Similar information shall be provided in the delivery advices accompanying the shipment of packed or bulk cement and on cement drums (*see* **9.3**).

10.3 BIS Certification Marking

The cement may also be marked with the Standard Mark.

10.3.1 The use of the Standard Mark is governed by the provisions of the *Bureau of Indian Standards Act*, 1986 and the Rules and Regulations made thereunder. The details of conditions under which a license for the use of the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

11 SAMPLING

11.1 A sample or samples for testing may be taken by the purchaser or his representative, or by any person appointed to superintend the work for the purpose of which the cement is required or by the latter's representative.

11.1.1 The samples shall be taken within three weeks of the delivery and all the tests shall be commenced within one week of sampling.

11.1.2 When it is not possible to test the samples within one week, the samples shall be packed and stored in air-tight containers and tested at the earliest but not later than 3 months since the receipt of samples for testing.

11.2 In addition to the requirements of **11.1**, the methods and procedure of sampling shall be in accordance with IS 3535.

11.3 The manufacturer or the supplier shall afford every facility, and shall provide all labour and materials for taking and packing the samples for testing the cement and for subsequent identification of cement sampled.

12 TESTS

12.1 The sample or samples of cement for test shall be taken as described in **11** and shall be tested in the manner described in the relevant clauses.

12.2 Independent Testing

12.2.1 If the purchaser or his representative requires independent tests, the samples shall be taken before or immediately after delivery at the option of the purchaser or his representative, and the tests shall be carried out in accordance with this standard on the written instructions of the purchaser or his representative.

12.2.2 The manufacturer/supplier shall supply, free of charge, the cement required for testing. Unless otherwise specified in the enquiry and order, the cost of the tests shall be borne as follows:

a) By the manufacturer/supplier, if the results show that the cement does not comply with the requirements of this standard, and
b) By the purchaser, if the results show that the cement complies with the requirement of this standard.

12.2.3 After a representative sample has been drawn, tests on the sample shall be carried out as expeditiously as possible (*see* **11.1.1** and **11.1.2**).

13 REJECTION

13.1 Cement may be rejected if it does not comply with any of the requirements of this standard.

13.2 Cement remaining in bulk storage at the factory, prior to shipment, for more than six months, or cement in bags, in local storage such as, in the hands of a vendor for more than 3 months after completion of tests, shall be retested before use and shall be rejected if it fails to conform to any of the requirements of this standard.

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
456 : 2000	Code of practice plain and reinforced concrete (*fourth revision*)
650 : 1991	Specification for standard sand for testing of cement (*second revision*)
1727 : 1967	Methods of test for pozzolanic materials (*first revision*)
1760 (Part 3) : 1992	Methods of chemical analysis of limestone, dolomite and allied materials: Part 3 Determination of iron oxide, alumina, calcium oxide and magnesia (*first revision*)
2580 : 1995	Textiles — Jute sacking bags for packing cement — Specification (*third revision*)
3535 : 1986	Methods of sampling hydraulic cement (*first revision*)
3812 (Part 1) : 2013	Specification for pulverized fuel ash: Part 1 For use as pozzolana in cement, cement mortar and concrete (*third revision*)
4031	Methods of physical tests for hydraulic cement:

IS No.	*Title*
(Part 2) : 1999	Determination of fineness by specific surface by Blaine air permeability method (*second revision*)
(Part 3) : 1988	Determination of soundness (*first revision*)
(Part 5) : 1988	Determination of initial and final setting times (*first revision*)
(Part 6) : 1988	Determination of compressive strength of hydraulic cement (other than masonry cement) (*first revision*)
(Part 8) : 1988	Determination of transverse and compressive strength of plastic mortar using prism (*first revision*)
4032 : 1985	Methods of chemical analysis of hydraulic cement (*first revision*)
4082 : 1996	Recommendations on stacking and storage of construction materials and components at site (*second revision*)
4845 : 1968	Definitions and terminology relating to hydraulic cement
4905 : 1968	Methods for random sampling
11652 : 1986	Specification for high density polyethylene (HDPE)/polypropylene (PP) woven sacks for packing cement (*second revision*)
11761 : 1986	Specification for multi-wall paper sacks for cement (*first revision*)
12089 : 1987	Specification for granulated slag for manufacture of Portland slag cement
12154 : 1987	Light weight jute bags for packing cement
12174 : 1987	Jute synthetic union bags for packing cement
15388 : 2003	Specification for Silica fume

ANNEX B

(*Foreword* and *Clause* 9.1.1)

TOLERANCE REQUIREMENTS FOR THE QUANTITY OF CEMENT PACKED IN BAGS

B-1 The average of the net quantity of cement packed in bags at the plant in a sample shall be equal to or more than 50 kg. The number of bags in a sample shall be as given below:

Batch Size	*Sample Size*
100-150	20
151-280	32
281-500	50
501-1 200	80
1 201-3 200	125
3 201 and over	200

The bags in a sample shall be selected at random. For methods of random sampling, IS 4905 may be referred to.

B-1.1 The number of bags in a sample showing a minus error greater than 2 percent of the specified net quantity (50 kg) shall be not more than 5 percent of the bags in the sample. Also the minus error in none of such bags in a sample shall exceed 4 percent of the specified net quantity of cement in the bag.

NOTE — The matter given in **B-1** and **B-1.1** are extracts based on the *Standards of Weights and Measures (Packaged Commodities) Rules*, 1977 to which reference shall be made for full details. Any modification made in these Rules and other related Acts and Rules would apply automatically.

B-1.2 In case of a wagon/truck load of up to 25 tonne, the overall tolerance on net quantity of cement shall be 0 to 0.5 percent.

NOTE — The mass of a jute sacking bag to hold 50 kg of cement is 531 g, the mass of a 6-ply paper bag to hold 50 kg of cement is approximately 400 g, the mass of a light weight jute bag to hold 50 kg of cement is approximately 450 g, the mass of a HDPE/PP woven sack to hold 50 kg of cement is approximately 70 g/71 g respectively, and the mass of a jute synthetic union bag to hold 50 kg of cement is approximately 420 g.

ANNEX C
(*Foreword*)

COMMITTEE COMPOSITION

Cement and Concrete Sectional Committee, CED 2

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In personal capacity (*EA-92, Maya Enclave, Hari Nagar, New Delhi*)	SHRI R. C. WASON
In personal capacity (*E-1, 402, White House Apartments, R.T. Nagar, Bangalore*)	SHRI S. A. REDDI

Organization	*Representative(s)*
BIS Directorate General	SHRI A. K. SAINI, Scientist 'G' and Head (Civ Engg) [Representing Director General (*Ex-officio*)]

Member Secretaries
SHRI SANJAY PANT
Scientist 'E' & Director (Civ Engg), BIS

SHRI S. ARUN KUMAR
Scientist 'C' (Civ Engg), BIS

Cement, Pozzolana and Cement Additives Subcommittee, CED 2 : 1

In personal capacity (*E-1, 402, White House Apartments, R.T. Nagar, Bangalore*)	SHRI S. A. REDDI (***Convener***)
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Cement Manufacturers' Association, Noida	DR D. GHOSH SHRI SANJAY JAIN (*Alternate*)
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BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.org.in

Regional Offices:		*Telephones*
Central :	Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern :	1/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
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(दूसरा पुनरीक्षण)

Indian Standard

ORDINARY PORTLAND CEMENT, 43 GRADE — SPECIFICATION

(Second Revision)

ICS 91.100.10

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

March 2013

Price Group 5

Cement and Concrete Sectional Committee, CED 2

FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was first published in 1976 under the title, 'Specification for high strength ordinary Portland cement' and subsequently revised in 1989 and rechristened as 'Specification for 43 grade ordinary Portland cement'. This revision incorporates the experience gained with the use of this specification and brings the standard in line with the latest developments in this field.

Since the first revision of this standard, a large number of amendments were issued from time-to-time in order to modify various requirements based on experience gained with the use of the standard and the requirements of the users, and also keeping in view the raw materials available in the country and found suitable for the manufacture of cement. The important amendments included: use of performance improvers for addition during clinker grinding stage, incorporation of requirement of chloride content for the cement used in structures other than prestressed concrete, permitting use of 25 kg, 10 kg, 5 kg, 2 kg and 1 kg bags for packing of cement, and requirement of packing cement for export. In view of the large number of amendments, the Sectional Committee decided to bring out this second revision of the standard incorporating all these amendments so as to make it more convenient for the users. Further, following are the other significant modifications incorporated in this revision:

a) Requirement for insoluble residue has been specified as 5.0 percent, maximum irrespective of addition of performance improver(s) or otherwise.
b) An upper limit of compressive strength at 28 days, equal to the minimum requirement plus 15 MPa, has been incorporated.
c) SO_3 content requirement has been revised to 3.5 percent maximum irrespective of C_3A content, primarily to accommodate use of coal/pet coke as fuel which may have higher sulphur content; subject to the cement conforming to all the requirements of the standard.
d) A clause has been introduced requiring manufacturer to furnish a certificate indicating alkali content if required by the purchaser.
e) Requirement of marking of type and amount of performance improver(s) on the bag has been incorporated.
f) Requirement of testing the cement samples at the earliest but not later than 3 months since the receipt of samples for testing, has been included.

With the increase in SO_3 content limit in this revision, suitable caution needs to be exercized for limiting the sulphates in concrete in accordance with the provision of IS 456 : 2000 'Code of practice for plain and reinforced concrete (*fourth revision*)'.

Quantity of cement packed in bags and the tolerance requirements for the quantity of cement packed in bags shall be in accordance with the relevant provisions of the *Standards of Weights and Measures (Packaged Commodities) Rules*, 1977 and **B-1.2** (*see* Annex B). Any modification in these rules in respect of tolerance on quantity of cement would apply automatically to this standard.

This standard contains Sl No. (viii) of Table 2 and **12.2.1** which give option to the purchaser and Sl No. (v) of Table 3 and **9.2**, **9.3**, **9.4** and **9.4.3**, which call for agreement between the purchaser and the supplier.

Specific requirements of ordinary Portland cement for manufacture of railway sleepers, designated as 43-S grade cement, are given in **5.2**, Table 3 and **10.1**. To differentiate it with normal grade, '43-S grade' shall be marked on the bags/packages for such cement in place of '43 grade'.

The composition of the technical Committee responsible for the formulation of this standard is given in Annex C.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

ORDINARY PORTLAND CEMENT, 43 GRADE — SPECIFICATION

(Second Revision)

1 SCOPE

This standard covers the manufacture and chemical and physical requirements of 43 grade ordinary Portland cement.

2 REFERENCES

The standards given in Annex A contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 4845 shall apply.

4 MANUFACTURE

4.1 Ordinary Portland cement, 43 grade shall be manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker so as to produce a cement capable of complying with this standard. No material shall be added after burning, other than gypsum (natural mineral or chemical, *see* Note), water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including colouring agents, which have proved not to be harmful.

NOTE — Chemical gypsum shall be added provided that the performance requirements of the final product as specified in this standard are met with.

4.1.1 Limit of addition of performance improver shall be as given in Table 1 and shall be inclusive of 1 percent additives as mentioned above.

If a combination of above performance improvers is added, the maximum limit of total addition shall be 5 percent.

5 CHEMICAL REQUIREMENTS

5.1 When tested in accordance with the methods given in IS 4032, ordinary Portland cement, 43 grade shall comply with the chemical requirements given in Table 2.

Table 1 Performance Improvers
(*Clause* 4.1.1)

Sl No.	Performance Improver	Percentage Addition by Mass, *Max*	Requirement
(1)	(2)	(3)	(4)
i)	Fly ash	5	Conforming to IS 3812 (Part 1)
ii)	Granulated slag	5	Conforming to IS 12089
iii)	Silica fume	5	Conforming to IS 15388
iv)	Limestone	5	$CaCO_3$ content calculated from CaO content shall not be less than 75 percent when tested in accordance with IS 1760 (Part 3)
v)	Rice husk ash	5	a) Reactive silica shall not be less than 80 percent when tested as per IS 3812 (Part 1) b) Pozzolanic activity index shall not be less than 90 percent when tested as per **10** of 1S 1727 c) Loss on ignition shall not be more than 5.0 percent when tested as per IS 1727
vi)	Metakaolin	5	a) Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) in percent by mass shall not be less than 94.0 percent when tested as per IS 1727 b) Loss on ignition shall not be more than 2.0 percent when tested as per IS 1727 c) Total alkalis as sodium oxide (as Na_2O equivalent) in percent by mass shall not be more than 1.5 percent when tested as per IS 4032 d) Particles retained on 45 micron IS sieve (wet sieving) shall not be more than 1.5 percent when tested as per 1S 1727

Table 2 Chemical Requirements for Ordinary Portland Cement, 43 Grade

(*Foreword* and *Clauses* 5.1 *and* 5.2)

Sl No. (1)	Characteristic (2)	Requirement (3)
i)	Ratio of percentage of lime to percentages of silica, alumina and iron oxide, when calculated by the formula: $\frac{CaO - 0.7\,SO_3}{2.8\,SiO_2 + 1.2\,Al_2O_3 + 0.65\,Fe_2O_3}$	0.66-1.02
ii)	Ratio of percentage of alumina to that of iron oxide, *Min*	0.66
iii)	Insoluble residue, percent by mass, *Max*	4.0
iv)	Magnesia, percent by mass, *Max*	6.0
v)	Total sulphur content calculated as sulphuric anhydride (SO_3), percent by mass, *Max*	3.5
vi)	Loss on ignition, percent by mass, *Max*	5.0
vii)	Chloride content, percent by mass, *Max*	0.1
viii)	Alkali content	0.05 (for prestressed structures) See Note

NOTE — Alkali aggregates reactions have been noticed in aggregates in some parts of the country. On large and important jobs where the concrete is likely to be exposed to humid atmosphere or wetting action, it is advisable that the aggregate be tested for alkali aggregate reaction. In the case of reactive aggregates, the use of cement with alkali content below 0.6 percent expressed as sodium oxide (Na_2O), is recommended. Where, however, such cements are not available, use of alternative means may be resorted to for which a reference may be made to **8.2.5.4** of IS 456. If so desired by the purchaser, the manufacturer shall carry out test for alkali content.

5.2 Cement used for railway sleepers shall additionally satisfy the following chemical/mineralogical requirements and shall be designated as 43-S grade:

a) Magnesia, percent by mass, *Max* — 5.0

b) Tricalcium aluminate content, percent by mass, *Max* — 10.0

c) Tricalcium silicate, percent by mass, *Min* — 45.0

NOTE — The tricalcium aluminate content (C_3A) and tricalcium silicate content (C_3S) are calculated by the formula:

C_3A = 2.65 (Al_2O_3) – 1.69 (Fe_2O_3)

C_3S = 4.07 (CaO) – 7.60 (SiO_2) – 6.72 (Al_2O_3) – 1.43 (Fe_2O_3) – 2.85 (SO_3)

where each symbol in brackets refers to the percent (by mass of total cement) of the oxide, excluding any contained in insoluble residue referred to at Sl No. (iii) of Table 2.

6 PHYSICAL REQUIREMENTS

Ordinary Portland cement, 43 grade shall comply with the physical requirements given in Table 3.

7 STORAGE

The cement shall be stored in such a manner as to permit easy access for proper inspection and identification, and in a suitable weather-tight building to protect the cement from dampness and to minimize warehouse deterioration (*see also* IS 4082).

8 MANUFACTURER'S CERTIFICATE

8.1 The manufacturer shall satisfy himself that the cement conforms to the requirements of this standard and, if requested, shall furnish a test certificate to this effect to the purchaser or his representative, within ten days of testing of the cement (except for 28 days compressive strength test results, which shall be furnished after completion of the test). The type and percentage addition of performance improver(s) shall also be indicated in the certificate.

8.2 The manufacturer shall furnish a certificate indicating the alkali content, if requested.

9 PACKING

9.1 The cement shall be packed in any of the following bags:

a) jute sacking bag conforming to IS 2580;

b) multi-wall paper sacks conforming to IS 11761;

c) light weight jute conforming to IS 12154;

d) HDPE/PP woven sacks conforming to IS 11652;

e) jute synthetic union bags conforming to IS 12174; or

f) any other approved composite bag.

Bags shall be in good condition at the time of inspection.

9.1.1 The net quantity of cement per bag shall be 50 kg subject to provisions and tolerance given in Annex B.

9.2 The net quantity of cement per bag may also be 25 kg, 10 kg, 5 kg, 2 kg or 1 kg subject to tolerances

Table 3 Physical Requirements for Ordinary Portland Cement, 43 Grade
(*Foreword* and *Clause* 6)

Sl No. (1)	Characteristic (2)	Requirement (3)	Method of Test, Ref to (4)
i)	Fineness, m^2/kg, *Min*	225 370 for 43-S grade	IS 4031 (Part 2)
ii)	Soundness:		IS 4031 (Part 3)
	a) By Le Chatelier method, mm, *Max*	10 (See Note 1)	
	b) By autoclave test method, percent, *Max*	0.8 (See Note 1)	
iii)	Setting time:		IS 4031 (Part 5)
	a) Initial, min, *Min*	30 60 for 43-S grade (See Note 2)	
	b) Final, min, *Max*	600 (See Note 2)	
iv)	Compressive strength, MPa (*see* Note 4):		IS 4031 (Part 6)
	a) 72 ± 1 h, *Min*	23	
	b) 168 ± 2 h, *Min*	33 37.5 for 43-S grade	
	c) 672 ± 4 h, *Min*	43	
	Max	58	
v)	Transverse strength (optional)	See Notes 3 and 4	IS 4031 (Part 8)

NOTES

1 In the event of cements failing to comply with any one or both the requirements of soundness specified in this table, further tests in respect of each failure shall be made as described in IS 4031 (Part 3), from another portion of the same sample after aeration. The aeration shall be done by spreading out the sample to a depth of 75 mm at a relative humidity of 50 to 80 percent for a total period of 7 days. The expansion of cements so aerated shall be not more than 5 mm and 0.6 percent when tested by Le Chatelier method and autoclave test respectively. For 43-S grade cement, the requirement of soundness of unaerated cement shall be maximum expansion of 5 mm when tested by the Le Chatelier method.

2 If cement exhibits false set, the ratio of final penetration measured after 5 min of completion of mixing period to the initial penetration measured exactly after 20 s of completion of mixing period, expressed as percent, shall be not less than 50. In the event of cement exhibiting false set, the initial and final setting time of cement when tested by the method described in IS 4031 (Part 5) after breaking the false set, shall conform to the value given in this table.

3 By agreement between the purchaser and the manufacturer, transverse strength test of plastic mortar in accordance with the method described in IS 4031 (Part 8) may be specified. The permissible values of the transverse strength shall be mutually agreed to between the purchaser and the supplier at the time of placing the order.

4 Notwithstanding the compressive and transverse strength requirements specified as per this table, the cement shall show a progressive increase in strength from the strength at 72 h.

as given in **9.2.1** and packed in suitable bags as agreed to between the purchaser and the manufacturer.

9.2.1 The number of bags in a sample taken for weighment showing a minus error greater than 2 percent of the specified net quantity shall be not more than 5 percent of the bags in the sample. Also the minus error in none of such bags in the sample shall exceed 4 percent of the specified net quantity of cement in the bag. However, the average of net quantity of cement in a sample shall be equal to or more than 25 kg, 10 kg, 5 kg, 2 kg or 1 kg, as the case may be.

9.3 Supplies of cement in bulk may be made by arrangement between the purchaser and the supplier (manufacturer or stockist).

NOTE — A single bag or container containing 1 000 kg and more, net quantity of cement shall be considered as the bulk supply of cement. Supplies of cement may also be made in intermediate bags/containers, for example, drums of 200 kg, by agreement between the purchaser and the manufacturer.

9.4 When cement is intended for export and if the purchaser so requires, packing of cement may be done in bags or in drums with net quantity of cement per bag or drum as agreed to between the purchaser and the manufacturer.

9.4.1 For this purpose, the permission of the certifying authority shall be obtained in advance for each export order.

9.4.2 The words 'FOR EXPORT' and the net quantity of cement per bag/drum shall be clearly marked in indelible ink on each bag/drum.

9.4.3 The packing material shall be as agreed to between the manufacturer and the purchaser.

9.4.4 The tolerance requirements for the quantity of cement packed in bags/drum shall be as given in **9.2.1** except the net quantity which shall be equal to or more than the quantity in **9.4**.

10 MARKING

10.1 Each bag of cement shall be legibly and indelibly marked with the following:

a) Manufacturer's name and his registered trade-mark;

b) The words ‘Ordinary Portland Cement, 43 Grade’ or ‘Ordinary Portland Cement, 43-S Grade’, whichever is applicable;
c) Net quantity, in kg;
d) The words ‘Use no Hooks’;
e) Batch/control unit number in terms of week, month and year of packing;
f) Address of the manufacturer; and
g) Type and percentage of performance improver(s) added, in case of addition of performance improvers.

10.2 Similar information shall be provided in the delivery advices accompanying the shipment of packed or bulk cement and on cement drums (*see* **9.3**).

10.3 BIS Certification Marking

The cement may also be marked with the Standard Mark.

10.3.1 The use of the Standard Mark is governed by the provisions of the *Bureau of Indian Standards Act*, 1986 and the Rules and Regulations made thereunder. The details of conditions under which a license for the use of the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

11 SAMPLING

11.1 A sample or samples for testing may be taken by the purchaser or his representative, or by any person appointed to superintend the work for the purpose of which the cement is required or by the latter’s representative.

11.1.1 The samples shall be taken within three weeks of the delivery and all the tests shall be commenced within one week of sampling.

11.1.2 When it is not possible to test the samples within one week, the samples shall be packed and stored in air-tight containers and tested at the earliest but not later than 3 months since the receipt of samples for testing.

11.2 In addition to the requirements of **11.1**, the methods and procedure of sampling shall be in accordance with IS 3535.

11.3 The manufacturer or the supplier shall afford every facility, and shall provide all labour and materials for taking and packing the samples for testing the cement and for subsequent identification of cement sampled.

12 TESTS

12.1 The sample or samples of cement for test shall be taken as described in **11** and shall be tested in the manner described in the relevant clauses.

12.2 Independent Testing

12.2.1 If the purchaser or his representative requires independent tests, the samples shall be taken before or immediately after delivery at the option of the purchaser or his representative, and the tests shall be carried out in accordance with this standard on the written instructions of the purchaser or his representative.

12.2.2 The manufacturer/supplier shall supply, free of charge, the cement required for testing. Unless otherwise specified in the enquiry and order, the cost of the tests shall be borne as follows:

a) By the manufacturer/supplier, if the results show that the cement does not comply with the requirements of this standard, and
b) By the purchaser, if the results show that the cement complies with the requirement of this standard.

12.2.3 After a representative sample has been drawn, tests on the sample shall be carried out as expeditiously as possible (*see* **11.1.1** and **11.1.2**).

13 REJECTION

13.1 Cement may be rejected if it does not comply with any of the requirements of this standard.

13.2 Cement remaining in bulk storage at the factory, prior to shipment, for more than six months, or cement in bags, in local storage such as, in the hands of a vendor for more than 3 months after completion of tests, shall be retested before use and shall be rejected if it fails to conform to any of the requirements of this standard.

ANNEX A
(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
456 : 2000	Code of practice plain and reinforced concrete (*fourth revision*)
650 : 1991	Specification for standard sand for testing of cement (*second revision*)
1727 : 1967	Methods of test for pozzolanic materials (*first revision*)
1760 (Part 3) : 1992	Methods of chemical analysis of limestone, dolomite and allied materials: Part 3 Determination of iron oxide, alumina, calcium oxide and magnesia (*first revision*)
2580 : 1995	Textiles — Jute sacking bags for packing cement — Specification (*third revision*)
3535 : 1986	Methods of sampling hydraulic cements (*first revision*)
3812 (Part 1) : 2013	Specification for pulverized fuel ash: Part 1 For use as Pozzolana in cement, cement mortar and concrete (*third revision*)
4031	Methods of physical tests for hydraulic cement
(Part 2) : 1999	Determination of fineness by specific surface by Blaine air permeability method (*second revision*)
(Part 3) : 1988	Determination of soundness (*first revision*)
(Part 5) : 1988	Determination of initial and final setting times (*first revision*)
(Part 6) : 1988	Determination of compressive strength of hydraulic cement (other than masonry cement) (*first revision*)
(Part 8) : 1988	Determination of transverse and compressive strength of plastic mortar using prism (*first revision*)
4032 : 1985	Methods of chemical analysis of hydraulic cement (*first revision*)
4082 : 1996	Recommendations on stacking and storage of construction materials and components at site (*second revision*)
4845 : 1968	Definitions and terminology relating to hydraulic cement
4905 : 1968	Methods for random sampling
11652 : 1986	Specification for high density polyethylene (HDPE)/polypropylene (PP) woven sacks for packing cement (*second revision*)
11761 : 1986	Specification for multi-wall paper sacks for cement (*first revision*)
12089 : 1987	Specification for granulated slag for manufacture of Portland slag cement
12154 : 1987	Light weight jute bags for packing cement
12174 : 1987	Jute synthetic union bags for packing cement
15388 : 2003	Specification for silica fume

ANNEX B
(*Foreword* and *Clause* 9.1.1)

TOLERANCE REQUIREMENTS FOR THE QUANTITY OF CEMENT PACKED IN BAGS

B-1 The average of the net quantity of cement packed in bags at the plant in a sample shall be equal to or more than 50 kg. The number of bags in a sample shall be as given below:

Batch Size	*Sample Size*
100-150	20
151-280	32
281-500	50
501-1 200	80
1 201-3 200	125
3 201 and over	200

The bags in a sample shall be selected at random. For methods of random sampling, IS 4905 may be referred to.

B-1.1 The number of bags in a sample showing a minus error greater than 2 percent of the specified net quantity (50 kg) shall be not more than 5 percent of the bags in the sample. Also the minus error in none of such bags in a sample shall exceed 4 percent of the specified net quantity of cement in the bag.

NOTE — The matter given in **B-1** and **B-1.1** are extracts based on the *Standards of Weights and Measures (Packaged*

Commodities) Rules, 1977 to which reference shall be made for full details. Any modification made in these Rules and other related Acts and Rules would apply automatically.

B-1.2 In case of a wagon/truck load of up to 25 tonne, the overall tolerance on net quantity of cement shall be 0 to 0.5 percent.

NOTE — The mass of a jute sacking bag to hold 50 kg of cement is 531 g, the mass of a 6-ply paper bag to hold 50 kg of cement is approximately 400 g, the mass of a light weight jute bag to hold 50 kg of cement is approximately 450 g, the mass of a HDPE/PP woven sack to hold 50 kg of cement is approximately 70 g/71 g respectively, and the mass of a jute synthetic union bag to hold 50 kg of cement is approximately 420 g.

ANNEX C
(*Foreword*)

COMMITTEE COMPOSITION

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Indian standard code for structural steel design for all types of structures are given below. These are the codes which can be referred during design of steel structures. Following are the codes generally used, for any specialized design, any other code may also be referred which are not listed here.

IS: 800 : 2007 – Code of Practice for general construction in Steel

IS: 802 Part 2 : 1978 – Code of Practice for use of Structural Steel in Overhead Transmission Towers-Fabrication, Galvanizing, Inspection and Packing

IS: 806 : 1968 – Code of Practice for USE OF Steel Tubes in General Building Construction

IS: 808 : 1989 – Dimensions for Hot Rolled Steel Beam, Column, Channel and Angle Sections

IS:814 : 2004 – Covered Electrodes for Manual Metal Arc Welding of Carbon and Carbon Manganese Steel Specification

IS:816 : 1969 – Code of Practice for use of Metal Arc Welding for General Construction in Mild Steel.

IS:1161 : 1998 – Specification For Steel Tubes for Structural Purposes.

IS:1182 : 1983 – Recommended practice for radiographic examination of fusion welded butt joints in steel plates

IS:1363 Part 1 & 3 : 2002 – Black Hexagonal Headed Bolts, Screws, Nuts & Locknuts of Product Grade C- Hexagon Head Bolts (M5-M64)

IS:1367 Part 1 To 3 & 5 To 7 : 2002 – Technical Supply Conditions for Threaded Steel Fasteners

IS:1852 : 1985 – Rolling and Cutting Tolerances for Hot Rolled Steel Products

IS:2062 : 1999 – Steel For General Structural Purposes- Specification

IS:3502 : 1994 – Specification For Steel Chequered Plates

IS:3658 : 1999 – Code of Practice for Liquid Penetrant Flaw Detection

IS:3757 : 1985 High Strength Friction Grip Structural Bolts

IS:4260 : 2004 – Recommended Practice for Ultrasonic Testing of Butt Welds in Ferritic Steel

IS:5334 : 2003 – Code of Practice for MagneticFlaw Detection of Welds

IS:5369 : 1975 – General Requirements for Plain Washers and Lock Washers.

IS:5372 : 1975- Specification – Taper Washers for Channels.

IS:5374 : 1975 – Specification – Taper Washers for I – Beams

IS:6639 : 2005 – Specification for Hexagon Bolts for Steel Structures

IS:7205 : 1974 Safety Code for Erection of Structural Steel Work

IS:7215 : 1974 – Tolerances for Fabrication Of Steel Structures

IS:7307 Part 1 – 1974 – Approval Tests for Welding Procedures Part 1- Fusion Welding of Steel

IS:7310 Part 1 : 1974 – Approval Tests for Welders working to Approved Welding Procedures Part 1- Fusion Welding of Steel

IS:7318 Part 1 : 1974 – Approval Tests for Welders when Welding Procedure Approval is not required. Part 1- Fusion Welding of Steel

IS:8500 : 1991 – Weldable structural steel (Medium and High Strength qualities)

IS:9595 : 1996 Recommendation for metal arc welding of carbon manganese steel

IS:12843 : 1989 – Tolerances for Erection Of Steel Structures.

IS 456 : 2000
(Reaffirmed 2005)

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ICS 91.100.30

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SECTION 3 GENERAL DESIGN CONSIDERATION

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SECTION 5 STRUCTURAL DESIGN (LIMIT STATE METHOD)

AMENDMENT NO. 1 JUNE 2001
TO
IS 456 : 2000 PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE

(Fourth Revision)

(*Page* 2, *Foreword, last but one line*) — Substitute 'ACI 318 : 1995' *for* 'ACI 318 : 1989'.

(*Page* 11, *clause* 4) — Delete the matter 'L_w — Horizontal distance between centres of lateral restraint'.

(*Page* 15, *clause* 5.5, *Title*) — Substitute 'Chemical Admixtures' *for* 'Admixtures'.

(*Page* 17, *clause* 7.1) — Substitute the following for the existing informal table:

Placing Conditions	*Degree of Workability*	*Slump (mm)*
(1)	(2)	(3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* 7.1.1
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns;	Medium	50-100
Slipform work; Pumped concrete	Medium	75-100
Trench fill; *In-situ* piling	High	100 -150
Tremie concrete	Very high	*See* 7.1.2

NOTE — For most of the placing conditions, internal vibrators (needle vibrators) are suitable. The diameter of the needle shall be determined based on the density and spacing of reinforcement bars and thickness of sections. For tremie concrete, vibrators are not required to be used (*see also* 13.3).

(*Page* 19, *Table* 4, *column* 8, *sub-heading*) — Substitute '[illegible]' *for* '[illegible]'.

(*Page* 27, *clause* 13.5.3) — Delete.

(*Page* 29, *clause* 15.3):

a) Substitute 'specimens' *for* 'samples' in lines 2, 6 and 7.

b) Substitute 'IS 9013' *for* 'IS 9103'.

(*Page* 29, *clause* 16.1) — Substitute 'conditions' *for* 'condition' in line 3 and the following matter for the existing matter against 'a)':

'a) The mean strength determined from any group of four non-overlapping consecutive test results complying with the appropriate limits in column 2 of Table 11.'

(*Page* 29, *clause* 16.3, *para* 2) — Substitute 'col 3' *for* 'col 2'.

(*Page* 29, *clause* 16.4, *line* 2) — Substitute '16.1 or 16.2 as the case may be' *for* '16.3'.

(*Page* 30, *Table* 11, *column* 3) — Substitute '$\geq f_{ck} - 3$' *for* '$\geq f_{ck}^{-3}$' and '$\geq f_{ck} - 4$' *for* '$\geq f_{ck}^{-4}$'

(*Page* 33, *clause* 21.3, *line* 2) — Substitute '[illegible]' *for* 'section'.

[*Page* 37, *clause* 23.1.2(c)] — Substitute 'b_f' *for* 'b_t', 'l_0' *for* 'l_o', 'b' *for* 'b' and 'b_w' *for* 'b_w' in the formulae.

(*Page* 46, *clause* 26.4.2) — Substitute '8.2.2' *for* '8.2.3'.

[*Page* 49, *clause* 26.5.3.2 (c) (2), *last line*] — Substitute '6 mm' *for* '16 mm'.

(*Page* 62, *clause* 32.2.5) — Substitute 'H_{we}^2' *for* 'H_{we}' in the explanation of e_a.

(*Page* 62, *clause* 32.3.1, *line* 4) — Substitute '32.4' *for* '32.3'.

[*Page* 62, *clause* 32.4.3 (b), *line* 6] — Insert 'τ_{cw}' between the words 'but' and 'shall'.

[*Page* 65, *clause* 34.2.4.1(a), *last line*] — Insert the following after the words 'depth of footing' :

'in case of footings on soils, and at a distance equal to half the effective depth of footing'.

(*Page* 68, *Table* 18, *col* 4) — Substitute '–' *for* '1.0' against the Load Combination *DL* + *IL*.

(*Page* 72, *clause* 40.1) — Substitute '*bd*' *for* 'b_d' in the formula.

(*Page* 83, *clause* B-4.3, *line* 2) — Delete the word 'and'.

(*Page* 85, *clause* B-5.5.1, *para* 2, *line* 6) — Substitute 'Table 24' *for* 'Table 23'.

(*Page* 85, *clause* B-5.5.2) — Substitute the following for the existing formula:

'$A_s = a_v b\,(\tau_v - 2d\,\tau_c / a_v) / \sigma_{sv} \geq 0.4\,a_v b / 0.87 f_y$'

(*Page* 90, *clause* D-1.11, *line* 1) — Substitute 'Where' *for* 'Torsion'.

(*Page* 93, *Fig.* 27) — Substitute 'l_{ef}/l' *for* 'l/L'.

(*Page* 95, *Annex* F):

a) The reference to Fig. 28 given in column 1 of the text along with the explanation of the symbols used in the Fig. 28 given thereafter may be read just before the formula given for the rectangular tension zone.

b) Substitute 'compression' *for* 'campression' in the explanation of symbol 'a'.

(*Pages* 98 *to* 100, *Annex* H) — Substitute the following for the existing Annex :

ANNEX H

(Foreword)

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Dr V. Thiruvengadam	School of Planning and Architecture, New Delhi

Special Ad-Hoc Group for Revision of IS 456

Convener

Dr H. C. Visvesvaraya
'Chandrika', at 15th Cross, 63-64 East Park Road,
Malleswaram, Bangalore 560003

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(CED 2)

AMENDMENT NO. 2 SEPTEMBER 2005
TO
IS 456 : 2000 PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE

(Fourth Revision)

(*Page* 13, *clause* **5.2.1.1**, *line* 1) — Substitute 'IS 3812 (Part 1)' *for* 'Grade 1 of IS 3812'

(*Page* 13, *clause* **5.2.1.2** *and corresponding Note*) — Substitute the following for the existing:

'Silica fume conforming to IS 15388 may be used as part replacement of cement provided uniform blending with the cement is ensured.

NOTE — Silica fume is usually used in proportion of 5 to 10 percent of the cement content of a mix.'

(*Page* 13, *Note under clause* **5.2.1.3**, *line* 5) — Substitute 'be' *for* 'range from being'.

(*Page* 25, *clause* **10.3.3**, *line* 4) — Delete the word 'and'.

(*Page* 65, *clause* **34.2.4.1**, *line* 1) — Substitute 'on' *for* 'or'

[*Page* 65, *clause* **34.3.1**(a), *line* 2] — Delete the words 'extending in each direction'

(*Page* 66, *clause* **34.4.3**, *line* 5) — Substitute 'not' *for* 'no'

(*Page* 78, *Annex* A) — Substitute the following for the existing entries for IS 3812 : 1981:

'IS No.	*Title*
IS 3812 (Part 1) : 2003	Specification for pulverized fuel ash Part 1 For use as pozzolana in cement, cement mortar and concrete (*second revision*)'

(*Page* 79, *Annex* A) — Add the following at the end:

'IS No.	*Title*
IS 15388 : 2003	Specification for silica fume'

2116 BIS/07—1

(*Page* 80, B-2.1.1, *informal table*) — Insert the following in the table:

'

M55
3.6

',

(*Page* 81, *Table* 21) — Insert the following row after the last row:

'(1)	(2)	(3)	(4)
M55	17.5	13.0	1.5'

(*Page* 91, *Table* 26, *Case No.* 2, *col* 2) — Substitute 'One Short Edge Discontinuous' *for* 'One Short Edge Continuous'.

[*Page* 96, G-1.1(c), *formula*] — Substitute '$M_{u,lim}$' *for* '$M_{u lim}$'.

[*Page* 96, G-1.1(d), *last line*] — Substitute '38.1' *for* '39.1'.

(CED 2)

AMENDMENT NO. 3 AUGUST 2007
TO
IS 456 : 2000 PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE

(Fourth Revision)

(*Page* 2, *Foreword*) — Insert the following after para 8:

'The provisions for Self Compacting Concrete have been included for guidance (*see* Annex J).'

(*Page* 10) — Add the following at the end:

'ANNEX J SELF COMPACTING CONCRETE'

(*Page* 15, *clause* **5.4.4**, *last sentence*) — Delete.

(*Page* 15, *clause* **5.6.2**) — Add the following at the end:

'Reduction in design bond strength of coated bars shall be looked into.'

(*Page* 15, *clause* **5.6.3**) — Add the following after the clause and renumber the existing clause '**5.7**' as '**5.8**'.

'**5.7 Fibres**

Fibres may be added to concrete for special applications to enhance properties, for which specialist literature may be referred to.'

(*Page* 15, *clause* **6.1.3**) — Substitute the following for the existing clause:

'Concrete of grades lower than those given in Table 5 may be used for lean concrete, foundation for masonry walls or temporary reinforced concrete construction.'

[*Page* 17, *clause* **7.1** (*see also Amendment No.* 1)] — In the informal table, delete the words '*In-situ* piling' in column 1.

(*Page* 23, *Table* 9) — Number the existing note as 'NOTE 1' and add the following 'NOTE 2':

'NOTE 2 – Quantity of water required from durability point of view may be less than the value given above.'

(*Page* 29, *clause* **15.1.1**, *last line*) — Add 'in accordance with 16' at the end.

(*Page* 30, *Table* 11, *col* 2) — Substitute 'f_{ck} + 3 N/mm^2' *for* 'f_{ck} + 4 N/mm^2' against 'M 20 or above'.

[*Page* 30, *Table* 11, *col* 3 (*see also Amendment No.* 1)] — Substitute 'f_{ck} – 3 N/mm^2' *for* 'f_{ck} – 4 N/mm^2' against 'M 20 or above'.

(*Page* 42, *clause* **26.1.1**) — Add the following at the end:

'Congestion of reinforcement should be avoided during detailing. Various methods such as choosing the diameter and grade of steel carefully and bundling of reinforcement, if required, are available.'

[*Page* 45, *clause* **26.2.5.1**(a)] — Substitute the following for the existing:

'Lap splices shall not be used for bars larger than 32 mm. Bars larger than 32 mm shall be welded (*see* **12.4**) or mechanically spliced.'

[*Page* 46, *clause* **26.3.3**(b)(2), *last line*] — Substitute '300 mm' *for* '450 mm'.

[*Page* 47, *clause* **26.5.1.1**(b)] — Add the following note at the end:

'NOTE – The use of 4 percent reinforcement may involve practical difficulty in placing and compacting concrete; hence lower percentage is recommended.'

(*Page* 47, *clause* **26.5.1.2**) — Add the following note at the end:

'NOTE – The use of 4 percent reinforcement may involve practical difficulty in placing and compacting of concrete; hence lower percentage is recommended.'

(*Page* 52, *clause* **29.3.4**, *last line*) — Substitute '**32.5**' *for* '**32.4**'.

(*Page* 100, *Annex* H) — Add the following annex:

ANNEX J

(Foreword)

SELF COMPACTING CONCRETE

J-1 GENERAL

Self compacting concrete is a concrete that fills uniformly and completely every corner of formwork by its own weight without application of any vibration, without segregation, whilst maintaining homogeneity.

J-2 APPLICATION AREA

Self compacting concrete may be used in precast concrete applications or for concrete placed on site. It may be manufactured in a site batching plant or in a ready-mixed concrete plant and delivered to site by truck mixer. It may then be placed either by pumping or pouring into horizontal or vertical forms.

J-3 FEATURES OF FRESH SELF COMPACTING CONCRETE

The following are some of the features of self compacting concrete:

a) Slump flow: 600 mm, *Min.*

b) Sufficient amount of fines (< 0.125 mm) preferably in the range of 400 kg/m^3 to 600 kg/m^3. This can be achieved by having sand content more than 38 percent and using mineral admixture to the order of 25 percent to 50 percent by mass of cementitious materials.

c) Use of high range water reducing (HRWR) admixture and viscosity modifying agent (VMA) in appropriate dosages.

(CED 2)

Reprography Unit, BIS, New Delhi, India

Indian Standard

PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE

(Fourth Revision)

FOREWORD

This Indian Standard (Fourth Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was first published in 1953 under the title 'Code of practice for plain and reinforced concrete for general building construction' and subsequently revised in 1957. The code was further revised in 1964 and published under modified title 'Code of practice for plain and reinforced concrete', thus enlarging the scope of use of this code to structures other than general building construction also. The third revision was published in 1978, and it included limit state approach to design. This is the fourth revision of the standard. This revision was taken up with a view to keeping abreast with the rapid development in the field of concrete technology and to bring in further modifications/improvements in the light of experience gained while using the earlier version of the standard.

This revision incorporates a number of important changes. The major thrust in the revision is on the following lines:

a) In recent years, durability of concrete structures have become the cause of concern to all concrete technologists. This has led to the need to codify the durability requirements world over. In this revision of the code, in order to introduce in-built protection from factors affecting a structure, earlier clause on durability has been elaborated and a detailed clause covering different aspects of design of durable structure has been incorporated.

b) Sampling and acceptance criteria for concrete have been revised. With this revision acceptance criteria has been simplified in line with the provisions given in BS 5328 (Part 4):1990 'Concrete: Part 4 Specification for the procedures to be used in sampling, testing and assessing compliance of concrete'.

Some of the significant changes incorporated in Section 2 are as follows:

a) All the three grades of ordinary Portland cement, namely 33 grade, 43 grade and 53 grade and sulphate resisting Portland cement have been included in the list of types of cement used (in addition to other types of cement).

b) The permissible limits for solids in water have been modified keeping in view the durability requirements.

c) The clause on admixtures has been modified in view of the availability of new types of admixtures including superplasticizers.

d) In Table 2 'Grades of Concrete', grades higher than M 40 have been included.

e) It has been recommended that minimum grade of concrete shall be not less than M 20 in reinforced concrete work (*see also* 6.1.3).

f) The formula for estimation of modulus of elasticity of concrete has been revised.

g) In the absence of proper correlation between compacting factor, vee-bee time and slump, workability has now been specified only in terms of slump in line with the provisions in BS 5328 (Parts 1 to 4)

h) Durability clause has been enlarged to include detailed guidance concerning the factors affecting durability. The table on 'Environmental Exposure Conditions' has been modified to include 'very severe' and 'extreme' exposure conditions. This clause also covers requirements for shape and size of member, depth of concrete cover, concrete quality, requirement against exposure to aggressive chemical and sulphate attack, minimum cement requirement and maximum water cement ratio, limits of chloride content, alkali silica reaction, and importance of compaction, finishing and curing.

j) A clause on 'Quality Assurance Measures' has been incorporated to give due emphasis to good practices of concreting.

k) Proper limits have been introduced on the accuracy of measuring equipments to ensure accurate batching of concrete

m) The clause on 'Construction Joints' has been modified.

n) The clause on 'Inspection' has been modified to give more emphasis on quality assurance.

The significant changes incorporated in Section 3 are as follows:

a) Requirements for 'Fire Resistance' have been further detailed.

b) The figure for estimation of modification factor for tension reinforcement used in calculation of basic values of span to effective depth to control the deflection of flexural member has been modified.

c) Recommendations regarding effective length of cantilever have been added.

d) Recommendations regarding deflection due to lateral loads have been added.

e) Recommendations for adjustments of support moments in restrained slabs have been included.

f) In the determination of effective length of compression members, stability index has been introduced to determine sway or no sway conditions.

g) Recommendations have been made for lap length of hooks for bars in direct tension and flexural tension.

h) Recommendations regarding strength of welds have been modified.

j) Recommendations regarding cover to reinforcement have been modified. Cover has been specified based on durability requirements for different exposure conditions. The term 'nominal cover' has been introduced. The cover has now been specified based on durability requirement as well as for fire requirements.

The significant change incorporated in Section 4 is the modification of the clause on Walls. The modified clause includes design of walls against horizontal shear.

In Section 5 on limit state method a new clause has been added for calculation of enhanced shear strength of sections close to supports. Some modifications have also been made in the clause on Torsion. Formula for calculation of crack width has been added (separately given in Annex F).

Working stress method has now been given in Annex B so as to give greater emphasis to limit state design. In this Annex, modifications regarding torsion and enhanced shear strength on the same lines as in Section 5 have been made.

Whilst the common methods of design and construction have been covered in this code, special systems of design and construction of any plain or reinforced concrete structure not covered by this code may be permitted on production of satisfactory evidence regarding their adequacy and safety by analysis or test or both (*see* 19).

In this code it has been assumed that the design of plain and reinforced cement concrete work is entrusted to a qualified engineer and that the execution of cement concrete work is carried out under the direction of a qualified and experienced supervisor.

In the formulation of this standard, assistance has been derived from the following publications:

BS 5328 : Part 1 : 1991 Concrete : Part 1 Guide to specifying concrete, British Standards Institution

BS 5328 : Part 2 : 1991 Concrete : Part 2 Methods for specifying concrete mixes, British Standards Institution

BS 5328 : Part 3 : 1990 Concrete : Part 3 Specification for the procedures to be used in producing and transporting concrete, British Standards Institution

BS 5328 : Part 4 : 1990 Concrete : Part 4 Specification for the procedures to be used in sampling, testing and assessing compliance of concrete, British Standards Institution

BS 8110 : Part 1 : 1985 Structural use of concrete : Part 1 Code of practice for design and construction, British Standards Institution

BS 8110 : Part 2 : 1985 Structural use of concrete : Part 2 Code of practice for special circumstances, British Standards Institution

ACI 319 : 1989 Building code requirements for reinforced concrete, American Concrete Institute

AS 3600 : 1988 Concrete structures, Standards Association of Australia

DIN 1045 July 1988 Structural use of concrete, design and construction, Deutsches Institut fur Normung E.V.

CEB-FIP Model code 1990, Comite Euro - International Du Beton

The composition of the technical committee responsible for the formulation of this standard is given in Annex H.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

SECTION 1 GENERAL

1 SCOPE

1.1 This standard deals with the general structural use of plain and reinforced concrete.

1.1.1 For the purpose of this standard, plain concrete structures are those where reinforcement, if provided is ignored for determination of strength of the structure.

1.2 Special requirements of structures, such as shells, folded plates, arches, bridges, chimneys, blast resistant structures, hydraulic structures, liquid retaining structures and earthquake resistant structures, covered in respective standards have not been covered in this standard; these standards shall be used in conjunction with this standard.

2 REFERENCES

The Indian Standards listed in Annex A contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 4845 and IS 6461 (Parts 1 to 12) shall generally apply.

4 SYMBOLS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each; where other symbols are used, they are explained at the appropriate place:

- A – Area
- b – Breadth of beam, or shorter dimension of a rectangular column
- b_{ef} – Effective width of slab
- b_f – Effective width of flange
- b_w – Breadth of web or rib
- D – Overall depth of beam or slab or diameter of column; dimension of a rectangular column in the direction under consideration
- D_f – Thickness of flange
- DL – Dead load
- d – Effective depth of beam or slab
- d' – Depth of compression reinforcement from the highly compressed face
- E_c – Modulus of elasticity of concrete
- EL – Earthquake load
- E_s – Modulus of elasticity of steel
- e – Eccentricity
- f_{ck} – Characteristic cube compressive strength of concrete
- f_{cr} – Modulus of rupture of concrete (flexural tensile strength)
- f_{ct} – Splitting tensile strength of concrete
- f_d – Design strength
- f_y – Characteristic strength of steel
- H_w – Unsupported height of wall
- H_{we} – Effective height of wall
- I_{ef} – Effective moment of inertia
- I_{gr} – Moment of inertia of the gross section excluding reinforcement
- I_r – Moment of intertia of cracked section
- K – Stiffness of member
- k – Constant or coefficient or factor
- L_d – Development length
- LL – Live load or imposed load
- L_w – Horizontal distance between centres of lateral restraint
- l – Length of a column or beam between adequate lateral restraints or the unsupported length of a column
- l_{ef} – Effective span of beam or slab or effective length of column
- l_{ex} – Effective length about *x-x* axis
- l_{ey} – Effective length about *y-y* axis
- l_n – Clear span, face-to-face of supports
- l'_n – l'_n for shorter of the two spans at right angles
- l_x – Length of shorter side of slab
- l_y – Length of longer side of slab
- l_0 – Distance between points of zero moments in a beam
- l_1 – Span in the direction in which moments are determined, centre to centre of supports
- l_2 – Span transverse to l_1, centre to centre of supports
- l'_2 – l_2 for the shorter of the continuous spans
- M – Bending moment
- m – Modular ratio
- n – Number of samples
- P – Axial load on a compression member
- q_0 – Calculated maximum bearing pressure

q_o	–	Calculated maximum bearing pressure of soil
r	–	Radius
s	–	Spacing of stirrups or standard deviation
T	–	Torsional moment
t	–	Wall thickness
V	–	Shear force
W	–	Total load
WL	–	Wind load
w	–	Distributed load per unit area
w_d	–	Distributed dead load per unit area
w_l	–	Distributed imposed load per unit area
x	–	Depth of neutral axis
Z	–	Modulus of section
z	–	Lever arm
α, β	–	Angle or ratio
γ_f	–	Partial safety factor for load
γ_m	–	Partial safety factor for material
δ_m	–	Percentage reduction in moment
ϵ_{cc}	–	Creep strain of concrete
σ_{cbc}	–	Permissible stress in concrete in bending compression
σ_{cc}	–	Permissible stress in concrete in direct compression
σ_{mc}	–	Permissible stress in metal in direct compression
σ_{sc}	–	Permissible stress in steel in compression
σ_{st}	–	Permissible stress in steel in tension
σ_{sv}	–	Permissible tensile stress in shear reinforcement
τ_{bd}	–	Design bond stress
τ_c	–	Shear stress in concrete
$\tau_{c,max}$	–	Maximum shear stress in concrete with shear reinforcement
τ_v	–	Nominal shear stress
ϕ	–	Diameter of bar

SECTION 2 MATERIALS, WORKMANSHIP, INSPECTION AND TESTING

5 MATERIALS

5.1 Cement

The cement used shall be any of the following and the type selected should be appropriate for the intended use:

a) 33 Grade ordinary Portland cement conforming to IS 269
b) 43 Grade ordinary Portland cement conforming to IS 8112
c) 53 Grade ordinary Portland cement conforming to IS 12269
d) Rapid hardening Portland cement conforming to IS 8041
e) Portland slag cement conforming to IS 455
f) Portland pozzolana cement (fly ash based) conforming to IS 1489 (Part 1)
g) Portland pozzolana cement (calcined clay based) conforming to IS 1489 (Part 2)
h) Hydrophobic cement conforming to IS 8043
j) Low heat Portland cement conforming to IS 12600
k) Sulphate resisting Portland cement conforming to IS 12330

Other combinations of Portland cement with mineral admixtures (*see* **5.2**) of quality conforming with relevant Indian Standards laid down may also be used in the manufacture of concrete provided that there are satisfactory data on their suitability, such as performance test on concrete containing them.

5.1.1 Low heat Portland cement conforming to IS 12600 shall be used with adequate precautions with regard to removal of formwork, etc.

5.1.2 High alumina cement conforming to IS 6452 or supersulphated cement conforming to IS 6909 may be used only under special circumstances with the prior approval of the engineer-in-charge. Specialist literature may be consulted for guidance regarding the use of these types of cements.

5.1.3 The attention of the engineers-in-charge and users of cement is drawn to the fact that quality of various cements mentioned in **5.1** is to be determined on the basis of its conformity to the performance characteristics given in the respective Indian Standard Specification for that cement. Any trade-mark or any trade name indicating any special features not covered in the standard or any qualification or other special performance characteristics sometimes claimed/indicated on the bags or containers or in advertisements alongside the 'Statutory Quality Marking' or otherwise have no relation whatsoever with the characteristics guaranteed by the Quality Marking as relevant to that cement. Consumers are, therefore, advised to go by the characteristics as given in the corresponding Indian Standard Specification or seek specialist advise to avoid any problem in concrete making and construction.

5.2 Mineral Admixtures

5.2.1 *Pozzolanas*

Pozzolanic materials conforming to relevant Indian Standards may be used with the permission of the engineer-in-charge, provided uniform blending with cement is ensured.

5.2.1.1 *Fly ash (pulverized fuel ash)*

Fly ash conforming to Grade 1 of IS 3812 may be used as part replacement of ordinary Portland cement provided uniform blending with cement is ensured.

5.2.1.2 *Silica fume*

Silica fume conforming to a standard approved by the deciding authority may be used as part replacement of cement provided uniform blending with the cement is ensured.

NOTE — The silica fume (very fine non-crystalline silicon dioxide) is a by-product of the manufacture of silicon, ferrosilicon or the like, from quartz and carbon in electric arc furnace. It is usually used in proportion of 5 to 10 percent of the cement content of a mix.

5.2.1.3 *Rice husk ash*

Rice husk ash giving required performance and uniformity characteristics may be used with the approval of the deciding authority.

NOTE — Rice husk ash is produced by burning rice husk and contain large proportion of silica. To achieve amorphous state, rice husk may be burnt at controlled temperature. It is necessary to evaluate the product from a particular source for performance and uniformity since it can range from being as deleterious as silt when incorporated in concrete. Water demand and drying shrinkage should be studied before using rice husk.

5.2.1.4 *Metakaoline*

Metakaoline having fineness between 700 to 900 m²/kg may be used as pozzolanic material in concrete.

NOTE — Metakaoline is obtained by calcination of pure or refined kaolintic clay at a temperature between 650°C and 850°C, followed by grinding to achieve a fineness of 700 to 900 m²/kg. The resulting material has high pozzolanicity.

5.2.2 *Ground Granulated Blast Furnace Slag*

Ground granulated blast furnace slag obtained by grinding granulated blast furnace slag conforming to IS 12089 may be used as part replacement of ordinary

Portland cements provided uniform blending with cement is ensured.

5.3 Aggregates

Aggregates shall comply with the requirements of IS 383. As far as possible preference shall be given to natural aggregates.

5.3.1 Other types of aggregates such as slag and crushed overburnt brick or tile, which may be found suitable with regard to strength, durability of concrete and freedom from harmful effects may be used for plain concrete members, but such aggregates should not contain more than 0.5 percent of sulphates as SO_3 and should not absorb more than 10 percent of their own mass of water.

5.3.2 Heavy weight aggregates or light weight aggregates such as bloated clay aggregates and sintered fly ash aggregates may also be used provided the engineer-in-charge is satisfied with the data on the properties of concrete made with them.

NOTE—Some of the provisions of the code would require modification when these aggregates are used; specialist literature may be consulted for guidance.

5.3.3 *Size of Aggregate*

The nominal maximum size of coarse aggregate should be as large as possible within the limits specified but in no case greater than one-fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all reinforcement thoroughly and fill the corners of the form. For most work, 20 mm aggregate is suitable. Where there is no restriction to the flow of concrete into sections, 40 mm or larger size may be permitted. In concrete elements with thin sections, closely spaced reinforcement or small cover, consideration should be given to the use of 10 mm nominal maximum size.

Plums above 160 mm and up to any reasonable size may be used in plain concrete work up to a maximum limit of 20 percent by volume of concrete when specifically permitted by the engineer-in-charge. The plums shall be distributed evenly and shall be not closer than 150 mm from the surface.

5.3.3.1 For heavily reinforced concrete members as in the case of ribs of main beams, the nominal maximum size of the aggregate should usually be restricted to 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to the reinforcement whichever is smaller.

5.3.4 Coarse and fine aggregate shall be batched separately. All-in-aggregate may be used only where specifically permitted by the engineer-in-charge.

5.4 Water

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel.

Potable water is generally considered satisfactory for mixing concrete. As a guide the following concentrations represent the maximum permissible values:

a) To neutralize 100 ml sample of water, using phenolphthalein as an indicator, it should not require more than 5 ml of 0.02 normal NaOH. The details of test are given in 8.1 of IS 3025 (Part 22).

b) To neutralize 100 ml sample of water, using mixed indicator, it should not require more than 25 ml of 0.02 normal H_2SO_4. The details of test shall be as given in 8 of IS 3025 (Part 23).

c) Permissible limits for solids shall be as given in Table 1.

5.4.1 In case of doubt regarding development of strength, the suitability of water for making concrete shall be ascertained by the compressive strength and initial setting time tests specified in 5.4.1.2 and 5.4.1.3.

5.4.1.1 The sample of water taken for testing shall represent the water proposed to be used for concreting, due account being paid to seasonal variation. The sample shall not receive any treatment before testing other than that envisaged in the regular supply of water proposed for use in concrete. The sample shall be stored in a clean container previously rinsed out with similar water.

5.4.1.2 Average 28 days compressive strength of at least three 150 mm concrete cubes prepared with water proposed to be used shall not be less than 90 percent of the average of strength of three similar concrete cubes prepared with distilled water. The cubes shall be prepared, cured and tested in accordance with the requirements of IS 516.

5.4.1.3 The initial setting time of test block made with the appropriate cement and the water proposed to be used shall not be less than 30 min and shall not differ by ± 30 min from the initial setting time of control test block prepared with the same cement and distilled water. The test blocks shall be prepared and tested in accordance with the requirements of IS 4031 (Part 5).

5.4.2 The *p*H value of water shall be not less than 6.

5.4.3 *Sea Water*

Mixing or curing of concrete with sea water is not recommended because of presence of harmful salts in sea water. Under unavoidable circumstances sea water may be used for mixing or curing in plain concrete with no embedded steel after having given due consideration to possible disadvantages and precautions including use of appropriate cement system.

Table 1 Permissible Limit for Solids

(*Clause* 5.4)

Sl No.		Tested as per	Permissible Limit, Max
i)	Organic	IS 3025 (Part 18)	200 mg/l
ii)	Inorganic	IS 3025 (Part 18)	3 000 mg/l
iii)	Sulphates (as SO_3)	IS 3025 (Part 24)	400 mg/l
iv)	Chlorides (as Cl)	IS 3025 (Part 32)	2 000 mg/l for concrete not containing embedded steel and 500 mg/l for reinforced concrete work
v)	Suspended matter	IS 3025 (Part 17)	2 000 mg/l

5.4.4 Water found satisfactory for mixing is also suitable for curing concrete. However, water used for curing should not produce any objectionable stain or unsightly deposit on the concrete surface. The presence of tannic acid or iron compounds is objectionable.

5.5 Admixtures

5.5.1 Admixture, if used shall comply with IS 9103. Previous experience with and data on such materials should be considered in relation to the likely standards of supervision and workmanship to the work being specified.

5.5.2 Admixtures should not impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement.

5.5.3 The workability, compressive strength and the slump loss of concrete with and without the use of admixtures shall be established during the trial mixes before use of admixtures.

5.5.4 The relative density of liquid admixtures shall be checked for each drum containing admixtures and compared with the specified value before acceptance.

5.5.5 The chloride content of admixtures shall be independently tested for each batch before acceptance.

5.5.6 If two or more admixtures are used simultaneously in the same concrete mix, data should be obtained to assess their interaction and to ensure their compatibility.

5.6 Reinforcement

The reinforcement shall be any of the following:

a) Mild steel and medium tensile steel bars conforming to IS 432 (Part 1).

b) High strength deformed steel bars conforming to IS 1786.

c) Hard-drawn steel wire fabric conforming to IS 1566.

d) Structural steel conforming to Grade A of IS 2062.

5.6.1 All reinforcement shall be free from loose mill scales, loose rust and coats of paints, oil, mud or any other substances which may destroy or reduce bond. Sand blasting or other treatment is recommended to clean reinforcement.

5.6.2 Special precautions like coating of reinforcement may be required for reinforced concrete elements in exceptional cases and for rehabilitation of structures. Specialist literature may be referred to in such cases.

5.6.3 The modulus of elasticity of steel shall be taken as $200\ kN/mm^2$. The characteristic yield strength of different steel shall be assumed as the minimum yield stress/0.2 percent proof stress specified in the relevant Indian Standard.

5.7 Storage of Materials

Storage of materials shall be as described in IS 4082.

6 CONCRETE

6.1 Grades

The concrete shall be in grades designated as per Table 2.

6.1.1 The characteristic strength is defined as the strength of material below which not more than 5 percent of the test results are expected to fall.

6.1.2 The minimum grade of concrete for plain and reinforced concrete shall be as per Table 5.

6.1.3 Concrete of grades lower than those given in Table 5 may be used for plain concrete constructions, lean concrete, simple foundations, foundation for masonry walls and other simple or temporary reinforced concrete construction.

6.2 Properties of Concrete

6.2.1 *Increase of Strength with Age*

There is normally a gain of strength beyond 28 days. The quantum of increase depends upon the grade and type of cement, curing and environmental conditions, etc. The design should be based on 28 days characteristic strength of concrete unless there is a evidence to

Table 2 Grades of Concrete

(Clause 6.1, 9.2.2, 15.1.1 and 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm²
(1)	(2)	(3)
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

NOTES

1 In the designation of concrete mix M refers to the mix and the number to the specified compressive strength of 150 mm size cube at 28 days, expressed in N/mm².

2 For concrete of compressive strength greater than M 55, design parameters given in the standard may not be applicable and the values may be obtained from specialized literatures and experimental results.

justify a higher strength for a particular structure due to age.

6.2.1.1 For concrete of grade M 30 and above, the rate of increase of compressive strength with age shall be based on actual investigations.

6.2.1.2 Where members are subjected to lower direct load during construction, they should be checked for stresses resulting from combination of direct load and bending during construction.

6.2.2 *Tensile Strength of Concrete*

The flexural and splitting tensile strengths shall be obtained as described in IS 516 and IS 5816 respectively. When the designer wishes to use an estimate of the tensile strength from the compressive strength, the following formula may be used:

Flexural strength, $f_{cr} = 0.7\sqrt{f_{ck}}$ N/mm²

where f_{ck} is the characteristic cube compressive strength of concrete in N/mm².

6.2.3 *Elastic Deformation*

The modulus of elasticity is primarily influenced by the elastic properties of the aggregate and to a lesser extent by the conditions of curing and age of the concrete, the mix proportions and the type of cement. The modulus of elasticity is normally related to the compressive strength of concrete.

6.2.3.1 The modulus of elasticity of concrete can be assumed as follows:

$$E_c = 5\,000\sqrt{f_{ck}}$$

where

E_c is the short term static modulus of elasticity in N/mm².

Actual measured values may differ by ± 20 percent from the values obtained from the above expression.

6.2.4 *Shrinkage*

The total shrinkage of concrete depends upon the constituents of concrete, size of the member and environmental conditions. For a given humidity and temperature, the total shrinkage of concrete is most influenced by the total amount of water present in the concrete at the time of mixing and, to a lesser extent, by the cement content.

6.2.4.1 In the absence of test data, the approximate value of the total shrinkage strain for design may be taken as 0.000 3 (for more information, *see* IS 1343).

6.2.5 *Creep of Concrete*

Creep of concrete depends, in addition to the factors listed in **6.2.4**, on the stress in the concrete, age at loading and the duration of loading. As long as the stress in concrete does not exceed one-third of its characteristic compressive strength, creep may be assumed to be proportional to the stress.

6.2.5.1 In the absence of experimental data and detailed information on the effect of the variables, the ultimate creep strain may be estimated from the following values of creep coefficient (that is, ultimate creep strain/elastic strain at the age of loading); for long span structure, it is advisable to determine actual creep strain, likely to take place:

Age at Loading	*Creep Coefficient*
7 days	2.2
28 days	1.6
1 year	1.1

NOTE — The ultimate creep strain, estimated as described above does not include the elastic strain.

6.2.6 *Thermal Expansion*

The coefficient of thermal expansion depends on nature of cement, the aggregate, the cement content, the relative humidity and the size of sections. The value of coefficient of thermal expansion for concrete with different aggregates may be taken as below:

Type of Aggregate	*Coefficient of Thermal Expansion for Concrete/°C*
Quartzite	1.2 to 1.3×10^{-5}
Sandstone	0.9 to 1.2×10^{-5}
Granite	0.7 to 0.95×10^{-5}
Basalt	0.8 to 0.95×10^{-5}
Limestone	0.6 to 0.9×10^{-5}

7 WORKABILITY OF CONCRETE

7.1 The concrete mix proportions chosen should be such that the concrete is of adequate workability for the placing conditions of the concrete and can properly be compacted with the means available. Suggested ranges of workability of concrete measured in accordance with IS 1199 are given below:

Placing Conditions	*Degree of Workability*	*Slump* (mm)
(1)	(2)	(3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* 7.1.1
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns;	Medium	50-100
Slipform work; Pumped concrete		75-100
Trench fill; *In-situ* piling	High	100-150
Tremie concrete	Very high	*See* 7.1.2

NOTE - For most of the placing conditions, internal vibrators (needle vibrators) are suitable. The diameter of the needle shall be determined based on the density and spacing of reinforcement bars and thickness of sections. For tremie concrete, vibrators are not required to be used (*see also* 13.3).

7.1.1 In the 'very low' category of workability where strict control is necessary, for example, pavement quality concrete, measurement of workability by determination of compacting factor will be more appropriate than slump (*see* IS 1199) and a value of compacting factor of 0.75 to 0.80 is suggested.

7.1.2 In the 'very high' category of workability, measurement of workability by determination of flow will be appropriate (*see* IS 9103).

8 DURABILITY OF CONCRETE

8.1 General

A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service. The materials and mix proportions specified and used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.

8.1.1 One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. Impermeability is governed by the constituents and workmanship used in making the concrete. With normal-weight aggregates a suitably low permeability is achieved by having an adequate cement content, sufficiently low free water/cement ratio, by ensuring complete compaction of the concrete, and by adequate curing.

The factors influencing durability include:

a) the environment;

b) the cover to embedded steel;

c) the type and quality of constituent materials;

d) the cement content and water/cement ratio of the concrete;

e) workmanship, to obtain full compaction and efficient curing; and

f) the shape and size of the member.

The degree of exposure anticipated for the concrete during its service life together with other relevant factors relating to mix composition, workmanship, design and detailing should be considered. The concrete mix to provide adequate durability under these conditions should be chosen taking account of the accuracy of current testing regimes for control and compliance as described in this standard.

8.2 Requirements for Durability

8.2.1 *Shape and Size of Member*

The shape or design details of exposed structures should be such as to promote good drainage of water and to avoid standing pools and rundown of water. Care should also be taken to minimize any cracks that may collect or transmit water. Adequate curing is essential to avoid the harmful effects of early loss of moisture (*see* 13.5). Member profiles and their intersections with other members shall be designed and detailed in a way to ensure easy flow of concrete and proper compaction during concreting.

Concrete is more vulnerable to deterioration due to chemical or climatic attack when it is in thin sections, in sections under hydrostatic pressure from one side only, in partially immersed sections and at corners and edges of elements. The life of the structure can be lengthened by providing extra cover to steel, by chamfering the corners or by using circular cross-sections or by using surface coatings which prevent or reduce the ingress of water, carbon dioxide or aggressive chemicals.

8.2.2 *Exposure Conditions*

8.2.2.1 *General environment*

The general environment to which the concrete will be exposed during its working life is classified into five levels of severity, that is, mild, moderate, severe, very severe and extreme as described in Table 3.

Table 3 Environmental Exposure Conditions

(*Clauses* 8.2.2.1 *and* 35.3.2)

Sl No.	Environment	Exposure Conditions
(1)	(2)	(3)
i)	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area
ii)	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet
		Concrete exposed to condensation and rain
		Concrete continuously under water
		Concrete in contact or buried under non-aggressive soil/ground water
		Concrete surfaces sheltered from saturated salt air in coastal area
iii)	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation
		Concrete completely immersed in sea water
		Concrete exposed to coastal environment
iv)	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet
		Concrete in contact with or buried under aggressive sub-soil/ground water
v)	Extreme	Surface of members in tidal zone
		Members in direct contact with liquid/solid aggressive chemicals

8.2.2.2 *Abrasive*

Specialist literatures may be referred to for durability requirements of concrete surfaces exposed to abrasive action, for example, in case of machinery and metal tyres.

8.2.2.3 *Freezing and thawing*

Where freezing and thawing actions under wet conditions exist, enhanced durability can be obtained by the use of suitable air entraining admixtures. When concrete lower than grade M 50 is used under these conditions, the mean total air content by volume of the fresh concrete at the time of delivery into the construction should be:

Nominal Maximum Size Aggregate (mm)	*Entrained Air Percentage*
20	5 ± 1
40	4 ± 1

Since air entrainment reduces the strength, suitable adjustments may be made in the mix design for achieving required strength.

8.2.2.4 *Exposure to sulphate attack*

Table 4 gives recommendations for the type of cement, maximum free water/cement ratio and minimum cement content, which are required at different sulphate concentrations in near-neutral ground water having pH of 6 to 9.

For the very high sulphate concentrations in Class 5 conditions, some form of lining such as polyethylene or polychloroprene sheet; or surface coating based on asphalt, chlorinated rubber, epoxy; or polyurethane materials should also be used to prevent access by the sulphate solution.

8.2.3 *Requirement of Concrete Cover*

8.2.3.1 The protection of the steel in concrete against corrosion depends upon an adequate thickness of good quality concrete.

8.2.3.2 The nominal cover to the reinforcement shall be provided as per **26.4**.

8.2.4 *Concrete Mix Proportions*

8.2.4.1 *General*

The free water-cement ratio is an important factor in governing the durability of concrete and should always be the lowest value. Appropriate values for minimum cement content and the maximum free water-cement ratio are given in Table 5 for different exposure conditions. The minimum cement content and maximum water-cement ratio apply to 20 mm nominal maximum size aggregate. For other sizes of aggregate they should be changed as given in Table 6.

8.2.4.2 *Maximum cement content*

Cement content not including fly ash and ground granulated blast furnace slag in excess of 450 kg/m^3 should not be used unless special consideration has been given in design to the increased risk of cracking due to drying shrinkage in thin sections, or to early thermal cracking and to the increased risk of damage due to alkali silica reactions.

Table 4 Requirements for Concrete Exposed to Sulphate Attack

(Clauses 8.2.2.4 and 9.1.2)

Sl No.	Class	Concentration of Sulphates, Expressed as SO_3			Type of Cement	Dense, Fully Compacted Concrete, Made with 20 mm Nominal Maximum Size Aggregates Complying with IS 383	
		In Soil		In Ground Water		Minimum Cement Content kg/m^3	Maximum Free Water-Cement Ratio
		Total SO_3 Percent	SO_3 in 2:1 Water: Soil Extract g/l	g/l			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	1	Traces (< 0.2)	Less than 1.0	Less than 0.3	Ordinary Portland cement or Portland slag cement or Portland pozzolana cement	280	0.55
ii)	2	0.2 to 0.5	1.0 to 1.9	0.3 to 1.2	Ordinary Portland cement or Portland slag cement or Portland pozzolana cement	330	0.50
					Supersulphated cement or sulphate resisting Portland cement	310	0.50
iii)	3	0.5 to 1.0	1.9 to 3.1	1.2 to 2.5	Supersulphated cement or sulphate resisting Portland cement	330	0.50
					Portland pozzolana cement or Portland slag cement	350	0.45
iv)	4	1.0 to 2.0	3.1 to 5.0	2.5 to 5.0	Supersulphated or sulphate resisting Portland cement	370	0.45
v)	5	More than 2.0	More than 5.0	More than 5.0	Sulphate resisting Portland cement or supersulphated cement with protective coatings	400	0.40

NOTES

1 Cement content given in this table is irrespective of grades of cement.

2 Use of supersulphated cement is generally restricted where the prevailing temperature is above 40°C.

3 Supersulphated cement gives an acceptable life provided that the concrete is dense and prepared with a water-cement ratio of 0.4 or less, in mineral acids, down to pH 3.5.

4 The cement contents given in col 6 of this table are the minimum recommended. For SO_3 contents near the upper limit of any class, cement contents above these minimum are advised.

5 For severe conditions, such as thin sections under hydrostatic pressure on one side only and sections partly immersed, considerations should be given to a further reduction of water-cement ratio.

6 Portland slag cement conforming to IS 455 with slag content more than 50 percent exhibits better sulphate resisting properties.

7 Where chloride is encountered along with sulphates in soil or ground water, ordinary Portland cement with C_3A content from 5 to 8 percent shall be desirable to be used in concrete, instead of sulphate resisting cement. Alternatively, Portland slag cement conforming to IS 455 having more than 50 percent slag or a blend of ordinary Portland cement and slag may be used provided sufficient information is available on performance of such blended cements in these conditions.

8.2.5 *Mix Constituents*

8.2.5.1 *General*

For concrete to be durable, careful selection of the mix and materials is necessary, so that deleterious constituents do not exceed the limits.

8.2.5.2 *Chlorides in concrete*

Whenever there is chloride in concrete there is an increased risk of corrosion of embedded metal. The higher the chloride content, or if subsequently exposed to warm moist conditions, the greater the risk of corrosion. All constituents may contain chlorides and concrete may be contaminated by chlorides from the external environment. To minimize the chances of deterioration of concrete from harmful chemical salts, the levels of such harmful salts in concrete coming from concrete materials, that is, cement, aggregates water and admixtures, as well as by diffusion from the environment should be limited. The total amount of chloride content (as Cl) in the concrete at the time of placing shall be as given in Table 7.

The total acid soluble chloride content should be calculated from the mix proportions and the measured chloride contents of each of the constituents. Wherever possible, the total chloride content of the concrete should be determined.

8.2.5.3 *Sulphates in concrete*

Sulphates are present in most cements and in some aggregates; excessive amounts of water-soluble sulphate from these or other mix constituents can cause expansion and disruption of concrete. To prevent this, the total water-soluble sulphate content of the concrete mix, expressed as SO_3, should not exceed 4 percent by mass of the cement in the mix. The sulphate content should be calculated as the total from the various constituents of the mix.

The 4 percent limit does not apply to concrete made with supersulphated cement complying with IS 6909.

8.2.5.4 *Alkali-aggregate reaction*

Some aggregates containing particular varieties of silica may be susceptible to attack by alkalis (Na_2O and K_2O) originating from cement or other sources, producing an expansive reaction which can cause cracking and disruption of concrete. Damage to concrete from this reaction will normally only occur when all the following are present together:

a) A high moisture level, within the concrete;

b) A cement with high alkali content, or another source of alkali;

c) Aggregate containing an alkali reactive constituent.

Where the service records of particular cement/aggregate combination are well established, and do not include any instances of cracking due to alkali-aggregate reaction, no further precautions should be necessary. When the materials are unfamiliar, precautions should take one or more of the following forms:

a) Use of non-reactive aggregate from alternate sources.

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses* 6.1.2, 8.2.4.1 *and* 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60		300	0.55	M 20
ii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

NOTES

1 Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in 5.2. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part 1) and IS 455 respectively.

2 Minimum grade for plain concrete under mild exposure condition is not specified.

Table 6 Adjustments to Minimum Cement Contents for Aggregates Other Than 20 mm Nominal Maximum Size

(*Clause* 8.2.4.1)

Sl No.	Nominal Maximum Aggregate Size mm	Adjustments to Minimum Cement Contents in Table 5 kg/m³
(1)	(2)	(3)
i)	10	+40
ii)	20	0
iii)	40	–30

Table 7 Limits of Chloride Content of Concrete

(*Clause* 8.2.5.2)

Sl No.	Type or Use of Concrete	Maximum Total Acid Soluble Chloride Content Expressed as kg/m³ of Concrete
(1)	(2)	(3)
i)	Concrete containing metal and steam cured at elevated temperature and pre-stressed concrete	0.4
ii)	Reinforced concrete or plain concrete containing embedded metal	0.6
iii)	Concrete not containing embedded metal or any material requiring protection from chloride	3.0

b) Use of low alkali ordinary Portland cement having total alkali content not more than 0.6 percent (as Na_2O equivalent).

Further advantage can be obtained by use of fly ash (Grade I) conforming to IS 3812 or granulated blastfurnace slag conforming to IS 12089 as part replacement of ordinary Portland cement (having total alkali content as Na_2O equivalent not more than 0.6 percent), provided fly ash content is at least 20 percent or slag content is at least 50 percent.

c) Measures to reduce the degree of saturation of the concrete during service such as use of impermeable membranes.

d) Limiting the cement content in the concrete mix and thereby limiting total alkali content in the concrete mix. For more guidance specialist literatures may be referred.

8.2.6 *Concrete in Aggressive Soils and Water*

8.2.6.1 *General*

The destructive action of aggressive waters on concrete is progressive. The rate of deterioration decreases as the concrete is made stronger and more impermeable, and increases as the salt content of the water increases. Where structures are only partially immersed or are in contact with aggressive soils or waters on one side only, evaporation may cause serious concentrations of salts with subsequent deterioration, even where the original salt content of the soil or water is not high.

NOTE — Guidance regarding requirements for concrete exposed to sulphate attack is given in 8.2.2.4.

8.2.6.2 *Drainage*

At sites where alkali concentrations are high or may become very high, the ground water should be lowered by drainage so that it will not come into direct contact with the concrete.

Additional protection may be obtained by the use of chemically resistant stone facing or a layer of plaster of Paris covered with suitable fabric, such as jute thoroughly impregnated with bituminous material.

8.2.7 *Compaction, Finishing and Curing*

Adequate compaction without segregation should be ensured by providing suitable workability and by employing appropriate placing and compacting equipment and procedures. Full compaction is particularly important in the vicinity of construction and movement joints and of embedded water bars and reinforcement.

Good finishing practices are essential for durable concrete.

Overworking the surface and the addition of water/cement to aid in finishing should be avoided; the resulting laitance will have impaired strength and durability and will be particularly vulnerable to freezing and thawing under wet conditions.

It is essential to use proper and adequate curing techniques to reduce the permeability of the concrete and enhance its durability by extending the hydration of the cement, particularly in its surface zone (*see* 13.5).

8.2.8 *Concrete in Sea-water*

Concrete in sea-water or exposed directly along the sea-coast shall be at least M 20 Grade in the case of plain concrete and M 30 in case of reinforced concrete. The use of slag or pozzolana cement is advantageous under such conditions.

8.2.8.1 Special attention shall be given to the design of the mix to obtain the densest possible concrete; slag, broken brick, soft limestone, soft sandstone, or other porous or weak aggregates shall not be used.

8.2.8.2 As far as possible, preference shall be given to precast members unreinforced, well-cured and hardened, without sharp corners, and having trowel-smooth finished surfaces free from crazing, cracks or other defects; plastering should be avoided.

8.2.8.3 No construction joints shall be allowed within 600 mm below low water-level or within 600 mm of the upper and lower planes of wave action. Where unusually severe conditions or abrasion are anticipated, such parts of the work shall be protected by bituminous or silico-fluoride coatings or stone facing bedded with bitumen.

8.2.8.4 In reinforced concrete structures, care shall be taken to protect the reinforcement from exposure to saline atmosphere during storage, fabrication and use. It may be achieved by treating the surface of reinforcement with cement wash or by suitable methods.

9 CONCRETE MIX PROPORTIONING

9.1 Mix Proportion

The mix proportions shall be selected to ensure the workability of the fresh concrete and when concrete is hardened, it shall have the required strength, durability and surface finish.

9.1.1 The determination of the proportions of cement, aggregates and water to attain the required strengths shall be made as follows:

a) By designing the concrete mix; such concrete shall be called 'Design mix concrete', or

b) By adopting nominal concrete mix; such concrete shall be called 'Nominal mix concrete'.

Design mix concrete is preferred to nominal mix. If design mix concrete cannot be used for any reason on the work for grades of M 20 or lower, nominal mixes may be used with the permission of engineer-in-charge, which, however, is likely to involve a higher cement content.

9.1.2 *Information Required*

In specifying a particular grade of concrete, the following information shall be included:

a) Type of mix, that is, design mix concrete or nominal mix concrete;

b) Grade designation;

c) Type of cement;

d) Maximum nominal size of aggregate;

e) Minimum cement content (for design mix concrete);

f) Maximum water-cement ratio;

g) Workability;

h) Mix proportion (for nominal mix concrete);

j) Exposure conditions as per Tables 4 and 5;

k) Maximum temperature of concrete at the time of placing;

m) Method of placing; and

n) Degree of supervision.

9.1.2.1 In appropriate circumstances, the following additional information may be specified:

a) Type of aggregate,

b) Maximum cement content, and

c) Whether an admixture shall or shall not be used and the type of admixture and the condition of use.

9.2 Design Mix Concrete

9.2.1 As the guarantor of quality of concrete used in the construction, the constructor shall carry out the mix design and the mix so designed (not the method of design) shall be approved by the employer within the limitations of parameters and other stipulations laid down by this standard.

9.2.2 The mix shall be designed to produce the grade of concrete having the required workability and a characteristic strength not less than appropriate values given in Table 2. The target mean strength of concrete mix should be equal to the characteristic strength plus 1.65 times the standard deviation.

9.2.3 Mix design done earlier not prior to one year may be considered adequate for later work provided there is no change in source and the quality of the materials.

9.2.4 *Standard Deviation*

The standard deviation for each grade of concrete shall be calculated, separately.

9.2.4.1 *Standard deviation based on test strength of sample*

a) *Number of test results of samples*—The total number of test strength of samples required to constitute an acceptable record for calculation of standard deviation shall be not less than 30. Attempts should be made to obtain the 30 samples, as early as possible, when a mix is used for the first time.

b) *In case of significant changes in concrete*—When significant changes are made in the production of concrete batches (for example changes in the materials used, mix design, equipment or technical control), the standard deviation value shall be separately calculated for such batches of concrete.

c) *Standard deviation to be brought up to date*—The calculation of the standard deviation shall be brought up to date after every change of mix design.

9.2.4.2 *Assumed standard deviation*

Where sufficient test results for a particular grade of concrete are not available, the value of standard deviation given in Table 8 may be assumed for design of mix in the first instance. As soon as the results of samples are available, actual calculated standard deviation shall be used and the mix designed properly.

However, when adequate past records for a similar grade exist and justify to the designer a value of standard deviation different from that shown in Table 8, it shall be permissible to use that value.

Table 8 Assumed Standard Deviation

(*Clause* 9.2.4.2 and Table 11)

Grade of Concrete	Assumed Standard Deviation N/mm²
M 10 M 15	3.5
M 20 M 25	4.0
M 30 M 35 M 40 M 45 M 50	5.0

NOTE—The above values correspond to the site control having proper storage of cement; weigh batching of all materials; controlled addition of water; regular checking of all materials, aggregate gradings and moisture content; and periodical checking of workability and strength. Where there is deviation from the above the values given in the above table shall be increased by 1N/mm².

9.3 Nominal Mix Concrete

Nominal mix concrete may be used for concrete of M 20 or lower. The proportions of materials for nominal mix concrete shall be in accordance with Table 9.

9.3.1 The cement content of the mix specified in Table 9 for any nominal mix shall be proportionately increased if the quantity of water in a mix has to be increased to overcome the difficulties of placement and compaction, so that the water-cement ratio as specified is not exceeded.

10 PRODUCTION OF CONCRETE

10.1 Quality Assurance Measures

10.1.1 In order that the properties of the completed structure be consistent with the requirements and the assumptions made during the planning and the design, adequate quality assurance measures shall be taken. The construction should result in satisfactory strength, serviceability and long term durability so as to lower the overall life-cycle cost. Quality assurance in construction activity relates to proper design, use of adequate materials and components to be supplied by the producers, proper workmanship in the execution of works by the contractor and ultimately proper care during the use of structure including timely maintenance and repair by the owner.

10.1.2 Quality assurance measures are both technical and organizational. Some common cases should be specified in a general Quality Assurance Plan which shall identify the key elements necessary to provide fitness of the structure and the means by which they are to be provided and measured with the overall purpose to provide confidence that the realized project will work satisfactorily in service fulfilling intended needs. The job of quality control and quality assurance would involve quality audit of both the inputs as well as the outputs. Inputs are in the form of materials for concrete; workmanship in all stages of batching, mixing, transportation, placing, compaction and curing; and the related plant, machinery and equipments; resulting in the output in the form of concrete in place. To ensure proper performance, it is necessary that each step in concreting which will be covered by the next step is inspected as the work proceeds (*see also* 17).

Table 9 Proportions for Nominal Mix Concrete

(*Clauses* 9.3 *and* 9.3.1)

Grade of Concrete	Total Quantity of Dry Aggregates by Mass per 50 kg of Cement, to be Taken as the Sum of the Individual Masses of Fine and Coarse Aggregates, kg, *Max*	Proportion of Fine Aggregate to Coarse Aggregate (by Mass)	Quantity of Water per 50 kg of Cement, *Max* l
(1)	(2)	(3)	(4)
M 5	800	Generally 1:2 but subject to an upper limit of 1:1½ and a lower limit of 1:2½	60
M 7.5	625		45
M 10	480		34
M 15	330		32
M 20	250		30

NOTE—The proportion of the fine to coarse aggregates should be adjusted from upper limit to lower limit progressively as the grading of fine aggregates becomes finer and the maximum size of coarse aggregate becomes larger. Graded coarse aggregate shall be used.

Example

For an average grading of fine aggregate (that is, Zone II of Table 4 of IS 383), the proportions shall be 1:1½, 1:2 and 1:2½ for maximum size of aggregates 10 mm, 20 mm and 40 mm respectively.

10.1.3 Each party involved in the realization of a project should establish and implement a Quality Assurance Plan, for its participation in the project. Supplier's and subcontractor's activities shall be covered in the plan. The individual Quality Assurance Plans shall fit into the general Quality Assurance Plan. A Quality Assurance Plan shall define the tasks and responsibilities of all persons involved, adequate control and checking procedures, and the organization and maintaining adequate documentation of the building process and its results. Such documentation should generally include:

a) test reports and manufacturer's certificate for materials, concrete mix design details;
b) pour cards for site organization and clearance for concrete placement;
c) record of site inspection of workmanship, field tests;
d) non-conformance reports, change orders;
e) quality control charts; and
f) statistical analysis.

NOTE — Quality control charts are recommended wherever the concrete is in continuous production over considerable period.

10.2 Batching

To avoid confusion and error in batching, consideration should be given to using the smallest practical number of different concrete mixes on any site or in any one plant. In batching concrete, the quantity of both cement and aggregate shall be determined by mass; admixture, if solid, by mass; liquid admixture may however be measured in volume or mass; water shall be weighed or measured by volume in a calibrated tank (*see also* IS 4925).

Ready-mixed concrete supplied by ready-mixed concrete plant shall be preferred. For large and medium project sites the concrete shall be sourced from ready-mixed concrete plants or from on site or off site batching and mixing plants (*see* IS 4926).

10.2.1 Except where it can be shown to the satisfaction of the engineer-in-charge that supply of properly graded aggregate of uniform quality can be maintained over a period of work, the grading of aggregate should be controlled by obtaining the coarse aggregate in different sizes and blending them in the right proportions when required, the different sizes being stocked in separate stock-piles. The material should be stock-piled for several hours preferably a day before use. The grading of coarse and fine aggregate should be checked as frequently as possible, the frequency for a given job being determined by the engineer-in-charge to ensure that the specified grading is maintained.

10.2.2 The accuracy of the measuring equipment shall be within ± 2 percent of the quantity of cement being measured and within ± 3 percent of the quantity of aggregate, admixtures and water being measured.

10.2.3 Proportion/Type and grading of aggregates shall be made by trial in such a way so as to obtain densest possible concrete. All ingredients of the concrete should be used by mass only.

10.2.4 Volume batching may be allowed only where weigh-batching is not practical and provided accurate bulk densities of materials to be actually used in concrete have earlier been established. Allowance for bulking shall be made in accordance with IS 2386 (Part 3). The mass volume relationship should be checked as frequently as necessary, the frequency for the given job being determined by engineer-in-charge to ensure that the specified grading is maintained.

10.2.5 It is important to maintain the water-cement ratio constant at its correct value. To this end, determination of moisture contents in both fine and coarse aggregates shall be made as frequently as possible, the frequency for a given job being determined by the engineer-in-charge according to weather conditions. The amount of the added water shall be adjusted to compensate for any observed variations in the moisture contents. For the determination of moisture content in the aggregates, IS 2386 (Part 3) may be referred to. To allow for the variation in mass of aggregate due to variation in their moisture content, suitable adjustments in the masses of aggregates shall also be made. In the absence of exact data, only in the case of nominal mixes, the amount of surface water may be estimated from the values given in Table 10.

Table 10 Surface Water Carried by Aggregate
(*Clause* 10.2.5)

Sl No.	Aggregate	Approximate Quantity of Surface Water	
		Percent by Mass	l/m³
(1)	(2)	(3)	(4)
i)	Very wet sand	7.5	120
ii)	Moderately wet sand	5.0	80
iii)	Moist sand	2.5	40
iv)	[1)]Moist gravel or crushed rock	1.25-2.5	20-40

[1)] Coarser the aggregate, less the water it will carry.

10.2.6 No substitutions in materials used on the work or alterations in the established proportions, except as permitted in **10.2.4** and **10.2.5** shall be made without additional tests to show that the quality and strength of concrete are satisfactory.

10.3 Mixing

Concrete shall be mixed in a mechanical mixer. The mixer should comply with IS 1791 and IS 12119. The mixers shall be fitted with water measuring (metering) devices. The mixing shall be continued until there is a uniform distribution of the materials and the mass is uniform in colour and consistency. If there is segregation after unloading from the mixer, the concrete should be remixed.

10.3.1 For guidance, the mixing time shall be at least 2 min. For other types of more efficient mixers, manufacturers recommendations shall be followed; for hydrophobic cement it may be decided by the engineer-in-charge.

10.3.2 Workability should be checked at frequent intervals (*see* IS 1199).

10.3.3 Dosages of retarders, plasticisers and superplasticisers shall be restricted to 0.5, 1.0 and 2.0 percent respectively by weight of cementitious materials and unless a higher value is agreed upon between the manufacturer and the constructor based on performance test.

11 FORMWORK

11.1 General

The formwork shall be designed and constructed so as to remain sufficiently rigid during placing and compaction of concrete, and shall be such as to prevent loss of slurry from the concrete. For further details regarding design, detailing, etc, reference may be made to IS 14687. The tolerances on the shapes, lines and dimensions shown in the drawing shall be within the limits given below:

a) Deviation from specified dimensions of cross-section of columns and beams	+ 12 / – 6 mm
b) Deviation from dimensions of footings	
1) Dimensions in plan	+ 50 / – 12 mm
2) Eccentricity	0.02 times the width of the footing in the direction of deviation but not more than 50 mm
3) Thickness	± 0.05 times the specified thickness

These tolerances apply to concrete dimensions only, and not to positioning of vertical reinforcing steel or dowels.

11.2 Cleaning and Treatment of Formwork

All rubbish, particularly, chippings, shavings and sawdust shall be removed from the interior of the forms before the concrete is placed. The face of formwork in contact with the concrete shall be cleaned and treated with form release agent. Release agents should be applied so as to provide a thin uniform coating to the forms without coating the reinforcement.

11.3 Stripping Time

Forms shall not be released until the concrete has achieved a strength of at least twice the stress to which the concrete may be subjected at the time of removal of formwork. The strength referred to shall be that of concrete using the same cement and aggregates and admixture, if any, with the same proportions and cured under conditions of temperature and moisture similar to those existing on the work.

11.3.1 While the above criteria of strength shall be the guiding factor for removal of formwork, in normal circumstances where ambient temperature does not fall below 15°C and where ordinary Portland cement is used and adequate curing is done, following striking period may deem to satisfy the guideline given in 11.3:

Type of Formwork	*Minimum Period Before Striking Formwork*
a) Vertical formwork to columns, walls, beams	16-24 h
b) Soffit formwork to slabs (Props to be refixed immediately after removal of formwork)	3 days
c) Soffit formwork to beams (Props to be refixed immediately after removal of formwork)	7 days
d) Props to slabs:	
1) Spanning up to 4.5 m	7 days
2) Spanning over 4.5 m	14 days
e) Props to beams and arches:	
1) Spanning up to 6 m	14 days
2) Spanning over 6 m	21 days

For other cements and lower temperature, the stripping time recommended above may be suitably modified.

11.3.2 The number of props left under, their sizes and disposition shall be such as to be able to safely carry the full dead load of the slab, beam or arch as the case may be together with any live load likely to occur during curing or further construction.

11.3.3 Where the shape of the element is such that the formwork has re-entrant angles, the formwork shall be removed as soon as possible after the concrete has set, to avoid shrinkage cracking occurring due to the restraint imposed.

12 ASSEMBLY OF REINFORCEMENT

12.1 Reinforcement shall be bent and fixed in accordance with procedure specified in IS 2502. The high strength deformed steel bars should not be re-bent or straightened without the approval of engineer-in-charge.

Bar bending schedules shall be prepared for all reinforcement work.

12.2 All reinforcement shall be placed and maintained in the position shown in the drawings by providing proper cover blocks, spacers, supporting bars, etc.

12.2.1 Crossing bars should not be tack-welded for assembly of reinforcement unless permitted by engineer-in-charge.

12.3 Placing of Reinforcement

Rough handling, shock loading (prior to embedment) and the dropping of reinforcement from a height should be avoided. Reinforcement should be secured against displacement outside the specified limits.

12.3.1 *Tolerances on Placing of Reinforcement*

Unless otherwise specified by engineer-in-charge, the reinforcement shall be placed within the following tolerances:

a) for effective depth 200 mm or less — ± 10 mm

b) for effective depth more than 200 mm — ± 15 mm

12.3.2 *Tolerance for Cover*

Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by $^{+10}_{\ 0}$ mm.

Nominal cover as given in **26.4.1** should be specified to all steel reinforcement including links. Spacers between the links (or the bars where no links exist) and the formwork should be of the same nominal size as the nominal cover.

Spacers, chairs and other supports detailed on drawings, together with such other supports as may be necessary, should be used to maintain the specified nominal cover to the steel reinforcement. Spacers or chairs should be placed at a maximum spacing of 1m and closer spacing may sometimes be necessary.

Spacers, cover blocks should be of concrete of same strength or PVC.

12.4 Welded Joints or Mechanical Connections

Welded joints or mechanical connections in reinforcement may be used but in all cases of important connections, tests shall be made to prove that the joints are of the full strength of bars connected. Welding of reinforcements shall be done in accordance with the recommendations of IS 2751 and IS 9417.

12.5 Where reinforcement bars upto 12 mm for high strength deformed steel bars and up to 16 mm for mild steel bars are bent aside at construction joints and afterwards bent back into their original positions, care should be taken to ensure that at no time is the radius of the bend less than 4 bar diameters for plain mild steel or 6 bar diameters for deformed bars. Care shall also be taken when bending back bars, to ensure that the concrete around the bar is not damaged beyond the band.

12.6 Reinforcement should be placed and tied in such a way that concrete placement be possible without segregation of the mix. Reinforcement placing should allow compaction by immersion vibrator. Within the concrete mass, different types of metal in contact should be avoided to ensure that bimetal corrosion does not take place.

13 TRANSPORTING, PLACING, COMPACTION AND CURING

13.1 Transporting and Handling

After mixing, concrete shall be transported to the formwork as rapidly as possible by methods which will prevent the segregation or loss of any of the ingredients or ingress of foreign matter or water and maintaining the required workability.

13.1.1 During hot or cold weather, concrete shall be transported in deep containers. Other suitable methods to reduce the loss of water by evaporation in hot weather and heat loss in cold weather may also be adopted.

13.2 Placing

The concrete shall be deposited as nearly as practicable in its final position to avoid rehandling. The concrete shall be placed and compacted before initial setting of concrete commences and should not be subsequently disturbed. Methods of placing should be such as to preclude segregation. Care should be taken to avoid displacement of reinforcement or movement of formwork. As a general guidance, the maximum permissible free fall of concrete may be taken as 1.5 m.

13.3 Compaction

Concrete should be thoroughly compacted and fully worked around the reinforcement, around embedded fixtures and into corners of the formwork.

13.3.1 Concrete shall be compacted using mechanical vibrators complying with IS 2505, IS 2506, IS 2514 and IS 4656. Over vibration and under vibration of concrete are harmful and should be avoided. Vibration of very wet mixes should also be avoided.

Whenever vibration has to be applied externally, the design of formwork and the disposition of vibrators should receive special consideration to ensure efficient compaction and to avoid surface blemishes.

13.4 Construction Joints and Cold Joints

Joints are a common source of weakness and, therefore, it is desirable to avoid them. If this is not possible, their number shall be minimized. Concreting shall be carried out continuously up to construction joints, the position and arrangement of which shall be indicated by the designer. Construction joints should comply with IS 11817.

Construction joints shall be placed at accessible locations to permit cleaning out of laitance, cement slurry and unsound concrete, in order to create rough/uneven surface. It is recommended to clean out laitance and cement slurry by using wire brush on the surface of joint immediately after initial setting of concrete and to clean out the same immediately thereafter. The prepared surface should be in a clean saturated surface dry condition when fresh concrete is placed, against it.

In the case of construction joints at locations where the previous pour has been cast against shuttering the recommended method of obtaining a rough surface for the previously poured concrete is to expose the aggregate with a high pressure water jet or any other appropriate means.

Fresh concrete should be thoroughly vibrated near construction joints so that mortar from the new concrete flows between large aggregates and develop proper bond with old concrete.

Where high shear resistance is required at the construction joints, shear keys may be provided.

Sprayed curing membranes and release agents should be thoroughly removed from joint surfaces.

13.5 Curing

Curing is the process of preventing the loss of moisture from the concrete whilst maintaining a satisfactory temperature regime. The prevention of moisture loss from the concrete is particularly important if the water-cement ratio is low, if the cement has a high rate of strength development, if the concrete contains granulated blast furnace slag or pulverised fuel ash. The curing regime should also prevent the development of high temperature gradients within the concrete.

The rate of strength development at early ages of concrete made with supersulphated cement is significantly reduced at lower temperatures. Supersulphated cement concrete is seriously affected by inadequate curing and the surface has to be kept moist for at least seven days.

13.5.1 *Moist Curing*

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of sacking, canvas, hessian or similar materials and kept constantly wet for at least seven days from the date of placing concrete in case of ordinary Portland Cement and at least 10 days where mineral admixtures or blended cements are used. The period of curing shall not be less than 10 days for concrete exposed to dry and hot weather conditions. In the case of concrete where mineral admixtures or blended cements are used, it is recommended that above minimum periods may be extended to 14 days.

13.5.2 *Membrane Curing*

Approved curing compounds may be used in lieu of moist curing with the permission of the engineer-in-charge. Such compounds shall be applied to all exposed surfaces of the concrete as soon as possible after the concrete has set. Impermeable membranes such as polyethylene sheeting covering closely the concrete surface may also be used to provide effective barrier against evaporation.

13.5.3 For the concrete containing Portland pozzolana cement, Portland slag cement or mineral admixture, period of curing may be increased.

13.6 Supervision

It is exceedingly difficult and costly to alter concrete once placed. Hence, constant and strict supervision of all the items of the construction is necessary during the progress of the work, including the proportioning and mixing of the concrete. Supervision is also of extreme importance to check the reinforcement and its placing before being covered.

13.6.1 Before any important operation, such as concreting or stripping of the formwork is started, adequate notice shall be given to the construction supervisor.

14 CONCRETING UNDER SPECIAL CONDITIONS

14.1 Work in Extreme Weather Conditions

During hot or cold weather, the concreting should be done as per the procedure set out in IS 7861 (Part 1) or IS 7861 (Part 2).

14.2 Under-Water Concreting

14.2.1 When it is necessary to deposit concrete under water, the methods, equipment, materials and proportions of the mix to be used shall be submitted to and approved by the engineer-in-charge before the work is started.

14.2.2 Under-water concrete should have a slump recommended in 7.1. The water cement ratio shall not exceed 0.6 and may need to be smaller, depending on the grade of concrete or the type of chemical attack. For aggregates of 40 mm maximum particle size, the cement content shall be at least 350 kg/m^3 of concrete.

14.2.3 Coffer-dams or forms shall be sufficiently tight to ensure still water if practicable, and in any case to reduce the flow of water to less than 3 m/min through the space into which concrete is to be deposited. Coffer-dams or forms in still water shall be sufficiently tight to prevent loss of mortar through the walls. De-watering by pumping shall not be done while concrete is being placed or until 24 h thereafter.

14.2.4 Concrete cast under water should not fall freely through the water. Otherwise it may be leached and become segregated. Concrete shall be deposited continuously until it is brought to the required height. While depositing, the top surface shall be kept as nearly level as possible and the formation of seams avoided. The methods to be used for depositing concrete under water shall be one of the following:

a) *Tremie*—The concrete is placed through vertical pipes the lower end of which is always inserted sufficiently deep into the concrete which has been placed previously but has not set. The concrete emerging from the pipe pushes the material that has already been placed to the side and upwards and thus does not come into direct contact with water.

   When concrete is to be deposited under water by means of tremie, the top section of the tremie shall be a hopper large enough to hold one entire batch of the mix or the entire contents the transporting bucket, if any. The tremie pipe shall be not less than 200 mm in diameter and shall be large enough to allow a free flow of concrete and strong enough to withstand the external pressure of the water in which it is suspended, even if a partial vacuum develops inside the pipe. Preferably, flanged steel pipe of adequate strength for the job should be used. A separate lifting device shall be provided for each tremie pipe with its hopper at the upper end. Unless the lower end of the pipe is equipped with an approved automatic check valve, the upper end of the pipe shall be plugged with a wadding of the gunny sacking or other approved material before delivering the concrete to the tremie pipe through the hopper, so that when the concrete is forced down from the hopper to the pipe, it will force the plug (and along with it any water in the pipe) down the pipe and out of the bottom end, thus establishing a continuous stream of concrete. It will be necessary to raise slowly the tremie in order to cause a uniform flow of the concrete, but the tremie shall not be emptied so that water enters the pipe. At all times after the placing of concrete is started and until all the concrete is placed, the lower end of the tremie pipe shall be below the top surface of the plastic concrete. This will cause the concrete to build up from below instead of flowing out over the surface, and thus avoid formation of laitance layers. If the charge in the tremie is lost while depositing, the tremie shall be raised above the concrete surface, and unless sealed by a check valve, it shall be re-plugged at the top end, as at the beginning, before refilling for depositing concrete.

b) *Direct placement with pumps*—As in the case of the tremie method, the vertical end piece of the pipe line is always inserted sufficiently deep into the previously cast concrete and should not move to the side during pumping.

c) *Drop bottom bucket*—The top of the bucket shall be covered with a canvas flap. The bottom doors shall open freely downward and outward when tripped. The bucket shall be filled completely and lowered slowly to avoid backwash. The bottom doors shall not be opened until the bucket rests on the surface upon which the concrete is to be deposited and when discharged, shall be withdrawn slowly until well above the concrete.

d) *Bags* — Bags of at least 0.028 m³ capacity of jute or other coarse cloth shall be filled about two-thirds full of concrete, the spare end turned under so that bag is square ended and securely tied. They shall be placed carefully in header and stretcher courses so that the whole mass is interlocked. Bags used for this purpose shall be free from deleterious materials.

e) *Grouting*—A series of round cages made from 50 mm mesh of 6 mm steel and extending over the full height to be concreted shall be prepared and laid vertically over the area to be concreted so that the distance between centres of the cages and also to the faces of the concrete shall not exceed one metre. Stone aggregate of not less than 50 mm nor more than 200 mm size shall be deposited outside the steel cages over the full area and height to be concreted with due care to prevent displacement of the cages.

   A stable 1:2 cement-sand grout with a water-cement ratio of not less than 0.6 and not more than 0.8 shall be prepared in a mechanical mixer and sent down under pressure (about 0.2 N/mm²) through 38 to 50 mm diameter pipes terminating into steel cages, about 50 mm above the bottom of the concrete. As the grouting proceeds, the pipe shall be raised gradually up to a height of not more than 6 000 mm above its starting level after which it may be withdrawn and placed into the next cage for further grouting by the same procedure.

   After grouting the whole area for a height of about 600 mm, the same operation shall be repeated, if necessary, for the next layer of

600 mm and so on.

The amount of grout to be sent down shall be sufficient to fill all the voids which may be either ascertained or assumed as 55 percent of the volume to be concreted.

14.2.5 To minimize the formulation of laitance, great care shall be exercised not to disturb the concrete as far as possible while it is being deposited.

15 SAMPLING AND STRENGTH OF DESIGNED CONCRETE MIX

15.1 General

Samples from fresh concrete shall be taken as per IS 1199 and cubes shall be made, cured and tested at 28 days in accordance with IS 516.

15.1.1 In order to get a relatively quicker idea of the quality of concrete, optional tests on beams for modulus of rupture at 72 ± 2 h or at 7 days, or compressive strength tests at 7 days may be carried out in addition to 28 days compressive strength test. For this purpose the values should be arrived at based on actual testing. In all cases, the 28 days compressive strength specified in Table 2 shall alone be the criterion for acceptance or rejection of the concrete.

15.2 Frequency of Sampling

15.2.1 *Sampling Procedure*

A random sampling procedure shall be adopted to ensure that each concrete batch shall have a reasonable chance of being tested that is, the sampling should be spread over the entire period of concreting and cover all mixing units.

15.2.2 *Frequency*

The minimum frequency of sampling of concrete of each grade shall be in accordance with the following:

Quantity of Concrete in the Work, m³	*Number of Samples*
1 - 5	1
6 - 15	2
16 - 30	3
31 - 50	4
51 and above	4 plus one additional sample for each additional 50 m³ or part thereof

NOTE — At least one sample shall be taken from each shift. Where concrete is produced at continuous production unit, such as ready-mixed concrete plant, frequency of sampling may be agreed upon mutually by suppliers and purchasers.

15.3 Test Specimen

Three test specimens shall be made for each sample for testing at 28 days. Additional samples may be required for various purposes such as to determine the strength of concrete at 7 days or at the time of striking the formwork, or to determine the duration of curing, or to check the testing error. Additional samples may also be required for testing samples cured by accelerated methods as described in IS 9103. The specimen shall be tested as described in IS 516.

15.4 Test Results of Sample

The test results of the sample shall be the average of the strength of three specimens. The individual variation should not be more than ±15 percent of the average. If more, the test results of the sample are invalid.

16 ACCEPTANCE CRITERIA

16.1 Compressive Strength

The concrete shall be deemed to comply with the strength requirements when both the following condition are met:

a) The mean strength determined from any group of four consecutive test results compiles with the appropriate limits in col 2 of Table 11.

b) Any individual test result complies with the appropriate limits in col 3 of Table 11.

16.2 Flexural Strength

When both the following conditions are met, the concrete complies with the specified flexural strength.

a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm².

b) The strength determined from any test result is not less than the specified characteristic strength less 0.3 N/mm².

16.3 Quantity of Concrete Represented by Strength Test Results

The quantity of concrete represented by a group of four consecutive test results shall include the batches from which the first and last samples were taken together with all intervening batches.

For the individual test result requirements given in col 2 of Table 11 or in item (b) of 16.2, only the particular batch from which the sample was taken shall be at risk.

Where the mean rate of sampling is not specified the maximum quantity of concrete that four consecutive test results represent shall be limited to 60 m³.

16.4 If the concrete is deemed not to comply persuant to 16.3, the structural adequacy of the parts affected shall be investigated (*see* 17) and any consequential action as needed shall be taken.

16.5 Concrete of each grade shall be assessed separately.

16.6 Concrete is liable to be rejected if it is porous or honey-combed, its placing has been interrupted without providing a proper construction joint, the reinforcement has been displaced beyond the tolerances specified, or construction tolerances have not been met. However, the hardened concrete may be accepted after carrying out suitable remedial measures to the satisfaction of the engineer-in-charge.

17 INSPECTION AND TESTING OF STRUCTURES

17.1 Inspection

To ensure that the construction complies with the design an inspection procedure should be set up covering materials, records, workmanship and construction.

17.1.1 Tests should be made on reinforcement and the constituent materials of concrete in accordance with the relevant standards. Where applicable, use should be made of suitable quality assurance schemes.

17.1.2 Care should be taken to see that:

a) design and detail are capable of being executed to a suitable standard, with due allowance for dimensional tolerances;
b) there are clear instructions on inspection standards;
c) there are clear instructions on permissible deviations;
d) elements critical to workmanship, structural performance, durability and appearance are identified; and
e) there is a system to verify that the quality is satisfactory in individual parts of the structure, especially the critical ones.

17.2 Immediately after stripping the formwork, all concrete shall be carefully inspected and any defective work or small defects either removed or made good before concrete has thoroughly hardened.

17.3 Testing

In case of doubt regarding the grade of concrete used, either due to poor workmanship or based on results of cube strength tests, compressive strength tests of concrete on the basis of **17.4** and/or load test (*see* **17.6**) may be carried out.

17.4 Core Test

17.4.1 The points from which cores are to be taken and the number of cores required shall be at the discretion of the engineer-in-charge and shall be representative of the whole of concrete concerned. In no case, however, shall fewer than three cores be tested.

17.4.2 Cores shall be prepared and tested as described in IS 516.

17.4.3 Concrete in the member represented by a core test shall be considered acceptable if the average equivalent cube strength of the cores is equal to at least 85 percent of the cube strength of the grade of concrete specified for the corresponding age and no individual core has a strength less than 75 percent.

17.5 In case the core test results do not satisfy the requirements of **17.4.3** or where such tests have not been done, load test (**17.6**) may be resorted to.

17.6 Load Tests for Flexural Member

17.6.1 Load tests should be carried out as soon as

Table 11 Characteristic Compressive Strength Compliance Requirement

(*Clauses* 16.1 *and* 16.3)

Specified Grade	Mean of the Group of 4 Non-Overlapping Consecutive Test Results in N/mm²	Individual Test Results in N/mm²
(1)	(2)	(3)
M 15	$\geq f_{ck}$ + 0.825 × established standard deviation (rounded off to nearest 0.5 N/mm²) or f_{ck} + 3 N/mm², whichever is greater	$\geq f_{ck}$ − 3 N/mm²
M 20 or above	$\geq f_{ck}$ + 0.825 × established standard deviation (rounded off to nearest 0.5 N/mm²) or f_{ck} + 4 N/mm², whichever is greater	$\geq f_{ck}$ − 4 N/mm²

NOTE — In the absence of established value of standard deviation, the values given in Table 8 may be assumed, and attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.

possible after expiry of 28 days from the time of placing of concrete.

17.6.2 The structure should be subjected to a load equal to full dead load of the structure plus 1.25 times the imposed load for a period of 24 h and then the imposed load shall be removed.

NOTE — Dead load includes self weight of the structural members plus weight of finishes and walls or partitions, if any, as considered in the design.

17.6.3 The deflection due to imposed load only shall be recorded. If within 24 h of removal of the imposed load, the structure does not recover at least 75 percent of the deflection under superimposed load, the test may be repeated after a lapse of 72 h. If the recovery is less than 80 percent, the structure shall be deemed to be unacceptable.

17.6.3.1 If the maximum deflection in mm, shown during 24 h under load is less than $40l^2/D$, where l is the effective span in m; and D, the overall depth of the section in mm, it is not necessary for the recovery to be measured and the recovery provisions of 17.6.3 shall not apply.

17.7 Members Other Than Flexural Members

Members other than flexural members should be preferably investigated by analysis.

17.8 Non-destructive Tests

Non-destructive tests are used to obtain estimation of the properties of concrete in the structure. The methods adopted include ultrasonic pulse velocity [*see* IS 13311 (Part 1)] and rebound hammer [IS 13311 (Part 2)], probe penetration, pullout and maturity. Non-destructive tests provide alternatives to core tests for estimating the strength of concrete in a structure, or can supplement the data obtained from a limited number of cores. These methods are based on measuring a concrete property that bears some relationship to strength. The accuracy of these methods, in part, is determined by the degree of correlation between strength and the physical quality measured by the non-destructive tests.

Any of these methods may be adopted, in which case the acceptance criteria shall be agreed upon prior to testing.

SECTION 3 GENERAL DESIGN CONSIDERATION

18 BASES FOR DESIGN

18.1 Aim of Design

The aim of design is the achievement of an acceptable probability that structures being designed will perform satisfactorily during their intended life. With an appropriate degree of safety, they should sustain all the loads and deformations of normal construction and use and have adequate durability and adequate resistance to the effects of misuse and fire.

18.2 Methods of Design

18.2.1 Structure and structural elements shall normally be designed by Limit State Method. Account should be taken of accepted theories, experiment and experience and the need to design for durability. Calculations alone do not produce safe, serviceable and durable structures. Suitable materials, quality control, adequate detailing and good supervision are equally important.

18.2.2 Where the Limit State Method can not be conveniently adopted, Working Stress Method (*see* Annex B) may be used.

18.2.3 *Design Based on Experimental Basis*

Designs based on experimental investigations on models or full size structure or element may be accepted if they satisfy the primary requirements of 18.1 and subject to experimental details and the analysis connected therewith being approved by the engineer-in-charge.

18.2.3.1 Where the design is based on experimental investigation on full size structure or element, load tests shall be carried out to ensure the following:

a) The structure shall satisfy the requirements for deflection (*see* 23.2) and cracking (*see* 35.3.2) when subjected to a load for 24 h equal to the characteristic load multiplied by 1.33 γ_f, where γ_f shall be taken from Table 18, for the limit state of serviceability. If within 24 h of the removal of the load, the structure does not show a recovery of at least 75 percent of the maximum deflection shown during the 24 h under the load, the test loading should be repeated after a lapse of 72 h. The recovery after the second test should be at least 75 percent of the maximum deflection shown during the second test.

NOTE—If the maximum deflection in mm, shown during 24 h under load is less than 40 l^2/D where l is the effective span in m; and D is the overall depth of the section in mm, it is not necessary for the recovery to be measured.

b) The structure shall have adequate strength to sustain for 24 h, a total load equal to the characteristic load multiplied by 1.33 γ_f where γ_f shall be taken from Table 18 for the limit state of collapse.

18.3 Durability, Workmanship and Materials

It is assumed that the quality of concrete, steel and other materials and of the workmanship, as verified by inspections, is adequate for safety, serviceability and durability.

18.4 Design Process

Design, including design for durability, construction and use in service should be considered as a whole. The realization of design objectives requires compliance with clearly defined standards for materials, production, workmanship and also maintenance and use of structure in service.

19 LOADS AND FORCES

19.1 General

In structural design, account shall be taken of the dead, imposed and wind loads and forces such as those caused by earthquake, and effects due to shrinkage, creep, temperature, etc, where applicable.

19.2 Dead Loads

Dead loads shall be calculated on the basis of unit weights which shall be established taking into consideration the materials specified for construction.

19.2.1 Alternatively, the dead loads may be calculated on the basis of unit weights of materials given in IS 875 (Part 1). Unless more accurate calculations are warranted, the unit weights of plain concrete and reinforced concrete made with sand and gravel or crushed natural stone aggregate may be taken as 24 kN/m³ and 25 kN/m³ respectively.

19.3 Imposed Loads, Wind Loads and Snow Loads

Imposed loads, wind loads and snow loads shall be assumed in accordance with IS 875 (Part 2), IS 875 (Part 3) and IS 875 (Part 4) respectively.

19.4 Earthquake Forces

The earthquake forces shall be calculated in accordance with IS 1893.

19.5 Shrinkage, Creep and Temperature Effects

If the effects of shrinkage, creep and temperature are liable to affect materially the safety and serviceability of the structure, these shall be taken into account in the calculations (*see* 6.2.4, 6.2.5 and 6.2.6) and IS 875 (Part 5).

19.5.1 In ordinary buildings, such as low rise dwellings whose lateral dimension do not exceed 45 m, the effects due to temperature fluctuations and shrinkage and creep can be ignored in design calculations.

19.6 Other Forces and Effects

In addition, account shall be taken of the following forces and effects if they are liable to affect materially the safety and serviceability of the structure:

a) Foundation movement (*see* IS 1904),
b) Elastic axial shortening,
c) Soil and fluid pressures [*see* IS 875 (Part 5)],
d) Vibration,
e) Fatigue,
f) Impact [*see* IS 875 (Part 5)],
g) Erection loads [*see* IS 875 (Part 2)], and
h) Stress concentration effect due to point load and the like.

19.7 Combination of Loads

The combination of loads shall be as given in IS 875 (Part 5).

19.8 Dead Load Counteracting Other Loads and Forces

When dead load counteracts the effects due to other loads and forces in structural member or joint, special care shall be exercised by the designer to ensure adequate safety for possible stress reversal.

19.9 Design Load

Design load is the load to be taken for use in the appropriate method of design; it is the characteristic load in case of working stress method and characteristic load with appropriate partial safety factors for limit state design.

20 STABILITY OF THE STRUCTURE

20.1 Overturning

The stability of a structure as a whole against overturning shall be ensured so that the restoring moment shall be not less than the sum of 1.2 times the maximum overturning moment due to the characteristic dead load and 1.4 times the maximum overturning moment due to the characteristic imposed loads. In cases where dead load provides the restoring moment, only 0.9 times the characteristic dead load shall be considered. Restoring moment due to imposed loads shall be ignored.

20.1.1 The anchorages or counterweights provided for overhanging members (during construction and service) should be such that static equilibrium should remain, even when overturning moment is doubled.

20.2 Sliding

The structure shall have a factor against sliding of not less than 1.4 under the most adverse combination of the applied characteristic forces. In this case only 0.9 times the characteristic dead load shall be taken into account.

20.3 Probable Variation in Dead Load

To ensure stability at all times, account shall be taken of probable variations in dead load during construction, repair or other temporary measures. Wind and seismic loading shall be treated as imposed loading.

20.4 Moment Connection

In designing the framework of a building provisions shall be made by adequate moment connections or by a system of bracings to effectively transmit all the horizontal forces to the foundations.

20.5 Lateral Sway

Under transient wind load the lateral sway at the top should not exceed $H/500$, where H is the total height of the building. For seismic loading, reference should be made to IS 1893.

21 FIRE RESISTANCE

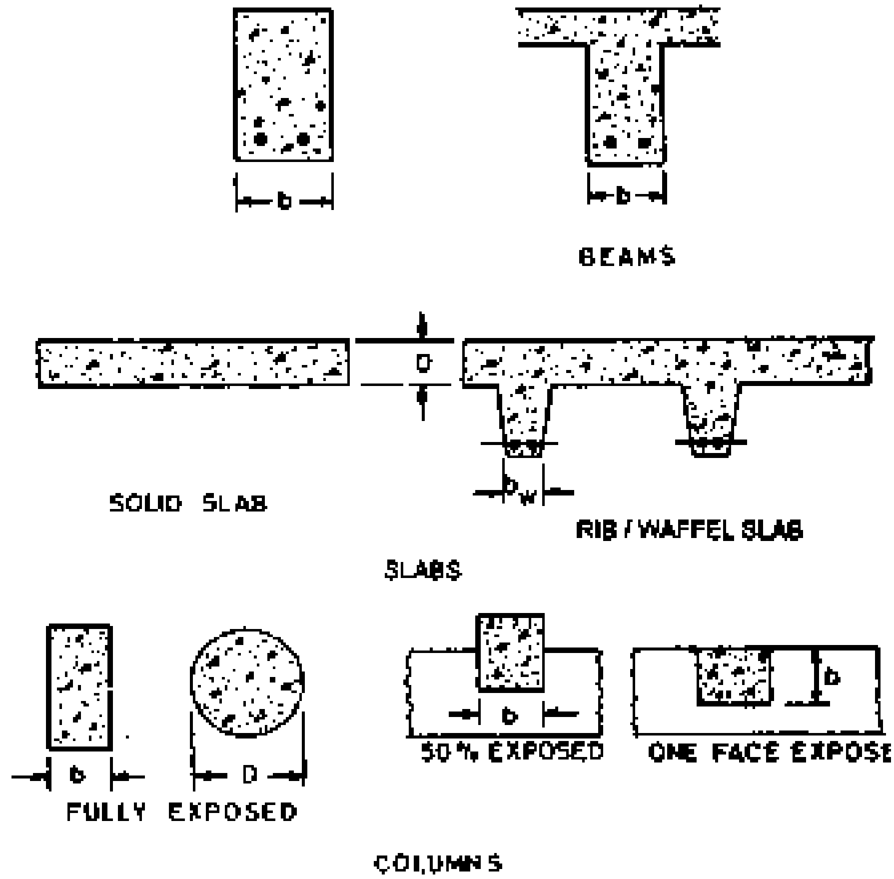
21.1 A structure or structural element required to have fire resistance should be designed to possess an appropriate degree of resistance to flame penetration; heat transmission and failure. The fire resistance of a structural element is expressed in terms of time in hours in accordance with IS 1641. Fire resistance of concrete elements depends upon details of member size, cover to steel reinforcement detailing and type of aggregate (normal weight or light weight) used in concrete. General requirements for fire protection are given in IS 1642.

21.2 Minimum requirements of concrete cover and member dimensions for normal-weight aggregate concrete members so as to have the required fire resistance shall be in accordance with 26.4.3 and Fig. 1 respectively.

21.3 The reinforcement detailing should reflect the changing pattern of the structural section and ensure that both individual elements and the structure as a whole contain adequate support, ties, bonds and anchorages for the required fire resistance.

21.3.1 Additional measures such as application of fire resistant finishes, provision of fire resistant false ceilings and sacrificial steel in tensile zone, should be adopted in case the nominal cover required exceeds 40 mm for beams and 35 mm for slabs, to give protection against spalling.

21.4 Specialist literature may be referred to for determining fire resistance of the structures which have not been covered in Fig. 1 or Table 16A.



Fire Resistance h	Minimum Beam Width b	Rib Width of Slabs b_w	Minimum Thickness of Floors D	Column Dimension (b or D): Fully Exposed	Column Dimension (b or D): 50% Exposed	Column Dimension (b or D): One Face Exposed	Minimum Wall Thickness: $p<0.4\%$	Minimum Wall Thickness: $0.4\%\le p\le 1\%$	Minimum Wall Thickness: $p>1\%$
	mm	mm	mm	mm	mm	mm	mm	mm	mm
0.5	200	125	75	150	125	100	150	100	100
1	200	125	95	200	160	120	150	120	100
1.5	200	125	110	250	200	140	175	140	100
2	200	125	125	300	200	160	-	160	100
3	240	150	150	400	300	200	-	200	150
4	280	175	170	450	350	240	-	240	180

NOTES

1 These minimum dimensions relate specifically to the covers given in Table 16A.

2 p is the percentage of steel reinforcement.

FIG. 1 MINIMUM DIMENSIONS OF REINFORCED CONCRETE MEMBERS FOR FIRE RESISTANCE

22 ANALYSIS

22.1 General

All structures may be analyzed by the linear elastic theory to calculate internal actions produced by design loads. In lieu of rigorous elastic analysis, a simplified analysis as given in 22.4 for frames and as given in 22.5 for continuous beams may be adopted.

22.2 Effective Span

Unless otherwise specified, the effective span of a member shall be as follows:

a) *Simply Supported Beam or Slab*—The effective span of a member that is not built integrally with its supports shall be taken as clear span plus the effective depth of slab or beam or centre to centre of supports, whichever is less.

b) *Continuous Beam or Slab* — In the case of continuous beam or slab, if the width of the support is less than 1/12 of the clear span, the effective span shall be as in **22.2** (a). If the supports are wider than 1/12 of the clear span or 600 mm whichever is less, the effective span shall be taken as under:

   1) For end span with one end fixed and the other continuous or for intermediate spans, the effective span shall be the clear span between supports;

   2) For end span with one end free and the other continuous, the effective span shall be equal to the clear span plus half the effective depth of the beam or slab or the clear span plus half the width of the discontinuous support, whichever is less;

   3) In the case of spans with roller or rocker bearings, the effective span shall always be the distance between the centres of bearings.

c) *Cantilever* — The effective length of a cantilever shall be taken as its length to the face of the support plus half the effective depth except where it forms the end of a continuous beam where the length to the centre of support shall be taken.

d) *Frames* — In the analysis of a continuous frame, centre to centre distance shall be used.

22.3 Stiffness

22.3.1 *Relative Stiffness*

The relative stiffness of the members may be based on the moment of inertia of the section determined on the basis of any one of the following definitions:

a) *Gross section* — The cross-section of the member ignoring reinforcement;

b) *Transformed section* — The concrete cross-section plus the area of reinforcement transformed on the basis of modular ratio (see **B-1.3**); or

c) *Cracked section* — The area of concrete in compression plus the area of reinforcement transformed on the basis of modular ratio.

The assumptions made shall be consistent for all the members of the structure throughout any analysis.

22.3.2 For deflection calculations, appropriate values of moment of inertia as specified in Annex C should be used.

22.4 Structural Frames

The simplifying assumptions as given in **22.4.1** to **22.4.3** may be used in the analysis of frames.

22.4.1 *Arrangement of Imposed Load*

a) Consideration may be limited to combinations of:

   1) Design dead load on all spans with full design imposed load on two adjacent spans, and

   2) Design dead load on all spans with full design imposed load on alternate spans.

b) When design imposed load does not exceed three-fourths of the design dead load, the load arrangement may be design dead load and design imposed load on all the spans.

NOTE — For beams and slabs continuous over support 22.4.1(a) may be assumed.

22.4.2 *Substitute Frame*

For determining the moments and shears at any floor or roof level due to gravity loads, the beams at that level together with columns above and below with their far ends fixed may be considered to constitute the frame.

22.4.2.1 Where side sway consideration becomes critical due to unsymmetry in geometry or loading, rigorous analysis may be required.

22.4.3 For lateral loads, simplified methods may be used to obtain the moments and shears for structures that are symmetrical. For unsymmetrical or very tall structures, more rigorous methods should be used.

22.5 Moment and Shear Coefficients for Continuous Beams

22.5.1 Unless more exact estimates are made, for beams of uniform cross-section which support substantially uniformly distributed loads over three or more spans which do not differ by more than 15 percent of the longest, the bending moments and shear forces used in design may be obtained using the coefficients given in Table 12 and Table 13 respectively.

For moments at supports where two unequal spans meet or in case where the spans are not equally loaded, the average of the two values for the negative moment at the support may be taken for design.

Where coefficients given in Table 12 are used for calculation of bending moments, redistribution referred to in **22.7** shall not be permitted.

22.5.2 *Beams and Slabs Over Free End Supports*

Where a member is built into a masonry wall which develops only partial restraint, the member shall be designed to resist a negative moment at the face of the support of $Wl/24$ where W is the total design load and l is the effective span, or such other restraining moment as may be shown to be applicable. For such a condition shear coefficient given in Table 13 at the end support may be increased by 0.05.

Table 12 Bending Moment Coefficients
(*Clause* 22.5.1)

Type of Load	Span Moments		Support Moments	
	Near Middle of End Span	At Middle of Interior Span	At Support Next to the End Support	At Other Interior Supports
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	$+\frac{1}{12}$	$+\frac{1}{16}$	$-\frac{1}{10}$	$-\frac{1}{12}$
Imposed load (not fixed)	$+\frac{1}{10}$	$+\frac{1}{12}$	$-\frac{1}{9}$	$-\frac{1}{9}$

NOTE — For obtaining the bending moment, the coefficient shall be multiplied by the total design load and effective span.

Table 13 Shear for Coefficients
(*Clauses* 22.5.1 *and* 22.5.2)

Type of Load	At End Support	At Support Next to the End Support		At All Other Interior Supports
		Outer Side	Inner Side	
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	0.4	0.6	0.55	0.5
Imposed load (not fixed)	0.45	0.6	0.6	0.6

NOTE — For obtaining the shear force, the coefficient shall be multiplied by the total design load.

22.6 Critical Sections for Moment and Shear

22.6.1 For monolithic construction, the moments computed at the face of the supports shall be used in the design of the members at those sections. For non-monolithic construction the design of the member shall be done keeping in view **22.2**.

22.6.2 *Critical Section for Shear*

The shears computed at the face of the support shall be used in the design of the member at that section except as in **22.6.2.1**.

22.6.2.1 When the reaction in the direction of the applied shear introduces compression into the end region of the member, sections located at a distance less than d from the face of the support may be designed for the same shear as that computed at distance d (*see* Fig. 2).

NOTE — The above clauses are applicable for beams generally carrying uniformly distributed load or where the principal load is located farther than $2d$ from the face of the support.

22.7 Redistribution of Moments

Redistribution of moments may be done in accordance with **37.1.1** for limit state method and in accordance with **B-1.2** for working stress method. However, where simplified analysis using coefficients is adopted, redistribution of moments shall not be done.

23 BEAMS

23.0 Effective Depth

Effective depth of a beam is the distance between the centroid of the area of tension reinforcement and the maximum compression fibre, excluding the thickness of finishing material not placed monolithically with the member and the thickness of any concrete provided to allow for wear. This will not apply to deep beams.

23.1 T-Beams and L-Beams

23.1.1 *General*

A slab which is assumed to act as a compression flange of a T-beam or L-beam shall satisfy the following:

a) The slab shall be cast integrally with the web, or the web and the slab shall be effectively bonded together in any other manner; and

b) If the main reinforcement of the slab is parallel to the beam, transverse reinforcement shall be provided as in Fig. 3; such reinforcement shall not be less than 60 percent of the main reinforcement at mid span of the slab.

23.1.2 *Effective Width of Flange*

In the absence of more accurate determination, the effective width of flange may be taken as the following

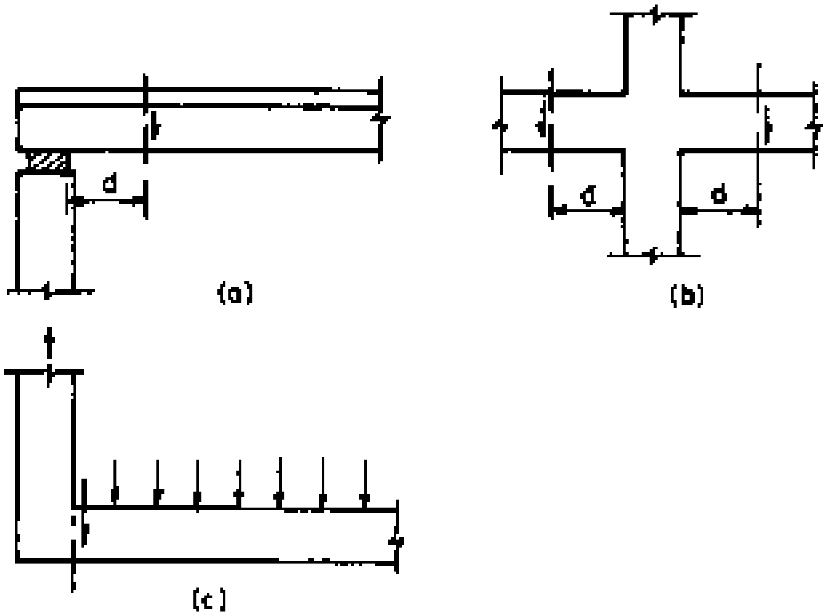


FIG. 2 TYPICAL SUPPORT CONDITIONS FOR LOCATING FACTORED SHEAR FORCE

but in no case greater than the breadth of the web plus half the sum of the clear distances to the adjacent beams on either side.

a) For T-beams, $b_f = \frac{l_0}{6} + b_w + 6D_f$

b) For L-beams, $b_f = \frac{l_0}{12} + b_w + 3D_f$

c) For isolated beams, the effective flange width shall be obtained as below but in no case greater than the actual width:

$$\text{T-beam, } b_f = \frac{l_0}{\left(\frac{l_0}{b}\right)+4} + b_w$$

$$\text{L-beam, } b_f = \frac{0.5\ l_0}{\left(\frac{l_0}{b}\right)+4} + b_w$$

where

b_f = effective width of flange,

l_0 = distance between points of zero moments in the beam,

b_w = breadth of the web,

D_f = thickness of flange, and

b = actual width of the flange.

NOTE — For continuous beams and frames, 'l_0' may be assumed as 0.7 times the effective span.

23.2 Control of Deflection

The deflection of a structure or part thereof shall not adversely affect the appearance or efficiency of the structure or finishes or partitions. The deflection shall generally be limited to the following:

a) The final deflection due to all loads including the effects of temperature, creep and shrinkage and measured from the as-cast level of the supports of floors, roofs and all other horizontal members, should not normally exceed span/250.

b) The deflection including the effects of temperature, creep and shrinkage occurring after erection of partitions and the application of finishes should not normally exceed span/350 or 20 mm whichever is less.

23.2.1 The vertical deflection limits may generally be assumed to be satisfied provided that the span to depth ratios are not greater than the values obtained as below:

a) Basic values of span to effective depth ratios for spans up to 10 m.

Cantilever	7
Simply supported	20
Continuous	26

b) For spans above 10 m, the values in (a) may be multiplied by 10/span in metres, except for cantilever in which case deflection calculations should be made.

c) Depending on the area and the stress of steel for tension reinforcement, the values in (a) or (b) shall be modified by multiplying with the modification factor obtained as per Fig. 4.

d) Depending on the area of compression reinforcement, the value of span to depth ratio be further modified by multiplying with the modification factor obtained as per Fig. 5.

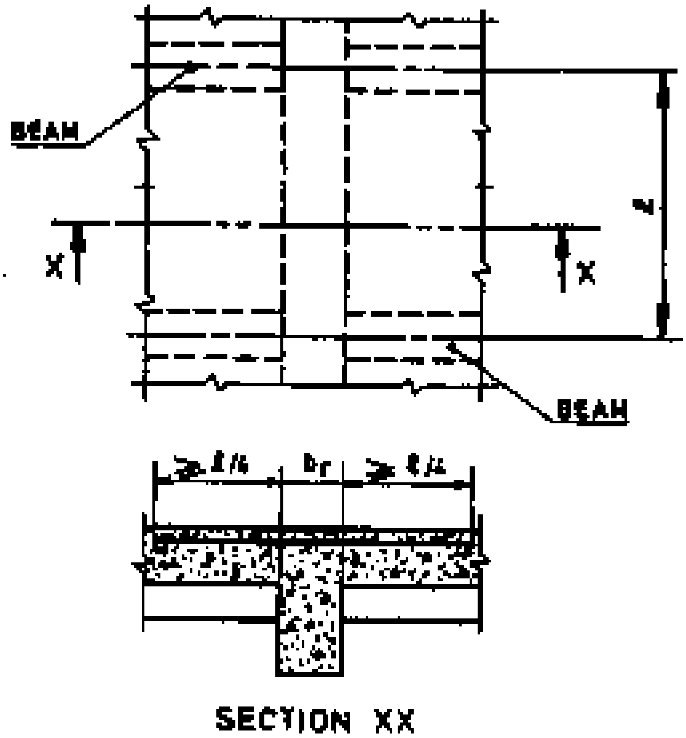
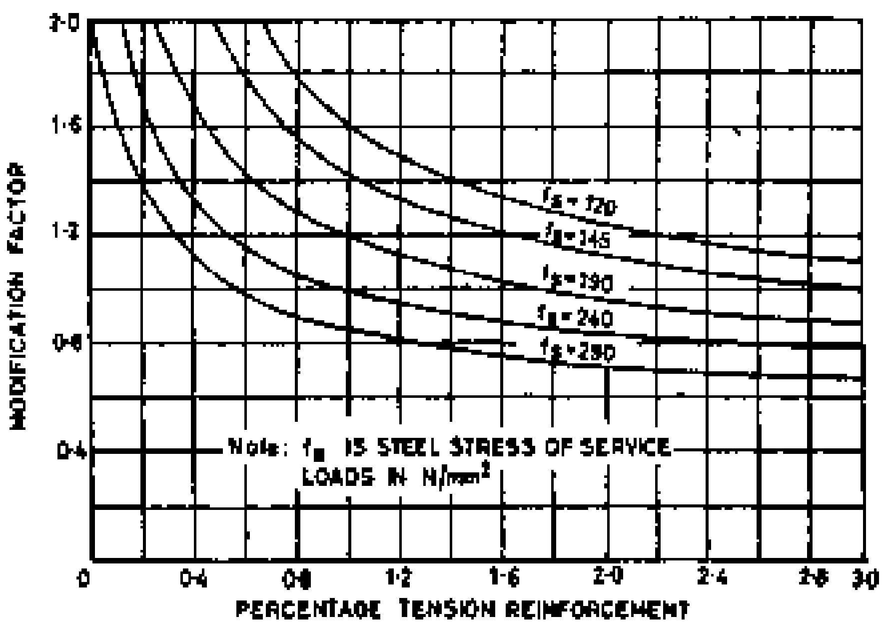


FIG. 3 TRANSVERSE REINFORCEMENT IN FLANGE OF T-BEAM WHEN MAIN REINFORCEMENT OF SLAB IS PARALLEL TO THE BEAM

e) For flanged beams, the values of (a) or (b) be modified as per Fig. 6 and the reinforcement percentage for use in Fig. 4 and 5 should be based on area of section equal to $b_f\, d$.

NOTE — When deflections are required to be calculated, the method given in Annex C may be used.



$$f_s = 0.58\, f_y \frac{\text{Area of cross-section of steel required}}{\text{Area of cross-section of steel provided}}$$

FIG. 4 MODIFICATION FACTOR FOR TENSION REINFORCEMENT

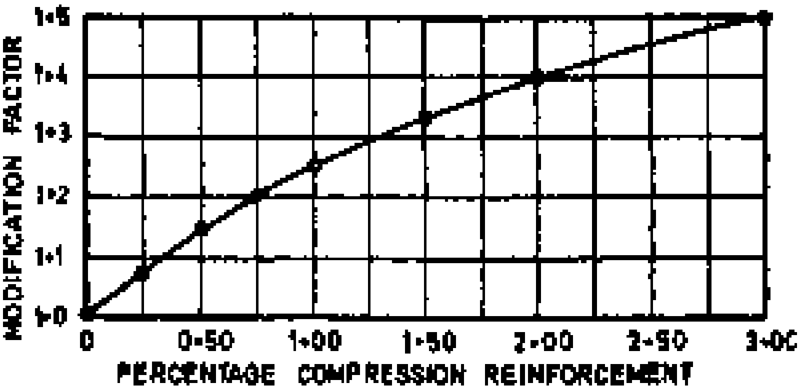


FIG. 5 MODIFICATION FACTOR FOR COMPRESSION REINFORCEMENT

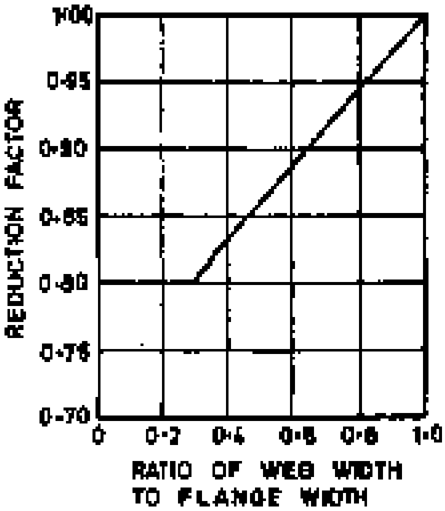


FIG. 6 REDUCTION FACTORS FOR RATIOS OF SPAN TO EFFECTIVE DEPTH FOR FLANGED BEAMS

23.3 Slenderness Limits for Beams to Ensure Lateral Stability

A simply supported or continuous beam shall be so proportioned that the clear distance between the lateral restraints does not exceed 60 b or $\frac{250\,b^2}{d}$ whichever is less, where d is the effective depth of the beam and b the breadth of the compression face midway between the lateral restraints.

For a cantilever, the clear distance from the free end of the cantilever to the lateral restraint shall not exceed 25 b or $\frac{100\,b^2}{d}$ whichever is less.

24 SOLID SLABS

24.1 General

The provisions of **23.2** for beams apply to slabs also.

NOTES

1 For slabs spanning in two directions, the shorter of the two spans should be used for calculating the span to effective depth ratios.

2 For two-way slabs of shorter spans (up to 3.5 m) with mild steel reinforcement, the span to overall depth ratios given below may generally be assumed to satisfy vertical deflection limits for loading class up to 3 kN/m².

Simply supported slabs	35
Continuous slabs	40

For high strength deformed bars of grade Fe 415, the values given above should be multiplied by 0.8.

24.2 Slabs Continuous Over Supports

Slabs spanning in one direction and continuous over supports shall be designed according to the provisions applicable to continuous beams.

24.3 Slabs Monolithic with Supports

Bending moments in slabs (except flat slabs) constructed monolithically with the supports shall be calculated by taking such slabs either as continuous over supports and capable of free rotation, or as members of a continuous framework with the supports, taking into account the stiffness of such supports. If such supports are formed due to beams which justify fixity at the support of slabs, then the effects on the supporting beam, such as, the bending of the web in the transverse direction of the beam and the torsion in the longitudinal direction of the beam, wherever applicable, shall also be considered in the design of the beam.

24.3.1 For the purpose of calculation of moments in slabs in a monolithic structure, it will generally be sufficiently accurate to assume that members connected to the ends of such slabs are fixed in position and direction at the ends remote from their connections with the slabs.

24.3.2 *Slabs Carrying Concentrated Load*

24.3.2.1 If a solid slab supported on two opposite edges, carries concentrated loads the maximum bending moment caused by the concentrated loads shall be assumed to be resisted by an effective width of slab (measured parallel to the supporting edges) as follows:

a) For a single concentrated load, the effective width shall be calculated in accordance with the following equation provided that it shall not exceed the actual width of the slab:

$$b_{ef} = kx\left(1 - \frac{x}{l_{ef}}\right) + a$$

where

b_{ef} = effective width of slab,

k = constant having the values given in Table 14 depending upon the ratio of the width of the slab (l') to the effective span l_{ef},

x = distance of the centroid of the concentrated load from nearer support,

l_{ef} = effective span, and

a = width of the contact area of the concentrated load from nearer support measured parallel to the supported edge.

And provided further that in case of a load near the unsupported edge of a slab, the effective width shall not exceed the above value nor half the above value plus the distance of the load from the unsupported edge.

b) For two or more concentrated loads placed in a line in the direction of the span, the bending moment per metre width of slab shall be calculated separately for each load according to its appropriate effective width of slab calculated as in (a) above and added together for design calculations.

c) For two or more loads not in a line in the direction of the span, if the effective width of slab for one load does not overlap the effective width of slab for another load, both calculated as in (a) above, then the slab for each load can be designed separately. If the effective width of slab for one load overlaps the effective width of slab for an adjacent load, the overlapping portion of the slab shall be designed for the combined effect of the two loads.

Table 14 Values of *k* for Simply Supported and Continuous Slabs

(*Clause* 24.3.2.1)

l'/l_{ef}	*k* for Simply Supported Slabs	*k* for Continuous Slabs
0.1	0.4	0.4
0.2	0.8	0.8
0.3	1.16	1.16
0.4	1.48	1.44
0.5	1.72	1.68
0.6	1.96	1.84
0.7	2.12	1.96
0.8	2.24	2.08
0.9	2.36	2.16
1.0 and above	2.48	2.24

d) For cantilever solid slabs, the effective width shall be calculated in accordance with the following equation:

$$b_{ef} = 1.2\, a_1 + a$$

where

b_{ef} = effective width,

a_1 = distance of the concentrated load from the face of the cantilever support, and

a = width of contact area of the concentrated load measured parallel to the supporting edge.

Provided that the effective width of the cantilever slab shall not exceed one-third the length of the cantilever slab measured parallel to the fixed edge.

And provided further that when the concentrated load is placed near the extreme ends of the length of cantilever slab in the direction parallel to the fixed edge, the effective width shall not exceed the above value, nor shall it exceed half the above value plus the distance of the concentrated load from the extreme end measured in the direction parallel to the fixed edge.

24.3.2.2 For slabs other than solid slabs, the effective width shall depend on the ratio of the transverse and longitudinal flexural rigidities of the slab. Where this ratio is one, that is, where the transverse and longitudinal flexural rigidities are approximately equal, the value of effective width as found for solid slabs may be used. But as the ratio decreases, proportionately smaller value shall be taken.

24.3.2.3 Any other recognized method of analysis for cases of slabs covered by 24.3.2.1 and 24.3.2.2 and for all other cases of slabs may be used with the approval of the engineer-in-charge.

24.3.2.4 The critical section for checking shear shall be as given in 34.2.4.1.

24.4 Slabs Spanning in Two Directions at Right Angles

The slabs spanning in two directions at right angles and carrying uniformly distributed load may be designed by any acceptable theory or by using coefficients given in Annex D. For determining bending moments in slabs spanning in two directions at right angles and carrying concentrated load, any accepted method approved by the engineer-in-charge may be adopted.

NOTE—The most commonly used elastic methods are based on Pigeaud's or Wester-gaard's theory and the most commonly used limit state of collapse method is based on Johansen's yield-line theory.

24.4.1 *Restrained Slab with Unequal Conditions at Adjacent Panels*

In some cases the support moments calculated from Table 26 for adjacent panels may differ significantly. The following procedure may be adopted to adjust them:

a) Calculate the sum of moments at midspan and supports (neglecting signs).
b) Treat the values from Table 26 as fixed end moments.
c) According to the relative stiffness of adjacent spans, distribute the fixed end moments across the supports, giving new support moments.
d) Adjust midspan moment such that, when added to the support moments from (c) (neglecting signs), the total should be equal to that from (a).

If the resulting support moments are significantly greater than the value from Table 26, the tension steel over the supports will need to be extended further. The procedure should be as follows:

1) Take the span moment as parabolic between supports: its maximum value is as found from (d).
2) Determine the points of contraflexure of the new support moments [from (c)] with the span moment [from (1)].
3) Extend half the support tension steel at each end to at least an effective depth or 12 bar diameters beyond the nearest point of contraflexure.
4) Extend the full area of the support tension steel at each end to half the distance from (3).

24.5 Loads on Supporting Beams

The loads on beams supporting solid slabs spanning in two directions at right angles and supporting uniformly distributed loads, may be assumed to be in accordance with Fig. 7.

25 COMPRESSION MEMBERS

25.1 Definitions

25.1.1 Column or strut is a compression member, the effective length of which exceeds three times the least lateral dimension.

25.1.2 *Short and Slender Compression Members*

A compression member may be considered as short when both the slenderness ratios $\frac{l_{ex}}{D}$ and $\frac{l_{ey}}{b}$ are less than 12:

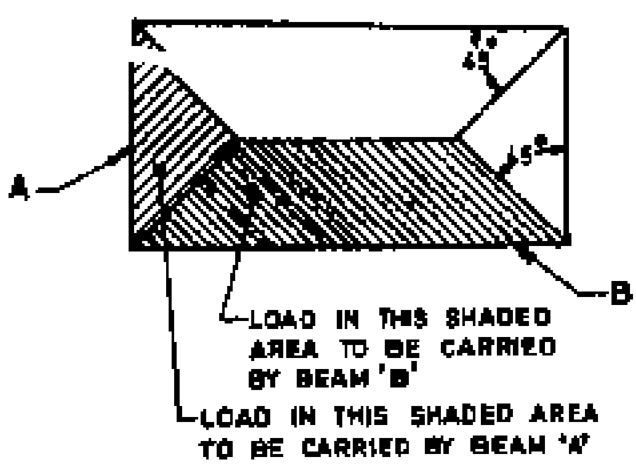


FIG. 7 LOAD CARRIED BY SUPPORTING BEAMS

where

l_{ex} = effective length in respect of the major axis,

D = depth in respect of the major axis,

l_{ey} = effective length in respect of the minor axis, and

b = width of the member.

It shall otherwise be considered as a slender compression member.

25.1.3 *Unsupported Length*

The unsupported length, l, of a compression member shall be taken as the clear distance between end restraints except that:

a) in flat slab construction, it shall be clear distance between the floor and the lower extremity of the capital, the drop panel or slab whichever is the least.

b) in beam and slab construction, it shall be the clear distance between the floor and the underside of the shallower beam framing into the columns in each direction at the next higher floor level.

c) in columns restrained laterally by struts, it shall be the clear distance between consecutive struts in each vertical plane, provided that to be an adequate support, two such struts shall meet the columns at approximately the same level and the angle between vertical planes through the struts shall not vary more than 30° from a right angle. Such struts shall be of adequate dimensions and shall have sufficient anchorage to restrain the member against lateral deflection.

d) in columns restrained laterally by struts or beams, with brackets used at the junction, it shall be the clear distance between the floor and the lower edge of the bracket, provided that the bracket width equals that of the beam strut and is at least half that of the column.

25.2 Effective Length of Compression Members

In the absence of more exact analysis, the effective length l_{ef} of columns may be obtained as described in Annex E.

25.3 Slenderness Limits for Columns

25.3.1 The unsupported length between end restraints shall not exceed 60 times the least lateral dimension of a column.

25.3.2 If, in any given plane, one end of a column is unrestrained, its unsupported length, l, shall not exceed

$$\frac{100\,b^2}{D}.$$

where

b = width of that cross-section, and

D = depth of the cross-section measured in the plane under consideration.

25.4 Minimum Eccentricity

All columns shall be designed for minimum eccentricity, equal to the unsupported length of column/500 plus lateral dimensions/30, subject to a minimum of 20 mm. Where bi-axial bending is considered, it is sufficient to ensure that eccentricity exceeds the minimum about one axis at a time.

26 REQUIREMENTS GOVERNING REINFORCEMENT AND DETAILING

26.1 General

Reinforcing steel of same type and grade shall be used as main reinforcement in a structural member. However, simultaneous use of two different types or grades of steel for main and secondary reinforcement respectively is permissible.

26.1.1 Bars may be arranged singly, or in pairs in contact, or in groups of three or four bars bundled in contact. Bundled bars shall be enclosed within stirrups or ties. Bundled bars shall be tied together to ensure the bars remaining together. Bars larger than 32 mm diameter shall not be bundled, except in columns.

26.1.2 The recommendations for detailing for earthquake-resistant construction given in IS 13920 should be taken into consideration, where applicable (*see also* IS 4326).

26.2 Development of Stress in Reinforcement

The calculated tension or compression in any bar at any section shall be developed on each side of the section by an appropriate development length or end anchorage or by a combination thereof.

26.2.1 *Development Length of Bars*

The development length L_d is given by

$$L_d = \frac{\phi\,\sigma_s}{4\,\tau_{bd}}$$

where

ϕ = nominal diameter of the bar,

σ_s = stress in bar at the section considered at design load, and

τ_{bd} = design bond stress given in **26.2.1.1**.

NOTES

1 The development length includes anchorage values of hooks in tension reinforcement.

2 For bars of sections other than circular, the development length should be sufficient to develop the stress in the bar by bond.

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress, τ_{bd}, N/mm^2	1.2	1.4	1.5	1.7	1.9

For deformed bars conforming to IS 1786 these values shall be increased by 60 percent.

For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

The values of bond stress in working stress design, are given in B-2.1.

26.2.1.2 *Bars bundled in contact*

The development length of each bar of bundled bars shall be that for the individual bar, increased by 10 percent for two bars in contact, 20 percent for three bars in contact and 33 percent for four bars in contact.

26.2.2 *Anchoring Reinforcing Bars*

26.2.2.1 *Anchoring bars in tension*

a) Deformed bars may be used without end anchorages provided development length requirement is satisfied. Hooks should normally be provided for plain bars in tension.

b) *Bends and hooks* — Bends and hooks shall conform to IS 2502

   1) *Bends*—The anchorage value of bend shall be taken as 4 times the diameter of the bar for each 45° bend subject to a maximum of 16 times the diameter of the bar.

   2) *Hooks*—The anchorage value of a standard U-type hook shall be equal to 16 times the diameter of the bar.

26.2.2.2 *Anchoring bars in compression*

The anchorage length of straight bar in compression shall be equal to the development length of bars in compression as specified in 26.2.1. The projected length of hooks, bends and straight lengths beyond bends if provided for a bar in compression, shall only be considered for development length.

26.2.2.3 *Mechanical devices for anchorage*

Any mechanical or other device capable of developing the strength of the bar without damage to concrete may be used as anchorage with the approval of the engineer-in-charge.

26.2.2.4 *Anchoring shear reinforcement*

a) *Inclined bars* — The development length shall be as for bars in tension; this length shall be measured as under:

   1) In tension zone, from the end of the sloping or inclined portion of the bar, and

   2) In the compression zone, from the mid depth of the beam.

b) *Stirrups*—Notwithstanding any of the provisions of this standard, in case of secondary reinforcement, such as stirrups and transverse ties, complete development lengths and anchorage shall be deemed to have been provided when the bar is bent through an angle of at least 90° round a bar of at least its own diameter and is continued beyond the end of the curve for a length of at least eight diameters, or when the bar is bent through an angle of 135° and is continued beyond the end of the curve for a length of at least six bar diameters or when the bar is bent through an angle of 180° and is continued beyond the end of the curve for a length of at least four bar diameters.

26.2.2.5 *Bearing stresses at bends*

The bearing stress in concrete for bends and hooks described in IS 2502 need not be checked. The bearing stress inside a bend in any other bend shall be calculated as given below:

$$\text{Bearing stress} = \frac{F_{bt}}{r\phi}$$

where

F_{bt} = tensile force due to design loads in a bar or group of bars,

r = internal radius of the bend, and

ϕ = size of the bar or, in bundle, the size of bar of equivalent area.

For limit state method of design, this stress shall not exceed $\frac{1.5 f_{ck}}{1 + 2\phi/a}$ where f_{ck} is the characteristic cube strength of concrete and a, for a particular bar or group of bars in contact shall be taken as the centre to centre distance between bars or groups of bars perpendicular to the plane of the bend; for a bar or group of bars adjacent to the face of the member a shall be taken as the cover plus size of bar (ϕ). For working stress method of design, the bearing stress shall not exceed $\frac{f_{ck}}{1 + 2\phi/a}$.

26.2.2.6 If a change in direction of tension or compression reinforcement induces a resultant force acting outward tending to split the concrete, such force should be taken up by additional links or stirrups. Bent tension bar at a re-entrant angle should be avoided.

26.2.3 *Curtailment of Tension Reinforcement in Flexural Members*

26.2.3.1 For curtailment, reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance equal to the effective depth of the member or 12 times the bar diameter, whichever is greater except at simple support or end of cantilever. In addition 26.2.3.2 to 26.2.3.5 shall also be satisfied.

NOTE — A point at which reinforcement is no longer required to resist flexure is where the resistance moment of the section, considering only the continuing bars, is equal to the design moment.

26.2.3.2 Flexural reinforcement shall not be terminated in a tension zone unless any one of the following conditions is satisfied:

a) The shear at the cut-off point does not exceed two-thirds that permitted, including the shear strength of web reinforcement provided.

b) Stirrup area in excess of that required for shear and torsion is provided along each terminated bar over a distance from the cut-off point equal to three-fourths the effective depth of the member. The excess stirrup area shall be not less than $0.4\, bs/f_y$, where b is the breadth of beam, s is the spacing and f_y is the characteristic strength of reinforcement in N/mm². The resulting spacing shall not exceed $d/8\, \beta_b$ where β_b is the ratio of the area of bars cut-off to the total area of bars at the section, and d is the effective depth.

c) For 36 mm and smaller bars, the continuing bars provide double the area required for flexure at the cut-off point and the shear does not exceed three-fourths that permitted.

26.2.3.3 *Positive moment reinforcement*

a) At least one-third the positive moment reinforcement in simple members and one-fourth the positive moment reinforcement in continuous members shall extend along the same face of the member into the support, to a length equal to $L_d/3$.

b) When a flexural member is part of the primary lateral load resisting system, the positive reinforcement required to be extended into the support as described in (a) shall be anchored to develop its design stress in tension at the face of the support.

c) At simple supports and at points of inflection, positive moment tension reinforcement shall be limited to a diameter such that L_d computed for f_d by 26.2.1 does not exceed

$$\frac{M_1}{V} + L_0$$

where

M_1 = moment of resistance of the section assuming all reinforcement at the section to be stressed to f_d;

f_d = $0.87\, f_y$ in the case of limit state design and the permissible stress σ_{st} in the case of working stress design;

V = shear force at the section due to design loads;

L_0 = sum of the anchorage beyond the centre of the support and the equivalent anchorage value of any hook or mechanical anchorage at simple support; and at a point of inflection, L_0 is limited to the effective depth of the members or 12ϕ, whichever is greater; and

ϕ = diameter of bar.

The value of M_1/V in the above expression may be increased by 30 percent when the ends of the reinforcement are confined by a compressive reaction.

26.2.3.4 *Negative moment reinforcement*

At least one-third of the total reinforcement provided for negative moment at the support shall extend beyond the point of inflection for a distance not less than the effective depth of the member of 12ϕ or one-sixteenth of the clear span whichever is greater.

26.2.3.5 *Curtailment of bundled bars*

Bars in a bundle shall terminate at different points spaced apart by not less than 40 times the bar diameter except for bundles stopping at a support.

26.2.4 *Special Members*

Adequate end anchorage shall be provided for tension reinforcement in flexural members where reinforcement stress is not directly proportional to moment, such as sloped, stepped, or tapered footings; brackets; deep beams; and members in which the tension reinforcement is not parallel to the compression face.

26.2.5 *Reinforcement Splicing*

Where splices are provided in the reinforcing bars, they shall as far as possible be away from the sections of maximum stress and be staggered. It is recommended that splices in flexural members should not be at sections where the bending moment is more than 50 percent of the moment of resistance; and not more than half the bars shall be spliced at a section.

Where more than one-half of the bars are spliced at a section or where splices are made at points of maximum stress, special precautions shall be taken, such as increasing the length of lap and/or using spirals or closely-spaced stirrups around the length of the splice.

26.2.5.1 *Lap splices*

a) Lap splices shall not be used for bars larger than 36 mm; for larger diameters, bars may be welded (*see* **12.4**); in cases where welding is not practicable, lapping of bars larger than 36 mm may be permitted, in which case additional spirals should be provided around the lapped bars.

b) Lap splices shall be considered as staggered if the centre to centre distance of the splices is not less than 1.3 times the lap length calculated as described in (c).

c) Lap length including anchorage value of hooks for bars in flexural tension shall be L_d (*see* **26.2.1**) or 30ϕ whichever is greater and for direct tension shall be $2L_d$ or 30ϕ whichever is greater. The straight length of the lap shall not be less than 15ϕ or 200 mm. The following provisions shall also apply:

Where lap occurs for a tension bar located at:

1) top of a section as cast and the minimum cover is less than twice the diameter of the lapped bar, the lap length shall be increased by a factor of 1.4.

2) corner of a section and the minimum cover to either face is less than twice the diameter of the lapped bar or where the clear distance between adjacent laps is less than 75 mm or 6 times the diameter of lapped bar, whichever is greater, the lap length should be increased by a factor of 1.4.

Where both condition (1) and (2) apply, the lap length should be increased by a factor of 2.0.

NOTE—Splices in tension members shall be enclosed in spirals made of bars not less than 6 mm diameter with pitch not more than 100 mm.

d) The lap length in compression shall be equal to the development length in compression, calculated as described in **26.2.1**, but not less than 24ϕ.

e) When bars of two different diameters are to be spliced, the lap length shall be calculated on the basis of diameter of the smaller bar.

f) When splicing of welded wire fabric is to be carried out, lap splices of wires shall be made so that overlap measured between the extreme cross wires shall be not less than the spacing of cross wires plus 100 mm.

g) In case of bundled bars, lapped splices of bundled bars shall be made by splicing one bar at a time; such individual splices within a bundle shall be staggered.

26.2.5.2 *Strength of welds*

The following values may be used where the strength of the weld has been proved by tests to be at least as great as that of the parent bar.

a) *Splices in compression* — For welded splices and mechanical connection, 100 percent of the design strength of joined bars.

b) *Splices in tension*

1) 80 percent of the design strength of welded bars (100 percent if welding is strictly supervised and if at any cross-section of the member not more than 20 percent of the tensile reinforcement is welded).

2) 100 percent of design strength of mechanical connection.

26.2.5.3 *End-bearing splices*

End-bearing splices shall be used only for bars in compression. The ends of the bars shall be square cut and concentric bearing ensured by suitable devices.

26.3 Spacing of Reinforcement

26.3.1 For the purpose of this clause, the diameter of a round bar shall be its nominal diameter, and in the case of bars which are not round or in the case of deformed bars or crimped bars, the diameter shall be taken as the diameter of a circle giving an equivalent effective area. Where spacing limitations and minimum concrete cover (*see* **26.4**) are based on bar diameter, a group of bars bundled in contact shall be treated as a single bar of diameter derived from the total equivalent area.

26.3.2 *Minimum Distance Between Individual Bars*

The following shall apply for spacing of bars:

a) The horizontal distance between two parallel main reinforcing bars shall usually be not less than the greatest of the following:

1) The diameter of the bar if the diameters are equal,

2) The diameter of the larger bar if the diameters are unequal, and

3) 5 mm more than the nominal maximum size of coarse aggregate.

NOTE—This does not preclude the use of larger size of aggregates beyond the congested reinforcement in the same member, the size of aggregates may be reduced around congested reinforcement to comply with this provision.

b) Greater horizontal distance than the minimum specified in (a) should be provided wherever possible. However when needle vibrators are used the horizontal distance between bars of a group may be reduced to two-thirds the nominal maximum size of the coarse aggregate, provided that sufficient space is left between groups of bars to enable the vibrator to be immersed.

c) Where there are two or more rows of bars, the bars shall be vertically in line and the minimum vertical distance between the bars shall be 15 mm, two-thirds the nominal maximum size of aggregate or the maximum size of bars, whichever is greater.

26.3.3 *Maximum Distance Between Bars in Tension*

Unless the calculation of crack widths shows that a greater spacing is acceptable, the following rules shall be applied to flexural members in normal internal or external conditions of exposure.

a) *Beams* — The horizontal distance between parallel reinforcement bars, or groups, near the tension face of a beam shall not be greater than the value given in Table 15 depending on the amount of redistribution carried out in analysis and the characteristic strength of the reinforcement.

b) *Slabs*

1) The horizontal distance between parallel main reinforcement bars shall not be more than three times the effective depth of solid slab or 300 mm whichever is smaller.

2) The horizontal distance between parallel reinforcement bars provided against shrinkage and temperature shall not be more than five times the effective depth of a solid slab or 450 mm whichever is smaller.

26.4 Nominal Cover to Reinforcement

26.4.1 *Nominal Cover*

Nominal cover is the design depth of concrete cover to all steel reinforcements, including links. It is the dimension used in design and indicated in the drawings. It shall be not less than the diameter of the bar.

26.4.2 *Nominal Cover to Meet Durability Requirement*

Minimum values for the nominal cover of normal-weight aggregate concrete which should be provided to all reinforcement, including links depending on the condition of exposure described in 8.2.3 shall be as given in Table 16.

26.4.2.1 However for a longitudinal reinforcing bar in a column nominal cover shall in any case not be less than 40 mm, or less than the diameter of such bar. In the case of columns of minimum dimension of 200 mm or under, whose reinforcing bars do not exceed 12 mm, a nominal cover of 25 mm may be used.

26.4.2.2 For footings minimum cover shall be 50 mm.

26.4.3 *Nominal Cover to Meet Specified Period of Fire Resistance*

Minimum values of nominal cover of normal-weight aggregate concrete to be provided to all reinforcement including links to meet specified period of fire resistance shall be given in Table 16A.

26.5 Requirements of Reinforcement for Structural Members

26.5.1 *Beams*

26.5.1.1 *Tension reinforcement*

a) *Minimum reinforcement*—The minimum area of tension reinforcement shall be not less than that

Table 15 Clear Distance Between Bars

(*Clause* 26.3.3)

f_y	Percentage Redistribution to or from Section Considered				
	− 30	− 15	0	+ 15	+ 30
	Clear Distance Between Bars				
N/mm²	mm	mm	mm	mm	mm
250	215	260	300	300	300
415	125	155	180	210	235
500	105	130	150	175	195

NOTE — The spacings given in the table are not applicable to members subjected to particularly aggressive environments unless in the calculation of the moment of resistance, f_y has been limited to 300 N/mm² in limit state design and σ_{st} limited to 165 N/mm² in working stress design.

Table 16 Nominal Cover to Meet Durability Requirements

(*Clause* 26.4.2)

Exposure	Nominal Concrete Cover in mm not Less Than
Mild	20
Moderate	30
Severe	45
Very severe	50
Extreme	75

NOTES

1 For main reinforcement up to 12 mm diameter bar for mild exposure the nominal cover may be reduced by 5 mm.

2 Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by $^{+10}_{0}$ mm

3 For exposure condition 'severe' and 'very severe', reduction of 5 mm may be made, where concrete grade is M35 and above.

Table 16A
Nominal Cover to Meet Specified Period of Fire Resistance

(*Clauses* 21.4 and 26.4.3 and *Fig.* 1)

Fire Resis-tance	Nominal Cover						
	Beams		Slabs		Ribs		Columns
	Simply supported	Continuous	Simply supported	Continuous	Simply supported	Continuous	
h	mm	mm	mm	mm	mm	mm	mm
0.5	20	20	20	20	20	20	40
1	20	20	20	20	20	20	40
1.5	20	20	25	20	<u>35</u>	20	40
2	<u>40</u>	30	<u>35</u>	25	45	<u>35</u>	40
3	60	<u>40</u>	45	<u>35</u>	55	45	40
4	70	50	55	45	65	55	40

NOTES

1 The nominal covers given relate specifically to the minimum member dimensions given in Fig. 1.

2 Cases that lie below the bold line require attention to the additional measures necessary to reduce the risks of spalling (*see* 21.3.1).

given by the following:

$$\frac{A_s}{bd} = \frac{0.85}{f_y}$$

where

A_s = minimum area of tension reinforcement,

b = breadth of beam or the breadth of the web of T-beam,

d = effective depth, and

f_y = characteristic strength of reinforcement in N/mm².

b) *Maximum reinforcement*—The maximum area of tension reinforcement shall not exceed 0.04 bD.

26.5.1.2 *Compression reinforcement*

The maximum area of compression reinforcement shall not exceed 0.04 bD. Compression reinforcement in beams shall be enclosed by stirrups for effective lateral restraint. The arrangement of stirrups shall be as specified in 26.5.3.2.

26.5.1.3 *Side face reinforcement*

Where the depth of the web in a beam exceeds 750 mm, side face reinforcement shall be provided along the two faces. The total area of such reinforcement shall be not less than 0.1 percent of the web area and shall be distributed equally on two faces at a spacing not exceeding 300 mm or web thickness whichever is less.

26.5.1.4 *Transverse reinforcement in beams for shear and torsion*

The transverse reinforcement in beams shall be taken around the outer-most tension and compression bars. In T-beams and I-beams, such reinforcement shall pass around longitudinal bars located close to the outer face of the flange.

26.5.1.5 *Maximum spacing of shear reinforcement*

The maximum spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75 d for vertical stirrups and d for inclined stirrups at 45°, where d is the effective depth of the section under consideration. In no case shall the spacing exceed 300 mm.

26.5.1.6 *Minimum shear reinforcement*

Minimum shear reinforcement in the form of stirrups shall be provided such that:

$$\frac{A_{sv}}{b s_v} \geq \frac{0.4}{0.87 f_y}$$

where

- A_{sv} = total cross-sectional area of stirrup legs effective in shear,
- s_v = stirrup spacing along the length of the member,
- b = breadth of the beam or breadth of the web of flanged beam, and
- f_y = characteristic strength of the stirrup reinforcement in N/mm² which shall not be taken greater than 415 N/mm².

Where the maximum shear stress calculated is less than half the permissible value and in members of minor structural importance such as lintels, this provision need not be complied with.

26.5.1.7 *Distribution of torsion reinforcement*

When a member is designed for torsion (*see* 41 or B-6) torsion reinforcement shall be provided as below:

a) The transverse reinforcement for torsion shall be rectangular closed stirrups placed perpendicular to the axis of the member. The spacing of the stirrups shall not exceed the least of x_1, $\frac{x_1 + y_1}{4}$ and 300 mm, where x_1 and y_1 are respectively the short and long dimensions of the stirrup.

b) Longitudinal reinforcement shall be placed as close as is practicable to the corners of the cross-section and in all cases, there shall be at least one longitudinal bar in each corner of the ties. When the cross-sectional dimension of the member exceeds 450 mm, additional longitudinal bars shall be provided to satisfy the requirements of minimum reinforcement and spacing given in 26.5.1.3.

26.5.1.8 Reinforcement in flanges of T-and L-beams shall satisfy the requirements in 23.1.1(b). Where flanges are in tension, a part of the main tension reinforcement shall be distributed over the effective flange width or a width equal to one-tenth of the span, whichever is smaller. If the effective flange width exceeds one-tenth of the span, nominal longitudinal reinforcement shall be provided in the outer portions of the flange.

26.5.2 *Slabs*

The rules given in 26.5.2.1 and 26.5.2.2 shall apply to slabs in addition to those given in the appropriate clauses.

26.5.2.1 *Minimum reinforcement*

The mild steel reinforcement in either direction in slabs shall not be less than 0.15 percent of the total cross-sectional area. However, this value can be reduced to 0.12 percent when high strength deformed bars or welded wire fabric are used.

26.5.2.2 *Maximum diameter*

The diameter of reinforcing bars shall not exceed one-eight of the total thickness of the slab.

26.5.3 *Columns*

26.5.3.1 *Longitudinal reinforcement*

a) The cross-sectional area of longitudinal reinforcement, shall be not less than 0.8 percent nor more than 6 percent of the gross cross-sectional area of the column.

   NOTE — The use of 6 percent reinforcement may involve practical difficulties in placing and compacting of concrete; hence lower percentage is recommended. Where bars from the columns below have to be lapped with those in the column under consideration, the percentage of steel shall usually not exceed 4 percent.

b) In any column that has a larger cross-sectional area than that required to support the load, the minimum percentage of steel shall be based upon the area of concrete required to resist the direct stress and not upon the actual area.

c) The minimum number of longitudinal bars provided in a column shall be four in rectangular columns and six in circular columns.

d) The bars shall not be less than 12 mm in diameter.

e) A reinforced concrete column having helical reinforcement shall have at least six bars of longitudinal reinforcement within the helical reinforcement.

f) In a helically reinforced column, the longitudinal bars shall be in contact with the helical reinforcement and equidistant around its inner circumference.

g) Spacing of longitudinal bars measured along the periphery of the column shall not exceed 300 mm.

h) In case of pedestals in which the longitudinal reinforcement is not taken in account in strength calculations, nominal longitudinal reinforcement not less than 0.15 percent of the cross-sectional area shall be provided.

NOTE — Pedestal is a compression member, the effective length of which does not exceed three times the least lateral dimension.

26.5.3.2 *Transverse reinforcement*

a) *General*—A reinforced concrete compression member shall have transverse or helical reinforcement so disposed that every longitudinal bar nearest to the compression face has effective lateral support against buckling subject to provisions in (b). The effective lateral support is given by transverse reinforcement either in the form of circular rings capable of taking up circumferential tension or by polygonal links (lateral ties) with internal angles not exceeding 135°. The ends of the transverse reinforcement shall be properly anchored [*see* **26.2.2.4** (b)].

b) *Arrangement of transverse reinforcement*

1) If the longitudinal bars are not spaced more than 75 mm on either side, transverse reinforcement need only to go round corner and alternate bars for the purpose of providing effective lateral supports (*see* Fig. 8).

2) If the longitudinal bars spaced at a distance of not exceeding 48 times the diameter of the tie are effectively tied in two directions, additional longitudinal bars in between these bars need to be tied in one direction by open ties (*see* Fig. 9).

3) Where the longitudinal reinforcing bars in a compression member are placed in more than one row, effective lateral support to the longitudinal bars in the inner rows may be assumed to have been provided if:

i) transverse reinforcement is provided for the outer-most row in accordance with **26.5.3.2**, and

ii) no bar of the inner row is closer to the nearest compression face than three times the diameter of the largest bar in the inner row (*see* Fig. 10).

4) Where the longitudinal bars in a compression member are grouped (not in contact) and each group adequately tied with transverse reinforcement in accordance with **26.5.3.2**, the transverse reinforcement for the compression member as a whole may be provided on the assumption that each group is a single longitudinal bar for purpose of determining the pitch and diameter of the transverse reinforcement in accordance with **26.5.3.2**. The diameter of such transverse reinforcement need not, however, exceed 20 mm (*see* Fig. 11).

c) *Pitch and diameter of lateral ties*

1) *Pitch*—The pitch of transverse reinforcement shall be not more than the least of the following distances:

i) The least lateral dimension of the compression members;

ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and

iii) 300 mm.

2) *Diameter*—The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than 16 mm.

d) *Helical reinforcement*

1) *Pitch*—Helical reinforcement shall be of regular formation with the turns of the helix spaced evenly and its ends shall be anchored properly by providing one and a half extra turns of the spiral bar. Where an increased load on the column on the strength of the helical reinforcement is allowed for, the pitch of helical turns shall be not more than 75 mm, nor more than one-sixth of the core diameter of the column, nor less than 25 mm, nor less than three times the diameter of the steel bar forming the helix. In other cases, the requirements of **26.5.3.2** shall be complied with.

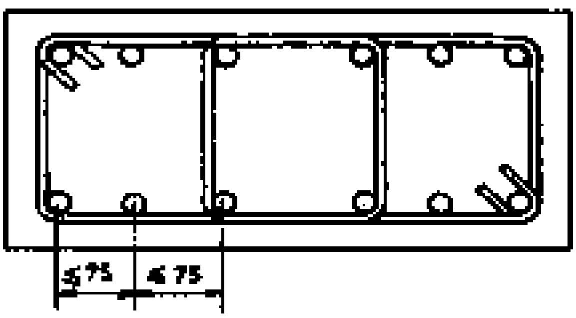
2) The diameter of the helical reinforcement shall be in accordance with **26.5.3.2** (c) (2).

26.5.3.3 In columns where longitudinal bars are offset at a splice, the slope of the inclined portion of the bar with the axis of the column shall not exceed 1 in 6, and the portions of the bar above and below the offset shall be parallel to the axis of the column. Adequate horizontal support at the offset bends shall be treated as a matter of design, and shall be provided by metal ties, spirals, or parts of the floor construction. Metal ties or spirals so designed shall be placed near (not more than eight-bar diameters from) the point of bend. The horizontal thrust to be resisted shall be assumed as one and half times the horizontal components of the nominal stress in the inclined portion of the bar. Offset bars shall be bent before they are placed in the forms. Where column faces are offset 75 mm or more, splices of vertical bars adjacent to the offset face shall be made by separate dowels overlapped as specified in **26.2.5.1**.

27 EXPANSION JOINTS

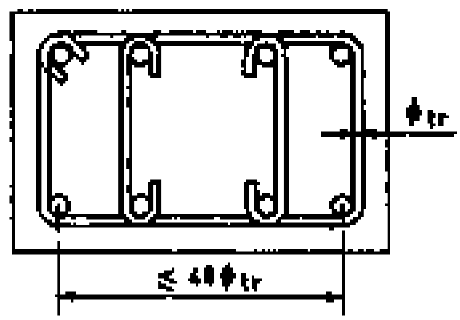
27.1 Structures in which marked changes in plan dimensions take place abruptly shall be provided with expansion on joints at the section where such changes occur. Expansion joints shall be so provided that the necessary movement occurs with a minimum resistance at the joint. The structures adjacent to the joint should preferably be supported on separate columns or walls but not necessarily on separate foundations. Reinforcement shall not extend across an expansion joint and the break between the sections shall be complete.

27.2 The details as to the length of a structure where expansion joints have to be provided can be determined after taking into consideration various factors, such as temperature, exposure to weather, the time and season of the laying of the concrete, etc. Normally structures exceeding 45 m in length are designed with one or more expansion joints. However in view of the large number of factors involved in deciding the location, spacing and nature of expansion joints, the provision of expansion joint in reinforced cement concrete structures should be left to the discretion of the designer. IS 3414 gives the design considerations, which need to be examined and provided for.



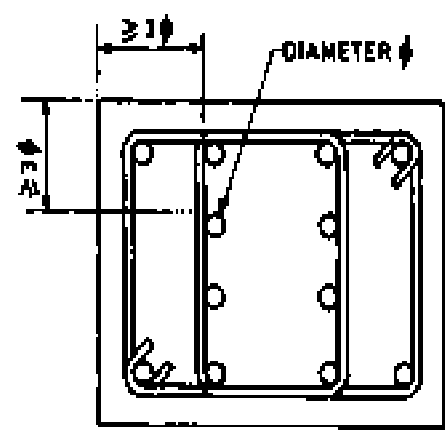
All dimensions in millimetres.

FIG. 8



All dimensions in millimetres.

FIG. 9



All dimensions in millimetres.

FIG. 10

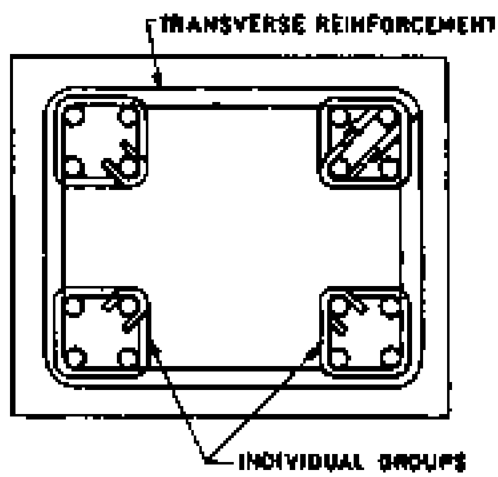


FIG. 11

SECTION 4 SPECIAL DESIGN REQUIREMENTS FOR STRUCTURAL MEMBERS AND SYSTEMS

28 CONCRETE CORBELS

28.1 General

A corbel is a short cantilever projection which supports a load bearing member and where:

a) the distance a_v between the line of the reaction to the supported load and the root of the corbel is less than d (the effective depth of the root of the corbel); and

b) the depth at the outer edge of the contact area of the supported load is not less than one-half of the depth at the root of the corbel.

The depth of the corbel at the face of the support is determined in accordance with **40.5.1**.

28.2 Design

28.2.1 *Simplifying Assumptions*

The concrete and reinforcement may be assumed to act as elements of a simple strut-and-tie system, with the following guidelines:

a) The magnitude of the resistance provided to horizontal force should be not less than one-half of the design vertical load on the corbel (*see also* **28.2.4**).

b) Compatibility of strains between the strut-and-tie at the corbel root should be ensured.

It should be noted that the horizontal link requirement described in **28.2.3** will ensure satisfactory serviceability performance.

28.2.2 *Reinforcement Anchorage*

At the front face of the corbel, the reinforcement should be anchored either by:

a) *welding to a transverse bar of equal strength* — in this case the bearing area of the load should stop short of the face of the support by a distance equal to the cover of the tie reinforcement, or

b) *bending back the bars to form a loop* — in this case the bearing area of the load should not project beyond the straight portion of the bars forming the main tension reinforcement.

28.2.3 *Shear Reinforcement*

Shear reinforcement should be provided in the form of horizontal links distributed in the upper two-third of the effective depth of root of the corbel; this reinforcement should be not less than one-half of the area of the main tension reinforcement and should be adequately anchored.

28.2.4 *Resistance to Applied Horizontal Force*

Additional reinforcement connected to the supported member should be provided to transmit this force in its entirety.

29 DEEP BEAMS

29.1 General

a) A beam shall be deemed to be a deep beam when the ratio of effective span to overall depth, $\frac{l}{D}$ is less than:

1) 2.0 for a simply supported beam; and

2) 2.5 for a continuous beam.

b) A deep beam complying with the requirements of **29.2** and **29.3** shall be deemed to satisfy the provisions for shear.

29.2 Lever Arm

The lever arm z for a deep beam shall be determined as below:

a) For simply supported beams:

$z = 0.2\,(l + 2D)$ when $1 \le \frac{l}{D} \le 2$

or

$z = 0.6\,l$ when $\frac{l}{D} < 1$

b) For continuous beams:

$z = 0.2\,(l + 1.5\,D)$ when $1 \le \frac{l}{D} \le 2.5$

or

$z = 0.5\,l$ when $\frac{l}{D} < 1$

where l is the effective span taken as centre to centre distance between supports or 1.15 times the clear span, whichever is smaller, and D is the overall depth.

29.3 Reinforcement

29.3.1 *Positive Reinforcement*

The tensile reinforcement required to resist positive bending moment in any span of a deep beam shall

a) extend without curtailment between supports;

b) be embedded beyond the face of each support, so that at the face of the support it shall have a development length not less than $0.8\,L_d$; where L_d is the development length (*see* **26.2.1**), for the design stress in the reinforcement; and

c) be placed within a zone of depth equal to $0.25\ D - 0.05\ l$ adjacent to the tension face of the beam where D is the overall depth and l is the effective span.

29.3.2 *Negative Reinforcement*

a) *Termination of reinforcement* — For tensile reinforcement required to resist negative bending moment over a support of a deep beam:

1) It shall be permissible to terminate not more than half of the reinforcement at a distance of $0.5\ D$ from the face of the support where D is as defined in **29.2**; and
2) The remainder shall extend over the full span.

b) *Distribution*—When ratio of clear span to overall depth is in the range 1.0 to 2.5, tensile reinforcement over a support of a deep beam shall be placed in two zones comprising:

1) a zone of depth $0.2\ D$, adjacent to the tension face, which shall contain a proportion of the tension steel given by

$$0.5\left(\frac{l}{D} - 0.5\right)$$

where

l = clear span, and

D = overall depth.

2) a zone measuring $0.3\ D$ on either side of the mid-depth of the beam, which shall contain the remainder of the tension steel, evenly distributed.

For span to depth ratios less than unity, the steel shall be evenly distributed over a depth of $0.8\ D$ measured from the tension face.

29.3.3 *Vertical Reinforcement*

If forces are applied to a deep beam in such a way that hanging action is required, bars or suspension stirrups shall be provided to carry all the forces concerned.

29.3.4 *Side Face Reinforcement*

Side face reinforcement shall comply with requirements of minimum reinforcement of walls (*see* **32.4**).

30 RIBBED, HOLLOW BLOCK OR VOIDED SLAB

30.1 General

This covers the slabs constructed in one of the ways described below:

a) As a series of concrete ribs with topping cast on forms which may be removed after the concrete has set;

b) As a series of concrete ribs between precast blocks which remain part of the completed structure; the top of the ribs may be connected by a topping of concrete of the same strength as that used in the ribs; and

c) With a continuous top and bottom face but containing voids of rectangular, oval or other shape.

30.2 Analysis of Structure

The moments and forces due to design loads on continuous slabs may be obtained by the methods given in Section 3 for solid slabs. Alternatively, the slabs may be designed as a series of simply supported spans provided they are not exposed to weather or corrosive conditions; wide cracks may develop at the supports and the engineer shall satisfy himself that these will not impair finishes or lead to corrosion of the reinforcement.

30.3 Shear

Where hollow blocks are used, for the purpose of calculating shear stress, the rib width may be increased to take account of the wall thickness of the block on one side of the rib; with narrow precast units, the width of the jointing mortar or concrete may be included.

30.4 Deflection

The recommendations for deflection in respect of solid slabs may be applied to ribbed, hollow block or voided construction. The span to effective depth ratios given in **23.2** for a flanged beam are applicable but when calculating the final reduction factor for web width, the rib width for hollow block slabs may be assumed to include the walls of the blocks on both sides of the rib. For voided slabs and slabs constructed of box or I-section units, an effective rib width shall be calculated assuming all material below the upper flange of the unit to be concentrated in a rectangular rib having the same cross-sectional area and depth.

30.5 Size and Position of Ribs

In-situ ribs shall be not less than 65 mm wide. They shall be spaced at centres not greater than 1.5 m apart and their depth, excluding any topping, shall be not more than four times their width. Generally ribs shall be formed along each edge parallel to the span of one way slabs. When the edge is built into a wall or rests on a beam, a rib at least as wide as the bearing shall be formed along the edge.

30.6 Hollow Blocks and Formers

Blocks and formers may be of any suitable material. Hollow clay tiles for the filler type shall conform to IS 3951 (Part 1). When required to contribute to the structural strength of a slab they shall:

a) be made of concrete or burnt clay; and
b) have a crushing strength of at least 14 N/mm² measured on the net section when axially loaded in the direction of compressive stress in the slab.

30.7 Arrangement of Reinforcement

The recommendations given in 26.3 regarding maximum distance between bars apply to areas of solid concrete in this form of construction. The curtailment, anchorage and cover to reinforcement shall be as described below:

a) At least 50 percent of the total main reinforcement shall be carried through at the bottom on to the bearing and anchored in accordance with 26.2.3.3.
b) Where a slab, which is continuous over supports, has been designed as simply supported, reinforcement shall be provided over the support to control cracking. This reinforcement shall have a cross-sectional area of not less than one-quarter that required in the middle of the adjoining spans and shall extend at least one-tenth of the clear span into adjoining spans.
c) In slabs with permanent blocks, the side cover to the reinforcement shall not be less than 10 mm. In all other cases, cover shall be provided according to 26.4.

30.8 Precasts Joists and Hollow Filler Blocks

The construction with precast joists and hollow concrete filler blocks shall conform to IS 6061 (Part 1) and precast joist and hollow clay filler blocks shall conform to IS 6061 (Part 2).

31 FLAT SLABS

31.1 General

The term flat slab means a reinforced concrete slab with or without drops, supported generally without beams, by columns with or without flared column heads (*see* Fig. 12). A flat slab may be solid slab or may have recesses formed on the soffit so that the soffit comprises a series of ribs in two directions. The recesses may be formed by removable or permanent filler blocks.

31.1.1 For the purpose of this clause, the following definitions shall apply:

a) *Column strip* — Column strip means a design strip having a width of 0.25 l_2, but not greater than 0.25 l_1 on each side of the column centre-line, where l_1 is the span in the direction moments are being determined, measured centre to centre of supports and l_2 is the span transverse to l_1, measured centre to centre of supports.
b) *Middle strip* — Middle strip means a design strip bounded on each of its opposite sides by the column strip.
c) *Panel* — Panel means that part of a slab bounded on each of its four sides by the centre-line of a column or centre-lines of adjacent spans.

31.2 Proportioning

31.2.1 *Thickness of Flat Slab*

The thickness of the flat slab shall be generally controlled by considerations of span to effective depth ratios given in 23.2.

For slabs with drops conforming to 31.2.2, span to effective depth ratios given in 23.2 shall be applied directly; otherwise the span to effective depth ratios obtained in accordance with provisions in 23.2 shall be multiplied by 0.9. For this purpose, the longer span shall be considered. The minimum thickness of slab shall be 125 mm.

31.2.2 *Drop*

The drops when provided shall be rectangular in plan, and have a length in each direction not less than one-third of the panel length in that direction. For exterior panels, the width of drops at right angles to the non-continuous edge and measured from the centre-line of the columns shall be equal to one-half the width of drop for interior panels.

31.2.3 *Column Heads*

Where column heads are provided, that portion of a column head which lies within the largest right circular cone or pyramid that has a vertex angle of 90° and can be included entirely within the outlines of the column and the column head, shall be considered for design purposes (*see* Fig.12).

31.3 Determination of Bending Moment

31.3.1 *Methods of Analysis and Design*

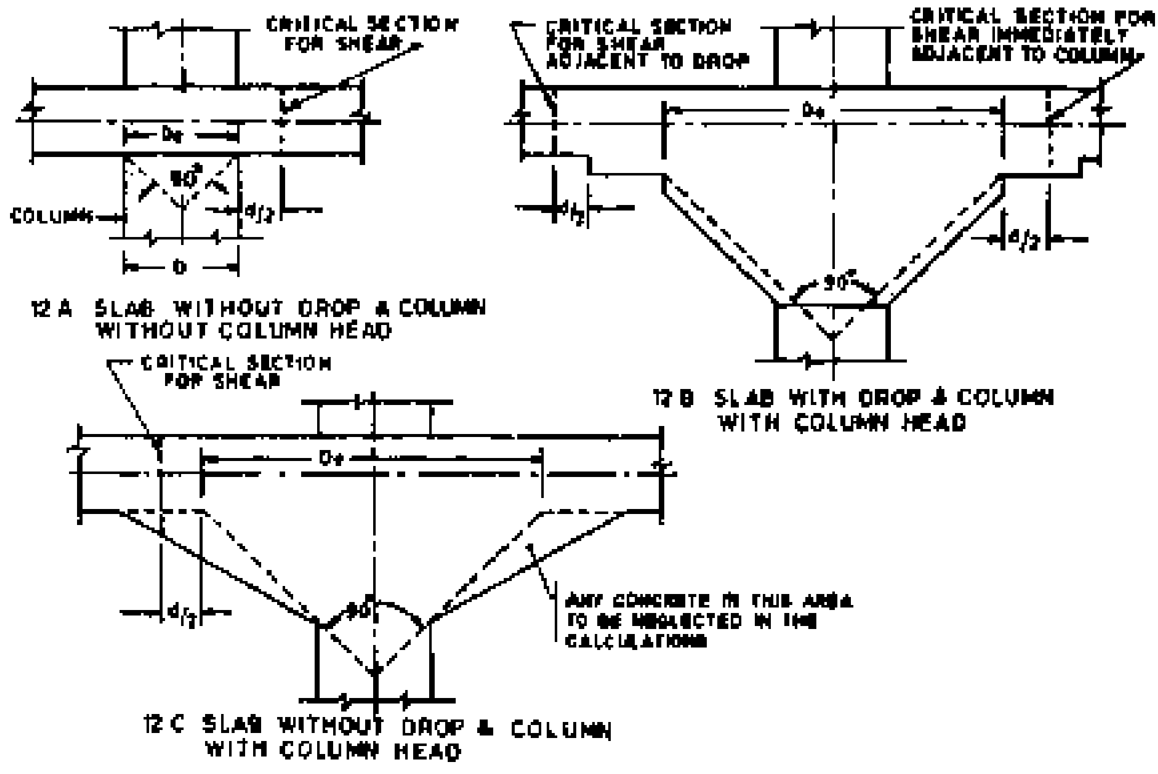
It shall be permissible to design the slab system by one of the following methods:

a) The direct design method as specified in 31.4, and
b) The equivalent frame method as specified in 31.5.

In each case the applicable limitations given in 31.4 and 31.5 shall be met.

31.3.2 *Bending Moments in Panels with Marginal Beams or Walls*

Where the slab is supported by a marginal beam with a depth greater than 1.5 times the thickness of the slab, or by a wall, then:



NOTE — D_e is the diameter of column or column head to be considered for design and d is effective depth of slab or drop as appropriate.

FIG. 12 CRITICAL SECTIONS FOR SHEAR IN FLAT SLABS

a) the total load to be carried by the beam or wall shall comprise those loads directly on the wall or beam plus a uniformly distributed load equal to one-quarter of the total load on the slab, and

b) the bending moments on the half-column strip adjacent to the beam or wall shall be one-quarter of the bending moments for the first interior column strip.

31.3.3 *Transfer of Bending Moments to Columns*

When unbalanced gravity load, wind, earthquake, or other lateral loads cause transfer of bending moment between slab and column, the flexural stresses shall be investigated using a fraction, α of the moment given by:

$$\alpha = \frac{1}{1+\frac{2}{3}\sqrt{a_1/a_2}}$$

where

a_1 = overall dimension of the critical section for shear in the direction in which moment acts, and

a_2 = overall dimension of the critical section for shear transverse to the direction in which moment acts.

A slab width between lines that are one and one-half slab or drop panel thickness; 1.5 *D*, on each side of the column or capital may be considered effective, *D* being the size of the column.

Concentration of reinforcement over column head by closer spacing or additional reinforcement may be used to resist the moment on this section.

31.4 Direct Design Method

31.4.1 *Limitations*

Slab system designed by the direct design method shall fulfil the following conditions:

a) There shall be minimum of three continuous spans in each direction,

b) The panels shall be rectangular, and the ratio of the longer span to the shorter span within a panel shall not be greater than 2.0,

c) It shall be permissible to offset columns to a maximum of 10 percent of the span in the direction of the offset notwithstanding the provision in (b),

d) The successive span lengths in each direction shall not differ by more than one-third of the longer span. The end spans may be shorter but not longer than the interior spans, and

e) The design live load shall not exceed three times the design dead load.

31.4.2 *Total Design Moment for a Span*

31.4.2.1 In the direct design method, the total design moment for a span shall be determined for a strip bounded laterally by the centre-line of the panel on each side of the centre-line of the supports.

31.4.2.2 The absolute sum of the positive and average negative bending moments in each direction shall be taken as:

$$M_0 = \frac{W l_n}{8}$$

where

M_0 = total moment;

W = design load on an area $l_2 l_n$;

l_n = clear span extending from face to face of columns, capitals, brackets or walls, but not less than 0.65 l_1;

l_1 = length of span in the direction of M_0; and

l_2 = length of span transverse to l_1.

31.4.2.3 Circular supports shall be treated as square supports having the same area.

31.4.2.4 When the transverse span of the panels on either side of the centre-line of supports varies, l_2 shall be taken as the average of the transverse spans.

31.4.2.5 When the span adjacent and parallel to an edge is being considered, the distance from the edge to the centre-line of the panel shall be substituted for l_2 in **31.4.2.2**.

31.4.3 *Negative and Positive Design Moments*

31.4.3.1 The negative design moment shall be located at the face of rectangular supports, circular supports being treated as square supports having the same area.

31.4.3.2 In an interior span, the total design moment M_0 shall be distributed in the following proportions:

Negative design moment	0.65
Positive design moment	0.35

31.4.3.3 In an end span, the total design moment M_0 shall be distributed in the following proportions.

Interior negative design moment:

$$0.75 - \frac{0.10}{1+\dfrac{1}{\alpha_c}}$$

Positive design moment:

$$0.63 - \frac{0.28}{1+\dfrac{1}{\alpha_c}}$$

Exterior negative design moment:

$$\frac{0.65}{1+\dfrac{1}{\alpha_c}}$$

α_c is the ratio of flexural stiffness of the exterior columns to the flexural stiffness of the slab at a joint taken in the direction moments are being determined and is given by

$$\alpha_c = \frac{\Sigma K_c}{K_s}$$

where

K_c = sum of the flexural stiffness of the columns meeting at the joint; and

K_s = flexural stiffness of the slab, expressed as moment per unit rotation.

31.4.3.4 It shall be permissible to modify these design moments by up to 10 percent, so long as the total design moment, M_0 for the panel in the direction considered is not less than that required by **31.4.2.2**.

31.4.3.5 The negative moment section shall be designed to resist the larger of the two interior negative design moments determined for the spans framing into a common support unless an analysis is made to distribute the unbalanced moment in accordance with the stiffness of the adjoining parts.

31.4.4 *Distribution of Bending Moments Across the Panel Width*

Bending moments at critical cross-section shall be distributed to the column strips and middle strips as specified in **31.5.5** as applicable.

31.4.5 *Moments in Columns*

31.4.5.1 Columns built integrally with the slab system shall be designed to resist moments arising from loads on the slab system.

31.4.5.2 At an interior support, the supporting members above and below the slab shall be designed to resist the moment M given by the following equation, in direct proportion to their stiffnesses unless a general analysis is made:

$$M = 0.08\,\frac{(w_d + 0.5 w_l)\, l_2\, l_n^2 - w'_d\, l'_2\, (l'_n)^2}{1+\dfrac{1}{\alpha_c}}$$

where

w_d, w_l = design dead and live loads respectively, per unit area;

l_2 = length of span transverse to the direction of M;

l_n = length of the clear span in the direction of M_0 measured face to face of supports;

α_c = $\frac{\Sigma K_c}{\Sigma K_s}$ where K_c and K_s are as defined in 31.4.3.3; and

w'_d, l'_2 and l'_n refer to the shorter span.

31.4.6 *Effects of Pattern Loading*

In the direct design method, when the ratio of live load to dead load exceeds 0.5 :

a) the sum of the flexural stiffnesses of the columns above and below the slab, ΣK_c, shall be such that α_c is not less than the appropriate minimum value $\alpha_{c,min}$ specified in Table 17, or

b) if the sum of the flexural stiffnesses of the columns, ΣK_c, does not satisfy (a), the positive design moments for the panel shall be multiplied by the coefficient β_s given by the following equation:

$$\beta_s = 1 + \left(\frac{2 - \frac{w_d}{w_l}}{4 + \frac{w_d}{w_l}} \right) \left(1 - \frac{\alpha_c}{\alpha_{c,min}} \right)$$

α_c is the ratio of flexural stiffness of the columns above and below the slab to the flexural stiffness of the slabs at a joint taken in the direction moments are being determined and is given by:

$$\alpha_c = \frac{\Sigma K_c}{\Sigma K_s}$$

where K_c and K_s are flexural stiffnesses of column and slab respectively.

31.5 Equivalent Frame Method

31.5.1 *Assumptions*

The bending moments and shear forces may be determined by an analysis of the structure as a continuous frame and the following assumptions may be made:

a) The structure shall be considered to be made up of equivalent frames on column lines taken longitudinally and transversely through the building. Each frame consists of a row of equivalent columns or supports, bounded laterally by the centre-line of the panel on each side of the centre-line of the columns or supports. Frames adjacent and parallel to an edge shall be bounded by the edge and the centre-line of the adjacent panel.

b) Each such frame may be analyzed in its entirety, or, for vertical loading, each floor thereof and the roof may be analyzed separately with its columns being assumed fixed at their remote ends. Where slabs are thus analyzed separately, it may be assumed in determining the bending moment at a given support that the slab is fixed at any support two panels distant therefrom provided the slab continues beyond the point.

c) For the purpose of determining relative stiffness of members, the moment of inertia of any slab or column may be assumed to be that of the gross cross-section of the concrete alone.

d) Variations of moment of inertia along the axis of the slab on account of provision of drops shall be taken into account. In the case of recessed or coffered slab which is made solid in the region of the columns, the stiffening effect may be ignored provided the solid part of the slab does not extend more than $0.15\ l_{ef}$ into the span measured from the centre-line of the columns. The stiffening effect of flared column heads may be ignored.

31.5.2 *Loading Pattern*

31.5.2.1 When the loading pattern is known, the structure shall be analyzed for the load concerned.

Table 17 Minimum Permissible Values of α_c

(*Clause* 31.4.6)

Imposed Load/Dead Load	Ratio $\frac{l_2}{l_1}$	Value of $\alpha_{c,min}$
(1)	(2)	(3)
0.5	0.5 to 2.0	0
1.0	0.5	0.6
1.0	0.8	0.7
1.0	1.0	0.7
1.0	1.25	0.8
1.0	2.0	1.2
2.0	0.5	1.3
2.0	0.8	1.5
2.0	1.0	1.6
2.0	1.25	1.9
2.0	2.0	4.9
3.0	0.5	1.8
3.0	0.8	2.0
3.0	1.0	2.3
3.0	1.25	2.8
3.0	2.0	13.0

31.5.2.2 When the live load is variable but does not exceed three-quarters of the dead load, or the nature of the live load is such that all panels will be loaded simultaneously, the maximum moments may be assumed to occur at all sections when full design live load is on the entire slab system.

31.5.2.3 For other conditions of live load/dead load ratio and when all panels are not loaded simultaneously,

a) maximum positive moment near midspan of a panel may be assumed to occur when three-quarters of the full design live load is on the panel and on alternate panels; and

b) maximum negative moment in the slab at a support may be assumed to occur when three-quarters of the full design live load is on the adjacent panels only.

31.5.2.4 In no case shall design moments be taken to be less than those occurring with full design live load on all panels.

31.5.3 *Negative Design Moment*

31.5.3.1 At interior supports, the critical section for negative moment, in both the column strip and middle strip, shall be taken at the face of rectilinear supports, but in no case at a distance greater than 0.175 l_1 from the centre of the column where l_1 is the length of the span in the direction moments are being determined, measured centre-to-centre of supports.

31.5.3.2 At exterior supports provided with brackets or capitals, the critical section for negative moment in the direction perpendicular to the edge shall be taken at a distance from the face of the supporting element not greater than one-half the projection of the bracket or capital beyond the face of the supporting element.

31.5.3.3 Circular or regular polygon shaped supports shall be treated as square supports having the same area.

31.5.4 *Modification of Maximum Moment*

Moments determined by means of the equivalent frame method, for slabs which fulfil the limitations of **31.4** may be reduced in such proportion that the numerical sum of the positive and average negative moments is not less than the value of total design moment M_o specified in **31.4.2.2**.

31.5.5 *Distribution of Bending Moment Across the Panel Width*

31.5.5.1 *Column strip : Negative moment at an interior support*

At an interior support, the column strip shall be designed to resist 75 percent of the total negative moment in the panel at that support.

31.5.5.2 *Column strip : Negative moment at an exterior support*

a) At an exterior support, the column strip shall be designed to resist the total negative moment in the panel at that support.

b) Where the exterior support consists of a column or a wall extending for a distance equal to or greater than three-quarters of the value of l_2, the length of span transverse to the direction moments are being determined, the exterior negative moment shall be considered to be uniformly distributed across the length l_2.

31.5.5.3 *Column strip : Positive moment for each span*

For each span, the column strip shall be designed to resist 60 percent of the total positive moment in the panel.

31.5.5.4 *Moments in the middle strip*

The middle strip shall be designed on the following bases:

a) That portion of the design moment not resisted by the column strip shall be assigned to the adjacent middle strips.

b) Each middle strip shall be proportioned to resist the sum of the moments assigned to its two half middle strips.

c) The middle strip adjacent and parallel to an edge supported by a wall shall be proportioned to resist twice the moment assigned to half the middle strip corresponding to the first row of interior columns.

31.6 Shear in Flat Slab

31.6.1 The critical section for shear shall be at a distance *d*/2 from the periphery of the column/capital/drop panel, perpendicular to the plane of the slab where *d* is the effective depth of the section (*see* Fig. 12). The shape in plan is geometrically similar to the support immediately below the slab (*see* Fig. 13A and 13B).

NOTE — For column sections with re-entrant angles, the critical section shall be taken as indicated in Fig. 13C and 13D.

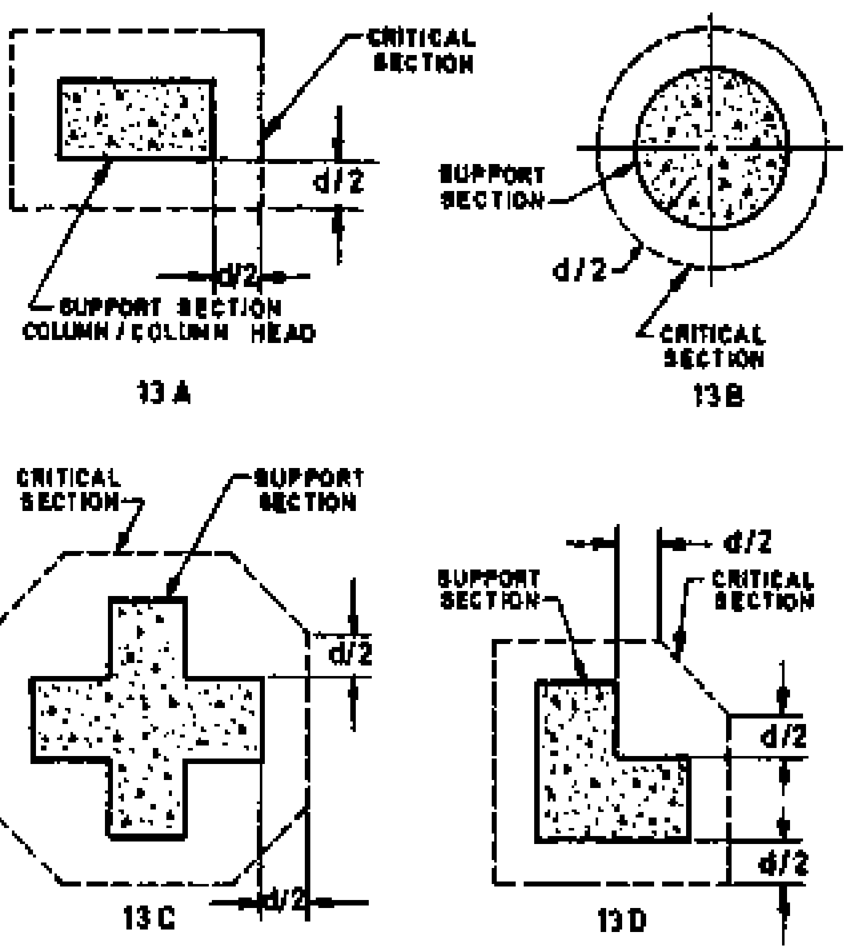
31.6.1.1 In the case of columns near the free edge of a slab, the critical section shall be taken as shown in Fig. 14.

31.6.1.2 When openings in flat slabs are located at a distance less than ten times the thickness of the slab from a concentrated reaction or when the openings are located within the column strips, the critical sections specified in **31.6.1** shall be modified so that the part of the periphery of the critical section which is enclosed by radial projections of the openings to the centroid of the reaction area shall be considered ineffective (*see* Fig. 15), and openings shall not encroach upon column head.

31.6.2 *Calculation of Shear Stress*

The shear stress τ_v shall be the sum of the values calculated according to **31.6.2.1** and **31.6.2.2**.

31.6.2.1 The nominal shear stress in flat slabs shall be taken as $V / b_o d$ where V is the shear force due to design load, b_o is the periphery of the critical section and d is the effective depth.



NOTE — d is the effective depth of the flat slab/drop.

FIG. 13 CRITICAL SECTIONS IN PLAN FOR SHEAR IN FLAT SLABS

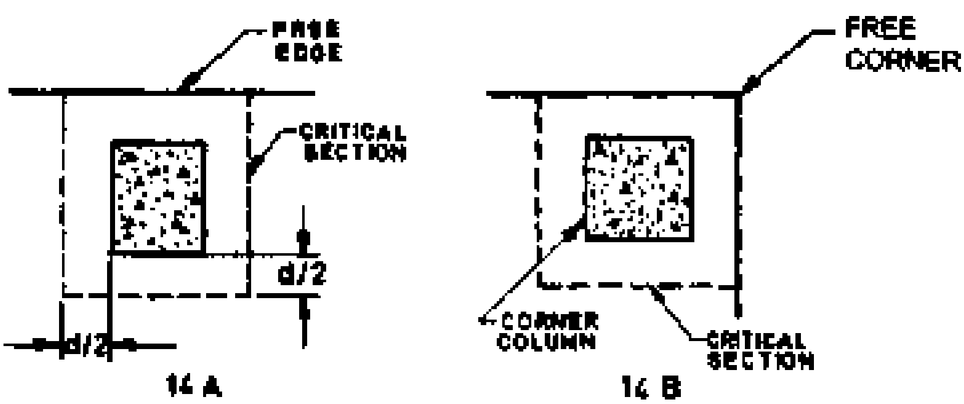


FIG. 14 EFFECT OF FREE EDGES ON CRITICAL SECTION FOR SHEAR

31.6.2.2 When unbalanced gravity load, wind, earthquake or other forces cause transfer of bending moment between slab and column, a fraction $(1 - \alpha)$ of the moment shall be considered transferred by eccentricity of the shear about the centroid of the critical section. Shear stresses shall be taken as varying linearly about the centroid of the critical section. The value of α shall be obtained from the equation given in 31.3.3.

31.6.3 *Permissible Shear Stress*

31.6.3.1 When shear reinforcement is not provided, the calculated shear stress at the critical section shall not exceed $k_s \tau_c$.

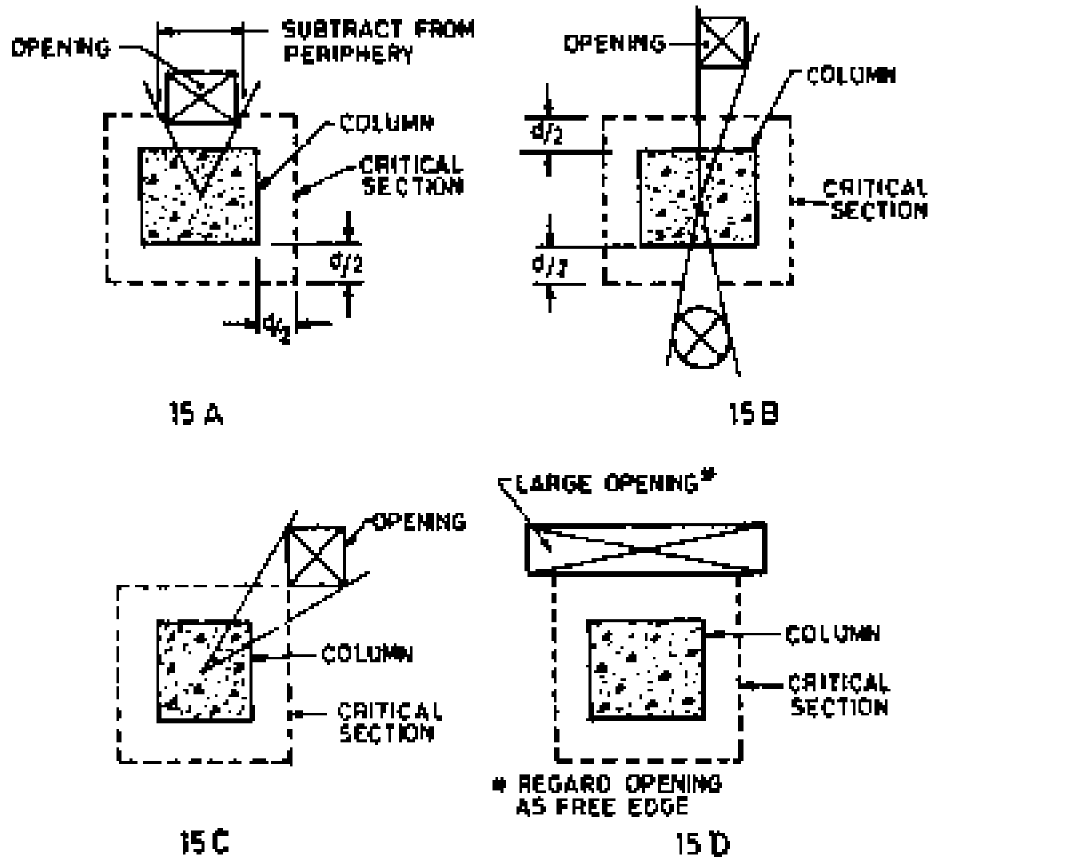


FIG. 15 EFFECT OF OPENINGS ON CRITICAL SECTION FOR SHEAR

where

$k_s = (0.5 + \beta_c)$ but not greater than 1, β_c being the ratio of short side to long side of the column/capital; and

$\tau_c = 0.25\sqrt{f_{ck}}$ in limit state method of design, and $0.16\sqrt{f_{ck}}$ in working stress method of design.

31.6.3.2 When the shear stress at the critical section exceeds the value given in **31.6.3.1**, but less than 1.5 τ_c shear reinforcement shall be provided. If the shear stress exceeds 1.5 τ_c, the flat slab shall be redesigned. Shear stresses shall be investigated at successive sections more distant from the support and shear reinforcement shall be provided up to a section where the shear stress does not exceed 0.5 τ_c. While designing the shear reinforcement, the shear stress carried by the concrete shall be assumed to be 0.5 τ_c and reinforcement shall carry the remaining shear.

31.7 Slab Reinforcement

31.7.1 *Spacing*

The spacing of bars in a flat slab, shall not exceed 2 times the slab thickness, except where a slab is of cellular or ribbed construction.

31.7.2 *Area of Reinforcement*

When drop panels are used, the thickness of drop panel for determination of area of reinforcement shall be the lesser of the following:

a) Thickness of drop, and

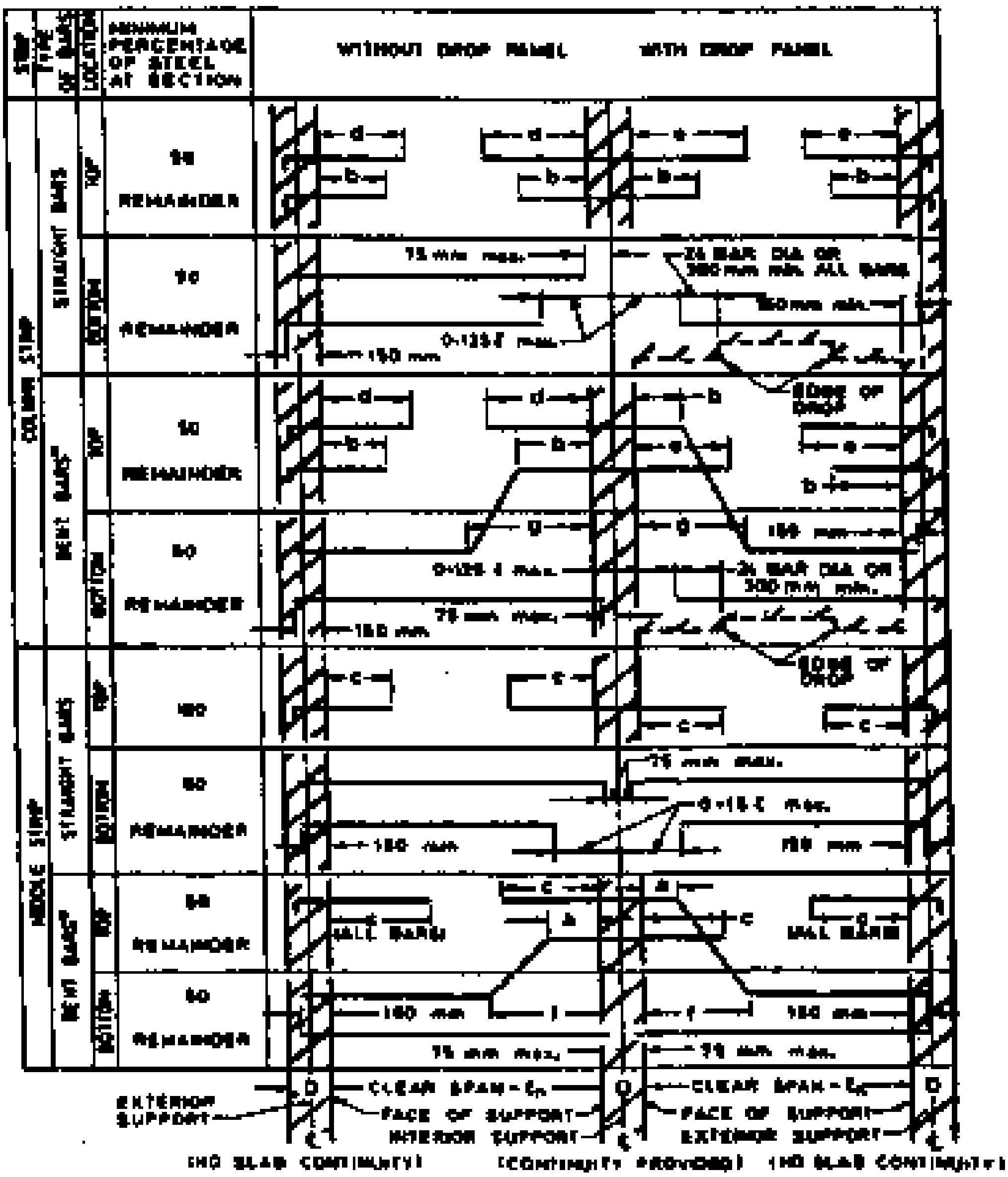
b) Thickness of slab plus one quarter the distance between edge of drop and edge of capital.

31.7.3 *Minimum Length of Reinforcement*

a) Reinforcement in flat slabs shall have the minimum lengths specified in Fig. 16. Larger lengths of reinforcement shall be provided when required by analysis.

b) Where adjacent spans are unequal, the extension of negative reinforcement beyond each face of the common column shall be based on the longer span.

c) The length of reinforcement for slabs in frames not braced against sideways and for slabs resisting lateral loads shall be determined by analysis but shall not be less than those prescribed in Fig. 16.



	Bar Length from Face of Support						
	Minimum Length					Maximum Length	
Mark	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Length	0.14 l_n	0.20 l_n	0.22 l_n	0.30 l_n	0.33 l_n	0.20 l_n	0.24 l_n

* Bent bars at exterior supports may be used if a general analysis is made.

NOTE — *D* is the diameter of the column and the dimension of the rectangular column in the direction under consideration.

FIG. 16 MINIMUM BEND JOINT LOCATIONS AND EXTENSIONS FOR REINFORCEMENT IN FLAT SLABS

31.7.4 *Anchoring Reinforcement*

a) All slab reinforcement perpendicular to a discontinuous edge shall have an anchorage (straight, bent or otherwise anchored) past the internal face of the spandrel beam, wall or column, of an amount:

   1) *For positive reinforcement* — not less than 150 mm except that with fabric reinforcement having a fully welded transverse wire directly over the support, it shall be permissible to reduce this length to one-half of the width of the support or 50 mm, whichever is greater; and

   2) *For negative reinforcement* — such that the design stress is developed at the internal face, in accordance with Section 3.

b) Where the slab is not supported by a spandrel beam or wall, or where the slab cantilevers beyond the support, the anchorage shall be obtained within the slab.

31.8 Openings in Flat Slabs

Openings of any size may be provided in the flat slab if it is shown by analysis that the requirements of strength and serviceability are met. However, for openings conforming to the following, no special analysis is required.

a) Openings of any size may be placed within the middle half of the span in each direction, provided the total amount of reinforcement required for the panel without the opening is maintained.

b) In the area common to two column strips, not more than one-eighth of the width of strip in either span shall be interrupted by the openings. The equivalent of reinforcement interrupted shall be added on all sides of the openings.

c) In the area common to one column strip and one middle strip, not more than one-quarter of the reinforcement in either strip shall be interrupted by the openings. The equivalent of reinforcement interrupted shall be added on all sides of the openings.

d) The shear requirements of 31.6 shall be satisfied.

32 WALLS

32.1 General

Reinforced concrete walls subjected to direct compression or combined flexure and direct compression should be designed in accordance with Section 5 or Annex B provided the vertical reinforcement is provided in each face. Braced walls subjected to only vertical compression may be designed as per empirical procedure given in 32.2. The minimum thickness of walls shall be 100 mm.

32.1.1 Guidelines or design of walls subjected to horizontal and vertical loads are given in 32.3.

32.2 Empirical Design Method for Walls Subjected to Inplane Vertical Loads

32.2.1 *Braced Walls*

Walls shall be assumed to be braced if they are laterally supported by a structure in which all the following apply:

a) Walls or vertical braced elements are arranged in two directions so as to provide lateral stability to the structure as a whole.

b) Lateral forces are resisted by shear in the planes of these walls or by braced elements.

c) Floor and roof systems are designed to transfer lateral forces.

d) Connections between the wall and the lateral supports are designed to resist a horizontal force not less than

   1) the simple static reactions to the total applied horizontal forces at the level of lateral support; and

   2) 2.5 percent of the total vertical load that the wall is designed to carry at the level of lateral support.

32.2.2 *Eccentricity of Vertical Load*

The design of a wall shall take account of the actual eccentricity of the vertical force subject to a minimum value of 0.05 t.

The vertical load transmitted to a wall by a discontinuous concrete floor or roof shall be assumed to act at one-third the depth of the bearing area measured from the span face of the wall. Where there is an *in-situ* concrete floor continuous over the wall, the load shall be assumed to act at the centre of the wall.

The resultant eccentricity of the total vertical load on a braced wall at any level between horizontal lateral supports, shall be calculated on the assumption that the resultant eccentricity of all the vertical loads above the upper support is zero.

32.2.3 *Maximum Effective Height to Thickness Ratio*

The ratio of effective height to thickness, H_{we}/t shall not exceed 30.

32.2.4 *Effective Height*

The effective height of a braced wall shall be taken as follows:

a) Where restrained against rotation at both ends by

1) floors $0.75\ H_w$ or

2) intersecting walls or similar members $0.75\ L_1$

whichever is the lesser.

b) Where not restrained against rotation at both ends by

1) floors $1.0\ H_w$ or

2) intersecting walls or similar members $1.0\ L_1$

whichever is the lesser.

where

H_w = the unsupported height of the wall

L_1 = the horizontal distance between centres of lateral restraint.

32.2.5 *Design Axial Strength of Wall*

The design axial strength P_{uw} per unit length of a braced wall in compression may be calculated from the following equation

$$P_{uw} = 0.3\,(t - 1.2\,e - 2e_a)\,f_{ck}$$

where

t = thickness of the wall,

e = eccentricity of load measured at right angles to the plane of the wall determined in accordance with **32.2.2**, and

e_a = additional eccentricity due to slenderness effect taken as $H_{we} / 2\,500\,t$.

32.3 Walls Subjected to Combined Horizontal and Vertical Forces

32.3.1 When horizontal forces are in the plane of the wall, it may be designed for vertical forces in accordance with **32.2** and for horizontal shear in accordance with **32.3**. In plane bending may be neglected in case a horizontal cross-section of the wall is always under compression due to combined effect of horizontal and vertical loads.

32.3.2 Walls subjected to horizontal forces perpendicular to the wall and for which the design axial load does not exceed $0.04\,f_{ck}\,A_g$, shall be designed as slabs in accordance with the appropriate provisions under **24**, where A_g is gross area of the section.

32.4 Design for Horizontal Shear

32.4.1 *Critical Section for Shear*

The critical section for maximum shear shall be taken at a distance from the base of $0.5\ L_w$ or $0.5\ H_w$ whichever is less.

32.4.2 *Nominal Shear Stress*

The nominal shear stress τ_{vw} in walls shall be obtained as follows:

$$\tau_{vw} = V_u / t.d$$

where

V_u = shear force due to design loads,

t = wall thickness,

d = $0.8 \times L_w$ where L_w is the length of the wall.

32.4.2.1 *Under no circumstances* shall the nominal shear stress τ_{vw} in walls exceed $0.17\,f_{ck}$ in limit state method and $0.12\,f_{ck}$ in working stress method.

32.4.3 *Design Shear Strength of Concrete*

The design shear strength of concrete in walls, τ_{cw}, without shear reinforcement shall be taken as below:

a) For $H_w / L_w \leq 1$

$$\tau_{cw} = (3.0 - H_w / L_w)\,K_1\,\sqrt{f_{ck}}$$

where K_1 is 0.2 in limit state method and 0.13 in working stress method.

b) For $H_w / L_w > 1$

Lesser of the values calculated from (a) above and from

$$\tau_{cw} = K_2\,\sqrt{f_{ck}}\,\frac{H_w / L_w + 1}{H_w / L_w - 1}$$

where K_2 is 0.045 in limit state method and 0.03 in working stress method, but shall be not less than $K_1\sqrt{f_{ck}}$ in any case, where K_1 is 0.15 in limit state method and 0.10 in working stress method.

32.4.4 *Design of Shear Reinforcement*

Shear reinforcement shall be provided to carry a shear equal to $V_u - \tau_{cw}\,t\,(0.8\,L_w)$. In case of working stress method V_u is replaced by V. The strength of shear reinforcement shall be calculated as per **40.4** or **B-5.4** with A_{sv} defined as below:

$$A_{sv} = \rho_w\,(0.8\,L_w)\,t$$

where ρ_w is determined as follows:

a) For walls where $H_w / L_w \leq 1$, ρ_w shall be the lesser of the ratios of either the vertical reinforcement area or the horizontal reinforcement area to the cross-sectional area of wall in the respective direction.

b) For walls where $H_w / L_w > 1$, ρ_w shall be the ratio of the horizontal reinforcement area to the cross-sectional area of wall per vertical metre.

32.5 Minimum Requirements for Reinforcement in Walls

The reinforcement for walls shall be provided as below:

a) the minimum ratio of vertical reinforcement to gross concrete area shall be:

   1) 0.001 2 for deformed bars not larger than 16 mm in diameter and with a characteristic strength of 415 N/mm² or greater.

   2) 0.001 5 for other types of bars.

   3) 0.001 2 for welded wire fabric not larger than 16 mm in diameter.

b) Vertical reinforcement shall be spaced not farther apart than three times the wall thickness nor 450 mm.

c) The minimum ratio of horizontal reinforcement to gross concrete area shall be:

   1) 0.002 0 for deformed bars not larger than 16 mm in diameter and with a characteristic strength of 415 N/mm² or greater.

   2) 0.002 5 for other types of bars.

   3) 0.002 0 for welded wire fabric not larger than 16 mm in diameter.

d) Horizontal reinforcement shall be spaced not farther apart than three times the wall thickness nor 450 mm.

NOTE — The minimum reinforcement may not always be sufficient to provide adequate resistance to the effects of shrinkage and temperature.

32.5.1 For walls having thickness more than 200 mm, the vertical and horizontal reinforcement shall be provided in two grids, one near each face of the wall.

32.5.2 Vertical reinforcement need not be enclosed by transverse reinforcement as given in **26.5.3.2** for column, if the vertical reinforcement is not greater than 0.01 times the gross sectional area or where the vertical reinforcement is not required for compression.

33 STAIRS

33.1 Effective Span of Stairs

The effective span of stairs without stringer beams shall be taken as the following horizontal distances:

a) Where supported at top and bottom risers by beams spanning parallel with the risers, the distance centre-to-centre of beams;

b) Where spanning on to the edge of a landing slab, which spans parallel, with the risers (*see* Fig. 17), a distance equal to the going of the stairs plus at each end either half the width of the landing or one metre, whichever is smaller; and

c) Where the landing slab spans in the same direction as the stairs, they shall be considered as acting together to form a single slab and the span determined as the distance centre-to-centre of the supporting beams or walls, the going being measured horizontally.

33.2 Distribution of Loading on Stairs

In the case of stairs with open wells, where spans partly crossing at right angles occur, the load on areas common to any two such spans may be taken as one-half in each direction as shown in Fig. 18. Where flights or landings are embedded into walls for a length of not less than 110 mm and are designed to span in the direction of the flight, a 150 mm strip may be deducted from the loaded area and the effective breadth of the section increased by 75 mm for purposes of design (*see* Fig. 19).

33.3 Depth of Section

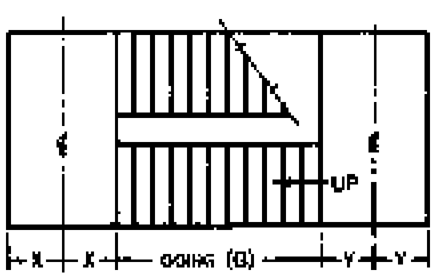
The depth of section shall be taken as the minimum thickness perpendicular to the soffit of the staircase.

34 FOOTINGS

34.1 General

Footings shall be designed to sustain the applied loads, moments and forces and the induced reactions and to ensure that any settlement which may occur shall be as nearly uniform as possible, and the safe bearing capacity of the soil is not exceeded (*see* IS 1904).

34.1.1 In sloped or stepped footings the effective



X	Y	SPAN IN METRES
≤1 m	≤1 m	G + X + Y
≤1 m	≥1 m	G + X + 1
≥1 m	≤1 m	G + Y + 1
≥1 m	≥1 m	G + 1 + 1

FIG. 17 EFFECTIVE SPAN FOR STAIRS SUPPORTED AT EACH END BY LANDINGS SPANNING PARALLEL WITH THE RISERS

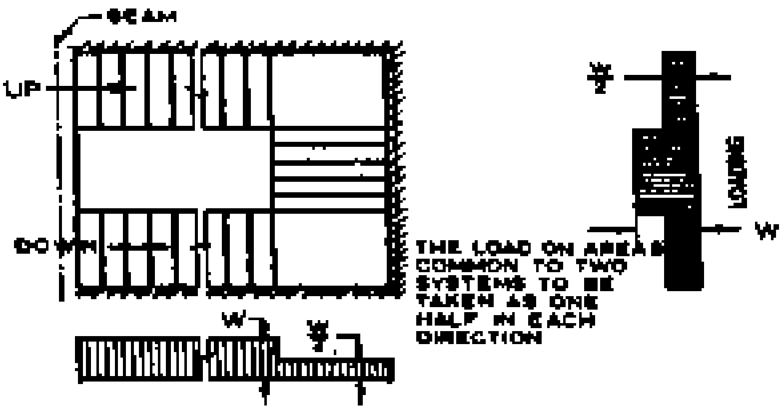


Fig. 18 Loading on Stairs with Open Wells

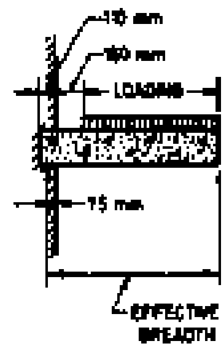


Fig. 19 Loading on Stairs Built into Walls

cross-section in compression shall be limited by the area above the neutral plane, and the angle of slope or depth and location of steps shall be such that the design requirements are satisfied at every section. Sloped and stepped footings that are designed as a unit shall be constructed to assure action as a unit.

34.1.2 *Thickness at the Edge of Footing*

In reinforced and plain concrete footings, the thickness at the edge shall be not less than 150 mm for footings on soils, nor less than 300 mm above the tops of piles for footings on piles.

34.1.3 In the case of plain concrete pedestals, the angle between the plane passing through the bottom edge of the pedestal and the corresponding junction edge of the column with pedestal and the horizontal plane (*see* Fig. 20) shall be governed by the expression:

$$\tan\alpha \le 0.9\sqrt{\frac{100\,q_0}{f_{ck}}+1}$$

where

q_0 = calculated maximum bearing pressure at the base of the pedestal in N/mm², and

f_{ck} = characteristic strength of concrete at 28 days in N/mm².

34.2 Moments and Forces

34.2.1 In the case of footings on piles, computation for moments and shears may be based on the assumption that the reaction from any pile is concentrated at the centre of the pile.

34.2.2 For the purpose of computing stresses in footings which support a round or octagonal concrete column or pedestal, the face of the column or pedestal shall be taken as the side of a square inscribed within the perimeter of the round or octagonal column or pedestal.

34.2.3 *Bending Moment*

34.2.3.1 The bending moment at any section shall be determined by passing through the section a vertical

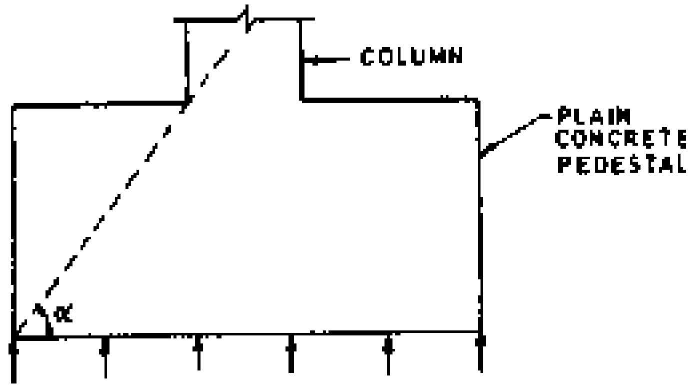


Fig. 20

plane which extends completely across the footing, and computing the moment of the forces acting over the entire area of the footing on one side of the said plane.

34.2.3.2 The greatest bending moment to be used in the design of an isolated concrete footing which supports a column, pedestal or wall, shall be the moment computed in the manner prescribed in 34.2.3.1 at sections located as follows:

a) At the face of the column, pedestal or wall, for footings supporting a concrete column, pedestal or wall;
b) Halfway between the centre-line and the edge of the wall, for footings under masonry walls; and
c) Halfway between the face of the column or pedestal and the edge of the gusseted base, for footings under gusseted bases.

34.2.4 *Shear and Bond*

34.2.4.1 The shear strength of footings is governed by the more severe of the following two conditions:

a) The footing acting essentially as a wide beam, with a potential diagonal crack extending in a plane across the entire width; the critical section for this condition shall be assumed as a vertical section located from the face of the column, pedestal or wall at a distance equal to the effective depth of footing for footings on piles.
b) Two-way action of the footing, with potential diagonal cracking along the surface of truncated cone or pyramid around the concentrated load; in this case, the footing shall be designed for shear in accordance with appropriate provisions specified in 31.6.

34.2.4.2 In computing the external shear or any section through a footing supported on piles, the entire reaction from any pile of diameter D_p whose centre is located $D_p/2$ or more outside the section shall be assumed as producing shear on the section; the reaction from any pile whose centre is located $D_p/2$ or more inside the section shall be assumed as producing no shear on the section. For intermediate positions of the pile centre, the portion of the pile reaction to be assumed as producing shear on the section shall be based on straight line interpolation between full value at $D_p/2$ outside the section and zero value at $D_p/2$ inside the section.

34.2.4.3 The critical section for checking the development length in a footing shall be assumed at the same planes as those described for bending moment in 34.2.3 and also at all other vertical planes where abrupt changes of section occur. If reinforcement is curtailed, the anchorage requirements shall be checked in accordance with 26.2.3.

34.3 Tensile Reinforcement

The total tensile reinforcement at any section shall provide a moment of resistance at least equal to the bending moment on the section calculated in accordance with 34.2.3.

34.3.1 Total tensile reinforcement shall be distributed across the corresponding resisting section as given below:

a) In one-way reinforced footing, the reinforcement extending in each direction shall be distributed uniformly across the full width of the footing;
b) In two-way reinforced square footing, the reinforcement extending in each direction shall be distributed uniformly across the full width of the footing; and
c) In two-way reinforced rectangular footing, the reinforcement in the long direction shall be distributed uniformly across the full width of the footing. For reinforcement in the short direction, a central band equal to the width of the footing shall be marked along the length of the footing and portion of the reinforcement determined in accordance with the equation given below shall be uniformly distributed across the central band:

$$\frac{\text{Reinforcement in central band width}}{\text{Total reinforcement in short direction}} = \frac{2}{\beta + 1}$$

where β is the ratio of the long side to the short side of the footing. The remainder of the reinforcement shall be uniformly distributed in the outer portions of the footing.

34.4 Transfer of Load at the Base of Column

The compressive stress in concrete at the base of a column or pedestal shall be considered as being transferred by bearing to the top of the supporting pedestal or footing. The bearing pressure on the loaded area shall not exceed the permissible bearing stress in direct compression multiplied by a value equal to

$\sqrt{\frac{A_1}{A_2}}$ but not greater than 2;

where

A_1 = supporting area for bearing of footing, which in sloped or stepped footing may be taken as the area of the lower base of the largest frustum of a pyramid or cone contained wholly within the footing and having for its upper base, the area actually loaded and having side slope of one vertical to two horizontal; and

A_2 = loaded area at the column base.

For working stress method of design the permissible bearing stress on full area of concrete shall be taken as $0.25 f_{ck}$; for limit state method of design the permissible bearing stress shall be $0.45\ f_{ck}$.

34.4.1 Where the permissible bearing stress on the concrete in the supporting or supported member would be exceeded, reinforcement shall be provided for developing the excess force, either by extending the longitudinal bars into the supporting member, or by dowels (*see* 34.4.3).

34.4.2 Where transfer of force is accomplished by reinforcement, the development length of the reinforcement shall be sufficient to transfer the compression or tension to the supporting member in accordance with 26.2.

34.4.3 Extended longitudinal reinforcement or dowels of at least 0.5 percent of the cross-sectional area of the supported column or pedestal and a minimum of four bars shall be provided. Where dowels are used, their diameter shall no exceed the diameter of the column bars by more than 3 mm.

34.4.4 Column bars of diameters larger than 36 mm, in compression only can be dowelled at the footings with bars of smaller size of the necessary area. The dowel shall extend into the column, a distance equal to the development length of the column bar and into the footing, a distance equal to the development length of the dowel.

34.5 Nominal Reinforcement

34.5.1 Minimum reinforcement and spacing shall be as per the requirements of solid slab.

34.5.2 The nominal reinforcement for concrete sections of thickness greater than 1 m shall be 360 mm² per metre length in each direction on each face. This provision does not supersede the requirement of minimum tensile reinforcement based on the depth of the section.

SECTION 5 STRUCTURAL DESIGN (LIMIT STATE METHOD)

35 SAFETY AND SERVICEABILITY REQUIREMENTS

35.1 General

In the method of design based on limit state concept, the structure shall be designed to withstand safely all loads liable to act on it throughout its life; it shall also satisfy the serviceability requirements, such as limitations on deflection and cracking. The acceptable limit for the safety and serviceability requirements before failure occurs is called a 'limit state'. The aim of design is to achieve acceptable probabilities that the structure will not become unfit for the use for which it is intended, that is, that it will not reach a limit state.

35.1.1 All relevant limit states shall be considered in design to ensure an adequate degree of safety and serviceability. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states.

35.1.2 For ensuring the above objective, the design should be based on characteristic values for material strengths and applied loads, which take into account the variations in the material strengths and in the loads to be supported. The characteristic values should be based on statistical data if available; where such data are not available they should be based on experience. The 'design values' are derived from the characteristic values through the use of partial safety factors, one for material strengths and the other for loads. In the absence of special considerations these factors should have the values given in **36** according to the material, the type of loading and the limit state being considered.

35.2 Limit State of Collapse

The limit state of collapse of the structure or part of the structure could be assessed from rupture of one or more critical sections and from buckling due to elastic or plastic instability (including the effects of sway where appropriate) or overturning. The resistance to bending, shear, torsion and axial loads at every section shall not be less than the appropriate value at that section produced by the probable most unfavourable combination of loads on the structure using the appropriate partial safety factors.

35.3 Limit States of Serviceability

35.3.1 *Deflection*

Limiting values of deflections are given in **23.2**.

35.3.2 *Cracking*

Cracking of concrete should not adversely affect the appearance or durability of the structure; the acceptable limits of cracking would vary with the type of structure and environment. Where specific attention is required to limit the designed crack width to a particular value, crack width calculation may be done using formula given in Annex F.

The practical objective of calculating crack width is merely to give guidance to the designer in making appropriate structural arrangements and in avoiding gross errors in design, which might result in concentration and excessive width of flexural crack.

The surface width of the cracks should not, in general, exceed 0.3 mm in members where cracking is not harmful and does not have any serious adverse effects upon the preservation of reinforcing steel nor upon the durability of the structures. In members where cracking in the tensile zone is harmful either because they are exposed to the effects of the weather or continuously exposed to moisture or in contact soil or ground water, an upper limit of 0.2 mm is suggested for the maximum width of cracks. For particularly aggressive environment, such as the 'severe' category in Table 3, the assessed surface width of cracks should not in general, exceed 0.1 mm.

35.4 Other Limit States

Structures designed for unusual or special functions shall comply with any relevant additional limit state considered appropriate to that structure.

36 CHARACTERISTIC AND DESIGN VALUES AND PARTIAL SAFETY FACTORS

36.1 Characteristic Strength of Materials

The term 'characteristic strength' means that value of the strength of the material below which not more than 5 percent of the test results are expected to fall. The characteristic strength for concrete shall be in accordance with Table 2. Until the relevant Indian Standard Specifications for reinforcing steel are modified to include the concept of characteristic strength, the characteristic value shall be assumed as the minimum yield stress/0.2 percent proof stress specified in the relevant Indian Standard Specifications.

36.2 Characteristic Loads

The term 'characteristic load' means that value of load which has a 95 percent probability of not being exceeded during the life of the structure. Since data are not available to express loads in statistical terms, for the purpose of this standard, dead loads given in IS 875 (Part 1), imposed loads given in IS 875 (Part 2), wind loads given in IS 875 (Part 3), snow load as given in IS 875 (Part 4) and seismic forces given in IS 1893 shall be assumed as the characteristic loads.

36.3 Design Values

36.3.1 *Materials*

The design strength of the materials, f_d is given by

$$f_d = \frac{f}{\gamma_m}$$

where

f = characteristic strength of the material (*see* 36.1), and

γ_m = partial safety factor appropriate to the material and the limit state being considered.

36.3.2 *Loads*

The design load, F_d is given by

$$F_d = F\gamma_f$$

where

F = characteristic load (*see* 36.2), and

γ_f = partial safety factor appropriate to the nature of loading and the limit state being considered.

36.3.3 *Consequences of Attaining Limit State*

Where the consequences of a structure attaining a limit state are of a serious nature such as huge loss of life and disruption of the economy, higher values for γ_f and γ_m than those given under 36.4.1 and 36.4.2 may be applied.

36.4 Partial Safety Factors

36.4.1 *Partial Safety Factor* γ_f *for Loads*

The values of γ_f given in Table 18 shall normally be used.

36.4.2 *Partial Safety Factor* γ_m *for Mateiral Strength*

36.4.2.1 When assessing the strength of a structure or structural member for the limit state of collapse, the values of partial safety factor, γ_m should be taken as 1.5 for concrete and 1.15 for steel.

NOTE — γ_m values are already incorporated in the equations and tables given in this standard for limit state design.

36.4.2.2 When assessing the deflection, the material properties such as modulus of elasticity should be taken as those associated with the characteristic strength of the material.

37 ANALYSIS

37.1 Analysis of Structure

Methods of analysis as in 22 shall be used. The material strength to be assumed shall be characteristic values in the determination of elastic properties of members irrespective of the limit state being considered. Redistribution of the calculated moments may be made as given in 37.1.1.

37.1.1 *Redistribution of Moments in Continuous Beams and Frames*

The redistribution of moments may be carried out satisfying the following conditions:

a) Equilibirum between the interal forces and the external loads is maintained.

b) The ultimate moment of resistance provided at any section of a member is not less than 70 percent of the moment at that section obtained from an elastic maximum moment diagram covering all appropriate combinations of loads.

c) The elastic moment at any section in a member due to a particular combination of loads shall

Table 18 Values of Partial Safety Factor γ_f for Loads

(*Clauses* 18.2.3.1, 36.4.1 *and* B-4.3)

Load Combination	Limit State of Collapse			Limit States of Serviceability		
	DL	*IL*	*WL*	*DL*	*IL*	*WL*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
DL + *IL*	1.5		1.0	1.0	1.0	–
DL + *WL*	1.5 or 0.9*	–	1.5	1.0	–	1.0
DL + *IL* + *WL*		1.2		1.0	0.8	0.8

NOTES

1 While considering earthquake effects, substitute *EL* for *WL*.

2 For the limit states of serviceability, the values of γ_f given in this table are applicable for short term effects. While assessing the long term effects due to creep the dead load and that part of the live load likely to be permanent may only be considered.

* This value is to be considered when stability against overturning or stress reversal is critical.

not be reduced by more than 30 percent of the numerically largest moment given anywhere by the elastic maximum moments diagram for the particular member, covering all appropriate combination of loads.

d) At sections where the moment capacity after redistribution is less than that from the elastic maximum moment diagram, the following relationship shall be satisfied:

$$\frac{x_u}{d} + \frac{\delta M}{100} \leq 0.6$$

where

x_u = depth of neutral axis,

d = effective depth, and

δM = percentage reduction in moment.

e) In structures in which the structural frame provides the lateral stability, the reductions in moment allowed by condition 37.1.1 (c) shall be restricted to 10 percent for structures over 4 storeys in height.

37.1.2 *Analysis of Slabs Spanning in Two Directions at Right Angles*

Yield line theory or any other acceptable method may be used. Alternatively the provisions given in Annex D may be followed.

38 LIMIT STATE OF COLLAPSE : FLEXURE

38.1 Assumptions

Design for the limit state of collapse in flexure shall be based on the assumptions given below:

a) Plane sections normal to the axis remain plane after bending.

b) The maximum strain in concrete at the outermost compression fibre is taken as 0.003 5 in bending.

c) The relationship between the compressive stress distribution in concrete and the strain in concrete may be assumed to be rectangle, trapezoid, parabola or any other shape which results in prediction of strength in substantial agreement with the results of test. An acceptable stress-strain curve is given in Fig. 21. For design purposes, the compressive strength of concrete in the structure shall be assumed to be 0.67 times the characteristic strength. The partial safety factor γ_m = 1.5 shall be applied in addition to this.

NOTE — For the stress-strain curve in Fig. 21 the design stress block parameters are as follows (*see* Fig. 22):

Area of stress block	$= 0.36 f_{ck} \cdot x_u$
Depth of centre of compressive force from the extreme fibre in compression	$= 0.42 x_u$

where

f_{ck} = characteristic compressive strength of concrete, and

x_u = depth of neutral axis.

d) The tensile strength of the concrete is ignored.

e) The stresses in the reinforcement are derived from representative stress-strain curve for the type of steel used. Typical curves are given in Fig. 23. For design purposes the partial safety factor γ_m, equal to 1.15 shall be applied.

f) The maximum strain in the tension reinforcement in the section at failure shall not be less than:

$$\frac{f_y}{1.15 E_s} + 0.002$$

where

f_y = characteristic strength of steel, and

E_s = modulus of elasticity of steel.

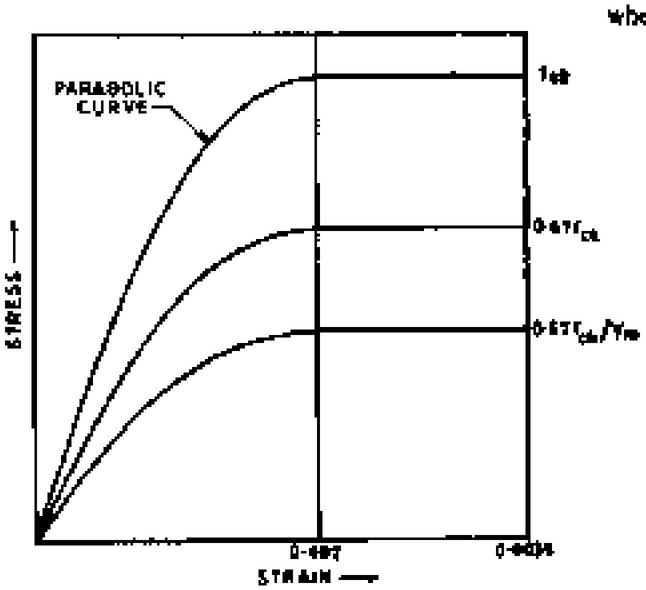


FIG. 21 STRESS-STRAIN CURVE FOR CONCRETE

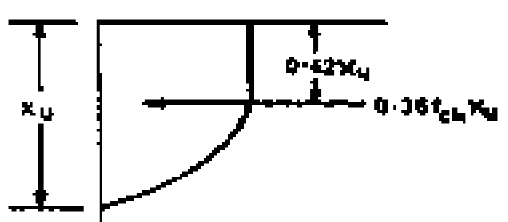
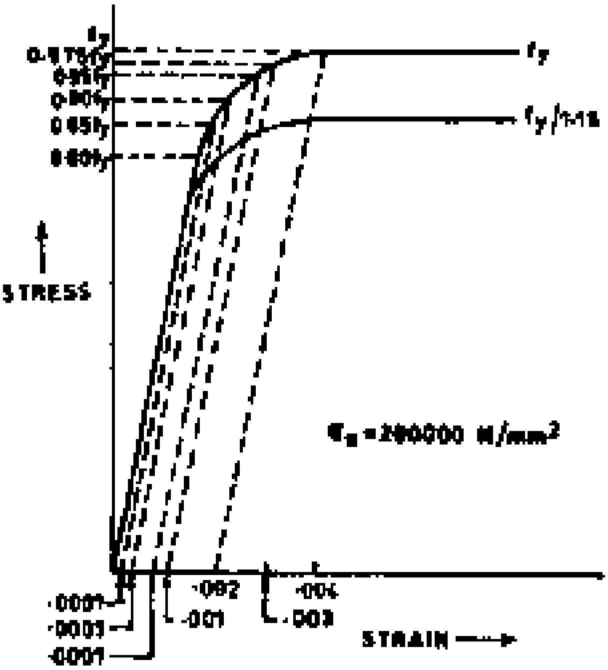
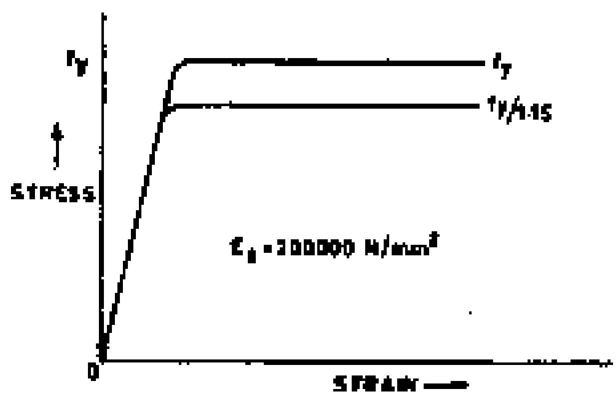


FIG. 22 STRESS BLOCK PARAMETERS



23A Cold Worked Deformed Bar



23B Steel Bar with Definite Yield Point

Fig. 23 Representative Stress-Strain Curves for Reinforcement

NOTE — The limiting values of the depth of neutral axis for different grades of steel based on the assumptions in 38.1 are as follows.

f_y	$x_{u,max}/d$
250	0.53
415	0.48
500	0.46

The expression for obtaining the moments of resistance for rectangular and T-Sections, based on the assumptions of 38.1, are given in Annex G.

39 LIMIT STATE OF COLLAPSE : COMPRESSION

39.1 Assumptions

In addition to the assumptions given in 38.1 (a) to 38.1 (e) for flexure, the following shall be assumed:

a) The maximum compressive strain in concrete in axial compression is taken as 0.002.

b) The maximum compressive strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending and when there is no tension on the section shall be 0.0035 minus 0.75 times the strain at the least compressed extreme fibre.

39.2 Minimum Eccentricity

All members in compression shall be designed for the minimum eccentricity in accordance with 25.4. Where calculated eccentricity is larger, the minimum eccentricity should be ignored.

39.3 Short Axially Loaded Members in Compression

The member shall be designed by considering the assumptions given in **39.1** and the minimum eccentricity. When the minimum eccentricity as per **25.4** does not exceed 0.05 times the lateral dimension, the members may be designed by the following equation:

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

where

P_u = axial load on the member,

f_{ck} = characteristic compressive strength of the concrete,

A_c = Area of concrete,

f_y = characteristic strength of the compression reinforcement, and

A_{sc} = area of longitudinal reinforcement for columns.

39.4 Compression Members with Helical Reinforcement

The strength of compression members with helical reinforcement satisfying the requirement of **39.4.1** shall be taken as 1.05 times the strength of similar member with lateral ties.

39.4.1 The ratio of the volume of helical reinforcement to the volume of the core shall not be less than $0.36 (A_g/A_k - 1) f_{ck}/f_y$

where

A_g = gross area of the section,

A_k = area of the core of the helically reinforced column measured to the outside diameter of the helix,

f_{ck} = characteristic compressive strength of the concrete, and

f_y = characteristic strength of the helical reinforcement but not exceeding 415 N/mm².

39.5 Members Subjected to Combined Axial Load and Uniaxial Bending

A member subjected to axial force and uniaxial bending shall be designed on the basis of **39.1** and **39.2**.

NOTE — The design of member subject to combined axial load and uniaxial bending will involve lengthy calculation by trial and error. In order to overcome these difficulties interaction diagrams may be used. These have been prepared and published by BIS in 'SP : 16 Design aids for reinforced concrete to IS 456'.

39.6 Members Subjected to Combined Axial Load and Biaxial Bending

The resistance of a member subjected to axial force and biaxial bending shall be obtained on the basis of assumptions given in **39.1** and **39.2** with neutral axis so chosen as to satisfy the equilibrium of load and moments about two axes. Alternatively such members may be designed by the following equation:

$$\left[\frac{M_{ux}}{M_{ux1}}\right]^{\alpha_n} + \left[\frac{M_{uy}}{M_{uy1}}\right]^{\alpha_n} \le 1.0$$

where

M_{ux}, M_{uy} = moments about *x* and *y* axes due to design loads,

M_{ux1}, M_{uy1} = maximum uniaxial moment capacity for an axial load of P_u, bending about *x* and *y* axes respectively, and

α_n is related to P_u/P_{uz}

where $P_{uz} = 0.45 f_{ck} \cdot A_c + 0.75 f_y \cdot A_{sc}$

For values of P_u/P_{uz} = 0.2 to 0.8, the values of α_n vary linearly from 1.0 to 2.0. For values less than 0.2, α_n is 1.0; for values greater than 0.8, α_n is 2.0.

39.7 Slender Compression Members

The design of slender compression members (*see* **25.1.1**) shall be based on the forces and the moments determined from an analysis of the structure, including the effect of deflections on moments and forces. When the effect of deflections are not taken into account in the analysis, additional moment given in **39.7.1** shall be taken into account in the appropriate direction.

39.7.1 The additional moments M_{ax} and M_{ay} shall be calculated by the following formulae:

$$M_{ax} = \frac{P_u D}{2\,000}\left\{\frac{l_{ex}}{D}\right\}^2$$

$$M_{ay} = \frac{P_u b}{2\,000}\left\{\frac{l_{ey}}{b}\right\}^2$$

where

P_u = axial load on the member,

l_{ex} = effective length in respect of the major axis,

l_{ey} = effective length in respect of the minor axis,

D = depth of the cross-section at right angles to the major axis, and

b = width of the member.

For design of section, **39.5** or **39.6** as appropriate shall apply.

NOTES

1 A column may be considered braced in a given plane if lateral stability to the structure as a whole is provided by walls or bracing or buttressing designed to resist all lateral forces in that plane. It should otherwise be considered as unbraced.

2 In the case of a braced column without any transverse loads occurring in its height, the additional moment shall be added to an initial moment equal to sum of 0.4 M_{u1} and 0.6 M_{u2} where M_{u2} is the larger end moment and M_{u1} is the smaller end moment (assumed negative if the column is bent in double curvature). In no case shall the initial moment be less than 0.4 M_{u2} nor the total moment including the initial moment be less than M_{u2}. For unbraced columns, the additional moment shall be added to the end moments.

3 Unbraced compression members, at any given level or storey, subject to lateral load are usually constrained to deflect equally. In such cases slenderness ratio for each column may be taken as the average for all columns acting in the same direction.

39.7.1.1 The values given by equation 39.7.1 may be multiplied by the following factor:

$$k = \frac{P_{uz} - P_u}{P_{uz} - P_b} \leq 1$$

where

P_u = axial load on compression member,

P_{uz} = as defined in 39.6, and

P_b = axial load corresponding to the condition of maximum compressive strain of 0.003 5 in concrete and tensile strain of 0.002 in outer most layer of tension steel.

40 LIMIT STATE OF COLLAPSE : SHEAR

40.1 Nominal Shear Stress

The nominal shear stress in beams of uniform depth shall be obtained by the following equation:

$$\tau_v = \frac{V_u}{b\,d}$$

where

V_u = shear force due to design loads;

b = breadth of the member, which for flanged section shall be taken as the breadth of the web, b_w; and

d = effective depth.

40.1.1 *Beams of Varying Depth*

In the case of beams of varying depth the equation shall be modified as:

$$\tau_v = \frac{V_u \pm \dfrac{M_u}{d} \tan \beta}{b\,d}$$

where

τ_v, V_u, b and d are the same as in 40.1,

M_u = bending moment at the section, and

β = angle between the top and the bottom edges of the beam.

The negative sign in the formula applies when the bending moment M_u increases numerically in the same direction as the effective depth d increases, and the positive sign when the moment decreases numerically in this direction.

40.2 Design Shear Strength of Concrete

40.2.1 The design shear strength of concrete in beams without shear reinforcement is given in Table 19.

40.2.1.1 For solid slabs, the design shear strength for concrete shall be $\tau_c k$, where k has the values given below:

Overall Depth of Slab, mm	300 or more	275	250	225	200	175	150 or less
k	1.00	1.05	1.10	1.15	1.20	1.25	1.30

NOTE — This provision shall not apply to flat slabs for which 31.6 shall apply.

40.2.2 *Shear Strength of Members under Axial Compression*

For members subjected to axial compression P_u, the design shear strength of concrete, given in Table 19, shall be multiplied by the following factor :

$$\delta = 1 + \frac{3P_u}{A_g f_{ck}} \text{ but not exceeding 1.5}$$

where

P_u = axial compressive force in Newtons,

A_g = gross area of the concrete section in mm², and

f_{ck} = characteristic compressive strength of concrete.

40.2.3 *With Shear Reinforcement*

Under no circumstances, even with shear reinforcement, shall the nominal shear stress in beams τ_v exceed $\tau_{c,max}$ given in Table 20.

40.2.3.1 For solid slabs, the nominal shear stress shall not exceed half the appropriate values given in Table 20.

40.3 Minimum Shear Reinforcement

When τ_v is less than τ_c given in Table 19, minimum shear reinforcement shall be provided in accordance with 26.5.1.6.

40.4 Design of Shear Reinforcement

When τ_v exceeds τ_c given in Table 19, shear reinforcement shall be provided in any of the following forms:

a) Vertical stirrups,

b) Bent-up bars along with stirrups, and

Table 19 Design Shear Strength of Concrete, τ_c, N/mm²

(*Clauses* 40.2.1, 40.2.2, 40.3, 40.4, 40.5.3, 41.3.2, 41.3.3 *and* 41.4.3)

$100\frac{A_s}{bd}$	Concrete Grade					
	M 15	M 20	M 25	M 30	M 35	M 40 and above
(1)	(2)	(3)	(4)	(5)	(6)	(7)
≤ 0.15	0.28	0.28	0.29	0.29	0.29	0.30
0.25	0.35	0.36	0.36	0.37	0.37	0.38
0.50	0.46	0.48	0.49	0.50	0.50	0.51
0.75	0.54	0.56	0.57	0.59	0.59	0.60
1.00	0.60	0.62	0.64	0.66	0.67	0.68
1.25	0.64	0.67	0.70	0.71	0.73	0.74
1.50	0.68	0.72	0.74	0.76	0.78	0.79
1.75	0.71	0.75	0.78	0.80	0.82	0.84
2.00	0.71	0.79	0.82	0.84	0.86	0.88
2.25	0.71	0.81	0.85	0.88	0.90	0.92
2.50	0.71	0.82	0.88	0.91	0.93	0.95
2.75	0.71	0.82	0.90	0.94	0.96	0.98
3.00 and above	0.71	0.82	0.92	0.96	0.99	1.01

NOTE — The term A_s is the area of longitudinal tension reinforcement which continues at least one effective depth beyond the section being considered except at support where the full area of tension reinforcement may be used provided the detailing conforms to 26.2.2 and 26.2.3

Table 20 Maximum Shear Stress, $\tau_{c\,max}$, N/mm²

(*Clauses* 40.2.3, 40.2.3.1, 40.5.1 *and* 41.3.1)

Concrete Grade	M 15	M 20	M 25	M 30	M 35	M 40 and above
$\tau_{c\,max}$, N/mm²	2.5	2.8	3.1	3.5	3.7	4.0

c) Inclined stirrups.

Where bent-up bars are provided, their contribution towards shear resistance shall not be more than half that of the total shear reinforcement.

Shear reinforcement shall be provided to carry a shear equal to $V_u - \tau_c bd$. The strength of shear reinforcement V_{us} shall be calculated as below:

a) For vertical stirrups:

$$V_{us} = \frac{0.87 f_y A_{sv} d}{s_v}$$

b) For inclined stirrups or a series of bars bent-up at different cross-sections:

$$V_{us} = \frac{0.87 f_y A_{sv} d}{s_v}(\sin\alpha + \cos\alpha)$$

c) For single bar or single group of parallel bars, all bent-up at the same cross-section:

$$V_{us} = 0.87 f_y A_{sv} \sin\alpha$$

where

A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance s_v,

s_v = spacing of the stirrups or bent-up bars along the length of the member,

τ_v = nominal shear stress,

τ_c = design shear strength of the concrete,

b = breadth of the member which for flanged beams, shall be taken as the breadth of the web b_w,

f_y = characteristic strength of the stirrup or bent-up reinforcement which shall not be taken greater than 415 N/mm²,

α = angle between the inclined stirrup or bent- up bar and the axis of the member, not less than 45°, and

d = effective depth.

NOTES

1 Where more than one type of shear reinforcement is used to reinforce the same portion of the beam, the total shear resistance shall be computed as the sum of the resistance for the various types separately.

2 The area of the stirrups shall not be less than the minimum specified in 26.5.1.6.

40.5 Enhanced Shear Strength of Sections Close to Supports

40.5.1 *General*

Shear failure at sections of beams and cantilevers without shear reinforcement will normally occur on plane inclined at an angle 30° to the horizontal. If the angle of failure plane is forced to be inclined more steeply than this [because the section considered (*X* - *X*) in Fig. 24 is close to a support or for other reasons], the shear force required to produce failure is increased.

The enhancement of shear strength may be taken into account in the design of sections near a support by increasing design shear strength of concrete to $2d\,\tau_c / a_v$ provided that design shear stress at the face of the support remains less than the values given in Table 20. Account may be taken of the enhancement in any situation where the section considered is closer to the face of a support or concentrated load than twice the effective depth, *d*. To be effective, tension reinforcement should extend on each side of the point where it is intersected by a possible failure plane for a distance at least equal to the effective depth, or be provided with an equivalent anchorage.

40.5.2 *Shear Reinforcement for Sections Close to Supports*

If shear reinforcement is required, the total area of this is given by:

$$A_s = a_v b\,(\tau_v - 2d\,\tau_c / a_v) / 0.87 f_y \geq 0.4 a_v b / 0.87 f_y$$

This reinforcement should be provided within the middle three quarters of a_v, where a_v is less than *d*, horizontal shear reinforcement will be effective than vertical.

40.5.3 *Enhanced Shear Strength Near Supports (Simplified Approach)*

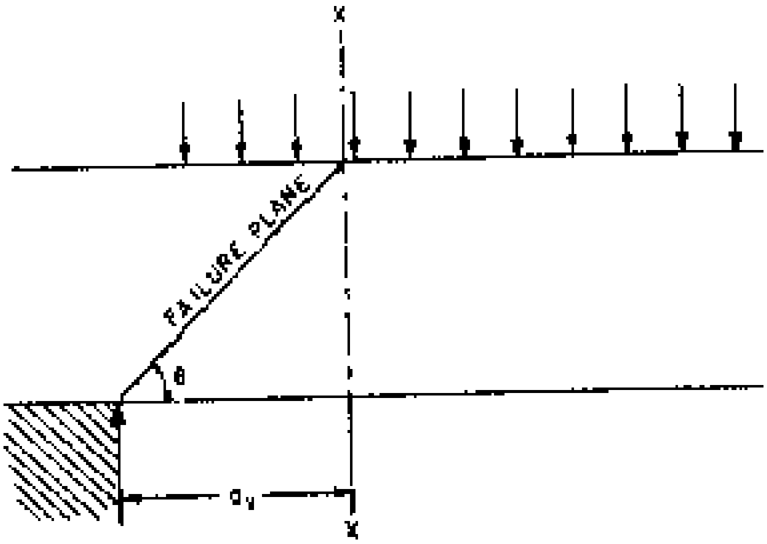
The procedure given in **40.5.1** and **40.5.2** may be used for all beams. However for beams carrying generally uniform load or where the principal load is located farther than 2*d* from the face of support, the shear stress may be calculated at a section a distance *d* from the face of support. The value of τ_c is calculated in accordance with Table 19 and appropriate shear reinforcement is provided at sections closer to the support, no further check for shear at such sections is required.

41 LIMIT STATE OF COLLAPSE : TORSION

41.1 General

In structures, where torsion is required to maintain equilibrium, members shall be designed for torsion in accordance with **41.2**, **41.3** and **41.4**. However, for such indeterminate structures where torsion can be eliminated by releasing redundant restraints, no specific design for torsion is necessary, provided torsional stiffness is neglected in the calculation of internal forces. Adequate control of any torsional cracking is provided by the shear reinforcement as per **40**.

NOTE — The approach to design in this clause is as follows: Torsional reinforcement is not calculated separately from that required for bending and shear. Instead the total longitudinal reinforcement is determined for a fictitious bending moment which is a function of actual bending moment and torsion,



NOTE — The shear causing failure is that acting on section *X*–*X*.

FIG. 24 SHEAR FAILURE NEAR SUPPORTS

similarly web reinforcement is determined for a fictitious shear which is a function of actual shear and torsion.

41.1.1 The design rules laid down in **41.3** and **41.4** shall apply to beams of solid rectangular cross-section. However, these clauses may also be applied to flanged beams, by substituting b_w for b in which case they are generally conservative; therefore specialist literature may be referred to.

41.2 Critical Section

Sections located less than a distance d, from the face of the support may be designed for the same torsion as computed at a distance d, where d is the effective depth.

41.3 Shear and Torsion

41.3.1 *Equivalent Shear*

Equivalent shear, V_e, shall be calculated from the formula:

$$V_e = V_u + 1.6\frac{T_u}{b}$$

where

V_e = equivalent shear,

V_u = shear,

T_u = torsional moment, and

b = breadth of beam.

The equivalent nominal shear stress, τ_{ve} in this case shall be calculated as given in **40.1**, except for substituting V_u by V_e. The values of τ_{ve} shall not exceed the values of $\tau_{c\,max}$ given in Table 20.

41.3.2 If the equivalent nominal shear stress, τ_{ve} does not exceed τ_c given in Table 19, minimum shear reinforcement shall be provided as per **26.5.1.6**.

41.3.3 If τ_{ve} exceeds τ_c given in Table 19, both longitudinal and transverse reinforcement shall be provided in accordance with **41.4**.

41.4 Reinforcement in Members Subjected to Torsion

41.4.1 Reinforcement for torsion, when required, shall consist of longitudinal and transverse reinforcement.

41.4.2 *Longitudinal Reinforcement*

The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_{e1}, given by

$$M_{e1} = M_u + M_t$$

where

M_u = bending moment at the cross-section, and

$$M_t = T_u\left(\frac{1 + D/b}{1.7}\right)$$

where

T_u is the torsional moment, D is the overall depth of the beam and b is the breadth of the beam.

41.4.2.1 If the numerical value of M_t as defined in **41.4.2** exceeds the numerical value of the moment M_u, longitudinal reinforcement shall be provided on the flexural compression face, such that the beam can also withstand an equivalent M_{e2} given by $M_{e2} = M_t - M_u$, the moment M_{e2} being taken as acting in the opposite sense to the moment M_u.

41.4.3 *Transverse Reinforcement*

Two legged closed hoops enclosing the corner longitudinal bars shall have an area of cross-section A_{sv}, given by

$$A_{sv} = \frac{T_u\, s_v}{b_1\, d_1\,(0.87\, f_y)} + \frac{V_u\, s_v}{2.5\, d_1\,(0.87\, f_y)},$$

but the total transverse reinforcement shall not be less than

$$\frac{(\tau_{ve} - \tau_c)\, b.s_v}{0.87\, f_y}$$

where

T_u = torsional moment,

V_u = shear force,

s_v = spacing of the stirrup reinforcement,

b_1 = centre-to-centre distance between corner bars in the direction of the width,

d_1 = centre-to-centre distance between corner bars,

b = breadth of the member,

f_y = characteristic strength of the stirrup reinforcement,

τ_{ve} = equivalent shear stress as specified in **41.3.1**, and

τ_c = shear strength of the concrete as per Table 19.

42 LIMIT STATE OF SERVICEABILITY: DEFLECTION

42.1 Flexural Members

In all normal cases, the deflection of a flexural member will not be excessive if the ratio of its span to its effective depth is not greater than appropriate ratios given in **23.2.1**. When deflections are calculated according to Annex C, they shall not exceed the permissible values given in **23.2**.

43 LIMIT STATE OF SERVICEABILITY: CRACKING

43.1 Flexural Members

In general, compliance with the spacing requirements of reinforcement given in **26.3.2** should be sufficient to control flexural cracking. If greater spacing are required, the expected crack width should be checked by formula given in Annex F.

43.2 Compression Members

Cracks due to bending in a compression member subjected to a design axial load greater than $0.2 f_{ck} A_c$, where f_{ck} is the characteristic compressive strength of concrete and A_c is the area of the gross section of the member, need not be checked. A member subjected to lesser load than $0.2 f_{ck} A_c$ may be considered as flexural member for the purpose of crack control (*see* **43.1**).

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
269 : 1989	Specification for ordinary Portland cement, 33 grade (*fourth revision*)
383 : 1970	Specification for course and fine aggregates from natural sources for concrete (*second revision*)
432 (Part 1) : 1982	Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part 1 Mild steel and medium tensile steel bars (*third revision*)
455 : 1989	Specification for Portland slag cement (*fourth revision*)
516 : 1959	Method of test for strength of concrete
875	Code of practice for design loads (other than earthquake) for buildings and structures :
(Part 1) : 1987	Dead loads — Unit weights of building material and stored materials (*second revision*)
(Part 2) : 1987	Imposed loads (*second revision*)
(Part 3) : 1987	Wind loads (*second revision*)
(Part 4) : 1987	Snow loads (*second revision*)
(Part 5) : 1987	Special loads and load combinations (*second revision*)
1199 : 1959	Methods of sampling and analysis of concrete
1343 : 1980	Code of practice for prestressed concrete (*first revision*)
1489	Specification for Portland pozzolana cement :
(Part 1) : 1991	Fly ash based (*third revision*)
(Part 2) : 1991	Calcined clay based (*third revision*)
1566 : 1982	Specification for hard-drawn steel wire fabric for concrete reinforcement (*second revision*)
1641 : 1988	Code of practice for fire safety of buildings (general): General principles of fire grading and classification (*first revision*)
1642 : 1989	Code of practice for fire safety of buildings (general) : Details of construction (*first revision*)
1786 : 1985	Specification for high strength deformed steel bars and wires for concrete reinforcement (*third revision*)
1791 : 1968	Specification for batch type concrete mixers (*second revision*)
1893 : 1984	Criteria for earthquake resistant design of structures (*fourth revision*)
1904 : 1986	Code of practice for design and construction of foundations in soils : General requirements (*third revision*)
2062 : 1992	Steel for general structural purposes (*fourth revision*)
2386 (Part 3) : 1963	Methods of test for aggregates for concrete : Part 3 Specific gravity, density, voids, absorption and bulking
2502 : 1963	Code of practice for bending and fixing of bars for concrete reinforcement
2505 : 1980	Concrete vibrators — Immersion type — General requirements
2506 : 1985	General requirements for screed board concrete vibrators (*first revision*)
2514 : 1963	Specification for concrete vibrating tables
2751 : 1979	Recommended practice for welding of mild steel plain and deformed bars for reinforced construction (*first revision*)
3025	Methods of sampling and test (physical and chemical) for water and waste water :
(Part 17) : 1984	Non-filterable residue (total suspended solids) (*first revision*)
(Part 18) : 1984	Volatile and fixed residue (total filterable and non-filterable) (*first revision*)

IS No.	*Title*
(Part 22) : 1986	Acidity (*first revision*)
(Part 23) : 1986	Alkalinity (*first revision*)
(Part 24) : 1986	Sulphates (*first revision*)
(Part 32) : 1988	Chloride (*first revision*)
3414 : 1968	Code of practice for design and installation of joints in buildings
3812 : 1981	Specification for fly ash for use as pozzolana and admixture (*first revision*)
3951 (Part 1) : 1975	Specification for hollow clay tiles for floors and roofs : Part 1 Filler type (*first revision*)
4031(Part 5) : 1988	Methods of physical tests for hydraulic cement : Part 5 Determination of initial and final setting times (*first revision*)
4082 : 1996	Recommendations on stacking and storage of construction materials and components at site (*second revision*)
4326 : 1993	Code of practice for earthquake resistant design and construction of buildings (*second revision*)
4656 : 1968	Specification for form vibrators for concrete
4845 : 1968	Definitions and terminology relating to hydraulic cement
4925 : 1968	Specification for concrete batching and mixing plant
4926 : 1976	Specification for ready-mixed concrete (*second revision*)
5816 : 1999	Method of test for splitting tensile strength of concrete (*first revision*)
6061	Code of practice for construction of floor and roof with joists and filler blocks :
(Part 1) : 1971	With hollow concrete filler blocks
(Part 2) : 1971	With hollow clay filler blocks (*first revision*)
6452 : 1989	Specification for high alumina cement for structural use
6461	Glossary of terms relating to cement:
(Part 1) : 1972	Concrete aggregates
(Part 2) : 1972	Materials
(Part 3) : 1972	Concrete reinforcement
(Part 4) : 1972	Types of concrete
(Part 5) : 1972	Formwork for concrete
(Part 6) : 1972	Equipment, tool and plant
(Part 7) : 1973	Mixing, laying, compaction, curing and other construction aspect
(Part 8) : 1973	Properties of concrete
(Part 9) : 1973	Structural aspects
(Part 10) : 1973	Tests and testing apparatus
(Part 11) : 1973	Prestressed concrete
(Part 12) : 1973	Miscellaneous
6909 : 1990	Specification for supersulphated cement
7861	Code of practice for extreme weather concreting :
(Part 1) : 1975	Recommended practice for hot weather concreting
(Part 2) : 1975	Recommended practice for cold weather concreting
8041 : 1990	Specification for rapid hardening Portland cement (*second revision*)
8043 : 1991	Specification for hydrophobic Portland cement (*second revision*)
8112 : 1989	Specification for 43 grade ordinary Portland cement (*first revision*)
9013 : 1978	Method of making, curing and determining compressive strength of accelerated cured concrete test specimens
9103 : 1999	Specification for admixtures for concrete (*first revision*)
9417 : 1989	Recommendations for welding cold worked bars for reinforced concrete construction (*first revision*)
11817 : 1986	Classification of joints in buildings for accommodation of dimensional deviations during construction
12089 : 1987	Specification for granulated slag for manufacture of Portland slag cement
12119 : 1987	General requirements for pan mixers for concrete

IS No.	*Title*
12269 : 1987	Specification for 53 grade ordinary Portland cement
12330 : 1988	Specification for sulphate resisting Portland cement
12600 : 1989	Specification for low heat Portland cement
13311	Methods of non-destructive testing of concrete :
(Part 1) : 1992	Ultrasonic pulse velocity
(Part 2) : 1992	Rebound hammer
13920 : 1993	Code of practice for ductile detailing of reinforced concrete structures subjected to seismic forces
14687 : 1999	Guidelines for falsework for concrete structures

ANNEX B

(*Clauses* 18.2.2, 22.3.1, 22.7, 26.2.1 *and* 32.1)

STRUCTURAL DESIGN (WORKING STRESS METHOD)

B-1 GENERAL

B-1.1 General Design Requirements

The general design requirements of Section 3 shall apply to this Annex.

B-1.2 Redistribution of Moments

Except where the simplified analysis using coefficients (*see* **22.5**) is used, the moments over the supports for any assumed arrangement of loading, including the dead load moments may each be increased or decreased by not more than 15 percent, provided that these modified moments over the supports are used for the calculation of the corresponding moments in the spans.

B-1.3 Assumptions for Design of Members

In the methods based on elastic theory, the following assumptions shall be made:

a) At any cross-section, plane sections before bending remain plain after bending.

b) All tensile stresses are taken up by reinforcement and none by concrete, except as otherwise specifically permitted.

c) The stress-strain relationship of steel and concrete, under working loads, is a straight line.

d) The modular ratio m has the value $\frac{280}{3\sigma_{cbc}}$

where σ_{cbc} is permissible compressive stress due to bending in concrete in N/mm² as specified in Table 21.

NOTE — The expression given for m partially takes into account long-term effects such as creep. Therefore this m is not the same as the modular ratio derived based on the value of E_c given in **6.2.3.1**.

B-2 PERMISSIBLE STRESSES

B-2.1 Permissible Stresses in Concrete

Permissible stresses for the various grades of concrete shall be taken as those given in Tables 21 and 23.

NOTE — For increase in strength with age **6.2.1** shall be applicable. The values of permissible stress shall be obtained by interpolation between the grades of concrete.

B-2.1.1 *Direct Tension*

For members in direct tension, when full tension is taken by the reinforcement alone, the tensile stress shall be not greater than the values given below:

Grade of Concrete	M 10	M 15	M 20	M 25	M 30	M 35	M 40	M 45	M 50
Tensile Stress N/mm²	1.2	2.0	2.8	3.2	3.6	4.0	4.4	4.8	5.2

The tensile stress shall be calculated as $\frac{F_t}{A_c + m A_{st}}$

where

F_t = total tension on the member minus pre-tension in steel, if any, before concreting;

A_c = cross-sectional area of concrete excluding any finishing material and reinforcing steel;

m = modular ratio; and

A_{st} = cross-sectional area of reinforcing steel in tension.

B-2.1.2 *Bond Stress for Deformed Bars*

In the case of deformed bars conforming to IS 1786, the bond stresses given in Table 21 may be increased by 60 percent.

B-2.2 Permissible Stresses in Steel Reinforcement

Permissible stresses in steel reinforcement shall not exceed the values specified in Table 22.

B-2.2.1 In flexural members the value of σ_{st} given in Table 22 is applicable at the centroid of the tensile reinforcement subject to the condition that when more than one layer of tensile reinforcement is provided, the stress at the centroid of the outermost layer shall not exceed by more than 10 percent the value given in Table 22.

B-2.3 Increase in Permissible Stresses

Where stresses due to wind (or earthquake) temperature and shrinkage effects are combined with those due to dead, live and impact load, the stresses specified in Tables 21, 22 and 23 may be exceeded upto a limit of $33\frac{1}{3}$ percent. Wind and seismic forces need not be considered as acting simultaneously.

Table 21 Permissible Stresses in Concrete

(*Clauses* B-1.3, B-2.1, B-2.1.2, B-2.3 *and* B-4.2)

All values in N/mm²

Grade of Concrete	Permissible Stress in Compression		Permissible Stress in Bond (Average) for Plain Bars in Tension
	Bending	Direct	
(1)	(2)	(3)	(4)
	σ_{cbc}	σ_{cc}	τ_{bd}
M 10	3.0	2.5	—
M 15	5.0	4.0	0.6
M 20	7.0	5.0	0.8
M 25	8.5	6.0	0.9
M 30	10.0	8.0	1.0
M 35	11.5	9.0	1.1
M 40	13.0	10.0	1.2
M 45	14.5	11.0	1.3
M 50	16.0	12.0	1.4

NOTES

1 The values of permissible shear stress in concrete are given in Table 23.

2 The bond stress given in col 4 shall be increased by 25 percent for bars in compression.

B-3 PERMISSIBLE LOADS IN COMPRESSION MEMBERS

B-3.1 Pedestals and Short Columns with Lateral Ties

The axial load P permissible on a pedestal or short column reinforced with longitudinal bars and lateral ties shall not exceed that given by the following equation :

$$P = \sigma_{cc} A_c + \sigma_{sc} A_{sc}$$

where

σ_{cc} = permissible stress in concrete in direct compression,

A_c = cross-sectional area of concrete excluding any finishing material and reinforcing steel,

σ_{sc} = permissible compressive stress for column bars, and

A_{sc} = cross-sectional area of the longitudinal steel.

NOTE — The minimum eccentricity mentioned in 25.4 may be deemed to be incorporated in the above equation.

B-3.2 Short Columns with Helical Reinforcement

The permissible load for columns with helical reinforcement satisfying the requirement of 39.4.1 shall be 1.05 times the permissible load for similar member with lateral ties or rings.

B-3.3 Long Columns

The maximum permissible stress in a reinforced concrete column or part thereof having a ratio of effective column length to least lateral dimension above 12 shall not exceed that which results from the multiplication of the appropriate maximum permissible stress as specified under B-2.1 and B-2.2 by the coefficient C_r given by the following formula:

$$C_r = 1.25 - \frac{l_{ef}}{48\,b}$$

where

C_r = reduction coefficient;

l_{ef} = effective length of column; and

b = least lateral dimension of column; for column with helical reinforcement, b is the diameter of the core.

For more exact calculations, the maximum permissible stresses in a reinforced concrete column or part thereof having a ratio of effective column length to least lateral radius of gyration above 40 shall not exceed those which result from the multiplication of the appropriate maximum permissible stresses specified under B-2.1 and B-2.2 by the coefficient C_r given by the following formula:

$$C_r = 1.25 - \frac{l_{ef}}{160\,i_{min}}$$

where i_{min} is the least radius of gyration.

B-3.4 Composite Columns

a) *Allowable load* — The allowable axial load P on a composite column consisting of structural steel or cast-iron column thoroughly encased in concrete reinforced with both longitudinal and spiral reinforcement, shall not exceed that given by the following formula:

$$P = \sigma_{cc} A_c + \sigma_{sc} A_{sc} + \sigma_{m} A_{m}$$

Table 22 Permissible Stresses in Steel Reinforcement

(*Clauses* B-2.2, B-2.2.1, B-2.3 *and* B-4.2)

Sl No.	Type of Stress in Steel Reinforcement	Permissible Stresses in N/mm²		
		Mild Steel Bars Conforming to Grade 1 of IS 432 (Part 1)	Medium Tensile Steel Conforming to IS 432 (Part 1)	High Yield Strength Deformed Bars Conforming to IS 1786 (Grade Fe 415)
(1)	(2)	(3)	(4)	(5)
i)	Tension (σ_{st} or σ_{sv})			
	a) Up to and including 20 mm	140	Half the guaranteed yield stress subject to a maximum of 190	230
	b) Over 20 mm	130		230
ii)	Compression in column bars (σ_{sc})	130	130	190
iii)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1.5 times the modular ratio or σ_{sc} whichever is lower		
iv)	Compression in bars in a beam or slab where the compressive resistance of the concrete is not taken into account:			
	a) Up to and including 20 mm	140	Half the guaranteed yield stress subject to a maximum of 190	190
	b) Over 20 mm	130		190

NOTES

1 For high yield strength deformed bars of Grade Fe 500 the permissible stress in direct tension and flexural tension shall be $0.55 f_y$. The permissible stresses for shear and compression reinforcement shall be as for Grade Fe 415.

2 For welded wire fabric conforming to IS 1566, the permissible value in tension σ_{st} is 230 N/mm².

3 For the purpose of this standard, the yield stress of steels for which there is no clearly defined yield point should be taken to be 0.2 percent proof stress.

4 When mild steel conforming to Grade II of IS 432 (Part 1) is used, the permissible stresses shall be 90 percent of the permissible stresses in col 3, or if the design details have already been worked out on the basis of mild steel conforming to Grade I of IS 432 (Part 1); the area of reinforcement shall be increased by 10 percent of that required for Grade I steel.

where

- σ_{cc} = permissible stress in concrete in direct compression;
- A_c = net area of concrete section; which is equal to the gross area of the concrete section $- A_{sc} - A_m$;
- σ_{sc} = permissible compressive stress for column bars;
- A_{sc} = cross-sectional area of longitudinal bar reinforcement;
- σ_{met} = allowable unit stress in metal core, not to exceed 125 N/mm² for a steel core, or 70 N/mm² for a cast iron core; and
- A_m = the cross-sectional area of the steel or cast iron core.

b) *Metal core and reinforcement* — The cross-sectional area of the metal core shall not exceed 20 percent of the gross area of the column. If a hollow metal core is used, it shall be filled with concrete. The amount of longitudinal and spiral reinforcement and the requirements as to spacing of bars, details of splices and thickness of protective shell outside the spiral, shall conform to require- ments of 26.5.3. A clearance of at least 75 mm shall be maintained between the spiral and the metal core at all points, except that when the core consists of a structural steel H-column, the minimum clearance may be reduced to 50 mm.

c) *Splices and connections of metal cores* — Metal cores in composite columns shall be accurately milled at splices and positive provisions shall be made for alignment of one core above another. At the column base, provisions shall be made to transfer the load to the footing at safe unit stresses in accordance with **34**. The base of the metal section shall be designed to transfer the load from the entire composite columns to the footing, or it may be designed to transfer the load from the metal section only, provided it is placed in the pier or pedestal as to leave ample section of concrete above the base for the transfer of load from the reinforced concrete section of the column by means of bond on the vertical reinforcement and by direct compression on the concrete. Transfer of loads to the metal core shall be provided for by the use of bearing members, such as billets, brackets or other positive connections, these shall be provided at the top of the metal core and at intermediate floor levels where required. The column as a whole shall satisfy the requirements of formula given under (a) at any point, in addition to this, the reinforced concrete portion shall be designed to carry, according to **B-3.1** or **B-3.2** as the case may be, all floor loads brought into the column at levels between the metal brackets or connections. In applying the formulae under **B-3.1** or **B-3.2** the gross area of column shall be taken to be the area of the concrete section outside the metal core, and the allowable load on the reinforced concrete section shall be further limited to 0.28 f_{ck} times gross sectional area of the column.

d) *Allowable Load on Metal Core Only* — The metal core of composite columns shall be designed to carry safely any construction or other loads to be placed upon them prior to their encasement in concrete.

B-4 MEMBERS SUBJECTED TO COMBINED AXIAL LOAD AND BENDING

B-4.1 Design Based on Uncracked Section

A member subjected to axial load and bending (due to eccentricity of load, monolithic construction, lateral forces, etc) shall be considered safe provided the following conditions are satisfied:

a) $\dfrac{\sigma_{cc,cal}}{\sigma_{cc}} + \dfrac{\sigma_{cbc,cal}}{\sigma_{cbc}} \leq 1$

where

$\sigma_{cc,cal}$ = calculated direct compressive stress in concrete,

σ_{cc} = permissible axial compressive stress in concrete,

$\sigma_{cbc,cal}$ = calculated bending compressive stress in concrete, and

σ_{cbc} = permissible bending compressive stress in concrete.

b) The resultant tension in concrete is not greater than 35 percent and 25 percent of the resultant compression for biaxial and uniaxial bending respectively, or does not exceed three-fourths, the 7 day modulus of rupture of concrete.

NOTES

1 $\sigma_{cc,cal} = \dfrac{P}{A_c + 1.5 m A_{sc}}$ for columns with ties where P, A_c and A_{sc} defined in **B-3.1** and m is the modular ratio.

2 $\sigma_{cbc,cal} = \dfrac{M}{Z}$ where M equals the moment and Z equals modulus of section. In the case of sections subject to moments in two directions, the stress shall be calculated separately and added algebraically.

B-4.2 Design Based on Cracked Section

If the requirements specified in **B-4.1** are not satisfied, the stresses in concrete and steel shall be calculated by the theory of cracked section in which the tensile resistance of concrete is ignored. If the calculated stresses are within the permissible stress specified in Tables 21, 22 and 23 the section may be assumed to be safe.

NOTE — The maximum stress in concrete and steel may be found from tables and charts based on the cracked section theory or directly by determining the no-stress line which should satisfy the following requirements:

a) The direct load should be equal to the algebraic sum of the forces on concrete and steel,

b) The moment of the external loads about any reference line should be equal to the algebraic sum of the moment of the forces in concrete (ignoring the tensile force in concrete) and steel about the same line, and

c) The moment of the external loads about any other reference lines should be equal to the algebraic sum of the moment of the forces in concrete (ignoring the tensile force in concrete) and steel about the same line.

B-4.3 Members Subjected to Combined Direct Load and Flexure

Members subjected to combined direct load and flexure and shall be designed by limit state method as in **39.5** after applying appropriate load factors as given in Table 18.

B-5 SHEAR

B-5.1 Nominal Shear Stress

The nominal shear stress τ_v in beams or slabs of uniform depth shall be calculated by the following equation.

$$\tau_v = \frac{V}{bd}$$

where

V = shear force due to design loads.

b = breadth of the member, which for flanged sections shall be taken as the breadth of the web, and

d = effective depth.

B-5.1.1 *Beams of Varying Depth*

In the case of beams of varying depth, the equation shall be modified as:

$$\tau_v = \frac{V \pm \frac{M \tan \beta}{d}}{bd}$$

where

τ_v, V, b and d are the same as in B-5.1,

M = bending moment at the section, and

β = angle between the top and the bottom edges of the beam.

The negative sign in the formula applies when the bending moment M increases numerically in the same direction as the effective depth d increases, and the positive sign when the moment decreases numerically in this direction.

B-5.2 Design Shear Strength of Concrete

B-5.2.1 The permissible shear stress in concrete in beams without shear reinforcement is given in Table 23.

B-5.2.1.1 For solid slabs the permissible shear stress in concrete shall be $k\tau_c$ where k has the value given below:

Overall depth of slab, mm	300 or more	275	250	225	200	175	150 or less
k	1.00	1.05	1.10	1.15	1.20	1.25	1.30

NOTE — This does not apply to flat slabs for which 31.6 shall apply.

B-5.2.2 *Shear Strength of Members Under Axial Compression*

For members subjected to axial compression P, the permissible shear stress in concrete τ_c given in Table 23, shall be multiplied by the following factor:

$$\delta = 1 + \frac{5P}{A_g f_{ck}}, \text{ but not exceeding } 1.5$$

where

P = axial compressive force in N,

A_g = gross area of the concrete section in mm², and

f_{ck} = characteristic compressive strength of concrete.

B-5.2.3 *With Shear Reinforcement*

When shear reinforcement is provided the nominal shear stress τ_v in beams shall not exceed $\tau_{c,max}$ given in Table 24.

Table 23 Permissible Shear Stress in Concrete

(*Clauses* B-2.1, B-2.3, B-4.2, B-5.2.1, B-5.2.2, B-5.3, B-5.4, B-5.5.1, B-5.5.3, B-6.3.2, B-6.3.3 *and* B-6.4.3 and *Table* 21)

$100\frac{A_s}{bd}$	Permissible Shear Stress in Concrete, τ_c, N/mm²					
	Grade of Concrete					
	M 15	M 20	M 25	M 30	M 35	M 40 and above
(1)	(2)	(3)	(4)	(5)	(6)	(7)
≤ 0.15	0.18	0.18	0.19	0.20	0.20	0.20
0.25	0.22	0.22	0.23	0.23	0.23	0.23
0.50	0.29	0.30	0.31	0.31	0.31	0.32
0.75	0.34	0.35	0.36	0.37	0.37	0.38
1.00	0.37	0.39	0.40	0.41	0.42	0.42
1.25	0.40	0.42	0.44	0.45	0.45	0.46
1.50	0.42	0.45	0.46	0.48	0.49	0.49
1.75	0.44	0.47	0.49	0.50	0.52	0.52
2.00	0.44	0.49	0.51	0.53	0.54	0.55
2.25	0.44	0.51	0.53	0.55	0.56	0.57
2.50	0.44	0.51	0.55	0.57	0.58	0.60
2.75	0.44	0.51	0.56	0.58	0.60	0.62
3.00 and above	0.44	0.51	0.57	0.60	0.62	0.63

NOTE — A_s is that area of longitudinal tension reinforcement which continues at least one effective depth beyond the section being considered except at supports where the full area of tension reinforcement may be used provided the detailing conforms to 26.2.2 and 26.2.3

B-5.2.3.1 For slabs, τ_v shall not exceed half the value of $\tau_{c,max}$ given in Table 24.

B-5.3 Minimum Shear Reinforcement

When τ_v is less than τ_c given in Table 23, minimum shear reinforcement shall be provided in accordance with **26.5.1.6**.

B-5.4 Design of Shear Reinforcement

When τ_v exceeds τ_c given in Table 23, shear reinforcement shall be provided in any of the following forms:

a) Vertical stirrups,

b) Bent-up bars along with stirrups, and

c) Inclined stirrups.

Where bent-up bars are provided, their contribution towards shear resistance shall not be more than half that of the total shear reinforcement.

Shear reinforcement shall be provided to carry a shear equal to $V - \tau_c . bd$. The strength of shear reinforcement V_s shall be calculated as below:

a) For vertical stirrups

$$V_s = \frac{\sigma_{sv} A_{sv} d}{s_v}$$

b) For inclined stirrups or a series of bars bent-up at different cross-sections.

$$V_s = \frac{\sigma_{sv} A_{sv} d}{s_v} (\sin \alpha + \cos \alpha)$$

c) For single bar or single group of parallel bars, all bent-up at the same cross-section:

$$V_s = \sigma_{sv} A_{sv} \sin \alpha$$

where

A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance,

s_v = spacing of the stirrups or bent-up bars along the length of the member,

τ_c = design shear strength of the concrete,

b = breadth of the member which for flanged beams, shall be taken as the breadth of the web b_w,

σ_{sv} = permissible tensile stress in shear reinforcement which shall not be taken greater than 230 N/mm²,

α = angle between the inclined stirrup or bent-up bar and the axis of the member, not less than 45°, and

d = effective depth.

NOTE — Where more than one type of shear reinforcement is used to reinforce the same portion of the beam, the total shear resistance shall be computed as the sum of the resistance for the various types separately. The area of the stirrups shall not be less than the minimum specified in **26.5.1.6**.

B-5.5 Enhanced Shear Strength of Sections Close to Supports

B-5.5.1 *General*

Shear failure at sections of beams and cantilevers without shear reinforcement will normally occur on plane inclined at an angle 30° to the horizontal. If the angle of failure plane is forced to be inclined more steeply than this [because the section considered $(X - X)$ in Fig. 24 is close to a support or for other reasons], the shear force required to produce failure is increased.

The enhancement of shear strength may be taken into account in the design of sections near a support by increasing design shear strength of concrete, τ_c to $2d\,\tau_c/a_v$ provided that the design shear stress at the face of support remains less than the values given in Table 23. Account may be taken of the enhancement in any situation where the section considered is closer to the face of a support of concentrated load than twice the effective depth, d. To be effective, tension reinforcement should extend on each side of the point where it is intersected by a possible failure plane for a distance at least equal to the effective depth, or be provided with an equivalent anchorage.

B-5.5.2 *Shear Reinforcement for Sections Close to Supports*

If shear reinforcement is required, the total area of this is given by:

$$A_s = a_v b\,(\tau_v - 2d\,\tau_c/a_v)/0.87 f_y \geq 0.4 a_v b/0.87 f_y$$

This reinforcement should be provided within the middle three quarters of a_v. Where a_v is less than d, horizontal shear reinforcement will be more effective than vertical.

Table 24 Maximum Shear Stress, $\tau_{c,max}$ N/mm²

(*Clauses* B-5.2.3, B-5.2.3.1, B-5.5.1 *and* B-6.3.1)

Concrete Grade	M 15	M 20	M 25	M 30	M 35	M 40 and above
$\tau_{c,max}$, N/mm²	1.6	1.8	1.9	2.2	2.3	2.5

B-5.5.3 *Enhanced Shear Strength Near Supports (Simplified Approach)*

The procedure given in **B-5.5.1** and **B-5.5.2** may be used for all beams. However for beams carrying generally uniform load or where the principal load is located further than 2 *d* from the face of support, the shear stress may be calculated at a section a distance *d* from the face of support. The value of τ_c is calculated in accordance with Table 23 and appropriate shear reinforcement is provided at sections closer to the support, no further check for such section is required.

B-6 TORSION

B-6.1 *General*

In structures where torsion is required to maintain equilibrium, members shall be designed for torsion in accordance with **B-6.2**, **B-6.3** and **B-6.4**. However, for such indeterminate structures where torsion can be eliminated by releasing redundant restraints, no specific design for torsion is necessary provided torsional stiffness is neglected in the calculation of internal forces. Adequate control of any torsional cracking is provided by the shear reinforcement as per **B-5**.

NOTE — The approach to design in this clause for torsion is as follows:

Torsional reinforcement is not calculated separately from that required for bending and shear. Instead the total longitudinal reinforcement is determined for a fictitious bending moment which is a function of actual bending moment and torsion, similarly web reinforcement is determined for a fictitious shear which is a function of actual shear and torsion.

B-6.1.1 The design rules laid down in **B-6.3** and **B-6.4** shall apply to beams of solid rectangular cross-section. However, these clauses may also be applied to flanged beams by substituting b_w for *b*, in which case they are generally conservative; therefore specialist literature may be referred to.

B-6.2 Critical Section

Sections located less than a distance *d*, from the face of the support may be designed for the same torsion as computed at a distance *d*, where *d* is the effective depth.

B-6.3 Shear and Torsion

B-6.3.1 *Equivalent Shear*

Equivalent shear, V_e shall be calculated from the formula:

$$V_e = V + 1.6\frac{T}{b}$$

where

V_e = equivalent shear,

V = shear,

T = torsional moment, and

b = breadth of beam.

The equivalent nominal shear stress, τ_{ve}, in this case shall be calculated as given in **B-5.1**, except for substituting V by V_e. The values of τ_{ve} shall not exceed the values of $\tau_{c\,max}$ given in Table 24.

B-6.3.2 If the equivalent nominal shear stress τ_{ve} does not exceed τ_c given in Table 23, minimum shear reinforcement shall be provided as specified in **26.5.1.6**.

B-6.3.3 If τ_{ve} exceeds τ_c given in Table 23, both longitudinal and transverse reinforcement shall be provided in accordance with **B-6.4**.

B-6.4 Reinforcement in Members Subjected to Torsion

B-6.4.1 Reinforcement for torsion, when required, shall consist of longitudinal and transverse reinforcement.

B-6.4.2 *Longitudinal Reinforcement*

The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_{e1}, given by

$$M_{e1} = M + M_t$$

where

M = bending moment at the cross-section, and

$M_t = T\dfrac{(1+D/b)}{1.7}$, where T is the torsional moment, D is the overall depth of the beam and b is the breadth of the beam.

B-6.4.2.1 If the numerical value of M_t as defined in **B-6.4.2** exceeds the numerical value of the moment M, longitudinal reinforcement shall be provided on the flexural compression face, such that the beam can also withstand an equivalent moment M_{e2} given by $M_{e2} = M_t - M$, the moment M_{e2} being taken as acting in the opposite sense to the moment M.

B-6.4.3 *Transverse Reinforcement*

Two legged closed hoops enclosing the corner longitudinal bars shall have an area of cross-section A_{sv}, given by

$$A_{sv} = \frac{T \cdot s_v}{b_1 d_1 \sigma_{sv}} + \frac{V \cdot s_v}{2.5 d_1 \sigma_{sv}}$$, but the total

transverse reinforcement shall not be less than

$$\frac{(\tau_{ve} - \tau_c)\, b \cdot s_v}{\sigma_{sv}}$$

where

T = torsional moment,

V = shear force,

s_v = spacing of the stirrup reinforcement,

b_1 = centre to centre distance between corner bars in the direction of the width,

d_1 = centre-to-centre distance between corner bars in the direction of the depth,

b = breadth of the member,

σ_{sv} = permissible tensile stress in shear reinforcement,

τ_{ve} = equivalent shear stress as specified in **B-6.3.1**, and

τ_c = shear strength of the concrete as specified in Table 23

ANNEX C

(*Clauses* 22.3.2, 23.2.1 *and* 42.1)

CALCULATION OF DEFLECTION

C-1 TOTAL DEFLECTION

C-1.1 The total deflection shall be taken as the sum of the short-term deflection determined in accordance with C-2 and the long-term deflection, in accordance with C-3 and C-4.

C-2 SHORT-TERM DEFLECTION

C-2.1 The short-term deflection may be calculated by the usual methods for elastic deflections using the short-term modulus of elasticity of concrete, E_c and an effective moment of inertia I_{eff} given by the following equation:

$$I_{eff} = \frac{I_r}{1.2 - \frac{M_r}{M}\frac{z}{d}\left(1 - \frac{x}{d}\right)\frac{b_w}{b}}; \text{ but}$$

$$I_r \le I_{eff} \le I_{gr}$$

where

I_r = moment of inertia of the cracked section,

M_r = cracking moment, equal to $\frac{f_{cr} I_{gr}}{y_t}$ where

f_{cr} is the modulus of rupture of concrete, I_{gr} is the moment of inertia of the gross section about the centroidal axis, neglecting the reinforcement, and y_t is the distance from centroidal axis of gross section, neglecting the reinforcement, to extreme fibre in tension,

M = maximum moment under service loads,

z = lever arm,

x = depth of neutral axis,

d = effective depth,

b_w = breadth of web, and

b = breadth of compression face.

For continuous beams, deflection shall be calculated using the values of I_r, I_{gr} and M_r modified by the following equation:

$$X_e = k_1\left[\frac{X_1 + X_2}{2}\right] + (1 - k_1)X_o$$

where

X_e = modified value of X,

X_1, X_2 = values of X at the supports,

X_o = value of X at mid span,

k_1 = coefficient given in Table 25, and

X = value of I_r, I_{gr} or M_r as appropriate.

C-3 DEFLECTION DUE TO SHRINKAGE

C-3.1 The deflection due to shrinkage a_{cs} may be computed from the following equation:

$$a_{cs} = k_3\, \psi_{cs}\, l^2$$

where

k_3 is a constant depending upon the support conditions,

0.5 for cantilevers,

0.125 for simply supported members,

0.086 for members continuous at one end, and

0.063 for fully continuous members.

ψ_{cs} is shrinkage curvature equal to $k_4 \frac{\varepsilon_{cs}}{D}$

where ε_{cs} is the ultimate shrinkage strain of concrete (*see* 6.2.4).

$$k_4 = 0.72 \times \frac{p_t - p_c}{\sqrt{p_t}} \le 1.0 \text{ for } 0.25 \le p_t - p_c < 1.0$$

$$= 0.65 \times \frac{p_t - p_c}{\sqrt{p_t}} \le 1.0 \text{ for } p_t - p_c \ge 1.0$$

Table 25 Values of Coefficient, k_1

(*Clause* C-2.1)

k_2	0.5 or less	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
k_1	0	0.03	0.08	0.16	0.30	0.50	0.73	0.91	0.97	1.0

NOTE — k_2 is given by

$$k_2 = \frac{M_1 + M_2}{M_{F1} + M_{F2}}$$

where

M_1, M_2 = support moments, and

M_{F1}, M_{F2} = fixed end moments.

where $p_t = \frac{100 A_{st}}{bd}$ and $p_c = \frac{100 A_{sc}}{bd}$

and D is the total depth of the section, and l is the length of span.

C-4 DEFLECTION DUE TO CREEP

C-4.1 The creep deflection due to permanent loads $a_{cc(perm)}$ may be obtained from the following equation:

$$a_{cc(perm)} = a_{icc(perm)} - a_{i(perm)}$$

where

$a_{icc(perm)}$ = initial plus creep deflection due to permanent loads obtained using an elastic analysis with an effective modulus of elasticity,

$E_{ce} = \frac{E_c}{1+\theta}$; θ being the creep coefficient,

and

$a_{i(perm)}$ = short-term deflection due to permanent load using E_c.

ANNEX D

(*Clauses* 24.4 *and* 37.1.2)

SLABS SPANNING IN TWO DIRECTIONS

D-1 RESTRAINED SLABS

D-1.0 When the corners of a slab are prevented from lifting, the slab may be designed as specified in **D-1.1** to **D-1.11**.

D-1.1 The maximum bending moments per unit width in a slab are given by the following equations:

$$M_x = \alpha_x \, w \, l_x^2$$

$$M_y = \alpha_y \, w \, l_x^2$$

where

α_x and α_y are coefficients given in Table 26,

w = total design load per unit area,

M_x, M_y = moments on strips of unit width spanning l_x and l_y respectively, and

l_x and l_y = lengths of the shorter span and longer span respectively.

D-1.2 Slabs are considered as divided in each direction into middle strips and edge strips as shown in Fig. 25 the middle strip being three-quarters of the width and each edge strip one-eight of the width.

D-1.3 The maximum moments calculated as in **D-1.1** apply only to the middle strips and no redistribution shall be made.

D-1.4 Tension reinforcement provided at mid-span in the middle strip shall extend in the lower part of the slab to within 0.25 l of a continuous edge, or 0.15 l of a discontinuous edge.

D-1.5 Over the continuous edges of a middle strip, the tension reinforcement shall extend in the upper part of the slab a distance of 0.15 l from the support, and at least 50 percent shall extend a distance of 0.3 l.

D-1.6 At a discontinuous edge, negative moments may arise. They depend on the degree of fixity at the edge of the slab but, in general, tension reinforcement equal to 50 percent of that provided at mid-span extending 0.1 l into the span will be sufficient.

D-1.7 Reinforcement in edge strip, parallel to that edge, shall comply with the minimum given in Section 3 and the requirements for torsion given in **D-1.8** to **D-1.10**.

D-1.8 Torsion reinforcement shall be provided at any corner where the slab is simply supported on both edges meeting at that corner. It shall consist of top and bottom reinforcement, each with layers of bars placed parallel to the sides of the slab and extending from the edges a minimum distance of one-fifth of the shorter span. The area of reinforcement in each of these four layers shall be three-quarters of the area required for the maximum mid-span moment in the slab.

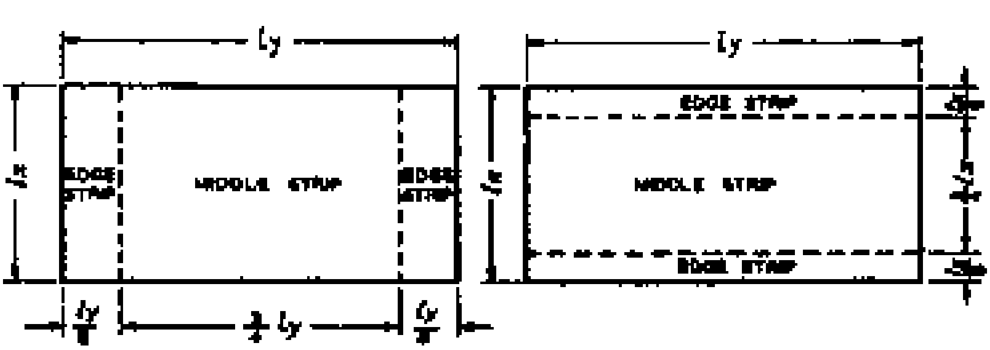
D-1.9 Torsion reinforcement equal to half that described in **D-1.8** shall be provided at a corner contained by edges over only one of which the slab is continuous.

D-1.10 Torsion reinforcements need not be provided at any corner contained by edges over both of which the slab is continuous.

D-1.11 Torsion l_y / l_x is greater than 2, the slabs shall be designed as spanning one way.

D-2 SIMPLY SUPPORTED SLABS

D-2.1 When simply supported slabs do not have adequate provision to resist torsion at corners and to prevent the corners from lifting, the maximum



25A For Span l_x 25B For Span l_y

Fig. 25 Division of Slab into Middle and Edge Strips

Table 26 Bending Moment Coefficients for Rectangular Panels Supported on Four Sides with Provision for Torsion at Corners

(Clauses D-1.1 and 24.4.1)

Case No.	Type of Panel and Moments Considered	Short Span Coefficients α_x (Values of l_y/l_x)								Long Span Coefficients α_y for All Values of l_y/l_x
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	*Interior Panels:*									
	Negative moment at continuous edge	0.032	0.037	0.043	0.047	0.051	0.053	0.060	0.065	0.032
	Positive moment at mid-span	0.024	0.028	0.032	0.036	0.039	0.041	0.045	0.049	0.024
2	*One Short Edge Continuous:*									
	Negative moment at continuous edge	0.037	0.043	0.048	0.051	0.055	0.057	0.064	0.068	0.037
	Positive moment at mid-span	0.028	0.032	0.036	0.039	0.041	0.044	0.048	0.052	0.028
3	*One Long Edge Discontinuous:*									
	Negative moment at continuous edge	0.037	0.044	0.052	0.057	0.063	0.067	0.077	0.085	0.037
	Positive moment at mid-span	0.028	0.033	0.039	0.044	0.047	0.051	0.059	0.065	0.028
4	*Two Adjacent Edges Discontinuous:*									
	Negative moment at continuous edge	0.047	0.053	0.060	0.065	0.071	0.075	0.084	0.091	0.047
	Positive moment at mid-span	0.035	0.040	0.045	0.049	0.053	0.056	0.063	0.069	0.035
5	*Two Short Edges Discontinuous:*									
	Negative moment at continuous edge	0.045	0.049	0.052	0.056	0.059	0.060	0.065	0.069	—
	Positive moment at mid-span	0.035	0.037	0.040	0.043	0.044	0.045	0.049	0.052	0.035
6	*Two Long Edges Discontinuous:*									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.045
	Positive moment at mid-span	0.035	0.043	0.051	0.057	0.063	0.068	0.080	0.088	0.035
7	*Three Edges Discontinuous (One Long Edge Continuous):*									
	Negative moment at continuous edge	0.057	0.064	0.071	0.076	0.080	0.084	0.091	0.097	—
	Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.064	0.069	0.073	0.043
8	*Three Edges Discontinuous (One Short Edge Continuous):*									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.057
	Positive moment at mid-span	0.043	0.051	0.059	0.065	0.071	0.076	0.087	0.096	0.043
9	*Four Edges Discontinuous:*									
	Positive moment at mid-span	0.056	0.064	0.072	0.079	0.085	0.089	0.100	0.107	0.056

moments per unit width are given by the following equation:

$$M_x = \alpha_x \, w \, l_x^2$$
$$M_y = \alpha_y \, w \, l_x^2$$

where

M_x, M_y, w, l_x, l_y are same as those in D-1.1.

and α_x and α_y are moment coefficients given in Table 27.

D-2.1.1 At least 50 percent of the tension reinforcement provided at mid-span should extend to the supports. The remaining 50 percent should extend to within 0.1 l_x or 0.1 l_y of the support, as appropriate.

Table 27 Bending Moment Coefficients for Slabs Spanning in Two Directions at Right Angles, Simply Supported on Four Sides

(Clause D-2.1)

l_y/l_x	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	2.5	3.0
α_x	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118	0.122	0.124
α_y	0.062	0.061	0.059	0.055	0.051	0.046	0.037	0.029	0.020	0.014

ANNEX E

(*Clause* 25.2)

EFFECTIVE LENGTH OF COLUMNS

E-1 In the absence of more exact analysis, the effective length of columns in framed structures may be obtained from the ratio of effective length to unsupported length l_{ef}/l given in Fig. 26 when relative displacement of the ends of the column is prevented and in Fig. 26 when relative lateral displacement of the ends is not prevented. In the latter case, it is recommended that the effective length ratio l_{ef}/l may not be taken to be less than 1.2.

NOTES

1 Figures 26 and 27 are reproduced from 'The Structural Engineer' No. 7, Volume 52, July 1974 by the permission of the Council of the Institution of Structural Engineers, U.K.

2 In Figs. 26 and 27, β_1 and β_2 are equal to $\frac{\Sigma K_c}{\Sigma K_c + \Sigma K_b}$

where the summation is to be done for the members framing into a joint at top and bottom respectively; and K_c and K_b being the flexural stiffness for column and beam respectively.

E-2 To determine whether a column is a no sway or a sway column, stability index Q may be computed as given below :

$$Q = \frac{\Sigma P_u \Delta_u}{H_u h_s}$$

where

ΣP_u = sum of axial loads on all column in the storey,

Δ_u = elastically computed first order lateral deflection,

H_u = total lateral force acting within the storey, and

h_s = height of the storey.

If $Q \leq 0.04$, then the column in the frame may be taken as no sway column, otherwise the column will be considered as sway column.

E-3 For normal usage assuming idealized conditions, the effective length l_{ef} of in a given plane may be assessed on the basis of Table 28.

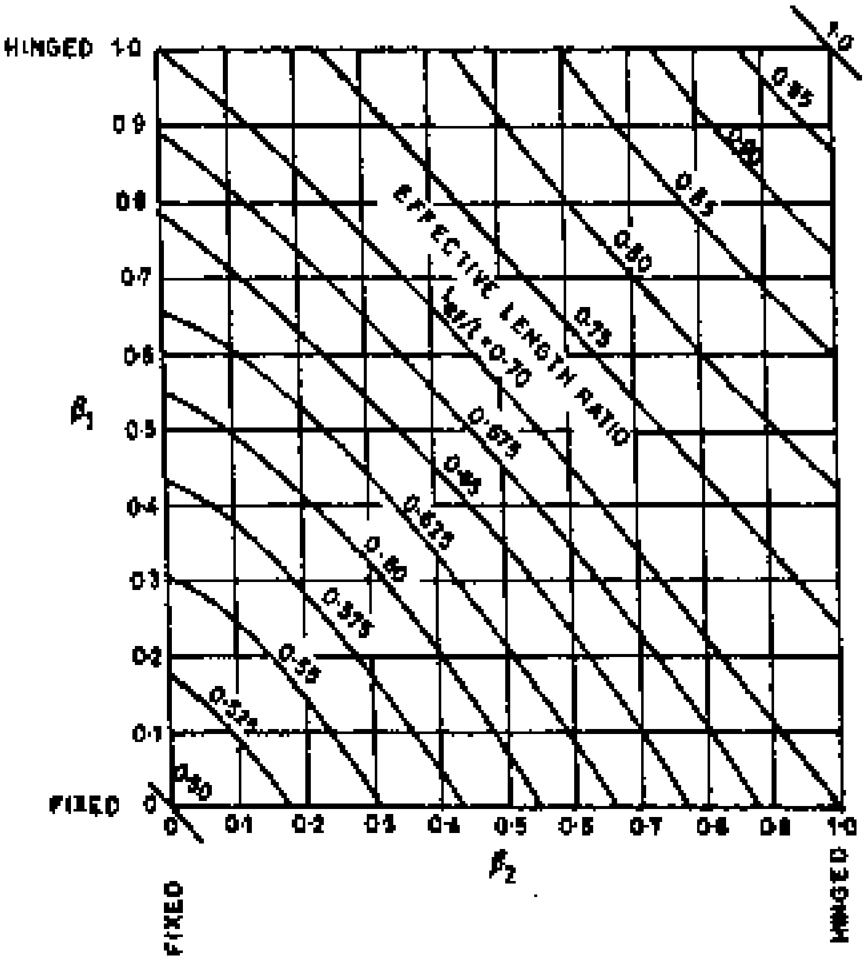


FIG. 26 EFFECTIVE LENGTH RATIOS FOR A COLUMN IN A FRAME WITH NO SWAY

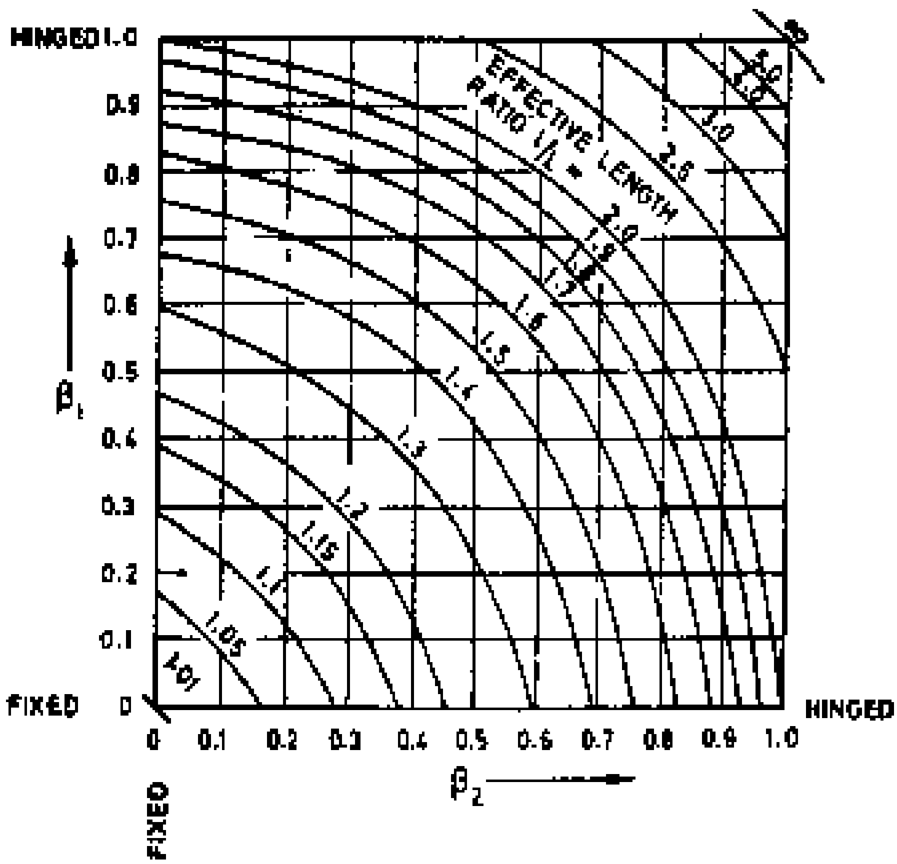
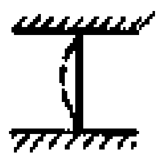
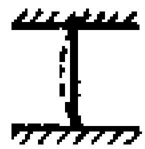
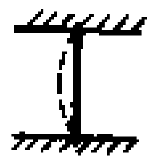
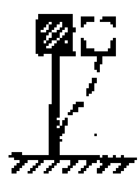
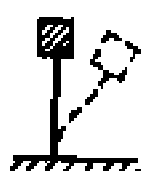
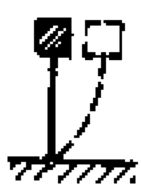
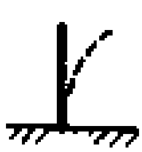


FIG. 27 EFFECTIVE LENGTH RATIOS FOR A COLUMN IN A FRAME WITHOUT RESTRAINT AGAINST SWAY

Table 28 Effective Length of Compression Members
(*Clause* E-3)

Degree of End Restraint of Compression Members	Symbol	Theoretical Value of Effective Length	Recommended Value of Effective Length
(1)	(2)	(3)	(4)
Effectively held in position and restrained against rotation in both ends		0.50 l	0.65 l
Effectively held in position at both ends, restrained against rotation at one end		0.70 l	0.80 l
Effectively held in position at both ends, but not restrained against rotation		1.00 l	1.00 l
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.00 l	1.20 l
Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position		—	1.50 l
Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position		2.00 l	2.00 l
Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end		2.00 l	2.00 l

NOTE — l is the unsupported length of compression member.

ANNEX F

(*Clauses* 35.3.2 *and* 43.1)

CALCULATION OF CRACK WIDTH

Provided that the strain in the tension reinforcement is limited to $0.8\ F_y / E_s$, the design surface crack width, which should not exceed the appropriate value given in **35.3.2** may be calculated from the following equation:

Design surface crack width

$$W_{cr} = \frac{3\ a_{cr}\ \varepsilon_m}{1 + \dfrac{2(a_{cr} - C_{min})}{h - x}}$$

where

a_{cr} = distance from the point considered to the surface of the nearest longitudinal bar.

C_{min} = minimum cover to the longitudinal bar;

ε_m = average steel strain at the level considered,

h = overall depth of the member, and

x = depth of the neutral axis.

The average steel strain ε_m may be calculated on the basis of the following assumption:

The concrete and the steel are both considered to be fully elastic in tension and in compression. The elastic modulus of the steel may be taken as 200 kN/mm² and the elastic modulus of the concrete is as derived from the equation given in **6.2.3.1** both in compression and in tension.

These assumptions are illustrated in Fig. 28,

where

h = the overall depth of the section,

x = the depth from the compression face to the neutral axis,

f_c = the maximum compressive stress in the concrete,

f_s = the tensile stress in the reinforcement, and

E_s = the modulus of elasticity of the reinforcement.

Alternatively, as an approximation, it will normally be satisfactory to calculate the steel stress on the basis of a cracked section and then reduce this by an amount equal to the tensile force generated by the triangular distributions, having a value of zero at the neutral axis and a value at the centroid of the tension steel of 1N/mm² instantaneously, reducing to 0.55 N/mm² in the long-term, acting over the tension zone divided by the steel area. For a rectangular tension zone, this gives

$$\varepsilon_m = \varepsilon_1 - \frac{b\ (h - x)(a - x)}{3 E_s A_s (d - x)}$$

where

A_s = area of tension reinforcement,

b = width of the section at the centroid of the tension steel,

ε_1 = strain at the level considered, calculated ignoring the stiffening of the concrete in the tension zone,

a = distance from the compression face to the point at which the crack width is being calculated, and

d = effective depth.

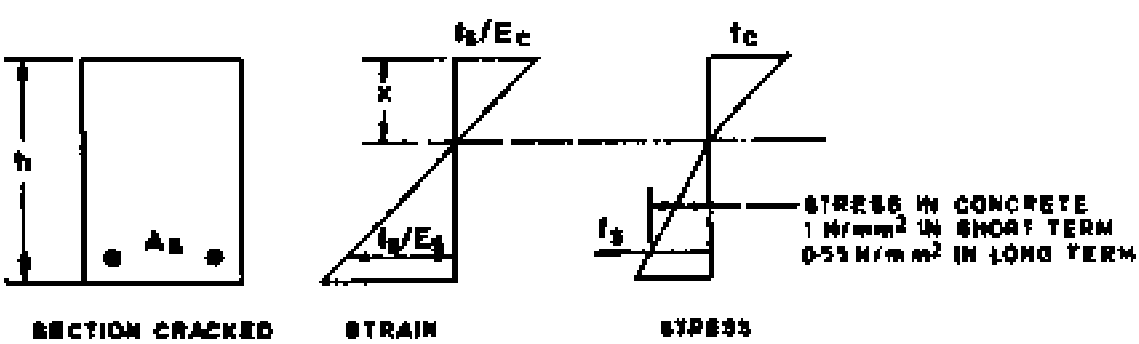


FIG. 28

ANNEX G

(Clause 38.1)

MOMENTS OF RESISTANCE FOR RECTANGULAR AND T-SECTIONS

G-0 The moments of resistance of rectangular and T-sections based on the assumptions of **38.1** are given in this annex.

G-1 RECTANGULAR SECTIONS

G-1.1 Sections Without Compression Reinforcement

The moment of resistance of rectangular sections without compression reinforcement should be obtained as follows :

a) Determine the depth of neutral axis from the following equation :

$$\frac{x_u}{d} = \frac{0.87\, f_y\, A_{st}}{0.36\, f_{ck}\, b.d}$$

b) If the value of x_u/d is less than the limiting value (*see* Note below **38.1**), calculate the moment of resistance by the following expression :

$$M_u = 0.87\, f_y\, A_{st}\, d\left(1 - \frac{A_{st}\, f_y}{bd\, f_{ck}}\right)$$

c) If the value of x_u/d is equal to the limiting value, the moment of resistance of the section is given by the following expression :

$$M_{u,lim} = 0.36\,\frac{x_{u,max}}{d}\left(1 - 0.42\,\frac{x_{u,max}}{d}\right)bd^2\, f_{ck}$$

d) If x_u/d is greater than the limiting value, the section should be redesigned.

In the above equations,

x_u = depth of neutral axis,

d = effective depth,

f_y = characteristic strength of reinforcement,

A_{st} = area of tension reinforcement,

f_{ck} = characteristic compressive strength of concrete,

b = width of the compression face,

$M_{u,lim}$ = limiting moment of resistance of a section without compression reinforcement, and

$x_{u,max}$ = limiting value of x_u from **38.1**.

G-1.2 Section with Compression Reinforcement

Where the ultimate moment of resistance of section exceeds the limiting value, $M_{u,lim}$ compression reinforcement may be obtained from the following equation :

$$M_u - M_{u,lim} = f_{sc}\, A_{sc}\,(d - d')$$

where

M_u, $M_{u,lim}$, d are same as in **G-1.1**,

f_{sc} = design stress in compression reinforcement corresponding to a strain of

$$0.0035\,\frac{(x_{u,max} - d')}{x_{u,max}}$$

where

$x_{u,max}$ = the limiting value of x_u from **38.1**,

A_{sc} = area of compression reinforcement, and

d' = depth of compression reinforcement from compression face.

The total area of tension reinforcement shall be obtained from the following equation :

$$A_{st} = A_{st1} + A_{st2}$$

where

A_{st} = area of the total tensile reinforcement,

A_{st1} = area of the tensile reinforcement for a singly reinforced section for $M_{u,lim}$, and

$A_{st2} = A_{sc} f_{sc} / 0.87 f_y$.

G-2 FLANGED SECTION

G-2.1 For $x_u < D_f$, the moment of resistance may be calculated from the equation given in **G-1.1**.

G-2.2 The limiting value of the moment of resistance of the section may be obtained by the following equation when the ratio D_f / d does not exceed 0.2 :

$$M_u = 0.36\,\frac{x_{u,max}}{d}\left(1 - 0.42\,\frac{x_{u,max}}{d}\right)f_{ck}\, b_w d^2 + 0.45\, f_{ck}\,(b_f - b_w)\,D_f\left(d - \frac{D_f}{2}\right)$$

where

M_u, $x_{u,max}$, d and f_{ck} are same as in **G-1.1**,

b_f = breadth of the compression face/flange,

b_w = breadth of the web, and

D_f = thickness of the flange.

G-2.2.1 When the ratio D_f/d exceeds 0.2, the moment of resistance of the section may be calculated by the following equation :

$$M_u = 0.36\frac{x_{u,\max}}{d}\left(1 - 0.42\frac{x_{u,\max}}{d}\right)f_{ck}\,b_w d^2 + 0.45\,f_{ck}\,(b_f - b_w)\,y_f\left(d - \frac{y_f}{2}\right)$$

where $y_f = (0.15\,x_u + 0.65\,D_f)$, but not greater than D_f, and the other symbols are same as in **G-1.1** and **G-2.2**.

G-2.3 For $x_{u,\max} > x_u > D_f$, the moment of resistance may be calculated by the equations given in **G-2.2** when D_f/x_u does not exceed 0.43 and **G-2.2.1** when D_f/x_u exceeds 0.43; in both cases substituting $x_{u,\max}$ by x_u.

ANNEX H

(Foreword)

COMMITTEE COMPOSITION

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'Chandrika', at 15th Cross,
63-64, Malleswaram, Bangalore 560 003

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(Continued from page 98)

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SPECIFICATION FOR FLAT TRANSPARENT SHEET GLASS

(Third Revision)

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Indian Standard

SPECIFICATION FOR FLAT TRANSPARENT SHEET GLASS

(Third Revision)

0. FOREWORD

0.1 This Indian Standard (Third Revision) was adopted by the Bureau of Indian Standards on 16 June 1987, after the draft finalized by the Glassware Sectional Committee had been approved by the Chemical Division Council.

0.2 This standard was first published in 1965 under the title 'Transparent sheet glass (selected quality)' and revised in 1971 by enlarging its scope and amalgamating IS : 1761-1960* with it. This standard was again revised in 1977 in order to give a systematic qualitywise classification and a rational series of nominal thickness of sheet glass in order to cover the entire range of production.

0.3 In this revision, Table 1 for nominal thickness has been modified. To upgrade the standard, Table 2 has been modified and allowable cluster of defects has been specified in Table 2 A, the central area in AA quality glass has been increased, the table for intensity of scratches, rubs and crush, and the determination of thickness of sheet glass and test for waviness have been modified.

0.4 In the formulation of this standard, due weightage has been given to international coordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This has been met by deriving assistance from the following publications:

12-GP-2 a-1970 Standard for glass, sheet, flat, clear. Canadian Government Specification Board, Canada.

DD-G-451 c-1968 Federal specification for glass, plate, sheet, figures (float, flat, for glazing, corrugated, mirrors and other uses). Federal Supply Service, USA.

JIS R 3202-1981 Float and polished Plate Glasses. Japanese Industrial Standard, Japan.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated,

*Specification for transparent sheet glass for glazing and framing purposes.

expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard prescribes the requirements and methods of sampling and test for flat transparent sheet glass for use in the manufacture of photographic plates, projection slides, silvered glass mirrors, toughened or laminated safety glasses and for glazing and framing purposes.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions and those given in IS : 1382-1981† shall apply.

2.1 Glass — An inorganic product of fusion which has cooled to a rigid condition without crystallizing. It is typically hard and brittle, and has a conchoidal fracture. It may be colourless or tinted and transparent to opaque. Masses or bodies of glass may be tinted, translucent or opaque by the presence of dissolved, morphous or crystalline material. Glass that does not contain such added materials is termed as 'clear' glass, even though the finished product may not be transparent in the ordinary sense as a result of the pattern furnished (wired, corrugated, figured).

2.2 Sheet Glass — Transparent, flat glass having glossy, fire-finished, apparently plane and smooth surfaces, but having a characteristic waviness of surface.

2.3 Central and Outer Areas — AA Quality — In the case of AA quality sheet glass, area enclosed by an ellipse or circle whose major and minor axis or diameter should not exceed 2/3 the length and width of the outside of sheet glass, the remaining area being considered as the outer area.

2.3.1 *Central and Outer Areas — A and B Qualities* — In the case of A and B quality sheet glass, area enclosed by an ellipse or circle whose major and minor axis or diameter do not exceed 1/2 the length and width of the outside of sheet glass; the remaining area being considered as the outer area.

*Rules for rounding off numerical values (*revised*).

†Glossary of terms relating to glass and glassware (*first revision*).

2.4 Crush — A lightly pitted area resulting in a dull grey appearance over the region.

2.5 Digs — Deep short scratches.

2.6 Dirt — A small particle of foreign matter embedded in the glass surface.

2.7 Gaseous Inclusions — Elongated bubbles in sheet glass.

2.8 Knot — A transparent area of incompletely assimilated glass having an irregular knotty or tangled finish.

2.9 Lines — Fine cords or strings, usually on the surface of sheet glass.

2.10 Open Gaseous Inclusions — Elongated bubbles at the surface of sheet glass which are open leaving a cavity in the finished surface.

2.11 Ream — Inclusions within the glass or layers or strings of glass which are not homogeneous with the main body of the glass

2.12 Rubs — Abrasion of the glass surfaces producing a frosted appearance. A 'rub' differs from a 'scratch' in having appreciable width.

2.13 Scratches — Any marking or tearing of the surface produced in manufacturing or handling, appearing as though it were done by a sharp or rough instrument.

2.14 Smoke — Streaked areas appearing as slight discoloration.

2.15 Stones — Any crystalline inclusion embedded in the glass.

2.16 Strings — Transparent lines appearing as though a thread of glass had been incorporated into the sheet.

2.17 Sulphur Stain — A surface defect in sheet glass, in the form of streaky lines or multi-coloured blemishes caused by sulphur dioxide, if present in kiln atmosphere.

2.18 Wave — Defect resulting from irregularities of the surface of glass making objects viewed at varying angles appear wavy or bent.

2.19 Intensity of Scratches, Rubs and Crush — When looking through glass and perpendicular to it, using daylight without direct sunlight, or with background light suitable for observing each type of defect, the visibility of the defects will be within the specified distance limits (*see* **5.2**) :

Intensity	*Distance limit*
Faint	Shall not be detectable beyond 50 cm.
Light	Detectable between 50-100 cm but not beyond 100 cm.
Medium	Detectable between 100-150 cm but not beyond 150 cm.
Heavy	Detectable beyond 150 cm.

2.20 Intensity of Reams, Strings and Lines — When evaluated using the shadowgraph, the intensities of these defects are defined as having shadowgraph read out at distances greater than or equal to the following (*see* 5.4) :

Intensity	*Distance*
Light	7.5 cm
Medium	5.0 cm
Heavy	2.5 cm

2.21 United CM — Half the perimeter of the glass sheet.

3. CLASSIFICATION

3.1 Sheet glass shall be classified into the following 4 qualities :

a) *AA Quality or Special Selected Quality (SSQ)* — Intended for use where superior quality of safety glass, high quality mirrors, photographic plates, projection slides, etc.

b) *A Quality or Selected Quality (SQ)* — Intended for selected glazing, manufacture of mirrors, safety glass, etc.

c) *B Quality or Ordinary Quality (OQ)* — Intended for glazing and framing purposes ; and

d) *C Quality or Greenhouse Quality (GQ)* — Intended for green house glazing, production of frosted glass, strips for flooring, etc.

4. REQUIREMENTS

4.1 Material — Sheet glass shall be flat, transparent and clear as judged by the unaided eye. It may, however, possess a light tint, when viewed edge-wise.

4.1.1 It shall be free from any cracks.

4.2 Dimensions — Nominal thickness, range of thickness and dimensional tolerance on cut sizes (length and width) of sheet glass shall be as prescribed in Table 1.

4.2.1 If agreed between the purchaser and the supplier, thickness other than those specified in Table 1 may be supplied. In such cases, range of thickness and tolerance on cut size shall be those which are applicable to immediate lower thickness specified in Table 1.

TABLE 1 NOMINAL THICKNESS, RANGE OF THICKNESS OF SHEET GLASS AND DIMENSIONAL TOLERANCE ON CUT SIZES

(*Clauses* 4.2 *and* 4.2.1)

SL No.	NOMINAL THICKNESS	RANGE OF THICKNESS	DIMENSIONAL TOLERANCE ON CUT SIZES
(1)	(2)	(3)	(4)
	mm	mm	± mm
i)	1·0	0·85 — 1·15	1·5
ii)	1·5	1·35 — 1·65	1·5
iii)	2·0	1·80 — 2·20	1·5
iv)	3·0	2·80 — 3·20	1·5
v)	3·5	3·30 — 3·70	2·0
vi)	4·0	3·80 — 4·20	2·0
vii)	5·0	4·70 — 5·30	2·0
viii)	5·5	5·20 — 5·80	2·0
ix)	6·3	5·90 — 6·70	2·0
x)	8·0	7·50 — 8·50	3·0
xi)	10·0	9·50 — 10·50	3·0
xii)	12·0	11·00 — 13·00	3·0
xiii)	15·0	13·50 — 16·50	4·0
xiv)	19·0	17·00 — 21·00	4·0
xv)	25·0	22·00 — 28·00	5·0
xvi)	32·0	28·50 — 35·50	6·0

4.3 Distribution of Allowable Defects — Sheet glass shall not have defects greater than those specified in Table 2.

4.3.1 *Allowable Cluster of Defects* — Sheet glass shall not have cluster of defects more than those specified in Table 2 A.

5. TESTS

5.1 Thickness — Thickness of sheet glass shall be measured as prescribed in Appendix B.

5.2 Scratches, Rubs and Crush — Place the sample of sheet glass in a vertical position approximately 50 cm from the viewer's position and look through it using either daylight without direct sunlight or a background light suitable for observing each type of defect (*see* 2.19).

NOTE — The distance of the viewer from the sample shall be adjusted as specified in 2.19 to ascertain the intensity of scratches, rubs and crush.

5.3 Bow — Depending on the side on which bow is present, stand the sample vertically on a wooden plank. Stretch a thread edge to edge. Measure the longest perpendicular distance from the thread to the surface of sheet glass facing the thread and express it as percentage of the length of sheet glass from edge to edge along the thread.

5.4 Reams, Strings and Lines — Focus a light projector with a 500 W lamp and an objective lens with an approximate 5 cm aperture and about 30 cm focal length on a flat white projection screen placed about 760 cm from the light source in a dark room. Place the sheet glass in a vertical position parallel to the screen between the light and the screen. Move the glass slowly towards the screen with a vertical oscillating motion. The shadowgraph read out is the distance at which the distortion just blends with the general shadow of the glass on the screen (*see* **2.20**).

TABLE 2 DISTRIBUTION OF ALLOWABLE DEFECTS IN SHEET GLASS
(*Clauses* 4.3 *and* A-2.1)

Sl No.	Defects	'AA' Quality Central	'AA' Quality Outer	'A' Quality Central	'A' Quality Outer	'B' Quality Central	'B' Quality Outer	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Gaseous inclusion, max size, mm	1·0	2·0	3·0	6·0	12·0	18·0	Separated by at least 30·0 cm
ii)	Opaque gaseous inclusion, max size mm	Nil	0·5	3·0	6·0	6·0	12·5	Separated by at least 60·0 cm
iii)	Knots, dirts and stones*, max size, mm	Nil	1·0	1·0	1·0	1·5	2·0	Separated by at least 60·0 cm
iv)	Scratches, rubs and crush	Faint	Faint	Faint	Light	Light	Medium	Separated by atleast 60·0 cm (*see* 2.19)
v)	Bow, percent, max	0·25	0·25	0·5	0·5	1·0	1·0	(*see* 5.3)
vi)	Reams, Strings and lines	Light	Light	Light	Light	Medium	Heavy	(*see* 2.20 and 5.4)
vii)	Waviness, mm	10	10	15·0	15·0	20·0	20·0	(*see* Appendix A)
viii)	Sulphur stains	Nil	Nil	Nil	Nil	Inconspicuous one allowed		
ix)	Corner breakage and chip	Not more than nominal thickness of sheet glass		Not more than nominal thickness of sheet glass		Not more than nominal thickness of sheet glass		

Note — 'C' quality sheet glass may have defect of any size or intensity but shall have no stones or knots which may cause breakage.

*There shall be none which hinders serviceability for automobile industry.

TABLE 2A ALLOWABLE CLUSTER OF DEFECTS MENTIONED UNDER SL. NO. (i), (ii) AND (iii) OF TABLE 2

SL No.	Quality of Sheet Glass	Central Area	Outer Area
(1)	(2)	(3)	(4)
i)	AA	Nil	One cluster of maximum 3 defects comprising only one from (iii) and 2 from either (i) or (ii), or one each from (i) and (ii) in an optional circle of 30 cm dia
ii)	A	One cluster of maximum 3 defects comprising only one from (iii) and 2 from either (i) or (ii), or one each from (i) and (ii) in an optional circle of 30 cm dia	One cluster of maximum 5 defects of any type mentioned in (i),(ii) and (iii) but the presence of stone should not be more than one in an optional circle of 30 cm dia
iii)	B	do	One cluster of maximum 6 defects of any type mentioned in (i), (ii) and (iii) but the presence of stone should not be more than one in optional circle of 30 cm dia

6. PACKING AND MARKING

6.1 Packing — Sheet glass shall be packed as agreed to between the purchaser and the supplier.

6.2 Marking — Packages containing sheet glass shall be marked with the following :

a) Name and quality (*see* **3.1**) of the material;

b) Nominal thickness and cut size (*see* **4.2**);

c) Name of the manufacturer or his recognized trade-mark, if any; and

d) Code or serial number to enable the lot to be traced from records.

6.2.1 The packages may also be marked with the Standard Mark

NOTE — The use of the Standard Mark is governed by the provisions of the Bureau of Indian Standards Act, 1986 and the Rules and Regulations made thereunder. The Standard Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by BIS and operated by the producer. Standard marked products are also continuously checked by BIS for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the Standard Mark may be granted to manufacturers or producers, may be obtained from the Bureau of Indian Standards.

7. SAMPLING

7.1 Representative samples of the material shall be drawn and adjudged for conformity with this specification as prescribed in Appendix C.

APPENDIX A

[*Table* 2, *Sl No.* (vii)]

TEST FOR WAVINESS

A-0. GENERAL

A-0.1 Waviness is judged by the amount of distortion of a projected vertical straight line when the sheet glass is moved through its length and width in a plane parallel to that of the projection screen.

A-1. APPARATUS

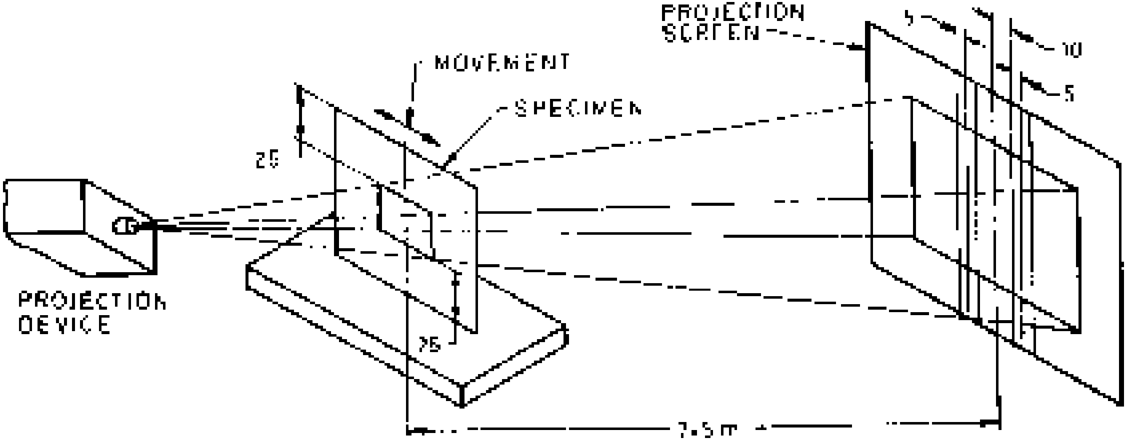
A-1.1 The apparatus consisting of a projector and screen is set up as shown in Fig. 1.

A-2. PROCEDURE

A-2.1 Draw one vertical straight central line on the projection screen and draw 3 straight lines on either side of this central line so that all the lines are parallel and the distances of the 3 lines from the central line on either side are 10·0, 15·0 and 20·0 mm respectively. Project one straight line from the projector so that it coincides with the central line. Next place the specimen between the projector and the projection screen at a distance of 7.5 m from the latter with the plane of the sample perpendicular to the projected light flux.

A-2.1.1 Move the specimen in a plane parallel to that of the screen and examine the distortion of the projected line image over all the portions except 25 mm from the boundary of the specimen. Furthermore, turn the specimen through 90 degrees within the same plane and repeat the test.

A-2.2 The sample shall be taken as having satisfied the requirement of the test if the distortion of the projected line on the screen does not exceed the values prescribed in Table 2 for respective qualities of sheet glass.



All dimensions in millimetres.

FIG 1. SET-UP FOR TESTING WAVINESS IN SHEETS GLASS

APPENDIX B

(*Clause* 5.1)

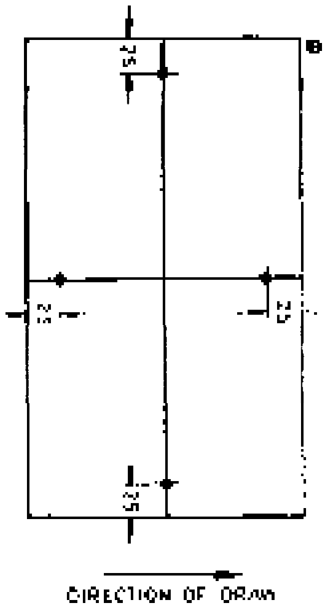
DETERMINATION OF THICKNESS OF SHEET GLASS

B-1. APPARATUS

B-1.1 Screw Calipers — with an accuracy of 0·01 mm.

B-2. PROCEDURE

B-2.1 Marking of Points — Divide the rectangular sheet into 4 equal segments as shown in Fig. 2.



All dimensions in millimetres.

FIG. 2 DETERMINATION OF THICKNESS

B-2.2 Measurement of Thickness — Measure the thickness of the glass sheet using screw calipers at all the four points, 1, 2, 3 and 4 as shown in Fig. 2. The individual thickness at each of the four points shall be within the range of nominal specified thickness.

APPENDIX C

(*Clause* 7.1)

SAMPLING OF FLAT TRANSPARENT SHEET GLASS

C-1. SCALE OF SAMPLING

C-1.1 *Lot* — In a single consignment, all the sheets of glass of the same quality and nominal thickness and belonging to the same batch of manufacture shall constitute a lot.

C-1.2 Samples shall be tested separately from each lot for ascertaining conformity of sheet glass to the requirements of this specification.

C-1.3 The number of sheets to be sampled from a lot for this purpose shall depend on lot size and shall be in accordance with col 1 and 3 of Table 3. If the sheets are packed in boxes or cartons, at least 20 percent of them, subject to minimum of 2 boxes shall be selected at random and opened for taking out the samples. From each selected box or carton, approximately equal number of sheets shall be selected from the top, middle and the bottom portions to give the required sample size.

TABLE 3 SCALE OF SAMPLING AND CRITERIA FOR CONFORMITY

(*Clauses* C-1.3, C-2.1, C-2.1.1, C-2.2 *and* C-2.3)

Lot Size	For Distribution of Visual Defects						Nominal Thickness and Tolerance on Cut Sizes		Sample Size for Testing Waviness
	Stage	Sample Size	Combined Size	C_1	C_2	C_3	Sample Size	C_4	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Up to 100	First	8	8	0	2	2	5	0	2
	Second	8	16						
101 to 300	First	13	13	0	3	4	8	1	3
	Second	13	26						
301 to 500	First	20	20	1	4	5	13	1	4
	Second	20	40						
501 to 1 000	First	32	32	2	5	7	20	2	5
	Second	32	64						
1 001 and above	First	50	50	3	7	9	30	3	6
	Second	50	100						

C-1.3.1 In order to ensure the randomness of selection of sheets from the lot, procedures given in IS : 4905-1968* may be followed.

C-2. NUMBER OF TESTS AND CRITERIA FOR CONFORMITY

C-2.1 Distribution of Visual Defects and Colour (Except Waviness) — Sample sheets selected in C-1.3 shall be examined for the requirements of colour and distribution of visual defects in two stages as shown in col 2 of Table 3. A glass sheet failing to satisfy any of these requirements shall be considered as defective. If the number of defective sheets found in the sample in the first stage is less than or equal to the corresponding number given in col 5 of Table 3, the lot shall be accepted. If it is equal to or greater than the corresponding number given in col 6 of Table 3, the lot shall be rejected without any further testing.

C-2.1.1 If the number of defective sheets found in the sample in the first stage lies between C_1 and C_2, a second such sample of the size prescribed in col 3 of Table 3 shall be taken and examined for colour and visual defects. The lot shall be considered as conforming to these requirements if the combined number of defectives in the first and second stage is less than the corresponding number C_3 given in col 7 of Table 3; otherwise the lot shall be rejected.

C-2.2 Nominal Thickness and Tolerance on Cut Size — The lot, which has satisfied the requirements given in C-2.1, shall be examined for these requirements. The sample sheets required for testing these characteristics shall be selected from those examined under C-2.1 and found satisfactory. The sample size for these tests shall be as given in col 8 of Table 3. The lot shall be considered to have met these requirements, if the number of defective sheets found in the sample is less than or equal to the corresponding number C_4 given in col 9 of Table 3.

C-2.3 Waviness — The lot, which has satisfied the requirements given in C-2.1 and C-2.2, shall be finally tested for waviness. The sample size for this purpose shall be as given in col 10 of Table 3. The sample sheets required for this testing shall be selected from those tested under C-2.2 and found satisfactory. The lot shall be considered to have satisfied the requirements for waviness if none of the sample sheets selected according to col 10 of Table 3 is found defective.

*Methods for random sampling.

(*Continued from page 1*)

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BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones: 331 01 31, 331 13 75 — Telegrams: Manaksanstha (Common to all Offices)

Regional Offices:		*Telephone*
Central	Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
*Eastern	: 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola, CALCUTTA 700054	36 24 99
Northern	: SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43 3 16 41
Southern	: C. I. T. Campus, MADRAS 600113	41 24 42 41 25 19 41 29 16
†Western	: Manakalaya, E9 MIDC, Marol, Andheri (*East*), BOMBAY 400093	6 32 92 95

Branch Offices:

'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48 2 63 49
‡Peenya Industrial Area 1st Stage, Bangalore Tumkur Road BANGALORE 560058	38 49 55 38 49 56
Gangotri Complex, 5th Floor, Bhadbhada Road, T. T. Nagar, BHOPAL 462003	6 67 16
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
53/5, Ward No. 29, R.G. Barua Road, 5th Byelane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg (Nampally Station Road), HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71 6 98 32
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76 21 82 92
Patliputra Industrial Estate, PATNA 800013	6 23 05
T.C. No. 14/1421, University P.O., Palayam TRIVANDRUM 695035	6 21 04 6 21 17

Inspection Offices (With Sale Point):

Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	2 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office in Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, Calcutta 700072 — 27 68 00

†Sales Office in Bombay is at Novelty Chambers, Grant Road, Bombay 400007 — 89 65 28

‡Sales Office in Bangalore is at Unity Building, Narasimharaja Square, Bangalore 560002 — 22 36 71

Reprography Unit, BIS, New Delhi, India

Code of practice and guidelines on glass

1) IS 1382: 1981 Glossary of terms related to glass & glassware (first revision)

2) IS 5437: 1994. Figured, rolled and wired glass – specification

3) IS 3548: 1988 Indian Standard, Code of practice for glazing in buildings

4) IS 10439: 1983. Indian Standard, Code of practice for patent glazing

5) IS 875: 1987 Indian Standard, Code of practice for design loads (other than earthquake) for buildings & structures, part 3: wind loads

6) IS 2553: 1990 Safety glass – specification (Part 1)

7) IS 2835: 1987 Specification for flat transparent sheet glass