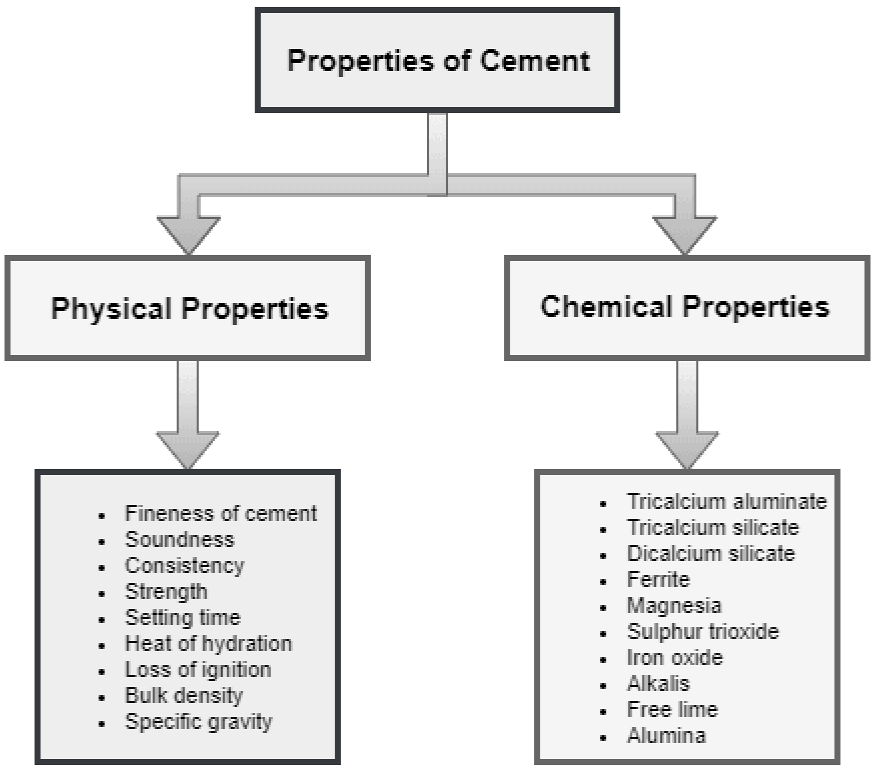
Concrete Technology

4th Sem

Properties of Cement- Physical & Chemical

Cement, a popular binding material, is a very important civil engineering material. This article concerns the physical and chemical properties of cement, as well as the methods to test cement properties.



Physical Properties of Cement

Different blends of cement used in construction are characterized by their physical properties. Some key parameters control the quality of cement. The physical properties of good cement are based on:

- Fineness of cement
- Soundness
- Consistency
- Strength
- Setting time
- Heat of hydration
- Loss of ignition
- Bulk density

- Specific gravity (Relative density)

These physical properties are discussed in details in the following segment. Also, you will find the test names associated with these physical properties.

Fineness of Cement

The size of the particles of the cement is its fineness. The required fineness of good cement is achieved through grinding the clinker in the last step of cement production process. As hydration rate of cement is directly related to the cement particle size, fineness of cement is very important.

Soundness of Cement

Soundness refers to the ability of cement to not shrink upon hardening. Good quality cement retains its volume after setting without delayed expansion, which is caused by excessive free lime and magnesia.

Tests:

Unsoundness of cement may appear after several years, so tests for ensuring soundness must be able to determine that potential.

- **Le Chatelier Test**
  This method, done by using Le Chatelier Apparatus, tests the expansion of cement due to lime. Cement paste (normal consistency) is taken between glass slides and submerged in water for 24 hours at 20+1°C. It is taken out to measure the distance between the indicators and then returned under water, brought to boil in 25-30 mins and boiled for an hour. After cooling the device, the distance between indicator points is measured again. In a good quality cement, the distance should not exceed 10 mm.
- **Autoclave Test**
  Cement paste (of normal consistency) is placed in an autoclave (high-pressure steam vessel) and slowly brought to 2.03 MPa, and then kept there for 3 hours. The change in length of the specimen (after gradually bringing the autoclave to room temperature and pressure) is measured and expressed in percentage. The requirement for good quality cement is a maximum of 0.80% autoclave expansion.
  Standard autoclave test: AASHTO T 107 and ASTM C 151: Autoclave Expansion of Portland Cement.

Consistency of Cement

The ability of cement paste to flow is consistency.

It is measured by Vicat Test.

In Vicat Test Cement paste of normal consistency is taken in the Vicat Apparatus. The plunger of the apparatus is brought down to touch the top surface of the cement. The plunger will penetrate the cement up to a certain depth depending on the consistency. A cement is said to have a normal consistency when the plunger penetrates 10±1 mm.

Strength of Cement

Three types of strength of cement are measured – compressive, tensile and flexural. Various factors affect the strength, such as water-cement ratio, cement-fine aggregate ratio, curing conditions, size and shape of a specimen, the manner of molding and mixing, loading conditions and age. While testing the strength, the following should be considered:

- Cement mortar strength and cement concrete strength are not directly related. Cement strength is merely a quality control measure.
- The tests of strength are performed on cement mortar mix, not on cement paste.
- Cement gains strength over time, so the specific time of performing the test should be mentioned.

Compressive Strength

It is the most common strength test. A test specimen (50mm) is taken and subjected to a compressive load until failure. The loading sequence must be within 20 seconds and 80 seconds.

Standard tests:

i. AASHTO T 106 and ASTM C 109: Compressive Strength of Hydraulic Cement Mortars (Using 50-mm or 2-in. Cube Specimens)
ii. ASTM C 349: Compressive Strength of Hydraulic Cement Mortars (Using Portions of Prisms Broken in Flexure)

Tensile strength

Though this test used to be common during the early years of cement production, now it does not offer any useful information about the properties of cement.

Flexural strength

This is actually a measure of tensile strength in bending. The test is performed in a 40 x40 x 160 mm cement mortar beam, which is loaded at its center point until failure.

Standard test:

i. ASTM C 348: Flexural Strength of Hydraulic Cement Mortars

Setting Time of Cement

Cement sets and hardens when water is added. This setting time can vary depending on multiple factors, such as fineness of cement, cement-water ratio, chemical content, and admixtures.

Cement used in construction should have an initial setting time that is not too low and a final setting time not too high. Hence, two setting times are measured:

- **Initial set:** When the paste begins to stiffen noticeably (typically occurs within 30-45 minutes)
- **Final set:** When the cement hardens, being able to sustain some load (occurs below 10 hours)

Again, setting time can also be an indicator of hydration rate.

Standard Tests:

i. AASHTO T 131 and ASTM C 191: Time of Setting of Hydraulic Cement by Vicat Needle
ii. AASHTO T 154: Time of Setting of Hydraulic Cement by Gillmore Needles
iii. ASTM C 266: Time of Setting of Hydraulic-Cement Paste by Gillmore Needles

Heat of Hydration

When water is added to cement, the reaction that takes place is called hydration. Hydration generates heat, which can affect the quality of the cement and also be beneficial in maintaining curing temperature during cold weather. On the other hand, when heat generation is high, especially in large structures, it may cause undesired stress. The heat of hydration is affected most by C_3S and C_3A present in cement, and also by water-cement ratio, fineness and curing temperature. The heat of hydration of Portland cement is calculated by determining the difference between the dry and the partially hydrated cement (obtained by comparing these at 7th and 28th days).

Standard Test:

ASTM C 186: Heat of Hydration of Hydraulic Cement

Loss of Ignition

Heating a cement sample at 900 - 1000°C (that is, until a constant weight is obtained) causes weight loss. This loss of weight upon heating is calculated as loss of ignition. Improper and prolonged storage or adulteration during transport or transfer may lead to pre-hydration and carbonation, both of which might be indicated by increased loss of ignition.

Standard Test:

AASHTO T 105 and ASTM C 114: Chemical Analysis of Hydraulic Cement

Bulk density

When cement is mixed with water, the water replaces areas where there would normally be air. Because of that, the bulk density of cement is not very important. Cement has a varying range of density depending on the cement composition percentage. The density of cement may be anywhere from 62 to 78 pounds per cubic foot.

Specific Gravity (Relative Density)

Specific gravity is generally used in mixture proportioning calculations. Portland cement has a specific gravity of 3.15, but other types of cement (for example, portland-blast-furnace-slag and portland-pozzolan cement) may have specific gravities of about 2.90.

Standard Test:

AASHTO T 133 and ASTM C 188: Density of Hydraulic Cement

Chemical Properties of Cement

The raw materials for cement production are limestone (calcium), sand or clay (silicon), bauxite (aluminum) and iron ore, and may include shells, chalk, marl, shale, clay, blast furnace slag, slate. Chemical analysis of cement raw materials provides insight into the chemical properties of cement.

1. **Tricalcium aluminate (C3A)**
   Low content of C3A makes the cement sulfate-resistant. Gypsum reduces the hydration of C_3A, which liberates a lot of heat in the early stages of hydration. C3A does not provide any more than a little amount of strength.
   Type I cement: contains up to 3.5% SO_3 (in cement having more than 8% C_3A)
   Type II cement: contains up to 3% SO_3 (in cement having less than 8% C_3A)
2. **Tricalcium silicate (C_3S)**
   C3S causes rapid hydration as well as hardening and is responsible for the cement's early strength gain an initial setting.
3. **Dicalcium silicate (C_2S)**
   As opposed to tricalcium silicate, which helps early strength gain, dicalcium silicate in cement helps the strength gain after one week.
4. **Ferrite (C_4AF)**
   Ferrite is a fluxing agent. It reduces the melting temperature of the raw materials in the kiln from 3,000°F to 2,600°F. Though it hydrates rapidly, it does not contribute much to the strength of the cement.
5. **Magnesia (MgO)**
   The manufacturing process of Portland cement uses magnesia as a raw material in dry process plants. An excess amount of magnesia may make the cement unsound and expansive, but a little amount of it can add strength to the cement. Production of MgO-based cement also causes less CO2 emission. All cement is limited to a content of 6% MgO.
6. **Sulphur trioxide**
   Sulfur trioxide in excess amount can make cement unsound.

7. **Iron oxide/ Ferric oxide**
   Aside from adding strength and hardness, iron oxide or ferric oxide is mainly responsible for the color of the cement.
8. **Alkalis**
   The amounts of potassium oxide (K_2O) and sodium oxide (Na_2O) determine the alkali content of the cement. Cement containing large amounts of alkali can cause some difficulty in regulating the setting time of cement. Low alkali cement, when used with calcium chloride in concrete, can cause discoloration. In slag-lime cement, ground granulated blast furnace slag is not hydraulic on its own but is "activated" by addition of alkalis. There is an optional limit in total alkali content of 0.60%, calculated by the equation $Na_2O + 0.658\ K_2O$.
9. **Free lime**
   Free lime, which is sometimes present in cement, may cause expansion.
10. **Silica fumes**
    Silica fume is added to cement concrete in order to improve a variety of properties, especially compressive strength, abrasion resistance and bond strength. Though setting time is prolonged by the addition of silica fume, it can grant exceptionally high strength. Hence, Portland cement containing 5-20% silica fume is usually produced for Portland cement projects that require high strength.
11. **Alumina**
    Cement containing high alumina has the ability to withstand frigid temperatures since alumina is chemical-resistant. It also quickens the setting but weakens the cement.

Chapter 8

Components of Concrete

Concrete is a mixture of sand, gravel, crushed rock, and/or other aggregates that are held together by a hardened paste of cement and water. The properties of concrete vary depending on the ingredients used and their proportions in the mix. Generally, concrete mix consists of 25 to 40 percent cement paste, 25 to 40 percent aggregate, and 7 to 15 percent concrete. When cement and water are combined, hydration (liberation of heat) occurs. The strength of concrete begins with hydration and increases as long as hydration continues. After 28 days, the relative strength increase levels off.

TYPES OF PORTLAND CEMENT

8-1. Various types of portland cement have been standardized for different uses. The type of construction, the chemical composition of the soil, the economy, and the speed of construction determine the type of cement used. The five types of portland cement are described below. Types I, II, and III are the most widely used; Types IV and V are used for specific applications.

NOTE: *Chapter 9* addresses air-entrained cement, which is a special type of cement made with an air-entraining admixture.

- **Type I, normal portland cement.** Type I cement is used in general construction. It is used for pavement construction where concrete is not subject to sulfate hazards or where heat generated through hydration does not cause an objectionable rise in temperature.
- **Type II, modified portland cement.** Type II cement generates lower heat at a slower rate than Type I, and it has improved resistance to sulfate. It is used in hot weather when moderate heat generation tends to minimize the rise in temperature; Type I may be preferable in cold weather. Type II cement can be used as a precaution in areas where sulfate concentrations are higher than normal but are not severe.
- **Type III, high-early-strength portland cement.** Type III cement is used when high strengths are needed very early in an operation. Forms can be removed in a short time, and the concrete can be put into quick service. It is also used to reduce the amount of time uncured cement is exposed to low temperatures. Type III cement usually cures in two days at 70°F and three days at 50°F. High strength can be obtained at an early stage more satisfactorily and economically with Type III cement than with Type I.
- **Type IV, low-heat portland cement.** Type IV cement is used when the amount and rate of generated heat must be kept to a minimum. It develops strength at a slower rate than Type I. Type IV is normally used in large, mass projects, such as concrete dams, to combat the rise

in temperature where heat generated during hardening may be a critical factor. It is seldom used for road or airfield construction.

- **Type V, sulfate-resistant portland cement.** Type V cement is used in structures that are exposed to severe sulfate action, such as areas that have water with a high acid content. It gains strength at a slower rate than Type I.

WATER

8-2. Water is mixed with cement to form a paste and produce hydration. Foreign materials in the water that tend to retard or change the chemical reaction are detrimental to concrete. Organic material and oil may inhibit the bond between the hydrated cement and the aggregate by coating the aggregate and preventing the paste from adhering to the aggregate. Several alkalies and acids react chemically with cement and retard normal hydration, and organic material may have the same effect. The result is a weakened paste, and the contaminating substance will likely cause deterioration or structural failure of the finished concrete.

SEA WATER

8-3. Sea water and cement can be mixed with satisfactory results; however, concrete strength may be reduced by 10 to 20 percent. Salt water acts as an accelerant much the same as calcium chloride ($CaCl_2$). Avoid using sea water in reinforced concrete if possible; but as a field expedient, decrease the water-to-cement ratio to offset the strength loss. If the water-to-cement ratio cannot be changed, consider the following to offset strength reduction:

- If using ocean water with an average salt content, multiply the design thickness by 1.15 to obtain a thickness of equal strength.
- If using water from a landlocked sea, such as the Dead Sea, with an extremely high salt content, multiply the design thickness by 1.25 to obtain a thickness of equal strength.

WELL WATER (SULFUR)

8-4. Avoid using water with a high sulfur content (normally present in wells and streams near underground mines) in concrete. If it is the best type of water available, however, use sulfur-resistant cements. Sulfur water that is not unpleasant to drink produces excellent results with Type V cement, good results with Type II cement, and fair results with other types of cement. If the water contains enough sulfates to make it unpleasant to drink, it produces good results with Type V cement, fair results with Type II cement, and marginal or unsatisfactory results with other types of cement. Some sulfur water may also contain acids or alkalies, and adding an accelerator may offset the harmful effects of these contaminants.

AGGREGATE

8-5. Aggregates can be added to cement paste as a filler; however, they affect the proportions and the economy of a mix and the qualities of the finished concrete. The most common fillers are crushed rock and natural deposits of sand and gravel. Artificial aggregates, such as blast-furnace slag or specially burned clay, can be used if natural aggregates are unavailable. A satisfactory, expedient aggregate can sometimes be produced by crushing the rubble from demolished structures.

TYPES

8-6. FA and CA can be used to produce concrete. Combining both types yields a well-graded mix that produces a strong, durable, almost voidless building stone. For portland-cement concrete, aggregate is considered fine when it passes a number 4 sieve and is retained on a number 200 sieve with 3 to 5 percent passing a number 100 sieve. Use FA to fill voids between CA particles and to reduce the amount of paste needed. Aggregate is considered coarse when it passes a 3-inch sieve and is retained on a number 4 sieve. CA is primarily used as a filler. For pavement, ensure that the maximum size CA does not exceed 2 inches or one-third the thickness of the slab. The larger the particle, the less paste is needed to coat the aggregate.

CHARACTERISTICS

8-7. To produce high-quality concrete, ensure that the aggregate is clean, hard, strong, durable, and round or cubical in shape. (See *FM 5-472* for information on testing bulk-specific gravity, absorption of aggregates, surface moisture of FA, and organic matter in sand.)

8-8. Organic matter, dirt, silt, clay, or chemicals may cause finished concrete to deteriorate by inhibiting the bond between the cement paste and the aggregate or by reacting with the constituents of the cement. Excessive fines may also inhibit bonding and produce a mix that is structurally weak and susceptible to breakdown by weathering. Wash the aggregate to remove harmful ingredients. To determine mix proportions, ensure that the aggregate is in a saturated, surface-dry condition or adjust the water-to-cement ratio to compensate for the amount of water contained in the aggregate.

8-9. Aggregate should be strong and resistant to abrasion from weathering and wear. Weak, friable, laminated, or very absorptive aggregate particles are likely to cause deterioration of the finished concrete. Inspect aggregate frequently to disclose weaknesses.

GRADATIONS

8-10. Aggregate gradation and size affect the relative proportions, workability, and economy of a mix and the watertightness and shrinkage of finished concrete. In general, aggregate used for concrete must be well-graded to produce a dense mass with minimum voids. Aggregate that is not well-graded may reduce the strength of finished concrete and increase the cost of the mix because of the additional paste required to fill voids. (See *FM 5-472* for a more detailed explanation of aggregate gradations.) *Table 8-1* lists the recommended limits for FA and CA.

Table 8-1. Recommended Aggregate Gradation Limits for Portland-Cement Concrete

Size Number	Nominal Size	Amounts Finer Than Laboratory Sieve (Square Openings), Percent by Weight								
		2 1/2 Inch	2 Inch	1 1/2 Inch	1 Inch	3/4 Inch	1/2 Inch	3/8 Inch	No. 4	No. 8
3, 5, 7	2 inch to No. 4	100	95-100	70-90	35-70	50-20	10-30	20-5	0-5	---
4, 6, 7	1 1/2 inch to No. 4	---	100	95-100	60-85	35-70	25-50	10-30	0-5	---
5, 7	1 inch to No. 4	---	---	100	95-100	60-80	25-60	15-45	0-10	0-5
6, 7	3/4 inch to No. 4	---	---	---	100	90-100	55-80	20-55	0-10	0-5
7	1/2 inch to No. 4	---	---	---	---	100	90-100	40-70	0-15	0-5
3	2 to 1 inch	100	90-100	35-70	0-15	0-15	0-15	---	---	---
4	1 1/2 to 3/4 inch	---	100	90-100	0-15	0-15	0-10	0-5	---	---

FINENESS MODULUS

8-11. The fineness modulus is an index of the relative fineness or coarseness of sand in a concrete mix. It is calculated by adding the cumulative percentages of an aggregate sample that is retained on each sieve of a specified series and dividing the result by 100. The sieves ordinarily used are numbers 3, 4, 8, 16, 50, and 100. Aggregate with a very low or high fineness modulus is not as satisfactory for concrete as aggregate with a medium fineness modulus.

BLENDING

8-12. If the aggregate gradation does not meet recommended limits due to the lack or abundance of certain particle sizes, blend the material to meet the requirements. Correct deficiencies by adding missing particles or screening out abundant particles.

ADMIXTURES

8-13. Admixtures used with portland cement are air-entraining agents, accelerators, retardants, plasticizers, cement-dispersing agents, concrete densifiers, and waterproofing agents. They are used to change the characteristics of a mix or a finished concrete. Do not use admixtures if the end result can be achieved more economically by altering mix proportions. This manual addresses admixtures used in concrete pavements; cement-dispersing agents, concrete densifiers, and waterproofing agents are only used for constructing structural members.

AIR-ENTRAINING AGENTS

8-14. Air-entraining agents increase the resistance to frost action and chemicals and improve the workability of a mix. These agents are liquids derived from wood resin, animal fats, vegetable oils, and other wetting agents (alkali salts, sulfonated organic compounds, various water-soluble soaps). Many different air-entraining agents can be used to produce air-entrained concrete.

ACCELERATORS

8-15. Accelerators are used in a concrete mix to hasten hydration, which increases generated heat and produces a high-early strength cement. $CaCl_2$ is the most widely used accelerator, and it can be used if it is economical and the increased hydration will not cause flash set or undue shrinkage. Use 1 to 2 percent $CaCl_2$ by weight of the cement. This amount increases the flexural strength by 40 to 90 percent on the first day and 5 to 35 percent by the third day when moist-cured at 70°F. Flexural strength increases are lower at 40°F, and acceleration is usually greatest during the first three days.

8-16. With the same water-to-cement ratio, the ultimate strength at one year is about the same or slightly higher for cement mixed with $CaCl_2$. Because $CaCl_2$ increases the workability of a mix, lower water-to-cement ratios can be used with subsequent increases in strength. Do not use $CaCl_2$ for curing, on the surface, or as an admixture. Sodium chloride (NaCl) can also be used to accelerate hydration, but it will reduce the strength of concrete.

RETARDANTS

8-17. Retardants are used when the rate of hydration must be slowed down to allow proper placement and consolidation of the concrete before it sets. They can also be used to increase the strength and durability of concrete when it is revibrated before it sets. Many commercial retardants are available; and they basically consist of fatty acids, sugars, and starches. Use retardants when the—

- Danger of flash set exists.
- Heat of hydration is expected to be excessively high.
- Cement comes in contact with high ground temperatures (as in grouting operations).
- Concrete is laid during hot weather.

PLASTICIZERS

8-18. Plasticizers are used to make the concrete more workable. Do not use them as substitutes for proper aggregate gradation. Some materials that can be used as plasticizers include—

- Admixtures, which increase the workability of a mix.
- Air-entraining agents.
- $CaCl_2$ and other pozzolans.
- Lime.

- Finely pulverized inert fillers, which increase the workability of a mix that is deficient in fines. They also increase the amount of mixing water required.

8-19. A pozzolan is a siliceous material that becomes cement-like when it is combined with lime. It is normally used as a cement replacement agent. Fly ash, volcanic ash, calcined diatomaceous earth, and calcined shale are examples of pozzolans.

8-20. Fly ash, the most widely used pozzolan, is a waste product from large, powdered-coal furnaces. Used as a cement replacement agent, fly ash can replace up to 50 percent of the cement by weight. Using fly ash changes nearly all the properties of concrete in its plastic and hardened states. In general, fly ash improves the workability of plastic concrete. If the same amount of aggregate is used in a mix, identical slumps are obtained with cement/fly-ash mixes and portland-cement mixes; however, cement/fly-ash mixes have a lower water-to-cement ratio. Fly ash acts as a plasticizer, improves the workability of a mix, and greatly reduces bleeding and segregation. When compared to modified portland cement, fly ash reduces the heat of hydration by 40 to 50 percent. Fly-ash concrete does not gain strength and durability as fast as portland-cement concrete during the first month of hydration. Although after the first year, the strength and durability of fly-ash concrete are equal to or greater than portland-cement concrete.

MATERIALS HANDLING AND STORAGE

AGGREGATE

8-21. Concrete quantities that justify batch plants also justify stockpiles of aggregates at batch, crushing, and screening plants. Stockpiling prevents shortages at the batch plant and the paver. Stockpile aggregates for concrete pavement using the procedures discussed in *Chapter 4* for bituminous pavements.

CEMENT

8-22. Sacked cement that will be stored for a long time should be in a warehouse or a shed that is as airtight as possible. Ensure that the floor of the shed is above ground, and close up all cracks in the walls. Store the sacks close together to reduce air circulation; however, do not stack them against a wall. Stack cement sacks on a raised, wooden platform and cover them with tarpaulins (*Figure 8-1*, page 8-8). Note that tarpaulins extend over the edge of the platform to prevent rain from collecting on the platform and reaching the bottom sacks. Use tarpaulins for protection against moisture even when storing a small amount of cement for a short time. Ensure that the concrete mixer is located near the storage shed.

8-23. Cement retains its quality indefinitely when it is kept dry. If it is packed tightly and stored for a long time, it may develop *warehouse pack*. To correct warehouse pack, roll the sacks on the floor. Cement must be free-flowing and free of lumps when it is used. If the lumps are hard to break up, test the cement for suitability (see *FM 5-472*).

Figure 8-1. Cement Stored Under Tarpaulins

8-24. Bulk portland cement is blown through ducts from railroad cars to cement bins and weighing hoppers. The hoppers stand alongside trucks, beyond the aggregate batcher, and dump the cement into each batch. Open cement sacks and dump them into each batch from a roadside platform. Stack the sacks on the platform or the dunnage and cover them with tarpaulins or roofing paper. When hauling cement, cover it on the truck beds with tightly fitted canvas to prevent loss from wind and avoid damage from light showers. Depending on the length of the haul and the weather conditions, unopened sacks of cement may have to be opened at the mixer and dumped into each batch.

8-25. Loading platforms may be located at any point along the route from the batching plant to the paver. Hand trucks and roller conveyors are useful at loading points. Two people can toss cement sacks using a lifting-and-swinging rhythm. Empty sacks by cutting the underside lengthwise with a sharp, curved linoleum knife and pulling the empty sack free. When handling cement, wear goggles, respirators, and gloves. Avoid skin irritation by precoating exposed skin surfaces with petroleum jelly or neat's-foot oil. Store water near the mixer or water trailers, and ensure that water containers are clean and rust-free.

Design codes Provisions

Grades of concrete

1.6. GRADES OF CONCRETE AND CHARACTERISTIC STRENGTH

(As per IS : 456 - 2000, Clause 6.1 Table 2)

Concrete is graded according to its compressive strength. Indian standard code IS : 456 - 2000 specifies fifteen grades of concrete (Table 1.1), designated as M10, M15, M 20, M 25, M 30, M 35, M 40, M 45, M 50, M 55, M 60, M 65, M 70 and M 80.

In the designation of concrete mix, the letter M refers to mix and the number to the specified characteristic compressive strength (f_{ck}) of 15 cm cubes after 28 days of curing. The characteristic compressive strength is expressed in N/mm^2 (or MPa).

☐ 1.6.1 Characteristic Strength : *(As per IS : 456 - 2000, Clause 6.1.1.)* :

The characteristic strength of concrete is defined as the strength of the material below which not more than 5% of the test results are expected to fall. For example M 25 grade of concrete is said to have characteristic strength of 25 N/mm^2, only if, out of 100 test cubes, prepared 95 test specimen should fail above 25 N/mm^2 and only 5 test results can fail below the value of 25 N/mm^2.

The value of characteristic strength of concrete for different grades is mentioned in Table 1.1.

Table 1.1. Grades of Concrete *(As per IS : 456 - 2000 Clause 6.1 Table 2)*

Type of Concrete	Designation of Grade	Characteristic compressive strength of 15 cm cube after 28 days of curing in N/mm² (MPa)
Ordinary Concrete	M10	10
	M15	15
	M20	20
Standard Concrete	M25	25
	M30	30
	M35	35
	M40	40
	M45	45
	M50	50
	M55	55
High Strength Concrete	M60	60
	M65	65
	M70	70
	M75	75
	M80	80

Where, M refers to the mix and the number to the specified compressive strength, of 150 mm size cubes at 28 days, expressed in N/mm^2.

❑ 1.6.2. Effect on Strength with Age : *(As per IS : 456-2000, Clause 6.2.1)* :

Concrete gain strength with age and normally the gain in compressive strength is after 28 days. The increase in strength of concrete material is dependent upon curing, grade of concrete used, type of cement, environmental conditions, etc.

The strength of concrete at 28 days, as a percentage of strength at one year, is 80%, therefore the design should be generally based on 28 days characteristic strength. For concretes of grades M 30 and above, the ratio of actual increase in compressive strength with age should be investigated by mix designs.

Following points should be kept in mind for using different grades of concrete :

1. As per IS : 456 - 2000 recommendation, minimum grade of concrete for RCC works shall not be less than M 20. Concretes lower than M 20 grades may be used for lean concrete bases and simple foundation for brick masonry walls.
2. M 30 and higher grades may be used for post-tensioned prestressed concrete members
3. M 40 and higher grades may be used for pre-tensioned prestressed concrete.

4. Design mix concrete is preferred than nominal mix for determination of the proportions of cement, aggregates and water to attain the required strength. This will result in economical and safe design.

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 is likely to involve high cement content.

1.7. RECOMMENDATIONS FOR CONCRETE MATERIALS AS PER IS : 456 : 2000 (FOURTH REVISION)

❑ 1.7.1. Cement *(As per clause 5.1)*:

Cement to be used can be of any of the following types depending upon the use in a particular situation.

(i) 33 Grade Ordinary Portland Cement (OPC) conforming to IS : 269.

(ii) 43 Grade OPC conforming to IS : 8112.

(iii) 53 Grade OPC conforming to IS : 12269.

(iv) Rapid hardening Portland cement conforming to IS : 8041.

(v) Portland slag cement conforming to IS : 455.

(vi) Portland Pozzolona Cement (PPC) (Fly ash based) conforming to IS : 1489 (Part I).

(vii) Low heat portland cement conforming to IS : 12600.

(viii) Sulphate resisting portland cement conforming to IS : 12330.

(ix) Hydrophobic cement conforming to IS : 8043.

(x) Portland pozzolona cement (calcined clay based) conforming to IS : 1489 (Part II).

For general RCC works either Ordinary Portland Cement (O.P.C.) or Portland Pozzolona Cement (P.P.C.) are being used. Other cements are used for special concretes which gives additional properties.

❑ 1.7.2. Aggregates *(As per Clause 5.3)*:

(a) Aggregates shall comply with the requirements of IS : 383 with preference given to use of natural aggregates.

(b) The nominal maximum size of coarse aggregate should be large as possible but in no case greater than $\frac{1}{4}$th of the minimum thickness of the member, provided that concrete can be placed around the reinforcement thoroughly and fill all the corners of the form.

(c) For most RCC works, 20 mm aggregates are suitable. But where there is no restriction for flow of concrete into sections, then 40 mm or larger size may be permitted. For thin sections, sizes of 10 mm nominal maximum size may be used.

(d) For heavily reinforced concrete members as in case of ribs of main beams, the nominal size of the aggregates should be restricted to 5 mm less than the minimum clear distance

between then main bars or 5 mm less than the minimum cover to the reinforcement which ever is smaller.

(e) Coarse and fine aggregates shall be batched separately.

❑ 1.7.3. Water *(As per Clause 5.4)* :

Water is used in concrete for workability and hydration of cement particles :

(i) Water to be used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials or other substances that may be deleterious to concrete or steel.

(ii) Potable (drinking) water is generally considered suitable for mixing concrete.

(iii) 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 as specification *IS* code.

(iv) The pH value of water shall not be less than 6.

(v) Mixing or curing of concrete with sea water is not recommended due to presence of harmful salts in sea water.

❑ 1.7.4. Admixtures :

Admixtures, if used, shall comply with IS : 9103.

Admixtures should not impair durability of concrete nor combine with the constituent to form *mful compounds nor increase the risk of corrosion of reinforcement.*

PART B

1. Define workability? Explain the factors affecting workability?

Workability

The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of a certain quantity of water is of vital importance. The quality of concrete satisfying the above requirements is termed as workable concrete.

Factors Affecting Workability

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

(a) Water Content (b) Mix Proportions

(c) Size of Aggregates (d) Shape of Aggregates

(e) Surface Texture of Aggregate (f) Grading of Aggregate

(g) Use of Admixtures.

(a) Water Content: Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability.

(b) Mix Proportions*:* Aggregate/cement ratio is an important factor influencing workability. The higher the aggregate/cement ratio, the leaner is the concrete. On the other hand, in case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

(c) Size of Aggregate: The bigger the size of the aggregate, the less is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction.

(d) Shape of Aggregates: The shape of aggregates influences workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate.

(e) Surface Texture: The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

(f) **Grading of Aggregates:** This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.

(g) **Use of Admixtures:** Of all the factors mentioned above, the most importfactor which affects the workability is the use of admixtures. It is to be noted that initial slump of concrete mix or what is called the slump of reference mix should be about 2 to 3 cm to enhance the slump many fold at a minimum doze. One should manipulate other factors to obtain initial slump of 2 to 3 cm in the reference mix. Without initial slump of 2 –n 3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical. Use of air-entraining agent being surface-active, reduces the internal friction between the particles. They also act as artificial fine aggregates of very smooth surface.

2. Explain the test for workability?

Measurement of Workability

Workability of concrete is a complex property. Numerous attempts have been made by many research workers to quantitatively measure this important and vital property of concrete. Some of the tests, measure the parameters very close to workability and provide useful information. The following tests are commonly employed to measure workability

(a) Slump Test

(b) Compacting Factor Test

(c) Flow Test

(d) Kelly Ball Test

(e) Vee Bee Consistometer Test.

Slump Test

- Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete.

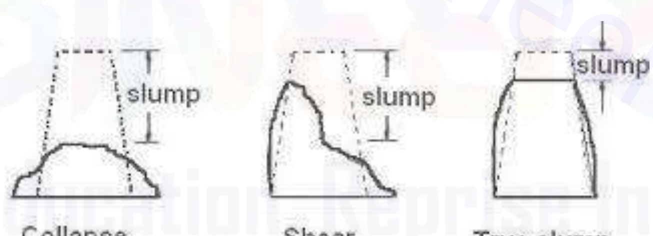
- Repeated batches of the same mix, brought to the same slump, will have the same water content and water cement ratio, provided the weights of aggregate, cement and admixtures are uniform and aggregate grading is within acceptable limits.

- Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. Quality of concrete can also be further assessed by giving a few tamping or blows by tamping rod to the base plate. The deformation shows the characteristics of concrete with respect to tendency for segregation. The apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as under:

Bottom diameter r: 20 cm

Top diameter : 10 cm

Height : 30 cm



Types of slump

The thickness of the metallic sheet for the mould should not be thinner than 1.6 mm. Sometimes the mould is provided with suitable guides for lifting vertically up. For tamping the concrete, a steel tamping rod 16 mm dia, 0.6 meter along with bullet end is used. The internal surface of the mould is thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. The mould is placed on a smooth, horizontal, rigid and non-absorbant surface The mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod takingcare to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred as SLUMP of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm. is taken as Slump of Concrete. Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation. It is seen that the slump test gives fairly good consistent results for a plastic-mix. This test is not sensitive for a stiff-mix. In case of dry-mix, no variation can be detected between mixes of different workability. In the case of rich mixes, the value is often satisfactory, their slump being sensitive to variations in workability.

K-SLUMP TESTER

It can be used to measure the slump directly in one minute after the tester is inserted in the fresh concrete to the level of the floater disc. This ester can also be used to measure the relative workability. A chrome plated steel tube with external and internal diameters of 1.9 and 1.6 cm respectively. The tube is 25 cm long and its lower part is used to make the test. The length of this part is 15.5 cm which includes the solid cone that facilitates inserting the tube into the concrete.

Two types of openings are provided in this part: 4 rectangular slots 5.1 cm long and 0.8 cm wide and 22 round holes 0.64 cm in diameter; all these openings are distributed uniformly in the lower part.

A disc floater 6 cm in diameter and 0.24 cm in thickness which divides the tube into two parts: the upper part serves as a handle and the lower one is for testing as already mentioned. The disc serves also to prevent the tester from sinking into the concrete beyond the preselected level.

A hollow plastic rod 1.3 cm in diameter and 25 cm long which contains a graduated scale in centimeters. This rod can move freely inside the tube and can be used to measure the height of mortar that flows into the tube and stays there. The rod is plugged at each end with a plastic cap to prevent concrete or any other material from seeping inside.

An aluminium cap 3 cm diameter and 2.25 cm long which has a little hole and a screw that can be used to set and adjust the reference zero of the apparatus. There is also in the upper part of the tube, a small pin which is used to support the measuring rod at the beginning of the test. The total weight of the apparatus is 226 g.

The following procedure is used:

(a) Wet the tester with water and shake off the excess.

(b)(b) Raise the measuring rod, tilt slightly and let it rest on the pin located inside the tester.

(c)(c) Insert the tester on the levelled surface of concrete vertically down until the disc floate rests at the surface of the concrete. Do not rotate while inserting or removing the tester.

(d) After 60 seconds, lower the measuring rod slowly until it rests on the surface of the concrete that has entered the tube and read the K-Slump directly on the scale of the measuring rod.

(e) Raise the measuring rod again and let it rest on its pin.

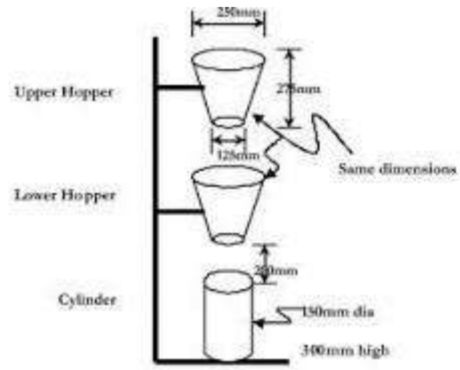
(f)(f) Remove the tester from the concrete vertically up and again lower the measuring rod slowly till it touches the surface of the concrete retained in the tube and read workability (W) directly on the scale of the measuring rod.

The K-slump apparatus is very simple, practical, and economical to use, both in the field and the laboratory. The K-slump tester can be used to measure slump in one minute in cylinders, pails,buckets, wheel-barrows, slabs or any other desired location where the fresh concrete is placed.

COMPACTING FACTOR TEST

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test.

The degree of compaction, called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to density of same concrete fully compacted. The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. In the case of a dry-mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion. The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades supplied with the apparatus. The outside of the cylinder is wiped clean. The concrete is filled up exactly upto the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as —Weight of partially compacted concrete.

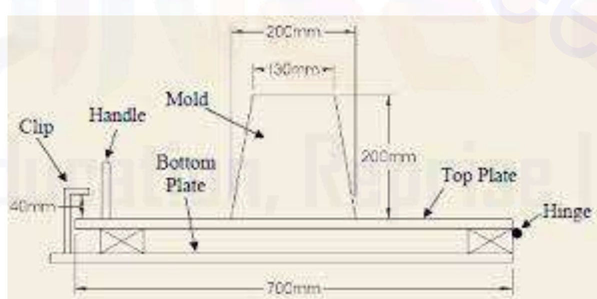


The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5 cm deep. The layers are heavily rammed or preferably vibrated so as to obtain full compaction. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10 gm. This weight is known as Weight of fully compacted concrete.

$$\text{The compaction factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

FLOW TEST

This is a laboratory test, which gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. In this test, a standard mass of concrete is subjected to jolting. The spread or the flow of the concrete is measured and this flow is related to workability.



Flow Table Test Apparatus

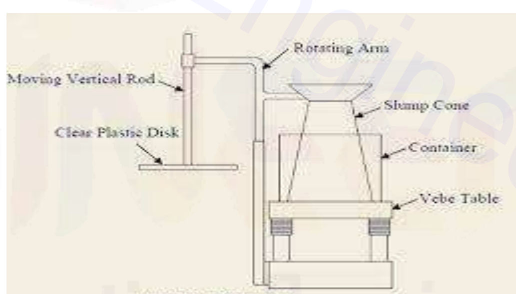
It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked. A mould made from smooth metal casting in the form of a frustum of a cone is used with the following internal dimensions. The base is 25 cm. in diameter, upper surface 17 cm. in diameter, and height of the cone is 12 cm. The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould

$$\text{Flow per cent} = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$$

The value could range anything from 0 to 150 per cent. A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

VEE BEE CONSISTOMETER TEST

This is a good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer. The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot. The electrical vibrator is then switched on and simultaneously a stop watch started.



Vebe Consistometer

The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape. This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test but the vibration is too vigorous for concrete with a slump greater than about 50 mm.

3. Explain segregation and Bleeding?

Segregation

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. If a sample of concrete exhibits a tendency for separation f say, coarse aggregate from the rest of the ingredients, then, that sample is said to be showing the tendency for segregation. Such concrete is not only going to be weak; lack of homogeneity is also going to induce all undesirable properties in the hardened concrete.

A well made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of waters makes a cohesive mix. Such concrete will not exhibit any tendency for segregation. The cohesive and fatty characteristics of matrix do not allow the aggregate to fall apart, at the same time, the matrix itself is sufficiently contained by the aggregate. Similarly, water also does not find it easy to move out freely from the rest of the ingredients.

The conditions favorable for segregation are, , the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation. Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation.

When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades, concrete shows a tendency for segregation. Conveyance of concrete by conveyor belts, wheel barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete. Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. It too wet a mix is excessively vibrated, it is likely that the concrete gets segregated.

A cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation. The use of air- entraining agent appreciably reduces segregation. Segregation is difficult to measure quantitatively, but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test or the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

Bleeding

Bleeding is sometimes referred as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding. Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel and floats, the aggregate goes down and the cement and water come up to the top surface. This formation of cement paste at the surface is known as Laitance. Water while traversing from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

While the mixing water is in the process of coming up, it may be intercepted by aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste. The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by revibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations.

Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement.Bleeding is an inherent phenomenon in concrete. All the same, it can be reduced by proper proportioning and uniform and complete mixing. The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding.

Method of Test for Bleeding of Concrete

This method covers determination of relative quantity of mixing water that will bleed from a sample of freshly mixed concrete A cylindrical container of approximately 0.01 m^3 capacity, having an inside diameter of 250 mm and inside height of 280 mm is used. A tamping bar similar to the one used for slump test is used. A pipette for drawing off free water from the surface, a graduated jar of 100 cm^3 capacity is required for test.

A sample of freshly mixed concrete is obtained. The concrete is filled in 50 mm layer for a depth of 250 ± 3 mm (5 layers) and each layer is tamped by giving strokes, and the top surface is made smooth by trowelling.

The test specimen is weighed and the weight of the concrete is noted. Knowing the total water content in 1 m^3 of concrete quantity of water in the cylindrical container is also calculated. The cylindrical container is kept in a level surface free from vibration at a temperature of 27°C ± 2°C. it is covered with a lid. Water accumulated at the top is drawn by means of pipette at 10 minutes interval for the first 40 minutes and at 30 minutes interval subsequently till bleeding ceases. To facilitate collection of bleeding water the container may be slightly tilted. All the bleeding water collected in a jar.

$$\text{Bleeding water percentage} = \frac{\text{Total quantity of bleeding water}}{\text{Total quantity of water in concrete}} \times 100$$

4.Explain the properties of fresh and hardened concrete?

PROPERTIES OF FRESH CONCRETE

The fresh concrete or plastic concrete is the initial stage of concrete period and it is counted from the mixing stage till it is transported, placed, compacted and finished in the position. The fresh concrete must satisfy the following requirements. Ideal Requirements of Fresh Concrete

i. Mixability

The mix should be able to produce a homogeneous and uniform fresh concrete from the constituent materials of each batch under the action of mixing forces.

ii. Stability

The mix should be stable meaning thereby it should not segregate during transporting and placing and also the tendency of the bleeding should be minimum.

iii. Mobility/Flowability

The mix should be mobile enough to surround all reinforcement without leaving any voids behind as well as to completely fill the formwork.

iv. Compactability

The mix should be amenable to proper and thorough minimum compaction into a dense compact concrete under the existing facilities of compaction at site.

v. Finishability

It should be able to obtain a uniform and satisfying surface finish.

PROPERTIES OF HARDENED CONCRETE

The concrete is a basic prime building material because of various properties being possessed during its hardened state which starts from the day it attains the full designed strength to the end of its life. For hardened concrete, the various properties which need consideration are as follows.

(A) STRENGTH

a. Compressive strength

b. Tensile strength

c. Flexural strength

d. Shear strength

e. Bond strength

(B) Durability

(C) Impermeability

(D) Dimensional Changes

(a) Elasticity

(b) Shrinkage

(c) Creep

(d) Thermal expansion

(e) Fatigue

(E) Fire Resistance

STRENGTH OF CONCRETE

The strength of concrete is the most important property as far as structural designs are concerned. Indirectly, it gives the idea of other properties (Impermeability, durability, wear resistance etc) also. A strong concrete is more dense, compact, impermeable and resistant to weathering and chemical attacks. Meaning thereby, the strength of concrete gives an overall idea of its quality. Strength of concrete is defined as the ability to resist force and for structural purposes, it is taken as the unit force required to cause rupture which may be caused by compressive stress, tensile stress, flexural stress, shear stress, bond stress etc.

Compressive Strength of Concrete

The compressive strength of concrete is considered the basic character of the concrete.Consequently, it is known as the **characteristic compressive strength of concrete (fck)** which is defined as that value below which not more than five percent of test results are expected to fall based on IS: 456-2000. In this definition the test results are based on 150 mm cube cured in water under temp. of 27 ± 2°C for 28 days and tested in the most saturated condition under direct compression.

Other strength viz, direct tensile stress, flexural stress, shear stress and bond stress also are directly proportional to the compressive stress. Higher is the compressive stress, higher is other stresses also. Not only stresses, other properties for example modulus of elasticity, abrasion and impact resistances, durability are also taken to be related to the compressive strength, hence, the compressive strength is an index of overall quality of concrete.

Factors Affecting Compressive Strength

Among the materials and mix variables, **water -cement ratio** is the most important parameter governing the compressive strength. Besides W/C ratio, following factors also affect the compressive strength.

- The characteristics of cement.
- The characteristics and properties of aggregates.
- The degree of compaction
- The efficiency of curing
- Age at the time of testing.
- Conditions of testing.

Water -Cement Ratio

The water -cement ratio, defined as the ratio of the mass of free water (i.e. excluding that absorbed by the aggregate) to that of cement in a mix, is the most important factor that controls the strength and many other properties of concrete. In practice, this ratio lies generally in the range of 0.35 to 0.65, although the purely chemical requirement (for the purpose of complete hydration of cement) is only about 0.25. The compressive strength of concrete at a given age and under normal temperature, depends primarily on w/c ratio; lower the w/c ratio, greater is the compressive strength and vice versa. This was first enunciated by Abrams as S = where S is the compressive strength, w/c is water -cement ratio of a fully compacted concrete mix, K 1 and K 2 are empirical constants.

In day- to-day practice, the constants K 1 and K2 are not evaluated, instead the relationship between compressive strength and w/c ratio are adopted which are supposed to be valid for a wide range of conditions. Effect of water - cement ratio on compressive strength at different ages. A reduction in the water cement ratio generally results in an increased quality of concrete in terms of strength, density, impermeability, reduced shrinkage and creep etc.

The probable reason, why lower w/c ratio gives higher strength of concrete may be found by considering the cement forms a paste with water and it is this paste that binds the different particles of aggregates. So thicker is the consistency of the paste, greater is its binding property. Another reason is that the quantity of water required for chemical combi-nation is very small (about 25% of the weight of cement) compared with that required for workability and the excess water ultimately on evaporation leaves pores.

The greater is the excess of water, greater is loss of strength and water - tightness. The tensile strength and bond strength with steel do not decrease with increase in w/c ratio to the same extent as compressive strength does. Say with increase in w/c ratio from 0.5 to 0.6, the decrease in tensile strength and bond strength is 10% but decrease in compressive strength is about 25%.

Characteristics and properties of cement

The type of cement and fineness of cement affect the strength of concrete. With respect to Ordinary Portlord cement (OPC), Rapid Hardening Portland Cement (RHPC) and Low Heal Portland Cement (141-1PC) give higher and lower strength respectively. The rate of gain of strength depends entirely upon fineness of the cement. Finer cement increases the rate of hydration And hydrolysis which results in early development of strength though the ultimate strength is not affected.

Characteristics And Properties Of Aggregates

The strength of concrete is governed by

- strength of aggregate
- strength of mortar
- bond strength between mortar and aggregate

The strength of aggregate is normally greater than the strength of mortar and bond between mortar and aggregate. The strength of mortar depends upon w/c ratio whereas bond between mortar and aggregate depends upon the strength of mortar and the size, shape, texture and grading of aggregate. Larger maximum size of coarse aggregate gives lower compressive strength of concrete. The reasons behind may be stated as follows. The larger maximum size aggregate gives lower surface area for development of gel bond which is responsible for lower strength. Aggregates of smaller size, angular aggregate and aggregate of rough surface texture provides more surface area and more consumption of cement and hence more bond strength. Bigger aggregate size causes a more heterogeneity in the concrete and this prevents uniform distribution of load when stressed. For larger size aggregate the transition zone becomes much weaker due to development of micro cracks which result in lower compressive strength.

The degree of compaction

Higher is the compaction of freshly mixed concrete, more is the reduction of the voids and consequently greater is the compressive strength of concrete.

The efficiency of curing

Curing is the name given to procedures used for promoting the hydration of cement, and consist of a control of temperature and of the moisture movement from and into the concrete.

Hydration of cement takes place in capillaries filled with water.

By keeping concrete saturated, loss of water by evaporation from the capillaries is prevented and loss of water by self desiccation (due to the chemical reactions of hydration of cement) from outside.

Cuing should be continued until the originally water filled space in the fresh cement paste has been filled by product of hydration to the desired extent. Curing temperature should be from 23° to 30°C (27°C average).

The curing must be adequate at favorable temperature for sufficient period which helps in attaining the maximum strength and other desirable properties. Age of Concrete The strength of concrete increases with age as the hydration of cement prolongs for a considerable time.

Conditions of Testing

After adequate curing, the concrete mould is tested in the moist saturated condition with surface wiped out under direct compression. The strength of concrete is influenced by moisture content at the time of testing, because moisture content in concrete provides lubrication effect and reduces the strength when compared with dry sample.Strength in dry sample = 1.10 to 1.20 times the strength of the saturated sample.

Strength of Prism Vs 150 mm Strength

The characteristic strength of concrete (fck) is based on 150 mm cube but if it is tested on the prism mould, the strength of prism specimen decreases with increase in height to the side ratio and stabilizes when this ratio is 5. Variation in Strength with Size of Cubes The characteristic strength of concrete is based on 150mm cube but the strength of concrete determined through the cube specimen varies with the size of cubes.

The strength of specimen increases with decrease in size and vise -versa as indicated in the Cube (150 mm) Strength Vs Cylinder (150 mm dia, 300 mm ht)

Strength If the concrete is tested on cylinder having 150 mm diameter and height 300 mm instead of 150 mm cube, the cube strength can be estimated as Cylinder strength (fcu) = 0.80 * cube strength (fck)

TENSILE STRENGTH

• Tensile strength of concrete under direct tension is very small and generally neglected in normal design practice. Although the value ranges from 8 to 12% of its compressive strength. An average value 10% is the proper choice. The direct tension method suffers the problem like holding the specimen properly in the testing machine and the application of uniaxial tensile load not being free of eccentricity.

• The tensile strength can be calculated indirectly by loading a concrete cylinder to the compressive force along the two opposite ends (with its axis horizontal)

• Due to uniform tensile stress acting horizontally along the length of cylinder, the cylinder splits into two halves. The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by

S = 2 where; S = Tensile stress in kg/cm 2 P = load causing rupture in kg

D = Dia in cm (15 cm)

L = Length in cm (30 cm)

• The indirect tensile stress is known as SPLITTING TENSILE STRENGTH.

FLEXURAL STRENGTH

The maximum tensile stress resisted by the plain concrete in flexure (bending) is called FLEXURAL STRENGTH (or MODULUS OF RUPTURE) expressed in N/mm 2 or kg/m ^{2} .

• The moste common plain concrete subjected to flexure is a highway/runway pavement. The strength of pavement concrete is evaluated by means of bending test on beam specimen.

• The flexural strength (modulus of rupture) is determined by testing standard test specimens of 150 mm x 150 mm x 700 mm over a span of 600 mm or 100 mm x 100 mm x 500 mm over a span of 400 min. under symmetrical two point loading

SHEAR STRENGTH

• Shear strength is the capacity of concrete to resist the sliding of the section over the adjacent section. A good amount of shear strength capacity is possessed by concrete depending upon the grade of concrete and percentage of tensile reinforcement in the section.

• It is difficult to obtain shear strength of concrete but I.S. code suggests the value for different grade of concrete.

BOND STRENGTH

• Bond strength is the shear stress at the interface of reinforcement bar and surrounding concrete developed to resist any force that tries slippage of the reinforcement to its surrounding concrete. It is determined by PULL OUT TEST . The av. bond strength is 10% of compressive strength of concrete The bond strength depends upon grade of concrete, higher the grade, higher is the value of bond strength.

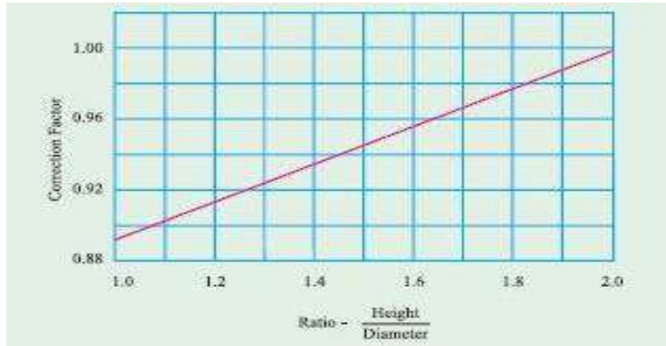
5) Explain in detail about the determination of Compressive and Flexural strength of concrete.

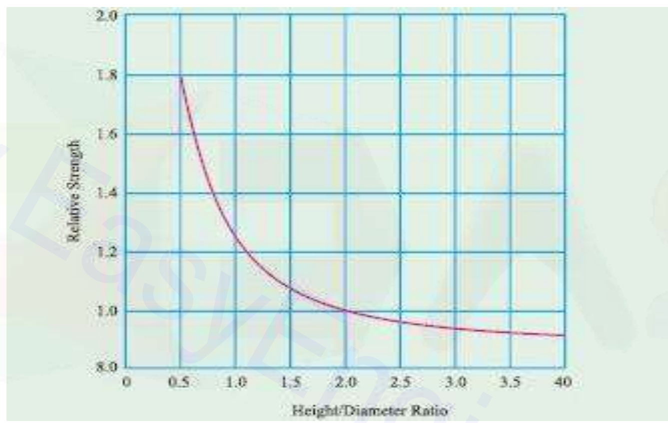
Compression Test

Compression test is the most common test conducted on hardened concrete,partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.The cube specimen is of the size 15 x 15 x 15 cm. If the largest nominal size of the aggregate does not exceed 20 mm, 10 cm size cubes may also be used as an alternative. Cylindrical test specimens have a length equal to twice the diameter. They are 15 cm in diameter and 30 cm long. Smaller test specimens may be used but a ratio of the diameter of the specimen to maximum size of aggregate, not less than 3 to 1 is maintained.

Failure of Compression Specimen

Due to compression load, the cube or cylinder undergoes lateral expansion owing to the Poisson‘s ratio effect. The steel platens do not undergo lateral expansion to the some extent that of concrete, with the result that steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel platens of the testing machine. It has been found that the lateral strain in the steel platens is only 0.4 of the lateral strain in the concrete. Due to ths the platen restrains the lateral expansion of the concrete in the parts of the specimen near its end. The degree of restraint exercised depends on the friction actually developed. When the friction is eliminated by applying grease, graphite or paraffin wax to the bearing surfaces the specimen exhibits a larger lateral expansion and eventually splits along its full length. With friction acting i.e., under normal conditions of test, the elements within the specimen is subjected to a shearing stress as well as compression. The magnitude of the shear stress decreases and the lateral expansion increases in distance from the platen. As a result of the restraint, in a specimen tested to destruction there is a relatively undamaged cone of height equal to $\sqrt{3}/2$ d . But if the specimen is longer than about 1.7 d, a part it of will be free from the restraining effect of the platen. Specimens whose length is less than 1.5 d, show a considerably higher strength than those with a greater length.





Effect of the Height/Diameter Ratio on Strength :

Normally, height of the cylinder —h� is made twice the diameter —d�, but sometimes, particularly, when the core is cut from the road pavements or airfield pavements or foundations concrete, it is not possible to keep the heigh/diameter ratio of 2:1. The diameter of the core depends upon the cutting tool, and the height of the core will depend upon the thickness of the concrete member. If the cut length of the core is too long. It can be trimmed to h/d ratio of 2 before testing. But with too short a core, it is necessary to estimate the strength of the same concrete, as if it had been determined on a specimen with h/d ratio equal to 2.

High strength concrete is less affected than the low strength concrete. Figure shows the influence of h/d ratio on the strength of cylinder for different strength levels.

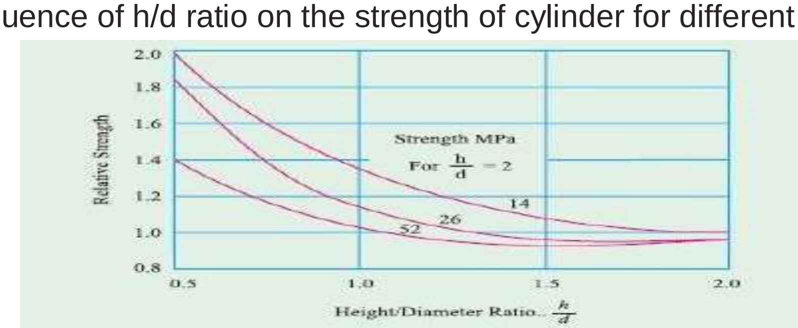


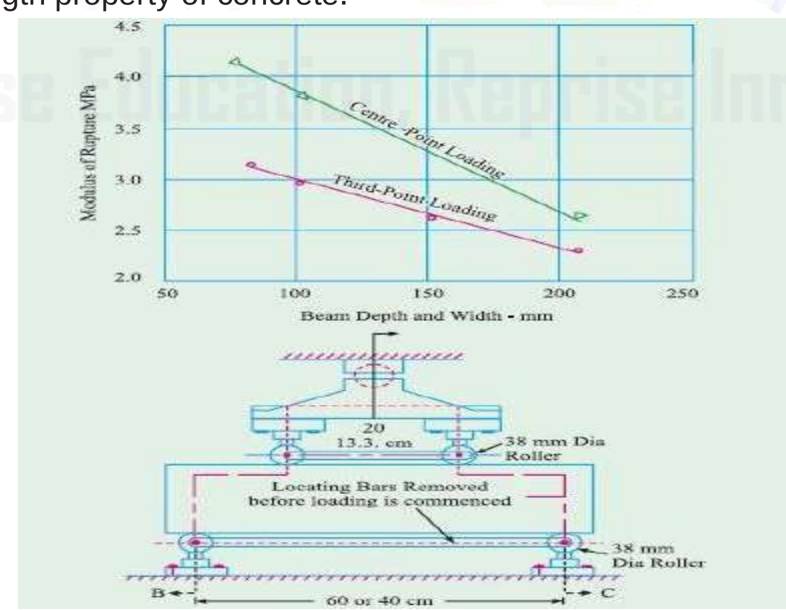
Figure shows the general pattern of influence of h/d ratio on the strength of cylinder. It is interesting to note that the restraining effect of the platens of the testing machine extends over the entire height of the cube but leaves unaffected a part of test cylinder because of greater height. It is, therefore, the strength of the cube made from identical concrete will be different from the strength of the cylinder. Normally strength of the cylinder is taken as 0.8 times the strength of the cube, but experiments have shown that there is no unique relationship between the strength of cube and strength of cylinder. It was seen that the strength relation varies with the level of the strength of concrete. For higher strength, the difference between the strength of cube and cylinder is becoming narrow. For 100 MPa concrete the ratio may become nearly 1.00.

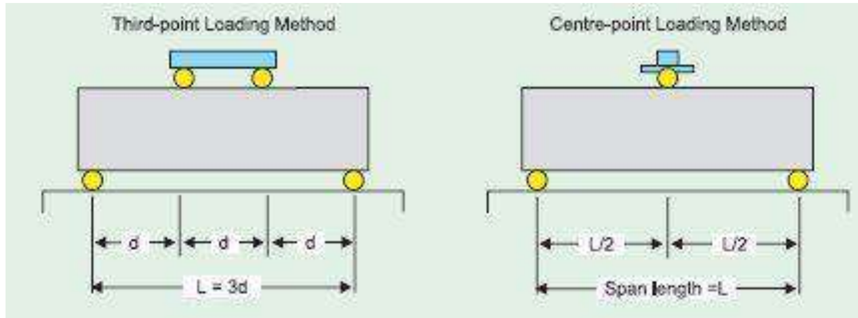
The Flexural Strength of Concrete :

Concrete is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons.

Determination of Tensile Strength :

Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the pull applied to the concrete. While a number of investigations involving the direct measurement of tensile strength have been made, beam tests are found to be dependable to measure flexural strength property of concrete.





Procedure :

Test specimens are stored in water at a temperature of 24° to 30°C for 48 hours before testing. They are tested immediately on removal from the water whilst they are still in a wet condition. The dimensions of each specimen should be noted before testing. No preparation of the surfaces is required.

Placing the Specimen in the Testing Machine :

The bearing surfaces of the supporting and loading rollers are wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers. The specimen is then placed in the machine in such a manner that the load is applied to the uppermost surface as cast in the mould, along two lines spaced 20.0 or 13.3 cm apart. The axis of the specimen is carefully aligned with the axis of the loading device. No packing is used between the bearing surfaces of the specimen and the rollers. The load is applied without shock and increasing continuously at a rate such that the extreme fibre stress increases at approximately 0.7 kg/sq cm/min that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.

The load is increased until the specimen fails, and the maximum load applied to the specimen during the test is recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure is noted.

The flexural strength of the specimen is expressed as the modulus of rupture fb which if ‗a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, is calculated to the nearest 0.05 MPa as follows:

$$f_b = \frac{P \times l}{b \times d^2}$$

When ‗a' is greater than 20.0 cm for 15.0 cm specimen or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = \frac{3p \times a}{b \times d^2}$$

when ‗a‘ is less than 20.0 cm but greater than 17.0 cm for 15.0 specimen, or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen where

b = measured width in cm of the specimen,
d = measured depth in cm of the specimen at the point of failure,
l = length in cm of the span on which the specimen was supported, and
p = maximum load in kg applied to the specimen.

If ‗a‘ is less than 17.0 cm for a 15.0 cm specimen, or less than 11.0 cm for a 10.0 cm specimen, the results of the test be discarded.

As mentioned earlier, it is difficult to measure the tensile strength of concrete directly. of late some methods have been used with the help of epoxy bonded end pieces to facilitate direct pulling. Attempts have also been made to find out direct tensile strength of concrete by making briquette of figure shape for direct pulling but this method was presenting some difficulty with grip and introduction of secondary stresses while being pulled. Whatever may be the methods adopted for finding out the ultimate direct tensile strength, it is almost impossible to apply truly axial load. There is always some eccentricity present. The stresses are changed due to eccentricity of loading.

These may introduce major error on the stresses developed regardless of specimen size and shape. The third problem is the stresses induced due to the grips. There is a tendency for the specimen to break near the ends. This problem is always overcome by reducing the section of the central portion of the test specimen. The method in which steel plates are glued with the epoxies to the ends of test specimen, eliminates stresses due to griping, but offers no solution for the eccentricity problem. All direct tension test methods require expensive universal testing machine.

5. Explain in detail about the determination of Young's Modulus and Stress-strain curve for concrete.

When reinforced concrete is designed by elastic theory it is assumed that a perfect bond exists between concrete and steel. The stress in steel is m times the stress in concrete

where

m is the ratio between modulus of elasticity of steel and concrete, known as modular ratio.

The accuracy of design will naturally be dependent upon the value of the modulus of elasticity of concrete, because the modulus of elasticity of steel is more or less a definite quantity. The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxial compression and measuring the deformations by means of dial gauges fixed between certain gauge length. Dial gauge reading divided by gauge length will give the strain and load applied divided by area of crosssection will give the stress. A series of readings are taken and the stress-strain relationship is established.The modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formulae for deflection and substituting other parameters.

The modulus of elasticity so found out from actual loading is called static modulus of elasticity. It is seen that even under short term loading concrete does not behave as an elastic material. However, up to about 10-15% of the ultimate strength of concrete, the stress-strain graph is not very much curved and hence can give more accurate value. For higher stresses the stress-strain relationship will be greatly curved and as such it will be inaccurate

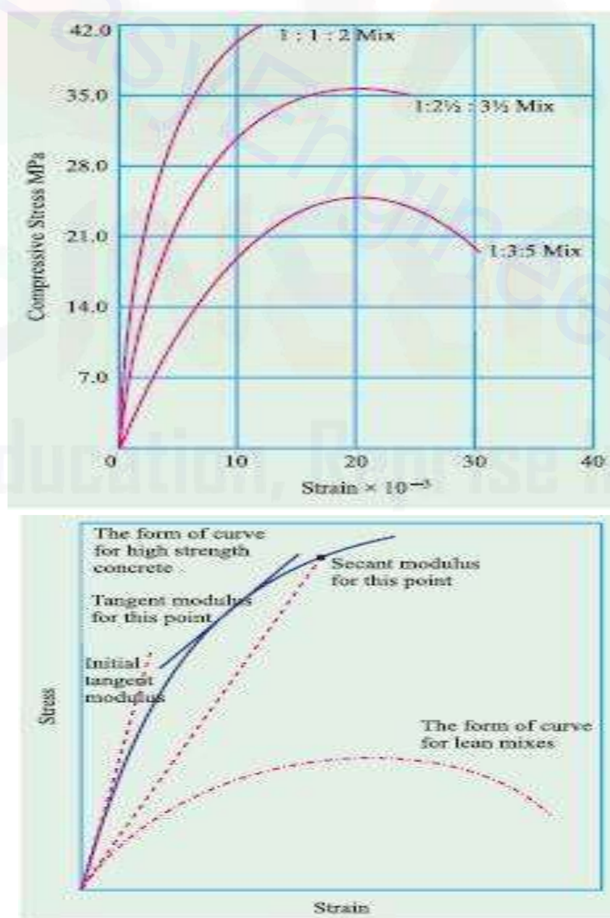


Figure shows stress strain relationship for various concrete mixes.

In view of the peculiar and complex behaviour of stress-strain relationship, the modulus of elasticity of concrete is defined in somewhat arbitrary manner. The modulus of elasticity of concrete is designated in various ways and they have been illustrated on the stress-strain curve in Fig.

The term Young‘s modulus of elasticity can strictly be applied only to the straight part of stress-strain curve. In the case of concrete, since no part of the graph is straight, the modulus of elasticity is found out with reference to the tangent drawn to the curve at the origin.

The modulus found from this tangent is referred as initial tangent modulus. This gives satisfactory results only at low stress value. For higher stress value it gives a misleading picture. Tangent can also be drawn at any other point on the stress-strain curve. The modulus of elasticity calculated with reference to this tangent is then called tangent modulus. The tangent modulus also does not give a realistic value of modulus of elasticity for the stress level much above or much below the point at which the tangent is drawn. The value of modulus of elasticity will be satisfactory only for stress level in the vicinity of the point considered.

A line can be drawn connecting a specified point on the stress-strain curve to the origin of the curve. If the modulus of elasticity is calculated with reference to the slope of this line, the modulus of elasticity is referred as secant modulus. If the modulus of elasticity is found out with reference to the chord drawn between two specified points on the stress-strain curve then such value of the modulus of elasticity is known as chord modulus. The modulus of elasticity most commonly used in practice is secant modulus. There is no standard method of determining the secant modulus. Sometime it is measured at stresses ranging from 3 to 14 MPa and sometime the secant is drawn to point representing a stress level of 15, 25, 33, or 50 per cent of ultimate strength. Since the value of secant modulus decreases with increase in stress, the stress at which the secant modulus has been found outshould always be stated.

Modulus of elasticity may be measured in tension, compression or shear. The modulus in tension is usually equal to the modulus in compression. It is interesting to note that the stress-strain relationship of aggregate alone shows a fairly good straight line. Similarly, stress-strain relationship of cement paste alone also shows a fairly good straight line. But the stress-strain relationship of concrete which is combination of aggregate and paste together shows a curved relationship. Perhaps this is due to the development of micro cracks at the interface of the aggregate and paste. Because of the failure of bond at the interface increases at a faster rate than that of the applied stress, the stress-strain curve continues to bend faster than increase of stress. Figure shows the stress-strain relationship for cement paste, aggregate and concrete.

Hardened Concrete

Lecture No. 14

Strength of Concrete

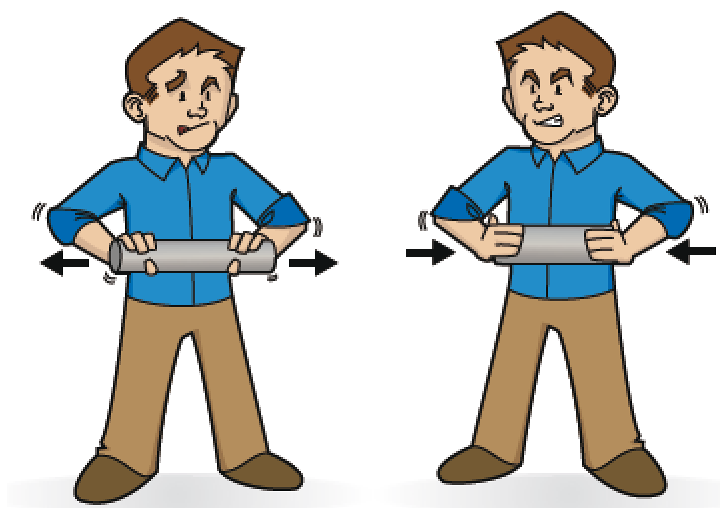
- Strength of concrete is commonly considered its most valuable property, although in many practical cases, other characteristics, such as durability and permeability may in fact be more important.

- Strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste.

- Strength of concrete could be defined as the ultimate load that causes failure (or is its resistance to rupture) and its units are force units divided by area (N/mm^2).

Strength of Concrete

- Characteristic strength - Compressive, Tensile and Flexure strength
- Modulus of Elasticity
- Creep and shrinkage of concrete



THE THREE S-WORDS

Stress: a weight or load applied to the concrete (in N)

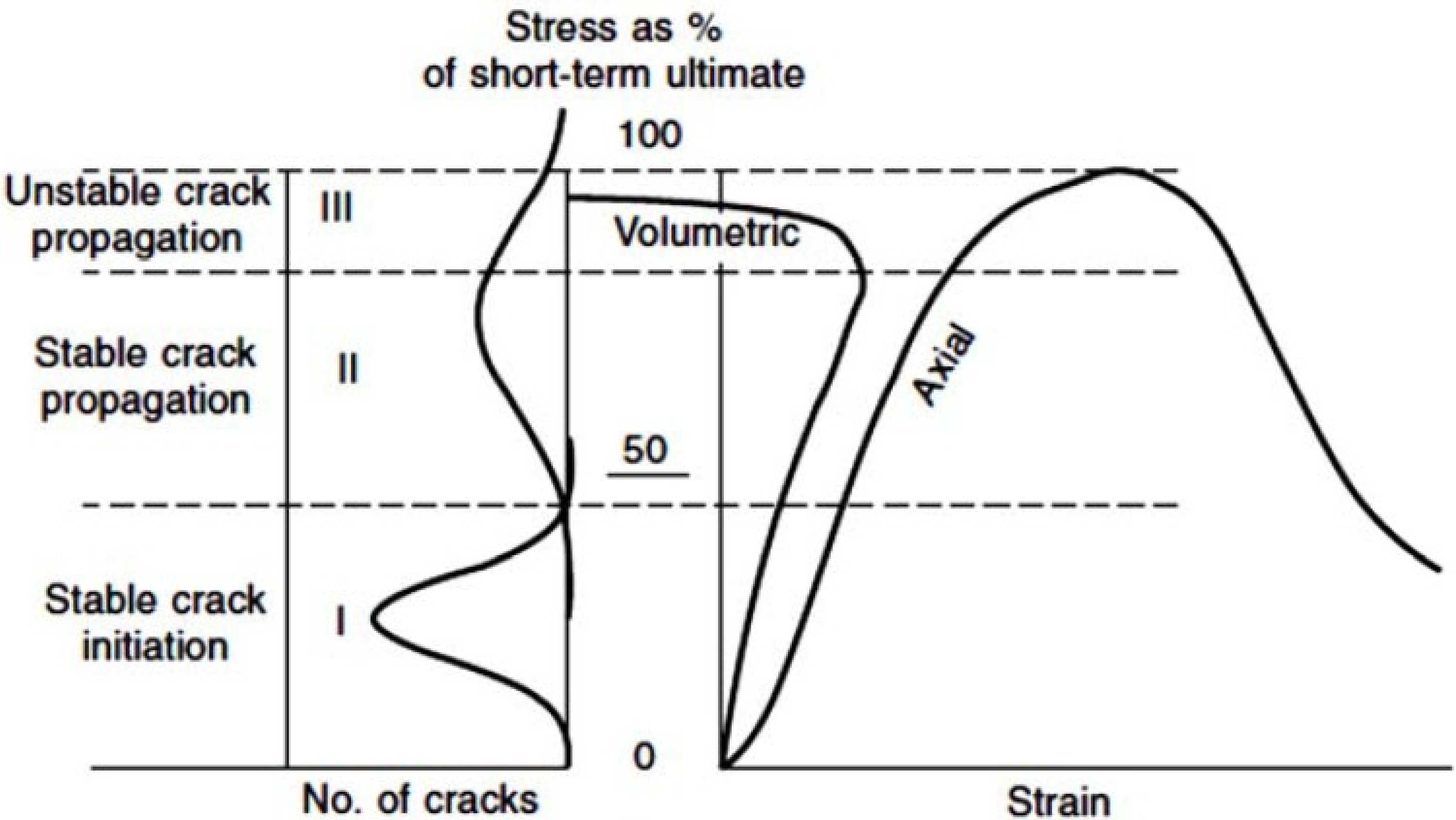
Strength: the concrete's ability to carry the weight or load (in N per square mm)

Strain: how much the concrete stretches or compresses (deforms) when carrying a load (in inches per mm)

Fracture and failure

- Concrete specimens subjected to any state of stress can support loads of up to 40–60% of ultimate without any apparent signs of distress.
- Below this level, any sustained load results in creep strain which is proportional to the applied stress and can be defined in terms of specific creep (i.e. creep strain per unit stress)
- As the load is increased above this level, soft but distinct noises of internal disruption can be heard until, at about 70–90% of ultimate, small fissures or cracks appear on the surface.
- At ultimate load and beyond; the specimens are increasingly disrupted and eventually fractured into a large number of separate pieces.

The stages of cracking (fracture) in concrete:



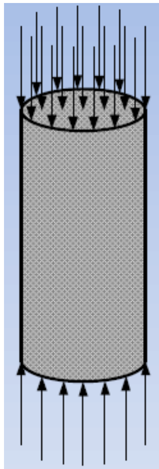
Types of Concrete Strength

- Compressive strength
- Tensile strength
- Shear strength
- Bond strength
- Impact strength
- Fatigue strength

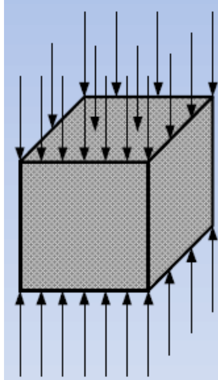
Compressive Strength

- The compressive strength of concrete is defined as the strength of 28 days old specimens tested under monotonic uniaxial compressive load.
- Testing of cylindrical samples with 15 cm diameter and 30 cm height is standard.
- Cube specimens of 15 cm × 15 cm × 15 cm are also being used.
- Normally, the compressive strength of concrete is determined by testing, and the tensile strength and modulus of elasticity are expressed in terms of the compressive strength.

Compressive Strength

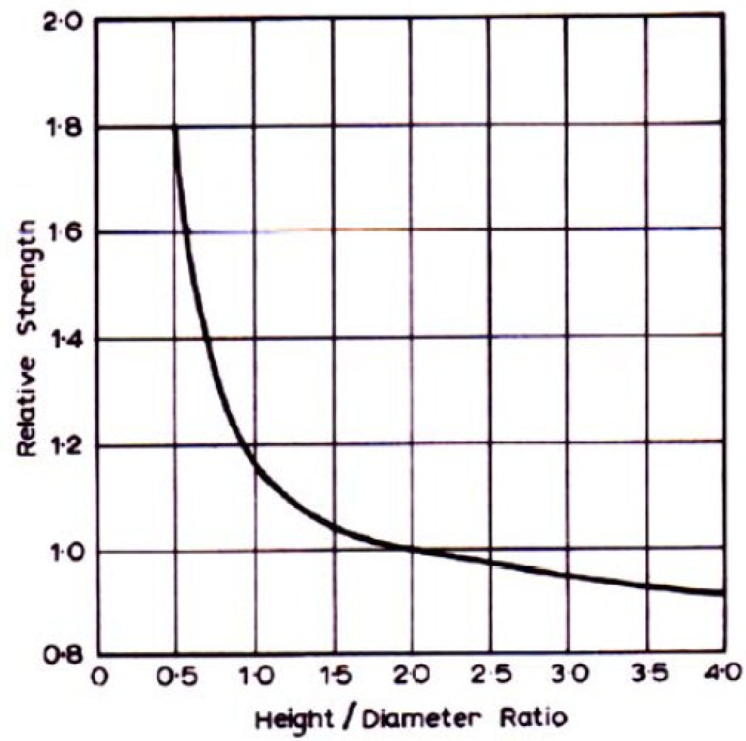


Cylinder Specimen



Cube Specimen

$$(f_c)_{cylinder} = (0.85 - 0.80)(f_c)_{cube}$$



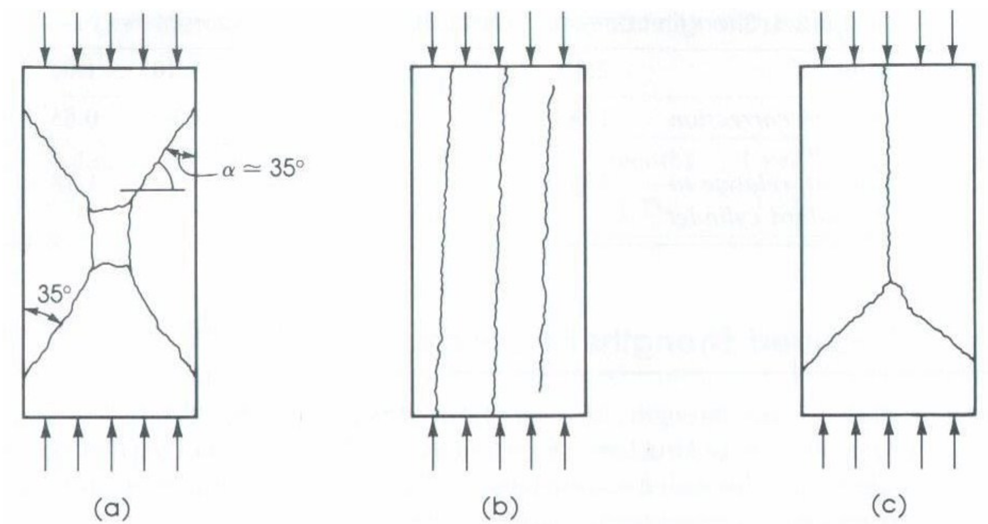
Compressive Strength

- There are three failure modes for cylinders.

a) Under axial compression concrete fails in shear.

b) The separation of the specimen into columnar pieces by what is known as splitting or columnar fracture.

c) Combination of shear and splitting failure.



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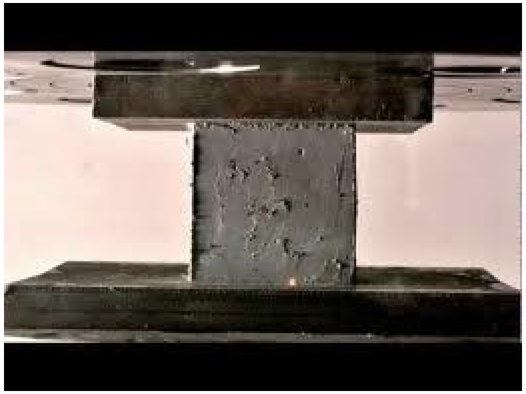
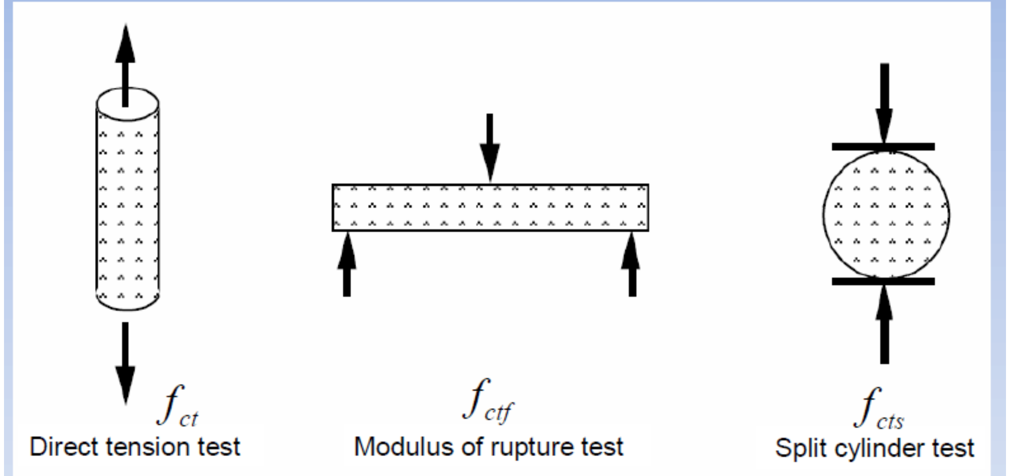
Compressive Strength



Tensile Strength of Concrete

- The tensile strength of concrete is much lower than the compressive strength, largely because of the ease with which cracks can propagate under tensile loads
- The tensile strength of concrete is measured in three ways: direct tension, splitting tension, and flexural tension



$$f_{ctf} > f_{cts} > f_{ct}$$

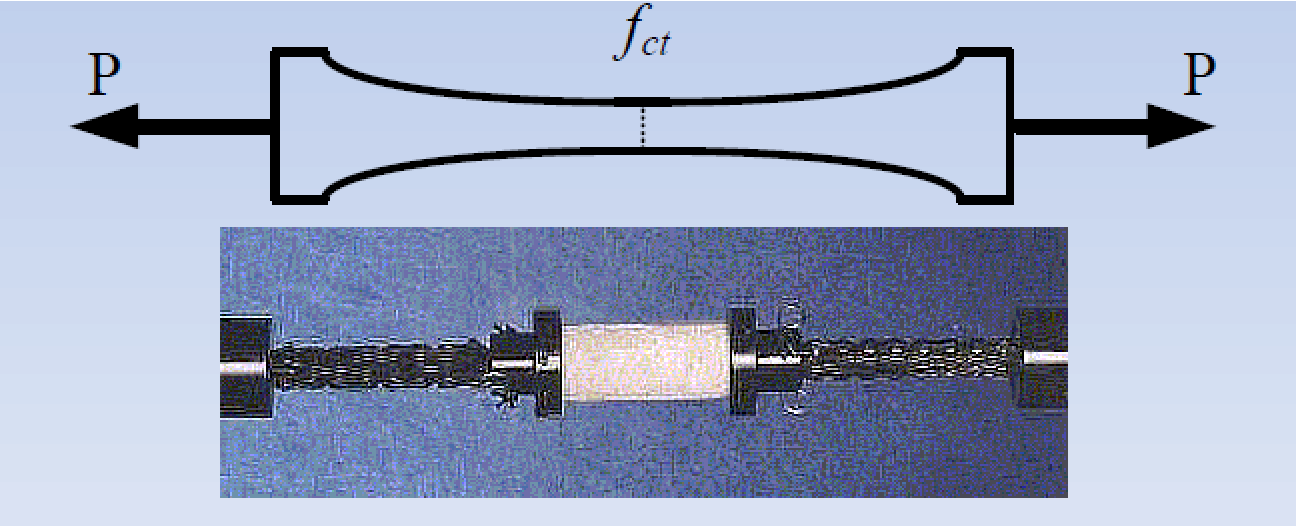
Tensile Strength of Concrete

- It is difficult to test concrete in direct (uniaxial) tension because of the problem of gripping the specimen satisfactorily and because there must be no eccentricity of the applied load. Therefore, direct tensile test is not standardized and rarely used

- Modulus of rupture test and splitting test are commonly used to determine the tensile strength of concrete

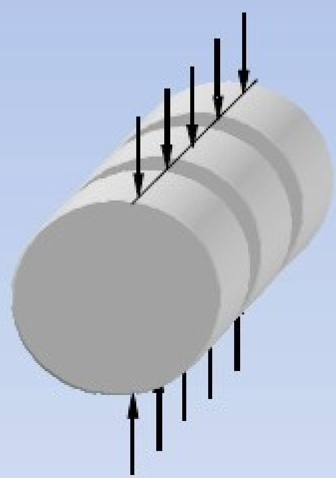
Tensile Strength of Concrete

- Direct-Tension Test:
  - The most direct way of measuring the tensile strength.
  - Not a practical test.

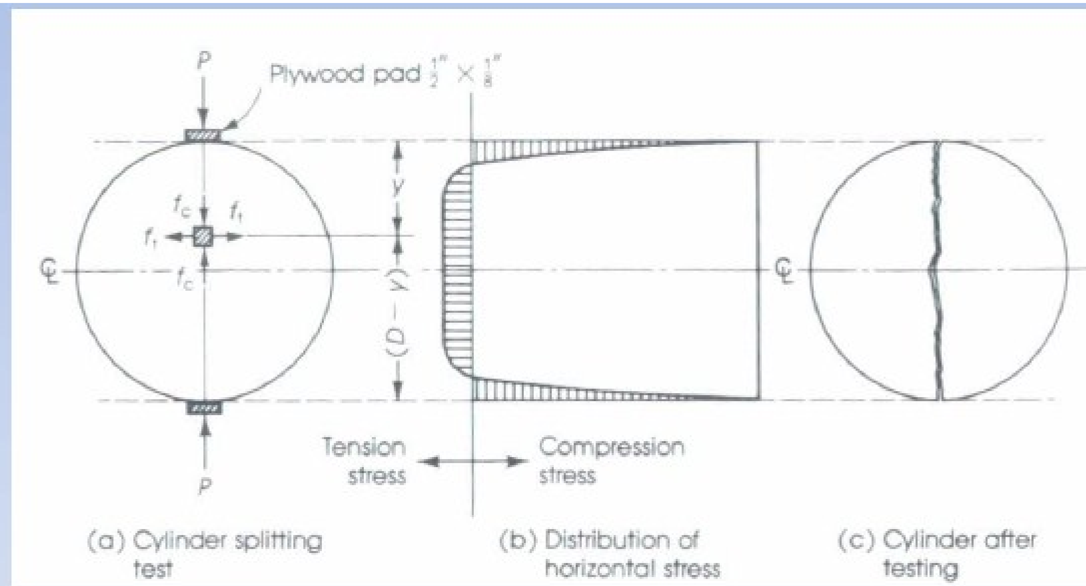


Tensile Strength of Concrete

- Split-Cylinder Test:

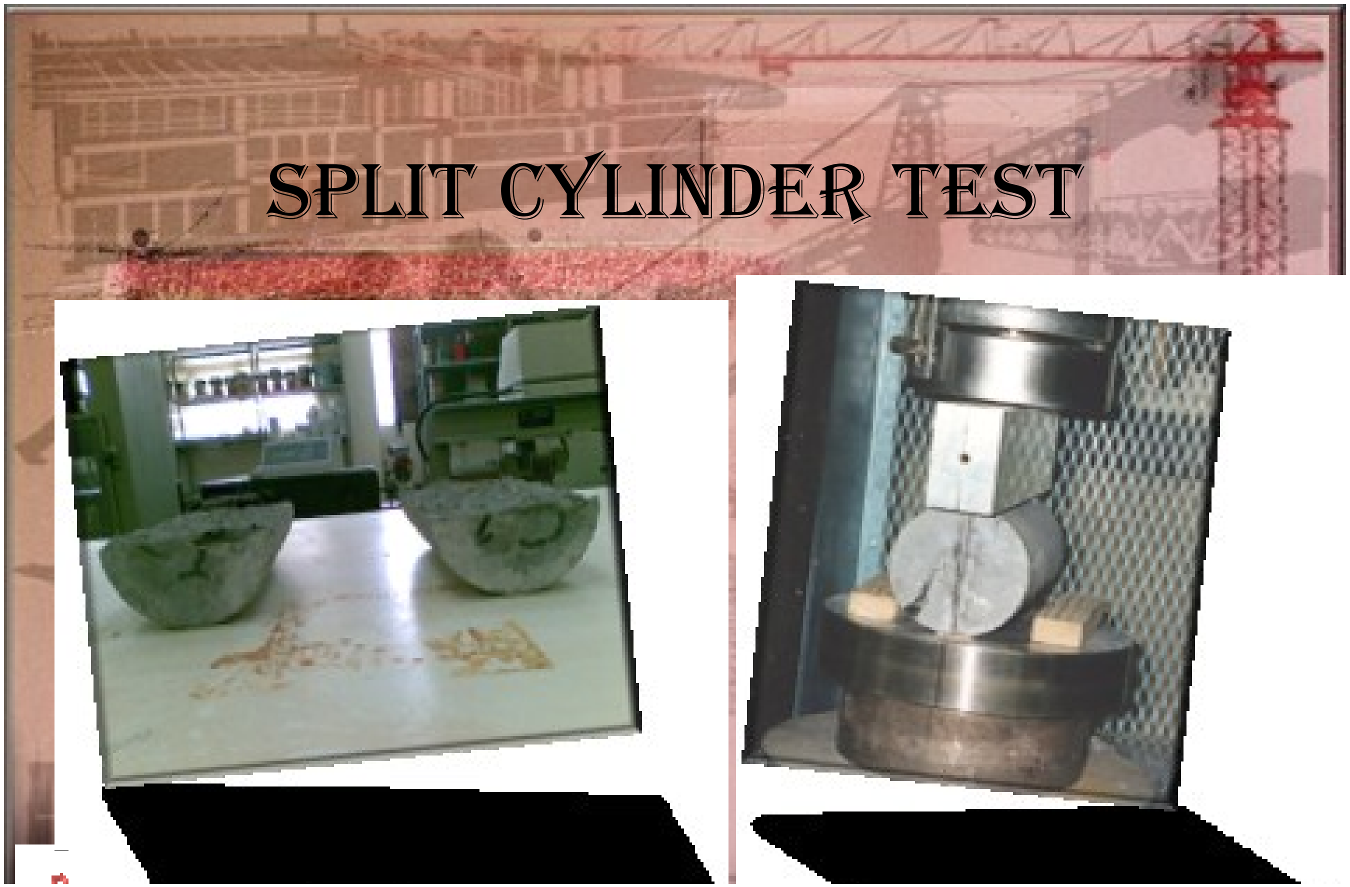


15cm × 30cm cylinder specimen



$$f_{cts} = \frac{2P}{\pi L D}$$

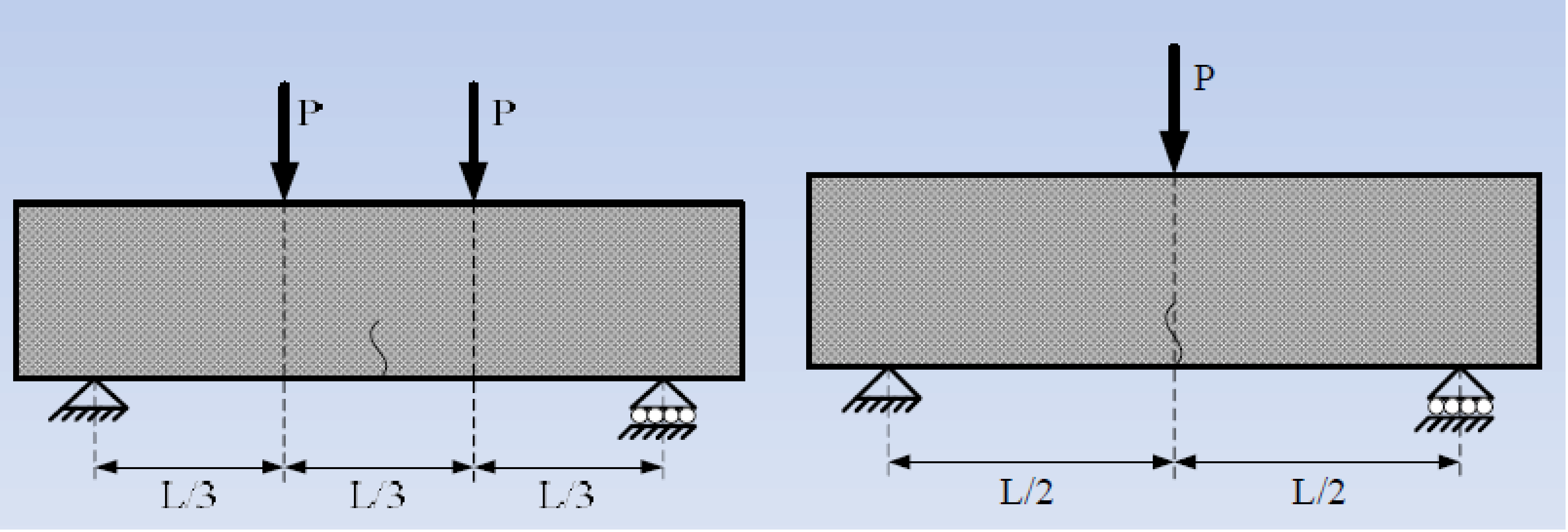
Tensile Strength of Concrete



Tensile Strength of Concrete

- Modulus of Rupture Test:
- Four-point bending (two-point loading)
- Three-point bending (third point loading)

$$f_{ctf} = \frac{6M}{b \cdot h^2}$$



Relationship Between Compressive and Tensile Strength of Concrete

- Tensile strength of concrete is proportional to the square-root of the compressive strength.
- The proportionality constant depends on many factors, such as the concrete strength and the test method used to determine the tensile strength.
- The following relations can be used as a rule of thumb:

$$\text{Direct tensile strength}: f_{ct} = 0.35\sqrt{f_c} \quad (f_c \text{ in MPa})$$

$$\text{Split tensile strength}: f_{cts} = 0.50\sqrt{f_c} \quad (f_c \text{ in MPa})$$

$$\text{Flexural tensile strength}: f_{ct} = 0.64\sqrt{f_c} \quad (f_c \text{ in MPa})$$

Concrete Strength

- Shear Strength
- Shear strength of concrete is taken approximately equal to 20 % its compressive strength
- Bond Strength
- The strength of bond between steel reinforcement and concrete is called as bond strength of concrete
- Bond strength develops primarily due to friction and adhesion between steel reinforcement and concrete
- In general, bond strength is approximately proportional to the compressive strength of concrete up to about 20 MPa

Concrete Strength

- Impact Strength
- Impact strength of concrete is of importance in driving concrete piles, in foundations for machines exerting impulsive loading, and also when accidental impact is possible, e.g. when handling precast concrete members
- There is no unique relation between impact strength and other strengths of concrete.
- However, some researchers have found that impact is related to the compressive strength, and it has been suggested that the impact strength varies from 0.50 to 0.75 of the compressive cube strength

Concrete Strength

- Fatigue Strength
- The strength of concrete against cyclic or repeated loading is called as its fatigue strength

Bond. The term 'bond' in reinforced concrete design refers to the adhesion between concrete and steel which resist the slipping of steel bar from the concrete.

The main assumption in the theory of reinforced concrete design is that there is a perfect bond of reinforcement with concrete. This bond develops due to shrinkage of concrete on drying. Without this bond, the reinforcement will not serve any purpose to arrest the widening of cracks in the tension zone.

To achieve increased bond between steel and concrete the following factors should be kept in view :

(*i*) Use rich mix of concrete.

(*ii*) The compaction and curing of concrete should be perfect.

(*iii*) Provide sufficient cover for reinforcement.

(*iv*) Use rough surface steel bars.

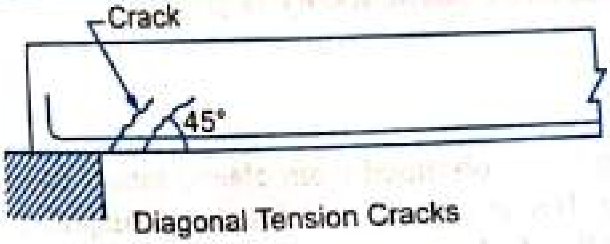
(*v*) Use deformed or twisted bars.

11.1. INTRODUCTION

Shear force is present in beams where there is a change in bending moment along the span. It is equal to the rate of change of bending moment. An exact analysis of shear in a reinforced concrete beam is quite complex. The various modes of cracks (failure) which could occur due to possible combination of shear and bending moment acting at a given section are as follows :

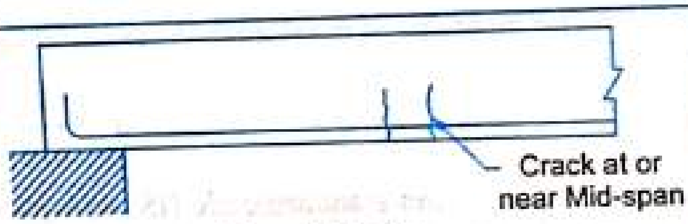
1. Diagonal tension cracks
2. Flexural cracks
3. Diagonal compression cracks
4. Flexure-shear cracks.

1. Diagonal Tension Cracks. These types of cracks occur when magnitude of shear force is large in relation to bending moment. Such cracks are normally at 45° with the horizontal and generally occur near the supports (Fig. 11.1).



Diagonal Tension Cracks

Fig. 11.1

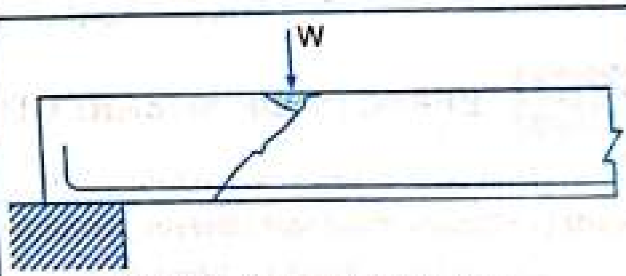


Flexural Cracks

Fig. 11.2

2. Flexural Cracks. These types of cracks occur when bending moment is large in relation to the shear force. Such cracks are normally at 90° with the horizontal at or near the mid-span (Fig. 11.2).

3. Diagonal Compression Cracks. These types of cracks take place by crushing of concrete in the compression zone near the point load as the diagonal crack formed independently penetrates in that zone (Fig. 11.3).



Diagonal Compression Cracks

Fig. 11.3

Shear reinforcement is essentially provided to prevent formation of cracks and failure of the beam due to shear. To guard against diagonal compression failure, the code has fixed the upper limit for maximum allowable shear stress in a member.

4. Flexure Shear Cracks. Sometimes, in between the supports and mid-span the cracks inclination vary from 45° to 90° gradually (Fig. 11.4).

Fig. 11.4

Prevention of cracks. The cracks can be prevented by providing reinforcement for diagonal tension. Reinforcement provided to avoid such cracks is called *shear reinforcement*. Shear reinforcement can be provided in any of the following forms :

(*i*) In the form of stirrups (vertical or inclined)
(*ii*) In the form of bent-up bars
(*iii*) Combination of (*i*) and (*ii*).

11.2. SHEAR STRESS IN R.C.C. BEAMS

In reinforced concrete beam, the concrete below the neutral axis is neglected and shear force is assumed to be resisted by the bond between the steel and the concrete. Hence shear stress in a R.C.C. beam increases from zero at the top face of the beam to its maximum value at the neutral axis. It remains uniform from neutral axis to the C.G. of the reinforcing bars (Fig. 11.5).

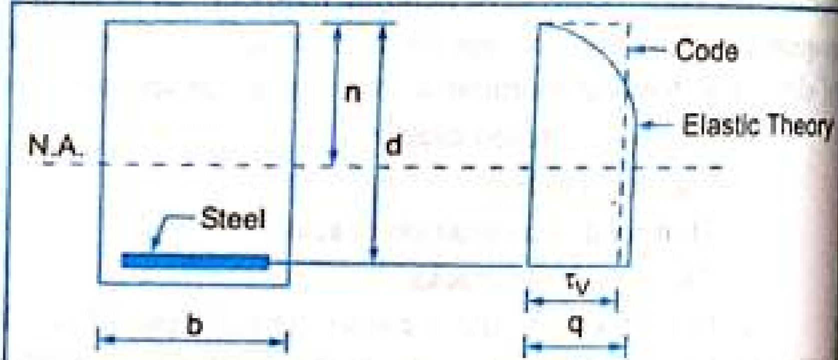


Fig. 11.5

The intensity of maximum shear stress (q) obtained from elastic theory is given by

$$q = \frac{V}{bjd} \quad \text{...(i)}$$

As per Indian standard code (IS: 456-2000), shear stress obtained from elastic theory does not represent the true behaviour of the R.C.C. beam in shear. Hence equation (*i*) has been simplified. IS code recommends the use of nominal shear stress (τ_v) for R.C.C. beams.

$$\tau_v = \frac{V}{bd}$$

where V = Shear force in beam at critical section.

11.4. CRITICAL SECTIONS FOR SHEAR DESIGN

The critical sections are those where the shear force is maximum and/or the cross-sectional area is minimum.

As per IS: 456-2000, the critical sections for shear design are :

(*i*) At a distance '*d*' (effective depth of beam) from the face of the support where the support offers a compressive reaction Fig. 11.7 (*a*).

(*ii*) At the face of the support where the support offers a tensile reaction [Fig. 11.7 (*b*)].

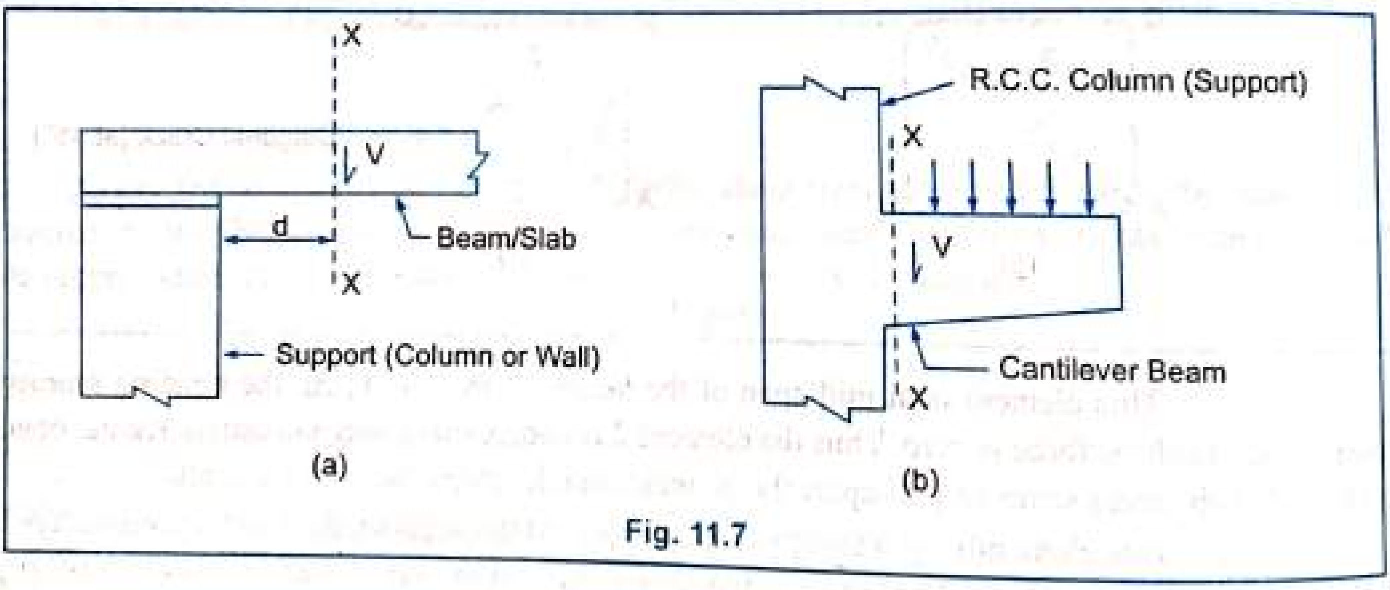


Fig. 11.7

11.5. NOMINAL SHEAR STRESS

In IS: 456-2000 the equation for shear stress $q = \frac{V}{bjd}$ has been simplified by dropping the lever arm factor (j) and by changing the term shear stress (q) by the term nominal shear stress (τ_v).

The formula for calculating nominal shear stress in beams or slabs of **uniform depth** specified in the code is

$$\tau_v = \frac{V}{bd}$$

where τ_v = Nominal shear stress

V = Shear force in beam at critical section

b = Breadth of the member

(For flanged sections, $b = b_w$ = Breadth of web)

d = Effective depth.

Nominal shear stress in beams of uniform width and **varying depth** (*e.g.* cantilever beams, footings etc.) is calculated as

$$\tau_v = \frac{V \pm \frac{M \tan \beta}{d}}{bd}$$

where V, b, d and τ_v has same meaning as above.

M = Bending moment at the section

β = Angle between the top and 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 and the positive sign when bending moment decreases in this direction.

11.6. SHEAR STRENGTH OF CONCRETE

Shear strength of concrete is to be considered in design. For beams, the shear strength of concrete varies according to the grade of concrete and the percentage of tension steel. The shear strength of concrete increases with the increase in the grade of concrete. Higher the grade, higher is the shear strength. The shear strength of concrete also increases with the increase in area of tensile reinforcement A_s.

Now as per calculated value of p and grade of concrete used, the value of designed shear strength of concrete can be obtained from Table-11.1. Table-11.1 shows the designed shear strength of concrete in beams without shear reinforcement.

For calculating shear strength of concrete, first find p.

$$p = \frac{100A_s}{bd}$$

where

p = Percent area of longitudinal steel

A_s = Area of tensile reinforcement which continues, atleast one effective depth beyond the section under consideration

b = Width of the beam

d = Effective depth of beam.

TABLE-11.1
Design Shear Strength of Concrete (τ_c)

$p = \frac{100A_s}{bd}$	Design Shear Strength of Concrete (τ_c) in N/mm² For Various Grades of Concrete					
	M 15	M 20	M 25	M 30	M 35	M 40 and above
≤ 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 & above	0.71	0.82	0.92	0.96	0.99	1.01

Note. A_s is the area of reinforcement which continues, atleast one effective depth beyond the section under consideration. At support, full area of tension steel may be used.

Solid Slabs. Shear strength of concrete for solid slabs shall be $k \times \tau_v$, where k has the valu given in Table-11.2.

TABLE-11.2

Overall Depth of Slab in 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

11.7. MAXIMUM SHEAR STRESS ($\tau_{c,\,max}$)

When nominal shear stress (τ_v) exceeds the shear strength of the concrete (τ_c), shear reinforcement is to be provided. But the nominal shear stress (τ_v) shall not exceed $\tau_{c,\,max}$. To prevent the possibility of cracking of concrete in the web of a member, the values of maximum shear stress in concrete are limited as given in Table-11.3. If $\tau_v < \tau_{c,\,max}$ then the section is to be redesigned, *i.e.*, the dimensions of the beam are to be changed so that τ_v become less than $\tau_{c,\,max}$.

TABLE-11.3
Maximum Shear Stress in Concrete ($\tau_{c,\,max}$)

Grade of Concrete	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

11.8. MINIMUM SHEAR REINFORCEMENT (NOMINAL SHEAR STEEL)

When nominal shear stress (τ_v) is less than or equal to shear strength of concrete (τ_c), no shear reinforcement is required to be designed. However, under such circumstances, minimum shear reinforcement (nominal shear steel) shall be provided as follows :

$$\frac{A_{sv}}{bS_v} \geq \frac{0.4}{0.87 f_y}$$

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 web of flanged beam

f_y = Characteristic strength of stirrup reinforcement, which shall not be greater than 415 N/mm².

The values given in Table-11.4 may be adopted for f_y.

TABLE-11.4

Characteristic Strength of Stirrup Reinforcement (f_y)

Steel	f_y (N/mm²)
Mild steel (Fe 250)	250
Fe 415 grade	415
Fe 500 grade	415

Note. Actual f_y value of Fe 500 grade steel is 500 N/mm², but the value is limited to 415 N/mm² (∵ Research has shown that shear stress greater than 415 N/mm² is not developed in shear reinforcement before failure).

Why Nominal Shear Steel (Minimum Shear Reinforcement) is Provided ?

Nominal shear steel is necessary to :

(i) guard against any sudden failure of a beam if concrete cover bursts and the bond to the tension steel is lost.

(ii) prevent brittle shear failure which can occur without shear steel.

(iii) prevent failure that can be caused by tension due to shrinkage and thermal stresses and internal cracking in the beam.

(iv) hold the reinforcement in place while pouring concrete.

(v) act as effective ties for the compression steel and make them effective.

Maximum Spacing of Stirrups.

Maximum spacing of vertical stirrups shall be **least** of the following :

(i) 0.75 d

(ii) 300 mm.

CRACKS IN CONCRETE

AND

ITS REMEDIAL MEASURES

CONTENT

SR. NO.	DESCRIPTION
1.	Introduction
2.	Classification of cracks
3.	Types of cracks
4.	Causes of crack and its remedies

"Cracks can be treated as cancer in R.C.C structure, as cancer which in its primary stage is curable to a certain extent but becomes danger to life in later stage; same happens with cracks"

"Prevention is better than cure"; prevention of cracks in concrete is better than repair.

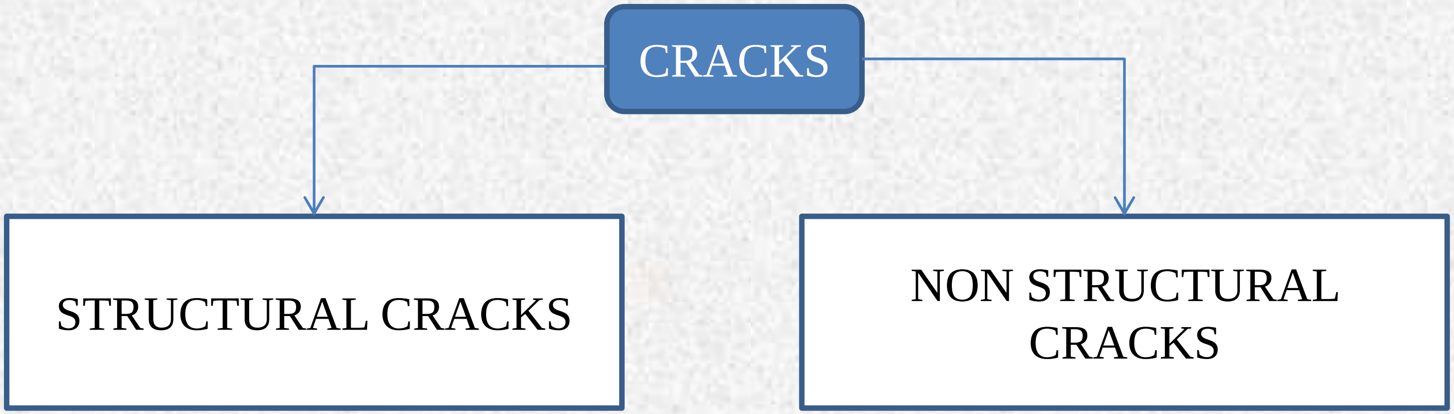
INTRODUCTION

- A crack is a complete or incomplete separation of concrete into two or more parts produced by breaking or fracturing.

- Cracking are early indications of failure of structure. It is vital to note that concrete does crack and this is usual. What is not normal is too much of cracks.

- Cracks affects the building artistic and it also destroys the wall’s integrity, affects the structure’s safety, even reduces the durability of structure.

CLASSIFICATION OF CRACKS



Due to :

- Incorrect design
- Faulty construction
- Overloading

Due to :

- Internal stress in building materials

TYPES OF CRACK BASED ON HARDENING OF CONCRETE

Before hardening

- Plastic
- Constructional movement

After hardening

- **Physical**
  - -Drying shrinkage
  - -crazing
- **Chemical**
  - -Corrosion of reinforcement
  - -Alkali aggregate reactions
- **Thermal**
  - -freeze/ thaws cycle
  - -Temperature variations
  - -Early thermal contradiction
- **Structural**
  - -Creep
  - -overloading

CAUSES OF CRACKS AND ITS REMEDIES

PLASTIC SHRINKAGE CRACKING

- It arises when the rate of evaporation of water from top layer of freshly laid concrete is greater than bleed water provided by underlying concrete, due to this surface concrete contracts.
- Due to the restraint shown by the concrete below the drying surface concrete layer the tensile stresses are develop in the weak and stiffening plastic concrete.
- These cracks usually are parallel to one another and are spaced 0.3m to 1m apart. These cracks may be as much as 5cm to 10cm in depth and up to 3mm in width.

- Plastic shrinkage cracking occur due to:

Temperature of air above concrete is high.
Low relative humidity .
Wind velocity above concrete is high.

- Preventive measures of plastic shrinkage include use of:

Styrene Butadiene latex co-plymer	as bonding agent
Fog nozzles	to saturate the air above concrete
Plastic sheeting	to cover concrete
Windbreaks	to decrease the wind velocity

DRYING SHRINKAGE

- After hardening, concrete starts drying. The excess water leaves the system causing contraction or shrinkage. This excess water, called water of convenience would have been added to get adequate workability and finish.

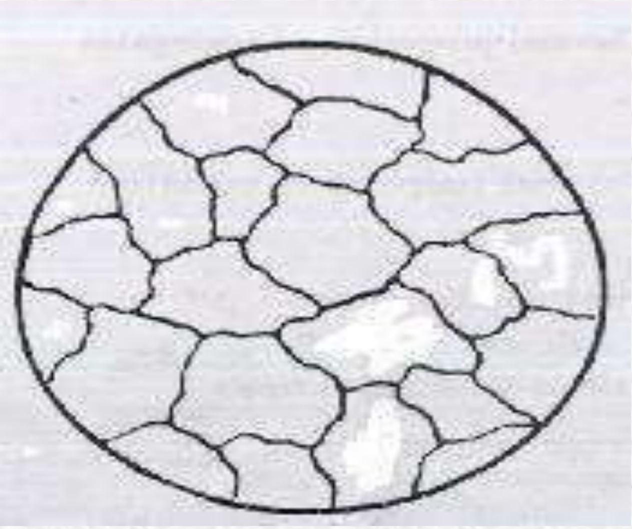
- The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume.

Smaller size of aggregate } more shrinkage
finer gel

➢ **PREVENTIVE MEASURES** :

- Rigid formwork.
- Use of acrylic polymer for crack filling and tile joint filling by mixing along with white cement.
- Leak proof formwork.
- Use of screed vibrator and float for surface finishing.
- Use of a ‘rich” concrete mix (400 kg/m^3 binder, W/C = 0.4) should be encouraged.

CONCRETE CRAZING



- Crazing is the development of a network of fine random cracks or fissures on the surface of concrete caused by shrinkage of the surface layer.

- These cracks are rarely more than 3mm deep, and are more noticeable on over floated or steel-troweled surfaces.

- **CAUSES** :

- Poor or inadequate curing.
- Intermittent wet curing and drying.
- Excessive floating
- Excessive laitance on surface.
- Finishing with float when bleed water is on the surface.
- Sprinkling cement on the surface to dry up the bleed water.

- **PREVENTIVE MEASURE :**

- Proper and early start of curing.
- Use of curing compound on the surface.
- Never sprinkle dry cement or a mixture of cement and fine sand on the surface of the plastic concrete.

THERMAL VARIATIONS

- Temperature difference within a concrete structure may be caused by portions of the structure losing heat of hydration at different rates at one portion of the structure to a different degree or at a different rate than another portion of the structure.

- These temperature differences result in differential volume change, leading to cracks.

- The more massive is the structure, the greater is the potential for temperature differential and restraint. Hardened concrete has a coefficient of thermal expansion that may range from 4 to 9 x 10^{-6} per deg. F.

➢ PREVENTIVE MEASURES:

- Controlling the rate at which the concrete cools by insulating the exposed concrete surface during first 5 days.
- Increasing the tensile strength of concrete.
- Reducing the concrete temperature at placement up to say 32 ˚C.
- Using low heat of hydration cement or using fly ash replacement of part of cement.
- Keeping steel formwork warm by air heating during winter.
- Use of thermally insulating material as formwork.
- Low grade of cement, OPC 33 grade is the best.

CRACKING DUE TO CHEMICAL REACTION

- Deleterious chemical reactions may cause cracking of concrete, due to materials used to make the concrete or materials that come into contact with the concrete after it has hardened.

- Concrete may crack with time as the result of slowly developing expansive reactions between aggregate containing active silica and alkalis derived from cement hydration, admixtures or external sources.

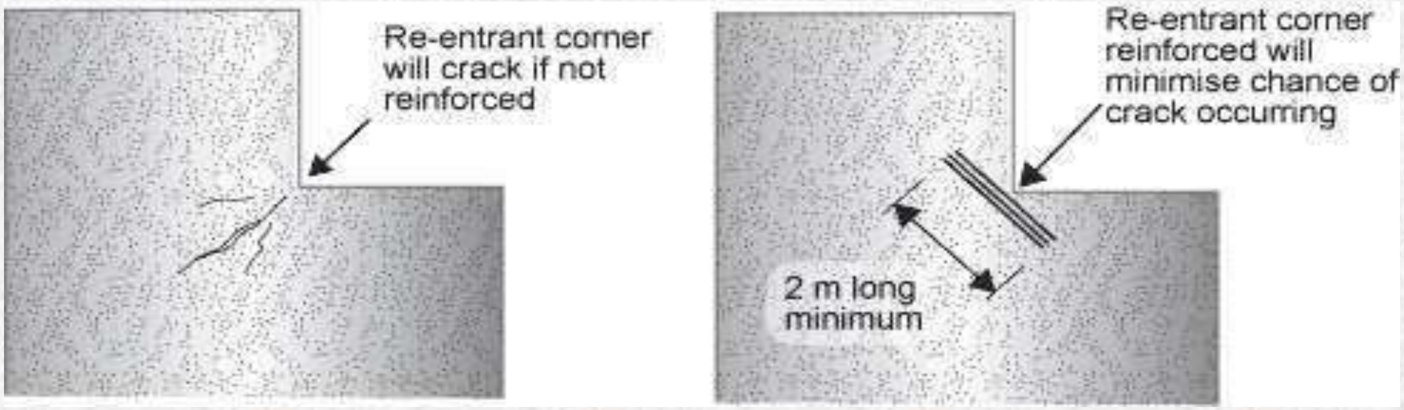
Alkali – silica reaction → Formation of gel pores → Local expansion

- **<u>PREVENTIVE MEASURES</u>:**

- Proper selection of aggregate – it should be innocuous to alkalinity.
- Cement with low alkalinity (preferably less than 0.5, IS:456 limit is 0.6).
- Use of Pozzolanas (like fly ash and blast furnace slag) which themselves contain very fine highly active silicon.

ERRORS IN DESIGN AND DETAILING

- Poorly detailed re entrant corners in walls, precast members and slabs.
- Restraint to members subjects to volume changes caused by variations in temperature and moisture.
- Lack of adequate contraction joints.
- Improper design of foundations resulting in differential movement within the structure.



WEATHERING

- It includes freezing and thawing, wetting and drying and heating and cooling.
- Damage due to freezing and thawing is the most common weather related to physical deterioration.
- Damage in hardened cement paste from freezing is caused by the movement of water to freezing sites and by hydraulic pressure generated by growth of ice crystal.

➢ **PREVENTIVE MEASURE** :

- Use of lowest practical water cement ratio and total water content
- Durable aggregate
- Adequate air entrainment
- Allowing structure to dry after curing

POOR CONSTRUCTION PRACTICE

- **Some poor construction practices that results in cracking are** :

- Adding water to improve workability
- Lack of curing
- Inadequate formwork support
- Inadequate compaction
- Placement of construction joints at high stress

➢ **PREVENTIVE MEASURES:**

- Proper monitoring and use of good quality of materials is required at the time of construction

STRUCTURAL OVERLOADS

- Concrete gets damaged due to structural overload which are very easy to detect. Precast member like beam and are generally subjected to this type of load.

- Most unfortunate things about cracks is due to structural overload are that cracks are detected at early stages.

➢ **PREVENTIVE MEASURE :**

- These types of cracks can be prevented if designer limit the load on structure .

FOUNDATION MOVEMENT AND SETTLEMENT OF SOIL

Shear cracks in buildings occur when there is large differential settlement of foundation and it may be either due to the following reasons:

- Unequal bearing pressure under different parts of the structure
- Bearing pressure on soil being in excess of safe bearing strength of the soil
- Low factor of safety in the design of foundation
- Local variation in the nature of supporting soil

➢ **Preventative Measure**:

- The design of foundation should be based on sound engineering principles and good practice.

VEGETATION

- Fast growing trees in the area around the walls can sometimes cause cracks in walls due to expansive action of roots growing under the foundation.
- The cracks occur in clay soil due to moisture contained by roots.

➢ **PREVENTIVE MEASURE:**

- Do not grow trees too close to the building. Remove any saplings of trees as soon as possible if they start growing in or near of walls.

REFRENCES

- Concrete Technology Book By MS Shetty
- Sciencedirect.com
- UltraTech Tech mailer – Issue 05 shrinkage cracks
- International Research Journal of Engineering and Technology (IRJET)
- IS 456 :2000 Plain and Reinforced concrete – code of practice

THANK YOU

Durability of Concrete

Lecture No. 21

Durability of Concrete

- A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service.
- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.
- 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

Durability of Concrete

- Concrete Deterioration can be caused by:
  - The use of inappropriate materials.
  - Poor construction practices.
- Environmental Related Causes of Concrete Durability Problems
  - Temperature.
  - Moisture.
  - Physical factors.
  - Chemical factors.
  - Biological factors.

Durability of Concrete

- These factors may be due to weathering conditions (temperature, and moisture changes), or to abrasion, attack by natural or industrial liquids and gases, or biological agents.
- Durability problems related to environmental causes include the following: steel corrosion, delamination, cracking, carbonation, sulfate attack, chemical attack, scaling, spalling, abrasion and cavitation.

Temperature

- Temperature variations will cause changes in the concrete volume. When temperature rises, the concrete slightly expands, and when temperature falls, the concrete contracts.
- Since concrete is usually restrained by foundations, subgrades, reinforcement, or connecting members, volume changes in concrete can produce significant stresses in the concrete. Tensile stresses can cause the concrete to crack

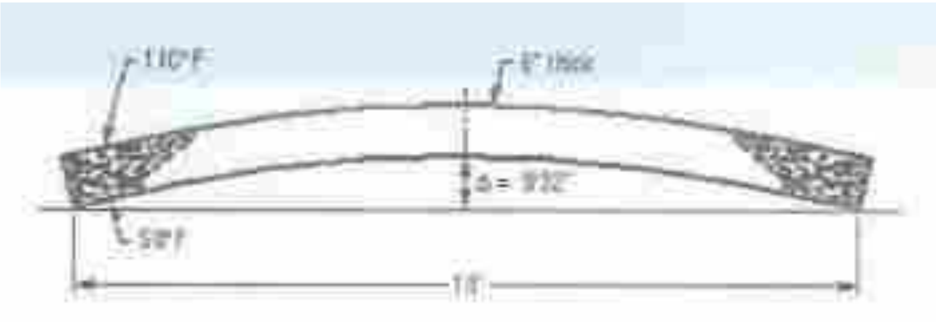


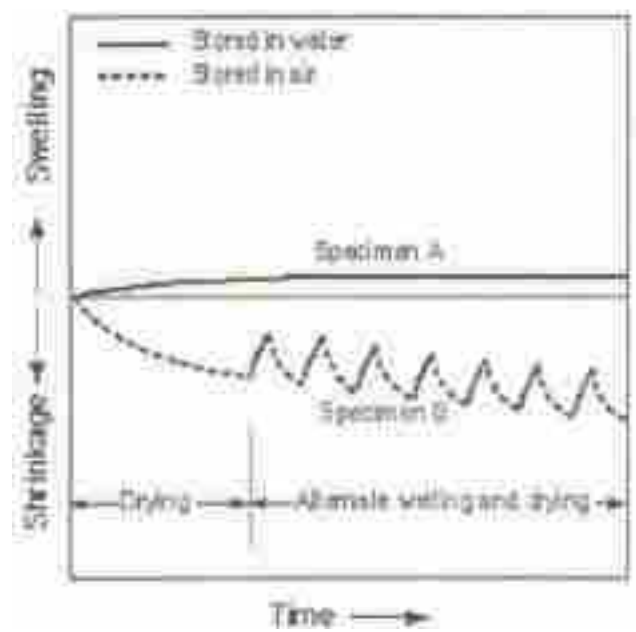
Figure 1. Warping of Concrete due to Temperature Difference

Temperature

- Temperatures greater than 95°C (203°F) can have significant effects on concrete.
- The total volume change in concrete is the sum of the volume changes of the cement paste and aggregates.
- At high temperatures, the cement paste will shrink due to dehydration of the calcium silicate hydrate (C-S-H), while the aggregate will expand.
- Seasonal changes in temperature range up to 50°C (90°F) between the summer and winter. Seasonal temperature changes cause higher stresses than daily temperature changes, and they result in more extensive cracking.

Moisture

- Changes in the moisture content in concrete will result in either concrete expansion or contraction.
- When concrete gains moisture, the concrete will slightly expand or swell. When concrete loses moisture, the concrete will contract or shrink.



Moisture

- Further, wetting and drying of the concrete can cause the concrete to alternately swell and shrink.
- This drying and shrinking of the concrete surface will cause the concrete surface to develop tensile stresses and possible cracks.
- If a section of the concrete is restrained, and if concrete joints are not provided, major random cracks may develop.
- The three main problems with moisture and concrete are as follows:
  - 1)Carbonation, 2)The moisture cycle, 3)Contaminants

Moisture

Moisture : Carbonation

- Carbon dioxide (CO_2) present in the atmosphere reacts in the presence of moisture with the hydrated cement minerals (i.e. the agent usually being the carbonic acid).
- The extent of carbonation depends on the permeability of the concrete and on the concentration of carbon dioxide in the air.
- The penetration of carbon dioxide beyond the exposed surface of concrete is extremely slow.
- The alkaline conditions of hydrated cement paste are neutralized by carbonation. This neutralization, by dropping the pH from over 12 to about 9, affects the protection ofreinforcing steel from corrosion.

Moisture : Moisture Cycles

- Stresses caused by changes in moisture content of the concrete may be additive to stresses caused by temperature changes.
- Tensile stresses usually increase the tendency for cracking, scaling, spalling, and delamination.
- Rapidly fluctuating humidity (up to 70% in one day) can lead to moisture changes in the concrete.
- If the moisture level at the reinforcing steel reaches 60% to 90% and sufficient chlorides are present, the steel will corrode.

Moisture : Moisture Cycles

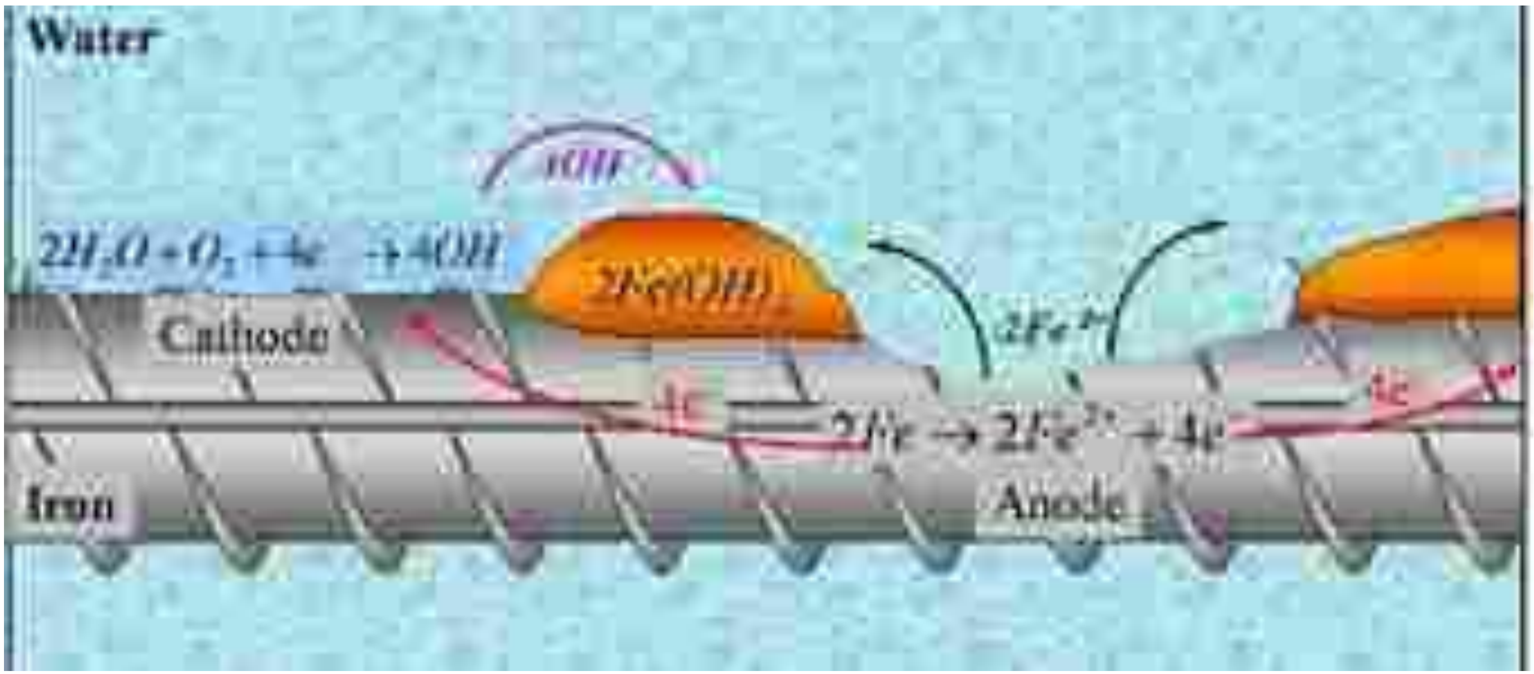
Table 1. Influence of Relative Humidity on the Corrosion of Steel in Concrete

Relative Humidity	Remarks	Corrosion Risk
Concrete sub-merged in water	Capillaries filled with calcium hydroxide solution. Oxygen must diffuse through solution-filled capillaries to steel.	No-corrosion to small risk.
90% to 95%	Pores filled with pore solution through which oxygen must diffuse.	Small to medium risk.
60% to 90%	Pores only partially filled. Water and oxygen reach steel easily.	Great risk.
below 60%	No or very little solution in pores.	No risk.

Moisture : Contaminants

- Contaminants in the water that is absorbed into the concrete may cause staining, steel corrosion, or sulphate attack.
- Contaminants include: chloride and sulphate salts, carbonates, etc.
- Alternate cycles of wetting and drying allow the concentration of salts to increase and thereby increase the severity of their attack.
- An increase in the size of salt crystals in the capillaries near the evaporating surface causes cracking and scaling.
- If the salts are drawn to the surface and deposited at places where water evaporates, efflorescence will occur.

Moisture : Contaminants



Physical Factors

- Under many circumstances, concrete surfaces are subjected to wear. Concrete wear may be caused by the sliding, scraping or impact of objects that fall onto the concrete.
- In hydraulic structures, the action of the abrasive materials carried by flowing water generally leads to erosion of the concrete.
- Another cause of damage to concrete in flowing water is cavitation.
- Abrasion damage to concrete may also be caused by subjecting the concrete to abrasive materials (such as sand) that are carried by wind or water.

Physical Factors

- That abrasion resistance is clearly related to the compressive strength of the concrete.
- Strong concrete has more resistance than weak concrete.
- Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance.
- Hard aggregates are more abrasion resistant than soft aggregates.

Physical Factors

- Concrete that is affected by cavitation has an irregular, jagged, and pitted surface.
- After an initial period of small damage, rapid deterioration will occur. This rapid deterioration is followed by damage to the concrete at a slower rate
- Cavitation can be a problem in any open channel where the velocity of the flowing water is higher than 12 mls . In a closed pipe or conduit, cavitation can occur at velocities as low as 7.5 mls.
- Concretes that have the best resistance to cavitation damage have a high strength, a low water-cement ratio, a small aggregate size that does not exceed 20 mm, and a good paste aggregate bond.

Physical Factors

Physical Factors

Physical Factors

- Fire around concrete structures can weaken the superstructure and decrease the concrete strength tremendously.
- Damage by fire may include total or partial collapse of the structure, distortion, excessive deflection and expansion, buckling of the steel, spalling and shattering of the concrete, discoloration, and reduction of the physical properties of the steel and concrete.
- The effect of increased temperatures on the strength of concrete is small and somewhat irregular below 250°C (482°F).

Physical Factors

Physical Factors

Table 2. Impact of Fire Temperature on Concrete

Temperature	Effect on Concrete
100°C to 250°C (212°F to 482°F)	Normal color, slight loss in compressive strength
250°C to 300°C (482°F to 572°F)	Color changes to pink, strength loss increases
300°C to 600°C (572°F to 1112°F)	Color is pink to red, strength loss continues
Above 600°C (1112°F)	Color changes to black, gray; very little residual strength
About 900°C (1652°F)	Color changes to buff; total loss of strength

Biological Factors

- Concrete may be damaged by live organisms such as plants, sponges, boring shells, or marine borers.
- Mosses and lichens, which are plants of a higher order, cause insignificant damage to concrete.
- These plants produce weak acids in the fine hair roots. The acids that are produced from mosses and lichens will attack the cement paste and cause the concrete to disintegrate and scale.
- In some cases, carbonic acids are produced from plants, such as mosses and lichens, when substances from these plants decompose. The carbonic acid that is produced will attack the concrete.

Biological Factors

Biological Factors

- Marine borers, such as mollusks and sponges, tend to form bore holes into underwater concrete structures.
- Marine borers reduce the concrete's load-carrying capacity as well as expose the concrete's outer reinforcing steel to the corrosive seawater.
- As the degree of interconnection increases, the surface material of the concrete crumbles.
- Disintegration of the surface layer exposes a new substrate of the concrete to the boring sponges. Deterioration of concrete due to a boring sponge attack is relatively slow.

BRITISH STANDARD

BS 1881-208:
1996

Testing concrete —

Part 208: Recommendations for the determination of the initial surface absorption of concrete

ICS 91.100.30

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by Technical Committee B/517, Concrete, to Subcommittee B/517/1, Concrete production and testing, upon which the following bodies were represented:

Association of Lightweight Aggregate Manufacturers
Association of Metropolitan Authorities
British Aggregate Construction Materials Industries
British Cement Association
British Civil Engineering Test Equipment Manufacturers' Association
British Precast Concrete Federation
British Ready Mixed Concrete Association
Building Employers' Confederation
Cement Admixtures Association
Cementitious Slag Makers' Association
Concrete Society
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment
Department of Transport (Highways Agency)
Electricity Association
Federation of Civil Engineering Contractors
Federation of Piling Specialists
Institute of Concrete Technology
Institution of Civil Engineers
Institution of Structural Engineers
Institution of Water and Environmental Management
National House-Building Council
Quality Ash Association
Sand and Grovel Association
Society of Chemical Industry

This British Standard, having been prepared under the direction of the Sector Board for Building and Civil Engineering, was published under the authority of the Standards Board and comes into effect on 15 September 1996

The following BSI references relate to the work on this standard:
Committee reference B/517/1
Draft for comment 95/106828 DC

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Amendments issued since publication

Amd. No.	Date	Comments

Contents

Foreword

This Part of BS 1881 has been prepared by Subcommittee B/517/1. It supersedes clause **6** of BS 1881-5:1970 which has been deleted. All aspects of testing concrete are included as Parts of BS 1881 from sampling fresh concrete to assessing concrete in structures. BS 1881-201:1986 *Guide to the use of non-destructive methods of test for hardened concrete* gives general guidance on the choice of non-destructive test methods and should be consulted for advice on methods which complement the measurement of initial surface absorption or are useful as alternatives.

In this Part of BS 1881, recommendations for surface absorption differ from those in clause **6** of BS 1881-5:1970 in the omission of the requirement for a measurement at 2 h after commencing the test since this is no longer regarded as providing useful additional information in practice. Recommendations on applications, factors influencing results and interpretation is also provided.

The method given in this standard provides a low pressure assessment of the water absorption of the concrete surface. Other tests currently under development involve higher pressures or surface drilling and the results from such tests will be governed by properties of the concrete not necessarily related to surface absorption.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 1881 gives recommendations for a method of determining the initial surface absorption of oven dried concrete, of concrete in the laboratory which cannot be oven dried and of site concrete. Recommendations are given on areas of application of this method and the interpretation of results.

2 References

2.1 Normative references

This Part of BS 1881 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 1881 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

2.2 Informative references

This Part of BS 1881 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 1881 the definitions in BS 6100-6.2 apply together with the following:

3.1
location

region of concrete that is being assessed and that, for practical purposes, is assumed to be of uniform quality

3.2
initial surface absorption

rate of flow of water into concrete per unit area at a stated interval from the start of the test and at a constant applied head

3.3
surface zone

zone of concrete immediately behind the surface

NOTE The thickness of the zone that influences the result of this test may range between a few millimetres and several centimetres depending on the nature and condition of the concrete.

4 Applications

4.1 General

This test method provides data for assessing the uniaxial water penetration characteristics of a concrete surface. The applied pressure of 200 mm head of water is worse than the severest weather exposure in the UK due to driving rain. The results may be considered to be related to the quality of finish and to the durability of the surface under the effects of natural weathering. The results are of little relevance to behaviour under higher water pressures, and cannot be used to assess the permeability of a body of concrete.

This test method can be applied to exposed aggregate or profiled surfaces provided that a watertight seal can be obtained with the apparatus. The test is not applicable to specimens or areas showing obvious porosity, honeycombing or cracking. Misleading results can be obtained when tests are performed on thin concrete sections through which water could penetrate during the test. Tests should not be repeated at positions within an area affected by previous tests.

4.2 Quality control

4.2.1 *Precast concrete*

The test is most reliably applied to precast concrete units which can be tested under standardized dry conditions. Results obtained may be compared with predetermined acceptance limits.

4.2.2 *Cast stone*

Details of recommended acceptance requirements for cast stone are given in BS 1217 on the basis of results obtained by this method.

4.2.3 *In situ concrete*

It is difficult to achieve standardized drying conditions for in situ concrete although generalized classification limits relating to surface weathering characteristics have been proposed which can be applied to in situ test results. The method has been successfully used on this basis to assess compliance with specifications for weathering performance[1].

Combinations of initial surface absorption and cover to reinforcement have been proposed[2].

4.3 Comparability surveys

Since it is sensitive to surface finish as well as to the quality of the concrete in the surface zone, the test provides a means of comparative assessment of these characteristics. With careful interpretation, the test may usefully be applied to in situ concrete construction.

[1] *Permeability testing of site concrete — A review of methods and experience.* Concrete Society Technical Report 31

[2] Levitt.M. The ISAT for limit state design for durability. Concrete. Vol 19, No.7, p 29. July 1985.

5 Factors influencing the initial surface absorption of concrete

Guidance concerning their influence upon the interpretation of results in practical circumstances is given in clause **9**. All the following factors affect the surface absorption of concrete:

a) moisture conditions;

b) concrete mix;

c) aggregate;

d) surface finish and type;

e) curing;

f) age of concrete;

g) cracking (visible cracks should be avoided);

h) water type;

i) temperature.

Although impurities in the water can influence the rate of absorption, this effect may be disregarded provided that the water is of potable quality. However, distilled or de-ionized water shall be used for calibrating the capillary tube (see **7.2**).

6 Apparatus

6.1 *Test assembly,* comprises a watertight cap which is sealed to the concrete surface and connected by means of flexible tubes to a reservoir and a capillary tube with a scale. A control tap is fitted to the connection between the reservoir and cap. A typical test assembly is illustrated in Figure 1.

6.2 *Cap,* of any suitable rigid non-corrodible impermeable material providing a minimum area of water contact with the surface to be tested of 5 000 mm^2.

NOTE It is useful for the cap to be made of a transparent material such as a clear acrylic, polyester or epoxy resin (reinforced if necessary) as this allows the operator to observe the filling of the cap with water and the displacement of the air.

An inlet and an outlet tube are fixed into the cap, the former connecting to the reservoir and the latter to the capillary tube. The outlet is so positioned that it is at the highest part of the cap to allow all trapped air to escape.

A suitable cap for clamping onto horizontal concrete specimens with a relatively smooth surface as illustrated in Figure 2. This has a soft elastomeric gasket to provide a watertight seal. It is possible for the gasket to be glued to the surface of smooth dry laboratory specimens. In cases where either the surface of the concrete is not smooth, or the cap cannot be clamped onto the surface to be tested, the cap should have a knife edge for contact with the concrete. Recommendations for fixing the cap to the test surface is given in **8.2**. A suitable cap for testing vertical or sloping surfaces or soffits is illustrated in Figure 3.

6.3 Connections

6.3.1 ***Inlet.*** The inlet tube to the cap is connected to the reservoir by a flexible tube of sufficient length to enable a head of water between 180 mm and 220 mm above the surface of the concrete under test to be maintained, and is fitted with a tap.

6.3.2 ***Outlet.*** The outlet tube from the cap is connected to the capillary tube by a flexible tube of sufficient length to enable the capillary tube to be set horizontally at a head of water between 180 mm and 220 mm above the surface of the concrete under test.

6.4 *Reservoir,* of glass or plastics material of about 100 mm diameter.

6.5 *Capillary tube and scale.* A length of precision bore glass capillary tubing at least 200 mm long and with a bore of 0.4 mm to 1.0 mm radius, determined as described in **7.2**, is fixed to a scale calibrated by the procedure described in **7.3**.

NOTE The length of capillary tubing necessary to accommodate the full range of possible initial surface absorption values indicated in Table 1 will depend upon the radius of the capillary bore and the cap size. The scale is marked in divisions as described in **7.3**.

For a cap of the minimum dimensions given in **6.2**, a capillary bore of 0.4 mm radius and concrete of high initial absorption, the length required would exceed 1 m. To limit the length of tube to a convenient value, a combination of cap size and capillary bore should be chosen to accommodate the range of initial surface absorptions anticipated. The more permeable the concrete, the larger the bore or the length needs to be. The capillary tube protrudes beyond one end of the scale for connection to the outlet of the cap.

6.6 *Stands and clamps,* to support the reservoir and capillary tube and scale, allowing for adjustments within the ranges given in **6.3**.

6.7 *Stop watch or clock,* accurate to 0.5 s.

6.8 *Measuring cylinder,* of 10 ml capacity conforming to BS 604.

6.9 *Thermometers,* accurate to the nearest 0.2 °C, suitable for measuring the temperature of the water and of the concrete surface.

6.10 *Drying oven,* ventilated, in which the temperature is controlled at (105 ± 5) °C.

6.11 *Cooling cabinet,* dry airtight vessel of sufficient capacity to contain the specimens to be tested.

6.12 *Balance,* of appropriate capacity to weigh the specimens to the accuracy required by **8.1.2**.

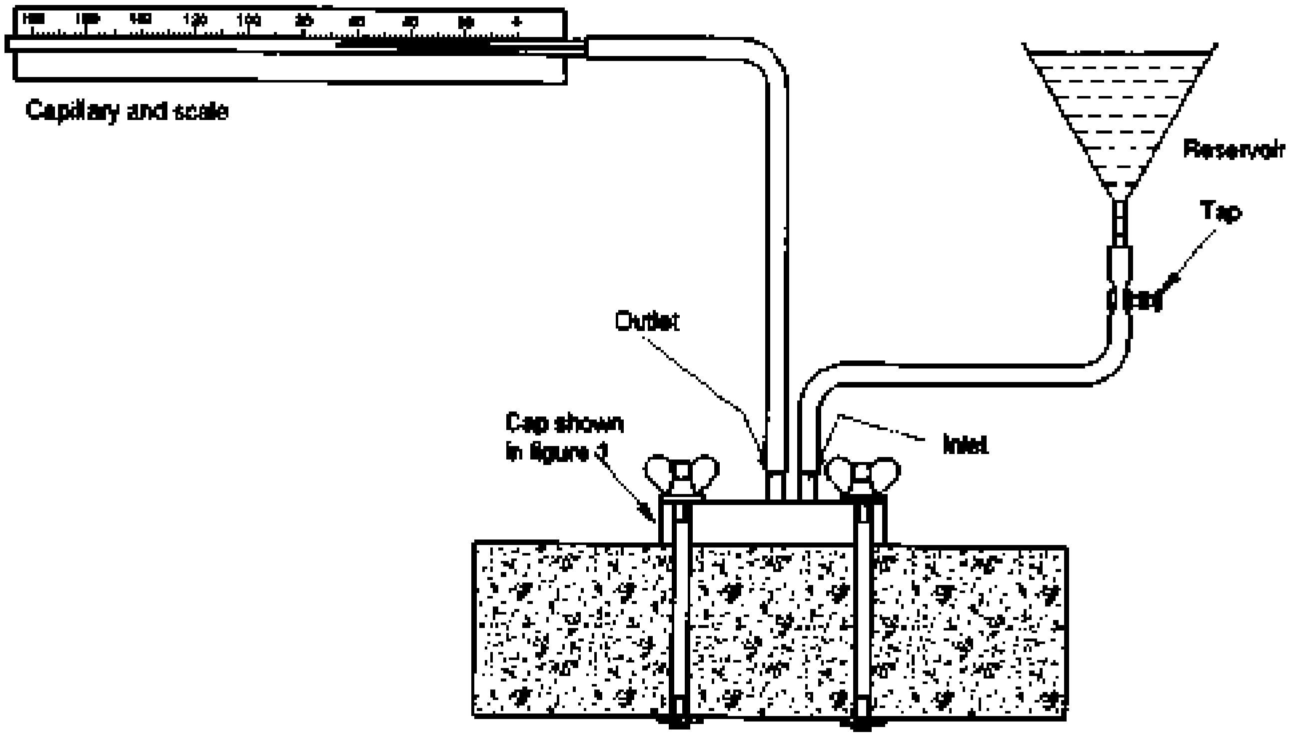

Figure 1 — Assembly of typical absorption apparatus

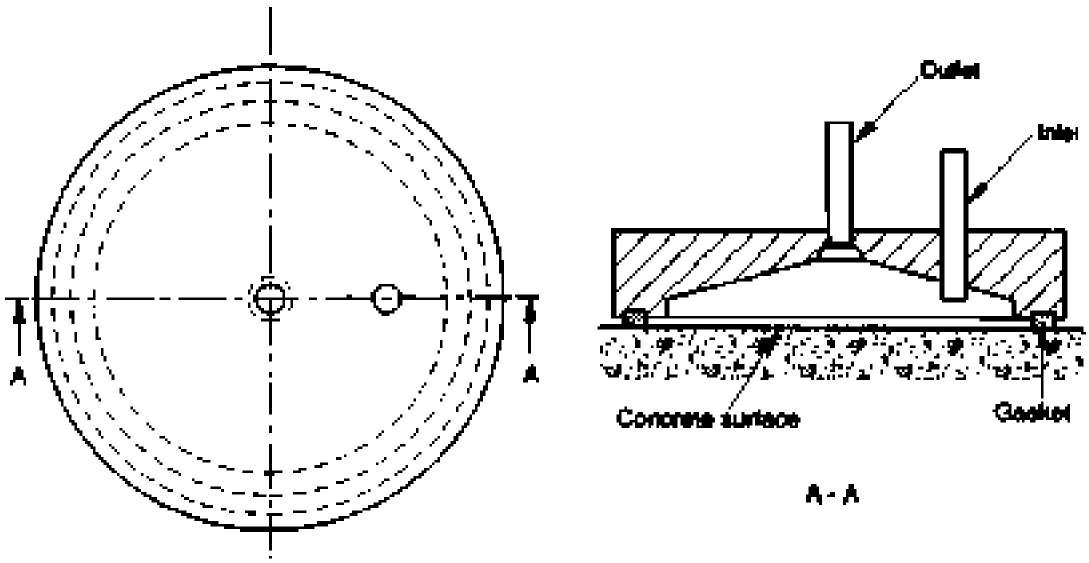

Figure 2 — Typical cap suitable for clamping onto a smooth horizontal surface

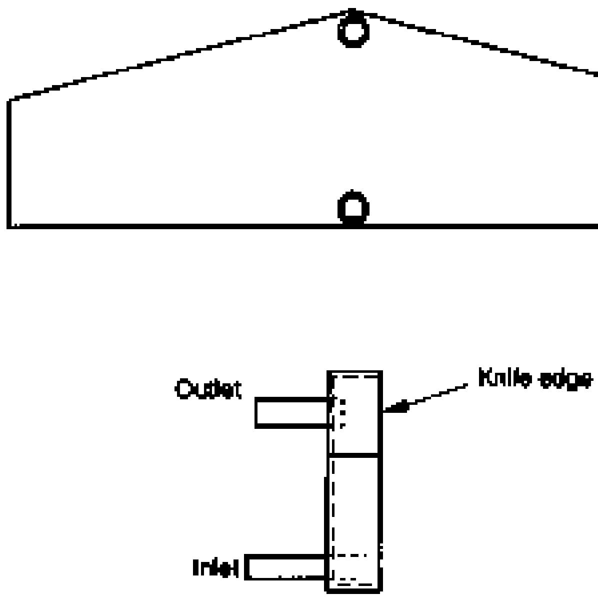

Figure 3 — Typical cap suitable for use on a vertical surface

7 Calibration of apparatus

7.1 General

The calibration of the capillary tube is arranged so that the movement of water along it during 1 min, as read directly from the scale, equals the initial surface absorption in ml/(m^2.s) at a constant head and temperature during the test.

7.2 Radius of bore of capillary tube

Measure the length of the capillary tube (**6.5**) and record it to the nearest millimetre. Flush the tube through with soap solution, followed by at least 25 ml of distilled or de-ionized water. Clamp the tube horizontally and connect it to the reservoir (**6.4**) by means of the flexible tube (**6.3.1**) fitted with a tap. Fix the reservoir such that a head of water of (200 ± 5) mm is maintained during the course of the calibration.

Close the tap and fill the reservoir with distilled or de-ionized water to the specified level. Determine the temperature of the water using the thermometer (**6.9**) and ensure that this is within 1 °C of ambient. Open the tap and, when a steady discharge occurs, place the measuring cylinder (**6.8**) under the open end and begin to collect the water. Record in seconds the time required to collect 10 ml of water.

Repeat this procedure twice more and calculate the mean of the three times.

Calculate the bore radius of the capillary tube, *r,* in millimetres, from the following equation:

$$r^4 = \frac{KL}{t}$$

where

- *L* is the length of the capillary tube (in millimetres);
- *t* is the mean time to collect 10 ml of water (in seconds);
- *K* is a coefficient incorporating the viscosity of water and the geometry of the apparatus obtained from the values below using linear interpolation between adjacent values.

Water temperature (°C):	10	15	20	25	30
Factor *K*:	0.0167	0.0145	0.0128	0.0 114	0.0100

7.3 Capillary scale

From the dimensions of the cap, taking account of the seal geometry, calculate the area of contact of the water with the specimen, A_1,and record this in mm^2. Calculate the area of the bore of the capillary, A_2, in mm^2 using the value of *r* calculated as described in **7.2** from:

$$A_2 = \pi r^2$$

Prepare a scale to mount behind the capillary tube marked off with at least 180 divisions, spaced $6 \times 10^{-4} A_1/A_2$ mm apart. Each such division will then represent 0.01 units of ml/(m^2.s).

8 Procedure

8.1 Selection and recommended preparation of specimens

8.1.1 ***Number of specimens***

Test at least three separate specimens or locations selected to be representative of the concrete under examination and suitable for test with the cap and clamping system to be used. Areas exhibiting surface cracking should normally be avoided. Mould oil or curing membranes may affect the results as can the procedures needed to remove them.

8.1.2 ***Oven dried specimens***

Dry the specimen in the oven (**6.10**) at (105 ± 5) °C until constant mass is achieved, i.e. not more than 0.1 % weight change over any 24 h drying period. When the specimen has reached constant mass, place it in the cooling cabinet (**6.11**) and allow the temperature in the cabinet to fall to within 2 °C of that of the room. Leave each specimen in the cabinet until required for testing. Concrete made with high alumina cement should not be conditioned by oven drying.

8.1.3 ***Non-oven dried specimens***

8.1.3.1 *Conditioning for laboratory testing*

Allow the concrete unit or specimen to remain in the laboratory for a minimum period of 48 h at a temperature of (20 ± 2) °C before testing.

8.1.3.2 *Conditions for site testing*

Protect the surface to be tested from water for a period of at least 48 h prior to the test. Do not allow contact between the protective material and the surface to be tested. Protect the surface from direct sunlight for at least 12 h prior to and during the test.

8.2 Fixing the cap

Slightly grease the gasket where it is made of a solid elastomer. Foamed elastomeric gaskets may or may not need greasing.

In the case of knife edged caps, form a seal round the outside of the cap to prevent any loss of water from under the knife edge. A variety of materials can be used, and should be firmly applied to the concrete and the edges of the cap to build a wall capable of withstanding the water pressure. One of the best materials is modelling clay into which enough grease can be kneaded to enable it to "wet" glass or metal. The colour may be selected to match the concrete.

A gentle application of heat to the test surface helps to remove residual moisture and may assist in the adhesion of the sealing compound. If this procedure is adopted it should be stated in the report.

Clamp the cap into position or fix into place and test by blowing gently down one of the tubes whilst closing the other. Leakage may occur in the course of a test under site conditions due to movement of the seal and can be detected by applying a small amount of soap solution to the outside of the joint. Carefully examine the sealing of the cap throughout each test and if any signs of leakage are observed discontinue the test.

8.3 Assembling the apparatus

Set up the reservoir so that when it is filled (see **8.5**) a head of 180 mm to 220 mm of water is applied to the surface of the concrete.

NOTE For non-horizontal surfaces measure the head of water from mid-height of the concrete under the cap.

Connect the reservoir to the inlet of the cap with the flexible tubing, which has the tap fitted to it.

Support the capillary tube, calibrated as described in clause **7**, horizontally just below the level of the surface of the water in the reservoir.

8.4 Temperature of water

In laboratory tests maintain the temperature of the water at (20 ± 2) °C.

In site tests no limits can be laid down, but take precautions to avoid undue fluctuations in the temperature of the water during the test.

8.5 Starting the test

Measure and report the temperature of the concrete surface adjacent to the cap to the nearest 1 °C.

Close the tap from the reservoir and fill the reservoir with water. Start the test by opening the tap to allow the water to run into the cap and record this start time. Flush all air from the cap through the capillary tube, assisted if necessary, by sharply pinching the flexible tubing. Replenish the reservoir to maintain the head of 180 mm to 220 mm of water and raise one end of the capillary tube just above the water level to prevent further outflow. Take care at all times to ensure that the reservoir does not empty itself.

8.6 Readings

Take readings normally after the following intervals from the start of the test:

— 10 min;

— 30 min; and

— 1 h.

As the test proceeds, the moisture content of the concrete will increase and capillary pores within the concrete adjacent to the test area become water filled. The rate of surface absorption will normally diminish as the duration of the test increases.

Just before the specified intervals lower the capillary tube so that water runs in to fill it completely and then fix it in a horizontal position at the same level as the surface of the water in the reservoir.

At each of the specified test intervals close the tap to allow water to flow back along the capillary tube. When the meniscus reaches the scale start the stop watch. After 5 s note the number of scale divisions the meniscus has moved and, by reference to Table 1, determine the period during which movement is to be measured.

Table 1 — Determination of period of movement

Number of scale divisions moved in 5 s	Period during which movement is measured
< 3	2 min
3 to 9	1 min
10 to 30	30 s
> 30	Record initial surface absorption as more than 3.60 ml/(m^2.s)
NOTE 1 division = 0.01 unit (see **7.3**).	

Record the number of scale divisions moved during the period selected from Table 1. When readings are taken over a 2 min or 30 s period, multiply the number of divisions by 0.5 or 2 respectively to convert the reading to a 1 min period. Record the actual or equivalent number of scale units traversed per min, which is 0.01 times the number of divisions, as the initial surface absorption in ml/(m^2.s) for that particular test interval. If the movement over the 5 s period exceeds 30 scale divisions record the initial surface absorption as more than 3.60 ml/(m^2.s).

If the reading taken 10 min after the start of the test is below 0.05 ml/(m^2.s), stop the test and record the result with the comment "concrete too impermeable to be sensitive to a longer term test". Similarly, where the 10 min reading is above 3.60 ml/(m^2.s), stop the test and record the result with the comment concrete too permeable to be within the sensitivity of the test method.

Between test intervals leave the tap open and maintain the level of the water in the reservoir at the specified head. The capillary tube may be tilted or raised a little to prevent overflow of the water.

9 Factors affecting test results

9.1 General

Detailed interpretation of results will depend upon the purpose and circumstances of use of the test, but the factors influencing results which are described in clause **5** should be given due consideration. Interpretation can be assisted by the recommendations given in the following clauses which is based on experience of using the method in the United Kingdom.

9.2 Sensitivity to initial moisture condition of non-oven dried specimens

Experience suggests that provided the conditioning has been carried out as described in **8.1.3**, then sensitivity to residual moisture is not high in relation to the influence of other factors. The effect of such moisture will decrease as the duration of the test increases.

9.3 Variability of concrete

The results reflect the variability, which may be considerable, of the condition of the surface and of concrete properties in the surface zone. Concrete subjected to site or laboratory conditioning is likely to yield more variable results than oven dried concrete. Oven drying may cause changes in the cement paste structure and can give different results from "naturally dry" concretes.

9.4 Period of test

In some instances, such as assessment of potential weathering characteristics or protection afforded to embedded steel, broad conclusions based on results of 10 min tests may be considered adequate. However, the effects of moisture condition indicated in **9.2** should not be overlooked. When the test area has been heated (see **8.2**) reliance upon 10 min values may not be justified.

9.5 Temperature of the concrete

Major variations in the surface temperature of the concrete, from the 20 °C value for which the equipment has been calibrated, are likely to influence results significantly owing to changes in viscosity of the water. The correction factors given in Table 2 should be used to convert site results to an equivalent 20 °C value.

Table 2 — Correction factors to convert readings to an equivalent value at 20 °C

Concrete surface temperature °C	Multiply by
5	1.5
10	1.3
15	1.1
20	1.0
25	0.9
30	0.8

10 Precision

It is not possible to give precision data as trials have not been carried out according to procedures given in this standard.

11 Test report

The following information should be included in the test report on each specimen or each location:

a) date, time and place of test;

b) age of concrete under test (if known);

c) identification and description of test specimen or element;

d) location within the element, where applicable;

e) positions tested, where applicable (with sketches);

f) detailed description of the surface of the concrete;

g) orientation of the test surface (horizontal, vertical or other direction);

h) description of the conditioning prior to test (including surface heat treatment);

i) method of sealing the cap;

j) area of water contact of the cap, dimensions of the cap and length of the capillary;

k) temperature of the concrete surface;

l) all initial surface absorption test results in ml/(m^2.s) as obtained in **8.6**;

m) results corrected to equivalent 20 °C values (see **9.5**).

blank

List of references (see clause 2)

Normative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS 604:1982, *Specification for graduated glass measuring cylinders.*
BS 1217:1986, *Specification for cast stone.*
BS 1881, *Testing concrete.*
  BS 1881-201:1990, *Guide to the use of non-destructive methods of test for hardened concrete*[3].
BS 6100, *Glossary of building and civil engineering terms.*
  BS 6100-6, *Concrete and plaster.*
  BS 6100-6.2:1986, *Concrete.*

Other publications

"Permeability testing of site concrete — A review of methods and experience". Concrete Society Report, 1988.

[3] Referred to in the foreword only.

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BRITISH STANDARD

BS EN 12390-8:2000

Testing hardened concrete —

Part 8: Depth of penetration of water under pressure

The European Standard EN 12390-8:2000 has the status of a British Standard

ICS 91.100.30

National foreword

This British Standard is the official English language version of EN 12390-8:2000. No existing British Standard is replaced.

The UK participation in its preparation was entrusted by Technical Committee B/517, Concrete, to Subcommittee B/517/1, Concrete production and testing, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 6, an inside back cover and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This British Standard, having been prepared under the direction of the Sector Committee for Building and Civil Engineering, was published under the authority of the Standards Committee and comes into effect on 15 December 2000

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Amendments issued since publication

Amd. No.	Date	Comments

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 12390-8

October 2000

ICS 91.100.30

English version

Testing hardened concrete - Part 8: Depth of penetration of water under pressure

Essai pour béton durci - Partie 8: Profondeur de pénétration d'eau sous pression

Prüfung von Festbeton - Teil 8: Wassereindringtiefe unter Druck

This European Standard was approved by CEN on 18 February 2000.

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Ref. No. EN 12390-8:2000 E

Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 104, Concrete (performance, production, placing and compliance criteria), the Secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2001, and conflicting national standards shall be withdrawn at the latest by December 2003.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This standard is one of a series concerned with testing concrete.

It is based on the draft International Standard ISO (DIS) 7031 - Concrete hardened - Determination of the depth of penetration of water under pressure.

The standard has been restricted to tests on specimens cured in water.

The requirement in the original draft ISO Standard for the average depth of penetration to be estimated has been omitted.

A draft for this standard was published in 1996 for CEN enquiry as prEN 12364. It was one of a series of individually numbered test methods for fresh or hardened concrete. For convenience it has now been decided to combine these separate draft standards into three new standards with separate parts for each method, as follows:

- Testing fresh concrete (EN 12350)

- Testing hardened concrete (EN 12390)

- Testing concrete in structures (EN 12504)

The series EN 12390 includes the following parts where the brackets give the numbers under which particular test methods were published for CEN enquiry:

EN 12390 Testing hardened concrete -

Part 1: Shape, dimensions and other requirements of specimens and moulds (former prEN 12356:1996)
Part 2: Making and curing specimens for strength tests (former prEN 12379:1996)
Part 3: Compressive strength of test specimens (former prEN 12394:1996)
Part 4: Compressive strength - Specification for testing machines (former prEN 12390:1996)
Part 5: Flexural strength of test specimens (former prEN 12359:1996)
Part 6: Tensile splitting strength of test specimens (former prEN 12362:1996)
Part 7: Density of hardened concrete (former prEN 12363:1996)
Part 8: Depth of penetration of water under pressure (former prEN 12364:1996)

1 Scope

This standard specifies a method for determining the depth of penetration of water under pressure in hardened concrete which has been water cured.

2 Principle

Water is applied under pressure to the surface of hardened concrete. The specimen is then split and the depth of penetration of the water front is measured.

3 Apparatus

3.1 Testing equipment

The test specimen, of given dimensions, shall be placed in any suitable equipment in such a manner that the water pressure can act on the test area and the pressure applied can be continuously indicated. An example of a test arrangement is shown in Figure 1.

NOTE 1 It is preferable that the apparatus should allow the other surfaces of the test specimen to be observed.

NOTE 2 The water pressure may be applied to the surface of the test specimen either from the bottom, or the top.

A necessary seal shall be made of rubber or other similar material.

The dimensions of a test area shall be approximately half of the length of the edge or diameter of the test surface.

4 Test specimen

The specimen shall be cubic, cylindrical or prismatic of length of edge, or diameter, not less than 150 mm.

5 Procedure

5.1 Preparation of the test specimen

Immediately after the specimen is de-moulded, roughen the surface to be exposed to water pressure, with a wire brush.

5.2 Application of water pressure

The test shall be started when the specimen is at least 28 days old. Do not apply the water pressure to a trowelled surface of a specimen. Place the specimen in the apparatus and apply a water pressure of (500 ± 50) kPa for (72 ± 2) h. During the test, periodically observe the appearance of the surfaces of the test specimen not exposed to the water pressure to note the presence of water. If leakage is observed then consider the validity of the result and record the fact.

NOTE The use of tap water is satisfactory.

5.3 Examination of specimen

After the pressure has been applied for the specified time, remove the specimen from the apparatus. Wipe the face on which the water pressure was applied to remove excess of water. Split the specimen in half, perpendicularly to the face on which the water pressure was applied. When splitting the specimen, and during the examination, place the face of the specimen exposed to the water pressure on the bottom. As soon as the split face has dried to such an extent that the water penetration front can be clearly seen, mark the water front on the specimen. Measure the maximum depth of penetration under the test area and record it to the nearest millimetre.

6 Test result

The maximum depth of penetration, expressed to the nearest millimetre, is the test result.

7 Test report

The report shall include:

a) identification of the test specimen;

b) date of start of the test;

c) description of the specimen;

d) direction of application of water pressure with respect to the casting direction;

e) maximum depth of penetration, in millimetres;

f) any leakage and consideration of the validity of the result; (if appropriate)

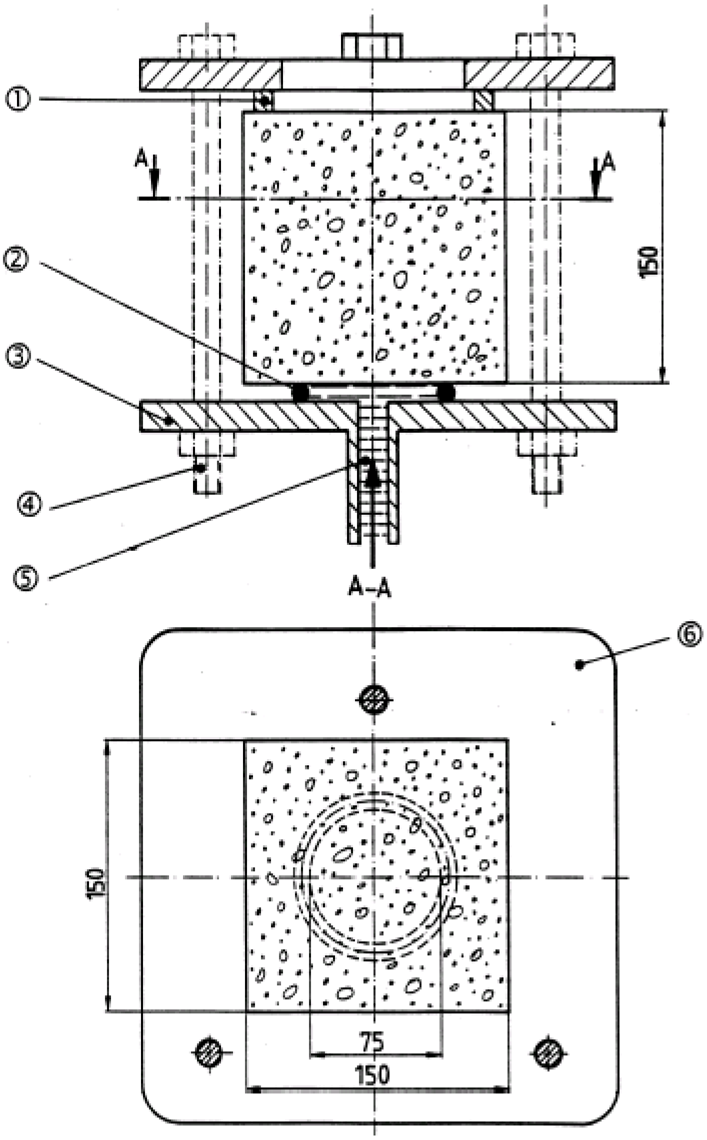
g) any deviation from standard test method;

h) a declaration by the person technically responsible for the test that it was carried out in accordance with this standard, except as noted in item g).

8 Precision

There is no precision data available.

Dimensions in millimetres



Key
1 Packing piece
2 Sealing ring
3 Scewed on plate
4 Screw-threaded rod
5 Water under pressure
6 Screwed on plate

Figure 1 - Example of test arrangement

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Designation: C 1585 – 04[ε1]

Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes[1]

This standard is issued under the fixed designation C 1585; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—A typo in Eq 1 was corrected editorially in December 2007.

1. Scope

1.1 This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field

C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C 125 Terminology Relating to Concrete and Concrete Aggregates

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 642 Test Method for Density, Absorption, and Voids in Hardened Concrete

C 1005 Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology C 125.

4. Significance and Use

4.1 The performance of concrete subjected to many aggressive environments is a function, to a large extent, of the penetrability of the pore system. In unsaturated concrete, the rate of ingress of water or other liquids is largely controlled by absorption due to capillary rise. This test method is based on that developed by Hall[3] who called the phenomenon "water sorptivity."

4.2 The water absorption of a concrete surface depends on many factors including: *(a)* concrete mixture proportions; *(b)* the presence of chemical admixtures and supplementary cementitious materials; *(c)* the composition and physical characteristics of the cementitious component and of the aggregates; *(d)* the entrained air content; *(e)* the type and duration of curing; *(f)* the degree of hydration or age; *(g)* the presence of microcracks; *(h)* the presence of surface treatments such as sealers or form oil; and *(i)* placement method including consolidation and finishing. Water absorption is also strongly affected by the moisture condition of the concrete at the time of testing.

4.3 This method is intended to determine the susceptibility of an unsaturated concrete to the penetration of water. In general, the rate of absorption of concrete at the surface differs from the rate of absorption of a sample taken from the interior. The exterior surface is often subjected to less than intended curing and is exposed to the most potentially adverse conditions. This test method is used to measure the water absorption rate of both the concrete surface and interior concrete. By drilling a core and cutting it transversely at selected depths, the absorption can be evaluated at different distances from the exposed surface. The core is drilled vertically or horizontally.

4.4 This test method differs from Test Method C 642 in which the specimens are oven dried, immersed completely in

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.66 on Concrete's Resistance to Fluid Penetration.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Hall, C., "Water Sorptivity of Mortars and Concretes: A Review," *Magazine of Concrete Research*, Vol. 41, No. 147, June 1989, pp. 51-61.

water at 21°C, and then boiled under water for 5 h. In this test method, only one surface is exposed to water at room temperature while the other surfaces are sealed simulating water absorption in a member that is in contact with water on one side only. Test Method C 642, on the other hand, is used to estimate the maximum amount of water that can be absorbed by a dry specimen and therefore provides a measure of the total, water permeable pore space.

5. Apparatus

5.1 *Pan*, a watertight polyethylene or other corrosion-resistant pan large enough to accommodate the test specimens with the surfaces to be tested exposed to water.

5.2 *Support Device*, rods, pins, or other devices, which are made of materials resistant to corrosion by water or alkaline solutions, and which allow free access of water to the exposed surface of the specimen during testing. Alternatively, the specimens can be supported on several layers of blotting paper or filter papers with a total thickness of at least 1 mm.

5.3 *Top-pan Balance*, complying with Specification C 1005 and with sufficient capacity for the test specimens and accurate to at least ± 0.01 g.

5.4 *Timing Device*, stop watch or other suitable timing device accurate to ± 1 s.

5.5 *Paper Towel or Cloth*, for wiping excess water from specimen surfaces.

5.6 *Water-Cooled Saw*, with diamond impregnated blade to cut test specimens from larger samples.

5.7 *Environmental Chamber*, a chamber allowing for air circulation and able to maintain a temperature of 50 ± 2°C and a relative humidity at 80 ± 3 %. Alternatively, an oven able to maintain a temperature of 50 ± 2°C and a dessicator large enough to contain the specimens to be tested is permitted. The relative humidity (RH) is controlled in the dessicator at 80 ± 0.5 % by a saturated solution of potassium bromide. The solubility of potassium bromide is 80.2 g/100 g of water at 50°C. The solution shall be maintained at the saturation point for the duration of the test. The presence of visible crystals in the solution provides acceptable evidence of saturation.

5.8 *Polyethylene Storage Containers*, with sealable lids, large enough to contain at least one test specimen but not larger than 5 times the specimen volume.

5.9 *Caliper*, to measure the specimen dimensions to the nearest 0.1 mm.

6. Reagents and Materials

6.1 *Potassium Bromide, Reagent Grade*, required if the oven and dessicator system described in 5.7 is used.

6.2 *Sealing Material*, strips of low permeability adhesive sheets, epoxy paint, vinyl electrician's tape, duct tape, or aluminium tape. The material shall not require a curing time longer than 10 minutes.

6.3 *Plastic Bag or Sheeting*, any plastic bag or sheeting that could be attached to the specimen to control evaporation from the surface not exposed to water. An elastic band is required to keep the bag or sheeting in place during the measurements.

7. Test Specimens

7.1 The standard test specimen is a 100 ± 6 mm diameter disc, with a length of 50 ± 3 mm. Specimens are obtained from either molded cylinders according to Practices C 31/C 31M or C 192/C 192M or drilled cores according to Test Method C 42/C 42M. The cross sectional area of a specimen shall not vary more than 1 % from the top to the bottom of the specimen. When cores are taken, they should be marked (see Note 1) so that the surface to be tested relative to the original location in the structure is clearly indicated.

NOTE 1—The surface to be exposed during testing shall not be marked or otherwise disturbed in such a manner as may modify the absorption rate of the specimen.

7.2 The average test results on at least 2 specimens (Note 2) shall constitute the test result. The test surfaces shall be at the same distance from the original exposed surface of the concrete.

NOTE 2—Concrete is not a homogeneous material. Also, an exterior surface of a concrete specimen seldom has the same porosity as the interior concrete. Therefore, replicate measurements are taken on specimens from the same depth to reduce the scatter of the data.

8. Sample Conditioning

8.1 Place test specimens in the environmental chamber at a temperature of 50 ± 2°C and RH of 80 ± 3 % for 3 days. Alternatively, place test specimens in a dessicator inside an oven at a temperature of 50 ± 2°C for 3 days. If the dessicator is used, control the relative humidity in the dessicator with a saturated solution of potassium bromide (see 5.7), but do not allow test specimens to contact the solution.

NOTE 3—To control the RH using the potassium bromide solution, the solution should be placed in the bottom of the dessicator, to ensure the largest surface of evaporation possible.

8.2 After the 3 days, place each specimen inside a sealable container (as defined in 5.8). Use a separate container for each specimen. Precautions must be taken to allow free flow of air around the specimen by ensuring minimal contact of the specimen with the walls of the container.

8.3 Store the container at 23 ± 2°C for at least 15 days before the start of the absorption procedure.

NOTE 4—Storage in the sealed container for at least 15 days results in equilibration of the moisture distribution within the test specimens and has been found[4] to provide internal relative humidities of 50 to 70 %. This is similar to the relative humidities found near the surface in some field structures.[5,6]

9. Procedure

9.1 Remove the specimen from the storage container and record the mass of the conditioned specimen to the nearest 0.01 g before sealing of side surfaces.

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[4] Bentz D. P., Ehlen M. A., Ferraris C. F., and Winpigler J. A., "Service Life Prediction Based on Sorptivity for Highway Concrete Exposed to Sulfate Attack and Freeze-Thaw Conditions," FHWA-RD-01-162, 2001.

[5] DeSouza S. J., Hooton R. D., and Bickley J. A., "Evaluation of Laboratory Drying Procedures Relevant to Field Conditions for Concrete Sorptivity Measurements," *Cement Concrete Aggr* 19: (2), Dec 1997, pp. 59-63.

[6] DeSouza S. J., Hooton R. D., and Bickley J. A., "A Field Test for Evaluating High Performance Concrete Covercrete Quality," *Can J Civil Eng*, 25: (3), Jun 1998, pp. 551-556.

9.2 Measure at least four diameters of the specimen at the surface to be exposed to water. Measure the diameters to the nearest 0.1 mm and calculate the average diameter to the nearest 0.1 mm.

9.3 Seal the side surface of each specimen with a suitable sealing material. Seal the end of the specimen that will not be exposed to water using a loosely attached plastic sheet (see 6.2). The plastic sheet can be secured using an elastic band or other equivalent system (see Fig. 1).

9.4 Use the procedure below to determine water absorption as a function of time. Conduct the absorption procedure at 23 ± 2°C with tap water conditioned to the same temperature.

9.5 *Absorption Procedure*:

9.5.1 Measure the mass of the sealed specimen to the nearest 0.01 g and record it as the initial mass for water absorption calculations.

9.5.2 Place the support device at the bottom of the pan and fill the pan with tap water so that the water level is 1 to 3 mm above the top of the support device. Maintain the water level 1 to 3 mm above the top of the support device for the duration of the tests.

NOTE 5—One method for keeping the water level constant is to install a water-filled bottle upside down such that the bottle opening is in contact with the water at the desired level.

9.5.3 Start the timing device and immediately place the test surface of the specimen on the support device (see Fig. 1). Record the time and date of initial contact with water.

9.5.4 Record the mass at the intervals shown in Table 1 after first contact with water. Using the procedure in 9.5.5, the first point shall be at 60 ± 2 s and the second point at 5 min ± 10 s. Subsequent measurements shall be within ± 2 min of 10 min, 20 min, 30 min, and 60 min. The actual time shall be recorded to within ± 10 s. Continue the measurements every hour, ± 5 min, up to 6 h, from the first contact of the specimen with water and record the time within ± 1 min. After the initial 6 h, take measurements once a day up to 3 days, followed by 3 measurements at least 24 h apart during days 4 to 7; take a final measurement that is at least 24 h after the measurement at 7 days. The actual time of measurements shall be recorded within ± 1 min. This will result in seven data points for contact time during days 2 through 8. Table 1 gives the target times of measurements and the tolerances for the times.

9.5.5 For each mass determination, remove the test specimen from the pan, stop the timing device if the contact time is less than 10 min, and blot off any surface water with a dampened paper towel or cloth. After blotting to remove excess water, invert the specimen so that the wet surface does not come in contact with the balance pan (to avoid having to dry the balance pan). Within 15 s of removal from the pan, measure the mass to the nearest 0.01 g. Immediately replace the specimen on the support device and restart the timing device.

10. Calculations

10.1 The absorption, I, is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. For the purpose of this test, the temperature dependence of the density of water is neglected and a value of 0.001 g/mm^3 is used. The units of I are mm.

$$I = \frac{m_t}{a*d} , \tag{1}$$

where:

I = the absorption,
m_t = the change in specimen mass in grams, at the time t,
a = the exposed area of the specimen, in mm^2, and
d = the density of the water in g/mm^3.

10.2 The initial rate of water absorption (mm/s$^{1/2}$) is defined as the slope of the line that is the best fit to I plotted against the square root of time (s$^{1/2}$). Obtain this slope by using least-squares, linear regression analysis of the plot of I versus time$^{1/2}$. For the regression analysis, use all the points from 1 min to 6 h, excluding points for times after the plot shows a clear change of slope. If the data between 1 min and 6 h do not follow a linear relationship (a correlation coefficient of less

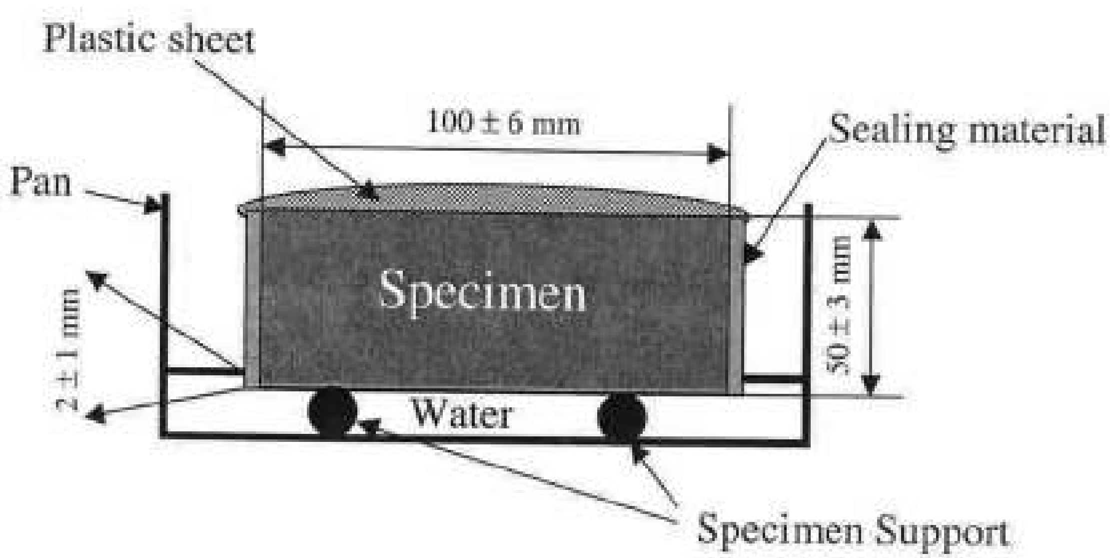


FIG. 1 Schematic of the Procedure

TABLE 1 Times and Tolernaces for the Measurements Schedule

Time	60 s	5 min	10 min	20 min	30 min	60 min	Every hour up to 6 h	Once a day up to 3 days	Day 4 to 7 3 measurements 24 h apart	Day 7 to 9 1 (one) measurement
Tolerance	2 s	10 s	2 min	2 min	2 min	2 min	5 min	2 h	2 h	2 h

than 0.98) and show a systematic curvature, the initial rate of absorption cannot be determined.

NOTE 6—Appendix X1 gives an example of absorption data and the results of regression analysis.

10.3 The secondary rate of water absorption ($mm/s^{1/2}$) is defined as the slope of the line that is the best fit to *I* plotted against the square root of time ($s^{1/2}$) using all the points from 1 *d* to 7 *d*. Use least-square linear regression to determine the slope. If the data between 1 *d* and 7 *d* do not follow a linear relationship (a correlation coefficient of less than 0.98) and show a systematic curvature, the secondary rate of water absorption cannot be determined.

11. Report

11.1 Report the following:

11.1.1 Date when concrete was sampled or cast,

11.1.2 Source of sample,

11.1.3 Relevant background information on sample such as mixture proportions, curing history, type of finishing, and age, if available,

11.1.4 Dimensions of specimen before sealing,

11.1.5 Mass of specimen before and after sealing,

11.1.6 A plot of absorption, *I*, in mm versus square root of time in $s^{1/2}$,

11.1.7 The average initial rate of water absorption calculated to the nearest 0.1×10^{-4} $mm/s^{1/2}$ and the individual initial absorption rates for the two or more specimens, and

11.1.8 The average secondary rate of water absorption calculated to the nearest 0.1×10^{-4} $mm/s^{1/2}$ and the individual absorption rates of the two or more specimens tested.

12. Precision and Bias

12.1 *Precision*—The repeatability coefficient of variation has been determined to be 6.0 % in preliminary measurements for the absorption as measured by this test method for a single laboratory and single operator. An interlaboratory program is being organized to develop the repeatability and reproducibility values.

12.2 *Bias*—The test method has no bias because the rate of water absorption determined can only be defined in terms of the test method.

13. Keywords

13.1 concrete; initial rate of water absorption; mortar; rate of absorption; secondary rate of water absorption

APPENDIX

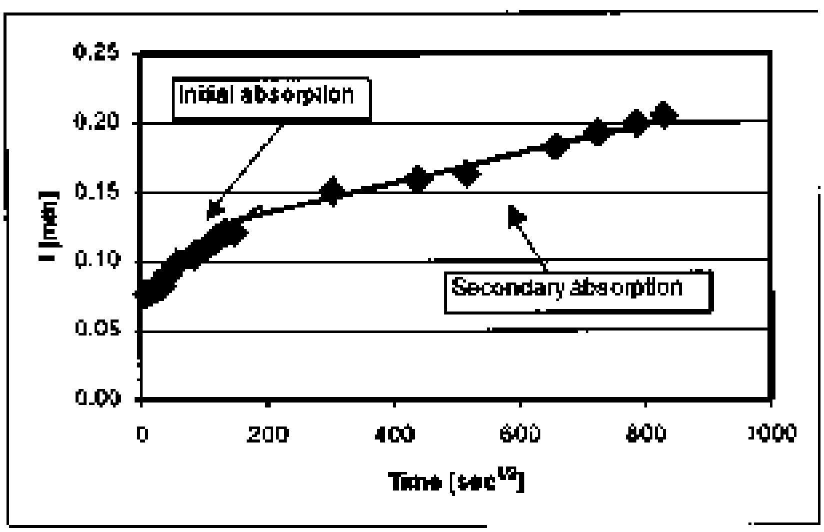
(Nonmandatory Information)

X1. EXAMPLE RATE OF WATER ABSORPTION TEST

TABLE X1.1 Example of Data Collected and Calculations

	Cast Date: 3/2/99 Test Date: 3/14/00
Sample No. F-68	Concrete Mixture: Standard mixture I
Sample Conditioning: Cast, steam cured, test face = top surface	
Sample: Age 378 days	Age at coring: Unknown
Mass of Conditioned disc: 750.5 g (prior to sealing sides)	Mass after sealing specimen: 761.8 g
Diameter (mm): 101.6	Exposed Area: 8107 mm^2
Thickness (mm): 50.8	
Water temp: 20.7°C	

Test Time		√Time ($s^{1/2}$)	Mass (g)	ΔMass (g)	ΔMass/area/density of water = *I* (mm)
Days	s				
	0	0	761.83	0.00	0.0000
	60	8	762.45	0.62	0.0765
	300	17	762.46	0.63	0.0777
	600	24	762.48	0.65	0.0802
	1200	35	762.50	0.67	0.0826
	1800	42	762.57	0.74	0.0913
	3600	60	762.63	0.80	0.0987
	7200	85	762.68	0.85	0.1048
	10800	104	762.73	0.90	0.1110
	14400	120	762.77	0.94	0.1159
	18000	134	762.81	0.98	0.1209
	21600	147	762.82	0.99	0.1221
1	92220	304	763.05	1.22	0.1505
2	193200	440	763.12	1.29	0.1591
3	268500	518	763.15	1.32	0.1628
5	432000	657	763.31	1.48	0.1826
6	527580	726	763.39	1.56	0.1924
7	622200	789	763.45	1.62	0.1998
8	691200	831	763.5	1.67	0.2060



Calculations:

Initial Absorption:
$I = S_i \sqrt{t} + b$ (points measured up to 6 h are used)
The initial rate of absorption is: $S_i = 3.5 \times 10^{-4}$ mm/√s $r = 0.99$

Secondary Absorption:
$I = S_s \sqrt{t} + b$ (points measured after the first day are used)
The secondary rate of absorption is: $S_s = 1.1 \times 10^{-4}$ mm/√s

FIG. X1.1 Example of Plot of The Data Shown in Table X1.1

VARIOUS STAGES OF MANUFACTURING OF CONCRETE

- ✓ BATCHING
- ✓ MIXING
- ✓ TRANSPORTING
- ✓ PLACING
- ✓ COMPACTING
- ✓ CURING
- ✓ FINISHING

BATCHING

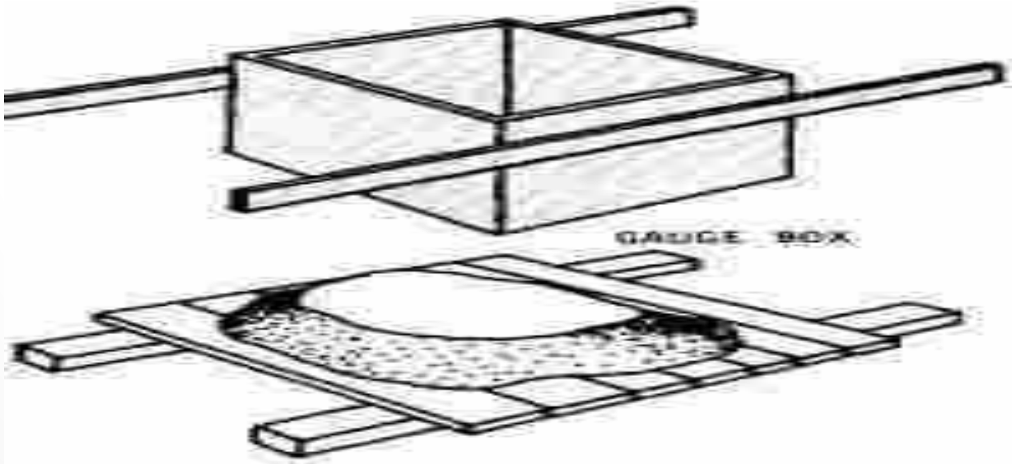
Batching is the process of measuring concrete mix ingredients by either mass or volume and introducing them into the mixer . To produce concrete of uniform quality, the ingredients must be measured accurately for each batch.

- ✓ Volume batching
- ✓ Weight batching

➢ Volume batching

- This method is generally adopted for small jobs .
- Gauge boxes are used for measuring the fine and coarse aggregate.
- The volume of gauge box is equal to the volume of one bag of cement.

- Gauge bow are also called as FARMAS
- They can be made of timbers or steel.
- They are made generally deep and narrow
- Bottomless gauge boxes are generally avoided.
- While filling the gauge boxes the material should be filled loosely,no compaction is allowed.



Weigh Batching

- Batching by weight is more preferable to volume batching ,as it is more accurate and leads to more uniform proportioning.
- It does not have uncertainties associated with bulking.

It's equipment falls into 3 general categories :

I. Manual,
II. Semi automatic,
III. Fully automatic.

1) In case of manual batching all weighing and batching of concrete are done manually. It is used for small jobs.

2)Semi automatic

In case of semi automatic batching the aggregate bin gates are opened by manually operated switches . And gates are closed automatically when the material has been delivered.

This system also contains interlock which prevents charging and discharging.

3)Fully automatic

In case of automatic batching the material are electrically activates by a single switch and complete autographic record are made of the weight of each material.

The batching plant comprises 2,3,4 or 6 compartment bins of several capacitie. Over the conveyer belt the weigh batchers discharging are provided below the bins

Mixing

The mixing should be ensure that the mass becomes Homogeneous , uniform in colour and consistency .

Methods of Mixing :

- 1.Hands(using hand shovels)
- 2.Stationary Mixers
- 3.Ready mix concrete

Hand Mixing

- Mixing ingredients of concrete by hands using ordinary tools like, hand shovels etc. This type of mixing is done for Less output of concrete.

Stationary Mixers

- Concrete is sometime mixed at jobsite in a stationary mixer having a size of 9 cubic meter .

- These mixers may be of :

1. **Tilting type ,**
2. **Non-Tilting type ,**

Tilting type mixer

- It consist a conical drum which rotates on an inclinable axis.
- It has only one opening.
- The drum charged directly and discharged by tilting and reversing the drum.

Non tilting type mixer

- The mixing drum is cylindrical in shape and revolves two – horizontal axis.
- It has opening on both sides.
- The ingredients are charged in from one opening.
- For discharging concrete chute is introducing to other opening by operating a lever.

Ready Mixed Concrete

Ready mixed concrete is proportioned and mixed off at the project site and is delivered to the construction area in a freshly mixed and unhardened state. It can be manufactured by any of the following methods:

- 1.Central-mixed concrete
- 2.Truck-mixed concrete

Central Mixed Concrete

- Central-mixed concrete
  - ➢ mixed completely in a stationary mixer

- delivered in
  - ✓ Agitator Trucks
  - ✓ A non-agitating truck

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Agitator Trucks

- **A vehicle carrying a drum or agitator body, in which freshly mixed concrete can be conveyed from the point of mixing to that of placing, the drum being rotated continuously to agitate the contents.**
- **Advantages:** Operate usually from central mixing plants
- **Watch for:** Timing of deliveries should suit job organization. Concrete crew and equipment must be ready onsite to handle concrete.
- **Used for:** Transporting concrete for all uses. Haul distances must allow discharge of concrete within 1½ hours.

Non-agitating Trucks

- **Used for:** Transport concrete on short hauls(small distance) over smooth roadways.
- **Advantages:** Cost of non-agitating equipment is lower than that of truck agitators or mixers.
- **Watch for:** Slump should be limited. Possibility of segregation. Height upon discharge is needed

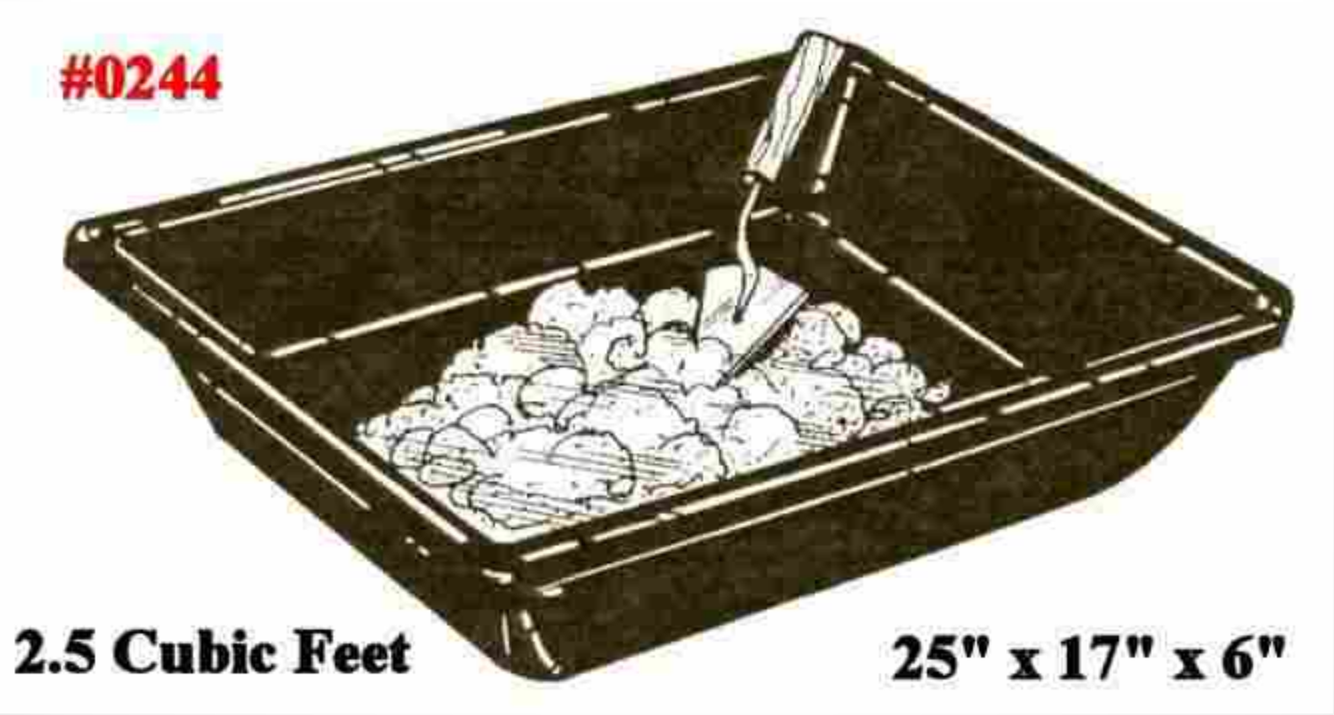
Truck-mixed concrete

- **Used for:** Intermittent (periodic) production of concrete at jobsite, or small quantities.

- **Advantages:** Combined materials transporter and batching and mixing system. One-man operation.

Transporting

- 1) Mortar Pan : Concrete is carried in small Quantities



Transporting

- 2) **Wheelbarrows and Buggies :** Short flat hauls on all types of onsite concrete construction

Transporting

- 3) Belt Conveyors : Conveying concrete horizontally or higher/lower level.

Transporting

- 4) Cranes and Buckets : Used for Work above ground level , Buckets use with Cranes, cableways, and helicopters.

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Transporting

- 5) Pumps : Conveying concrete from central discharge point to formwork.

Transporting

- 6) Transit Mixer : used for transporting the concrete over long distance particularly in RMC plant .

Compaction of concrete

- Compaction of concrete is process adopted for expelling the entrapped air from the concrete
- In the process of mixing , transporting and placing of concrete air is likely to get entrapped in the concrete .
- It has been found from the experimental studies that 1% air in the concrete approximately reduces the strength by 6%.
- If we don't expel this air, it will result into honeycombing and reduced strength

Different Methods Of Concrete Compaction

1) **Hand Compaction**

Rodding

Ramming

Tamping

2) **Compaction by Vibration**

Internal vibrator

Formwork Vibrator

Table Vibrator

Platform vibrator

Surface vibrator .

Hand Compaction

- Hand compaction is used for ordinary and unimportant structures. Workability should be decided in such a way that the chances of honeycombing should be minimum. The various methods of hand compaction are as given below:

❖ Rodding

It is a method of poking with 2m long, 16 mm dia. rod at sharp corners and edges. The thickness of layers for rodding should be 15 to 20 cm.

❖Ramming

- It is generally used for compaction on ground in plain concrete. It is not used either in RCC or on upper floors.

❖Tamping

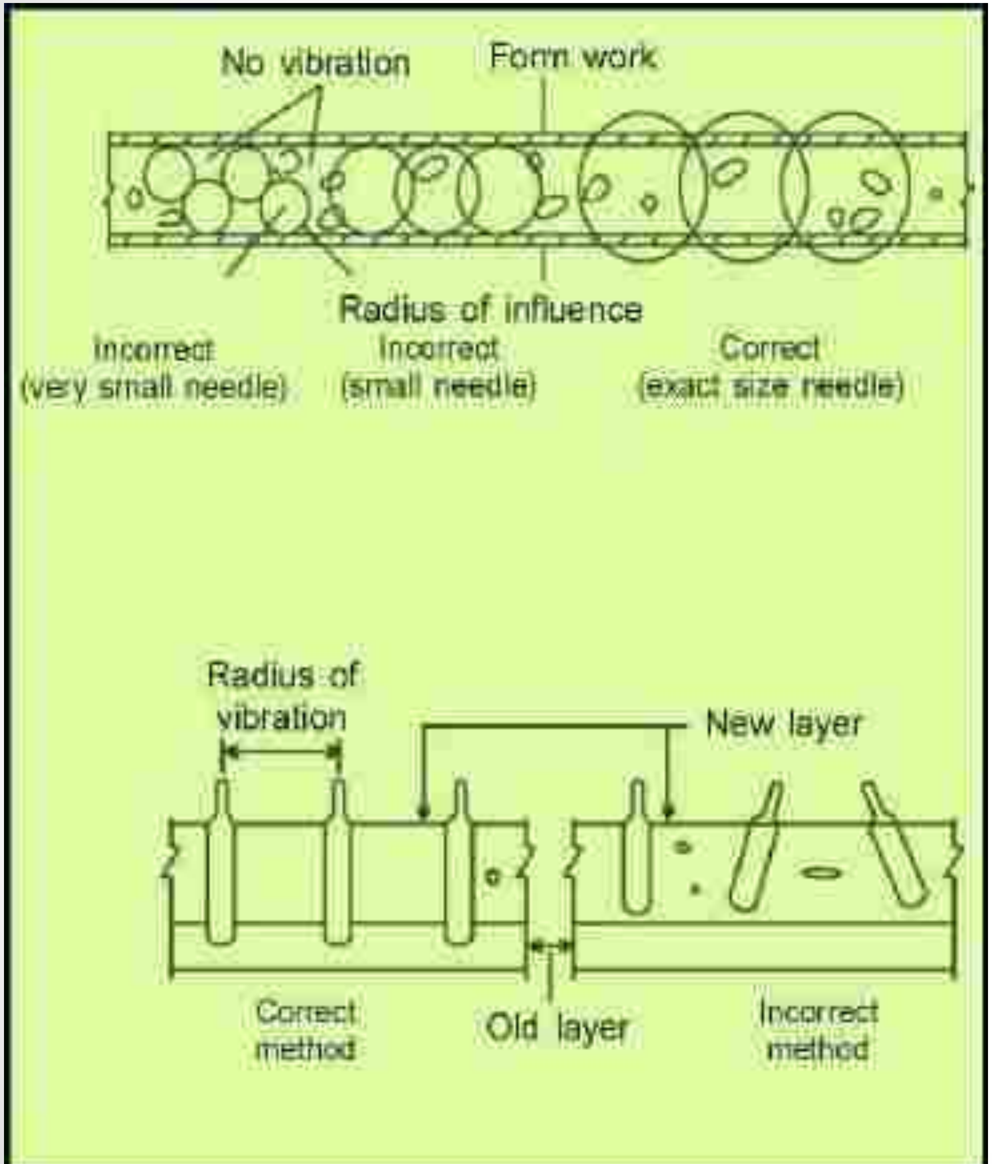
- It is a method in which the top surface is beaten by wooden cross beam of cross section 10 cm x 10 cm. both compaction and leveling are achieved simultaneously. It is mainly used for roof slabs and road pavements.

Compaction by Vibration

- Vibration is imparted to the concrete by mechanical means. It causes temporary liquefaction so that air bubbles come on to the top and expelled ultimately. Mechanical vibration can be of various types as given under.

❖ **Internal Vibration**

It is most commonly used technique of concrete vibration. Vibration is achieved due to eccentric weights attached to the shaft. The needle diameter varies from 20 mm to 75 mm and its length varies from 25 cm to 90 cm. the frequency range adopted is normally 3500 to 5000 rpm. The correct and incorrect methods of vibration using internal vibration needles are shown below.


No vibration
Form work
Radius of influence
Incorrect
(very small needle)
Incorrect
(small needle)
Correct
(exact size needle)
Radius of vibration
New layer
Correct method
Old layer
Incorrect method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EXTERME WEATHER CONCRETING:-

- in countries which experience extreme weather condition special problems are encountered in preparation, placement and curing of concrete.

- India has regions of extreme hot weather (hot –humid and hot-aird)as well as cold weather .

- The Indian standards dealing with extreme weather concreting are:-

  IS: 7861 (Part 1-1975)- Hot weather concreting

  IS: 7861 (Part 2-1981)- cold weather concreting

There are two major extreme weather conditions:-

- Hot weather concreting
- Cold weather concreting

HOT WEATHER CONCRETEING:-

- hot weather is any combination of the following conditions that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise causing detrimental results:

  - High concrete temperature;
  - Low relative humidity;
  - Wind speed
  - Solar radiation.
  - High ambient temperature.

Difficulties in Hot Weather:-

- Increased water demand.
- Accelerated slump loss.
- Increased rate of setting.
- Increased tendency of plastic shrinkage cracking.
- Critical need for prompt early curing

Temperature:-

- Certain precautions should be taken in order to reduce the difficulties in hot weather conditions.

- Temperature ranging from 10 to 15˚C is desirable, but such temperatures are not always practical.

- Many specifications require that concrete when placed should have a temperature of less than 29 to 32˚C.

Precautions Depends on:-

- Type of construction.
- Characteristics of the materials being used.
- The experience of placing and finishing crew in dealing with the atmospheric conditions in the site.

Precautions:-

- Use materials and mix proportions that have a good record in hot weather conditions.
- Cool the concrete or one or more of its ingredients.
- Use a concrete consistency that allows rapid placement.
- Reduce the time of transporting, placing, and finishing as possible.
- Schedule concrete placements to avoid extreme weather, such as at night or during favorable weather conditions.
- Consider the methods to limit moisture loss during placing and finishing such as sunshades, wind screens, fogging, and spraying.

Effect of High Concrete Temperature:-

- As concrete temperature increases there is a loss in slump that is often unadvisedly compensated for by adding water to the concrete at the jobsite. At higher temperatures a greater amount of water is required to hold slump constant than is needed at lower temperatures.

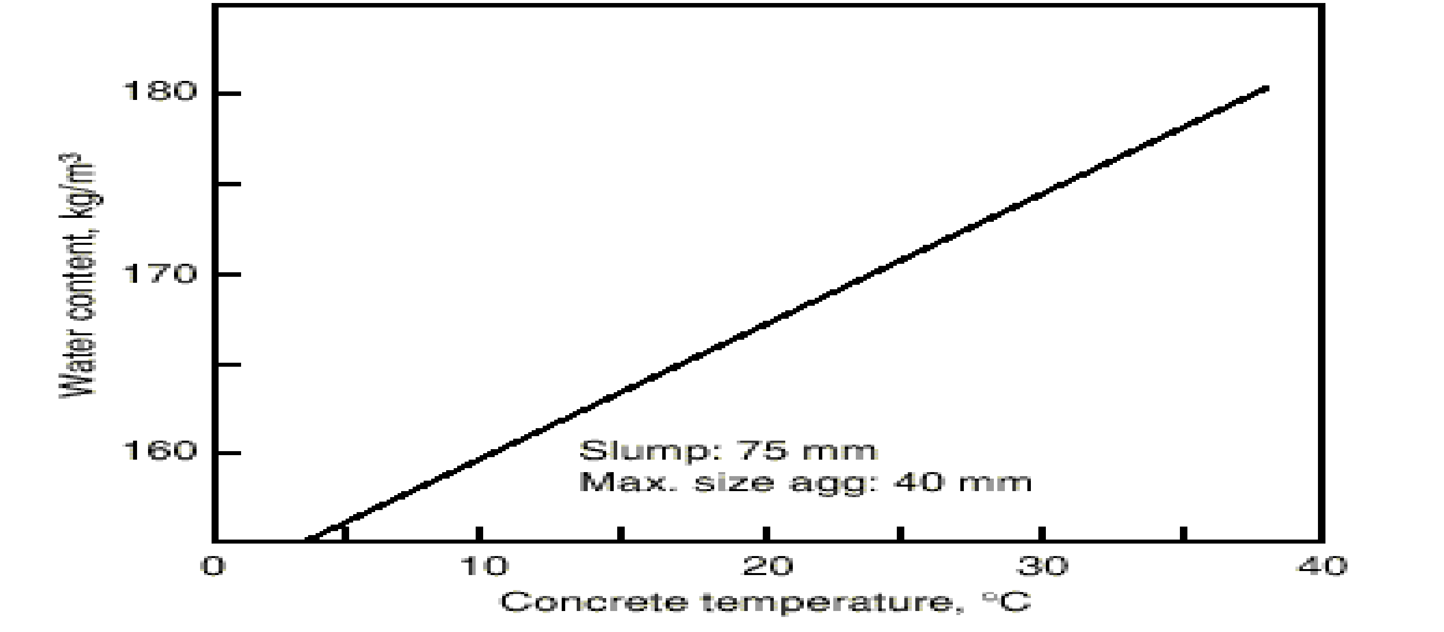

Fig. 13-2. The water requirement of a concrete mixture increases with an increase in concrete temperature (Bureau of Reclamation 1981).

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- **increase the rate of setting** and shorten the length of time within which the concrete can be transported, placed, and finished.
- Setting time can be reduced by 2 or more hours with a 10°C increase in concrete temperature

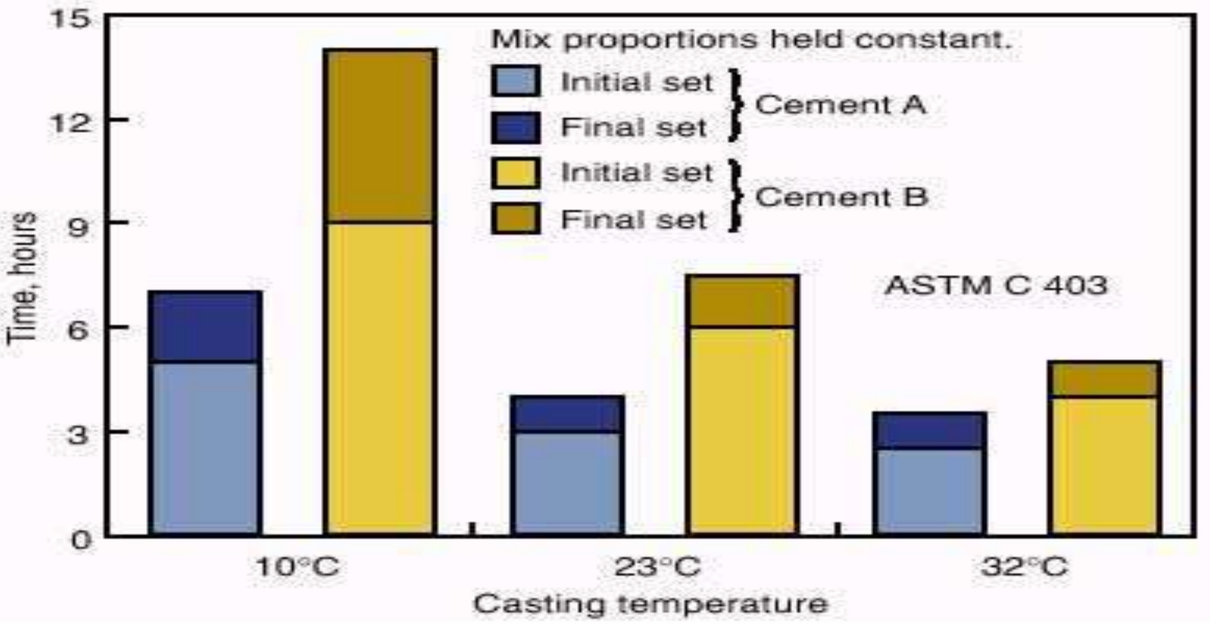


Fig. 13-3. Effect of concrete temperature on setting time (Burg 1996).

Cont..,

- There is an increased tendency for cracks to form both before and after hardening.
- Rapid evaporation of water from freshly placed concrete can cause plastic-shrinkage cracks before the surface has hardened.
- Cracks may also develop in the hardened concrete because of increased drying shrinkage due to higher water contents or thermal volume changes as the concrete cools.

Cooling Concrete Materials:-

- Lower the temperature of concrete materials before mixing.

- The contribution of each material is related to
  - Temperature.
  - Specific heat.
  - Quantity of each material.

Cont..,

adding ice for substituting water in the concrete mix

Fig. 13-6. Substituting ice for part of the mixing water will substantially lower concrete temperature. A crusher delivers finely crushed ice to a truck mixer reliably and quickly. (44236)

Cont..,

$$T\,(C^\circ) = \frac{0.22\,(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa} - 80 M_i}{0.22\,(M_a + M_c) + M_w + M_{wa} + M_i}$$

- where Mi is the mass in kilograms of ice

Table 13-2B. Effect of Ice (44 kg) on Temperature of Concrete

Material	Mass, M, kg	Specific heat kJ/kg • °C	Joules to vary temperature, 1°C	Initial temperature of material, T, °C	Total joules in material
	(1)	(2)	(3) Col.1 x Col. 2	(4)	(5) Col. 3 x Col. 4
Cement	335 (M_c)	0.92	308	66 (T_c)	20,328
Water	123 (M_w)	4.184	515	27 (T_w)	13,905
Total aggregate	1839 (M_a)	0.92	1692	27 (T_a)	45,684
Ice	44 (M_i)	4.184	184	0 (T_i)	0
			2699		
minus	44 (M_i) x heat of fusion, (335 kJ/kg) =				−14,740
					65,177

$$\text{Concrete temperature} = \frac{65{,}177}{2699} = 24.1°C$$

If ice is not adding the temp of concrete is 31.1˚C

Cont..,

- Adding liquid nitrogen

Fig. 13-1. Liquid nitrogen added directly into a truck mixer is an effective method of reducing concrete temperature for delivery to mass concrete placements or during hot-weather concreting. (69954)

Supplementary Cementitious Materials:-

- The use of supplementary materials (fly ash, ground granulated blast furnace slag) can help in hot weather conditions.

- These material slow the rate of setting as well as the rate of slump loss.

Preparation Before Placing:-

- Mixers, chutes, conveyor belts, hoppers, pump lines, and other equipments for handling concrete should be shaded, painted white, or covered with wet burlap to reduce solar heat.
- Forms, reinforcing steel, and subgrade should be fogged or sprinkled with cool water just before concrete is placed.
- Restrict placement of concrete to early morning, evening, or night time hours, especially in arid climates. This will help in minimizing thermal shrinkage and cracking of thick slabs and pavements.

Transporting, Placing, and Finishing:-

- Should be done as quickly as practical during hot weather.
- Delays contribute to the loss of slump and increase in concrete temperature.
- Prolonged mixing should be avoided.

Plastic Shrinkage Cracking :-

- Associated with hot-weather concreting,
- It can occur any time ambient conditions produce rapid evaporation of moisture from the concrete surface.
- These cracks occur when water evaporates from the surface faster than it can rise to the surface during the bleeding process.
- Rapid drying shrinkage creates tensile stresses in the surface that often result in short, irregular cracks.

- Plastic shrinkage cracking increases with:
  1. Low air temperature
  2. High concrete temperature
  3. Low humidity
  4. High wind speed

Fig. 13-7. Typical plastic shrinkage cracks. (1311)

Precautions to Minimize Plastic Shrinkage Cracking:-

1. Moisten concrete aggregates that are dry and absorptive.

2. Keep the concrete temperature low by cooling aggregates and mixing water.

3. Dampen the subgrade (**Fig. 13-9**) and fog forms prior to placing concrete.

4. Erect temporary windbreaks to reduce wind velocity over the concrete surface.

5. Erect temporary sunshades to reduce concrete surface temperatures.

6. Protect the concrete with temporary coverings, such as polyethylene sheeting, during any appreciable delay between placing and finishing.

7. Add plastic fibers to the concrete mixture to help reduce plastic shrinkage crack formation.

Methods to Minimize Plastic Drying Shrinkage:-

- Use of a fog spray will raise the relative humidity of the ambient air over the slab, thus reducing evaporation from the concrete.

- Fog nozzles atomize water using air pressure.

- Spray application of temporary moisture-retaining films (usually polymers).

- Reduction of time between placing and the start of curing by eliminating delays during construction.

Fig. 13-9. Dampening the subgrade, yet keeping it free of standing water will lessen drying of the concrete and reduce problems from hot weather conditions. (69955)

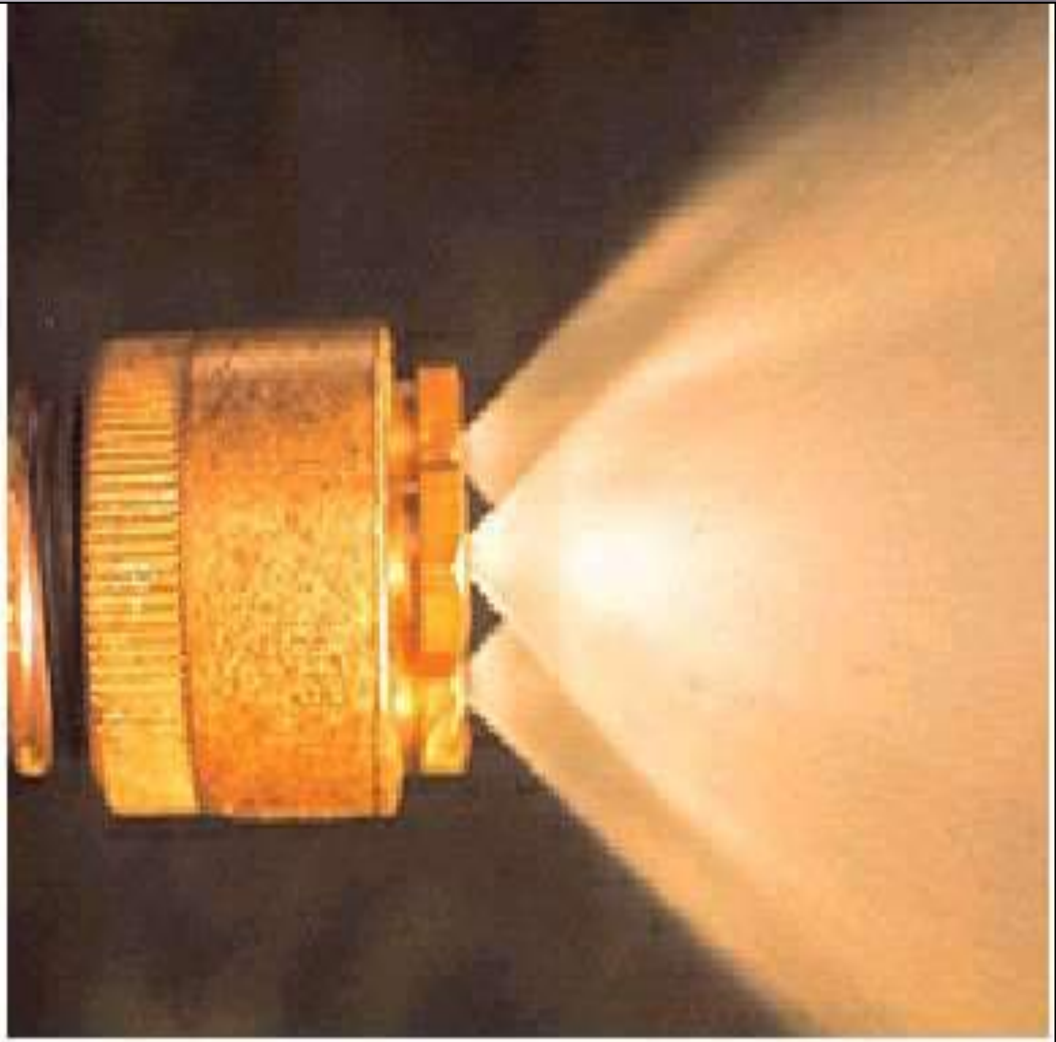


Fig. 13-10. Fog nozzle. (9853)

Fig. 13-11. Fogging cools the air and raises the relative humidity above flatwork to lessen rapid evaporation from the concrete surface, thus reducing cracking and improving surface durability. (69956)

Curing in Hot Weather :-

- The need for moist curing of concrete slabs is greatest during the first few hours after finishing.

- To prevent the drying of exposed concrete surfaces, moist curing should commence as soon as the surfaces are finished.

- When the air temperature is at or above 27°C, curing during the **basic curing** period should be accomplished by water spray or by using saturated absorptive fabric

- For mass concrete, curing should be by water for the basic curing period when the air temperature is at or above 20°C, in order to minimize the temperature rise of the concrete.

Admixtures:-

- **A retarding admixtures** can be very helpful in delaying the setting time, despite increased rate of slump loss resulting from their use.

- **A hydration control admixture** can be used to stop cement hydration and setting. As a general rule a 5°C to 9°C temperature rise per 45 kg of Portland cement can be expected from the heat of hydration.

Cold weather concreting:-

- Cold weather is defined by ACI Committee 306 as a period when for more than 3 successive days the average daily air temperature drops below 5°C (40°F) and stays below 10°C (50°F) for more than one-half of any 24 hour period.

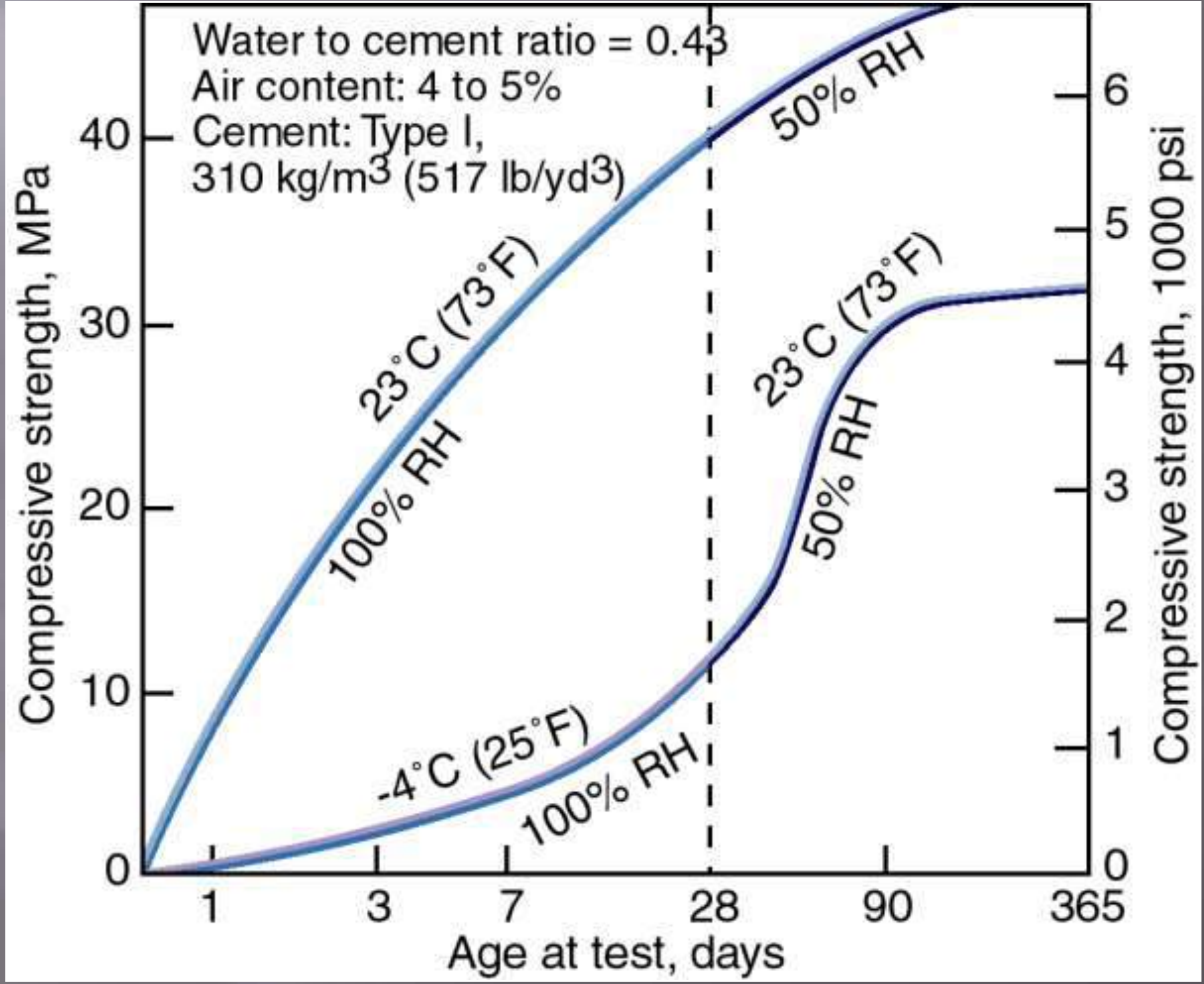
- Under these circumstances, all materials and equipment needed for adequate protection and curing .
- Normal concreting practices can be resumed once the ambient temperature is above 10°C (50°F) for more than half a day.

Cont..,

PREPERATION FOR CONCRETING

- Preparations should be made to protect the concrete; enclosures, windbreaks, portable heaters, insulated forms, and blankets should be ready to maintain the concrete temperature.
- Forms, reinforcing steel, and embedded fixtures must be clear of snow and ice at the time concrete is placed.
- Thermometers and proper storage facilities for test cylinders should be available to verify that precautions are adequate.

Effect of Temperature on Strength Development:-



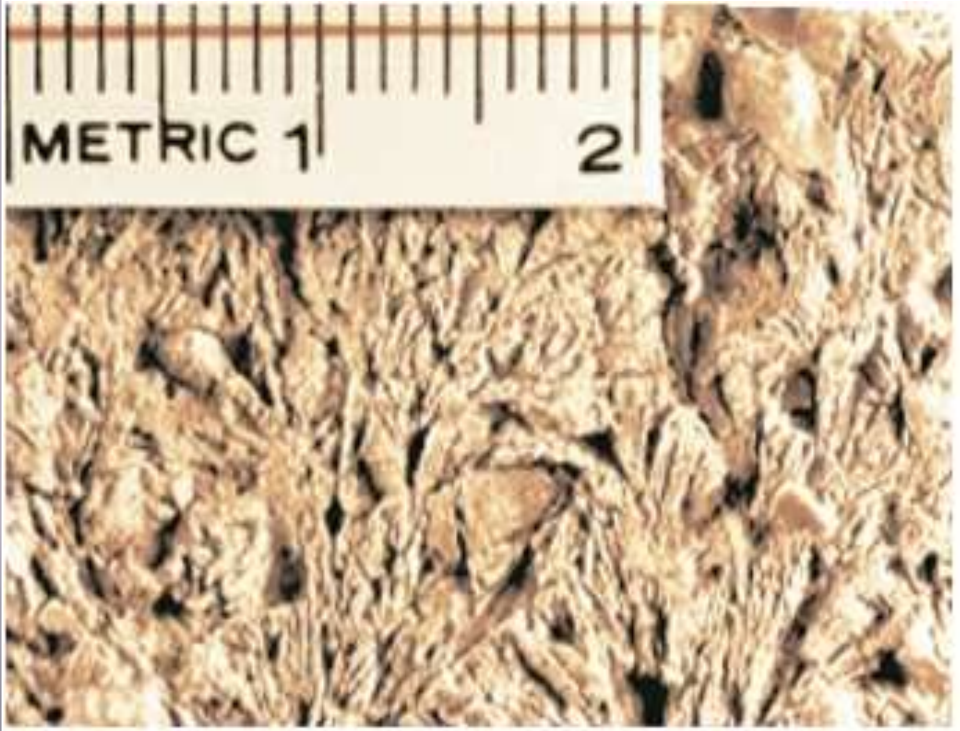
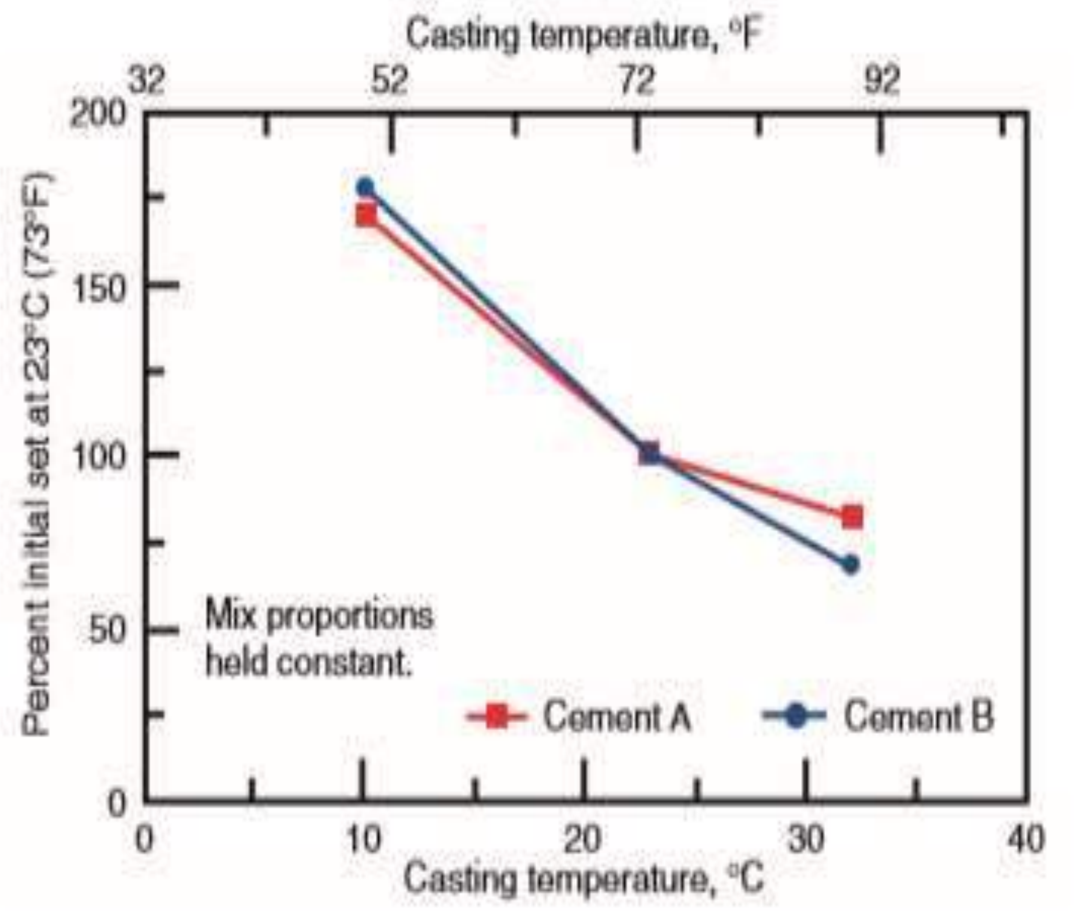


Fig. 14-2. Closeup view of ice impressions in paste of frozen fresh concrete. The ice crystal formations occur as unhardened concrete freezes. They do not occur in adequately hardened concrete. The disruption of the paste matrix by freezing can cause reduced strength gain and increased porosity. (44047)



Cont..,

EFFECT OF FROZEN WATER

- Up to 50% reduction of ultimate strength can occur if frozen -
  - Within a few hours
  - Before reaching a strength of 3.5 MPa (500 psi)

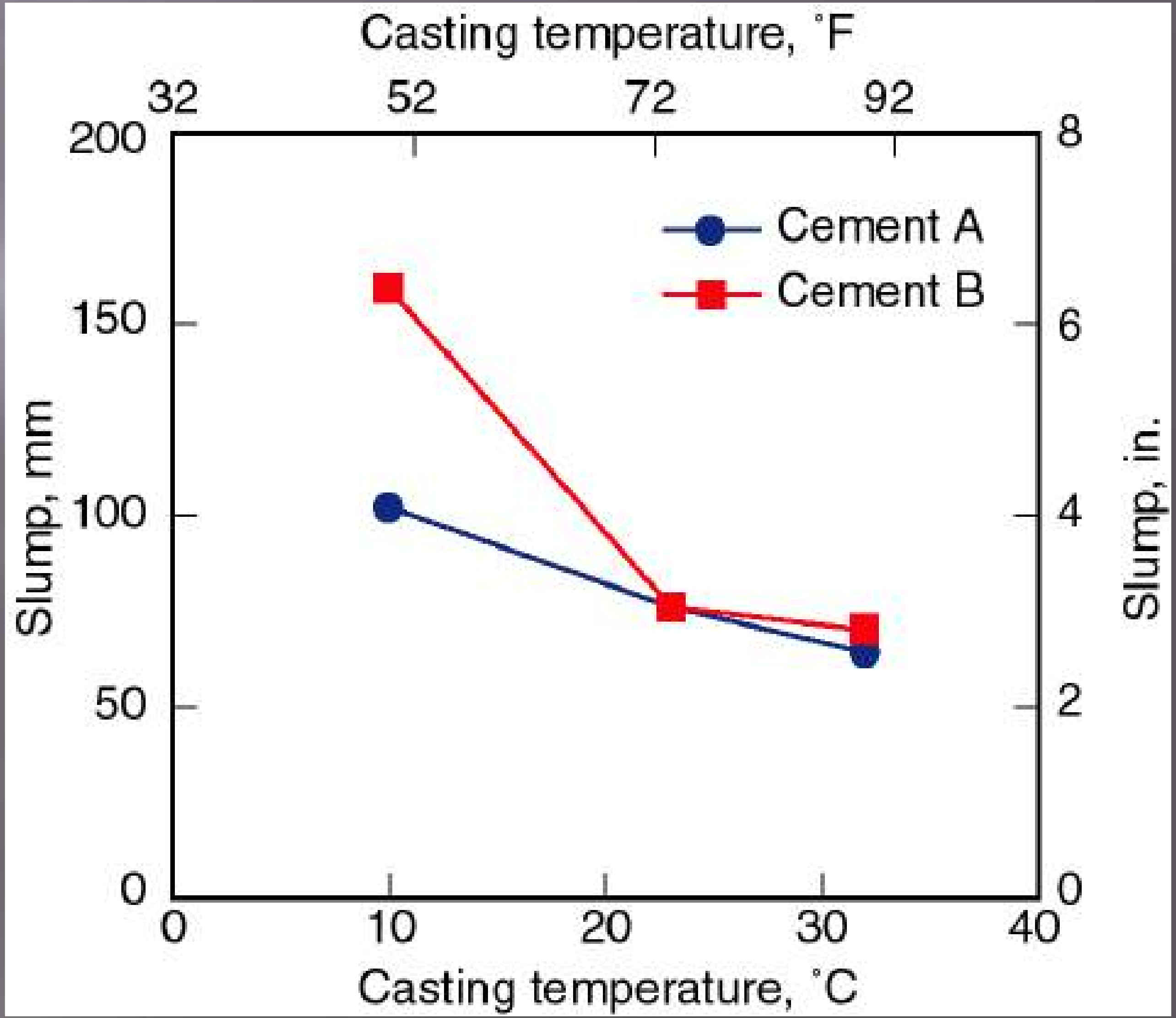
- Frozen only once at an early age -

  - Less resistance to weathering
  - More permeable

Thumb Rule

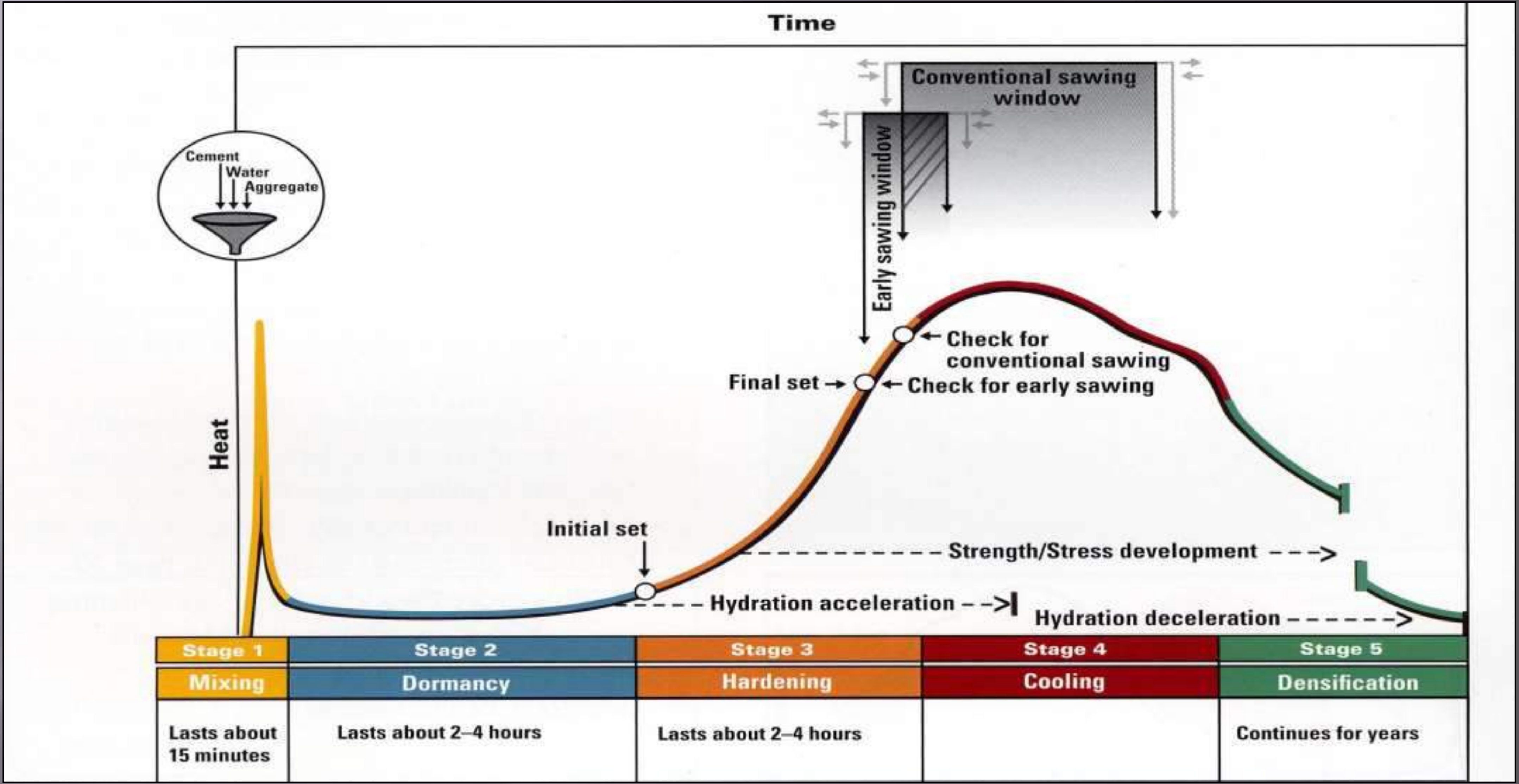
- "For every 10°C (18°F) reduction in concrete temperature, the times of setting of the concrete double, thus increasing the amount of time that the concrete is vulnerable to damage due to freezing."

Effect of Casting Temperature on Slump:-



HEAT OF HYDRATION:-

- Heat of hydration is useful in winter concreting as it contributes to the heat needed to provide a satisfactory curing temperature; often without other temporary heat sources, particularly in more massive elements.


Time
Conventional sawing window
Early sawing window
Cement
Water
Aggregate
Heat
Check for conventional sawing
Final set
Check for early sawing
Initial set
Strength/Stress development
Hydration acceleration
Hydration deceleration
Stage 1
Mixing
Lasts about 15 minutes
Stage 2
Dormancy
Lasts about 2–4 hours
Stage 3
Hardening
Lasts about 2–4 hours
Stage 4
Cooling
Stage 5
Densification
Continues for years

SPECIAL CONCRETE MIXTURES:-

- High strength at an early age is desirable in winter construction to reduce the length of time temporary protection is required.
- High-early-strength concrete can be obtained by using one or a combination of the following:

    1. Type III or HE high-early-strength cement
    2. Additional Portland cement (60 to 120 kg/m3 or 100 to 200 lb/yd3)
    3. Chemical accelerators

- Small amounts of an accelerator such as calcium chloride (at a maximum dosage of 2% by weight of Portland cement) can be used to accelerate the setting and early-age strength development of concrete in cold weather.
- Accelerators containing chlorides should not be used where there is an in-service potential for corrosion

Cont..,

- Specially designed accelerating admixtures allow concrete to be placed at temperatures down to -7°C (20°F).
- The purpose of these admixtures is to reduce the time of initial setting, but not necessarily to speed up strength gain. Covering concrete to keep out moisture and to retain heat of hydration is still necessary.
- traditional antifreeze solutions are used .

AIR-ENTRAINED CONCRETE:-

- To reduce freezing and thawing we can use air entrained concrete .
- Air entrainment provides the capacity to absorb stresses due to ice formation within the concrete.

Temperature of Materials on Concrete Temperatures:-

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

T = temperature of the freshly mixed concrete, a°C (°F)

T_a, T_c, T_w, and T_{wa} = temperature in °C (°F) of aggregates, cement, added mixing water, and free water on aggregates, respectively

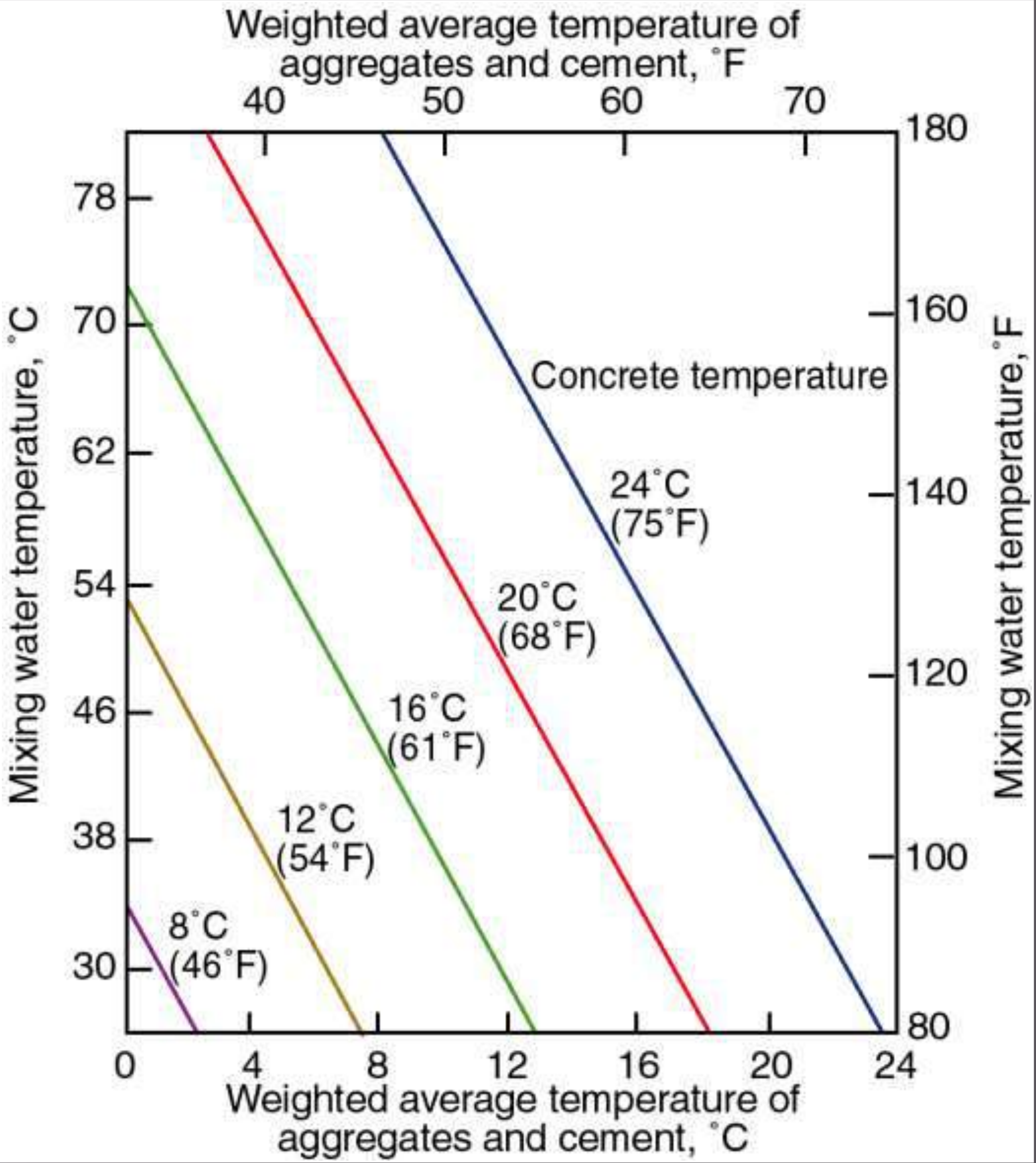
M_a, M_c, M_w, and M_{wa} = mass, kg (lb), of aggregates, cementing materials, added mixing water, and free water on aggregates, respectively

Heating Materials:-

- Water
- Aggregates

Heating Mix Water and aggregate:-

Mix data:
Aggregate = 1360 kg (3000 lb)
Moisture in aggregate = 27 kg (60 lb)
Added mixing water = 108 kg (240 lb)
Portland cement = 256 kg (564 lb)



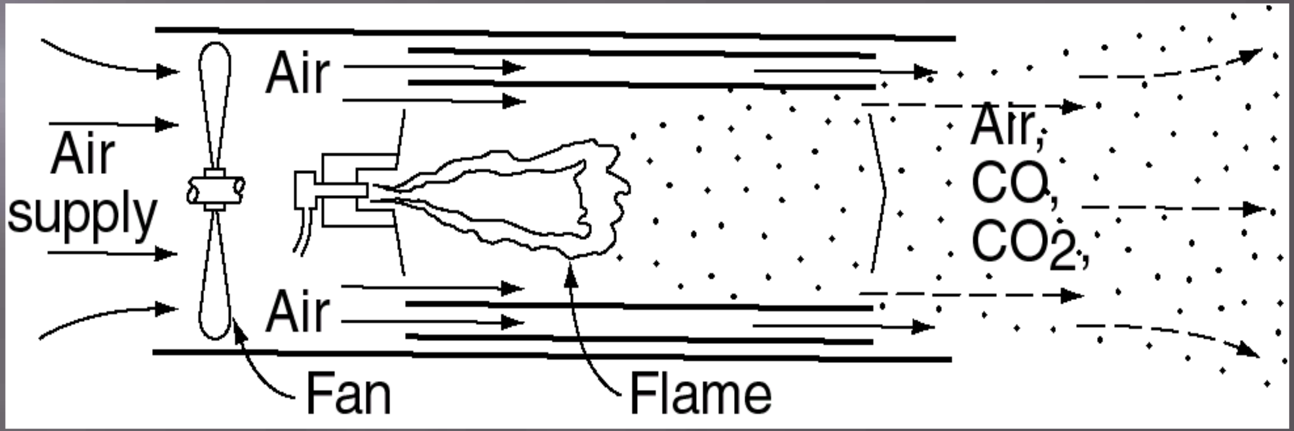
Retaining Heat of Hydration:-

Insulating Blankets:-

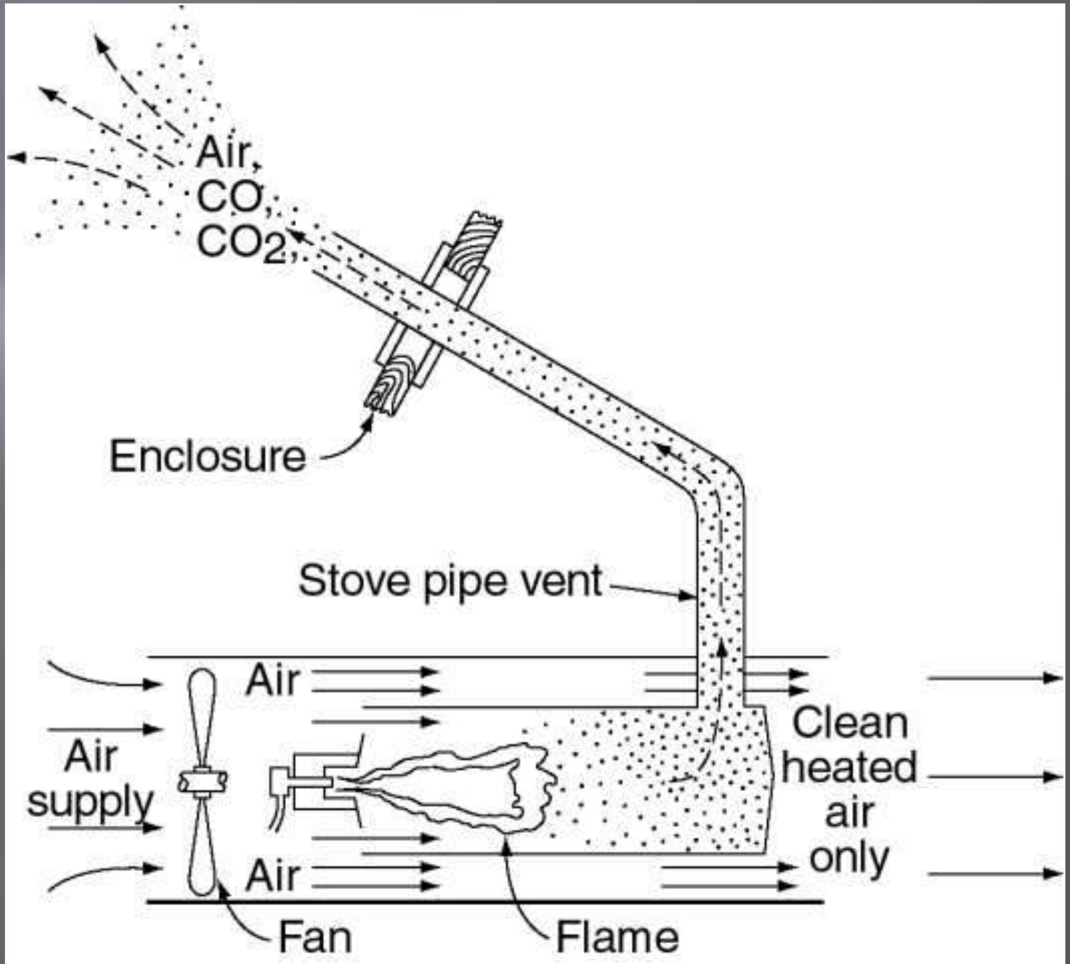
Enclosures:-

- Wood
- Canvas
- Tarpaulins
- Polyethylene Film

Direct-Fired Heater:-



Indirect-Fired Heater:-



Concrete Mix Design Procedure as per IS 10262 – 2009

Procedure for concrete mix design requires following step by step process:

1. Calculation of target strength of concrete
2. Selection of water-cement ratio
3. Determination of aggregate air content
4. Selection of water content for concrete
5. Selection of cement content for concrete
6. Calculation of aggregate ratio
7. Calculation of aggregate content for concrete
8. Trial mixes for testing concrete mix design strength

Step 1: Calculation of Target Strength of Concrete

Target strength is denoted by f_t which is obtained by characteristic compressive strength of concrete at 28 days (f_{ck}) and value of standard deviation (s)

$$\mathbf{f_t = f_{ck} + 1.65\ s}$$

Standard deviation can be taken from below table

Grade of concrete	**Standard deviation (N/mm^2)**
M10	3.5
M15	3.5
M20	4.0
M25	4.0
M30	5.0
M35	5.0
M40	5.0
M45	5.0
M50	5.0

Step 2: Selection of Water-Cement Ratio

Ratio of the weight of water to weight of cement in the concrete mix is water-cement ratio. It is the important consideration in concrete mix design to make the concrete workable. Water cement ratio is selected from the below curve for 28 days characteristic compressive strength of concrete.

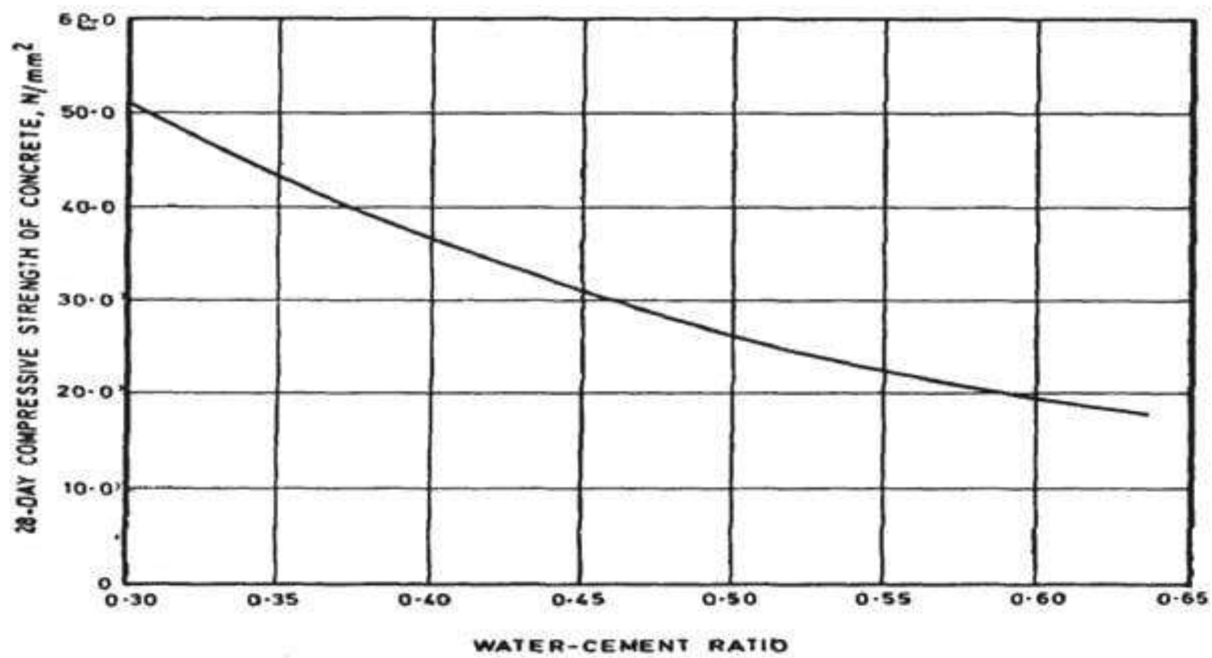


Fig: Selection of Water-Cement Ratio for Concrete Mix Design

Similarly, we can determine the water-cement ration from the 7-day concrete strength, the curves are divided on the basis of strength from water cement ratio is decided. Which is observed from the below graph.

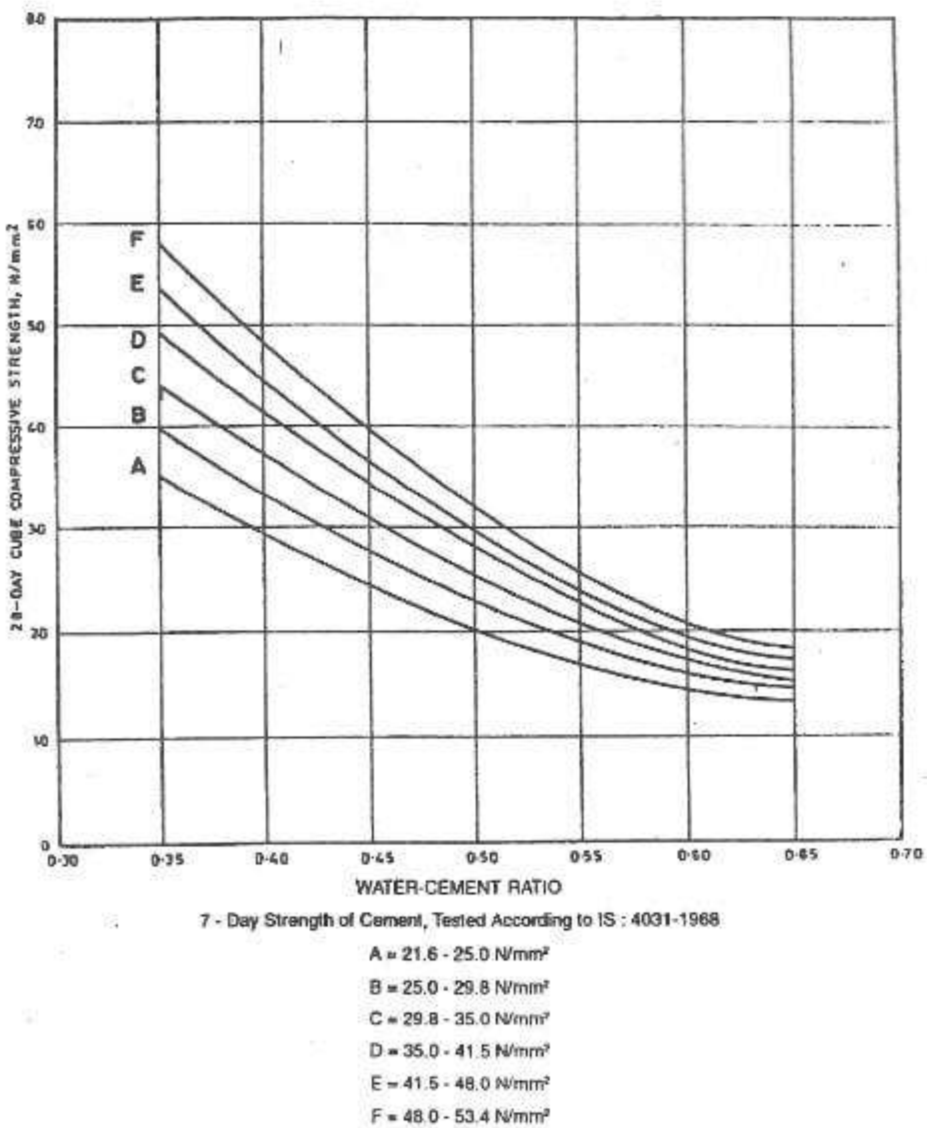


Fig: Concrete Compressive Strength vs. Water Cement Ratio

Step 3: Determination of Aggregate Air content

Air content in the concrete mix is determined by the nominal maximum size of aggregate used. Below table will give the entrapped air content in percentage of volume of concrete.

Nominal maximum size of aggregate	**Air content (% of volume of concrete)**
10mm	5%
20mm	2%
40mm	1%

Step 4: Selection of Water Content for Concrete

Select the water content which is useful to get required workability with the help of nominal maximum size of aggregate as given in below table. The table given below is used when only angular shaped aggregates are used in concrete as well as the slump should be 25 to 50mm.

Nominal maximum size of aggregate	**Maximum water content**
10mm	208
20mm	186
40mm	165

If the shape of aggregate or slump value is differing from above, then some adjustments are required as follows.

Condition	**Adjustment**
Sub angular aggregate	Reduce the selected value by 10%
Gravel with crushed stone	Reduce the selected value by 20kg
Rounded gravel	Reduce the selected value by 25kg
Using plasticizer	Decrease the selected value by 5-10%
Using superplasticizer	Decrease the selected value by 20-30%
For every increment of 25mm slump	Increase the selected value by 3%

Step 5: Selection of Cement Content for Concrete

Water – cement ratio is determined in step2 and quantity of water is determined in step -4. So, we can easily calculate the quantity of cement from these two conditions. But, the value obtained should satisfy the minimum conditions as given in the below table. The greater of the two values is decided as quantity of cement content.

Cement Content for Plain Cement Concrete

Exposure	**Plain Cement Concrete (P.C.C)**		
	Minimum Cement Content Kg/m^3	**Max Free Water – Cement Ratio**	**Minimum Grade of Concrete**
Mild	220	0.6	–
Moderate	240	0.6	M15
Severe	250	0.5	M20
Very severe	260	0.45	M20
Extreme	280	0.4	M25

Cement Content for Reinforced Concrete

Exposure	**Reinforced Cement Concrete (RCC)**		
	Minimum	**Max Free Water**	**Minimum Grade**

	Cement Content Kg/m^3	–Cement Ratio	of Concrete
Mild	300	0.55	M20
Moderate	300	0.5	M25
Severe	320	0.45	M30
Very severe	340	0.45	M35
Extreme	360	0.4	M40

Step 6: Calculation of Aggregate Ratio

For the given nominal maximum size of aggregate, we can calculate the ratio of volumes of coarse aggregate and volume of total aggregates for different zones of fine aggregates from the below table.

Nominal maximum size of aggregate	Ratio of volume of coarse aggregate and volume of total aggregate for different zones of fine aggregate			
	Zone – 1	Zone – 2	Zone – 3	Zone – 4
10mm	0.44	0.46	0.48	0.50
20mm	0.6	0.62	0.64	0.66
40mm	0.69	0.71	0.73	0.75

Step 7: Calculation of Aggregate Content for Concrete

We already determine the coarse aggregate volume ratio in the total aggregate volume. So, it is very easy that, 1 – volume of coarse aggregate will give the volume of fine aggregate. Alternatively, there are some formulae to find the volume of fine and coarse aggregates as follows.

Mass of fine aggregate is calculated from below formula

$$V = [W + \frac{C}{Gc} + (\frac{1}{(1-P)} \; X \; \frac{F.A}{Gf})] \times \frac{1}{1000}$$

Similarly, mass of coarse aggregate is calculated from below formula.

$$V = [W + \frac{C}{Gc} + (\frac{1}{P} \; X \; \frac{C.A}{Gca})] \times \frac{1}{1000}$$

Where, V = volume of concrete

W = water content

C = cement content

Gc = sp. Gravity of cement

P = aggregate ration obtained in step6

F.A & C.A = masses of fine and coarse aggregates

Gf & Gca = sp. Gravities of fine and coarse aggregates.

Step 8: Trial Mixes for Testing Concrete Mix Design Strength

Based on the values obtained above, conduct a trail test by making at least 3 cubes of 150mm size as per above standards. Test that cubes and verify whether the required strength is gained or not. If not, redesign the mix with proper adjustments until required strength of cube occurs.

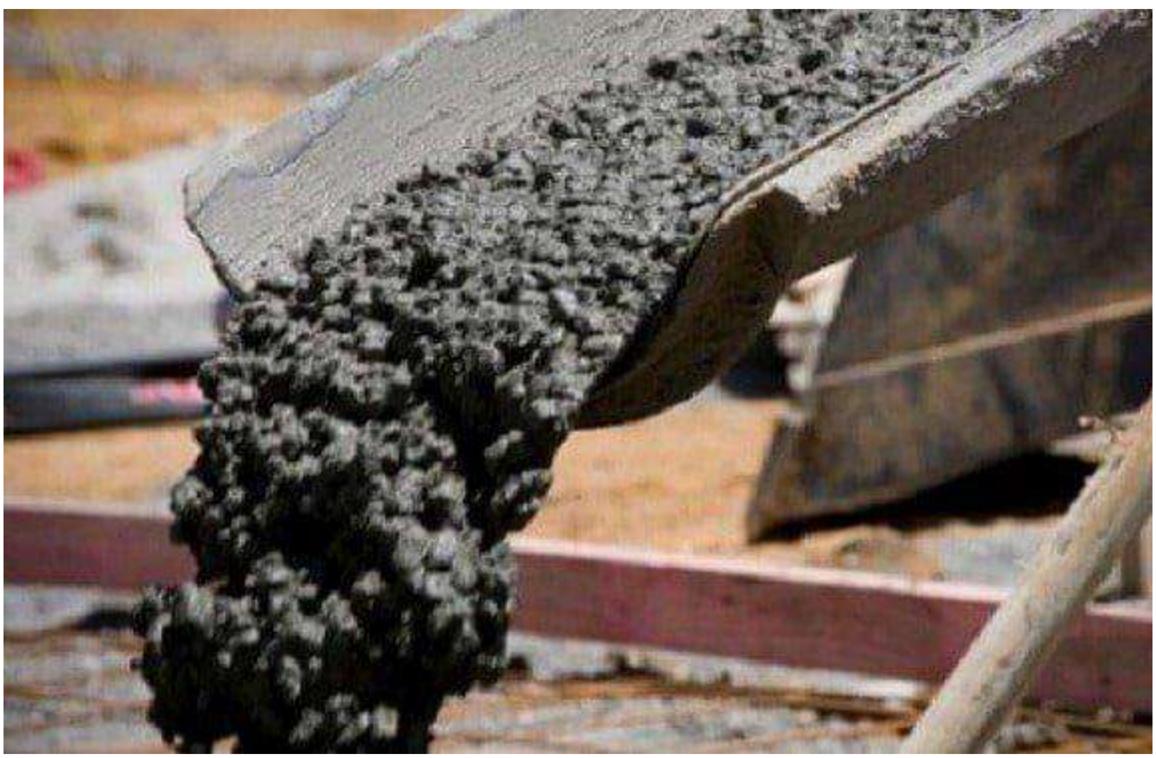
Concrete Mix Design Calculation for M20, M25, M30 Concrete with Procedure & Example

Concrete mix design is the process of finding right proportions of cement, sand and aggregates for concrete to achieve target strength in structures. So, concrete mix design can be stated as Concrete Mix = Cement:Sand:Aggregates.

The concrete mix design involves various steps, calculations and laboratory testing to find right mix proportions. This process is usually adopted for structures which requires higher grades of concrete such as M25 and above and large construction projects where quantity of concrete consumption is huge..

Benefits of concrete mix design is that it provides the right proportions of materials, thus making the concrete construction economical in achieving required strength of structural members. As, the quantity of concrete required for large constructions are huge, economy in quantity of materials such as cement makes the project construction economical.

Concrete Mix design of M20, M25, M30 and higher grade of concrete can be calculated from example below.



Concrete Mix Design

Data Required for Concrete Mix Design

(i) Concrete Mix Design Stipulation

(a) Characteristic compressive strength required in the field at 28 days grade designation — M 25

(b) Nominal maximum size of aggregate — 20 mm

(c) Shape of CA — Angular

(d) Degree of workability required at site — 50-75 mm (slump)

(e) Degree of quality control available at site — As per IS:456

(f) Type of exposure the structure will be subjected to (as defined in IS: 456) — Mild

(g) Type of cement: PSC conforming IS:455

(h) Method of concrete placing: pump able concrete

(ii) Test data of material (to be determined in the laboratory)

(a) Specific gravity of cement — 3.15

(b) Specific gravity of FA — 2.64

(c) Specific gravity of CA — 2.84

(d) Aggregate are assumed to be in saturated surface dry condition.

(e) Fine aggregates confirm to Zone II of IS – 383

Procedure for Concrete Mix Design of M25 Concrete

Step 1 — Determination Of Target Strength

Himsworth constant for 5% risk factor is 1.65. In this case standard deviation is taken from IS:456 against M 20 is 4.0.

$$f_{target} = f_{ck} + 1.65 \times S$$

$$= 25 + 1.65 \times 4.0 = 31.6 \text{ N/mm}^2$$

Where,

S = standard deviation in N/mm^2 = 4 (as per table -1 of IS 10262- 2009)

Step 2 — Selection of water / cement ratio:-

From Table 5 of IS 456, (page no 20)

Maximum water-cement ratio for Mild exposure condition = 0.55

Based on experience, adopt water-cement ratio as 0.5.

0.5<0.55, hence OK.

Step 3 — Selection of Water Content

From Table 2 of IS 10262- 2009,

Maximum water content = 186 Kg (for Nominal maximum size of aggregate — 20 mm)

Table for Correction in water content

Parameters	Values as per Standard reference condition	Values as per Present Problem	Departure	Correction in Water Content
Slump	25-50 mm	50-75	25	(+3/25) x 25 = +3
Shape of Aggregate	Angular	Angular	Nil	–
			Total	+3

Estimated water content = 186+ (3/100) x 186 = 191.6 kg /m^3

Step 4 — Selection of Cement Content

Water-cement ratio = 0.5

Corrected water content = 191.6 kg /m^3

Cement content =

From Table 5 of IS 456,

Minimum cement Content for mild exposure condition = 300 kg/m^3

383.2 kg/m^3 > 300 kg/m^3, hence, OK.

This value is to be checked for durability requirement from IS: 456.

In the present example against mild exposure and for the case of reinforced concrete the minimum cement content is 300 kg/m^3 which is less than 383.2 kg/m^3. Hence cement content adopted = 383.2 kg/m^3.

As per clause 8.2.4.2 of IS: 456

Maximum cement content = 450 kg/m^3.

Step 5: Estimation of Coarse Aggregate proportion:-

From Table 3 of IS 10262- 2009,

For Nominal maximum size of aggregate = 20 mm,

Zone of fine aggregate = Zone II

And For w/c = 0.5

Volume of coarse aggregate per unit volume of total aggregate = 0.62

Table for correction in estimation of coarse aggregate proportion

Parameter	**Values as per Standard reference condition**	**Values as per present problem**	**Departure**	**Correction in Coarse Aggregate proportion**	**Remarks**
W/c	0.5	0.5	Nil	–	See Note 1
Workability	–	pump able concrete	–	-10%	See Note 2
			Total	**-10%**	

Note 1: For every ±0.05 change in w/c, the coarse aggregate proportion is to be changed by 0.01. If the w/c is less than 0.5 (standard value), volume of coarse aggregate is required to be increased to reduce the fine aggregate content. If the w/c is more than 0.5, volume of coarse aggregate is to be reduced to increase the fine aggregate content. If coarse aggregate is not angular, volume of coarse aggregate may be required to be increased suitably, based on experience.

Note 2: For pump able concrete or congested reinforcement the coarse aggregate proportion may be reduced up to 10%.

Hence,

Volume of coarse aggregate per unit volume of total aggregate = 0.62 x 90% = 0.558

Volume of fine aggregate = 1 – 0.558 = 0.442

Step 6: Estimation of the mix ingredients

a) Volume of concrete = 1 m^3

b) Volume of cement = (Mass of cement / Specific gravity of cement) x (1/100)

= (383.2/3.15) x (1/1000) = 0.122 m^3

c) Volume of water = (Mass of water / Specific gravity of water) x (1/1000)

= (191.6/1) x (1/1000) = 0.1916 m^3

d) Volume of total aggregates = a – (b + c) = 1 – (0.122 + 0.1916) = 0.6864 m^3

e) Mass of coarse aggregates = 0.6864 x 0.558 x 2.84 x 1000 = 1087.75 kg/m^3

f) Mass of fine aggregates = 0.6864 x 0.442 x 2.64 x 1000 = 800.94 kg/m^3

Concrete Mix proportions for Trial Mix 1

Cement = 383.2 kg/m^3

Water = 191.6 kg/m^3

Fine aggregates = 800.94 kg/m^3

Coarse aggregate = 1087.75 kg/m^3

W/c = 0.5

For trial -1 casting of concrete in lab, to check its properties.

It will satisfy durability & economy.

For casting trial -1, mass of ingredients required will be calculated for 4 no's cube assuming 25% wastage.

Volume of concrete required for 4 cubes = 4 x (0.15^3 x1.25) = 0.016878 m^3

Cement = (383.2 x 0.016878) kg/m^3 = 6.47 kg

Water = (191.6 x 0.016878) kg/m^3 =3.23 kg

Coarse aggregate = (1087.75 x 0.016878) kg/m^3 =18.36 kg

Fine aggregates = (800.94 x 0.016878) kg/m^{3} = 13.52 kg

Step 7: Correction due to absorbing / moist aggregate:-

Since the aggregate is saturated surface dry condition hence no correction is required.

Step 8: Concrete Trial Mixes:-

Concrete Trial Mix 1:

The mix proportion as calculated in Step 6 forms trial mix1. With this proportion, concrete is manufactured and tested for fresh concrete properties requirement i.e. workability, bleeding and finishing qualities.

In this case,

Slump value = 25 mm

Compaction Factor = 0.844

So, from slump test we can say,

Mix is cohesive, workable and had a true slump of about 25 mm and it is free from segregation and bleeding.

Desired slump = 50-75 mm

So modifications are needed in trial mix 1 to arrive at the desired workability.

Concrete Trial Mix 2:

To increase the workability from 25 mm to 50-75 mm an increase in water content by +3% is to be made.

The corrected water content = 191.6 x 1.03 = 197.4 kg.

As mentioned earlier to adjust fresh concrete properties the water cement ratio will not be changed. Hence

Cement Content = (197.4/0.5) = 394.8 kg/m^3

Which also satisfies durability requirement.

Volume of all in aggregate = 1 – [{394.8/(3.15×1000)} + {197.4/(1 x 1000)}] = 0.6773 m^3

Mass of coarse aggregate = 0.6773 x 0.558 x 2.84 x 1000 = 1073.33 kg/m^3

Mass of fine aggregate = 0.6773 x 0.442 x 2.64 x 1000 = 790.3 kg/m^3

Concrete Mix Proportions for Trial Mix 2

Cement = 384.8 kg/m^3

Water = 197.4 kg/m^3

Fine aggregate =790.3 kg/m^3

Coarse aggregate = 1073.33 kg/m^3

For casting trial -2, mass of ingredients required will be calculated for 4 no's cube assuming 25% wastage.

Volume of concrete required for 4 cubes = 4 x (0.15^3 x1.25) = 0.016878 m^3

Cement = (384.8 x 0.016878) kg/m^3 = 6.66 kg

Water = (197.4 x 0.016878) kg/m^3 =3.33 kg

Coarse aggregate = (1073.33 x 0.016878) kg/m^3 =18.11 kg

Fine aggregates = (790.3 x 0.016878) kg/$m^{3\,=}$ 13.34 kg

In this case,

Slump value = 60 mm

Compaction Factor = 0.852

So, from slump test we can say,

Mix is very cohesive, workable and had a true slump of about 60 mm.

It virtually flowed during vibration but did not exhibit any segregation and bleeding.

Desired slump = 50-75 mm

So , it has achieved desired workability by satisfying the requirement of 50-75 mm slump value .

Now , we need to go for trial mix-3 .

Concrete Trial Mix 3:

In case of trial mix 3 water cement ratio is varied by +10% keeping water content constant. In the present example water cement ratio is raised to 0.55 from 0.5.

An increase of 0.05 in the w/c will entail a reduction in the coarse aggregate fraction by 0.01.

Hence the coarse aggregate as percentage of total aggregate = 0.558 – 0.01 = 0.548

W/c = 0.55

Water content will be kept constant.

Cement content = (197.4/0.55) = 358.9 kg/m^3

Hence, volume of all in aggregate

= 1 – [{(358.9/(3.15 x 1000)} + (197.4/1000)] =0.688 m^3

Mass of coarse aggregate = 0.688 x 0.548 x 2.84 x 1000 = 1070.75 kg/m^3

Mass of fine aggregate = 0.688 x 0.452 x 2.64 x 1000 = 821 kg/m^3

Concrete Mix Proportions of Trial Mix 3

Cement = 358.9 kg/m^3

Water = 197.4 kg/m^3

FA = 821 kg/m^3

CA = 1070.75 kg/m^3

For casting trial -3, mass of ingredients required will be calculated for 4 no’s cube assuming 25% wastage.

Volume of concrete required for 4 cubes = 4 x (0.15^3 x1.25) = 0.016878 m^3

Cement = (358.9 x 0.016878) kg/m^3 = 6.06 kg

Water = (197.4 x 0.016878) kg/m^3 =3.33 kg

Coarse aggregate = (1070.75 x 0.016878) kg/m^3 =18.07 kg

Fine aggregates = (821 x 0.016878) kg/m$^{3 =}$ 13.85 kg

In this case,

Slump value = 75 mm

Compaction Factor = 0.89

So, from slump test we can say,

Mix is stable, cohesive, and workable and had a true slump of about 75 mm.

Desired slump = 50-75 mm

So , it has achieved desired workability by satisfying the requirement of 50-75 mm slump value .

Now , we need to go for trial mix-4.

Concrete Trial Mix 4:

In this case water / cement ratio is decreased by 10% keeping water content constant.

W/c = 0.45

A reduction of 0.05 in w/c will entail and increase of coarse aggregate fraction by 0.01.

Coarse aggregate fraction = 0.558 +.01 =.568

W/c = 0.45 and water content = 197.4 kg/m^3

Cement content = (197.4/0.45) = 438.7 kg/m^3

Volume of all in aggregate

= 1 – [{438.7/(3.15 x 1000)} + (197.4/1000)] = 0.664 m^3

Mass of coarse aggregate = 0.664 x 0.568 x 2.84 x 1000 = 1071.11 kg/m^3

Mass of fine aggregate = 0.664 x 0.432 x 2.64 x 1000 = 757.28 kg/m^3

Concrete Mix Proportions of Trial Mix 4

Cement = 438.7 kg/m^3

Water = 197.4 kg/m^3

FA = 757.28 kg/m^3

CA = 1071.11 kg/m^3

For casting trial -4, mass of ingredients required will be calculated for 4 no's cube assuming 25% wastage.

Volume of concrete required for 4 cubes = 4 x (0.15^3 x1.25) = 0.016878 m^3

Cement = (438.7 x 0.016878) kg/m^3 = 7.4 kg

Water = (197.4 x 0.016878) kg/m^3 =3.33 kg

Coarse aggregate = (1071.11 x 0.016878) kg/m^3 =18.07 kg

Fine aggregates = (757.28 x 0.016878) kg/$m^{3\,=}$ 12.78 kg

A local correction due to moisture condition of aggregate is again applied on this proportions. With corrected proportions three concrete cubes are cast and tested for 28 days compressive strength.

A summary of all the trial mixes is given in the following Table.

Recommended mix proportion of ingredients for grade of concrete M25:

From Compressive Strength vs. c/w graph for target strength 31.6 MPa we get,

W/c = 0.44

water content = 197.4 kg/m^3

Cement content = (197.4/0.44) = 448.6 kg/m^3

Volume of all in aggregate

= 1 – [{448.6/(3.15 x 1000)} + (197.4/1000)] = 0.660 m^3

A reduction of 0.05 in w/c will entail and increase of coarse aggregate fraction by 0.01.

Coarse aggregate fraction = 0.558 +.01 =.568

Volume of fine aggregate = 1 – 0.568 = 0.432

Mass of coarse aggregate = 0.660 x 0.568 x 2.84 x 1000 = 1064.65 kg/m^3

Mass of fine aggregate = 0.660 x 0.432 x 2.64 x 1000 = 752.71 kg/m^3

contraction because of direct exposure to atmosphere. It is subjected to expansion and contraction during day and night or from season to season which may cause pushing and pulling to the supporting load bearing walls. This may lead to cracking of masonry walls. Thus the effect of temperature stresses can be reduced by providing expansion joints.

(ii) Deck slabs of a bridge is always provided with expansions joints and roller bearings for taking the temperature stresses.

(iii) Property designed reinforcement can take the expansion and contraction in concrete.

9.12. DEFECTS IN CONCRETE

Concrete is considered as a strong and durable building material but defects can occur in the concrete due to number of seasons during its life span. Even if, best material and strict quality control is employed to the concrete manufacturing, there is every possibility that it may lead to defects and deterioration.

The defects can be broadly classified into two categories :

1. Macro defects

2. Micro defects.

1. Macro defects :

These defects are clearly visible to the naked eye, for example, honey combing, formation of air pockets, bulges, projections, chipping, etc.

If these defects are present, concrete may have low strength and will rapidly deteriorate due to easy ingress of water and other chemicals. Invariably, structure will require repairs within few years of its construction. These defects if observed should be promptly attended to.

Causes will have to be analysed and defects removed before doing any additional protective treatment. The main causes of these defects are generally due to inadequacies in design and construction practices.

2. Micro defects :

These types of defects are not visible to the naked eye. For example, fine cracks, fine voids, fine capillary tubes, etc.

They are usually very fine voids caused by large capillary pores resulting from the use of low grades (strength) of concrete with high water to cement ratio. Fine cracks are generally present in concrete. They do not pose a serious threat to deterioration of concrete, initially, as they are generally not deep and are discontinuous. With lapse of time due to variation in temperatures, change in weathering conditions, change in loading conditions, they increases in depth, length and width and combine with other fine cracks to create continuous passage for moisture, chlorides, sulphates and other chemicals from the environment to enter and start corrosion of steel in concrete and other deleterious reactions.

Both macro and micro defects in concrete are harmful to the health of buildings and can cause deterioration of concrete depending on the extent of their presence, environmental conditions around the maintenance done during its life cycle.

Causes of Defects

(i) Poor quality of materials

(ii) Poor design of concrete mix

(iii) Poor construction practices/workmanship.

(iv) Lack of quality control

(v) Plastic shrinkage in freshly laid concrete mix.

(vi) Thermal stresses due to expansion and contraction.

(vii) Adverse weathering conditions

(viii) Natural calamities/accidents and subsidences.

(ix) Change in loading conditions or addition and alterations.

(x) Lack of repair and maintenance of a building

(xi) Exposure to chemicals.

(xii) Improper architectural and structural designs

(xiii) Aging effect of structures.

A. REPAIR AND MAINTENANCE OF CONCRETE

Repair and maintenance of concrete structure plays a vital role and is a governing factor in increasing the life of a structure.

The method and process involved in removing the defects in concrete is termed as repairing of concrete. Repair work is carried out as soon as the defects become visible on the surface of concrete. When periodic routine repair work is carried out it is termed as routine repair work.

The art of preserving and keeping the concrete structure in order, to increase its useful life is termed as maintenance of concrete.

The work of repair and maintenance must be carried out annually and that also before the commencing of monsoon season.

Identification and methods of repairing : Depending upon the extent of deterioration or damage, the building has to undergo repairs. Cracks in RCC members rapidly cause deterioration of the structure as they provide easy entry of moisture and other aggressive chemicals. This also ultimately results in corrosion and spalling of concrete.

Deteriorated or damaged building needs inevitable repairs to extend its useful life and to prevent collapse. If due to any reason the repairs are delayed, the repair cost increases considerably and further delay can even cause collapse.

Repairable concrete is to be identified and different methods of repair are recommended depending upon the seriousness of the defect.

METHODS OF REPAIRING

A. REPAIRING : Different methods are available for repairing new and old concrete works :

1. Dry pack method
2. Mortar replacement method
3. Concrete replacement method.

1. Dry Pack method : It is generally adopted for small holes of depth not exceeding 20 mm. The procedure adopted for repairing includes the following steps.

(i) Clean the hole properly with the help of compressed air so that there is no loose material.

(ii) Apply a layer of cement grout (mixture of cement and sand in a ratio 1 : 1 over the dried surface.

(iii) Immediately after that provide a dry pack material over the cement grout. Dry pack consist of cement and sand in the ratio 1 : 2. Water required should be properly designed so as to avoid shrinkage cracks.

(iv) Compact the dry pack so that the thickness of compacted material does not exceed 1 cm.

(v) Make the upper layer, of dry pack, rough to apply the other layer. Complete the thickness required in layers.

Note : This method is not suitable for filling holes where steel reinforcement is exposed.

2. Mortar replacement method : Mortar replacement method is suitable for repairing holes of intermediate sizes *i.e.*, depth varying between 25 mm and 100 mm. Following procedure is adopted to repair intermediate sized holes.

(i) Clean and wash the hole with a jet of water to remove the loose material.

(ii) A mortar mix (of ratio 1 : 4) is forced through a high pressure nozzle of a cement gun. The gun should be kept at a distance of 1 m from the hole. To fill the hole, the thickness of layer of cement mortar should not exceed 1·5 cm.

(iii) If needed then next layer should be placed over the previous layer after an interval of 30 minutes or more.

3. Concrete Replacement method : This method is suitable, for use in the following cases when the :

(a) holes are extended entirely through the concrete.

(b) Surface area of holes in PCC is more than 900 cm^2 and depth exceeding :

– 100 mm in new concrete

– 150 mm in old concrete.

(c) Surface area of holes in RCC is more than 450 cm^2

In case of the above mentioned cases it is required to replace the concrete in that defected zone by concrete replacement method. Following procedure is adopted.

(i) Clean the hole to remove all loose particles by jet of compressed air.

(ii) Wash the hole thoroughly and allow it to dry.

(iii) Apply a thin layer of mortar before fixing the formwork.

(iv) Place the prepared concrete in the hole and compact it uniformly. The prepared concrete should have same proportions of ingredients and w/c ratio as that was used earlier.

(v) Remove the formwork after 2 days of curing.

B. REPAIRING OF CRACKS :

The phenomenon of the appearance of cracks in concrete is often a subject that raises several questions. Either at the initial stage or with passage of time, cracks may appear in a concrete structure. It should first of all be accepted that cracks of some type or the other are inevitable in any concrete. They can be minimised to a large extent by proper practices.

Cracks in concrete may be big or small, structural or non-structural. All of them can be a nuisance by way of either spoiling the appearance or act as a medium for passage of atmospheric polluting gases and moisture to enter the body of concrete and cause distress.

The hair line cracks, though harmless, but have an adverse psychological effect. The formation of hair line cracks in concrete is known as **Crazing**.

Causes of Cracks : The following reasons can lead to hair line cracks :

(i) When the cement content is more than specified.

(ii) Due to unequal shrinkage of concrete.

(iii) Due to expansion and contraction (*i.e.*, temperature stresses).

(iv) Due to change in moisture content.

(v) Due to insufficient curing which fails to cool down the heat of hydration.

(vi) When excess trowelling is done.

(vii) Due to improper concreting practices.

(viii) Due to improper design.

(ix) Change in occupancy leading to change in loading.

(x) When ever the applied strain exceeds the strain capacity of concrete.

Hardened Concrete

Lecture No. 14

Strength of Concrete

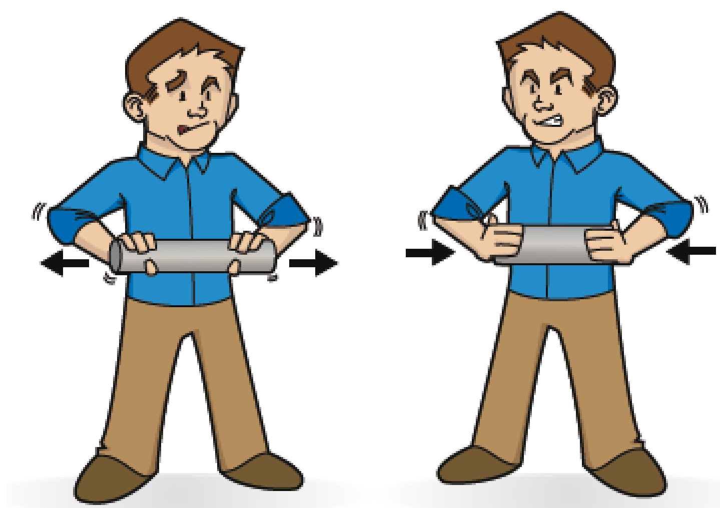
- Strength of concrete is commonly considered its most valuable property, although in many practical cases, other characteristics, such as durability and permeability may in fact be more important.

- Strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste.

- Strength of concrete could be defined as the ultimate load that causes failure (or is its resistance to rupture) and its units are force units divided by area (N/mm^2).

Strength of Concrete

- Characteristic strength - Compressive, Tensile and Flexure strength
- Modulus of Elasticity
- Creep and shrinkage of concrete



THE THREE S-WORDS

Stress: a weight or load applied to the concrete (in N)

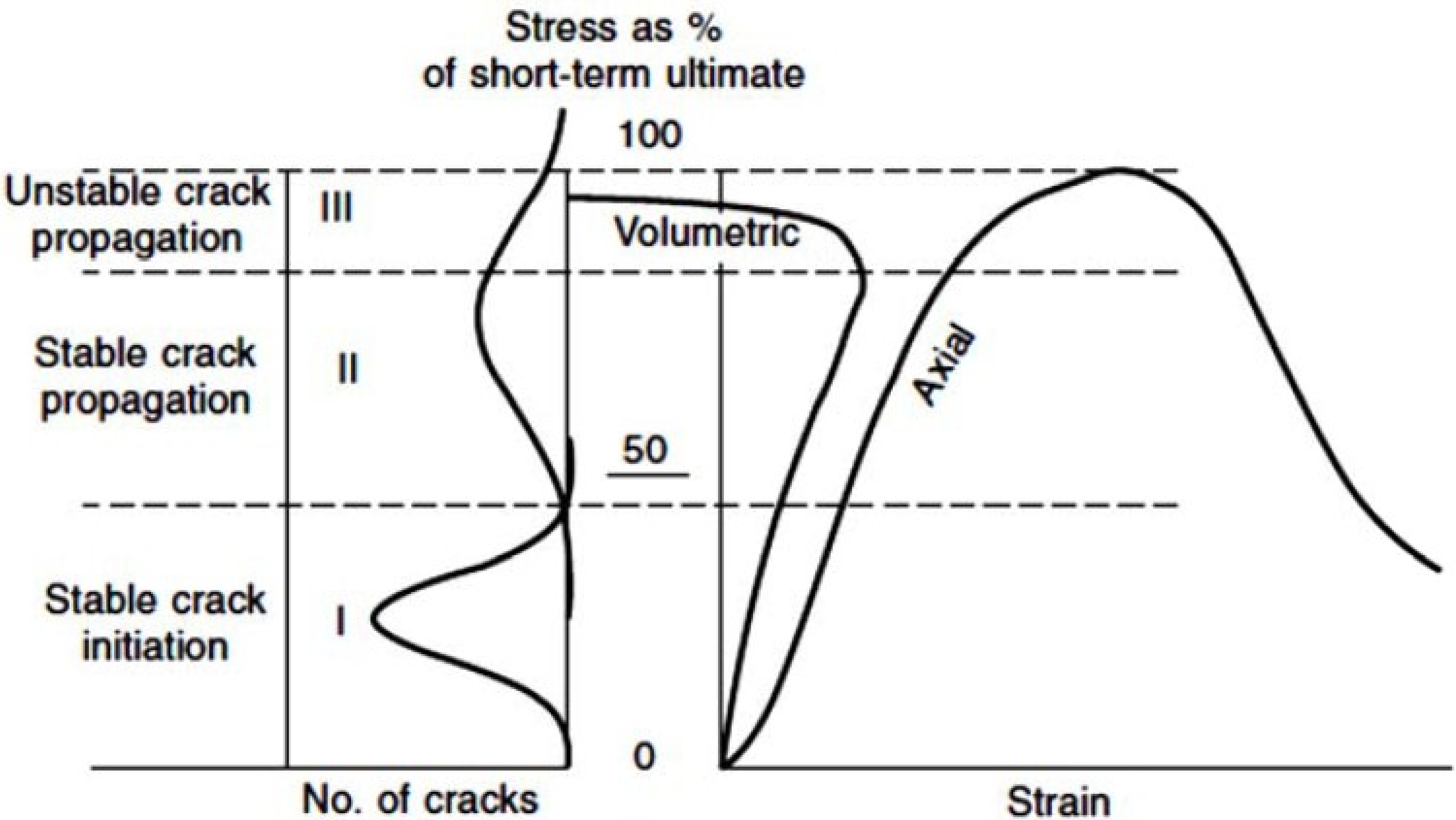
Strength: the concrete's ability to carry the weight or load (in N per square mm)

Strain: how much the concrete stretches or compresses (deforms) when carrying a load (in inches per mm)

Fracture and failure

- Concrete specimens subjected to any state of stress can support loads of up to 40–60% of ultimate without any apparent signs of distress.
- Below this level, any sustained load results in creep strain which is proportional to the applied stress and can be defined in terms of specific creep (i.e. creep strain per unit stress)
- As the load is increased above this level, soft but distinct noises of internal disruption can be heard until, at about 70–90% of ultimate, small fissures or cracks appear on the surface.
- At ultimate load and beyond; the specimens are increasingly disrupted and eventually fractured into a large number of separate pieces.

The stages of cracking (fracture) in concrete:



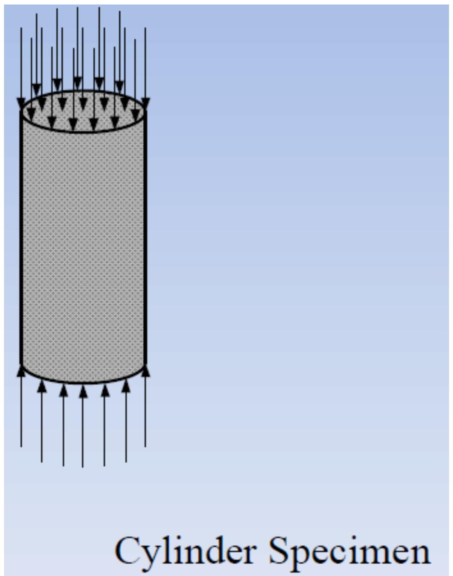
Types of Concrete Strength

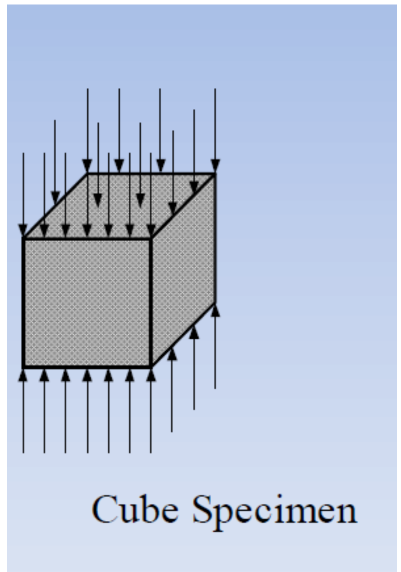
- Compressive strength
- Tensile strength
- Shear strength
- Bond strength
- Impact strength
- Fatigue strength

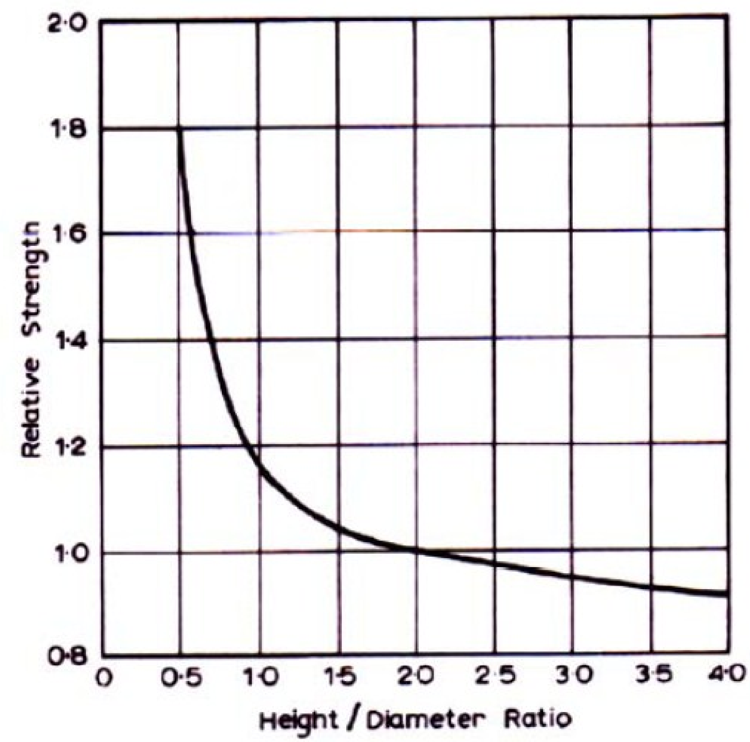
Compressive Strength

- The compressive strength of concrete is defined as the strength of 28 days old specimens tested under monotonic uniaxial compressive load.
- Testing of cylindrical samples with 15 cm diameter and 30 cm height is standard.
- Cube specimens of 15 cm × 15 cm × 15 cm are also being used.
- Normally, the compressive strength of concrete is determined by testing, and the tensile strength and modulus of elasticity are expressed in terms of the compressive strength.

Compressive Strength







$$(f_c)_{cylinder} = (0.85 - 0.80)(f_c)_{cube}$$

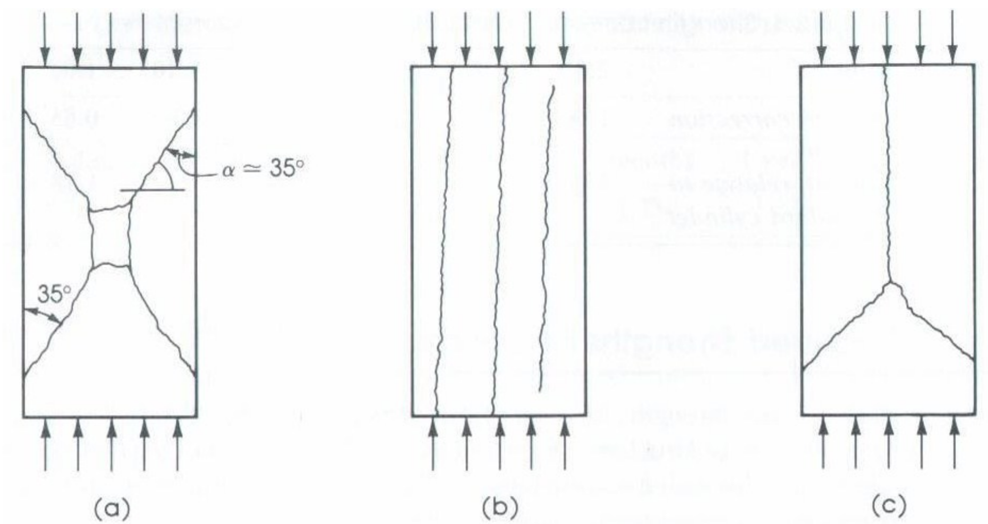
Compressive Strength

- There are three failure modes for cylinders.

a) Under axial compression concrete fails in shear.

b) The separation of the specimen into columnar pieces by what is known as splitting or columnar fracture.

c) Combination of shear and splitting failure.



Compressive Strength

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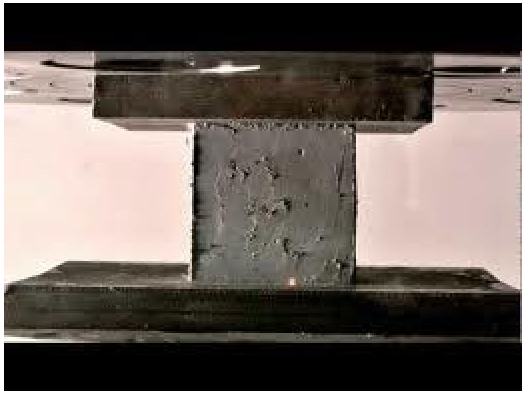
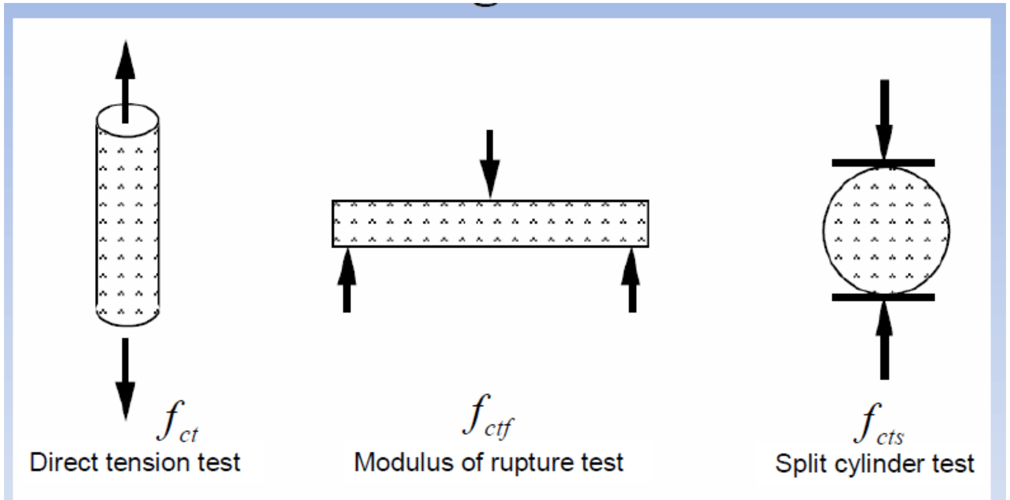
Compressive Strength



Tensile Strength of Concrete

- The tensile strength of concrete is much lower than the compressive strength, largely because of the ease with which cracks can propagate under tensile loads
- The tensile strength of concrete is measured in three ways: direct tension, splitting tension, and flexural tension



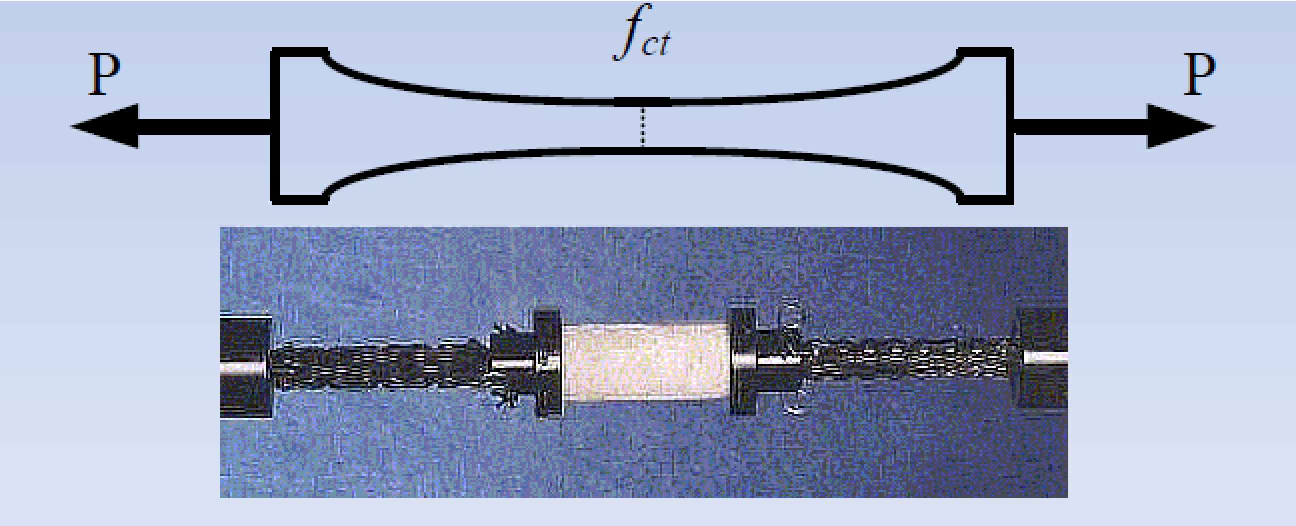
$$f_{ctf} > f_{cts} > f_{ct}$$

Tensile Strength of Concrete

- It is difficult to test concrete in direct (uniaxial) tension because of the problem of gripping the specimen satisfactorily and because there must be no eccentricity of the applied load. Therefore, direct tensile test is not standardized and rarely used
- Modulus of rupture test and splitting test are commonly used to determine the tensile strength of concrete

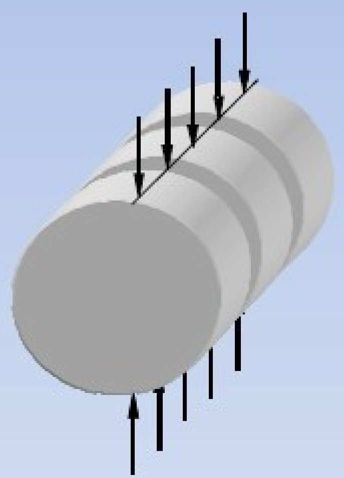
Tensile Strength of Concrete

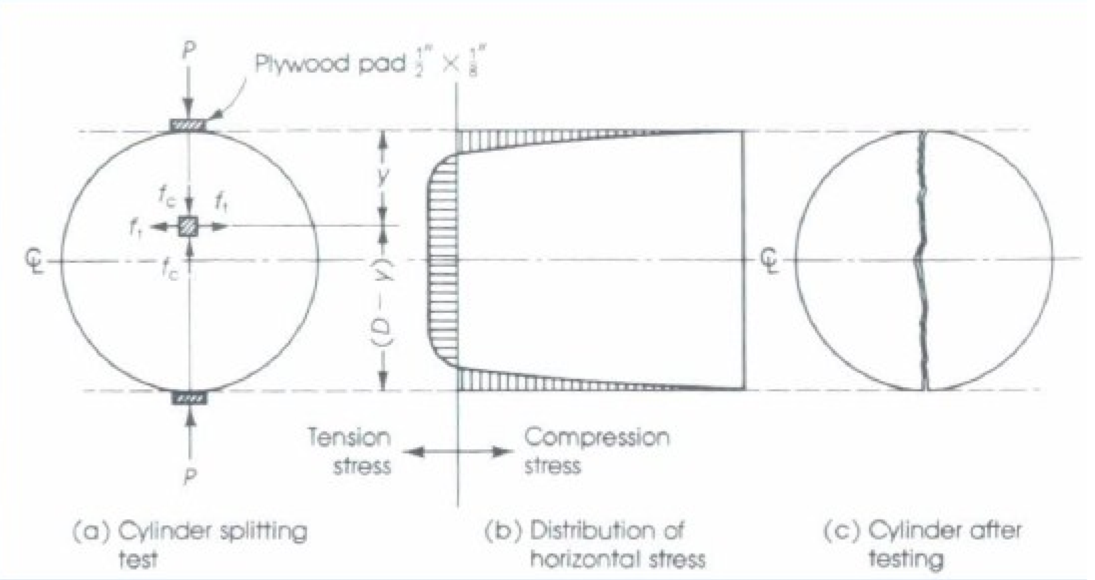
- Direct-Tension Test:
  - The most direct way of measuring the tensile strength.
  - Not a practical test.



Tensile Strength of Concrete

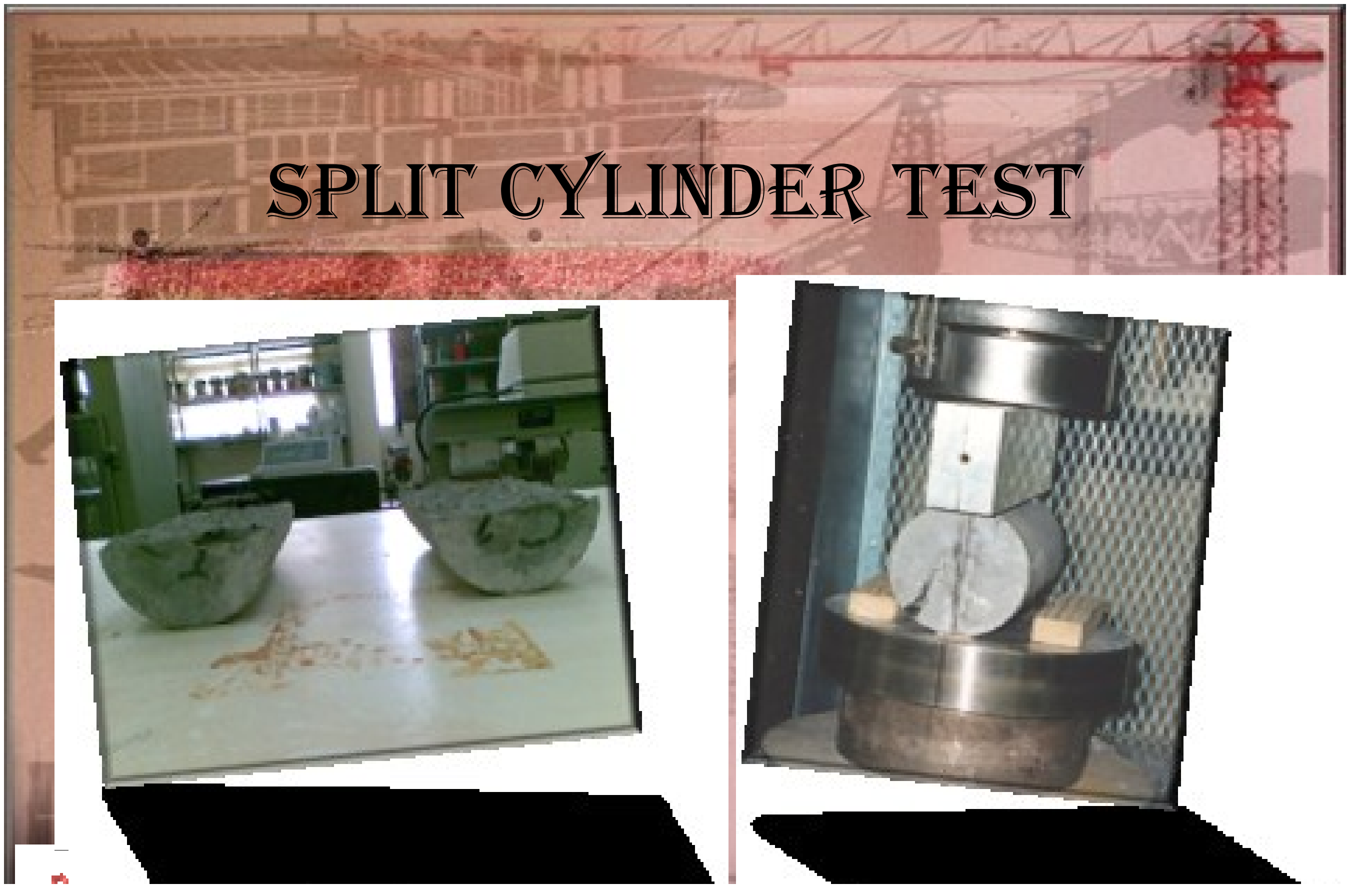
- Split-Cylinder Test:





$$f_{cts} = \frac{2P}{\pi L D}$$

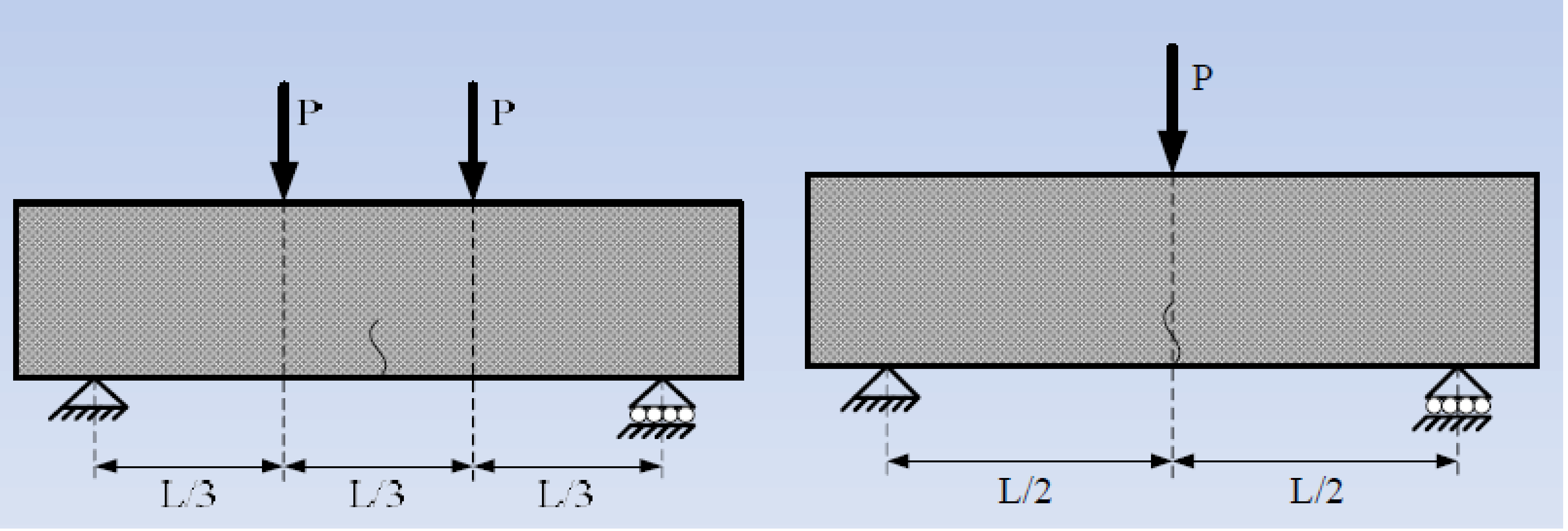
Tensile Strength of Concrete



Tensile Strength of Concrete

- Modulus of Rupture Test:
- Four-point bending (two-point loading)
- Three-point bending (third point loading)

$$f_{ctf} = \frac{6M}{b \cdot h^2}$$



Relationship Between Compressive and Tensile Strength of Concrete

- Tensile strength of concrete is proportional to the square-root of the compressive strength.
- The proportionality constant depends on many factors, such as the concrete strength and the test method used to determine the tensile strength.
- The following relations can be used as a rule of thumb:

$$\text{Direct tensile strength}: f_{ct} = 0.35\sqrt{f_c} \quad (f_c \text{ in MPa})$$

$$\text{Split tensile strength}: f_{cts} = 0.50\sqrt{f_c} \quad (f_c \text{ in MPa})$$

$$\text{Flexural tensile strength}: f_{ct} = 0.64\sqrt{f_c} \quad (f_c \text{ in MPa})$$

Concrete Strength

- Shear Strength
- Shear strength of concrete is taken approximately equal to 20 % its compressive strength
- Bond Strength
- The strength of bond between steel reinforcement and concrete is called as bond strength of concrete
- Bond strength develops primarily due to friction and adhesion between steel reinforcement and concrete
- In general, bond strength is approximately proportional to the compressive strength of concrete up to about 20 MPa

Concrete Strength

- Impact Strength
- Impact strength of concrete is of importance in driving concrete piles, in foundations for machines exerting impulsive loading, and also when accidental impact is possible, e.g. when handling precast concrete members
- There is no unique relation between impact strength and other strengths of concrete.
- However, some researchers have found that impact is related to the compressive strength, and it has been suggested that the impact strength varies from 0.50 to 0.75 of the compressive cube strength

Concrete Strength

- Fatigue Strength
- The strength of concrete against cyclic or repeated loading is called as its fatigue strength

Durability of Concrete

Lecture No. 21

Durability of Concrete

- A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service.
- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.
- 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

Durability of Concrete

- Concrete Deterioration can be caused by:
  - The use of inappropriate materials.
  - Poor construction practices.
- Environmental Related Causes of Concrete Durability Problems
  - Temperature.
  - Moisture.
  - Physical factors.
  - Chemical factors.
  - Biological factors.

Durability of Concrete

- These factors may be due to weathering conditions (temperature, and moisture changes), or to abrasion, attack by natural or industrial liquids and gases, or biological agents.
- Durability problems related to environmental causes include the following: steel corrosion, delamination, cracking, carbonation, sulfate attack, chemical attack, scaling, spalling, abrasion and cavitation.

Temperature

- Temperature variations will cause changes in the concrete volume. When temperature rises, the concrete slightly expands, and when temperature falls, the concrete contracts.
- Since concrete is usually restrained by foundations, subgrades, reinforcement, or connecting members, volume changes in concrete can produce significant stresses in the concrete. Tensile stresses can cause the concrete to crack

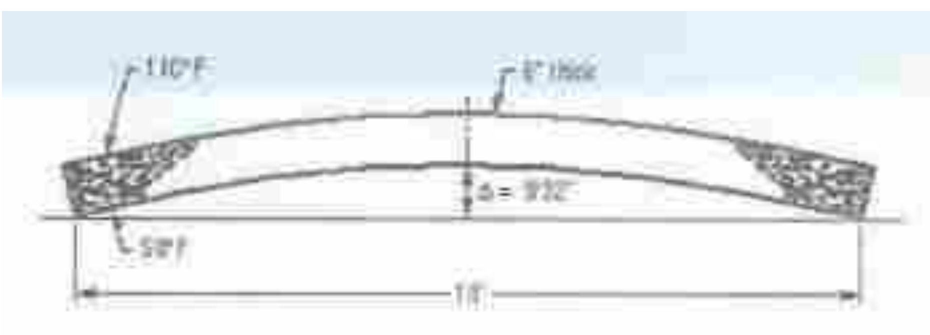


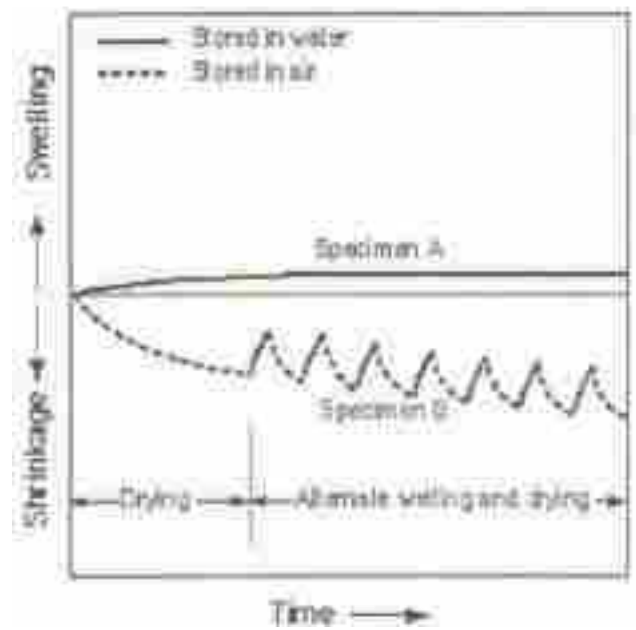
Figure 1. Warping of Concrete due to Temperature Difference

Temperature

- Temperatures greater than 95°C (203°F) can have significant effects on concrete.
- The total volume change in concrete is the sum of the volume changes of the cement paste and aggregates.
- At high temperatures, the cement paste will shrink due to dehydration of the calcium silicate hydrate (C-S-H), while the aggregate will expand.
- Seasonal changes in temperature range up to 50°C (90°F) between the summer and winter. Seasonal temperature changes cause higher stresses than daily temperature changes, and they result in more extensive cracking.

Moisture

- Changes in the moisture content in concrete will result in either concrete expansion or contraction.
- When concrete gains moisture, the concrete will slightly expand or swell. When concrete loses moisture, the concrete will contract or shrink.



Moisture

- Further, wetting and drying of the concrete can cause the concrete to alternately swell and shrink.
- This drying and shrinking of the concrete surface will cause the concrete surface to develop tensile stresses and possible cracks.
- If a section of the concrete is restrained, and if concrete joints are not provided, major random cracks may develop.
- The three main problems with moisture and concrete are as follows:
  - 1)Carbonation, 2)The moisture cycle, 3)Contaminants

Moisture

Moisture : Carbonation

- Carbon dioxide (CO_2) present in the atmosphere reacts in the presence of moisture with the hydrated cement minerals (i.e. the agent usually being the carbonic acid).
- The extent of carbonation depends on the permeability of the concrete and on the concentration of carbon dioxide in the air.
- The penetration of carbon dioxide beyond the exposed surface of concrete is extremely slow.
- The alkaline conditions of hydrated cement paste are neutralized by carbonation. This neutralization, by dropping the pH from over 12 to about 9, affects the protection ofreinforcing steel from corrosion.

Moisture : Moisture Cycles

- Stresses caused by changes in moisture content of the concrete may be additive to stresses caused by temperature changes.
- Tensile stresses usually increase the tendency for cracking, scaling, spalling, and delamination.
- Rapidly fluctuating humidity (up to 70% in one day) can lead to moisture changes in the concrete.
- If the moisture level at the reinforcing steel reaches 60% to 90% and sufficient chlorides are present, the steel will corrode.

Moisture : Moisture Cycles

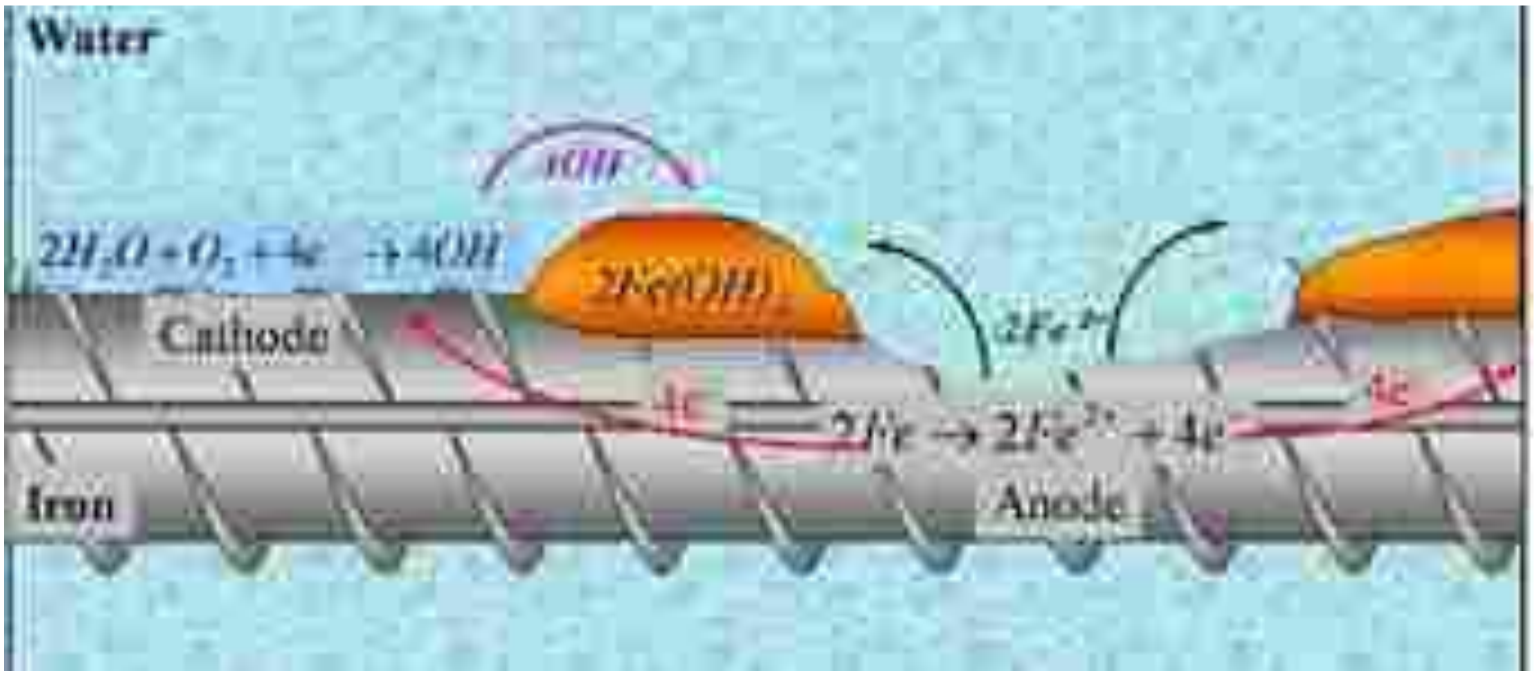
Table 1. Influence of Relative Humidity on the Corrosion of Steel in Concrete

Relative Humidity	Remarks	Corrosion Risk
Concrete sub-merged in water	Capillaries filled with calcium hydroxide solution. Oxygen must diffuse through solution-filled capillaries to steel.	No-corrosion to small risk.
90% to 95%	Pores filled with pore solution through which oxygen must diffuse.	Small to medium risk.
60% to 90%	Pores only partially filled. Water and oxygen reach steel easily.	Great risk.
below 60%	No or very little solution in pores.	No risk.

Moisture : Contaminants

- Contaminants in the water that is absorbed into the concrete may cause staining, steel corrosion, or sulphate attack.
- Contaminants include: chloride and sulphate salts, carbonates, etc.
- Alternate cycles of wetting and drying allow the concentration of salts to increase and thereby increase the severity of their attack.
- An increase in the size of salt crystals in the capillaries near the evaporating surface causes cracking and scaling.
- If the salts are drawn to the surface and deposited at places where water evaporates, efflorescence will occur.

Moisture : Contaminants



Physical Factors

- Under many circumstances, concrete surfaces are subjected to wear. Concrete wear may be caused by the sliding, scraping or impact of objects that fall onto the concrete.
- In hydraulic structures, the action of the abrasive materials carried by flowing water generally leads to erosion of the concrete.
- Another cause of damage to concrete in flowing water is cavitation.
- Abrasion damage to concrete may also be caused by subjecting the concrete to abrasive materials (such as sand) that are carried by wind or water.

Physical Factors

- That abrasion resistance is clearly related to the compressive strength of the concrete.
- Strong concrete has more resistance than weak concrete.
- Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance.
- Hard aggregates are more abrasion resistant than soft aggregates.

Physical Factors

- Concrete that is affected by cavitation has an irregular, jagged, and pitted surface.
- After an initial period of small damage, rapid deterioration will occur. This rapid deterioration is followed by damage to the concrete at a slower rate
- Cavitation can be a problem in any open channel where the velocity of the flowing water is higher than 12 mls . In a closed pipe or conduit, cavitation can occur at velocities as low as 7.5 mls.
- Concretes that have the best resistance to cavitation damage have a high strength, a low water-cement ratio, a small aggregate size that does not exceed 20 mm, and a good paste aggregate bond.

Physical Factors

Physical Factors

Physical Factors

- Fire around concrete structures can weaken the superstructure and decrease the concrete strength tremendously.
- Damage by fire may include total or partial collapse of the structure, distortion, excessive deflection and expansion, buckling of the steel, spalling and shattering of the concrete, discoloration, and reduction of the physical properties of the steel and concrete.
- The effect of increased temperatures on the strength of concrete is small and somewhat irregular below 250°C (482°F).

Physical Factors

Physical Factors

Table 2. Impact of Fire Temperature on Concrete

Temperature	Effect on Concrete
100°C to 250°C (212°F to 482°F)	Normal color, slight loss in compressive strength
250°C to 300°C (482°F to 572°F)	Color changes to pink, strength loss increases
300°C to 600°C (572°F to 1112°F)	Color is pink to red, strength loss continues
Above 600°C (1112°F)	Color changes to black, gray; very little residual strength
About 900°C (1652°F)	Color changes to buff; total loss of strength

Biological Factors

- Concrete may be damaged by live organisms such as plants, sponges, boring shells, or marine borers.
- Mosses and lichens, which are plants of a higher order, cause insignificant damage to concrete.
- These plants produce weak acids in the fine hair roots. The acids that are produced from mosses and lichens will attack the cement paste and cause the concrete to disintegrate and scale.
- In some cases, carbonic acids are produced from plants, such as mosses and lichens, when substances from these plants decompose. The carbonic acid that is produced will attack the concrete.

Biological Factors

Biological Factors

- Marine borers, such as mollusks and sponges, tend to form bore holes into underwater concrete structures.
- Marine borers reduce the concrete's load-carrying capacity as well as expose the concrete's outer reinforcing steel to the corrosive seawater.
- As the degree of interconnection increases, the surface material of the concrete crumbles.
- Disintegration of the surface layer exposes a new substrate of the concrete to the boring sponges. Deterioration of concrete due to a boring sponge attack is relatively slow.

BRITISH STANDARD

BS 1881-208: 1996

Testing concrete —

Part 208: Recommendations for the determination of the initial surface absorption of concrete

ICS 91.100.30

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by Technical Committee B/517, Concrete, to Subcommittee B/517/1, Concrete production and testing, upon which the following bodies were represented:

Association of Lightweight Aggregate Manufacturers
Association of Metropolitan Authorities
British Aggregate Construction Materials Industries
British Cement Association
British Civil Engineering Test Equipment Manufacturers' Association
British Precast Concrete Federation
British Ready Mixed Concrete Association
Building Employers' Confederation
Cement Admixtures Association
Cementitious Slag Makers' Association
Concrete Society
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment
Department of Transport (Highways Agency)
Electricity Association
Federation of Civil Engineering Contractors
Federation of Piling Specialists
Institute of Concrete Technology
Institution of Civil Engineers
Institution of Structural Engineers
Institution of Water and Environmental Management
National House-Building Council
Quality Ash Association
Sand and Grovel Association
Society of Chemical Industry

This British Standard, having been prepared under the direction of the Sector Board for Building and Civil Engineering, was published under the authority of the Standards Board and comes into effect on 15 September 1996

The following BSI references relate to the work on this standard:
Committee reference B/517/1
Draft for comment 95/106828 DC

ISBN 0 580 26201 4

Amendments issued since publication

Amd. No.	Date	Comments

Contents

Foreword

This Part of BS 1881 has been prepared by Subcommittee B/517/1. It supersedes clause **6** of BS 1881-5:1970 which has been deleted. All aspects of testing concrete are included as Parts of BS 1881 from sampling fresh concrete to assessing concrete in structures. BS 1881-201:1986 *Guide to the use of non-destructive methods of test for hardened concrete* gives general guidance on the choice of non-destructive test methods and should be consulted for advice on methods which complement the measurement of initial surface absorption or are useful as alternatives.

In this Part of BS 1881, recommendations for surface absorption differ from those in clause **6** of BS 1881-5:1970 in the omission of the requirement for a measurement at 2 h after commencing the test since this is no longer regarded as providing useful additional information in practice. Recommendations on applications, factors influencing results and interpretation is also provided.

The method given in this standard provides a low pressure assessment of the water absorption of the concrete surface. Other tests currently under development involve higher pressures or surface drilling and the results from such tests will be governed by properties of the concrete not necessarily related to surface absorption.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 1881 gives recommendations for a method of determining the initial surface absorption of oven dried concrete, of concrete in the laboratory which cannot be oven dried and of site concrete. Recommendations are given on areas of application of this method and the interpretation of results.

2 References

2.1 Normative references

This Part of BS 1881 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 1881 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

2.2 Informative references

This Part of BS 1881 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 1881 the definitions in BS 6100-6.2 apply together with the following:

3.1
location

region of concrete that is being assessed and that, for practical purposes, is assumed to be of uniform quality

3.2
initial surface absorption

rate of flow of water into concrete per unit area at a stated interval from the start of the test and at a constant applied head

3.3
surface zone

zone of concrete immediately behind the surface

NOTE The thickness of the zone that influences the result of this test may range between a few millimetres and several centimetres depending on the nature and condition of the concrete.

4 Applications

4.1 General

This test method provides data for assessing the uniaxial water penetration characteristics of a concrete surface. The applied pressure of 200 mm head of water is worse than the severest weather exposure in the UK due to driving rain. The results may be considered to be related to the quality of finish and to the durability of the surface under the effects of natural weathering. The results are of little relevance to behaviour under higher water pressures, and cannot be used to assess the permeability of a body of concrete.

This test method can be applied to exposed aggregate or profiled surfaces provided that a watertight seal can be obtained with the apparatus. The test is not applicable to specimens or areas showing obvious porosity, honeycombing or cracking. Misleading results can be obtained when tests are performed on thin concrete sections through which water could penetrate during the test. Tests should not be repeated at positions within an area affected by previous tests.

4.2 Quality control

4.2.1 *Precast concrete*

The test is most reliably applied to precast concrete units which can be tested under standardized dry conditions. Results obtained may be compared with predetermined acceptance limits.

4.2.2 *Cast stone*

Details of recommended acceptance requirements for cast stone are given in BS 1217 on the basis of results obtained by this method.

4.2.3 *In situ concrete*

It is difficult to achieve standardized drying conditions for in situ concrete although generalized classification limits relating to surface weathering characteristics have been proposed which can be applied to in situ test results. The method has been successfully used on this basis to assess compliance with specifications for weathering performance[1].

Combinations of initial surface absorption and cover to reinforcement have been proposed[2].

4.3 Comparability surveys

Since it is sensitive to surface finish as well as to the quality of the concrete in the surface zone, the test provides a means of comparative assessment of these characteristics. With careful interpretation, the test may usefully be applied to in situ concrete construction.

[1] *Permeability testing of site concrete — A review of methods and experience.* Concrete Society Technical Report 31

[2] Levitt.M. The ISAT for limit state design for durability. Concrete. Vol 19, No.7, p 29. July 1985.

5 Factors influencing the initial surface absorption of concrete

Guidance concerning their influence upon the interpretation of results in practical circumstances is given in clause **9**. All the following factors affect the surface absorption of concrete:

a) moisture conditions;

b) concrete mix;

c) aggregate;

d) surface finish and type;

e) curing;

f) age of concrete;

g) cracking (visible cracks should be avoided);

h) water type;

i) temperature.

Although impurities in the water can influence the rate of absorption, this effect may be disregarded provided that the water is of potable quality. However, distilled or de-ionized water shall be used for calibrating the capillary tube (see **7.2**).

6 Apparatus

6.1 *Test assembly,* comprises a watertight cap which is sealed to the concrete surface and connected by means of flexible tubes to a reservoir and a capillary tube with a scale. A control tap is fitted to the connection between the reservoir and cap. A typical test assembly is illustrated in Figure 1.

6.2 *Cap,* of any suitable rigid non-corrodible impermeable material providing a minimum area of water contact with the surface to be tested of 5 000 mm^2.

NOTE It is useful for the cap to be made of a transparent material such as a clear acrylic, polyester or epoxy resin (reinforced if necessary) as this allows the operator to observe the filling of the cap with water and the displacement of the air.

An inlet and an outlet tube are fixed into the cap, the former connecting to the reservoir and the latter to the capillary tube. The outlet is so positioned that it is at the highest part of the cap to allow all trapped air to escape.

A suitable cap for clamping onto horizontal concrete specimens with a relatively smooth surface as illustrated in Figure 2. This has a soft elastomeric gasket to provide a watertight seal. It is possible for the gasket to be glued to the surface of smooth dry laboratory specimens. In cases where either the surface of the concrete is not smooth, or the cap cannot be clamped onto the surface to be tested, the cap should have a knife edge for contact with the concrete. Recommendations for fixing the cap to the test surface is given in **8.2**. A suitable cap for testing vertical or sloping surfaces or soffits is illustrated in Figure 3.

6.3 Connections

6.3.1 ***Inlet.*** The inlet tube to the cap is connected to the reservoir by a flexible tube of sufficient length to enable a head of water between 180 mm and 220 mm above the surface of the concrete under test to be maintained, and is fitted with a tap.

6.3.2 ***Outlet.*** The outlet tube from the cap is connected to the capillary tube by a flexible tube of sufficient length to enable the capillary tube to be set horizontally at a head of water between 180 mm and 220 mm above the surface of the concrete under test.

6.4 *Reservoir,* of glass or plastics material of about 100 mm diameter.

6.5 *Capillary tube and scale.* A length of precision bore glass capillary tubing at least 200 mm long and with a bore of 0.4 mm to 1.0 mm radius, determined as described in **7.2**, is fixed to a scale calibrated by the procedure described in **7.3**.

NOTE The length of capillary tubing necessary to accommodate the full range of possible initial surface absorption values indicated in Table 1 will depend upon the radius of the capillary bore and the cap size. The scale is marked in divisions as described in **7.3**.

For a cap of the minimum dimensions given in **6.2**, a capillary bore of 0.4 mm radius and concrete of high initial absorption, the length required would exceed 1 m. To limit the length of tube to a convenient value, a combination of cap size and capillary bore should be chosen to accommodate the range of initial surface absorptions anticipated. The more permeable the concrete, the larger the bore or the length needs to be. The capillary tube protrudes beyond one end of the scale for connection to the outlet of the cap.

6.6 *Stands and clamps,* to support the reservoir and capillary tube and scale, allowing for adjustments within the ranges given in **6.3**.

6.7 *Stop watch or clock,* accurate to 0.5 s.

6.8 *Measuring cylinder,* of 10 ml capacity conforming to BS 604.

6.9 *Thermometers,* accurate to the nearest 0.2 °C, suitable for measuring the temperature of the water and of the concrete surface.

6.10 *Drying oven,* ventilated, in which the temperature is controlled at (105 ± 5) °C.

6.11 *Cooling cabinet,* dry airtight vessel of sufficient capacity to contain the specimens to be tested.

6.12 *Balance,* of appropriate capacity to weigh the specimens to the accuracy required by **8.1.2**.

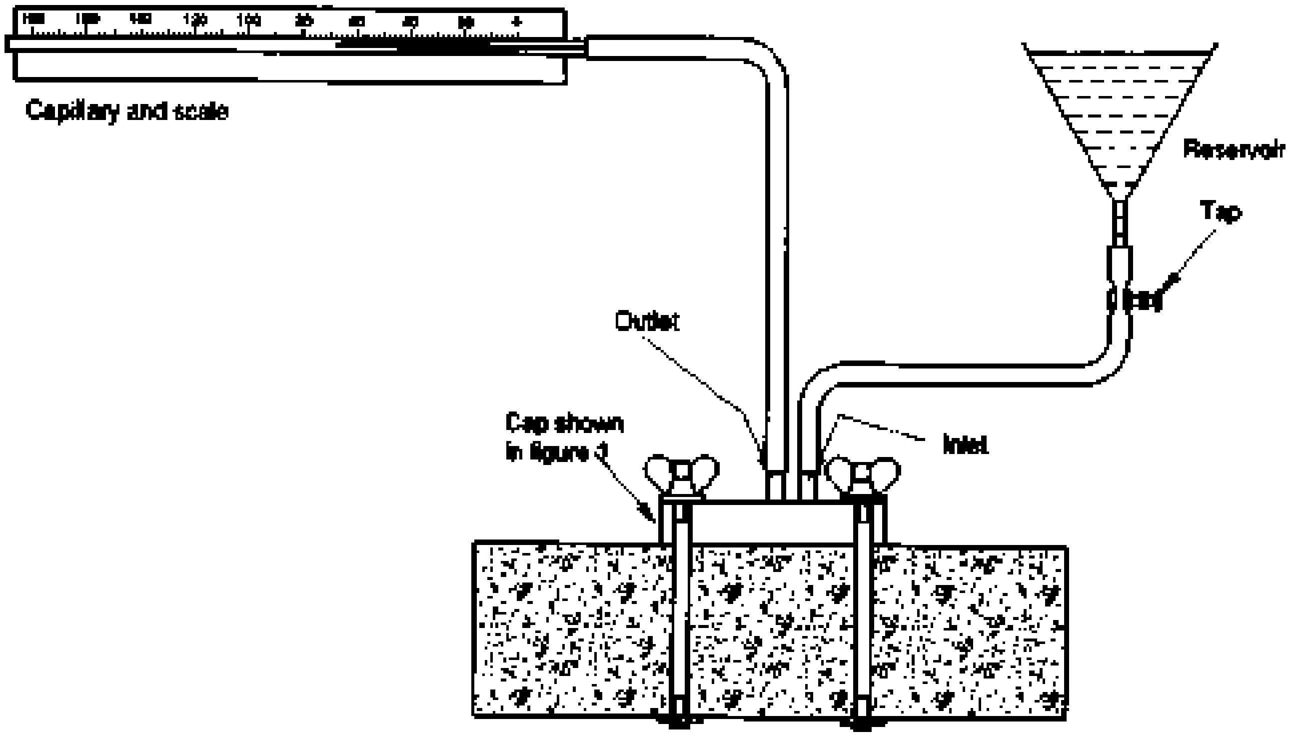


Figure 1 — Assembly of typical absorption apparatus

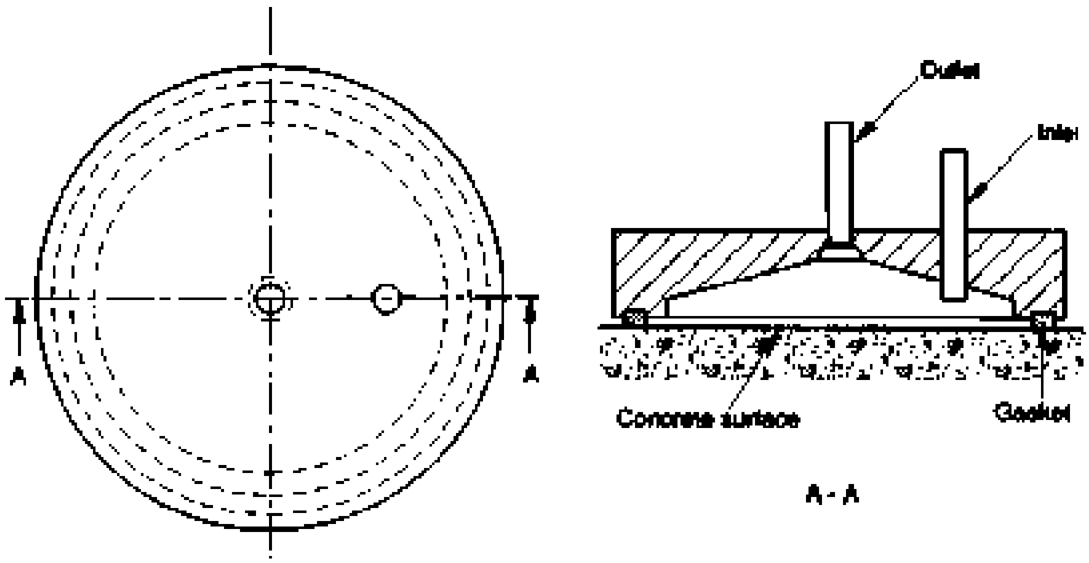


Figure 2 — Typical cap suitable for clamping onto a smooth horizontal surface

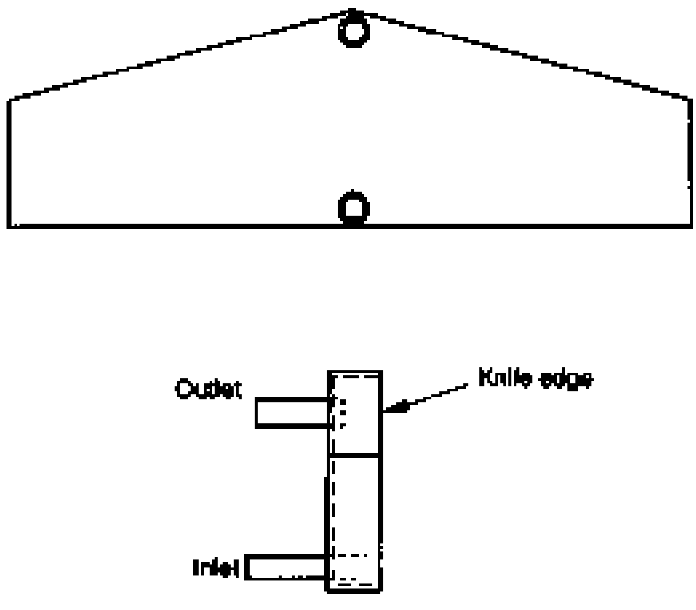


Figure 3 — Typical cap suitable for use on a vertical surface

7 Calibration of apparatus

7.1 General

The calibration of the capillary tube is arranged so that the movement of water along it during 1 min, as read directly from the scale, equals the initial surface absorption in ml/(m^2.s) at a constant head and temperature during the test.

7.2 Radius of bore of capillary tube

Measure the length of the capillary tube (**6.5**) and record it to the nearest millimetre. Flush the tube through with soap solution, followed by at least 25 ml of distilled or de-ionized water. Clamp the tube horizontally and connect it to the reservoir (**6.4**) by means of the flexible tube (**6.3.1**) fitted with a tap. Fix the reservoir such that a head of water of (200 ± 5) mm is maintained during the course of the calibration.

Close the tap and fill the reservoir with distilled or de-ionized water to the specified level. Determine the temperature of the water using the thermometer (**6.9**) and ensure that this is within 1 °C of ambient. Open the tap and, when a steady discharge occurs, place the measuring cylinder (**6.8**) under the open end and begin to collect the water. Record in seconds the time required to collect 10 ml of water.

Repeat this procedure twice more and calculate the mean of the three times.

Calculate the bore radius of the capillary tube, *r,* in millimetres, from the following equation:

$$r^4 = \frac{KL}{t}$$

where

- L is the length of the capillary tube (in millimetres);
- t is the mean time to collect 10 ml of water (in seconds);
- K is a coefficient incorporating the viscosity of water and the geometry of the apparatus obtained from the values below using linear interpolation between adjacent values.

Water temperature (°C):	10	15	20	25	30
Factor *K*:	0.0167	0.0145	0.0128	0.0 114	0.0100

7.3 Capillary scale

From the dimensions of the cap, taking account of the seal geometry, calculate the area of contact of the water with the specimen, A_1,and record this in mm^2. Calculate the area of the bore of the capillary, A_2, in mm^2 using the value of *r* calculated as described in **7.2** from:

$$A_2 = \pi r^2$$

Prepare a scale to mount behind the capillary tube marked off with at least 180 divisions, spaced $6 \times 10^{-4} A_1/A_2$ mm apart. Each such division will then represent 0.01 units of ml/(m^2.s).

8 Procedure

8.1 Selection and recommended preparation of specimens

8.1.1 ***Number of specimens***

Test at least three separate specimens or locations selected to be representative of the concrete under examination and suitable for test with the cap and clamping system to be used. Areas exhibiting surface cracking should normally be avoided. Mould oil or curing membranes may affect the results as can the procedures needed to remove them.

8.1.2 ***Oven dried specimens***

Dry the specimen in the oven (**6.10**) at (105 ± 5) °C until constant mass is achieved, i.e. not more than 0.1 % weight change over any 24 h drying period. When the specimen has reached constant mass, place it in the cooling cabinet (**6.11**) and allow the temperature in the cabinet to fall to within 2 °C of that of the room. Leave each specimen in the cabinet until required for testing. Concrete made with high alumina cement should not be conditioned by oven drying.

8.1.3 ***Non-oven dried specimens***

8.1.3.1 *Conditioning for laboratory testing*

Allow the concrete unit or specimen to remain in the laboratory for a minimum period of 48 h at a temperature of (20 ± 2) °C before testing.

8.1.3.2 *Conditions for site testing*

Protect the surface to be tested from water for a period of at least 48 h prior to the test. Do not allow contact between the protective material and the surface to be tested. Protect the surface from direct sunlight for at least 12 h prior to and during the test.

8.2 Fixing the cap

Slightly grease the gasket where it is made of a solid elastomer. Foamed elastomeric gaskets may or may not need greasing.

In the case of knife edged caps, form a seal round the outside of the cap to prevent any loss of water from under the knife edge. A variety of materials can be used, and should be firmly applied to the concrete and the edges of the cap to build a wall capable of withstanding the water pressure. One of the best materials is modelling clay into which enough grease can be kneaded to enable it to "wet" glass or metal. The colour may be selected to match the concrete.

A gentle application of heat to the test surface helps to remove residual moisture and may assist in the adhesion of the sealing compound. If this procedure is adopted it should be stated in the report.

Clamp the cap into position or fix into place and test by blowing gently down one of the tubes whilst closing the other. Leakage may occur in the course of a test under site conditions due to movement of the seal and can be detected by applying a small amount of soap solution to the outside of the joint. Carefully examine the sealing of the cap throughout each test and if any signs of leakage are observed discontinue the test.

8.3 Assembling the apparatus

Set up the reservoir so that when it is filled (see **8.5**) a head of 180 mm to 220 mm of water is applied to the surface of the concrete.

NOTE For non-horizontal surfaces measure the head of water from mid-height of the concrete under the cap.

Connect the reservoir to the inlet of the cap with the flexible tubing, which has the tap fitted to it.

Support the capillary tube, calibrated as described in clause **7**, horizontally just below the level of the surface of the water in the reservoir.

8.4 Temperature of water

In laboratory tests maintain the temperature of the water at (20 ± 2) °C.

In site tests no limits can be laid down, but take precautions to avoid undue fluctuations in the temperature of the water during the test.

8.5 Starting the test

Measure and report the temperature of the concrete surface adjacent to the cap to the nearest 1 °C.

Close the tap from the reservoir and fill the reservoir with water. Start the test by opening the tap to allow the water to run into the cap and record this start time. Flush all air from the cap through the capillary tube, assisted if necessary, by sharply pinching the flexible tubing. Replenish the reservoir to maintain the head of 180 mm to 220 mm of water and raise one end of the capillary tube just above the water level to prevent further outflow. Take care at all times to ensure that the reservoir does not empty itself.

8.6 Readings

Take readings normally after the following intervals from the start of the test:

— 10 min;

— 30 min; and

— 1 h.

As the test proceeds, the moisture content of the concrete will increase and capillary pores within the concrete adjacent to the test area become water filled. The rate of surface absorption will normally diminish as the duration of the test increases.

Just before the specified intervals lower the capillary tube so that water runs in to fill it completely and then fix it in a horizontal position at the same level as the surface of the water in the reservoir.

At each of the specified test intervals close the tap to allow water to flow back along the capillary tube. When the meniscus reaches the scale start the stop watch. After 5 s note the number of scale divisions the meniscus has moved and, by reference to Table 1, determine the period during which movement is to be measured.

Table 1 — Determination of period of movement

Number of scale divisions moved in 5 s	Period during which movement is measured
< 3	2 min
3 to 9	1 min
10 to 30	30 s
> 30	Record initial surface absorption as more than 3.60 ml/(m^2.s)
NOTE 1 division = 0.01 unit (see **7.3**).	

Record the number of scale divisions moved during the period selected from Table 1. When readings are taken over a 2 min or 30 s period, multiply the number of divisions by 0.5 or 2 respectively to convert the reading to a 1 min period. Record the actual or equivalent number of scale units traversed per min, which is 0.01 times the number of divisions, as the initial surface absorption in ml/(m^2.s) for that particular test interval. If the movement over the 5 s period exceeds 30 scale divisions record the initial surface absorption as more than 3.60 ml/(m^2.s).

If the reading taken 10 min after the start of the test is below 0.05 ml/(m^2.s), stop the test and record the result with the comment "concrete too impermeable to be sensitive to a longer term test". Similarly, where the 10 min reading is above 3.60 ml/(m^2.s), stop the test and record the result with the comment concrete too permeable to be within the sensitivity of the test method.

Between test intervals leave the tap open and maintain the level of the water in the reservoir at the specified head. The capillary tube may be tilted or raised a little to prevent overflow of the water.

9 Factors affecting test results

9.1 General

Detailed interpretation of results will depend upon the purpose and circumstances of use of the test, but the factors influencing results which are described in clause **5** should be given due consideration. Interpretation can be assisted by the recommendations given in the following clauses which is based on experience of using the method in the United Kingdom.

9.2 Sensitivity to initial moisture condition of non-oven dried specimens

Experience suggests that provided the conditioning has been carried out as described in **8.1.3**, then sensitivity to residual moisture is not high in relation to the influence of other factors. The effect of such moisture will decrease as the duration of the test increases.

9.3 Variability of concrete

The results reflect the variability, which may be considerable, of the condition of the surface and of concrete properties in the surface zone. Concrete subjected to site or laboratory conditioning is likely to yield more variable results than oven dried concrete. Oven drying may cause changes in the cement paste structure and can give different results from "naturally dry" concretes.

9.4 Period of test

In some instances, such as assessment of potential weathering characteristics or protection afforded to embedded steel, broad conclusions based on results of 10 min tests may be considered adequate. However, the effects of moisture condition indicated in **9.2** should not be overlooked. When the test area has been heated (see **8.2**) reliance upon 10 min values may not be justified.

9.5 Temperature of the concrete

Major variations in the surface temperature of the concrete, from the 20 °C value for which the equipment has been calibrated, are likely to influence results significantly owing to changes in viscosity of the water. The correction factors given in Table 2 should be used to convert site results to an equivalent 20 °C value.

Table 2 — Correction factors to convert readings to an equivalent value at 20 °C

Concrete surface temperature °C	**Multiply by**
5	1.5
10	1.3
15	1.1
20	1.0
25	0.9
30	0.8

10 Precision

It is not possible to give precision data as trials have not been carried out according to procedures given in this standard.

11 Test report

The following information should be included in the test report on each specimen or each location:

a) date, time and place of test;

b) age of concrete under test (if known);

c) identification and description of test specimen or element;

d) location within the element, where applicable;

e) positions tested, where applicable (with sketches);

f) detailed description of the surface of the concrete;

g) orientation of the test surface (horizontal, vertical or other direction);

h) description of the conditioning prior to test (including surface heat treatment);

i) method of sealing the cap;

j) area of water contact of the cap, dimensions of the cap and length of the capillary;

k) temperature of the concrete surface;

l) all initial surface absorption test results in ml/(m^2.s) as obtained in **8.6**;

m) results corrected to equivalent 20 °C values (see **9.5**).

List of references (see clause 2)

Normative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS 604:1982, *Specification for graduated glass measuring cylinders.*
BS 1217:1986, *Specification for cast stone.*
BS 1881, *Testing concrete.*
BS 1881-201:1990, *Guide to the use of non-destructive methods of test for hardened concrete*[3].
BS 6100, *Glossary of building and civil engineering terms.*
BS 6100-6, *Concrete and plaster.*
BS 6100-6.2:1986, *Concrete.*

Other publications

"Permeability testing of site concrete — A review of methods and experience". Concrete Society Report, 1988.

[3] Referred to in the foreword only.

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BRITISH STANDARD

BS EN 12390-8:2000

Testing hardened concrete —

Part 8: Depth of penetration of water under pressure

The European Standard EN 12390-8:2000 has the status of a British Standard

ICS 91.100.30

National foreword

This British Standard is the official English language version of EN 12390-8:2000. No existing British Standard is replaced.

The UK participation in its preparation was entrusted by Technical Committee B/517, Concrete, to Subcommittee B/517/1, Concrete production and testing, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 6, an inside back cover and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This British Standard, having been prepared under the direction of the Sector Committee for Building and Civil Engineering, was published under the authority of the Standards Committee and comes into effect on 15 December 2000

ISBN 0 580 36623 5

Amendments issued since publication

Amd. No.	Date	Comments

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 12390-8

October 2000

ICS 91.100.30

English version

Testing hardened concrete - Part 8: Depth of penetration of water under pressure

Essai pour béton durci - Partie 8: Profondeur de pénétration d'eau sous pression

Prüfung von Festbeton - Teil 8: Wassereindringtiefe unter Druck

This European Standard was approved by CEN on 18 February 2000.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 12390-8:2000 E

Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 104, Concrete (performance, production, placing and compliance criteria), the Secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2001, and conflicting national standards shall be withdrawn at the latest by December 2003.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This standard is one of a series concerned with testing concrete.

It is based on the draft International Standard ISO (DIS) 7031 - Concrete hardened - Determination of the depth of penetration of water under pressure.

The standard has been restricted to tests on specimens cured in water.

The requirement in the original draft ISO Standard for the average depth of penetration to be estimated has been omitted.

A draft for this standard was published in 1996 for CEN enquiry as prEN 12364. It was one of a series of individually numbered test methods for fresh or hardened concrete. For convenience it has now been decided to combine these separate draft standards into three new standards with separate parts for each method, as follows:

- Testing fresh concrete (EN 12350)
- Testing hardened concrete (EN 12390)
- Testing concrete in structures (EN 12504)

The series EN 12390 includes the following parts where the brackets give the numbers under which particular test methods were published for CEN enquiry:

EN 12390 Testing hardened concrete -

Part 1: Shape, dimensions and other requirements of specimens and moulds (former prEN 12356:1996)
Part 2: Making and curing specimens for strength tests (former prEN 12379:1996)
Part 3: Compressive strength of test specimens (former prEN 12394:1996)
Part 4: Compressive strength - Specification for testing machines (former prEN 12390:1996)
Part 5: Flexural strength of test specimens (former prEN 12359:1996)
Part 6: Tensile splitting strength of test specimens (former prEN 12362:1996)
Part 7: Density of hardened concrete (former prEN 12363:1996)
Part 8: Depth of penetration of water under pressure (former prEN 12364:1996)

1 Scope

This standard specifies a method for determining the depth of penetration of water under pressure in hardened concrete which has been water cured.

2 Principle

Water is applied under pressure to the surface of hardened concrete. The specimen is then split and the depth of penetration of the water front is measured.

3 Apparatus

3.1 Testing equipment

The test specimen, of given dimensions, shall be placed in any suitable equipment in such a manner that the water pressure can act on the test area and the pressure applied can be continuously indicated. An example of a test arrangement is shown in Figure 1.

NOTE 1 It is preferable that the apparatus should allow the other surfaces of the test specimen to be observed.

NOTE 2 The water pressure may be applied to the surface of the test specimen either from the bottom, or the top.

A necessary seal shall be made of rubber or other similar material.

The dimensions of a test area shall be approximately half of the length of the edge or diameter of the test surface.

4 Test specimen

The specimen shall be cubic, cylindrical or prismatic of length of edge, or diameter, not less than 150 mm.

5 Procedure

5.1 Preparation of the test specimen

Immediately after the specimen is de-moulded, roughen the surface to be exposed to water pressure, with a wire brush.

5.2 Application of water pressure

The test shall be started when the specimen is at least 28 days old. Do not apply the water pressure to a trowelled surface of a specimen. Place the specimen in the apparatus and apply a water pressure of (500 ± 50) kPa for (72 ± 2) h. During the test, periodically observe the appearance of the surfaces of the test specimen not exposed to the water pressure to note the presence of water. If leakage is observed then consider the validity of the result and record the fact.

NOTE The use of tap water is satisfactory.

5.3 Examination of specimen

After the pressure has been applied for the specified time, remove the specimen from the apparatus. Wipe the face on which the water pressure was applied to remove excess of water. Split the specimen in half, perpendicularly to the face on which the water pressure was applied. When splitting the specimen, and during the examination, place the face of the specimen exposed to the water pressure on the bottom. As soon as the split face has dried to such an extent that the water penetration front can be clearly seen, mark the water front on the specimen. Measure the maximum depth of penetration under the test area and record it to the nearest millimetre.

6 Test result

The maximum depth of penetration, expressed to the nearest millimetre, is the test result.

7 Test report

The report shall include:

a) identification of the test specimen;

b) date of start of the test;

c) description of the specimen;

d) direction of application of water pressure with respect to the casting direction;

e) maximum depth of penetration, in millimetres;

f) any leakage and consideration of the validity of the result; (if appropriate)

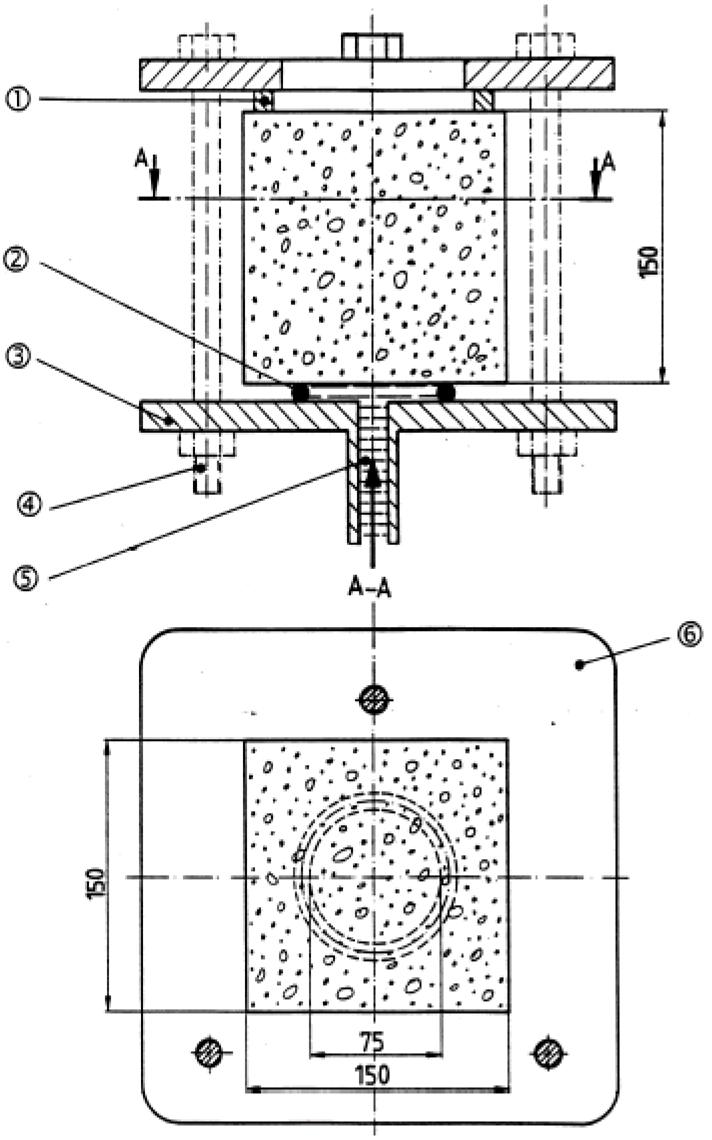
g) any deviation from standard test method;

h) a declaration by the person technically responsible for the test that it was carried out in accordance with this standard, except as noted in item g).

8 Precision

There is no precision data available.

Dimensions in millimetres



Key

1 Packing piece
2 Sealing ring
3 Scewed on plate
4 Screw-threaded rod
5 Water under pressure
6 Screwed on plate

Figure 1 - Example of test arrangement

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Designation: C 1585 – 04$^{\epsilon 1}$

Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes[1]

This standard is issued under the fixed designation C 1585; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—A typo in Eq 1 was corrected editorially in December 2007.

1. Scope

1.1 This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field

C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C 125 Terminology Relating to Concrete and Concrete Aggregates

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 642 Test Method for Density, Absorption, and Voids in Hardened Concrete

C 1005 Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology C 125.

4. Significance and Use

4.1 The performance of concrete subjected to many aggressive environments is a function, to a large extent, of the penetrability of the pore system. In unsaturated concrete, the rate of ingress of water or other liquids is largely controlled by absorption due to capillary rise. This test method is based on that developed by Hall[3] who called the phenomenon "water sorptivity."

4.2 The water absorption of a concrete surface depends on many factors including: *(a)* concrete mixture proportions; *(b)* the presence of chemical admixtures and supplementary cementitious materials; *(c)* the composition and physical characteristics of the cementitious component and of the aggregates; *(d)* the entrained air content; *(e)* the type and duration of curing; *(f)* the degree of hydration or age; *(g)* the presence of microcracks; *(h)* the presence of surface treatments such as sealers or form oil; and *(i)* placement method including consolidation and finishing. Water absorption is also strongly affected by the moisture condition of the concrete at the time of testing.

4.3 This method is intended to determine the susceptibility of an unsaturated concrete to the penetration of water. In general, the rate of absorption of concrete at the surface differs from the rate of absorption of a sample taken from the interior. The exterior surface is often subjected to less than intended curing and is exposed to the most potentially adverse conditions. This test method is used to measure the water absorption rate of both the concrete surface and interior concrete. By drilling a core and cutting it transversely at selected depths, the absorption can be evaluated at different distances from the exposed surface. The core is drilled vertically or horizontally.

4.4 This test method differs from Test Method C 642 in which the specimens are oven dried, immersed completely in

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.66 on Concrete's Resistance to Fluid Penetration.

Current edition approved Feb. 1, 2004. Published March 2004.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Hall, C., "Water Sorptivity of Mortars and Concretes: A Review," *Magazine of Concrete Research*, Vol. 41, No. 147, June 1989, pp. 51-61.

water at 21°C, and then boiled under water for 5 h. In this test method, only one surface is exposed to water at room temperature while the other surfaces are sealed simulating water absorption in a member that is in contact with water on one side only. Test Method C 642, on the other hand, is used to estimate the maximum amount of water that can be absorbed by a dry specimen and therefore provides a measure of the total, water permeable pore space.

5. Apparatus

5.1 *Pan*, a watertight polyethylene or other corrosion-resistant pan large enough to accommodate the test specimens with the surfaces to be tested exposed to water.

5.2 *Support Device*, rods, pins, or other devices, which are made of materials resistant to corrosion by water or alkaline solutions, and which allow free access of water to the exposed surface of the specimen during testing. Alternatively, the specimens can be supported on several layers of blotting paper or filter papers with a total thickness of at least 1 mm.

5.3 *Top-pan Balance*, complying with Specification C 1005 and with sufficient capacity for the test specimens and accurate to at least ± 0.01 g.

5.4 *Timing Device*, stop watch or other suitable timing device accurate to ± 1 s.

5.5 *Paper Towel or Cloth*, for wiping excess water from specimen surfaces.

5.6 *Water-Cooled Saw*, with diamond impregnated blade to cut test specimens from larger samples.

5.7 *Environmental Chamber*, a chamber allowing for air circulation and able to maintain a temperature of 50 ± 2°C and a relative humidity at 80 ± 3 %. Alternatively, an oven able to maintain a temperature of 50 ± 2°C and a dessicator large enough to contain the specimens to be tested is permitted. The relative humidity (RH) is controlled in the dessicator at 80 ± 0.5 % by a saturated solution of potassium bromide. The solubility of potassium bromide is 80.2 g/100 g of water at 50°C. The solution shall be maintained at the saturation point for the duration of the test. The presence of visible crystals in the solution provides acceptable evidence of saturation.

5.8 *Polyethylene Storage Containers*, with sealable lids, large enough to contain at least one test specimen but not larger than 5 times the specimen volume.

5.9 *Caliper*, to measure the specimen dimensions to the nearest 0.1 mm.

6. Reagents and Materials

6.1 *Potassium Bromide, Reagent Grade*, required if the oven and dessicator system described in 5.7 is used.

6.2 *Sealing Material*, strips of low permeability adhesive sheets, epoxy paint, vinyl electrician's tape, duct tape, or aluminium tape. The material shall not require a curing time longer than 10 minutes.

6.3 *Plastic Bag or Sheeting*, any plastic bag or sheeting that could be attached to the specimen to control evaporation from the surface not exposed to water. An elastic band is required to keep the bag or sheeting in place during the measurements.

7. Test Specimens

7.1 The standard test specimen is a 100 ± 6 mm diameter disc, with a length of 50 ± 3 mm. Specimens are obtained from either molded cylinders according to Practices C 31/C 31M or C 192/C 192M or drilled cores according to Test Method C 42/C 42M. The cross sectional area of a specimen shall not vary more than 1 % from the top to the bottom of the specimen. When cores are taken, they should be marked (see Note 1) so that the surface to be tested relative to the original location in the structure is clearly indicated.

NOTE 1—The surface to be exposed during testing shall not be marked or otherwise disturbed in such a manner as may modify the absorption rate of the specimen.

7.2 The average test results on at least 2 specimens (Note 2) shall constitute the test result. The test surfaces shall be at the same distance from the original exposed surface of the concrete.

NOTE 2—Concrete is not a homogeneous material. Also, an exterior surface of a concrete specimen seldom has the same porosity as the interior concrete. Therefore, replicate measurements are taken on specimens from the same depth to reduce the scatter of the data.

8. Sample Conditioning

8.1 Place test specimens in the environmental chamber at a temperature of 50 ± 2°C and RH of 80 ± 3 % for 3 days. Alternatively, place test specimens in a dessicator inside an oven at a temperature of 50 ± 2°C for 3 days. If the dessicator is used, control the relative humidity in the dessicator with a saturated solution of potassium bromide (see 5.7), but do not allow test specimens to contact the solution.

NOTE 3—To control the RH using the potassium bromide solution, the solution should be placed in the bottom of the dessicator, to ensure the largest surface of evaporation possible.

8.2 After the 3 days, place each specimen inside a sealable container (as defined in 5.8). Use a separate container for each specimen. Precautions must be taken to allow free flow of air around the specimen by ensuring minimal contact of the specimen with the walls of the container.

8.3 Store the container at 23 ± 2°C for at least 15 days before the start of the absorption procedure.

NOTE 4—Storage in the sealed container for at least 15 days results in equilibration of the moisture distribution within the test specimens and has been found[4] to provide internal relative humidities of 50 to 70 %. This is similar to the relative humidities found near the surface in some field structures.[5,6]

9. Procedure

9.1 Remove the specimen from the storage container and record the mass of the conditioned specimen to the nearest 0.01 g before sealing of side surfaces.

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[4] Bentz D. P., Ehlen M. A., Ferraris C. F., and Winpigler J. A., "Service Life Prediction Based on Sorptivity for Highway Concrete Exposed to Sulfate Attack and Freeze-Thaw Conditions," FHWA-RD-01-162, 2001.

[5] DeSouza S. J., Hooton R. D., and Bickley J. A., "Evaluation of Laboratory Drying Procedures Relevant to Field Conditions for Concrete Sorptivity Measurements," *Cement Concrete Aggr* 19: (2), Dec 1997, pp. 59-63.

[6] DeSouza S. J., Hooton R. D., and Bickley J. A., "A Field Test for Evaluating High Performance Concrete Covercrete Quality," *Can J Civil Eng*, 25: (3), Jun 1998, pp. 551-556.

9.2 Measure at least four diameters of the specimen at the surface to be exposed to water. Measure the diameters to the nearest 0.1 mm and calculate the average diameter to the nearest 0.1 mm.

9.3 Seal the side surface of each specimen with a suitable sealing material. Seal the end of the specimen that will not be exposed to water using a loosely attached plastic sheet (see 6.2). The plastic sheet can be secured using an elastic band or other equivalent system (see Fig. 1).

9.4 Use the procedure below to determine water absorption as a function of time. Conduct the absorption procedure at 23 ± 2°C with tap water conditioned to the same temperature.

9.5 *Absorption Procedure*:

9.5.1 Measure the mass of the sealed specimen to the nearest 0.01 g and record it as the initial mass for water absorption calculations.

9.5.2 Place the support device at the bottom of the pan and fill the pan with tap water so that the water level is 1 to 3 mm above the top of the support device. Maintain the water level 1 to 3 mm above the top of the support device for the duration of the tests.

NOTE 5—One method for keeping the water level constant is to install a water-filled bottle upside down such that the bottle opening is in contact with the water at the desired level.

9.5.3 Start the timing device and immediately place the test surface of the specimen on the support device (see Fig. 1). Record the time and date of initial contact with water.

9.5.4 Record the mass at the intervals shown in Table 1 after first contact with water. Using the procedure in 9.5.5, the first point shall be at 60 ± 2 s and the second point at 5 min ± 10 s. Subsequent measurements shall be within ± 2 min of 10 min, 20 min, 30 min, and 60 min. The actual time shall be recorded to within ± 10 s. Continue the measurements every hour, ± 5 min, up to 6 h, from the first contact of the specimen with water and record the time within ± 1 min. After the initial 6 h, take measurements once a day up to 3 days, followed by 3 measurements at least 24 h apart during days 4 to 7; take a final measurement that is at least 24 h after the measurement at 7 days. The actual time of measurements shall be recorded within ± 1 min. This will result in seven data points for contact time during days 2 through 8. Table 1 gives the target times of measurements and the tolerances for the times.

9.5.5 For each mass determination, remove the test specimen from the pan, stop the timing device if the contact time is less than 10 min, and blot off any surface water with a dampened paper towel or cloth. After blotting to remove excess water, invert the specimen so that the wet surface does not come in contact with the balance pan (to avoid having to dry the balance pan). Within 15 s of removal from the pan, measure the mass to the nearest 0.01 g. Immediately replace the specimen on the support device and restart the timing device.

10. Calculations

10.1 The absorption, *I*, is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. For the purpose of this test, the temperature dependence of the density of water is neglected and a value of 0.001 g/mm^3 is used. The units of *I* are mm.

$$I = \frac{m_t}{a*d} , \quad (1)$$

where:

I = the absorption,
m_t = the change in specimen mass in grams, at the time t,
a = the exposed area of the specimen, in mm^2, and
d = the density of the water in g/mm^3.

10.2 The initial rate of water absorption (mm/s$^{1/2}$) is defined as the slope of the line that is the best fit to *I* plotted against the square root of time (s$^{1/2}$). Obtain this slope by using least-squares, linear regression analysis of the plot of *I* versus time$^{1/2}$. For the regression analysis, use all the points from 1 min to 6 h, excluding points for times after the plot shows a clear change of slope. If the data between 1 min and 6 h do not follow a linear relationship (a correlation coefficient of less

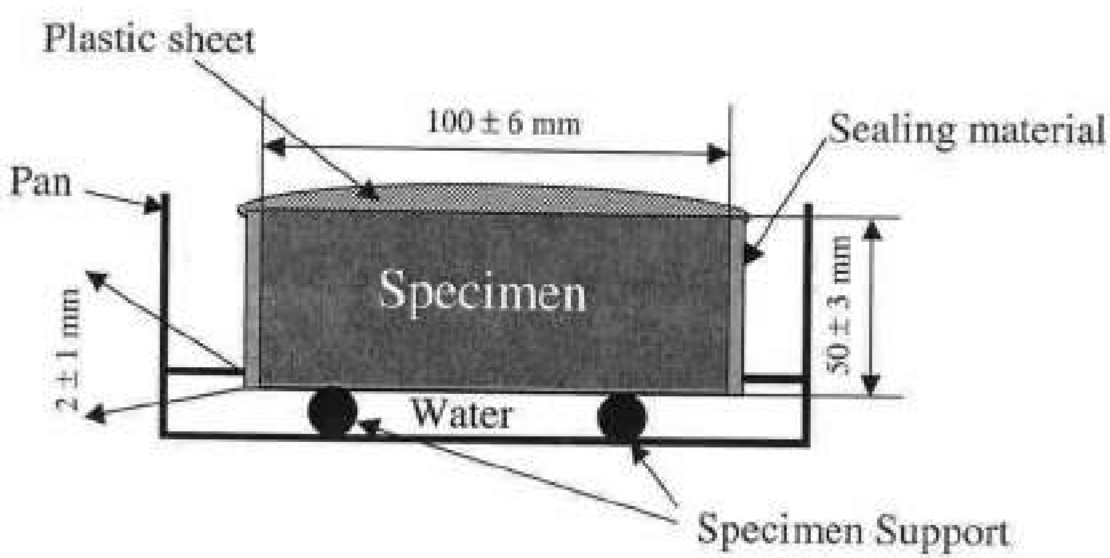


FIG. 1 Schematic of the Procedure

TABLE 1 Times and Tolernaces for the Measurements Schedule

Time	60 s	5 min	10 min	20 min	30 min	60 min	Every hour up to 6 h	Once a day up to 3 days	Day 4 to 7 3 measurements 24 h apart	Day 7 to 9 1 (one) measurement
Tolerance	2 s	10 s	2 min	2 min	2 min	2 min	5 min	2 h	2 h	2 h

than 0.98) and show a systematic curvature, the initial rate of absorption cannot be determined.

NOTE 6—Appendix X1 gives an example of absorption data and the results of regression analysis.

10.3 The secondary rate of water absorption (mm/$s^{1/2}$) is defined as the slope of the line that is the best fit to *I* plotted against the square root of time ($s^{1/2}$) using all the points from 1 *d* to 7 *d*. Use least-square linear regression to determine the slope. If the data between 1 *d* and 7 *d* do not follow a linear relationship (a correlation coefficient of less than 0.98) and show a systematic curvature, the secondary rate of water absorption cannot be determined.

11. Report

11.1 Report the following:

11.1.1 Date when concrete was sampled or cast,

11.1.2 Source of sample,

11.1.3 Relevant background information on sample such as mixture proportions, curing history, type of finishing, and age, if available,

11.1.4 Dimensions of specimen before sealing,

11.1.5 Mass of specimen before and after sealing,

11.1.6 A plot of absorption, *I*, in mm versus square root of time in $s^{1/2}$,

11.1.7 The average initial rate of water absorption calculated to the nearest 0.1×10^{-4} mm/$s^{1/2}$ and the individual initial absorption rates for the two or more specimens, and

11.1.8 The average secondary rate of water absorption calculated to the nearest 0.1×10^{-4} mm/$s^{1/2}$ and the individual absorption rates of the two or more specimens tested.

12. Precision and Bias

12.1 *Precision*—The repeatability coefficient of variation has been determined to be 6.0 % in preliminary measurements for the absorption as measured by this test method for a single laboratory and single operator. An interlaboratory program is being organized to develop the repeatability and reproducibility values.

12.2 *Bias*—The test method has no bias because the rate of water absorption determined can only be defined in terms of the test method.

13. Keywords

13.1 concrete; initial rate of water absorption; mortar; rate of absorption; secondary rate of water absorption

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE RATE OF WATER ABSORPTION TEST

TABLE X1.1 Example of Data Collected and Calculations

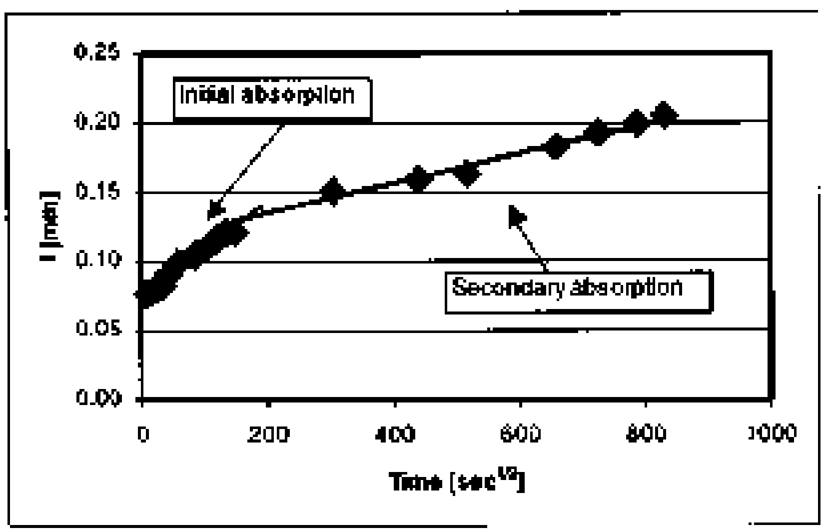
Sample No. F-68
Sample Conditioning: Cast, steam cured, test face = top surface
Sample: Age 378 days
Mass of Conditioned disc: 750.5 g (prior to sealing sides)
Diameter (mm): 101.6
Thickness (mm): 50.8
Water temp: 20.7°C

Cast Date: 3/2/99
Concrete Mixture: Standard mixture I

Age at coring: Unknown
Mass after sealing specimen: 761.8 g
Exposed Area: 8107 mm^2

Test Date: 3/14/00

Test Time		√Time ($s^{1/2}$)	Mass (g)	ΔMass (g)	ΔMass/area/density of water = *I* (mm)
Days	s				
	0	0	761.83	0.00	0.0000
	60	8	762.45	0.62	0.0765
	300	17	762.46	0.63	0.0777
	600	24	762.48	0.65	0.0802
	1200	35	762.50	0.67	0.0826
	1800	42	762.57	0.74	0.0913
	3600	60	762.63	0.80	0.0987
	7200	85	762.68	0.85	0.1048
	10800	104	762.73	0.90	0.1110
	14400	120	762.77	0.94	0.1159
	18000	134	762.81	0.98	0.1209
	21600	147	762.82	0.99	0.1221
1	92220	304	763.05	1.22	0.1505
2	193200	440	763.12	1.29	0.1591
3	268500	518	763.15	1.32	0.1628
5	432000	657	763.31	1.48	0.1826
6	527580	726	763.39	1.56	0.1924
7	622200	789	763.45	1.62	0.1998
8	691200	831	763.5	1.67	0.2060



Calculations:

Initial Absorption:
$I = S_i \sqrt{t} + b$ (points measured up to 6 h are used)
The initial rate of absorption is: $S_i = 3.5 \times 10^{-4}$ mm/√s $r = 0.99$

Secondary Absorption:
$I = S_s \sqrt{t} + b$ (points measured after the first day are used)
The secondary rate of absorption is: $S_s = 1.1 \times 10^{-4}$ mm/√s

FIG. X1.1 Example of Plot of The Data Shown in Table X1.1

NON-DESTRUCTIVE TESTING OF CONCRETE (NDT ON CONCRETE)

- It is a method of testing existing concrete structures to assess the strength and durability of concrete structure.
- In NDT without loading the specimen to failure we can measure strength of concrete.
- Now days this method has become a part of quality control process.
- This method helps us to investigate crack depth, micro cracks and deterioration of concrete.
- It requires skilled and experienced persons.

Purposes of Non-destructive Tests

- Estimating the in-situ compressive strength,uniformity, quality and homogeneity
- Identifying areas of lower integrity
- Detection of presence of imperfections
- Monitoring changes in the structure of the concrete.
- Condition of reinforcement steel with respect to corrosion
- Chloride, sulphate, alkali contents or degree of carbonation
- Measurement of Elastic Modulus
- Condition of grouting in prestressing cable ducts

DIFFERENT METHODS OF NDT

- Penetration method
- Rebound hammer method
- Pull out test method
- Ultrasonic pulse velocity method
- Radioactive methods

Penetration Tests on Concrete

- The Windsor probe is generally considered to be the best means of testing penetration.
- Equipment consists of a powder-actuated gun or driver, hardened alloy probes, loaded cartridges, a depth gauge for measuring penetration of probes and other related equipment.
- A probe, diameter 0.25 in. (6.5 mm) and length 3.125 in. (8.0 cm), is driven into the concrete by means of a precision powder charge.
- Depth of penetration provides an indication of the compressive strength of the concrete.
- Although calibration charts are provided by the manufacturer, the instrument should be calibrated for type of concrete and type and size of aggregate used.

Benefits and Limitations

- The test produces quite variable results and should not be expected to give accurate values of concrete strength.
- It has, however, the potential for providing a quick means of checking quality and maturity of in situ concrete.
- It also provides a means of assessing strength development with curing.
- The test is essentially non-destructive, since concrete and structural members can be tested in situ, with only minor patching of holes on exposed faces.

Rebound Hammer Method

- It is a surface hardness tester for which an empirical correlation has been established between strength and rebound number.
- The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer, which weighs about 4 lb (1.8 kg).
- It consists of a spring-controlled hammer mass that slides on a plunger within a tubular housing.
- The hammer is forced against the surface of the concrete by the spring and the distance of rebound is measured on a scale.
- The test surface can be horizontal, vertical or at any angle but the instrument must be calibrated in this position.

- Calibration can be done with cylinders (6 by 12 in., 15 by 30 cm) of the same cement and aggregate as will be used on the job.
- The cylinders are capped and firmly held in a compression machine.

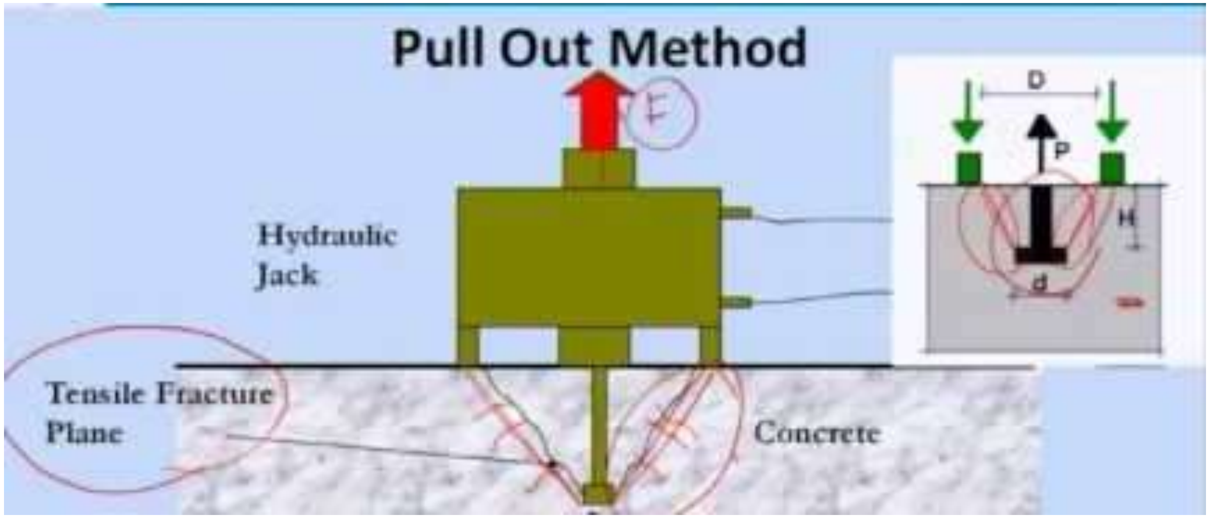
Limitations and Advantages

- The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength.
- The results are affected by factors such as

1. smoothness of surface
2. size and shape of specimen
3. moisture condition of the concrete
4. type of cement and coarse aggregate
5. extent of carbonation of surface.

Pull-Out Tests on Concrete

- A pull-out test measures, with a special ram, the force required to pull from the concrete a specially shaped steel rod whose enlarged end has been cast into the concrete to a depth of 3 in. (7.6 cm).
- The concrete is simultaneously in tension and in shear, but the force required to pull the concrete out can be related to its compressive strength.
- The pull-out technique can thus measure quantitatively the in-situ strength of concrete when proper correlations have been made.
- It has been found, over a wide range of strengths, that pull-out strengths have a coefficient of variation comparable to that of compressive strength.



Pull Out Method
F
D
P
H
d
Hydraulic Jack
Tensile Fracture Plane
Concrete

Advantages

- they do give information on the maturity and development of strength of a representative part of it..

Limitations

- The pull-out, of course, creates some minor damage.
- pullout tests do not measure the interior strength of mass concrete,

ULTRASONIC PULSE VELOCITY METHOD

- It is the only one of this type that shows potential for testing concrete strength in situ.
- It measures the time of travel of an ultrasonic pulse passing through the concrete.
- It consist of a pulse generator and a pulse receiver.
- Pulses are generated by shock-exciting piezoelectric crystals, with similar crystals used in the receiver.
- The time taken for the pulse to pass through the concrete is measured by electronic measuring circuits.
- It can be carried out on both laboratory-sized specimens and completed concrete structures.

- There must be smooth contact with the surface under test; a coupling medium such as a thin film of oil is mandatory.
- It is desirable for path-lengths to be at least 12 in. (30 cm) in order to avoid any errors introduced by heterogeneity.
- There is an increase in pulse velocity at below-freezing temperature owing to freezing of water; from 5 to 30°C (41 – 86°F) pulse velocities are not temperature dependent.
- The presence of reinforcing steel in concrete has an appreciable effect on pulse velocity.


200.3
Enter
Stop

APPLICATIONS AND LIMITATIONS

- It can be used on both existing structures and those under construction.
- if large differences in pulse velocity are found within a structure, it means that defective or deteriorated concrete is present.
- High pulse velocity readings are generally indicative of good quality concrete.
- It has been used to study the effects on concrete of freeze-thaw action, sulphate attack, and acidic waters.
- It can also be used to estimate the rate of hardening and strength development of concrete in the early stages to determine when to remove formwork.

- As concrete ages, the rate of increase of pulse velocity slows down.
- Accuracy depends on careful calibration and use of the same concrete mix proportions.
- It have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects.
- Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

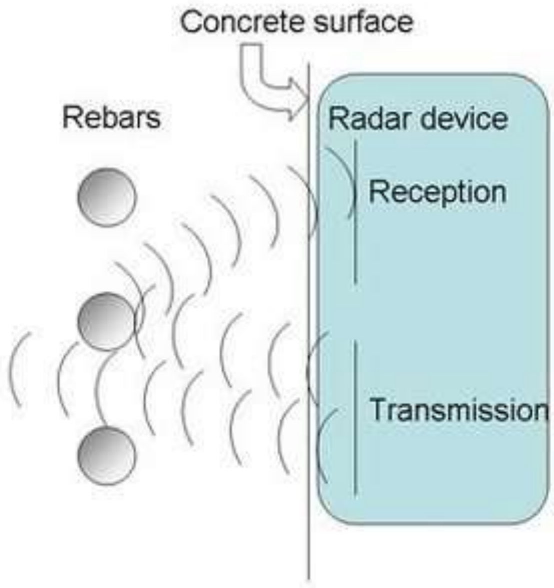
Table: Quality of Concrete and Pulse Velocity

General Conditions	Pulse Velocity ft/sec
Excellent	Above 15,000
Good	12,000-15,000
Questionable	10,000-12,000
Poor	7,000-10,000
Very Poor	below 7,000

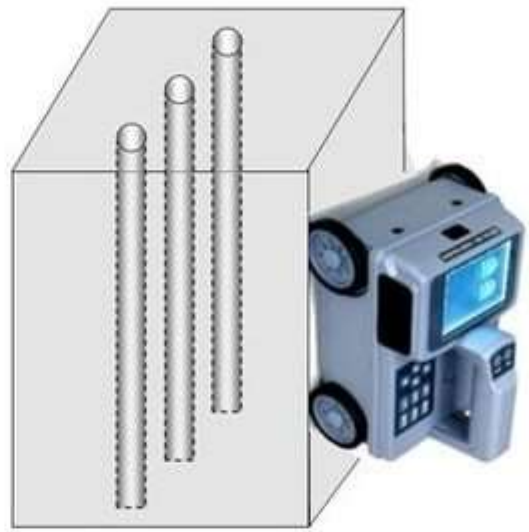
Radioactive Methods of NDT

- It can be used to detect the location of reinforcement, measure density.
- It can be used to check whether honeycombing has occurred in structural concrete units.
- Gamma radiography is increasingly accepted in England and Europe.
- The equipment is quite simple and running costs are small, although the initial price can be high.
- Concrete up to 18 in. (45 cm) thick can be examined without difficulty.

Measuring positions using reflections of EM waves



Reinforced concrete and radar device



UNIT-V

SPECIAL CONCRETE

1. Define light weight concrete.

The concrete is said to be light weight concrete whose density is between 300 to 1850 kg/m^3

2. Name some of the natural light weight aggregate

a. Pumice
b. Diatomite
c. Scoria
d. Volcanic cinders
e. Saw dust
f. Rice husk

3. Name some of the artificial light weight aggregate

a. Brick bat
b. Foamed slag
c. Cinder, clinker
d. Bloated clay
e. Sintered fly ash
f. Exfoliated vermiculite
g. Expanded perlite

4. Define Guniting or Shotcrete?

It is defined as a mortar conveyed through a hose and pneumatically projected at a high velocity on to a surface.

5. Define Polymer concrete?

Polymer concrete is part of group of concretes that use polymers to supplement or replace cement and uses polymer as a binder.

i. polymer impregnated concrete
ii. polymer cement concrete(pcc)
iii. polymer concrete

6.Define SIFCON?

Slurry Infiltrated Fibrous Reinforced Concrete (SIFCON) is a relatively new high performance and advanced material and can be considered as a special type of Steel Fiber Reinforced Concrete (SFRC).The technique of infiltrated layers of steel fibers with Portland cement based. Steel fibre bed is prepared and cement slurry is infiltrated .With this techniques macro-fibre content upto about 20% by volume can be achieved.

7.Define ferrocement?

Ferrocement is a relatively new material consisting of wire meshes and cement mortar. It consists of closely spaced wire meshes which are impregnated with rich cement mortar mix.

8. What is Geopolymer?

Geopolymer concrete is concrete based on an inorganic binder polymerized from Al-Si rich materials of geological or industrial origin, such as fly-ash. Geopolymer is used as the binder, instead of cement paste, to produce concrete.

9.Define Ready-mix concrete?

Concrete which is mixed in a stationary mixer in a central batching plant or in truck mixer and supplied in fresh condition to the purchaser either at site or into purchaser vehicle is called ready mix concrete.

10.Explain Fibre reinforced concrete

Fibre reinforced concrete is defined as the composite material consists of mixture of cement, mortar or concrete and discontinuous, discrete uniformly dispersed suitable fibres.

NATURAL FIBRES

Coconut fibre , Sugarcane, Straw, Jute fibres

SYNTHETIC FIBRES

Glass, carbon ,steel, polypropylene, nylon

PART B

1.Explain the Ready Mix Concrete?

Concrete which is mixed in a stationary mixer in a central batching plant or in truck mixer and supplied in fresh condition to the purchaser either at site or into purchaser vehicle is called ready mix concrete. The age of fresh concrete is 2 to 3 hours and should be delivered within 30 to 60 minutes.

Concrete itself is a mixture of Portland cement, water and aggregates comprising sand and gravel or crushed stone. In traditional work sites, each of these materials is procured separately and mixed in specified proportions at site to make concrete.

Ready Mixed Concrete is bought and sold by volume - usually expressed in cubic meters. The first ready-mix factory was built in the 1930s, but the industry did not begin to expand significantly until the 1980s, and it has continued to grow since then. The capacity is about 1.52 $m^{3.}$ The output of ready mix concrete is 30.58 $m^{3/}$ hr and can supply to a maximum of 1.33 m^3 for six times daily

Process:

A ready-mix concrete plant consists of silos that contain cement, sand, gravel and storage tanks of additives such as plasticizers, as well as a mixer to blend the components of concrete. These components are gravity fed into the preparation bin. The quality of concrete should be maintained.

The water dosage in particular must be very precise and the mixing itself must remain continuous and consistent. Finally, the concrete prepared in a batch plant is loaded into a mixer truck, also known as a transit mixer, which delivers it to the construction site. A concrete factory must be located within a radius of 20 to 30 km from the work site, depending on traffic conditions.

Storage silo → Belt conveyor → mixing plant → transit mixer or

or machine or batching unit

Components of RMC Plant:

- RMC Plant with Auxiliary or supporting equipment's.
- Transit mixer.
- Site equipment for handling concrete. (concrete pump)

Supporting equipment's:

- cement silos
- cement weight hopper
- aggregate bins
- conveyor

Properties:

- Good durability,
- High strength,
- Water tightness,
- Resistance to abrasion.

Advantages

- Speed in construction
- Elimination of storage needs
- Uniform and assured quantity of concrete
- Reduction in wastage
- RMC is eco-friendly
- Documentation of mix design
- Easy addition of admixtures

Disadvantages

- The materials are batched at a central plant, and the mixing begins at that plant, so the travelling time from the plant to the site is critical over longer distances.
- Generation of additional road traffic. Furthermore, access roads and site access have to be able to carry the greater weight of the ready-mix truck plus load.
- Concrete's limited time span between mixing and going-off means that ready-mix should be placed within 90 minutes of batching at the plant. Modern admixtures can modify that time span precisely, however, so the amount and type of admixture added to the mix is very important.

2. Explain the Light Weight Concrete?

Light weight concrete is produced by including large quantities of air in the aggregate, in the matrix or in between the aggregate particles, or by a combination of processes. Aggregate that weight less than about 1000kg/m^3 are used.

The light weight is due to the cellular structure or highly porous microstructure.

Natural light weight aggregates are made by processing igneous volcanic rocks such as pumice, scoria and tuff.

Synthetic light weight aggregates can be manufactured by thermal treatment from a variety of materials such as clay, shale, slate fly ash pallets, blast furnace slag.

Making:

The mixing procedure for light weight concrete is the same as for normal concrete and is produced in the same type of mixer or mixing plant. In first stage, the mortar is mixed i.e., cement, sand, admixtures, and about two-third of mixing water .in the second stage, the coarse aggregate is added with the rest of the water and final mixing is done. At times, light weight dry fines cause the material to form balls in the mixer. It can be avoided if less water is added at the start and then the amount is increased gradually .the size of the aggregate should be less than 8 or 10 mm.

Classification of light weight concretes:

i. By using porous light weight aggregate of low apparent specific gravity, i.e. lower than 2.6. This type of concrete is known as light weight aggregate concrete.

ii. By introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from the extremely fine voids produced by air entertainment. This type of concrete is variously known as aerated, cellular, foamed or gas concrete.

iii. By omitting the fine aggregate from the mix so that large amount of interstitial voids is present; normal weight coarse aggregate is generally used. This concrete is known as no-fine concretes.

Properties:

- Low compressive strength
- High water absorption and moisture content.
- High creep and shrinkage.
- Good thermal insulation due to air filled voids.
- Low thermal expansion.

Advantages

- Rapid and relatively simple construction.
- Economical in terms of transportation as well reduction in man power

- o Most of the light weight concrete have better nailing and sawing properties.
- o Significant reduction of overall weight and results in saving structural frames,

  footings and piles

Disadvantages:

- Inability to provide high compressive strength
- Less density
- Very sensitive to moisture content
- Mixing time is longer than conventional concrete to obtain proper mixing.

3.Explain polymer concrete?

Polymer concrete is part of group of concretes that use polymers to supplement or replace cement and uses polymer as a binder.

Process:

The main technique in producing PC is to minimize void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates. This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume.

The graded aggregates are prepacked and vibrated in a mould. Monomer is then diffused up through the aggregates and polymerization is initiated by radiation or chemical means. A silane coupling agent is added to the monomer to improve the bond strength between polymer and the aggregate. In polyester resins are used no polymerization is required. Polymer concrete can develop compressive strengths of the order of 140 MPa (20,000 psi) within hours or even minutes.

Such polymer concretes tend to be brittle and it is reported that dispersion of fibre reinforcement would improve the toughness and tensile strength of the material. The use of fibrous polyester concrete in the compressive region of reinforced concrete beams provides a high strength, ductile concrete at reasonable cost.

The types include polymer-impregnated concrete, polymer concrete, and polymer- Portland-cement concrete.

Properties:

- High tensile, flexural, and compressive strengths

- Good adhesion to most surfaces
- Good long-term durability with respect to freeze and thaw cycles
- Low permeability to water and aggressive solutions
- Good chemical resistance
- Good resistance against corrosion

Advantages:

- Rapid curing at ambient temperature.
- Lighter weight (only somewhat less dense than traditional concrete, depending on the resin content of the mix)
- Mines, tunnels, and highways.
- Pump manufacturing and chemical processing.
- Industries

Disadvantages

- More expensive
- The monomers can be volatile, combustible and toxic.
- Initiators which are used as catalyst are combustible and harmful to human skin

POLYMER IMPREGNATED CONCRETE

PIC is a hardened Portland cement concrete that has been impregnated with a monomer (low viscosity liquid organic material)and subsequently polymerized insitu. In this case the cement concrete is cast and cured in the conventional manner. After the concrete product gets hardened and dried, air from the voids is removed under partial vacuum and low viscosity monomer(styrene, vinyl chloride) is diffused through the pores of the concrete.

The concrete product is then finally subjected to polymerization by radiation or by heat treatment thereby converting the monomer filled in the voids into solid plastic.

Application:

- precast slabs for bridge decks,
- roads,
- marine structures
- food processing buildings

1. POLYMER CEMENT CONCRETE(PCC)

PCC is produced by incorporating an emulsion of a polymer or a monomer in ordinary Portland cement concrete. The ingredients comprising cement, aggregate and monomer are mixed with water and monomer in the concrete mix in the concrete is polymerized after placing concrete in position. The resultant concrete has improved :

- Strength,
- Adhesion
- Chemical resistance
- Impact and abrasion résistance
- Increased impermeability
- Reduced absorption

Application:

- o Marine Works

3.POLYMER CONCRETE

In polymer concrete polymer /monomer is used to act as binder in place of cement. The monomer and aggregate are mixed together and the monomer is polymerized after placement of concrete in position. It is imperative to pre-heat the coarse and fine aggregates while mixing monomer.

Application :

- Irrigation Works

4. Explain Fibre reinforced concrete?

Fibre reinforced concrete is defined as the composite material consists of mixture of cement, mortar or concrete and discontinuous, discrete uniformly dispersed suitable fibres.

 Plain cement concrete, due to its low tensile strength and impact resistance is considered to be o brittle material.

 However, marked improvement in these properties can be brought about by the addition of small diameter, short length, and randomly distributed fibres.

 The fibres can be imaginated as an aggregate with an extreme deviation in shape from the rounded smooth aggregate. The fibres interlock and entangle around aggregate particles and considerably reduce the workability, while the mix becomes more cohesive and less prone to segregation.

 The fibres suitable for reinforcing the concrete have been produced from steel, glass and organic polymers.

The major factors affecting the characteristics of fibre reinforced concrete are:

- water cement ratio;
- size of coarse aggregate
- mixing
- Percentage of fibres;
- Aspect ratio
- Diameter and length of fibres

The location and extent of cracking under load will depend upon the orientation and number of fibres in the cross section. The fibre stress strain the shrinkage and creep movements of unreinforced matrix. However fibres have been found to be more effective in controlling compression creep than tensile creep of unreinforced matrix.

Properties:

- Increased tensile and bending strength coir
- Improved ductility and resistance to cracking
- High impact strength and toughness
- Spalling resistance
- High energy absorption capacity

Application:

- Hydraulic structures
- Airfield and highway pavement
- Bridge decks
- Tunnel lining
- Heavy duty floors

Disadvantage:

- The main **disadvantage** associated with the fiber reinforced concrete is Fabrication. The process of incorporating fibers into the cement matrix is labor intensive.
- Costlier than the production of the plain concrete.

Types of fibres

Natural fibres
- Coconut fibre
- Sugarcane
- Straw
- Jute fibres

synthetic fibres
- glass
- carbon
- steel
- nylon polypropylene

SYNTHETIC FIBRES:

Steel fibre reinforced concrete

This type of concrete is formed by adding steel fibres in the ingredients of concrete. Round steel fibres are commonly used. The typical diameter lies in the range of .25 to .75 mm, by addition of 2 to 3 percent of fibre(by volume).

It is possible to achieve two or three times increase in the flexural strength of concrete and substantial increase in explosion resistance, crack resistance etc.

Application:

- Construction of pavement
- Bridge decks,
- Pressure vessels ,
- Tunnel lining

Glass fibre reinforced concrete:

Glass fibres are made up from 200 to 400 individual filaments which are highly bonded to make up a strand. These strands can be chopped into various lengths or combined into make cloth,mat or tape. The process of manufacture of glass-fibre cement products may involve spraying, premixing or incorporation of continuous rovings. It has been observed that addition of 10% of glass fibres by volume brings almost two folds increase in tensile strength and substantial increase in impact resistance of concrete.

Application:

- Used in sewer lining
- Roofing elements, swimming pool, tanks etc.
- Polypropylene and nylon fibres.
- Increase the impact strength.
- Possess very high tensile strength

Asbestos:

- I t is a mineral fibre
- Tensile strength varies between 560 and 980 N/mm^2.

Carbon fibres:

- Possess a tensile strength of 2110 to 2815N/ mm^2.
- Used in cladding, panels, shells

NATURAL FIBRES:

Coconut fibre as reinforcement

Natural reinforcing materials can be obtained at low cost and low levels of energy using local manpower and technology. Utilization of natural fibres as a form of concrete enhancement is of Particular interest to less developed regions where conventional construction materials are not readily available or are too expensive. Coconut and sisal-fibre reinforced concrete have been used for making roof tiles, corrugated sheets, pipes, silos and tanks. The dry cement and aggregates were mixed for two minutes by hand in a 0.1m3 laboratory mixer pan.

The mixing continued for further few minutes while about 80% of the water was added. The mixing was continued for another few minutes and the fibres were fed continuously to the concrete for a period of 2–3 min while stirring.

Finally, the remaining water along with super -plasticizer was added and the mixing was continued for an additional two minutes. This ensured a complete distribution of fibres throughout the concrete mix. For each mix, a total of six cylinders with dimension of 100×200mm and three cubes of 100mm were cast.

5. Explain

(i) High strength concrete

(ii) High performance concrete

(iii) Geo polymer concrete

(iv) Ferro cement

High strength concrete

The manufacture of high strength concrete will grow to find its due place in concrete construction for all the obvious benefits. In the modern batching plants high strength concrete is produced in a mechanical manner. Of course, one has to take care about mix proportioning, shape of aggregates, use of supplementary cementitious materials, silica fume and superplasticizers. With the modern equipments, understanding of the role of the constituent materials, production of high strength concrete has become a routine matter. There are special methods of making high strength concrete. They are given below.

(a) Seeding (b) Revibration (c) High speed slurry mixing;

(d) Use of admixtures (e) Inhibition of cracks (f) Sulphur impregnation

(g) Use of cementitious aggregates.

Seeding:

This involves adding a small percentage of finely ground, fully hydrated Portland cement to the fresh concrete mix. The mechanism by which this is supposed to aid strength development is difficult to explain. This method may not hold much promise.

Revibration:

Concrete undergoes plastic shrinkage. Mixing water creates continuous capillary channels, bleeding, and water accumulates at some selected places. All these reduce the strength of concrete. Controlled revibration removes all these defects and increases the strength of concrete.

High Speed slurry mixing:

This process involves the advance preparation of cement- water mixture which is then blended with aggregate to produce concrete. Higher compressive strength obtained is attributed to more efficient hydration of cement particles and water achieved in the vigorous blending of cement paste.

Use of Admixtures:

Use of water reducing agents are known to produce increased compressive strengths.

Inhibition of cracks:

Concrete fails by the formation and propagation of cracks. If the propagation of cracks is inhibited, the strength will be higher. Replacement of 2– 3% of fine aggregate by polythene or polystyrene ―lenticules 0.025 mm thick and 3 to 4 mm in diameter results in higher strength. They appear to act as crack arresters without necessitating extra water for workability. Concrete cubes made in this way have yielded strength upto 105 MPa.

Sulphur Impregnation:

Satisfactory high strength concrete have been produced by impregnating low strength porous concrete by sulphur. The process consists of moist curing the fresh concrete specimens for 24 hours, drying them at 120°C for 24 hours, immersing the specimen in molten sulphur under vacuum for 2 hours and then releasing the vacuum and soaking them for an additional ½ hour for further infiltration of sulphur. The sulphur-infiltrated concrete has given

strength upto 58 MPa.

Use of Cementitious aggregates:

It has been found that use of cementitious aggregates has yielded high strength. Cement found is kind of clinker. This glassy clinker when finely ground results in a kind of cement. When coarsely crushed, it makes a kind of aggregate known as ALAG. Using Alag as aggregate, strength upto 125 MPa has been obtained with water/cement ratio 0.32.

High performance concrete:

High Performance Concrete (HPC) is a specialized series of concretes designed to provide several benefits in the construction of concrete structures. High performance concrete possess high level of all characteristics of concrete, strength, durability, all service life for durability of concrete. Conventional concrete designed on the basis of compressive strength does not meet any functional requirements such as impermeability, resistance to frost, thermal cracking etc. While high strength concrete aims at enhancing strength. The term high performance concrete is used to refer concrete of required performance for the majority of construction applications.

Making:

The mixing sequence of high performance concrete is as follows. Loading of the aggregates and water, addition of the air entraining agent and mixing to develop a satisfactory air bubble system and stabilizing it. Mixing of cement. Addition of super plasticizer and mixed finally.

Properties:

- High workability.
- High durability
- Resistance to chemical attack.
- High strength
- High modulus of elasticity

Advantage:

- ease of placement and consolidation without affecting strength
- long-term mechanical properties
- early high strength
- toughness
- volume stability
- bridge decks, pavements and paving structures
- longer life in severe environments

Disadvantage:

- Highly expensive
- Proportion of admixtures should be accurate otherwise the properties get changed.

GEOPOLYMER CONCRETE :

Geopolymer concrete is concrete based on an inorganic binder polymerized from Al-Si rich materials of geological or industrial origin, such as fly-ash. Geopolymer is used as the binder, instead of cement paste, to produce concrete. The geopolymer paste binds the loose coarse aggregates, fine aggregates and other unreacted materials together to form the geopolymer concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods.

As in the Portland cement concrete, the aggregates occupy the largest volume, that is, pproximately 75 to 80% by mass, in geopolymer concrete. The silicon and the aluminum in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste that binds the aggregates and other unreacted materials.

PROCESS:

Materials

The materials needed to manufacture the geopolymer concrete are the same as those for making Portland cement concrete, except for the Portland cement. Low calcium (class F) dry fly ash obtained from a local power station was used as the source material. For the alkaline activator, a combination of sodium hydroxide solution and sodium silicate solution was used.

The sodium hydroxide solution was prepared by dissolving the sodium hydroxide solids, either in the form of pellets or flakes, in water. Extra water and Naphthalene Sulfonate-based superplasticizer were also added to improve the workability of the fresh fly ash-based geopolymer concrete. The sodium silicate solution used contained Na_2O=14.7%, SiO_2=29.4%, and 55.9% of water, by mass. All the liquids were mixed together before adding to the solids.

Mixing and Compacting

The aggregates in saturated surface dry condition and the dry fly ash were mixed in a pan mixer for 3-4 minutes. At the end of this mixing, the liquid component of the geopolymer concrete mixture, i.e. the combination of the alkaline solution, the superplasticiser and the extra water, was added to the solids, and the mixing continued for a specified period of time. In this study, the wet mixing period was designated as the ‗mixing time'.

The fresh concrete had a stiff consistency and was glossy in appearance. The fresh concrete was then cast in moulds. Compaction was performed using the usual practice, either by applying strokes or using vibration or a combination of both. After casting, the concrete samples were cured at an elevated temperature for a specified period of time.

Curing

Curing was carried out at a specified elevated temperature, either in an oven (dry curing) or in a steam chamber. At the end of the curing period, the test specimens were left in the mold for about six hours. The samples were then removed from the molds, and left to air dry in the room temperature before testing at a specified age

ENGINEERING PROPERTIES

- Compressive strengths ranging from 20-30MPa to 80-100MPa Ref. 1.
- Flexural strengths typically 2-3MPa higher than for OPC concrete at the same compressive strength
- Hardening in 5-7 days vs. 28 days for OPC concrete at ambient temperature.

- Does not generate any heat of hydration during curing due to the polymerization nature of its chemistry.
- Low specific creep: typ. 25-30 microstrains at 40% load, vs. 50-60 for OPC concrete.
- Low drying shrinkage: typ. 100-150 microstrains @ 1 yr., vs. 500-800 for OPC concrete.
- Excellent resistance to freeze-thaw cycles
- Adhesion to fresh and old concrete substrates, steel, glass, ceramics.
- Inherent protection of steel reinforcing due to low chloride diffusion rates.

SUPERIOR DURABILITY :

1) High level of resistance to a range of acids and salt solutions

- Na_2SO_4, $MgSO_4$, NaCl, Sulfuric Acid, Hydrochloric Acid
- Resistant to seawater corrosion

2) Not subject to deleterious alkali-aggregate reactions.
3) Impervious to water.
4) Fire resistance

No water molecules present in the geopolymer structure hence does not spall at high temperatures, unlike OPC concrete.

5) Does not burn or release toxic fumes, unlike organic polymers.

APPLICATIONS:

- metro/railroad systems,
- highways, bridges,
- marine infrastructure,
- dams, canal linings,
- water and sewage pipes,
- mine tailings.

ADVANTAGES:

- geopolymer concrete has significantly higher resistance to acid then ordinary concrete
- 80% reduction in CO_2 footprint comparing to OPC, opportunity to obtain tradable CO_2 certificates.
- Can be used in a wide range of ready-mix, pre-cast, and pre-stressed/pre-cast applications
- Excellent fire and heat resistance. It has the ability to remain stable in temperatures of more than 1200 ^{o}C

DISADVANTAGES

- o Activator is necessary to start the geopolymerisation process.
- o Due to the dangers of handling chemicals and the liability issues that ensue, geopolymer concrete is generally sold as a pre-cast or pre-mixed material

FERROCEMENT CONCRETE :

It is well known that conventional reinforced concrete members are too heavy, brittle, cannot be satisfactorily repaired if damaged, develop cracks and reinforcements are liable to be corroded. The above disadvantages of normal concrete make it inefficient for certain types of work.

Ferrocement is a relatively new material consisting of wire meshes and cement mortar.It consists of closely spaced wire meshes which are impregnated with rich cement mortar mix. The wire mesh is usually of 0.5 to 1.0 mm dia wire at 5 mm to 10 mm spacing and cement mortar is of cement sand ratio of 1 : 2 or 1 : 3 with water/cement ratio of 0.4 to 0.45. The ferrocement elements are usually of the order of 2 to 3 cm. in thickness with 2 to 3 mm external cover to the reinforcement.

The steel content varies between 300 kg to 500 kg per cubic meter of mortar. The basic idea behind this material is that concrete can undergo large strains in the neighborhood of the reinforcement and the magnitude of strains depends on the distribution and subdivision of reinforcement throughout of the mass of concrete.

6. Describe in detail about Shotcrete and its advantages.

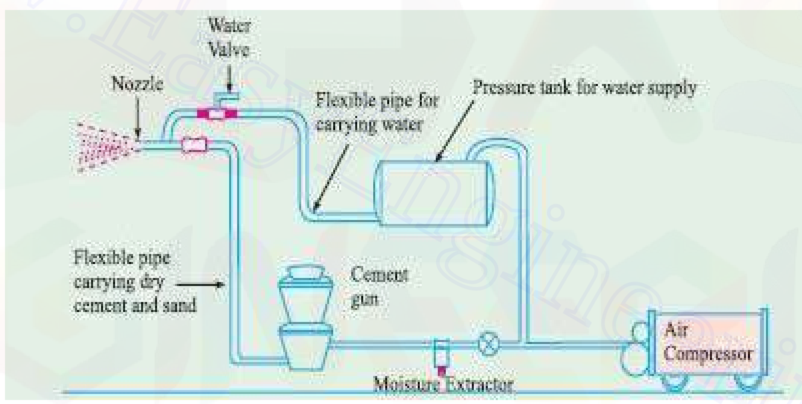
Shotcrete or Gunite can be defined as mortar conveyed through a hose and pneumatically projected at a high velocity on to a surface. Recently the method has been further developed by the introduction of small sized coarse aggregate into the mix deposited to obtain considerably greater thickness in one operation and also to make the process economical by reducing the cement content. Normally fresh material with zero slump can support itself without sagging or peeling off. The force of the jet impacting on the surface compact the material. Sometimes use of set accelerators to assist overhead placing is practised. The newly developed ―Redi-set cement can also be used for shotcreting process.

There is not much difference between guniting and shotcreting. Gunite was first used in the early 1900 and this process is mostly used for pneumatical application of mortar of less thickness, whereas shotcrete is a recent development on the similar principle of guniting for achieving greater thickness with small coarse aggregates.

There are two different processes in use, namely the Wet-mix process and the dry- Mix process. The dry mix process is more successful and generally used.

Dry-mix Process

The dry mix process consists of a number of stages and calls for some specialized plant. A typical small plant set-up is shown in FigThe stages involved in the dry mix process is given below:



- Cement and sand are thoroughly mixed.
- The cement/sand mixture is fed into a special air-pressurised mechanical feeder termed as _gun‘.
- The mixture is metered into the delivery hose by a feed wheel or distributor within the gun.
- This material is carried by compressed air through the delivery hose to a special nozzle.
- The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet.
- The wet mortar is jetted from the nozzle at high velocity onto the surface to be gunited.

The Wet-mix Process

In the wet-mix process the concrete is mixed with water as for ordinary concrete before conveying through the delivery pipe line to the nozzle, at which point it is jetted by compressed air, onto the work in the same way, as that of dry mix process. The wet-mix process has been generally discarded in favour of the dry-mix process, owing to the greater success of the latter.

The dry-mix methods makes use of high velocity or low velocity system. The high velocity gunite is produced by using a small nozzle and a high air pressure to produce a high nozzle velocity of about 90 to 120 metres per second. This results in exceptional good compaction. The lower velocity gunite is produced using large diameter hose for large output. The compaction will not be very high.

Advantages of Wet and Dry Process

Although it is possible to obtain more accurate control of the water/cement ratio with the wet process the fact that this ratio can be kept very low with the dry process largely overcomes the objection of the lack of accurate control. The difficulty of pumping light-weight aggregate concrete makes the dry process more suitable when this type of aggregate is used. The dry process on the other hand, is very sensitive to the water content of the sand, too wet a sand causes difficulties through blockade of the delivery pipeline, a difficulty which does not arise with the wet process. The lower water/cement ratio obtained with the dry process probably accounts for the lesser creep and greater durability of concrete produced in this way compared with concrete deposited by the wet process, but air-entraining agents can be use to improve the durability of concrete deposited by the latter means.

Admixtures generally can be used more easily with the wet process except for accelerators. Pockets of lean mix and of rebound can occur with the dry process. It is necessary for the nozzelman to have an area where he can dump unsatisfactory shotcrete obtained when he is adjusting the water supply or when he is having trouble with the equipment. These troubles and the dust hazard are less with the wet process, but wet process does not normally give such a dense concrete as the dry process. Work can be continued in more windly weather with the wet process than with the dry process, Owing to the high capacities obtainable with concrete pumps, a higher rate of laying of concrete can probably be achieved in the wet process than with the dry process.

CONTENTS

INTRODUCTION:

- Light weight concrete is a special concrete which weighs lighter than conventional concrete.
- Density of this concrete is considerably low (300 kg/m3 to 1850 kg/m3) when compared to normal concrete (2200kg/m3 to 2600kg/m3).
- Three types of LWC
  - Light weight aggregate concrete
  - Aerated concrete
  - No – fines concrete

PRINCIPLE BEHIND LWC:

The basic principle behind the making of light weight concrete is by inducing the air in concrete.

To achieve the above principle practically, there are 3 different ways.

- By replacing the conventional aggregates by cellular porous aggregates (Light weight agg. Concrete).
- By incorporating the air or gas bubbles in concrete (Aerated concrete).
- By omitting the sand from the concrete (No- fines concrete).

ADVANTAGES:

- Reduces the dead load of the building.
- Easy to handle and hence reduces the cost of transportation and handling.
- Improves the workability.
- Relatively low thermal conductivity
- Comparatively more durable
- Good resistance to freezing & thawing actio when compared to conventional concrete.

DISADVANTAGES

- Very Sensitive with water content in the mixture.
- Difficult to place and finish because of porosity and angularity of the aggregate .In some mixes the cement mortar may separate the aggregate and float towards the surface
- Mixing time is longer than conventional concrete to assure proper mixing .
- Lightweight Concrete are porous and shows poor resistance

APPLICATIONS

- Since the strength of L.W.C. is low, it is used in the construction of roof slabs, small houses with load bearing walls etc.
- It is also used in the construction of stairs, windows, garden walls, etc.
- In large buildings also, this is used in the construction of partition walls.
- These are moulded in the form of slabs and used as thermal insulators inside the building.

LIGHT WEIGHT AGGREGATE CONCRETE:

- Basically two types of light weight aggregates
    - Natural aggregates
    - Artificial aggregates
- Natural light weight aggregates are less preferred over artificial aggregates.
- Important natural aggregates – Pumice & Scoria
- Artificial aggregates are usually produced by expanding the rocks such as Shale, Slate, Perlite, Vermiculite, etc.,
- Type of aggregates decides the density of concrete.
- Density of concrete as low as 300 kg/m3 can be achieved.
- Compressive strength varies from 0.3Mpa to 40Mpa.

Natural light-weight aggregate	Artificial light-weight aggregate
(*a*) Pumice	(a) Artificial cinders
(*b*) Diatomite	(*b*) Coke breeze
(*c*) Scoria	(*c*) Foamed slag
(*d*) Volcanic cinders	(*d*) Bloated clay
(*e*) Sawdust	(*e*) Expanded shales and slate
(*f*) Rice husk	(*f*) Sintered fly ash
	(*g*) Exfoliated vermiculite
	(*h*) Expanded perlite
	(*i*) Thermocole beads.

PROPERTIES OF LIGHT WEIGHT AGGREGATES

- Pumice and Scoria are volcanic rocks having densities between 500kg/m3 to 900kg/m3.
- Natural aggregates have good insulating properties but subjected to high absorption and shrinkage.

PUMİCE

aggregate

blocks

1.1 Introduction

This section covers the following topics.

- Basic Concept
- Early Attempts of Prestressing
- Brief History
- Development of Building Materials

1.1.1 Basic Concept

A prestressed concrete structure is different from a conventional reinforced concrete structure due to the application of an **initial load on the structure prior to its use**. The initial load or ‘prestress’ is applied to enable the structure to counteract the stresses arising during its service period.

The prestressing of a structure is not the only instance of prestressing. The concept of prestressing existed before the applications in concrete. Two examples of prestressing before the development of prestressed concrete are provided.

Force-fitting of metal bands on wooden barrels

The metal bands induce a state of initial hoop compression, to counteract the hoop tension caused by filling of liquid in the barrels.

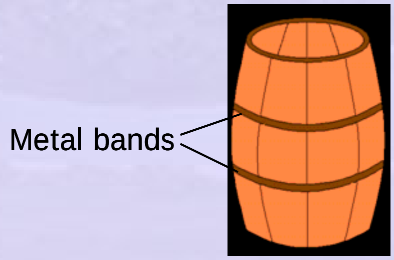


Figure 1-1.1 Force-fitting of metal bands on wooden barrels

Pre-tensioning the spokes in a bicycle wheel

The pre-tension of a spoke in a bicycle wheel is applied to such an extent that there will always be a residual tension in the spoke.

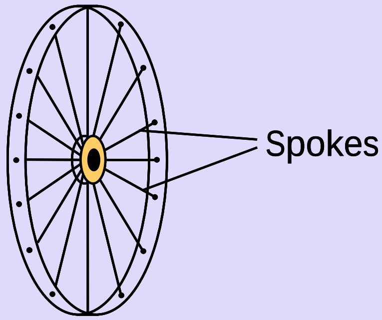


Figure 1-1.2 Pre-tensioning the spokes in a bicycle wheel

For concrete, internal stresses are induced (usually, by means of tensioned steel) for the following reasons.

- The tensile strength of concrete is only about 8% to 14% of its compressive strength.
- Cracks tend to develop at early stages of loading in flexural members such as beams and slabs.
- To prevent such cracks, compressive force can be suitably applied in the perpendicular direction.
- Prestressing enhances the bending, shear and torsional capacities of the flexural members.
- In pipes and liquid storage tanks, the hoop tensile stresses can be effectively counteracted by circular prestressing.

1.1.2 Early Attempts of Prestressing

Prestressing of structures was introduced in late nineteenth century. The following sketch explains the application of prestress.

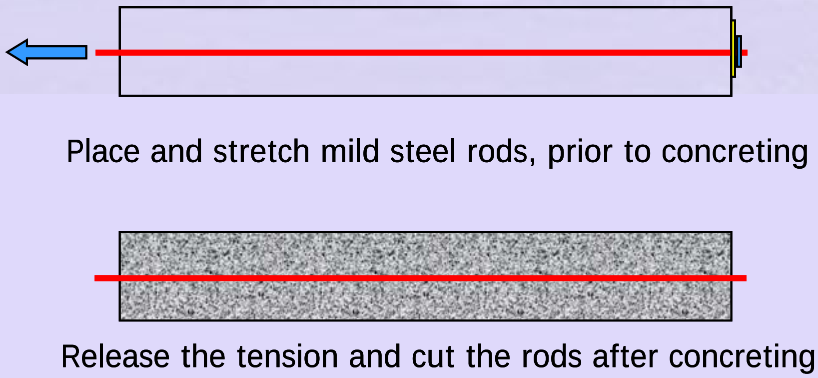


Figure 1-1.3 Prestressing of concrete beams by mild steel rods

Mild steel rods are stretched and concrete is poured around them. After hardening of concrete, the tension in the rods is released. The rods will try to regain their original length, but this is prevented by the surrounding concrete to which the steel is bonded. Thus, the concrete is now effectively in a state of pre-compression. It is capable of counteracting tensile stress, such as arising from the load shown in the following sketch.

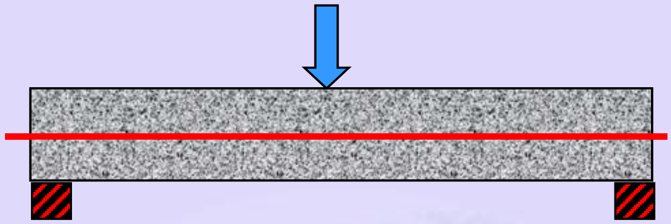


Figure 1-1.4 A prestressed beam under an external load

But, the early attempts of prestressing were not completely successful. It was observed that the effect of prestress reduced with time. The load resisting capacities of the members were limited. Under sustained loads, the members were found to fail. This was due to the following reason.

Concrete shrinks with time. Moreover under sustained load, the strain in concrete increases with increase in time. This is known as creep strain. The reduction in length due to **creep** and **shrinkage** is also applicable to the embedded steel, resulting in significant loss in the tensile strain.

In the early applications, the strength of the mild steel and the strain during prestressing were less. The residual strain and hence, the residual prestress was only about 10% of the initial value. The following sketches explain the phenomena.

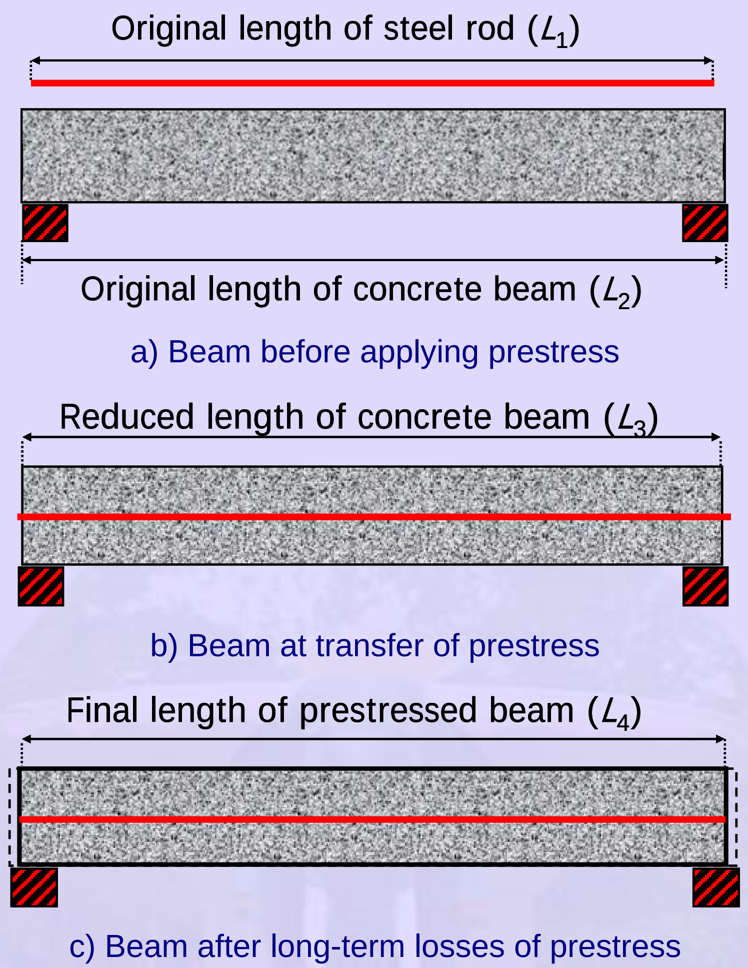


Figure 1-1.5 Variation of length in a prestressed beam

The residual strain in steel = original tensile strain in steel – compressive strains corresponding to short-term and long-term losses.

Original tensile strain in steel $= (L_2 - L_1)/L_1$

Compressive strain due to elastic shortening of beam (short-term loss in prestress) $= (L_2 - L_3)/L_1$

Compressive strain due to creep and shrinkage (long-term losses in prestress) $= (L_3 - L_4)/L_1$

Therefore, residual strain in steel $= (L_4 - L_1)/L_1$

The maximum original tensile strain in mild steel = Allowable stress / elastic modulus

$= 140 \text{ MPa} / 2\times10^5 \text{ MPa}$

$= 0.0007$

The total loss in strain due to elastic shortening, creep and shrinkage was also close to 0.0007. Thus, the residual strain was negligible.

The solution to increase the residual strain and the effective prestress are as follows.

- Adopt **high strength steel** with much higher original strain. This leads to the scope of high prestressing force.
- Adopt **high strength concrete** to withstand the high prestressing force.

1.1.3 Brief History

Before the development of prestressed concrete, two significant developments of reinforced concrete are the invention of Portland cement and introduction of steel in concrete. These are also mentioned as the part of the history. The key developments are mentioned next to the corresponding year.

1824 Aspdin, J., (England)

Obtained a patent for the manufacture of Portland cement.

1857 Monier, J., (France)

Introduced steel wires in concrete to make flower pots, pipes, arches and slabs.

The following events were significant in the development of prestressed concrete.

1886 Jackson, P. H., (USA)

Introduced the concept of tightening steel tie rods in artificial stone and concrete arches.

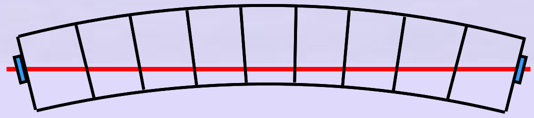


Figure 1-1.6 Steel tie rods in arches

1888 Doehring, C. E. W., (Germany)

Manufactured concrete slabs and small beams with embedded tensioned steel.

1908 Stainer, C. R., (USA)

Recognised losses due to shrinkage and creep, and suggested retightening the rods to recover lost prestress.

1923 Emperger, F., (Austria)

Developed a method of winding and pre- tensioning high tensile steel wires around concrete pipes.

1924 Hewett, W. H., (USA)

Introduced hoop-stressed horizontal reinforcement around walls of concrete tanks through the use of turnbuckles.

Thousands of liquid storage tanks and concrete pipes were built in the two decades to follow.

1925 Dill, R. H., (USA)

Used high strength unbonded steel rods. The rods were tensioned and anchored after hardening of the concrete.

Figure 1-1.7 Portrait of Eugene Freyssinet

(Reference: Collins, M. P. and Mitchell, D.,*Prestressed Concrete Structures*)

1926 Eugene Freyssinet (France)

Used high tensile steel wires, with ultimate strength as high as 1725 MPa and yield stress over 1240 MPa. In 1939, he developed conical wedges for end anchorages for post-tensioning and developed double-acting jacks. He is often referred to as the **Father of Prestressed concrete**.

1938 Hoyer, E., (Germany)

Developed 'long line' pre-tensioning method.

1940 Magnel, G., (Belgium)

Developed an anchoring system for post-tensioning, using flat wedges.

During the Second World War, applications of prestressed and precast concrete increased rapidly. The names of a few persons involved in developing prestressed concrete are mentioned. Guyon, Y., (France) built numerous prestressed concrete bridges in western and central Europe. Abeles, P. W., (England) introduced the concept of partial prestressing. Leonhardt, F., (Germany), Mikhailor, V., (Russia) and Lin, T. Y., (USA) are famous in the field of prestressed concrete.

The International Federation for Prestressing (FIP), a professional organisation in Europe was established in 1952. The Precast/Prestressed Concrete Institute (PCI) was established in USA in 1954.

Prestressed concrete was started to be used in building frames, parking structures, stadiums, railway sleepers, transmission line poles and other types of structures and elements.

In India, the applications of prestressed concrete diversified over the years. The first prestressed concrete bridge was built in 1948 under the Assam Rail Link Project. Among bridges, the Pamban Road Bridge at Rameshwaram, Tamilnadu, remains a classic example of the use of prestressed concrete girders.

Figure 1-1.8 Pamban Road Bridge at Rameshwaram, Tamilnadu
(Reference: http://www.ramnad.tn.nic.in)

1.1.4 Development of Building Materials

The development of prestressed concrete can be studied in the perspective of traditional building materials. In the ancient period, stones and bricks were extensively used. These materials are strong in compression, but weak in tension. For tension, bamboos and coir ropes were used in bridges. Subsequently iron and steel bars were used to resist tension. These members tend to buckle under compression. Wood and structural steel members were effective both in tension and compression.

In reinforced concrete, concrete and steel are combined such that concrete resists compression and steel resists tension. This is a **passive** combination of the two materials. In prestressed concrete high strength concrete and high strength steel are combined such that the full section is effective in resisting tension and compression. This is an **active** combination of the two materials. The following sketch shows the use of the different materials with the progress of time.

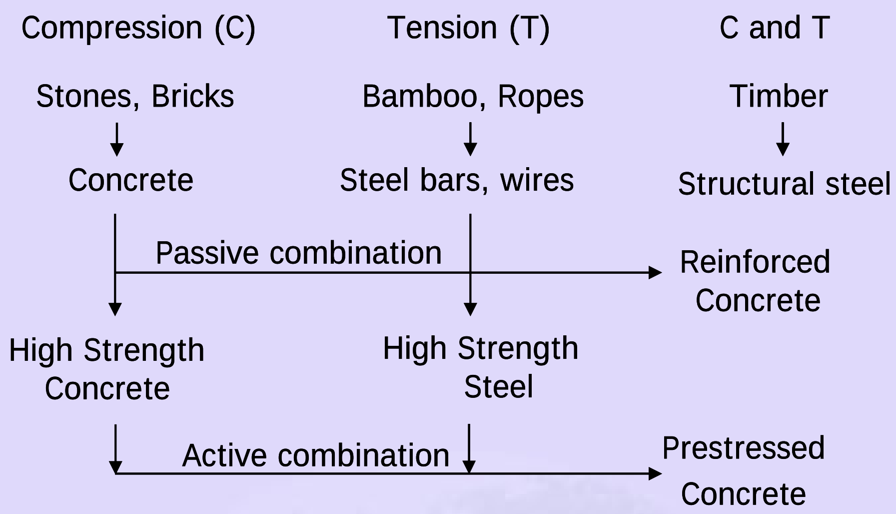


Figure 1-1.9 Development of building materials

(Reference: Lin, T. Y. and Burns, N. H., *Design of Prestressed Concrete Structures*)

1.2 Advantages and Types of Prestressing

This section covers the following topics.

- Definitions
- Advantages of Prestressing
- Limitations of Prestressing
- Types of Prestressing

1.2.1 Definitions

The terms commonly used in prestressed concrete are explained. The terms are placed in groups as per usage.

Forms of Prestressing Steel

Wires

Prestressing wire is a single unit made of steel.

Strands

Two, three or seven wires are wound to form a prestressing strand.

Tendon

A group of strands or wires are wound to form a prestressing tendon.

Cable

A group of tendons form a prestressing cable.

Bars

A tendon can be made up of a single steel bar. The diameter of a bar is much larger than that of a wire.

The different types of prestressing steel are further explained in Section 1.7, Prestressing Steel.

Nature of Concrete-Steel Interface

Bonded tendon

When there is adequate bond between the prestressing tendon and concrete, it is called a bonded tendon. Pre-tensioned and grouted post-tensioned tendons are bonded tendons.

Unbonded tendon

When there is no bond between the prestressing tendon and concrete, it is called unbonded tendon. When grout is not applied after post-tensioning, the tendon is an unbonded tendon.

Stages of Loading

The analysis of prestressed members can be different for the different stages of loading. The stages of loading are as follows.

1) Initial : It can be subdivided into two stages.
   a) During tensioning of steel
   b) At transfer of prestress to concrete.
2) Intermediate : This includes the loads during transportation of the prestressed members.
3) Final : It can be subdivided into two stages.
   a) At service, during operation.
   b) At ultimate, during extreme events.

1.2.2 Advantages of Prestressing

The prestressing of concrete has several advantages as compared to traditional reinforced concrete (RC) without prestressing. A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete.

The following text broadly mentions the advantages of a prestressed concrete member with an equivalent RC member. For each effect, the benefits are listed.

1) Section remains uncracked under service loads

- Reduction of steel corrosion
  - Increase in durability.
- Full section is utilised
  - Higher moment of inertia (higher stiffness)
  - Less deformations (improved serviceability).

- Increase in shear capacity.
- Suitable for use in pressure vessels, liquid retaining structures.
- Improved performance (resilience) under dynamic and fatigue loading.

2) High span-to-depth ratios

Larger spans possible with prestressing (bridges, buildings with large column-free spaces)

Typical values of span-to-depth ratios in slabs are given below.

Non-prestressed slab	28:1
Prestressed slab	45:1

For the same span, less depth compared to RC member.

- Reduction in self weight
- More aesthetic appeal due to slender sections
- More economical sections.

3) Suitable for precast construction

The advantages of precast construction are as follows.

- Rapid construction
- Better quality control
- Reduced maintenance
- Suitable for repetitive construction
- Multiple use of formwork
  - ⇒ Reduction of formwork
- Availability of standard shapes.

The following figure shows the common types of precast sections.

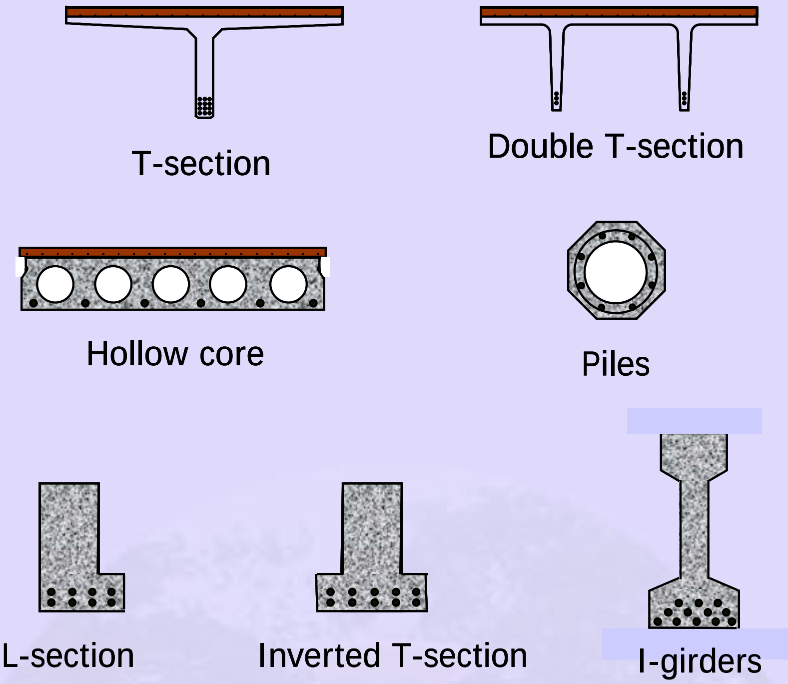


Figure 1-2.1 Typical precast members

1.2.3 Limitations of Prestressing

Although prestressing has advantages, some aspects need to be carefully addressed.

- Prestressing needs skilled technology. Hence, it is not as common as reinforced concrete.
- The use of high strength materials is costly.
- There is additional cost in auxiliary equipments.
- There is need for quality control and inspection.

1.2.4 Types of Prestressing

Prestressing of concrete can be classified in several ways. The following classifications are discussed.

Source of prestressing force

This classification is based on the method by which the prestressing force is generated. There are four sources of prestressing force: Mechanical, hydraulic, electrical and chemical.

External or internal prestressing

This classification is based on the location of the prestressing tendon with respect to the concrete section.

Pre-tensioning or post-tensioning

This is the most important classification and is based on the sequence of casting the concrete and applying tension to the tendons.

Linear or circular prestressing

This classification is based on the shape of the member prestressed.

Full, limited or partial prestressing

Based on the amount of prestressing force, three types of prestressing are defined.

Uniaxial, biaxial or multi-axial prestressing

As the names suggest, the classification is based on the directions of prestressing a member.

The individual types of prestressing are explained next.

Source of Prestressing Force

Hydraulic Prestressing

This is the simplest type of prestressing, producing large prestressing forces. The hydraulic jack used for the tensioning of tendons, comprises of calibrated pressure gauges which directly indicate the magnitude of force developed during the tensioning.

Mechanical Prestressing

In this type of prestressing, the devices includes weights with or without lever transmission, geared transmission in conjunction with pulley blocks, screw jacks with or without gear drives and wire-winding machines. This type of prestressing is adopted for mass scale production.

Now what are special concretes as I said special concretes are those that are not conventional not vary widely used but probably in the future they could be used more and more. This is a list of special concretes high strength concrete or high performance concrete, self-compacting or self-consolidating concrete, fibre reinforced concrete, lightweight and foamed concrete, shotcrete, porous or permeable concrete, roller compacted concrete.

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Autoclaved aerated concrete, high density concrete, heat resistant and refractory concrete, underwater concrete, polymer modified concrete, recycled aggregate concrete, geopolymer concrete. Now some of these we will go into little bit more detail.

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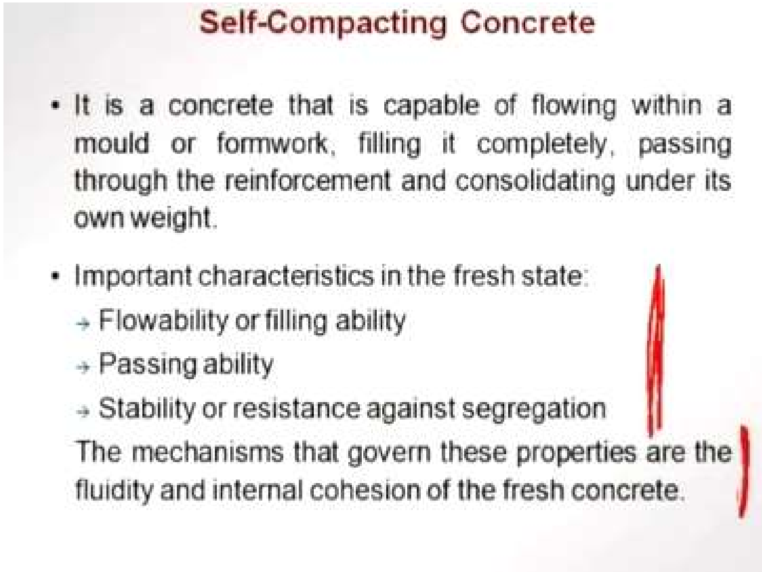

Now we will go onto another concrete which is catching up has been around in many countries for a long time it is called self-compacting or self-consolidating concrete. It is a concrete that is capable of flowing within a mould or formwork, fills it completely without any segregation can pass through reinforcement and consolidate under its own weight. Therefore, it is a concrete that does not need any vibration it can flow and fill up the formwork and not get stuck in the reinforcement.

In order to achieve this, we have certain important characteristics that the concrete should have in the fresh state. First of all, it should have a good flowability or filling ability, it should flow easily, it should pass through reinforcement and through narrow openings in the formwork. And thirdly and very importantly it should be stable or resistant against segregation, you should not have just the cement paste flowing and the aggregate staying at the place that it was dumped.

In order to get this, we need a concrete that is very good in fluidity and also having good cohesion, stickiness which will avoid segregation of the aggregates.

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Also this type of concrete requires new testing methods and I will show you quickly 4 testing methods that are used for checking self-compactibility. The first is the slump flow test, the slump flow test is basically done with the conventional slump cone however, we use a base plate and when the concrete is poured and lifted the concrete does not slump but completely flattens and we have to know measure the final diameter and also the time taken to reach 50 cm is measured.

So the mould and base plate are first wetted, the mould is held against the plate and we fill the concrete without any compaction, the mould is lifted as in the slump test and we allow the concrete to spread, the time taken for the spread to reach 50 cm is noted and the final spread diameter is also noted. So you will see in this video how the test is done, so here you can see the concrete being poured into the slump.

And as we said before we do not put it in layers or tamp like in the slump test but without any compaction slump cone is filled with concrete, after filling it topped off the base plate is cleaned, now what is being indicated is the 50 cm diameter, so someone with a stopwatch is going to measure the time taken to reach 50 centimeters about now, and then we allow the concrete to spread and finally take the diameter into orthogonal directions and record that as the spread diameter.

So these 2 parameters tell us respectively about the viscosity and also the flowability of the concrete, we want the concrete to flow slowly that is why the time is important it should be at least about 2 seconds and then we have now the spread being measured this can vary from about 500 millimeters to 750 millimeters depending on the structure and the type of application.

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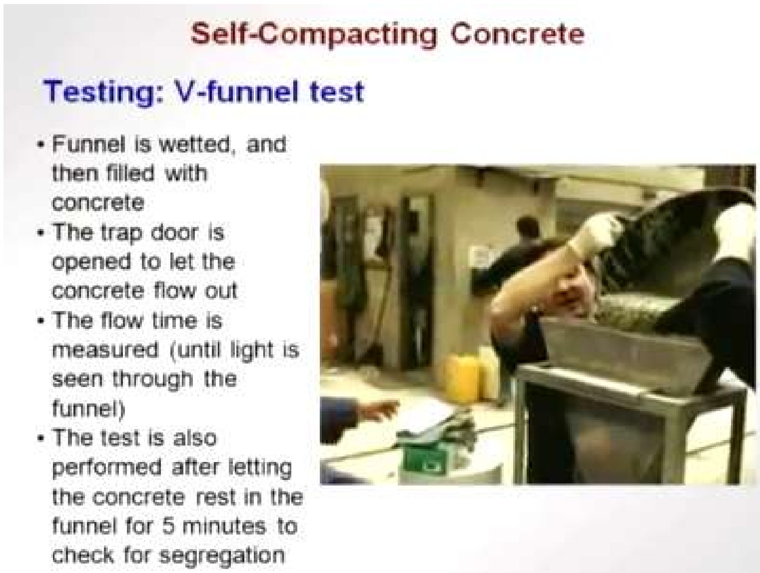

The next test is called the V-funnel test, so here basically we have a funnel, so we have a funnel here which is filled with concrete, the funnel is wetted filled with concrete and there is a trap door at the bottom which will be open to let the concrete flow through, the time taken for the concrete to flow through is measured, and this is usually done by looking from the top and seeing when we can see right through the funnel.

Now this test is also performed, once again this test is also performed once again after letting the concrete rest in the funnel for about 5 minutes, and this is then to check for segregation, if there was segregation then the concrete would not flow out easily after having sat in the funnel for 5 minutes, and if we check both the test times we will see that a concrete with segregation now has a much higher time to flow out then when the test is done immediately.

So let us see how this test is done, so we have here now the funnel being filled up and at the bottom of the funnel there is the trap door which will be open once concrete fills the funnel, and in this case we are going to see a test where the funnel trap door is open immediately after filling this can be now repeated and we can open the door after letting the concrete sit in the funnel for 5 minutes, if the concrete had a lots of segregation then you would see a big difference in the 2 tests times.

Now the trap door is being opened and someone with a stopwatch now sees from the top to see when the concrete has emptied from the funnel, so we see that the surface receding and we watch until the concrete has flown through the funnel, and when we see light through the tunnel, then you stop the stopwatch now, then that time is recorded as the V-funnel time.

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Another test which is used now for ensuring the concrete does not get stuck in reinforcement is the J-ring test, this is the same as the slump test or this is the same as the slump flow test but now a ring made up of reinforcement bars are placed around the slump cone, and when the cone is lifted the concrete has to pass through the reinforcement and flow along the base plate. The ring is made of reinforcement configuration that is as per specifications or the worst.

Now the next test is the J-ring test and here we have the slump flow test repeated with a ring of reinforcement around it so when the concrete has to flow, it has to flow through the reinforcement over the base plate. The ring is made such that the reinforcement configuration is as per specification or it represents the worst reinforcement density in that application that is a type of bars used on the spacing between the bars can represent the worst reinforcement density of the application.

Now we will see how this test is done, so we have now the base plate we have the slum cone set and around the slump cone you see the ring of reinforcement, the cone has been filled and now it is lifted and you can see the concrete flowing through the bars of the J-ring. Now if this was a bad concrete not self-compactible you would see the aggregates piled up in the center and only paste and water flowing through and reaching the edges.

But you see here in the present case we have a good concrete, now the spread is measured and compared with spread we that we had from the slump flow without the J-ring, this spread should not be more than should not differ by more than about 5 centimeters or 3 centimeters for us to understand that this concrete would flow through reinforcement cages without getting blocked. So this is a test for passing ability of the concrete.

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The next test is the L-box test, this also tells us about the passing ability it is a most stringent test however it is very difficult to do on site and it is a test that in my opinion is restricted to the laboratory. So here we have an L-shaped box where there is a vertical deposit which is filled with concrete after the concrete fills up this deposit there is a trap door that is open and there is reinforcement here through which the concrete flows.

And this horizontal channel has now to be filled with concrete as after it flows through the reinforcement and depending on whether it levels of in this horizontal channel or not we say whether it has passed the L-box test or not. So let us see how this is done, which one? The ratio of heights at. Now let us see the L-box test this is a test that is also used for looking at passing ability it is a more stringent test more difficult to do.

And therefore, it is confined more to the laboratories and not done much at the site, so we have here an L-shaped box we will see now how the test is done and I will explain the different features of this test, so here we have the L-shaped box it has a vertical deposit that is being filled now with concrete and at the bottom there is a trap door, and when this trap door is open the concrete flows through the reinforcement and it has to fill this horizontal channel.

So you see it is a little bit tricky test you need a couple of people to ensure that the trap door can be lifted up now the concrete flows through the reinforcement again this reinforcement checks the passing ability, and now the concrete floors into the channel the height of the concrete at this end and this end are measured on either end of the horizontal channel are measured and the ratio should be such that the heights do not vary by more than 20% that is the ratio of height should be more than 0.8.

The height should not differ by more than 20%, this is how the measurement of the height is being done, so here this is the height at the vertical deposit end before the concert passes through the bars and again height will be measured here, so what you see here is the height at the top is being measured knowing the depth of the channel, we can subtract the height measured to the surface from the total height and we can get the height of the concrete.

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General characteristics of self-compacting concrete we do not use very large aggregates generally the aggregate size is limited to 20 or 25 millimeters, there have been cases however of self-compacting concrete being made with even 40 mm aggregate but generally we limit the aggregate size to smaller aggregate, this is to facilitate the flow and avoid the risk of segregation. The pace content is about 400 liters per cubic meter.

In normal concrete it would be about 300 liters or even less. The water fines ratio is in the order of 0.3 to 0.36 less water because we want to avoid segregation, we want to have a compact microstructure. The fines content is quite high about 500 to 600 kg per meter cube of fines are necessary this is to again give flowability and restrict segregation, so this means we have a combination of cement mineral admixtures and fillers which is much more than normal reaching about 600 kilograms per meter cube in some cases.

Another aspect that is very different from normal concrete is that the coarse aggregate sand ratio is about 50/50=1, in normal concrete you would have much more coarse aggregate than sand but in self-compacting concrete they are about the same by weight. Additionally, we need a good superplasticizer which ensures the flowability, the fluidity. And lastly in most cases we use a viscosity modifier or a viscosity modifying agent to give more stability that is resistance to segregation and robustness.

Robustness is something very important which we are grappling with in most self-compacting concrete applications which means that we have to get the same concrete in every truck same self-compatibility one day to another. And therefore, we can have a consistent concrete, a consistent self-compacting concrete would be then be called a robust self-compacting concrete.

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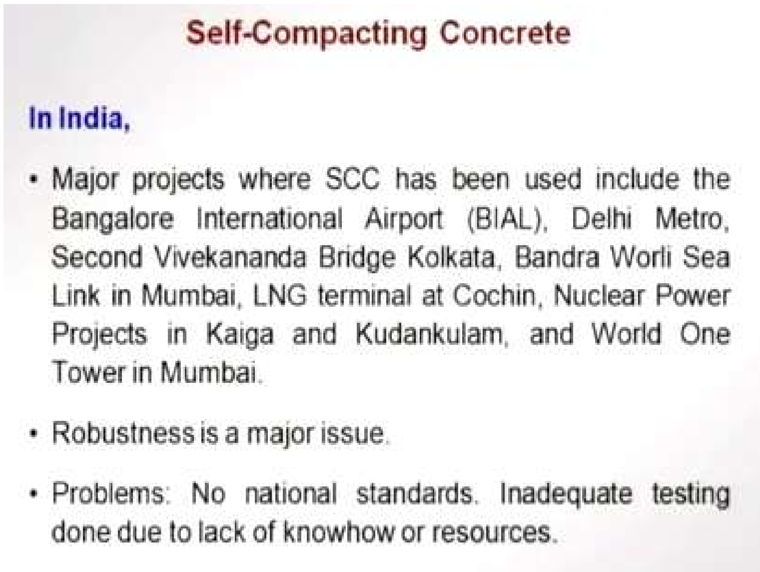

In India several projects have used self-compacting concrete including the Bangalore Airport, the Delhi metro, the second Vivekananda Bridge in Kolkata, the Bandra Worli sea link bridge in Mumbai. And other applications like liquid gas terminals one at Cochin, nuclear power plants in Kaiga and Kudankulam and some buildings like the World One Tower in Mumbai have used self-compacting concrete.

As I said robustness is a major issue it is a problem that is limiting the use of self-compacting concrete in India, other problems in India is that we do not have any national standards for self-compacting concrete and lot of cases inadequate testing is done due to lack of knowhow or resources. This situation is improving and we will see more and more applications of self-compacting concrete in India.

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Topic to be Discussed

- Introduction
- Need of Pervious Concrete
- Comparison
- Material
- Construction
- Application
- Advantages
- Disadvantages

INTRODUCTION

- **Pervious concrete** is a special type of concrete with a high porosity used for concrete flatwork applications.
- It allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge.

- It is also known as gap graded concrete or permeable concrete.
- Pervious concrete has little or no fine aggregate.

- It consists of 15 to 35% voids, allowing for quick drainage.

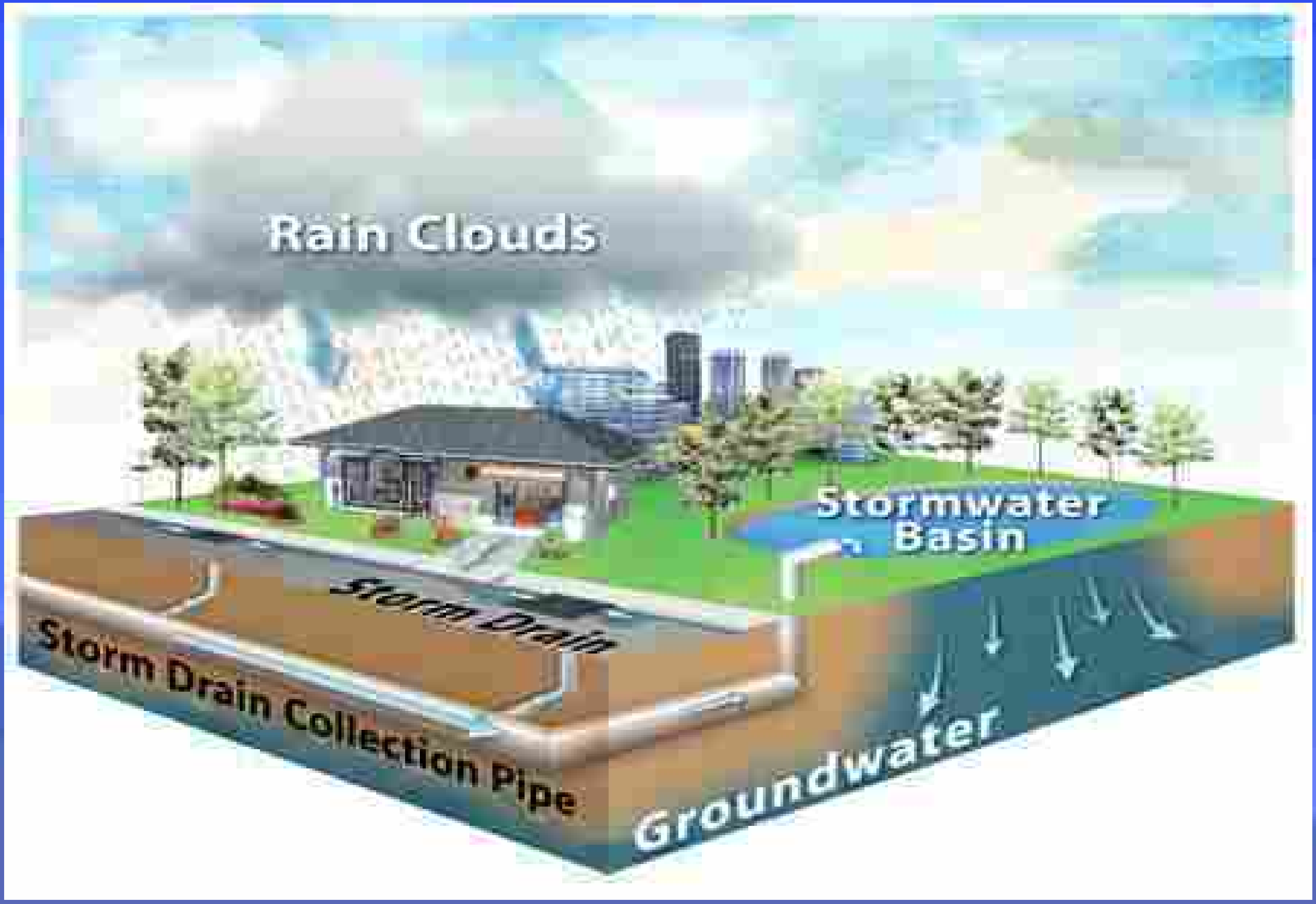
- The infiltration rate of pervious concrete will fall into the range of 80 to 720 liters per minute per square meter.

NEED OF PERVIOUS CONCRETE

- A large amount of rain water ends up falling on impervious surfaces such as parking lots, drive ways, sidewalks, ad streets rather than soaking into the soil.
- This creates an imbalance to the natural ecosystem and leads to a host of problems including erosion, floods, ground water level depletion and pollution of rivers, lakes etc..

- Instead of constructing them with conventional concrete or asphalt, we should be switching to pervious concrete or porous pavement.

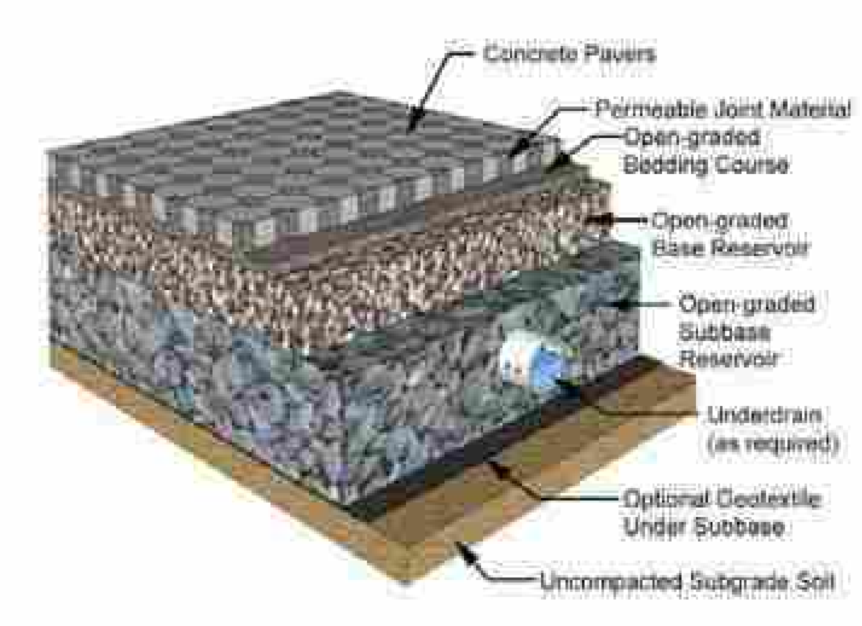
- Pervious concrete also naturally filters water from rainfall or storm and can reduce pollutant loads entering into streams, ponds and rivers.so in this way it helps in ground water recharge

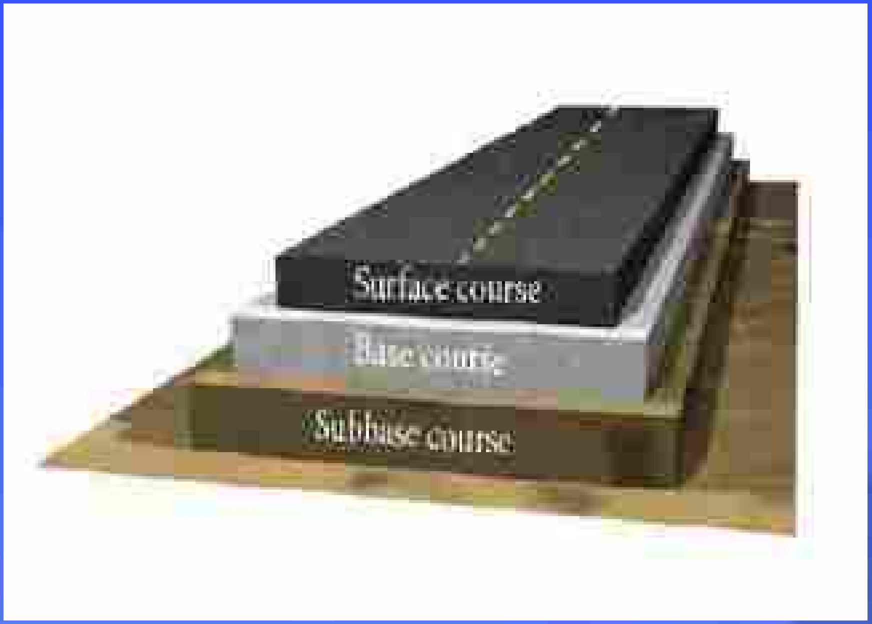


COMPARISON OF PERVIOUS AND IMPERVIOUS CONCRETE

PERVIOUS CONCRETE | **IMPERVIOUS CONCRETE**

FLEXIBLE PAVEMENT VS PERVIOUS PAVEMENT





Flexible Pavement

- Deformation in the subgrade is transferred to the upper layers
- Design is based on the load distributing characteristics of the component layers
- Have low flexural strength
- Load is transferred by grain to grain contact
- Have low completion cost but repair cost is high
- Have low life span (high maintenance cost)
- Strength of the road is highly dependent on the strength of the subgrade
- Rolling of the surfacing needed
- Road can be used for traffic with in 24hrs

Pervious Pavement

- • Deformation in the subgrade is not transferred to subsequent layers
- Design is based on flexural strength or slab action
- Have high flexural strength
- So such phenomenon of grain to grain load transfer exist
- Have low repair cost but completion cost is high
- Life span is more when compared to the flexible pavements (low maintenance cost)
- Surfacing can be directly laid on the subgrade
- Road cannot be used until 14 days of curing
- Force of friction is high
- No damage by oils and greases

MATERIALS

- Pervious concrete mainly consists of:
  - Ordinary Portland cement
  - Coarse aggregate (19mm – 9.5mm)
  - Water (Free from salts and impurities)

- In normal concrete the fine aggregates typically fills the voids between the coarse aggregates.

- In pervious concrete fine aggregate is non-existent or present in very small amounts (<10% by total weight of aggregates).

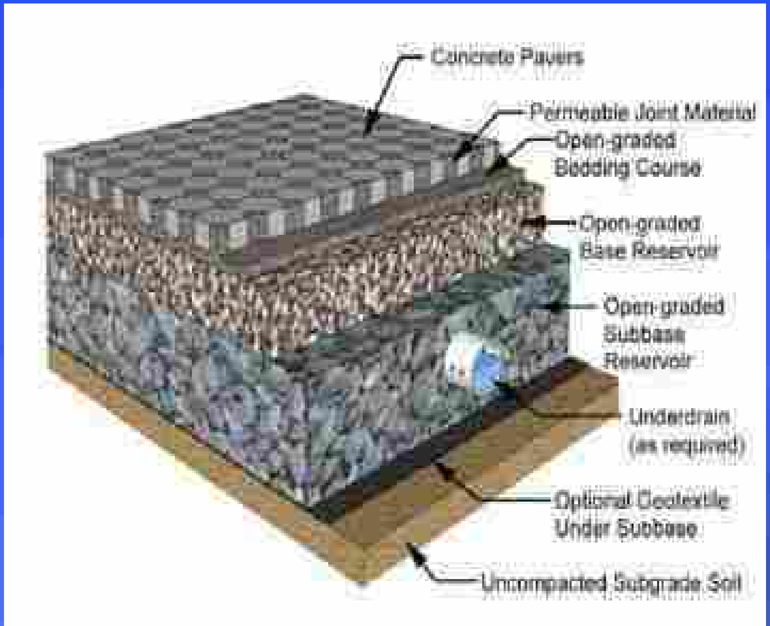
Ranges of Materials Proportions in Pervious Concrete.

MATERIAL	PROPORTIONS
Cementitious materials	270 to 415 Kg/m3
Aggregate	1190 to 1480 Kg/m3
Water: Cement ratio (by mass)	0.27 to 0.34
Aggregate: cement ratio (by mass)	4 to 4.5:1
Fine: coarse aggregate ratio (by mass)	0 to 1:1

CONSTRUCTION

Subgrade and Sub-base Preparation

- Uniformity of subgrade support is a key criterion for placing pervious pavement.
- Increasing the subgrade density decreases its permeability
- Pervious pavements contain minimal water and high porosity
- Care must be taken to ensure that the pavement does not dry out prematurely.



Batching and Mixing

- The special properties of pervious concrete require tighter control of mixture proportioning
- the water content of pervious concrete is limited to a narrow range to provide adequate strength and permeability
- Aggregate moisture level should be monitored carefully
- The correct water content will provide a mix with a sheen

Transportation

- As pervious concrete has a low water content, special attention is required during transportation and placement.
- A pervious pavement mixture should be discharged completely within one hour after initial mixing
- Its very low slump may make discharge from transit mixers slower than for conventional concrete

Placement and Consolidation

- A variety of placement techniques can be used for constructing pervious concrete pavements.
- It should be noted that pervious concrete mixtures cannot be pumped.

- It should be noted that pervious concrete mixtures cannot be pumped.

- Placement should be continuous, and spreading and strikeoff should be rapid
- Conventional formwork is used

Finishing

- pervious concrete pavements are not finished in the same way as conventional concrete pavements.

- Normal floating and troweling operations tend to close up the top surface of the voids, which defeats the purpose of pervious concrete.

Curing and Protection

- The open structure and relatively rough surface of pervious concrete exposes more surface area of the cement paste to evaporation, making curing even more essential than in conventional concreting.

- Water is needed for the chemical reactions of the cement.
- It is critical for pervious concrete to be cured promptly.

APPLICATIONS:

The various applications of pervious concrete are as follows:

- Residential roads, alleys, and driveways
- Low-volume pavements
- Sidewalks and pathways
- Parking areas
- Tennis courts
- Sub base for conventional concrete pavements
- Well linings
- Swimming pool decks
- Noise barriers.

PERVIOUS CONCRETE RESIDENTIAL STREET SHOWING WATER INFILTRATION

Walkway in Beijing, China built for 2008 Olympics

Residential Roads

Benefits of Pervious Concrete

Reduces stormwater runoff

Eliminates need for retention ponds and other costly stormwater management practices

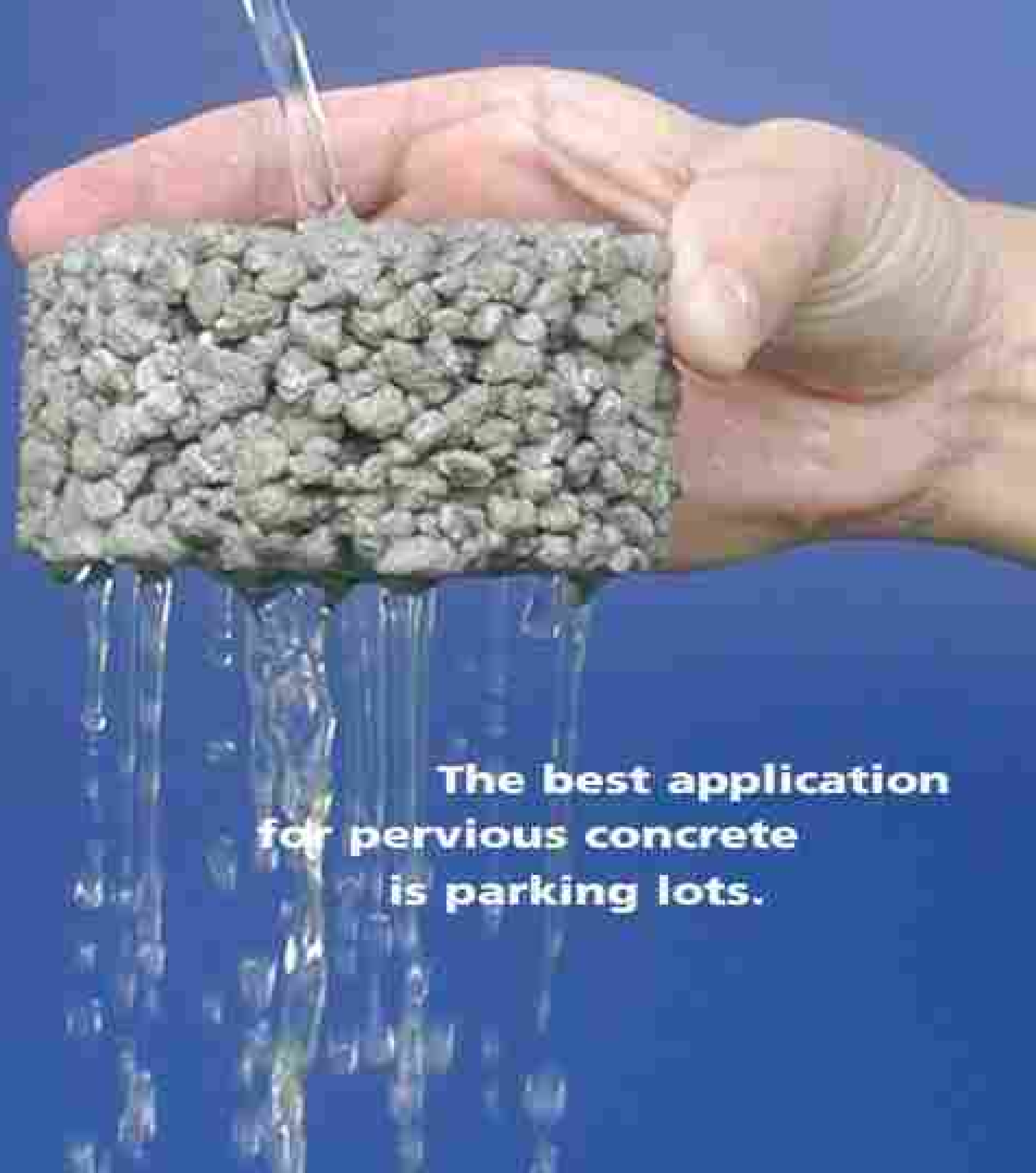
Replenishes water tables and aquifers

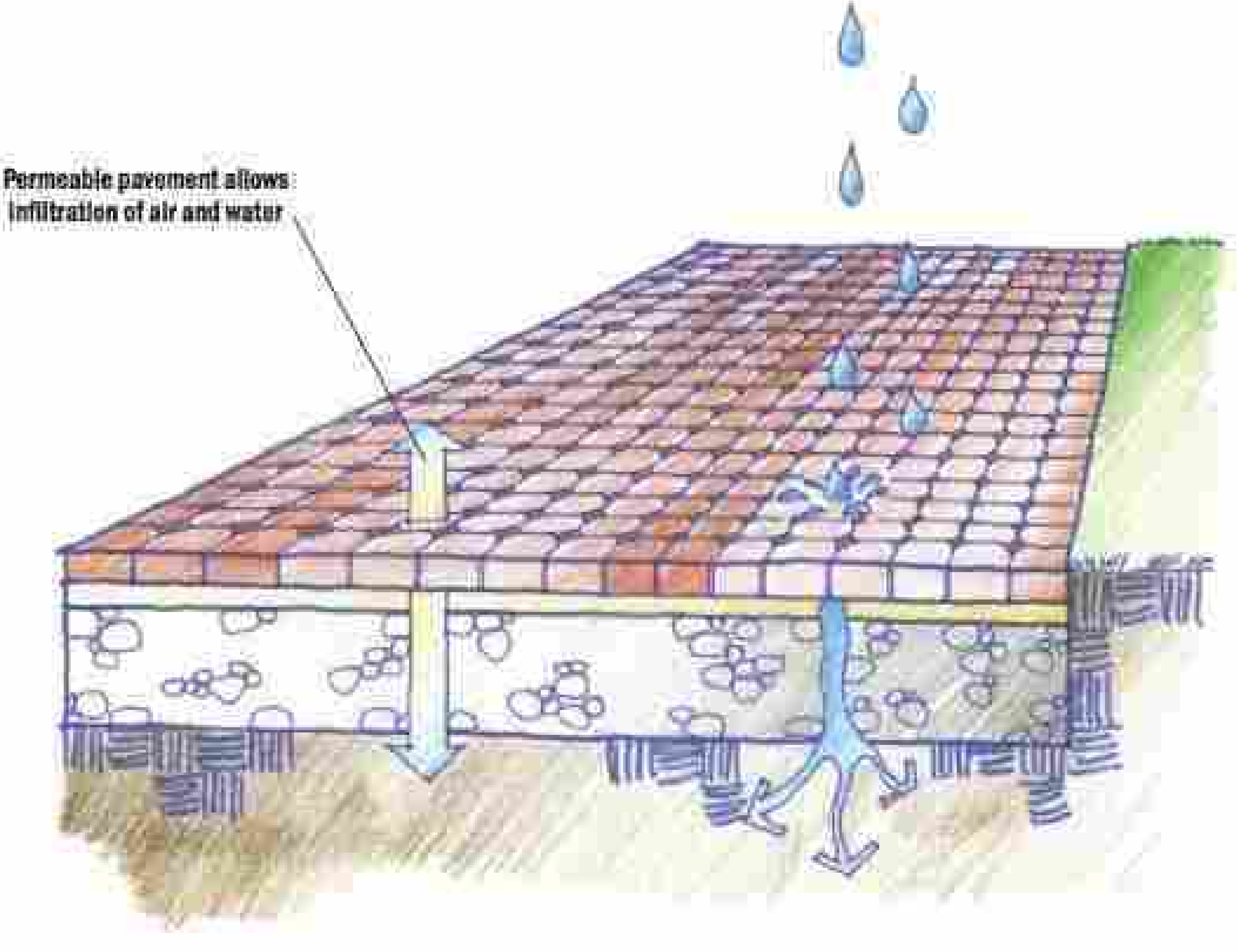
Allows for more efficient land development

Minimizes flash flooding and standing water

Prevents warm and polluted water from entering our streams

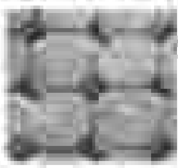
Surface pollutants are mitigated

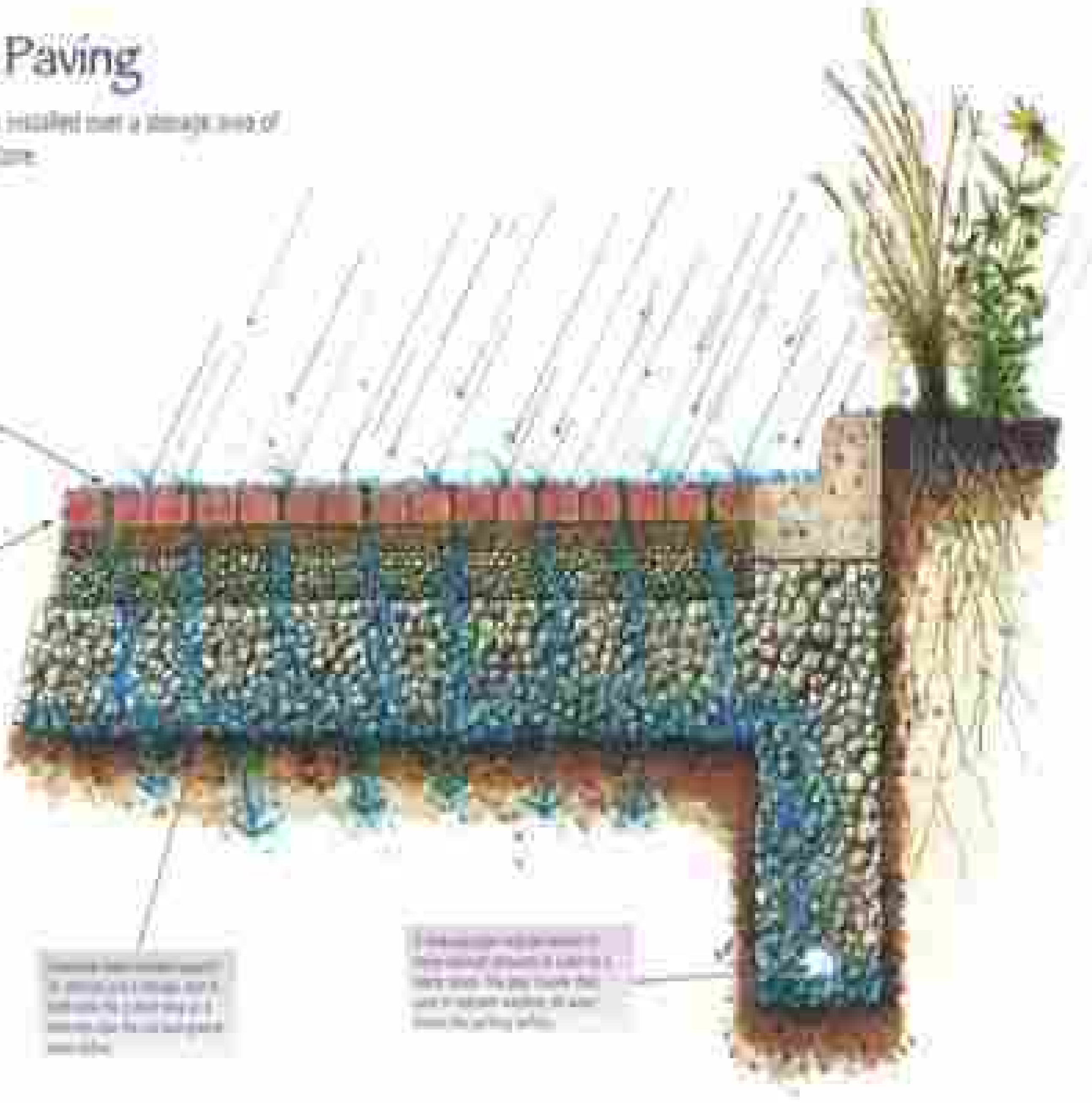



Permeable pavement allows infiltration of air and water

Pervious Paving

Modular paver blocks installed over a storage area of uniformly sized limestone.





Disadvantages

- Difficult in providing the reinforcement
- Frequent maintenance is required
- Compressive strength is comparatively less
- Require more time and experimental works for the construction
- It cant be used for the construction of bridges, buildings, dams and so on….

Pervious concrete in India

- Pervious concrete can be successfully used in India in applications such as parking lots, driveways, gullies/sidewalks, road platforms, etc.
- Massive urban migration in Indian cities is causing the ground water to go much deeper and is causing water shortages.
- In future with increased urbanization, diminishing ground water levels and focus on sustainability, technologies such as pervious concrete are likely to become even more popular in India as well as other countries.

CONTENT

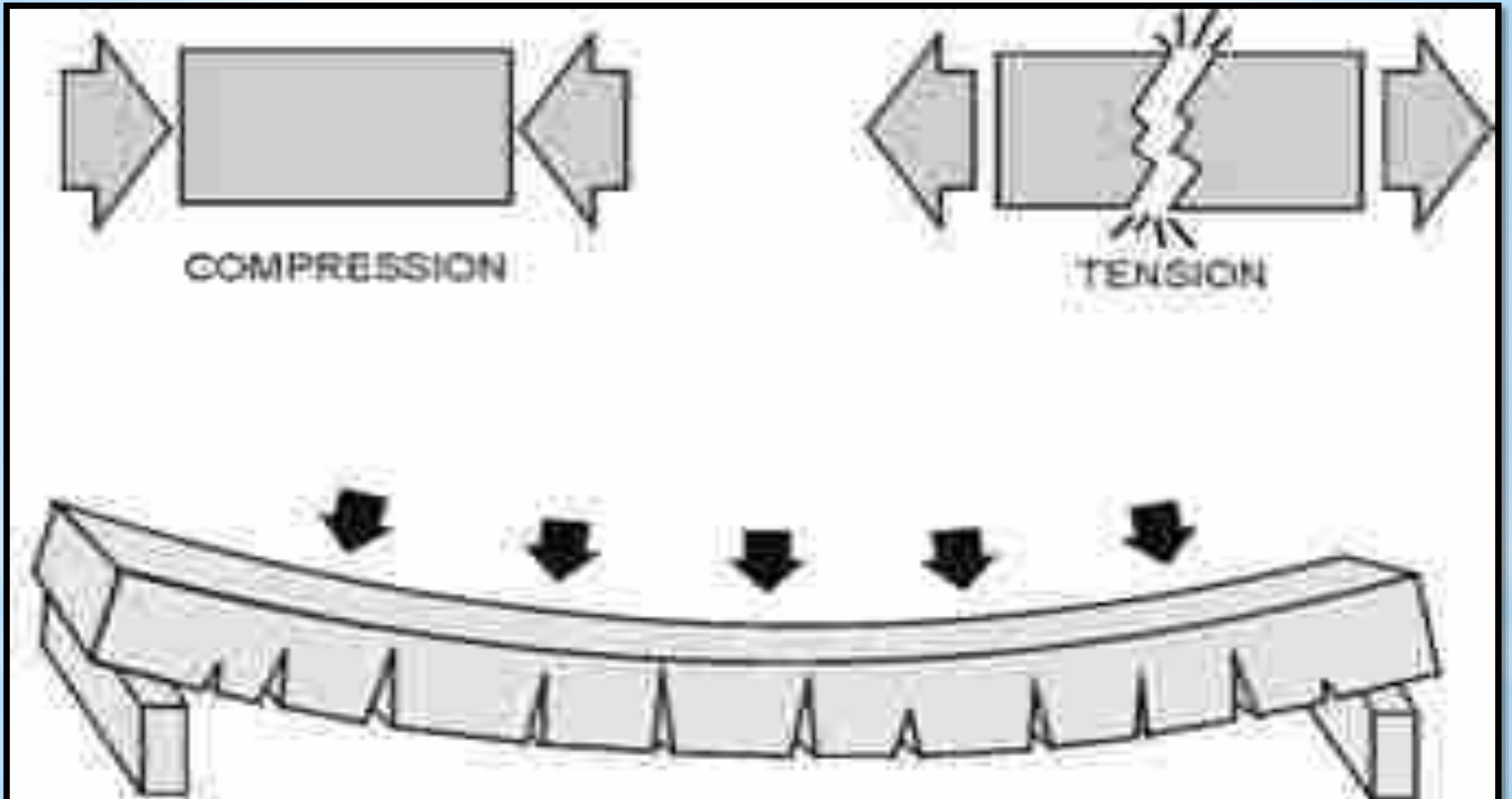
1. INTRODUCTION

DEFINITION –

Self healing concrete is a concrete which heals itself when it comes in contact with air and water, it produces lime on outer layer of concrete.

* In most of the traditional concrete mixtures 20-30% of the cement is left unhydrated.
* If cracking of the concrete occurs, unreacted cement grains may become exposed to moisture penetrating the crack.
* In that case the hydration process may start again and hydration products may fill up and heal the crack.

NECESSITY



FORCES ON CONCRETE -

CONTINUE…

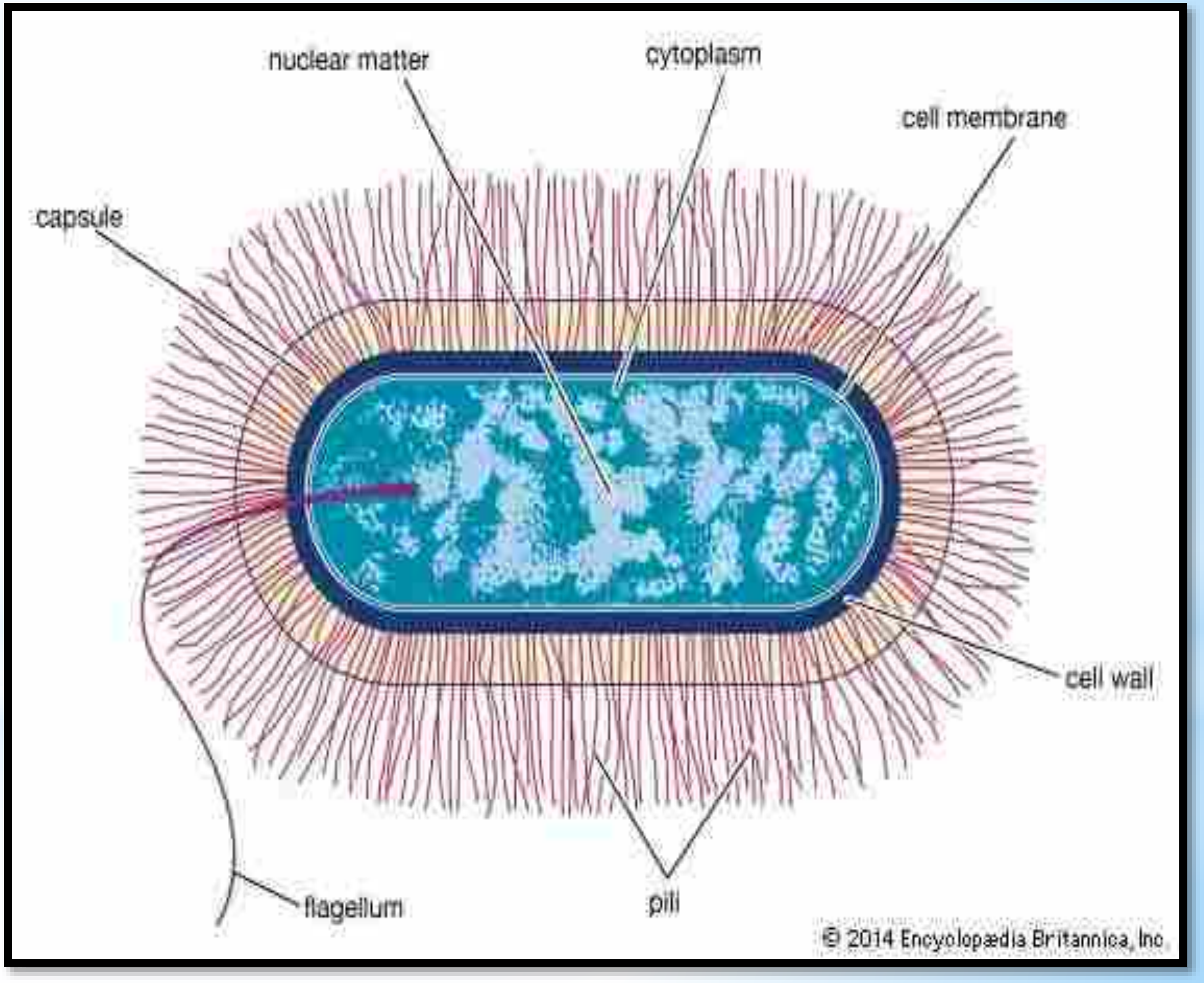
CONCRETE WITH REINFORCEMENT

CONTINUE…

LIME FILLED IN CRACKS

BACTERIA

It contains an outer layer of thick wall, which resist sunlight, chemical exposure etc.



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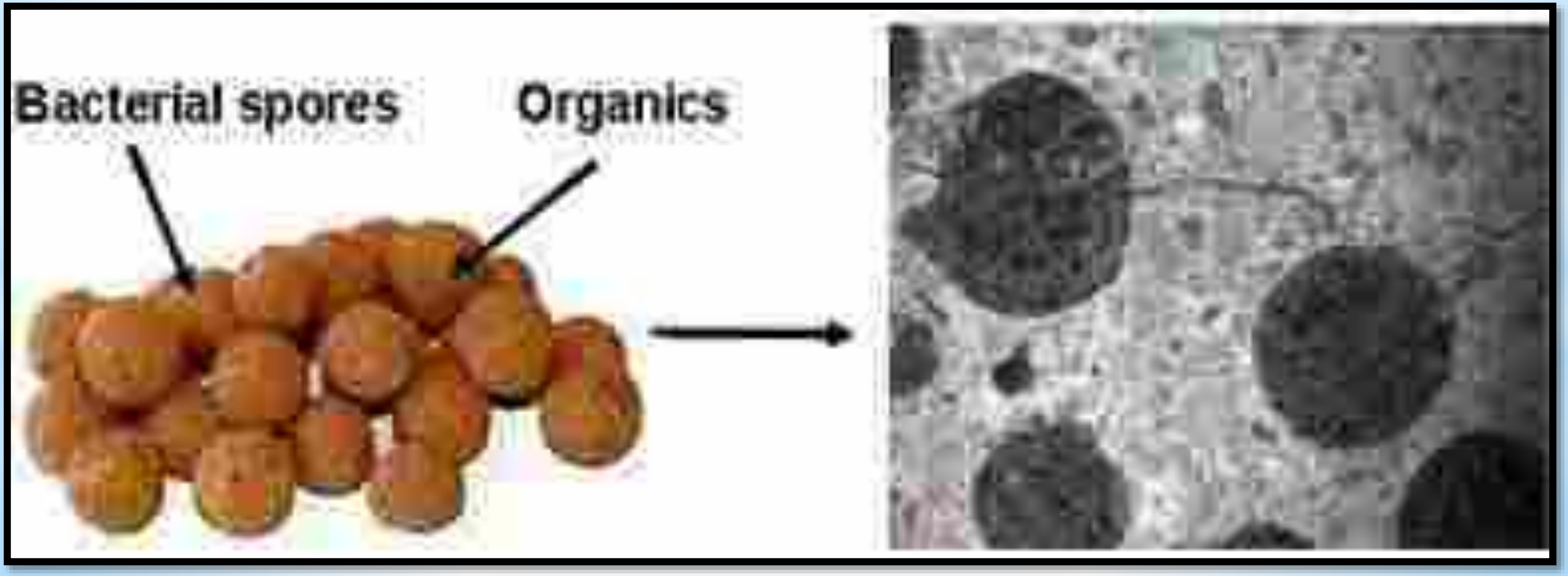
In 1877, Ferdinand Cohn claimed that with a bacteria known as “Genus Bacillus” concrete could be healed.

MIXING

* When spores fine aggregate, coarse aggregate and cement are mixed together, which results in Self Healing Concrete.
* But while mixing one precaution is taken that bacteria and cement are not allowed to mix together with the help of clay pellets.



WORKING OF SELF HEALING CONCRETE

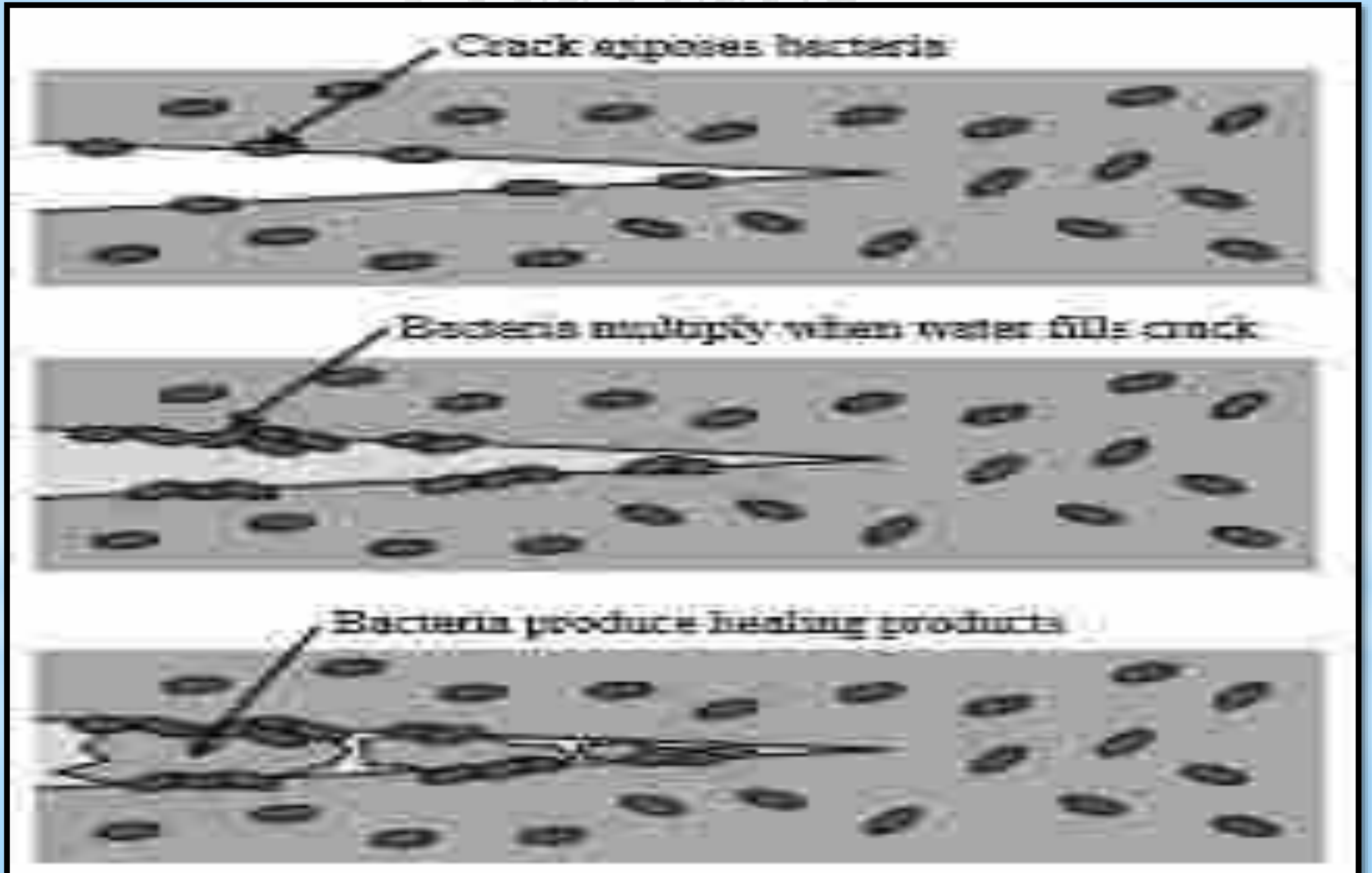
* Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures.

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$

(Calcium Lactate) (Lime)

* Specially selected types of the bacteria genus Bacillus, along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are added to the ingredients of the concrete when it is being mixed.

CONTINUE…



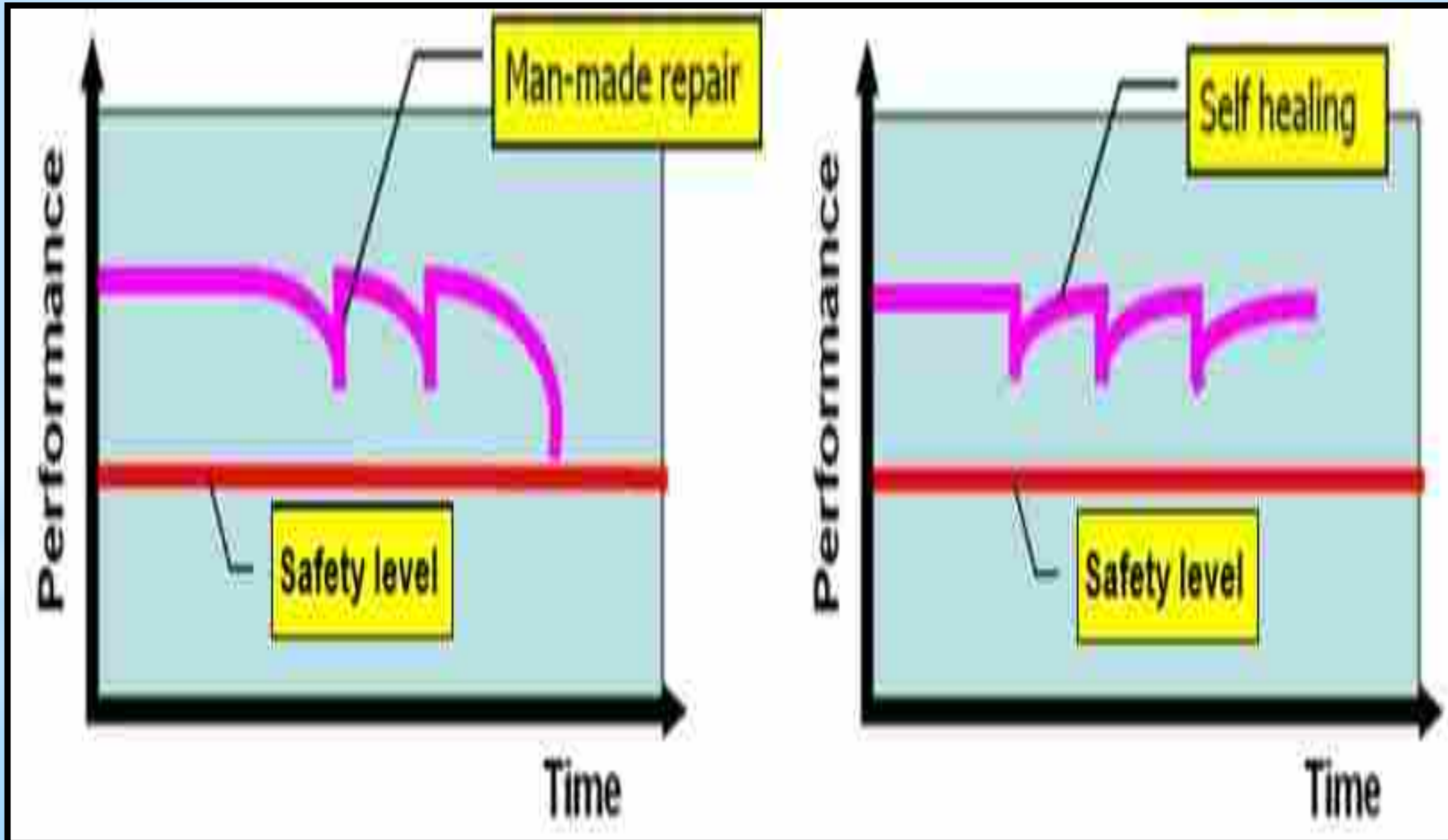
Crack exposes bacteria
Bacteria multiply when water fills crack
Bacteria produce healing products

TEST ON SELF HEALING CONCRETE

- In 2011, Jonkers and his team is doing testing and case study on self healing concrete.
- A small structure or part of a structure will be built with the self-healing material and observed over three to five years.
- Structures will be fitted with some panels of self-healing concrete and others with conventional concrete so that the behaviour of the two can be compared.
- Cracks will be made in the concrete that are much larger than the ones that have healed up in the laboratory to determine how well and fast they heal over time.

HENK JONKERS

COMPARISON BETWEEN SHC AND ORDINARY CONCRETE



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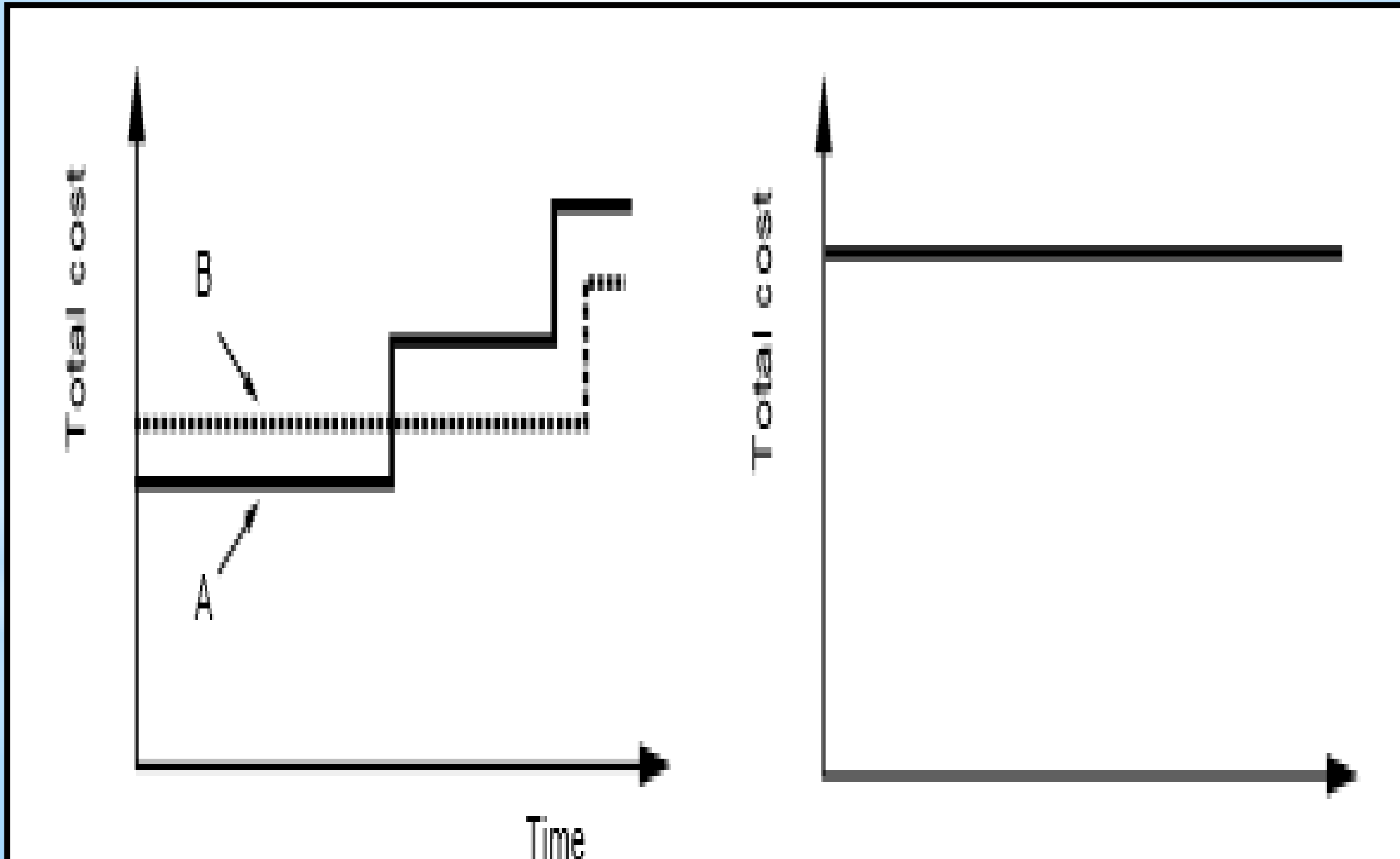

ADVANTAGES

CONTINUE...

DISADVANTAGES

1. Skilled labour are required.
2. Concrete is costly.

APPLICATIONS

1. Self healing epoxies can be incorporated on the metals to prevent corrosion.

2. Self healing is used on structure to prevent cracks on concrete.