GOVERNMENT POLYTECHNIC KENDRAPARA

DEPARTEMENT OF CIVIL ENGINEERING

LECTURE NOTES

ON

CONCRETE TECHNOLOGY

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CONTENTS

CHAPTER -1

Grades of concrete

Grade of concrete	(Cement: Sand: Aggregates)	Compressive strength (Mpa)
M5	1:5:10	5
M7.5	1:4:8	7.5
M10	1:3:6	10
M15	1:2:4	15
M20	1:1.5:3	20
M25	Design Mix	25
M30	Design Mix	30
M35	Design Mix	35
M40	Design Mix	40
M50	Design Mix	50
M70	Design Mix	70

Classification of Concrete Grades

The grades of concrete classify the concrete into four types:

- Lean Concrete
- Ordinary grade concrete
- Standard grade concrete
- High strength grade concrete

Advantages of Concrete

- Ingredients of concrete are readily available in most places.
- Unlike natural stones, concrete is free from defects and flaws.
- Concrete can be manufactured to the desired strength with an economy.
- The durability of concrete is very high.
- It can be cast to any desired shape.
- The casting of concrete can be done on the working site which makes it economical.
- The maintenance cost of concrete is almost negligible.
- The deterioration of concrete is not appreciable with age.
- Concrete makes a building fire-safe due to its non-combustible nature.
- Concrete can withstand high temperatures.
- Concrete is resistant to wind and water. Therefore, it is very useful in storm shelters.
- As a soundproofing material cinder concrete could be used.

Disadvantages of Concrete

- Compared to other binding materials, the tensile strength of concrete is relatively low.
- Concrete is less ductile.
- The weight of concrete is high compared to its strength.
- Concrete may contain soluble salts. Soluble salts cause efflorescence.

CHAPTER-2

CEMENT

Cement is a binder, a substance that sets and hardens and can bind other materials together. Cements used in construction can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to be used in the presence of water. Non-hydraulic cement will not set in wet conditions or underwater, rather it sets as it dries and reacts with carbon dioxide in the air. It can be attacked by some aggressive chemicals after setting. Hydraulic cement is made by replacing some of the cement in a mix with activated aluminum silicates, pozzolana, such as fly ash. The chemical reaction results in hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack (e.g., Portland cement).

Uses:-

- Cement mortar for Masonry work, plaster and pointing etc.
- Concrete for laying floors, roofs and constructing lintels, beams, weather- shed, stairs, pillars etc.
- Construction of water, wells, tennis courts, septic tanks, lamp posts, telephone cabins etc.
- Making joint for joints, pipes, etc.
- Manufacturing of precast pipes, garden seats, flower posts, etc.
- Preparation of foundation, water tight floors, footpaths, etc.

ORDINARY PORTLAND CEMENT:-

Ordinary Portland cement is the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450°C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement'(often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Portland cement may be grey or white.

- This type of cement use in construction when there is no exposure to sulphates in the soil or ground water.
- Lime saturation Factor is limited between i.e. 0.66 to 1.02.
- Free lime-cause the Cement to be unsound.
- Percentage of (AL_2O_3/Fe_2O_3) is not less than 0.66.
- Insoluble residue not more than 1.5%.
- Percentage of SO_3 limited by 2.5% when $C_3A < 7\%$ and not more than 3% when $C_3A > 7\%$.
- Loss of ignition -4%(max)
- Percentage of Mg0-5% (max.)
- Fineness -not less than 2250 cm^2/g.

Chemical constituents of cement:-

These are the different constituents which combine to make cement. These are their percentage content in order to give good cement.

Oxide Per cent content
CaO 60–67
SiO_2 17–25
Al_2O_3 3.0–8.0
Fe_2O_3 0.5–6.0
MgO 0.1–4.0
Alkalies(K_2O,Na_2O)
0.4–
1.3
SO_3 1.3–3.0

Hydration of Cement:-

The chemical reaction between cement and water in a proportioning mix is called as hydration of cement. It may be in concrete mix or in the making of mortar in the field work.

SETTING OF CEMENT:-

The action of changing mixed cement from a fluid state to a solid state is called setting of cement and time required for it to set is called setting time of cement. Setting time of cement is same as setting time of concrete.

SETTING TIME OF CEMENT:-

1. Initial Setting Time

Initial Setting Time is defined as the period elapsing between the time when water is added to the cement and the time at which the needle of 1 mm square section fails to pierce the test block to a depth of about 5 mm from the bottom of the mould. A period of 30 minutes is the minimum initial setting time, specified by ISI for ordinary and rapid hardening Portland cements and 60 minutes for low heat cement.

2. Final Setting Time

Final Setting Time is defined as the period elapsing between the time when water is added to cement and the time at which the needle of 1 mm square section with 5 mm diameter attachment makes an impression on the test block. 600 minutes is the maximum time specified for the final set for all the above mentioned Portland cement. IS: 269-1976 specifies the strengths in compression on the standard mortar-cube.

STRUCTURE OF HYDRATED CEMENT:-

The desirable engineering characteristics of hardened concrete —strength, dimensional stability, and durability —are influenced not only by the proportion but also by the properties of the hydrated cement paste, which, in turn, depend on the micro-structural features (i.e., the type, amount, and distribution of solids and voids).

Fresh cement paste is a plastic network of particles of cement in water but, once the cement paste has set, its apparent or gross volume remains approximately constant.

At any stage of hydration, the hardened paste consists of hydrates of the various compounds, referred to collectively as gel, crystals of Ca(OH)2, some minor components, un hydrated cement and the residue of water-filled spaces in the fresh paste.

VARIOUS TESTS ON CEMENT:

Basically two types of tests are under taken for assessing the quality of cement. These are either field test or lab tests. The current section describes these tests in details.

Field test:

There are four field tests may be carried out to as certain roughly the quality of cement. There are four types of field tests to access the colour, physical property, and strength of the cement as described below.

Colour:

- The colour of cement should be uniform.
- It should be typical cement colour i.e. grey colour with a light greenish shade.

Physical properties:

- Cement should feel smooth when touched between fingers.
- If hand is inserted in a bag or heap of cement, it should feel cool.

Presence of lumps:

- Cement should be free from lumps.
- For a moisture content of about 5 to 8%, this increase of volume may be much as 20 to 40 %, depending upon the grading of sand.

Strength:

- A thick paste of cement with water is made on a piece of thick glass and it is kept under water for 24 hours. It should set and not crack.

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Laboratory tests:

Six laboratory tests are conducted mainly for assessing the quality of cement. These are: fineness, compressive strength, consistency, setting time, soundness and tensile strength.

Fineness:

- This test is carried out to check proper grinding of cement.
- The fineness of cement particles may be determined either by sieve test or permeability apparatus test.
- In sieve test, the cement weighing 100 gm is taken and it is continuously passed for 15 minutes through standard BIS sieve no. 9.The residue is then weighed and this weight should not be more than 10% of original weight.
- In permeability apparatus test, specific area of cement particles is calculated. This test is better than sieve test. The specific surface acts as a measure of the frequency of particles of average size.

Compressive strength:

- This test is carried out to determine the compressive strength of cement.
- The mortar of cement and sand is prepared in ratio 1:3.
- Water is added to mortar in water cement ratio 0.4.
- The mortar is placed in moulds. The test specimens are in the form of cubes and the moulds are of metals. For 70.6 mm and 76 mm cubes, the cement required is 185gm and 235 gm respectively.
- Then the mortar is compacted in vibrating machine for 2 minutes and the moulds are placed in a damp cabin for 24 hours.
- The specimens are removed from the moulds and they are submerged in clean water for curing.

• The cubes are then tested in compression testing machine at the end of 3days and 7 days. Thus compressive strength was found out.

Consistency:

• The purpose of this test is to determine the percentage of water required for preparing cement pastes for other tests.
• Take 300 gm of cement and add 30 percent by weight or 90 gm of water to it.
• Mix water and cement thoroughly.
• Fill the mould of Vicat apparatus and the gauging time should be 3.75 to 4.25 minutes.
• Vicat apparatus consists of a needle is attached a movable rod with an indicator attached to it.
• There are three attachments: square needle, plunger and needle with annular collar.
• The plunger is attached to the movable rod.
• The plunger is gently lowered on the paste in the mould.
• The settlement of plunger is noted. If the penetration is between 5 mm to 7 mm from the bottom of mould, the water added is correct.
• If not process is repeated with different percentages of water till the desired penetration is obtained.
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Setting time:

• This test is used to detect the deterioration of cement due to storage. The test is performed to find out initial setting time and final setting time.
• Cement mixed with water and cement paste is filled in the Vicat mould.
• Square needle is attached to moving rod of Vicat apparatus.
• The needle is quickly released and it is allowed to penetrate the cement paste. In the beginning the needle penetrates completely. The procedure is repeated at regular intervals till the needle does not penetrate completely.(up to 5mm from bottom)
• Initial setting time =<30min for ordinary Portland cement and 60 min for low heat cement.
• The cement paste is prepared as above and it is filled in the Vicat mould.
• The needle with annular collar is attached to the moving rod of the Vicat apparatus.
• The needle is gently released. The time at which the needle makes an impression on test block and the collar fails to do so is noted.
• Final setting time is the difference between the time at which water was added to cement and time as recorded in previous step, and it is =<10hours.

Soundness:

• The purpose of this test is to detect the presence of uncombined lime in the cement.

- The cement paste is prepared.
- The mould is placed and it is filled by cement paste.
- It is covered at top by another glass plate. A small weight is placed at top and the whole assembly is submerged in water for 24 hours.
- The distance between the points of indicator is noted. The mould is again placed in water and heat is applied in such a way that boiling point of water is reached in about 30 minutes. The boiling of water is continued for one hour.
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- The distance between the points of indicator is again measured. The difference between the two readings indicates the expansion of cement and it should not exceed 10 mm.
-

Tensile strength:

- This test was formerly used to have an indirect indication of compressive strength of cement.
- The mortar of sand and cement is prepared.
- The water is added to the mortar.
- The mortar is placed in briquette moulds. The mould is filled with mortar and then a small heap of mortar is formed at its top. It is beaten down by a standard spatula till water appears on the surface. Same procedure is repeated for the other face of briquette.
- The briquettes are kept in a damp for 24 hours and carefully removed from the moulds.
- The briquettes are tested in a testing machine at the end of 3 and 7 days and average is found out.

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• It is covered at top by another glass plate. A small weight is placed at top and the whole assembly is submerged in water for 24 hours.

- The distance between the points of indicator is noted. The mould is again placed in water and heat is applied in such a way that boiling point of water is reached in about 30 minutes. The boiling of water is continued for one hour.
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- The briquettes are kept in a damp for 24 hours and carefully removed from the moulds.
- The briquettes are tested in a testing machine at the end of 3 and 7 days and average is found out.

Grade of cement:-

Grade of cement represents the specific 28 days compressive strength. The following three grades are given along with their compressive strengths

- 33 Grade OPC –33 MPa
- 43 Grade OPC – 43 MPa
- 53 Grade OPC – 53 MPa

CHAPTER-3

AGGREGATE

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone -like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete.

Classification of aggregates based on: Grain Size

If you separate aggregates by size, there are two overriding categories:

- Fine aggregates
- Coarse aggregates

The size of fine aggregates is defined as 4.75mm or smaller. That is, aggregates which can be passed through a number 4 sieve, with a mesh size of 4.75mm. Fine aggregates include things such as sand, silt and clay. Crushed stone and crushed gravel might also fall under this category.

Typically, fine aggregates are used to improve workability of a concrete mix.

Coarse aggregates measure above the 4.75mm limit. These are more likely to be natural stone or gravel that has not been crushed or processed. These aggregates will reduce the amount of water needed for a concrete mix, which may also reduce workability but improve its innate strength.

Classification of aggregates based on: Density

There are three weight-based variations of aggregates:

- Lightweight
- Standard
- High density

Different density aggregates will have much different applications. Lightweight and ultra lightweight aggregates are more porous than their heavier counterparts, so they can be put to great use in green roof construction, for example. They are also used in mixes for concrete blocks and pavements, as well as insulation and fireproofing.

High density aggregates are used to form heavyweight concrete. They are used for when high strength, durable concrete structures are required – building foundations or pipe work ballasting, for example.

Classification of aggregates based on: Geographical Origin

Another way to classify aggregates is by their origin. You can do this with two groups:

- Natural – Aggregates taken from natural sources, such as riverbeds, quarries and mines. Sand, gravel, stone and rock are the most common, and these can be fine or coarse.
- Processed – Also called ‘artificial aggregates’, or ‘by-product’ aggregates, they are commonly taken from industrial or engineering waste, then treated to form construction aggregates for high quality concrete. Common processed aggregates include industrial slag, as well as burnt clay.

Processed aggregates are used for both lightweight and high-density concrete mixes.

Classification of aggregates based on: Shape

Shape is one of the most effective ways of differentiating aggregates. The shape of your chosen aggregates will have a significant effect on the workability of your concrete. Aggregates purchased in batches from a reputable supplier can be consistent in shape, if required, but you can also mix aggregate shapes if you need to.

The different shapes of aggregates are:

- Rounded – Natural aggregates smoothed by weathering, erosion and attrition. Rocks, stone, sand and gravel found in riverbeds are your most common rounded aggregates. Rounded aggregates are the main factor behind workability.
- Irregular – These are also shaped by attrition, but are not fully rounded. These consist of small stones and gravel, and offer reduced workability to rounded aggregates.
- Angular – Used for higher strength concrete, angular aggregates come in the form of crushed rock

and stone. Workability is low, but this can be offset by filling voids with rounded or smaller aggregates.

- Flaky – Defined as aggregates that are thin in comparison to length and width. Increases surface area in a concrete mix.
- Elongated – Also adds more surface area to a mix – meaning more cement paste is needed. Elongated aggregates are longer than they are thick or wide.
- Flaky and elongated – A mix of the previous two – and the least efficient form of aggregate with regards to workability.

Particle shape and Texture:-

Aggregate particle shape and surface texture are important for proper compaction, deformation resistance, and workability. However, the ideal shape for HMA and PCC is different because aggregates serve different purposes in each material. In HMA, since aggregates are relied upon to provide stiffness and strength by interlocking with one another, cubic angular-shaped particles with a rough surface texture are best. However, in PCC, where aggregates are used as an inexpensive highstrength
material to occupy volume, workability is the major issue regarding particle shape. Therefore, in PCC rounded particles are better. Relevant particle shape/texture characteristics are discussed below.
Rounded particles create less particle-to-particle interlock than angular particles and thus provide better workability and easier compaction. However, in HMA less interlock is generally a disadvantage as rounded aggregate will continue to compact, shove and rut after construction. Thus angular particles are desirable for HMA (despite their poorer workability), while rounded particles are desirable for PCC because of their better workability.

Flat or Elongated Particles

These particles tend to impede compaction or break during compaction and thus, may decrease strength.

Smooth-Surfaced Particles

These particles have a lower surface-to-volume ratio than rough-surfaced particles and thus may be easier to coat with binder. However, in HMA asphalt tends to bond more effectively with roughsurfaced particles, and in PCC rough-surfaced particles provide more area to which the cement paste can bond. Thus, rough-surface particles are desirable for both HMA and PCC.

ENGINEERING PROPERTIES OF AGGREGATES:-

Aggregates are used in concrete to provide economy in the cost of concrete. Aggregates act as filler only. These do not react with cement and water.

But there are properties or characteristics of aggregate which influence the properties of resulting concrete mix. These are as follow.

1. Composition
2. Size & Shape
3. Surface Texture
4. Specific Gravity
5. Bulk Density
6. Voids
7. Porosity & Absorption
8. Bulking of Sand
9. Fineness Modulus of Aggregate
10. Surface Index of Aggregate
11. Deleterious Material
12. Crushing Value of Aggregate
13. Impact Value of Aggregate

14. Abrasion Value of Aggregate

1. COMPOSITION

Aggregates consisting of materials that can react with alkalies in cement and cause excessive expansion, cracking and deterioration of concrete mix should never be used. Therefore it is required to test aggregates to know whether there is presence of any such constituents in aggregate or not.

2. SIZE & SHAPE

The size and shape of the aggregate particles greatly influence the quantity of cement required in concrete mix and hence ultimately economy of concrete. For the preparation of economical concrete mix on should use largest coarse aggregates feasible for the structure. IS-456 suggests following recommendation to decide the maximum size of coarse aggregate to be used in P.C.C & R.C.C mix.

Maximum size of aggregate should be less than

- One-fourth of the minimum dimension of the concrete member.
- One-fifth of the minimum dimension of the reinforced concrete member.
- The minimum clear spacing between reinforced bars or 5 mm less than the minimum cover between the reinforced bars and form, whichever is smaller for heavily reinforced concrete members such as the ribs of the main bars.

Remember that the size & shape of aggregate particles influence the properties of freshly mixed concrete more as compared to those of hardened concrete.

3. SURFACE TEXTURE

The development of hard bond strength between aggregate particles and cement paste depends upon the surface texture, surface roughness and surface porosity of the aggregate particles.

If the surface is rough but porous, maximum bond strength develops. In porous surface aggregates, the bond strength increases due to setting of cement paste in the pores.

4. SPECIFIC GRAVITY

The ratio of weight of oven dried aggregates maintained for 24 hours at a temperature of 100 to 110^{0}C, to the weight of equal volume of water displaced by saturated dry surface aggregate is known as specific gravity of aggregates.

Specific gravities are primarily of two types.

- Apparent specific gravity
- Bulk specific gravity

Specific gravity is a mean to decide the suitability of the aggregate. Low specific gravity generally indicates porous, weak and absorptive materials, whereas high specific gravity indicates materials of good quality. Specific gravity of major aggregates falls within the range of 2.6 to 2.9.

Specific gravity values are also used while designing concrete mix.

5. BULK DENSITY

It is defined as the weight of the aggregate required to fill a container of unit volume. It is generally expressed in kg/litre.

Bulk density of aggregates depends upon the following 3 factors.

- Degree of compaction
- Grading of aggregates
- Shape of aggregate particles

6. VOIDS

The empty spaces between the aggregate particles are known as voids. The volume of void equals the difference between the gross volume of the aggregate mass and the volume occupied by the particles alone.

7. POROSITY & ABSORPTION

The minute holes formed in rocks during solidification of the molten magma, due to air bubbles, are known as pores. Rocks containing pores are called porous rocks.

Water absorption may be defined as the difference between the weight of very dry aggregates and the weight of the saturated aggregates with surface dry conditions.

Depending upon the amount of moisture content in aggregates, it can exist in any of the 4 conditions.

- Very dry aggregate (having no moisture)
- Dry aggregate (contain some moisture in its pores)
- Saturated surface dry aggregate (pores completely filled with moisture but no moisture on surface)
- Moist or wet aggregates (pores are filled with moisture and also having moisture on surface)

8. BULKING OF SAND

It can be defined as in increase in the bulk volume of the quantity of sand (i.e. fine aggregate) in a moist condition over the volume of the same quantity of dry or completely saturated sand. The ratio of the volume of moist sand due to the volume of sand when dry, is called bulking factor.

Fine sands bulk more than coarse sand

When water is added to dry and loose sand, a thin film of water is formed around the sand particles. Interlocking of air in between the sand particles and the film of water tends to push the particles apart due to surface tension and thus increase the volume. But in case of fully saturated sand the water films are broken and the volume becomes equal to that of dry sand.

9. FINENESS MODULUS

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by 100.

Fineness modulus is generally used to get an idea of how coarse or fine the aggregate is. More fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer.

10. SPECIFIC SURFACE OF AGGREGATE

The surface area per unit weight of the material is termed as specific surface. This is an indirect measure of the aggregate grading. Specific surface increases with the reduction in the size of aggregate particle. The specific surface area of the fine aggregate is very much more than that of coarse aggregate.

11. DELETERIOUS MATERIALS

Aggregates should not contain any harmful material in such a quantity so as to affect the strength and durability of the concrete. Such harmful materials are called deleterious materials. Deleterious materials may cause one of the following effects

- To interfere hydration of cement
- To prevent development of proper bond
- To reduce strength and durability
- To modify setting times

Deleterious materials generally found in aggregates, may be grouped as under

- Organic impurities
- Clay , silt & dust
- Salt contamination

12. CRUSHING VALUE

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

13. IMPACT VALUE

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

14. ABRASION VALUE OF AGGREGATES

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

SIEVE ANALYSIS:-

Sieve analysis is a technique used to determine the particle size distribution of a powder. This method is performed by sifting a powder sample through a stack of wire mesh sieves, separating it into discrete size ranges. A sieve shaker is used to vibrate the sieve stack for a specific period of time.

Sieve analysis is important for analyzing materials because particle size distribution can affect a wide range of properties, such as the strength of concrete, the solubility of a mixture, surface area properties and even their taste.

FINENESS MODULUS:-

The *Fineness Modulus* (FM) is an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100. Fineness modulus of sand (fine aggregate) is an index number which represents the mean size of the particles in sand. It is calculated by performing sieve analysis with standard sieves. The cumulative percentage retained on each sieve is added and subtracted by 100 gives the value of fineness modulus. Fineness modulus is generally used to get an idea of how coarse or fine the aggregate is. More fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer.

THE GRADING CURVE:-

The grading curve graphically represents the proportion of different grain sizes which the aggregate is composed of and which form part of the shortcrete mix. It provides useful information to find out: Whether the distribution of the different aggregate sizes is suitable for pumping.

GRADING OF AGGREGATES:-

Grading of aggregates is determining the average grain size of the aggregates before they are used in construction. This is applied to both coarse and fine aggregates. The aggregate sample is sieved through a set of sieves and weights retained on each sieve in percentage terms are summed up.

GAP GRADING AGGREGATE:-

Gap grading is defined as a grading in which one or more intermediate size fractions are absent. On a grading curve, it represents a horizontal line over the range of sizes that are absent.

MAXIMUM AGGREGATE SIZE:-

Typically, coarse aggregate sizes are larger than 4.75 mm (5 mm in British code), while fine aggregates form the portion below 4.75 mm. A maximum size up to 40 mm is used for coarse aggregate in most structural applications, while for mass concreting purposes such as dams, sizes up to 150 mm may be used.

ADMIXTURE

Admixture is a compound which is used in order to increase or decrease the initial and final setting time of cement.

Admixture and its types

Chemical admixtures are the ingredients in concrete other than Portland cement, water, and aggregate those are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

It is of various types-

Water-reducing admixtures usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio. This usually indicates that a higher strength concrete can be produced without increasing the amount of cement. Recent advancements in admixture technology have led to the development of mid-range water reducers. These admixtures reduce water content by at least 8 percent and tend to be more stable over a wider range of temperatures. Mid-range water reducers provide more consistent setting times than standard water reducers.

Retarding admixtures, which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

Accelerating admixtures increase the rate of early strength development; reduce the time required for proper curing and protection, and speed up the start of finishing operations. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.

Super plasticizers, also known as plasticizers or high-range water reducers (HRWR), reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and watercement ratio to make high-slump flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction. The effect of super plasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability. As a result of the slump loss, super plasticizers are usually added to concrete at the jobsite.

Corrosion-inhibiting admixtures fall into the specialty admixture category and are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while ASR inhibitors control durability problems associated with alkali-silica reactivity.

DOSASES:-

Super plasticizers are commonly known as High Range Water Reducers because it permits low water cement ratio as well as the workability also affected. In very recent decades, super plasticizers creates milestone in the advancement of chemical admixtures for Portland cement concrete. The dramatic effect of super plasticizer (SP) on properties of fresh and hardened concrete has studied and the properties of concrete inspected are compressive strength and slump test. To determine the optimum dosage for the admixture, an experimental investigation conducted and the effect of over dosage of the SP admixture experimented, together with one control mixed. The viscosity of grout and hence the workability of concrete influenced by the dosage of super plasticizer. From dosages of admixture, the difference between concrete mixes comes, which used at amounts 400 ml/100 kg, 600 ml/100 kg, 800 ml/100 kg, 1000 ml/100 kg and 1200 ml/100 kg of cement were prepared. By dosage 1.0% of SP, compressive strength is improved and after 28 days curing it is 57 N/mm2 , which is higher than that of control specimen.

CHAPTER-4

FRESH CONCRETE

Workability is the property of concrete which determines the amount of internal work necessary to produce full compaction. It is a measure with which concrete can be handled from the mixer stage to its final fully compacted stage.

FACTORS AFFECTING WORKABILITY OF CONCRETE:-

01. Water Content of the Concrete Mix:

Water content will have important influences on the workability in given volume of concrete. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which affect the workability.

Water requirement is mainly associated with absorption by aggregates surface& filling up the voids between aggregates.

- The strength of the concrete may get reduced.
- More quantity of water comes out from the surface of concrete resulting into bleeding.
- Cement slurry also escapes through the joints of formwork resulting into the loss of cement from concrete.

02. The Size of Aggregates:

Workability is mainly governed by the maximum size of aggregates. Water and paste require, will be not less if a chosen size of aggregates for concrete is bigger. Consequently, for a given quantity of water content & paste, bigger size aggregate will give higher workability.

Note: On the site, the maximum size of aggregate to be used will depend upon the many factors such as the handling, mixing and placing equipment, the thickness of section and quantity of reinforcement. Later two are very important.

03. The shape of Aggregates:

Angular, flaky & elongated aggregate reduces the workability of concrete.

Rounded or sub-rounded aggregates increase the workability due to the reduction of surface area for a given volume or weight. Therefore, an excess paste is available to give better lubricating effect.

Rounded shape aggregate has less frictional resistance and gives a high workability as compared to angular, flaky or elongated aggregates.

Note: River sand & gravel provide greater workability to concrete than crushed sand.

04. Surface Texture of Aggregates:

The roughly textured aggregates have more surface area than smoothly rounded aggregates of the same volume. Smooth rounded or glassy aggregates will give better workability than roughly textured aggregates. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

05. The Porosity of Aggregates:

Porous and non-saturated aggregate will require more water than non-absorbent aggregates. For the same degree of workability, latter will require less water. Overall, this factor is only of secondary importance.

06. Grading of Aggregates:

Grading of aggregates has the greatest influence on workability. The better the grading of aggregates, the less is the amount of void in concrete so well-graded aggregates should be used. When total voids are less in concrete, the excess paste is available to give better lubricating effect.

With excess amount of concrete paste present in the mixture, it becomes cohesive and fatty that prevents segregation of particles & least amount of compacting efforts is required to compact the concrete.

For a given workability, there is one value of coarse aggregate / Fine aggregate ratio, which needs the lower water content.

07. Uses of Concrete Admixtures:
This is one of the commonly used methods to enhance the workability of concrete. Concrete admixtures such as plasticizer and super plasticizers greatly improve the workability.
Air entraining agents are also used to increase the workability. Air entraining agents creates a large number of very tiny air bubbles. These bubbles get distributed throughout the mass of concrete and act as rollers and increase the workability.
Mineral admixtures like Pozzolanic materials are also used to improve the workability of concrete.
08. Ambient Temperature:
In hot weather, if temperature increases, the evaporation rate of mixing water also increases and hence fluid viscosity increases, too. This phenomenon affects the flowability of concrete and due to fast hydration of concrete; it will gain strength earlier which decreases the workability of fresh concrete.

Measurement of Workability:-

The followings tests for workability of concrete gives a measure of workability, which is applicable specifically concerning some particular methods. They bear no relationship to any of the common methods of placing and compacting concrete. So, the test results are only relative and should not be given any absolute measurement. We need to understand that each test has their importance, and as such there is no unique test to measure the workability of concrete in total. The significant advantage is the simplicity of the procedure with an ability to detect variation in the uniformity of a mix of given nominal proportion.
Types of tests for workability:-

- Slump Test
- Compacting Factor Test
- Flow Test
- Vee-Bee Consistometer Test

SLUMP TEST:-
The slump test is a means of assessing the consistency of fresh concrete. It is used, indirectly, as a means of checking that the correct amount of water has been added to the mix.
The steel slump cone is placed on a solid, impermeable, level base and filled with the fresh concrete in three equal layers. Each layer is rodded 25 times to ensure compaction. The third layer is finished off level with the top of the cone. The cone is carefully lifted up, leaving a heap of concrete that settles or 'slumps' slightly. The upturned slump cone is placed on the base to act as a reference, and the difference in level between its top and the top of the concrete is measured and recorded to the nearest 10mm to give the slump of the concrete.
When the cone is removed, the slump may take one of three forms. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways. In a collapse slump the concrete collapses completely. Only a true slump is of any use in the test. If a shear or collapse slump is achieved, a fresh sample should be taken and the test repeated. A collapse slump will generally mean that the mix is too wet or that it is a high workability mix, for which the flow test (see separate entry) is more appropriate.

• 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 upp r hopper up to the brim. The trap-door is opened so that the

concrete falls into the low r 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 up to 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.

The compaction factor =Weight of partially compacted concrete 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 a d the proneness to segregation. In this test, a standard mass of concrete is subjected to joint. The spread or the flow of the concrete is measured and this flow is related to workability.

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 over flowed 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.

Flow per cent =Spread diameter • in cm – 25 X 100

25

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 metal cylindrical pot of the con istomeconsists 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 sheetter. 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.

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.

SETTING TIME OF CEMENT:-

The concrete setting time mostly depends upon the w/c ratio, temperature conditions, type of cement, use of mineral admixture, use of plasticizer, in particular, retarding plasticizer. The significance of setting parameter of concrete is more important for site engineers than setting time of cement. For keeping the concrete we use retarding plasticizers, which increases setting time and the duration up to which concrete remains in the plastic condition is of special interest.

The concrete setting time is determined by using a penetrometer test.

The test procedure involves,

1. Taking a sufficient quantity of fresh concrete mix sample and sieves it through 4.75 mm sieve.
2. The mortar sample passed through the sieve is collected.
3. This mortar is then compacted by rodding, tapping, rocking or by vibrating.
4. Level the surface and keep it covered to prevent the loss of moisture.
5. Remove bleeding water, if any, using a pipette. Insert a needle of appropriate size, depending upon the degree of the setting of the mortar in the following manner.
6. Bring the bearing surface of the needle in contact with the mortar surface.
7. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5 on, as indicated by the scribe mark.
8. The time is taken to penetrate 25 mm depth could be about 10 seconds.
9. Record the force required to produce 25 mm penetration and the time of inserting from the to water is added to the cement.
10. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance.

- Plot a graph of penetration resistance as ordinate and elapsed time as abscissa.
- Test conducted must determine 6 penetration resistances.
- Continue the tests until one penetration resistance of at least 27.6 MPa is reached.
- Plot these penetration resistance values on the graph and connect each point.
- Now draw a horizontal line from penetration resistance equal to 3.5 MPa.
- The point of intersection of this with the smooth curve is read on the x-axis which gives the initial setting time.
- Similarly, a horizontal line is drawn from the penetration resistance of 27.6 MPa and point it cuts the smooth curve is read on the x-axis which gives the final set.

Effect of time and temp in workability:-

Temperature decreases the setting time by increasing hydration rate and that increase the early age strength of the concrete. This is an advantage that less time will be required before removing of form works on site, but this decrease the use of proper placement of concrete in the initial stages.

It indicates that the temperature has a negative effect on the workability of concrete as well as strength up to some extent. Temperature decreases the setting time by increasing hydration rate and that increase the early age strength of the concrete.

This is an advantage that less time will be required before removing of form works on site, but this decrease the use of proper placement of concrete in the initial stages. And if concrete is not properly laid, then strength distribution will not remain the same throughout the cross-section.

SEGREGATION:-

The tendency of separation of coarse aggregates grains from te concrete mass is called segregation.

BLEEDING:-

The tendency of water to rise to the surface of freshly laid concrete is known as bleeding.

MIXING AND VIBRATION OF CONCRETE:

Mixing is the uniform incorporation of the ingredients within the concrete mix and vibration usually means the mechanical process to assist in the removal of any entrapped air. The air entrapment causes a honeycomb effect which weakens the concrete,

There are calculations and processes for concrete to allow for movement, which often translates to vibration due to friction or the dissimilarity of materials, a serious concern as it would be the cause for structural fatigue and failure.
The stages of concrete production are:
1. Batching or measurement of materials
2. Mixing
3. Transporting
4. Placing
5. Compacting
6. Curing
7. Finishing

Batching of Materials

For good quality concrete a proper and accurate quantity of all the ingredients should be used.
The aggregates, cement and water should be measured wit h an accuracy of 3 per cent of batch quantity and the admixtures by 5 per cent of the batch quantity. There are two prevalent methods of batching materials, the volume batching and the weigh batching. The factors affecting the choice of batching method are the size of job, required production rate, and required standards of batching performance. For most important works weigh batching is recommended.
a) Volume Batching
b) Weigh Batching

Mixing

1. Hand Mixing
2. Machine Mixing
a) Tilting Mixers
b) Non-tilting Mixer
c) Reversing Drum Mixer
d) Pan-type or Stirring Mixer
e) Transit Mixer

Charging the Mixer and Mixing Time

The order of feeding the ingredients into the mixer is as follows:
About 25 per cent of water required for mixing is first introduced into the mixer drum to prevent any sticking of cement on the blades and bottom of the drum. Then the ingredients are discharged through the skip. In the skip the sequence of loading should be to add first half the coarse aggregate then half the fine aggregate and over this total cement and then the balance aggregates. After discharging the ingredients into the drum the balance water is introduced. The mixing time is counted from the instant complete water is fed into the mixer.
The speed of the mixers is generally 15 to 20 rpm. For proper mixing, the number of revolutions per minute required by the drum are 25 to 30. Time of mixing also depends on capacity of mixer.
A poor quality of concrete is obtained if the mixing time is reduced. On the other hand if the mixing time is increased it is uneconomical. However, it is found that if the mixing time is increased to 2 minutes the compressive strength of concrete produced is enhanced and beyond this time the improvement in compressive strength is insignificant. A prolonged mixing may cause segregation. Also, due to longer mixing periods the water may get absorbed by the aggregates or evaporate resulting in loss of workability and strength.

Transporting

Concrete should be transported to the place of deposition at the earliest without the loss of homogeneity obtained at the time of mixing. A maximum of 2 hours from the time of mixing is permitted if trucks with agitator and 1 hour if trucks without agitators are used for transporting concrete. Also it should be ensured that segregation does not take place during transportation and placement. The methods adopted for transporting concrete depend upon the size and importance of the job, the distance of the deposition place from the mixing place, and the nature of the terrain. Some of the methods of transporting concrete are as below:

a. Mortar Pan
b. Wheel Barrow
c. Chutes
d. Dumper
e. Bucket and Ropeway
f. Belt conveyor
g. Skip and Hoist
h. Pumping

Placing:

To achieve quality concrete it should be placed with utmost care securing the homogeneity achieved during mixing and the avoidance of segregation in transporting. Research has shown that a delayed placing of concrete results in a gain in ultimate compressive strength provided the concrete can be adequately compacted. For dry mixes in hot weather delay of half to one hour is allowed whereas for wet mixes in cold weather it may be several hours.

Compaction

After concrete is placed at the desired location, the next step in the process of concrete production is its compaction. Compaction consolidates fresh concrete within the moulds or frameworks and around embedded parts and reinforcement steel. Considerable quantity of air is entrapped in concrete during its production and there is possible partial segregation also. Both of these adversely affect the quality of concrete. Compaction of the concrete is the process to get rid of the entrapped air and voids, elimination of segregation occurred and to form a homogeneous dense mass. It has been found that 5 per cent voids in hardened concrete reduce the strength by over 30 per cent and 10 per cent voids reduce the strength by over 50 per cent. Therefore, the density and consequently the strength and durability of concrete largely depend upon the degree of compaction. For maximum strength driest possible concrete should be compacted 100 per cent.

The compaction of concrete can be achieved by the following methods.

1. Hand Compaction
2. Compaction by Vibration
a. Needle Vibrator:
b. Formwork Vibrator
3. Compaction by Spinning
4. Compaction by Jolting
5. Compaction by Rolling

Curing

Cement gains strength and hardness because of the chemical action between cement and water. This chemical reaction requires moisture, favourable temperature and time referred to as the curing period. Curing of freshly placed concrete is very important for optimum strength and durability. The major part of the strength in the initial period is contributed by the clinker compound C_3S and partly by C_2S, and is completed in about three weeks. The later strength contributed by C_2S is gradual and takes long time. As such sufficient water should be made available to concrete to allow it to gain full strength. *The process of keeping concrete damp for this purpose is known as curing*. The object is to prevent the loss of moisture from concrete due to evaporation or any other reason, supply additional moisture or heat and moisture to accelerate the gain of strength. Curing must be done for at least three weeks and in no case for less than ten days.

Approximately 14 litres of water is required to hydrate each bag of cement. Soon after the concrete is placed, the increase in strength is very rapid (3 to 7 days) and continues slowly thereafter for an indefinite period. Concrete moist cured for 7 days is about 50 per cent stronger than that which is exposed to dry air for the entire period. If the concrete is kept damp for one month, the strength is about double than that of concrete exposed only to dry air.

Methods of Curing:

Concrete may be kept moist by a number of ways. The methods consist in either supplying additional moisture to concrete during early hardening period by ponding, spraying, sprinkling, etc. or by preventing loss of moisture from concrete by sealing the surface of concrete by membrane formed by curing compounds. Following are some of the prevalent methods of curing.

1. Water Curing
2. Steam Curing
3. Curing by Infra Red Radiation:
4. Electrical Curing
5. Chemical Curing:

Finishing:

Concrete is basically used because of its high compressive strength. However, the finish of the ultimate product is not that pleasant. In past couple of decades efforts have been made to develop surface finishes to give a better appearance to concrete surfaces and are as follows.

1. Formwork Finishes
2. Surface Treatments
3. Applied Finishes

QUALITY OF MIXING WATER:-

The common specifications regarding quality of mixing water is water should be fit for drinking. Such water should have inorganic solid less than 1000 ppm. This content lead to a solid quantity 0.05% of mass of cement when w/c ratio is provided 0.5 resulting small effect on strength.

CHAPTER-5

HARDENED CONCRETE

WATER CEMENT RATIO

The water–cement ratio is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Workability can be resolved with the use of plasticizers or super-plasticizers.
A maximum of 0.5 ratio when concrete is exposed to freezing and thawing in a moist condition or to de-icing chemicals, and a maximum of 0.45 ratio for concrete in a severe or very severe sulphate condition.
However, a mix with a ratio of 0.35 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water–cement ratios of 0.45 to 0.60 are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flow ability.
Nature of strength of concrete:-
The strength can be defined as the ability to resist force. With-regard to concrete for structural purposes it can be defined as the unit force required to cause rupture. Strength is a good index of most of the other properties of practical importance. In general stronger concretes are stiffer, more water tight and more resistant to weathering etc.
Rupture of concrete may be caused by applied tensile stress, shearing stress or by compressive stress or a combination of two of the above stresses. Concrete being a brittle material is much weaker in tension and shear than compression and failures of concrete specimens under compressive load are essentially shear failures on oblique planes as shown in fig.
It is called as shear or cone failure. As the resistance to failure is due to both cohesion and internal friction, the angle of rupture is not 45° (plane of maximum shear stress), but is a function of the angle of internal friction. It can be shown mathematically that the angle ϕ which the plane of failure makes with the axis of loading is equal to $(45° – \phi/2)$ as shown in fig.
The angle of internal friction ϕ of concrete being of the order of 20°, the angle of inclination of the cone of failure in the conventional test specimen is approximately 35° as shown in fig.
Maturity of concrete:-
Concrete maturity is an index value that represents the progression of concrete curing. It is based on an equation that takes into account concrete temperature, time, and strength gain. Concrete maturity is an accurate way to determine real-time strength values of curing concrete.
Tension Vs. Compression of Concrete:-
Concrete has enormous compressive strength, the ability to withstand heavy weights or forces on it. It also gains strength as it ages. Concrete will solidify in a few hours and harden or set in a few days, but continues to gain strength for at least 28 days. Some very thick concrete structures, like dams, will continue to gain strength for months or years.
Concrete has almost no tensile strength, the ability to withstand pressing or stretching. Put a board between two supports and press down on the centre. It will bend. The top of the board is under compression, the bottom which bends is under tension. Concrete can resist the compression, but will break under the tension. Concrete cracks in roads and slabs are largely due to tension; different weights in different areas produce tensile forces.
The tension to compression ratio for concrete is about 10 to 15 percent. That is, it can withstand about 10 times the pushing force or compression of the pulling force or tension. Both strengths increase with age, but the ratio is steady. Portland cement concrete less than a year old has compression strength of 1,000 pounds per square inch (psi) and tension strength of 200 psi. Concrete more than a year old has compression psi of 2,000 pounds and tension psi of 400.

Factors affecting strength of concrete:
Concrete strength is affected by many factors, such as quality of raw materials, water/cement ratio, coarse/fine aggregate ratio, age of concrete, compaction of concrete, temperature, relative humidity and curing of concrete.
Relation between tensile and compressive strength of concrete:-
The theoretical compressive strength of concrete is eight times larger than its tensile strength. This implies a fixed relation between the compressive and tensile strength of concrete. In fact there is a close relation but not a direct proportionality. The ratio of tensile to compressive strength is lower for higher compressive strengths.
This may be due to the following two reasons:
(a) Formation of inferior quality gel due to improper curing.
(b) Development of more shrinkage cracks due to improper curing. The uses of pozzolanic materials have shown the increase in tensile strength.
Curing of Concrete:-
Curing of Concrete is a method by which the concrete is protected against loss of moisture required for hydration and kept within the recommended temperature range. Curing will increase the strength and decrease the permeability of hardened concrete.

TESTING OF HARDENED 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 like, 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.
I. The characteristics of cement.
II. The characteristics and properties of aggregates.
III. The degree of compaction
IV. The efficiency of curing
V. Age at the time of testing.
VI. Conditions of testing.
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
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 most common plain concrete subjected to flexure is a highway/runway pavement. The strength of pavement concrete is evaluated by means of bending 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.

PULL OUT TEST OF CONCRETE:

The pullout test produces a well defined in the concrete and measure a static strength property of concrete. The equipment is simple to assemble and operate. The compressive strength can be considered as proportional to the ultimate pullout force. The reliability of the test is reported as good.

NON-DESTRUCTIVE TESTING OF CONCRETE (NDT ON CONCRETE):-

Non destructive test is a method of testing existing concrete structures to assess the strength and durability of concrete structure. In the non destructive method of testing, without loading the specimen to failure (i.e. without destructing the concrete) we can measure strength of concrete. Now days this method has become a part of quality control process. This method of testing also helps us to investigate crack depth, micro cracks and deterioration of concrete.

Non destructive testing of concrete is a very simple method of testing but it requires skilled and experienced persons having some special knowledge to interpret and analyze test results. DIFFERENT METHODS OF NON-DESTRUCTIVE TESTING OF CONCRETE:-

Various non-destructive methods of testing concrete have been developed to analyze properties of hardened concrete, which are given below.

1. SURFACE HARDNESS TEST

These are of indentation type, include the Williams testing pistol and impact hammers, and are used only for estimation of concrete strength.

2. REBOUND HAMMER TEST

The rebound hammer test measures the elastic rebound of concrete and is primarily used for estimation of concrete strength and for comparative investigation.

3. PENETRATION AND PULLOUT TECHNIQUES

These include the use of the simbi hammer, spit pins, the Windsor probe, and the pullout test. These measure the penetration and pullout resistance of concrete and are used for strength estimation, but they can also be used for comparative studies.

NDT test on concrete

4. DYNAMIC OR VIBRATION TESTS

These include resonant frequency and mechanical sonic and ultrasonic pulse velocity methods. These are used to evaluate durability and uniformity of concrete and to estimate its strength and elastic properties.

5. COMBINED METHODS

The combined methods involving ultrasonic pulse velocity and rebound hammer have been used to estimate strength of concrete.

6. RADIOACTIVE AND NUCLEAR METHODS

These include the X-ray and Gamma ray penetration tests for measurement of density and thickness of concrete. Also, the neutron scattering and neutron activation methods are used for moisture and cement content determination.

7. MAGNETIC AND ELECTRICAL METHODS

The magnetic methods are primarily concerned with determining cover of reinforcement in concrete, whereas the electrical methods, including microwave absorption techniques, have been used to measure moisture content and thickness of concrete.

8. ACOUSTIC EMISSION TECHNIQUES

These have been used to study the initiation and growth of cracks in concrete.

ELASTICITY, CREEP, SHRINKAGE

Modulus of Elasticity of Concrete can be defined as the slope of the line drawn from stress of zero to a compressive stress of $0.45f'_c$. As concrete is a heterogeneous material. The strength of concrete is dependent on the relative proportion and modulus of elasticity of the aggregate.

Dynamic modulus is the ratio of stress to strain under vibratory conditions (calculated from data obtained from either free or forced vibration tests, in shear, compression, or elongation). It is a property of visco elastic materials.

Dynamic Modulus:-

The value of modulus of elasticity E_c determined by actual loading of concrete is known as static modulus of elasticity. This method of testing is known as destructive method as the specimen is stressed or loaded till its failure. The static modulus of elasticity does not represent the true elastic behaviour of concrete due to the phenomenon of creep. At higher stresses the modulus of elasticity is affected more seriously.

Thus a non-destructive method of testing known as dynamic method is adopted for determining the modulus of elasticity. In this case no stress is applied on the specimen. The modulus of elasticity is determined by subjecting the specimen to longitudinal vibration at their natural frequency that is why this is known as dynamic modulus.

Poisson's ratio:-

Poisson's ratio is the ratio of lateral strain to longitudinal strain in a material subjected to loading. Poisson's ratio varies between 0.1 for high strength concrete and 0.2 for weak mixes. It is normally taken as 0.15 for strength design and 0.2 for serviceability criteria.

Creep:-

Creep in concrete is defined as the deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. Creep does not necessarily cause concrete to fail or break apart. When a load is applied to concrete, it experiences an instantaneous elastic strain which develops into creep strain if the load is sustained.

Creep is factored in when concrete structures are designed.

Factors Affecting Creep:-

These are the factors which affects creep of concrete.

1. Aggregate
2. Mix Proportions
3. Age of concrete

The magnitude of creep strain is one to three times the value of the instantaneous elastic strain, it is proportional to cement-paste content and, thus, inversely proportional to aggregate volumetric content. The magnitude of creep is dependent upon the magnitude of the applied stress, the age and strength of the concrete, properties of aggregates and cementitious materials, amount of cement paste, size and shape of concrete specimen, volume to surface ratio, amount of steel reinforcement, curing conditions, and environmental conditions.

1. Influence of Aggregate:

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. An increase from 65 to 75 % of volumetric content of the aggregate will decrease the creep by 10 %.

The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

2. Influence of Mix Proportions:

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age:

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Therefore, creep is a "time-dependent" deformation. It works on the principle of Hooke's law (stress is directly proportional to strain).

Effects of Creep on Concrete and Reinforced Concrete:-

- In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can load to buckling.
- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.
- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.
- Loss of pre stress due to creep of concrete in pre stressed concrete structure.
- Because of rapid construction techniques, concrete members will experience loads that can be as large as the design loads at very early age; these can cause deflections due to cracking and early age low elastic modulus. So, creep has a significant effect on both the structural integrity and the economic impact that it will produce if predicted wrong.

Shrinkage:-

The volumetric changes of concrete structures due to the loss of moisture by evaporation is known as concrete shrinkage or shrinkage of concrete. It is a time-dependent deformation which reduces the volume of concrete without the impact of external forces.

Types of Shrinkage in Concrete:

To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage in concrete
(b) Drying Shrinkage in concrete
(c) Autogeneous Shrinkage in concrete
(d) Carbonation Shrinkage in concrete

The Types of shrinkage are explained as below:

a. Plastic Shrinkage:

Plastic shrinkage is contraction in volume due to water movement from the concrete while still in the plastic state, or before it sets. This movement of water can be during the hydration process or from the environmental conditions leading to evaporation of water that resides on the surface on the wet concrete. So, the more the concrete bleeds, the greater the plastic shrinkage should be. Plastic shrinkage is proportional to cement content and, therefore, inversely proportional to the w/c ratio.

Plastic shrinkage in concrete can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by fog spray that keeps the surface moist; or by working at night. Use of small quantity of aluminium powder is also suggested to offset the effect of plastic shrinkage. Similarly, expansive cement or shrinkage compensating cement also can be used for controlling the shrinkage during the setting of concrete.

b. Drying Shrinkage:

Just as the hydration of cement is an everlasting process, the drying shrinkage is also an everlasting process when concrete is subjected to drying conditions. The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen. 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. Under drying conditions, the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions. Cement paste shrinks more than mortar and mortar shrinks more than concrete. Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate. The magnitude of drying shrinkage is also a function of the fineness of gel. The finer the gel the more is the shrinkage.

c. Autogeneous Shrinkage:

Autogeneous shrinkage, also known as “basic shrinkage,” is the shrinkage due to chemical reactions between cement with water, known as hydration, and do not include environmental effects such as temperature and moisture changes. Its magnitude is usually ignored in concretes with w/c more than 0.40.

In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage. Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of a concrete dam.

d. Carbonation Shrinkage:

Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide [$Ca(OH)_2$] gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete very slowly. The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. Carbonation is accompanied by an increase in weight of the concrete and by shrinkage. Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place. Carbonation of concrete also results in increased strength and reduced permeability, possibly because water released by carbonation promotes the process of hydration and also calcium carbonate reduces the voids within the cement paste. As the magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage, this aspect is not of much significance

Factors affecting durability of concrete

Durability of Concrete is influenced by the factors shown in the following figure

Sulphate attack

- Sulphate attack denotes an increase in the volume of cement paste in concrete or mortar due to chemical action between the products of hydration of cement and solution containing sulphate, and also sodium, magnesium and Chlorides.
- In hardened concrete, calcium aluminate hydrate (CAH) can react with sulphate salt from outside, product of reaction is calcium sulphoaluminate, which can cause an increase in volume up to 227%
- Rate of sulphate attack increases with a saturated sulphate solution.
- A saturate solution of magnesium sulphate can cause serious damage to concrete with high w/c ratio.

Chloride Attack.

- Chlorides in concrete increases risk of corrosion of steel (Electrochemical reaction)
- Higher Chloride content or exposure to warm moist conditions increase the risk of corrosion.
- To minimize the chances of corrosion, the levels of chlorides in concrete should be limited
- Total amount of chloride content (as Cl) in concrete at the time of placing is provided by common specifications and standards.

Efflorescence:

Efflorescence in concrete is a whitish coloured powdered deposition of salts on the concrete surface that is formed due to evaporation of water from the concrete. It is caused when water soluble salts are present in the concrete material, which comes on to the surface while evaporation of water from the concre

CHAPTER-6

MIX DESIGN

The various factors affecting the choice of concrete mix design are:

1. Compressive strength of concrete
- Concrete compressive strength considered as the most important concrete property. It influences many other describable properties of the hardened concrete.
- The mean compressive strength (fcm) required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix.
- ISO 456-200, British Standard, and Eurocode utilize the term mean compressive strength which is slightly greater than characteristic compressive strength. However, ACI Code do not use such term.
- Other factors which influences the concrete compressive strength at given time and cured at a specified temperature is compaction degree.
- Concrete compressive strength is inversely proportional to the water-cement ratio.

Fig.1:Means compressive strength vs characteristic compressive strength

Fig.2: compressive strength of concrete

2. Workability of concrete
- Concrete workability for satisfactory placement and compaction depends on the size and shape of the section to be concreted, the amount and spacing of reinforcement, and concrete transportation; placement; and compaction technique.
- Additionally, use high workability concrete for the narrow and complicated section with numerous corners or inaccessible parts. This will ensure the achievement of full compaction with a reasonable amount of effort.
- Slump test values used to evaluate concrete workability.
- Slump test values for various reinforced concrete sections ranges from 25 mm to 175 mm.

3. Durability of concrete
- The ability of concrete to withstand harmful environment conditions termed as concrete durability.
- High strength concrete is generally more durable than low strength concrete.
- In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the utilized water-cement ratio.
- Concrete durability decreases with the increase of w/c ratio.

4. Maximum nominal size of aggregate
- Reinforcement spacing controls maximum aggregate size.
- Aggregate size is inversely proportional to cement requirement for water-cement ratio. This is because workability is directly proportional to size of aggregate
- However, the compressive strength tends to increase with the decrease in size of aggregate. Smaller aggregate size offers greater surface area for bonding with mortar mix that gives higher strength.
- IS 456:2000 and IS 1343:1980 recommends that the nominal size of the aggregate should be as large as possible.
- Finally, in accordance with ACI code, maximum aggregate size shall not exceed minimum reinforcement spacing, bar diameter, or 25mm.

Fig.3: Maximum aggregate size

5. Grading and type of aggregate

- Aggregate grading influences the mix proportions for a specified workability and water-cement ratio.
- The relative proportions between coarse and fine aggregate in concrete mix influence concrete strength.
- Well graded fine and coarse aggregate produce a dense concrete because of the achievement of ultimate packing density.
- If available aggregate, which obtained from natural source, does not confirm to the specified grading, the proportioning of two or more aggregate become essential.
- Additionally, for specific workability and water to cement ratio, type of aggregate affects aggregate to cement ratio.
- Lastly, An important feature of a satisfactory aggregate is the uniformity of the grading that achieved by mixing different size fractions.

Fig.7: aggregate grading types

6. Quality Control at site

- The degree of control could be evaluated by the variations in test results.
- The variation in strength results from the variations in the properties of the mix ingredients, in addition to lack of control of accuracy in batching, mixing, placing, curing and testing.
- Finally, the lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

ACCEPTANCE CRITERIA FOR DESIGN MIX CONCRETE

The concrete shall be deemed to comply with the strength requirements if:

a) Every sample has a test strength not less than the characteristic value; or

b) The strength of one or more samples though less than the characteristic value, is in each case not less than the greater of :

1) The characteristic strength minus 1.35 times the standard deviation; and

2) 0.80 times the characteristic strength ; and the average strength of all the samples is not less than the characteristic strength plus
times the standard deviation.

II. The concrete shall be deemed not to comply with the strength requirements if:

a) The strength of any sample is less than the greater of :

1) the characteristic strength mix is 1.35 times the standard deviation; and

2) 0.80 times the characteristic strength ; or

b) The average strength of all samples is less than the characteristic strength
plus
times the standard deviation.

III Concrete which does not meet the strength requirements as specified in I, but has a strength greater than that required by II may, at the discretion of the designer, be accepted as being structurally adequate without further testing.

IV. Concrete of each grade shall be assessed separately.

V Concrete shall be assessed daily for compliance.

VI. Concrete is liable to be rejected if it is porous or honey-combed; its placing has been interrupted

without providing a proper construction joint; the reinforcement has been
displaced beyond the tolerances specified; or construction tolerances have not been met. However, the hardened concrete may be accepted after carrying out suitable remedial
measures to the satisfaction.
VIII. Where the value of the average strength of the tests (preferably 30 tests or 15 tests) is less than shall be rejected.

CONCRETE MIX PROPERTIONING:-

Determination of the proportion of the concrete ingredients such as cement, fine aggregate, coarse aggregate, water and admixtures is called concrete mix. • A proper mix design only can gives the specified properties such as workability, strength, permeability and durability with economy.
Methods of Proportioning Concrete

- Arbitrary Method of Proportioning Concrete.
- Fineness Modulus Method of Proportioning Concrete.
- Minimum Void Method.
- Maximum Density Method:
- Water – Cement Ratio Method of Proportioning Concrete.

ARBITRARY METHOD OF PROPORTIONING CONCRETE:-

The general expression for the propertions of cement, sand and coarse aggregare in 1:n:2n by volume.

- 1:1:2 and 1:1.2::2.4 for very high strength
- 1:1.5:3 and 1:2:4 for normal works
- 1:3:6 and 1:4:8 for foundations and mass concrete works.

Recommended mixes of concrete:

The concrete as per IS 456:2000, the grades of concrete lower than M20 are not to be used in RCC work.

M10 1 : 3 : 6
M15 1 : 2 : 4
M20 1 : 1.5 : 3
M25 1 : 1 : 2

Fineness Modulus Method of Proportioning Concrete:-

The term fineness modulus is used to indicate an index number which is roughly proportional to the average size of the particle in the entire quantity of aggregates.
The fineness modulus is obtained by adding the percentage of weight of the material retained on the following sieve and divided by 100.
The coarser the aggregates, the higher the fineness modulus.
Sieve is adopted for:
All aggregates : 80 mm, 40 mm, 20 mm, 10 mm, and Nos. 480, 240, 120, 60, 30 and 15.
Coarse aggregates : mm, 40 mm, 20 mm, 10 mm, and No. 480.
Fine aggregates : Nos. 480, 240, 120, 60, 30 and 15.
Proportion of the fine aggregate to the combined aggregate by weight
Where, P = desired fineness modulus for a concrete mix of fine and coarse aggregates.
= fineness modulus of fine aggregate
= fineness modulus of coarse aggregate.

Minimum Void Method:-
It does not give satisfactory result.
The quantity of sand used should be such that it completely fills the voids of coarse aggregate. Similarly, the quantity of cement used shown such that it fills the voids of sand, so that a dense mix the minimum voids is obtained.
In actual practice, the quantity of fine aggregate used in the mix is about 10% more than the voids in the coarse aggregate and the quantity of cement is kept as about 15% more than the voids in the fine aggregate.
Maximum Density Method:
This method is not very Popular.
It is determined by the formula as
Where, D = maximum size of aggregate (i.e. coarse aggregate)
P = percentage of material finer than diameter d (by weight)
d = maximum size of fine aggregate.
A box is filled with varying proportions of fine and coarse aggregates. The proportion which gives heaviest weight is then adopted.
Water – Cement Ratio Method of Proportioning Concrete:-
According to the water – cement ratio law given by Abram as a result of many experiments, the strength of well compacted concrete with good workability is dependent only on the ratio.

- The lower water content produces stiff paste having greater binding property and hence the lowering the water-cement ratio within certain limits results in the increased strength.
- Similarly, the higher water content increases the workability, but lower the strength of concrete.
- The optimum water-cement ratio for the concrete of required compressive strength is decided from graphs and expressions developed from various experiments.
- Amount of water less than the optimum water decreases the strength and about 10% less may be insufficient to ensure complete setting of cement. An increase of 10% above the optimum may decrease the strength approximately by 15% while an increase in 50% may decrease the strength to one-half.
- According to Abram's Law water-cement law, lesser the water-cement ratio in a workable mix greater will be the strength.
- If water cement ratio is less than 0.4 to 0.5, complete hydration will not be secured.

Some practical values of water cement ratio for structure reinforced concrete

- 0.45 for 1 : 1 : 2 concrete
- 0.5 for 1 : 1.5 : 3 concrete
- 0.5 to 0.6 for 1 : 2 : 4 concrete.

Concrete vibrated by efficient mechanical vibrators require less water cement ratio, and hence have more strength.
Thumb Rules for deciding the quantity of water in concrete:
(i) Weight of water = 28% of the weight of cement + 4% of the weight of total

aggregate
(ii) (ii) Weight of water = 30% of the weight of cement + 5% of the weight of total aggregate.

BIS METHOD OF MIX DESIGN:-

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design.
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)

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

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.
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.

Step 3: Determination of Aggregate Air content:-

Nominal maximum size of aggregate Air content (% of volume of concrete)
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.

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.

CHAPTER-7

Concrete Production, Placement, & Curing Process

Concrete Production and placing Process includes following stages that are given below.

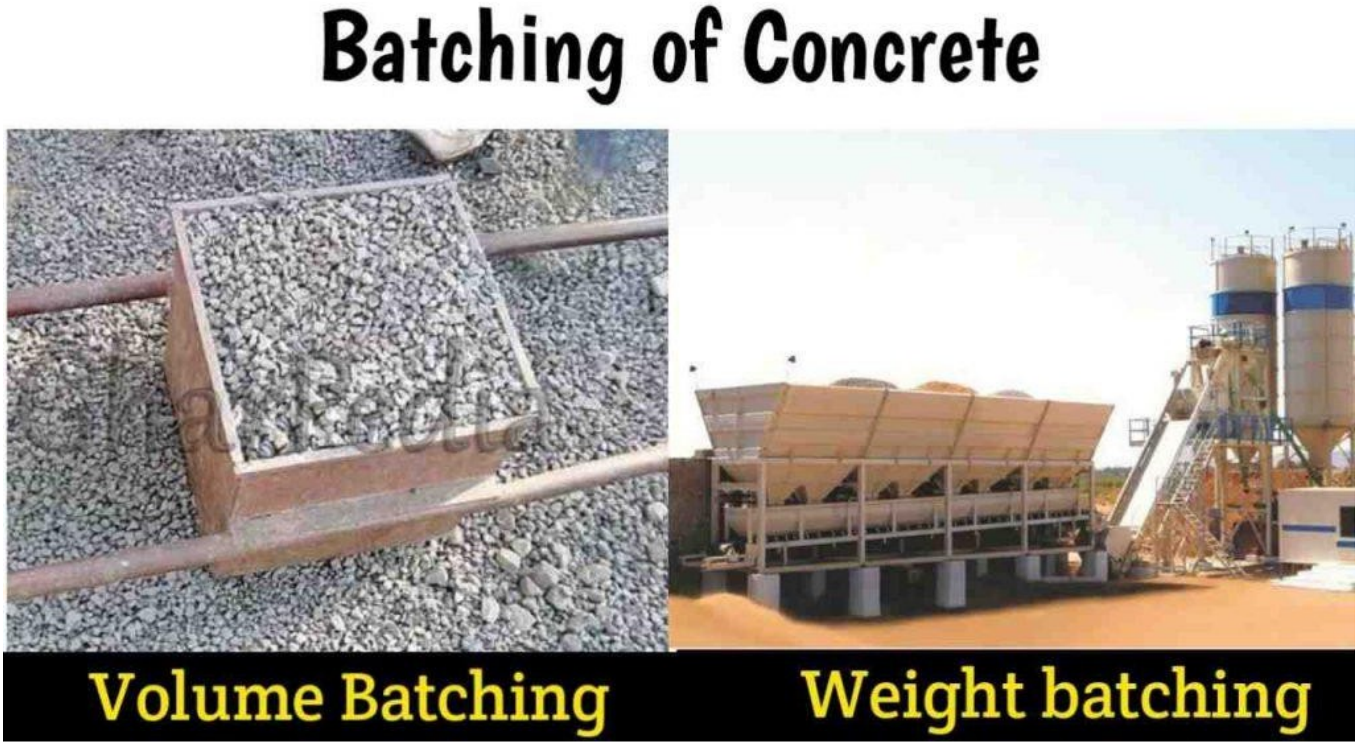
1. Batching of concrete
2. Mixing of concrete
3. Transportation of concrete
4. Placing of concrete
5. Compaction of concrete
6. Curing of concrete

1. Batching of concrete:

Batching is the process of measuring of material required for concrete mix by weight or volume.

Batching is done by two approaches.

- Volume batching
- Weight batching



i. Volume batching:

Volume batching is done by a typical gauge box that is known as "farmas" in the field. The volume of farma is 0.035m3 which is similar to the volume of 1 bag of cement.

Farma is made of timber, steel or plastic materials.

ii. Weight batching:

Weight batching is done manually or semi-automatically, or fully automatically. Mostly it is used in Ready mix concrete plants.

This type of batching is mostly used for large construction.

2. Mixing of concrete:

Mixing is necessary to make homogeneous concrete. To obtain a good quality of concrete, it is necessary to do proper mixing of concrete ingredients. The mixing of concrete depends on the types of mixing.

Generally mixing is done by three ways.

- Hand mixing
- Machine mixing
- Ready-mix concrete

i. Hand Mixing:

In this way mixing of concrete done by the hands of workers. This type of mixing is used for small construction work due to high time consumption. Also the quality of the concrete we get very less.

ii. Machine Mixing:
In this way, the mixing of concrete done by various types of machinery. It is used for medium to large construction work for example 3 to 4 story building construction.

Three types of machineries used for mixing of concrete.

- **Tilting type**
- **Non-tilting type**
- **Reversing type**

iii. Ready mix concrete:
Now a day's ready mix concrete become most popular for large construction because it gives high-quality concrete. Also, it gives the flexibility to do concreting work at the site where we can't able to produce concrete like the valley, mountains region, etc.

In valley regions, concrete ingredients like cement, aggregate, sand, water, and other materials are not easy to available. So we need to transport material from other locations which increase the cost of construction.

In this type of mixing, concrete mixing is done in a ready mix concrete plant that is situated on-site or another site. In the case of the RMC plant situated in another place, the concrete can be transported by the transit mixer to the construction site.

It is economical for large construction.
Ready mix concrete plant Consist the following parts:

- Batcher (to measure material)
- Conveyor system (to move ingredients of concrete to the concrete mixer)
- Silos (to store cement)
- Concrete Mixer (To mix concrete)
- Screw Conveyor (to convey cement from silos to the concrete mixer)
- Etc,

3. Transportation of concrete:

There are various methods used to transport concrete. Few of its are given below.

Mortar pan:
A mortar pan is used for small construction work in which concrete or mortar can be transported by laborers using a mortar pan.

Wheel Borrow:
The wheel borrow method of concrete transportation is suitable for long-distance concrete transportation on the site. It is majorly used for the construction of roads, slabs, etc.

Bucket & Ropeway:
Bucket & ropeway method of concrete transportation is used to transport concrete in valley areas.

Transit mixer:
A transit mixer is suitable for long-distance concrete transportation. It is used to transport a large volume of concrete to the construction site which is situated a long distance away from the mixing plant.

Skip & Hoist:
It is used in concreting of skyscraper building.

Pumps & pipelines:
Now a day's this type of concrete transportation is most popular for concreting work in tall structures. In this method, concrete is transported through the pipes by using pumps. In this method, concrete conveys from a central discharge point to formwork.
Belt conveyors:
It is used to convey concrete horizontally or inclined on the construction site.

4. Placing of concrete:
Placing of concrete is the process of deposition of concrete in its required position.

Placing of concrete under water is done by various methods.

- Tremie method
- Bagged method
- Bottom dump method, etc.

5. Compaction of concrete:
Compaction of concrete is a process in which concrete is compacted by various methods to remove entrapped air from the concrete and increase the strength of concrete.

By doing compaction of concrete, concrete becomes dense, impermeable due to that the durability of concrete increases.

Compaction of concrete done by two ways.

- Hand compaction
- Mechanical compaction

i. Hand compaction:
Hand compaction of concrete is done by various techniques.

- Roding
- Ramming
- Tamping

ii. Mechanical compaction:
Mechanical compaction is done by various type of vibrating machineries which are given below.

- Needle vibrator
- Form vibrator
- Table vibrator
- Surface vibrator

6. Curing of concrete:

Curing of concrete is defined as a process to maintain temperature and moisture of concrete during the hydration process of cement due to that hydration of cement completed and concrete gains maximum strength.

CHAPTER-8

Factors Affecting Quality of Concrete

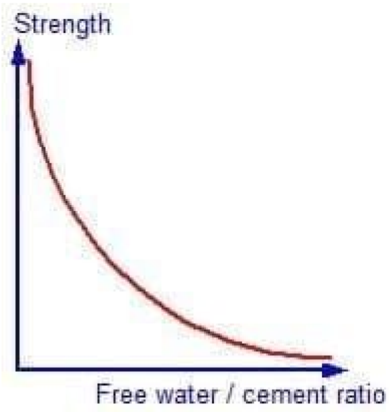
Concrete strength is affected by many factors, such as quality of raw materials, water/cement ratio, coarse/fine aggregate ratio, age of concrete, compaction of concrete, temperature, relative humidity and curing of concrete.

Quality of Raw Materials

Cement: Provided the cement conforms with the appropriate standard and it has been stored correctly (i.e. in dry conditions), it should be suitable for use in concrete. **Aggregates:** Quality of aggregates, its size, shape, texture, strength etc determines the strength of concrete. The presence of salts (chlorides and sulphates), silt and clay also reduces the strength of concrete. **Water:** frequently the quality of the water is covered by a clause stating "..the water should be fit for drinking..". This criterion though is not absolute and reference should be made to respective codes for testing of water construction purpose.

Water / Cement Ratio

The relation between water cement ratio and strength of concrete is shown in the plot as shown below:



The higher the water/cement ratio, the greater the initial spacing between the cement grains and the greater the volume of residual voids not filled by hydration products. There is one thing missing on the graph. For a given cement content, the workability of the concrete is reduced if the water/cement ratio is reduced. A lower water cement ratio means less water, or more cement and lower workability. However if the workability becomes too low the concrete becomes difficult to compact and the strength reduces. For a given set of materials and environment conditions, the strength at any age depends only on the water-cement ratio, providing full compaction can be achieved.

Coarse / fine aggregate ratio

Following points should be noted for coarse/fine aggregate ratio:

- If the proportion of fines is increased in relation to the coarse aggregate, the overall aggregate surface area will increase.
- If the surface area of the aggregate has increased, the water demand will also increase.
- Assuming the water demand has increased, the water cement ratio will increase.

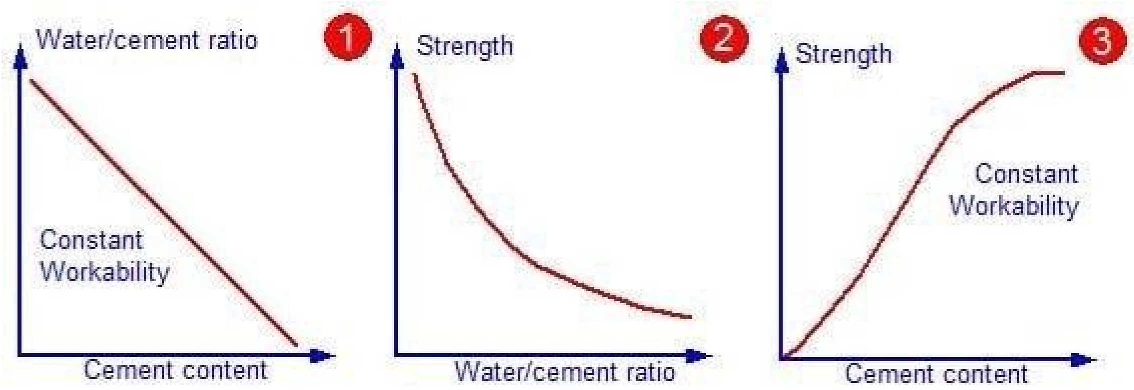
- Since the water cement ratio has increased, the compressive strength will decrease.

Aggregate / Cement Ratio

Following points must be noted for aggregate cement ratio:

- If the volume remains the same and the proportion of cement in relation to that of sand is increased the surface area of the solid will increase.
- If the surface area of the solids has increased, the water demand will stay the same for the constant workability.
- Assuming an increase in cement content for no increase in water demand, the water cement ratio will decrease.
- If the water cement ratio reduces, the strength of the concrete will increase.

The influence of cement content on workability and strength is an important one to remember and can be summarized as follows:



1. For a given workability an increase in the proportion of cement in a mix has little effect on the water demand and results in a reduction in the water/cement ratio.
2. The reduction in water/cement ratio leads to an increase in strength of concrete.
3. Therefore, for a given workability an increase in the cement content results in an increase in strength of concrete.

Age of concrete

The degree of hydration is synonymous with the age of concrete provided the concrete has not been allowed to dry out or the temperature is too low. In theory, provided the concrete is not allowed to dry out, then it wil always be increasing albeit at an ever reducing rate. For convenience and for most practical applications, it is generally accepted that the majority of the strength has been achieved by 28 days.

Compaction of concrete

Any entrapped air resulting from inadequate compaction of the plastic concrete will lead to a reduction in strength. If there was 10% trapped air in the concrete, the strength will fall down in the range of 30 to 40%.

Temperature

The rate of hydration reaction is temperature dependent. If the temperature increases the reaction also increases. This means that the concrete kept at higher temperature will gain strength more quickly than a similar concrete kept at a lower temperature. However, the final strength of the concrete kept at the higher temperature will be lower. This is because the physical form of the hardened cement paste is less well structured and more porous when hydration proceeds at faster rate. This is an important point to remember because temperature has a similar but more pronounced detrimental effect on permeability of the concrete.

Mixing

Once the ingredients are batched by volume or weight, they are introduced in a mixer and subjected to mixing. Initially, the dry ingredients are mixed for a small duration of time followed by the addition of water.

Once water is added, thorough mixing is carried out to ensure that the mass is homogenous, uniform in color, and consistent. Mixing may be done by hand or machine; however, the latter is preferred.

- For **small-scale concrete** works (e.g., repairing works), **hand mixing** can be done using a shovel. Fine and coarse aggregates are spread in alternate layers and cement is placed over them. Water is added and the ingredients are mixed till the attainment of uniform color. Manual mixing requires more cement than mechanical mixing to attain the same strength.

Fig.: Hand mixing of concrete

- For **medium and large-scale works**, machine mixing proves efficient in terms of delivering high-quality wet concrete. The machine mixer can either be a batch mixer or a continuous mixer.

3) Batch Mixer:

A batch mixer prepares concrete batch by batch. It can either be a tilting-drum type (T) mixer, a non-tilting drum (NT) type mixer, or a reversing (R) type mixer. Mixers with tilting drums are most commonly used.

a) Tilting drum (T) type mixers

Theyare either bowl-shaped or double conical frustum type. The material is added into the mixer by hand or is skip-fed. This type of mixer can easily be tilted in the downward direction for unloading mixed concrete.

The pros of using this mixer include the production of a concrete mix having relatively low workability, containing large aggregate sizes. However, a part of the cement mortar that clings or adheres to the mixer drum is often left out and not discharged which makes the use of this mixer a little disadvantageous.

Fig.: Tilting drum (T) type mixer

b)Non-tilting drum (NT) type mixers

Itconsist of cylindrical drums that are incapable of tilting. However, the drum is open from two sides and revolves about the horizontal axis. The dry mix is entered into the mixer at one end and the wet concrete is discharged from the other end. This type of mixer causes segregation owing to the slow discharge of concrete through it.

Fig.: Non-tilting drum (NT) type mixer

c)Reversing drum (R) type mixers

They are used for important concrete works. They are also termed forced action type mixers. The mixer consists of blades of two types functioning for different causes. One set of blades is used for mixing the concrete whilst the rotation of the drum, while the other set discharges the wet concrete as the drum is reversed.

Fig.: Reversing drum (R) type mixer

d) Pan type mixers

They are immovable and manufacture concrete either in the precast factory or at the central mixing plant. Their use is particularly worthwhile for stiff, homogeneous, and cohesive mixes. The pan or drum consists of two halves that are capable of rotating about the horizontal axis.

The circumferential speed at which both the halves rotate is different. This propels the concrete towards the center of the drum, producing some stirring up or turbulence that ultimately yields a homogenous mix of heterogenous concrete.

Fig.: Pan-type mixer

Batch mixers are available in various capacities. For general works, (10/7) th or (1/4) th cubic yard capacity mixers are used. 10/7 means that 10 cubic feet of dry ingredients will produce 7 cubic feet of wet concrete. The mixing time in no case is to be less than 90 seconds post addition of water for 1 cement bag capacity mixer.

The ready mixed concrete is batched in a central batching plant and delivered to the job site usually in trucks having mixers mounted on them. The concrete may be subjected to mixing during transportation or after arrival at the site. The concrete prepared using batch mixing can be kept workable or plastic for 1.5 hours by slow revolutions of the mixer.

However, it is preferred to add some water and mix again after the arrival at the site. This is termed as **retempering** of concrete and it aims at mobilizing the workability of concrete by adding some water into the prepared mix.

e) Continuous Mixer:

As the name suggests, these mixers are capable of providing a continuous discharge of wet concrete till the operation is deliberately put to a pause. The materials are loaded into the drum of the mixer that operates by the slow and continuous spinning of the blades mounted inside.

These mixers are used for large-scale projects that require an uninterrupted outflow of concrete during construction operations as in the case of a dam or bridge.

Fig.: Continuous mixer

Control on Mixing Time

In order to prevent cement from adhering to the blades or bottom of the mixer, a small quantity of water (about 25%) is usually added to the drum. The dry ingredients are then introduced into the mixer in sequential order, adding half the coarse and fine aggregates first, followed by the addition of the entire cement. After this, the remaining half of coarse and fine aggregates is added followed by the addition of remaining water.

The mixing time is initiated once the entire pre-determined water quantity is fed into the mixer. The mixer speed is generally kept between 25 to 30 rpm and the mixing time also hinges on the mixer capacity.

Transportation

The concrete is carried or transported to the site where it is to be placed or deposited. It should be ensured that during transportation neither does the concrete harden before time nor does it segregate or bleed. The transportation of concrete can be accomplished either manually or mechanically.

a) Manual transportation

It can be done using barrows or buckets and is employed for small concrete activities when the place of deposition is close to the place of mixing.

b) Mechanical transportation

It is preferred when the place of deposition is distant from the place of mixing. It is done using belt conveyors, dumpers, pumps, and lifts. In every case, the partial setting of concrete is to be prevented by consuming minimum time in transiting the concrete.

Dumpers, lorries, or trucks can transport concrete up to 5km and prove economical. During the transit process, the concrete should be covered with tarpaulins to prevent the evaporation of water.

Placing of Concrete

Placing of concrete refers to its deposition at the requisite site in the required shape. While placing the concrete, large lifts and free-falls must be avoided.

This possibly leads to segregation of concrete. When the concreting operating is to be halted for a certain duration of time, it is imperative to make grooves or construction joints in the finished work before its setting and hardening

Curing

When the concrete initially hardens and sets in place, moisture escape from the concrete body can create voids and ultimately result in huge strength loss. This is because concrete keeps on gaining strength for several weeks once it hardens initially.

Therefore, concrete needs to retain water that otherwise may evaporate leaving pores inside the body. To help concrete gain strength, curing is to be done and the method adopted depends upon the site conditions. The following curing techniques can generally be adopted:

- By jute bags
- By ponding
- By the sprinkling of water
- By immersing in water
- By steam
- By construction chemicals (chemical curing)

Fig.: Curing by the sprinkling of water

Fig.: Ponding of concrete

Fig.: Steam curing of concrete

REQUIREMENTS FOR DURABILITY OF CONCRETE

1. One of the major properties of concrete affecting its durability is its permeability.

The more permeable a concrete is the less durable it will be.

Because when concrete is permeable it helps to the ingress of deleterious agent that affects both concrete and embedded reinforcement.

2. The factors which influence the durability of concrete are

- environment,
- cover to embedded steel,
- type and quality of construction materials,
- cement content and
- water-cement ratio,
- workmanship during compaction
- curing, and
- shape and size of the member.

CHAPTER-9

SPECIAL CONCRETE

Introduction

• Special types of concrete are those with out-of-the-ordinary properties or those produced by unusual techniques. Concrete is by definition a composite material consisting essentially of a binding medium and aggregate particles, and it can take manyforms.

• These concretes do have advantages as well asdisadvantages.

Types of special concrete

1. High Volume Fly AshConcrete.

2. Silica fumesconcrete.

3. GGBS, Slag based concrete.

4. Ternary blend concrete.

5. Light weight concrete.

6. Polymerconcrete.

7. Self-Compacting Concrete.

8. Coloured Concrete.

9. Fibre-reinforced Concrete. 10.Pervious Concrete. 11.Water-proofConcrete.

12. Temperature Controlled Concrete.

Silica fume concrete

• Very fine non-crystalline silica produced in electric arc furnaces as aby-product.

• Highly reactive pozzolana used to improve mortar andconcrete.

• Silica fume in concrete produces two types of effectviz.

• Physicaleffect

• Chemicaleffect

• The transition zone is a thin layer between the bulk hydrated cement paste and the aggregate particles in concrete. This zone is the weakest component in concrete, and it isalso the most permeable area. Silica fume plays a significant role in the transition zone through both its physical and chemicaleffects.

Physical Effect

• The presenceof any type of very small particles willimproveconcrete properties. Thiseffectistermedeither—particlepacking||or—microfilling||.

• Physical mechanisms do play a significant role, particularly at earlyages.

Chemical Effect

• Silica fume is simply a very effective pozzolanic material.

• Pozzolanic means a siliceous or siliceous and aluminous material, which in itself possess little or no cementious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementious properties.

High performance concrete

High-performance concrete (HPC) is concrete that has been designed to be more durable and, if necessary, stronger than conventional concrete. HPC mixtures are composed of essentially the same materials as conventional concrete mixtures, but the proportions are designed, or engineered, to provide the strength and durability needed for the structural and environmental requirements of the project. High-strength concrete is defined as having a specified compressive strength of 8000 psi (55 MPa) or greater. The value of 8000 psi (55 MPa) was selected because it represented a strength level at which special care is required for production and testing of the concrete and at which special structural design requirements may be needed.

Shortcrete

Shotcrete is a method of applying concrete projected at high velocity primarily on to a vertical or overhead surface. The impact created by the application consolidates the concrete. Although the hardened properties of shotcrete are similar to those of conventional cast-in-place concrete, the nature of the placement process results in an excellent bond with most substrates, and rapid or instant capabilities, particularly on complex forms or shapes. The shotcrete process requires less formwork and can be more economical than conventionally placed concrete. Shotcrete is applied using a wet- or dry-mix process. The wet-mix shotcrete process mixes all ingredients, including water, before introduction into the delivery hose. The dry-mix shotcrete process adds water to the mix at the nozzle. Shotcrete is used in new construction and repairs and is suitable for curved and thin elements

Guniting

Guniting is a procedure in which repairing concrete work can be done that has been harmed due to inferior work or other reasons and providing an impervious layer is also used.

For the application of slope stabilization and certain rehabilitation purposes, the guniting process is used in construction such as in the construction of retaining walls, swimming pool construction, tunnel construction, concrete repair works, and in fluid tank construction.

Ready mix concrete

concrete that is manufactured in a factory or within a batching plant based on the standard required specifications. The prepared concrete mix is then taken to the work site within transit mixers mounted over a truck.

This type of concrete guarantee higher durability and sustainability. As the work is carried out by an expert supplier, the mixture formed is precise and of higher quality. Special concrete mixtures too can be made efficiently by this concrete manufacturing method.

CHAPTER-10

Different types of Deterioration in Concrete Structures

Corrosion of Embedded Metals in concrete

When steel corrodes, the resulting rust occupies a greater volume than the steel. This expansion creates tensile stresses in the concrete, which can eventually cause cracking, delamination, and spalling. Steel corrodes because it is not a naturally occurring material. Rather, iron ore is smelted and refined to produce steel. The production steps that transform iron ore into steel add energy to the metal. The corrosion of structural steel is an electrochemical process that requires the simultaneous presence of moisture and oxygen. Essentially, the iron in the steel is oxidised to produce rust, which occupies a greater volume than the steel.

Freeze thaw deterioration in concrete

Freeze-thaw damage is a potentially serious deterioration process that occurs in concrete structures in cold climates. Premature damage to concrete slabs during freezing and thawing cycles represents a major challenge to pavement durability and resilience. When water freezes, it expands about 9%. As the water in moist concrete freezes, it produces pressure in the capillaries and pores of the concrete. If the pressure exceeds the tensile strength of the concrete, the cavity will dilate and rupture. The accumulative effect of successive freeze-thaw cycles and disruption of paste and aggregate can eventually cause significant expansion and cracking, scaling, and crumbling of the concrete Freeze/thaw damage occurs in concrete when the water molecules in concrete freeze and expand beyond the volume constraints of the concrete.

Chemical attack in concrete

Chemical attack is one of the more common causes of deterioration of concrete in industry today. Animal fats, natural and artificial oils, acids, alkalis, and various industrial salts are all damaging to concrete. Chemical attack occurs due to pollution products and following discharge activity on the insulator surface. Examination of field-aged insulators has found formation of uniform thin pollution layers on the surface. A chemical attack involves dissolution of substances or chemical reactions between substances and components of the concrete. Reaction products might cause problems, due to dissolution or expansion.

Alkali-Aggregate Reactivity in concrete

Alkali-aggregate reactions can be either alkali-carbonate reactions (ACRs) or alkali-silica reactions (ASRs). In ACR, the reaction is between the alkalies (sodium and potassium) and certain carbonate rocks, particularly calcitic dolomite and dolomitic limestones, present in some aggregates. It is a deleterious swelling reaction that occurs over time in concrete between the highly alkaline cement paste and the reactive amorphous (i.e., non-crystalline) silica found in many common aggregates, given sufficient moisture. This deleterious chemical reaction causes the expansion of the altered aggregate by the formation of a soluble and viscous gel of sodium silicate. This hygroscopic gel swells and increases in volume when absorbing water: it exerts an expansive pressure inside the siliceous aggregate, causing spalling and loss of strength of the concrete, finally leading to its failure.

Abrasion Erosion in concrete

The abrasion damage caused by the grinding action of silt, sand, and rock. The grinding action will remove the concrete surface and expose the aggregates in some cases. Hydraulic concrete structures frequently experience long-term abrasive erosion by water-borne sand, resulting in surface damage, eventually limiting their service life. Abrasion damage occurs when the surface of concrete is unable to resist wear caused by rubbing and friction. As the outer paste of concrete wears, the fine and coarse aggregate are exposed and abrasion and impact will cause additional degradation that is related to aggregate-to-paste bond strength and hardness of the aggregate

Plastic Shrinkage in concrete

Loss of water from fresh concrete, which leads to plastic shrinkage, can occur in a couple of ways. The predominant mode is, however, through evaporation from an exposed surface. Concrete can also lose water through suction by the subbase or, depending on the type of material used in its manufacture, the formwork. Such loss of water can aggravate the effects of surface evaporation. It is generally accepted that the loss of water from the paste fraction of concrete due to external factors generates negative capillary pressures that cause the volume of the paste to contract, hence the shrinkage. The rate of water evaporation is usually aggravated by a combination of high wind speed, low relative humidity, and high ambient and concrete temperatures.

Drying Shrinkage in concrete

The loss of moisture from concrete after it hardens, and hence drying shrinkage, is inevitable unless the concrete is completely submerged in water or is in an environment with 100 percent relative humidity. Thus, drying shrinkage is a phenomenon that routinely occurs and merits careful consideration in the design and construction of concrete structures. The actual mechanisms by which drying shrinkage occurs are complex, but it is generally agreed upon that they involve the loss of adsorbed water from the hydrated cement paste.When concrete is initially exposed to a drying condition – one in which there is a difference between the relative humidity of the environment and that of the concrete – it first loses free water. In the larger capillary pores this results in little or no shrinkage. In the finer water-filled capillary pores (2.5 to 50 nm size) due to loss of moisture, curved menisci are formed, and the surface tension of water pulls the walls of the pores

The following measures are taken to prevent deterioration of concrete:

1. From the consideration of permeability, the **water-cement ratio** is usually limited to **0.45 to 0.55**.

2. The **cement** content should be such that it ensures sufficient alkalinity to prevent corrosion of reinforcement. For concreting under marine environment, minimum cement content of **350 kg/m** or more is to be used

3. The water-cement ratio and the cement content must provide enough paste to overfill the voids in **compacted concrete**.

4. Use of Portland slag cement or Portland pozzolana cement is advantageous for **concreting in sea water**.

5. Use of Portland cement having **C3A** content less than **5%** is suitable for concreting under sulphate environment.

6. The super-sulphated cement provides acceptable durability against the **acidic environment**.

7. Addition of hydraulic additives is also helpful to prevent the deterioration of concrete.

8. It is possible to attain a marked improvement in the quality of concrete by encouraging natural or artificial carbonation of the surface layer.

9. Deterioration of concrete can also be prevented by treating the concrete with solutions of suitable salts or even acids in minor concentration.

10. The durability of concrete can also be increased by impregnating the pores with a suitable polyme

Corrosion of Steel Reinforcement: Causes, Effects and Remedies

Concrete, in itself, has poor tensile strength. To increase the tensile strength of concrete, steel reinforcement is used. Steel bars are embedded within the concrete mass. These steel bars carry most of the tensile load applied to the concrete.

The concrete renders the steel bars passive due to its highly alkaline nature, thus preventing them from corrosion. Still, due to various other reasons, the steel bars may get corroded over a long period of time. And due to the corrosion of the steel bars, various weaknesses arise in the concrete structure, which may eventually collapse if not taken proper care of within suitable time.

Corrosion of steel reinforcement bars is basically an electrochemical reaction. Small anodes and cathodes are created and a flow of ions between these two electrodes lead to the corrosion of the steel bars

The main factors responsible for corrosion of reinforcement bars are:

1. **Loss of alkalinity due to carbonation** – When the steel surface is left unprotected in the atmosphere, rust begins to form on the steel surface and gradually flakes off.
2. **Loss of alkalinity due to chlorides** – Chloride ions tend to de-passivate the steel surface by destroying the alkalinity of the concrete.
3. **Cracks in concrete** – Cracks may expose the steel bars to the atmosphere and hence increase carbonation.
4. **Moisture pathways** – Regular wetting of the concrete may lead to water reaching the steel reinforcement bars by diffusion through the pore structure of the concrete or cracks present in the concrete. Rusting of the steel bars follow thereafter.

5. **Insufficient Cover:** Insufficient dimension of concrete cover.

Prevention of concrete corrosion

Corrosion of steel reinforcement bars may be prevented or at least delayed by practising good measures. Also, damaged steel bars can be repaired and the concrete structure can be restored properly. Some steps are given below:

1. **Providing Sufficient Concrete Cover:** A good amount of concrete cover should be provided over the steel reinforcement bars. This ensures proper maintenance of the alkaline nature within the concrete and the passivity of the steel bars. The steel bars should be precisely placed in position
2. **Use of Good Quality Concrete:** High quality concrete must be used. It helps to maintain proper alkaline nature. For the concrete, a water/cement ratio of 0.4 or less is to be maintained. Excessive water may damage the steel bars
3. **Proper Compaction fo Concrete:** Concrete must be completely compacted such that there are no air voids or pockets present inside
4. **Use of FBE coated Bars:** Fusion Bonded Epoxy Coating (FBEC) may be applied on the steel bars to prevent them from corrosion. Epoxy powder is spread electrostatically on to the steel bars. The powder melts and flows over the bars upon heating, forming a protective coating. They are thermoset polymer coatings because application of heat will not melt the coating. Apart from rebar it also has wide application in pipeline construction
5. **Use of Cement Based Polymers:** Cement based polymers can be used in the concrete to enhance its protection against corrosion capabilities. The cement based polymers act as a binder in the concrete. They also increase the durability, tensile strength and vibration damping of the concrete
6. **RCPT test to assess degree of Corrosion:** The Rapid Chloride Permeability Test (RCPT) may be performed to assess the degree of corrosion. The quantity of electrical current that passes through a sample 50 mm thick and 100 mm in diameter in 6 hours is measured. Based on this a qualitative rating is made of the permeability of the concrete
7. **Use of Migratory Corrosion Inhibitors:** Migratory corrosion inhibitors may be used in the concrete mix or may be applied on the hardened surface of the concrete. These inhibitors diffuse through the concrete cover and reach the steel bars to protect them against corrosion. Calcium nitrite based inhibitors are quite common

CHAPTER-11

Repair technology for concrete structure

Types of Concrete Defects - Causes, Prevention

Various types of defects which can be observed in hardened concrete surface and their prevention methods are explained below:

1. Cracking

Cracks are formed in concrete due to many reasons but when these cracks are very deep, it is unsafe to use that concrete structure. Various reasons for cracking are improper mix design, insufficient curing, omission of expansion and contraction joints, use of high slump concrete mix, unsuitable sub-grade etc. To prevent cracking, use low water – cement ratio and maximize the coarse aggregate in concrete mix, admixtures containing calcium chloride must be avoided. Surface should be prevented against rapid evaporation of moisture content. Loads must be applied on the concrete surface only after gaining its maximum strength.

Cracking

Fig 1: Cracking

2. Crazing

Crazing also called as pattern cracking or map cracking, is the formation of closely spaced shallow cracks in an uneven manner. Crazing occurs due to rapid hardening of top surface of concrete due to high temperatures or if the mix contains excess water content or due to insufficient curing. Pattern cracking can be avoided by proper curing, by dampening the sub-grade to resist absorption of water from concrete, by providing protection to the surface from rapid temperature changes.

Crazing

Fig 2: Crazing or Pattern Cracking

3. Blistering

Blistering is the formation of hollow bumps of different sizes on concrete surface due to entrapped air under the finished concrete surface. It may cause due to excessive vibration of concrete mix or presence of excess entrapped air in mix or due to improper finishing. Excessive evaporation of water on the top surface of concrete will also cause blistering. It can be prevented by using good proportion of ingredients in concrete mix, by covering the top surface which reduces evaporation and using appropriate techniques for placing and finishing.

Concrete Blisters

Fig 3: Concrete Blisters

4. Delamination

Delamination is also similar to blistering. In this case also, top surface of concrete gets separated from underlying concrete. Hardening of top layer of concrete before the hardening of underlying concrete will lead to delamination. It is because the water and air bleeding from underlying concrete are struck between these two surfaces, hence space will be formed. Like blistering, delamination can also be prevented by using proper finishing techniques. It is better to start the finishing after bleeding process has run its course.

Delamination

Fig 4: Delamination

5. Dusting

Dusting, also called as chalking is the formation of fine and loose powdered concrete on the hardened concrete by disintegration. This happens due to the presence of excess amount of water in concrete. It causes bleeding of water from concrete, with this fine particles like cement or sand will rise to the top and consequent wear causes dust at the top surface. To avoid dusting, use low slump concrete mix to obtain hard concrete surface with good wear resistance. Use water reducing admixtures to obtain adequate slump. It is also recommended to use better finishing techniques and finishing should be started after removing the bleed water from concrete surface.

Dusting

Fig 5: Dusting

6. Curling

When a concrete slab is distorted into curved shape by upward or downward movement of edges or corners, it is called curling. It occurs mainly due to the differences in moisture content or temperature between slab surface (top) and slab base (bottom). Curling of concrete slab may be upward curling or downward curling. When the top surface is dried and cooled before bottom surface, it begins to shrink and upward curling takes place. When bottom surface is dried and cooled due to high temperature and high moisture content, it will shrink before top surface and downward curling occurs. To prevent curling, use low shrink concrete mix, provide control joints, provide heavy reinforcement at edges or provide edges with great thickness.

Curling

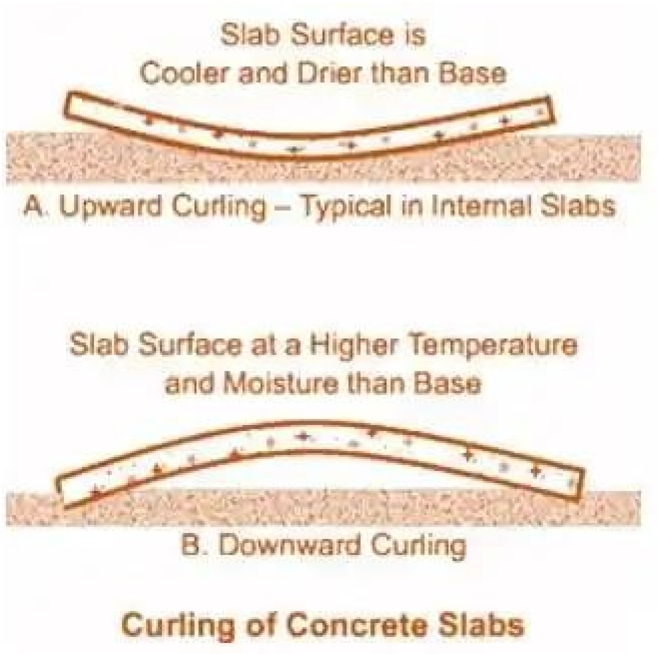


Fig 6: Curling of Concrete Slab

7. Efflorescence

Efflorescence is the formation of deposits of salts on the concrete surface. Formed salts generally white in color. It is due to the presence of soluble salts in the water which is used in making concrete mix. When concrete is hardening, these soluble salts gets lifted to the top surface by hydro static pressure and after complete drying salt deposits are formed on the surface. It can be prevented by using clean and pure water for mixing, using chemically ineffective aggregates etc. And make sure that cement should not contain alkalis more than 1% of its weight.

Efflorescence

Fig 7: Efflorescence

Injection materials

The selection of the appropriate injection material is the first key factor for a successful cracking repair. The main materials requirements are the strong adhesion to the concrete, low viscosity, flexibility and mechanical resistance suitable to structural or non-structural repairing, capacity of deformation after hardening, volumetric shrinkage control and chemical stability of the components mix that compose the product of injection .

Crack width is a crucial characteristic for injection material choice. Generally, lower width cracks require an injection material with lower viscosity so they can enter in the void easily and with lower injection pressure.

Cracks activity also has a huge influence in the material choice. In the case of passive/dead cracks with small dimension, the best solution is the injection of rigid materials. In active cracks it is necessary to apply a flexible material, with capacity of deformation after hardening [16].

The water presence will also affect the use of materials due to the chemical reactions (expansive) of certain materials with the water molecules and to the materials adhesion (or the lack of it) with the concrete in case of moist cracks.

Resins

Resins are the most used materials in injection systems. Epoxy resins have high compressive and tensile strength comparing with concrete and, as a rigid material, they are used in structural repairs ensuring the efficient transfer of strengths and recovering the structure rigidity conditions , due to the strong adhesion between epoxy resins and concrete. The main injection epoxy products properties are the hardening without shrinkage, the low viscosity, the applicability at low temperature and the fact that they guarantee a barrier against water infiltration and corrosive elements entering . On the negative side, regular epoxy resins are too sensitive to water/moisture presence and water affects also the adhesion between epoxy and concrete, can reduce their strength, and also the bad performance of these products at high temperature.

Polyurethane resins are flexible and guarantee a strong adhesion with the concrete in wet or dry cracks. Within each polyurethane resins products, one can distinguish (i) polyurethane foams and (ii) polyurethane gel. These two types of products have different characteristics and, consequently, different functions, but, in general, these solutions are used in conjunction, complement each other and make the best use possible of the properties of each one [15]. Polyurethane foams expand in contact with water, being used in areas with water flow to staunch temporary the water entering. Its expansive speedily reaction in contact with water form a flexible and elastic foam .

For a permanent waterproofing, the cracks with polyurethane foam could be reinjected with not expansive resins like (i) polyurethane gel resins, that are flexible, with a high chemical resistance, recommendable to fill cracks permanently with variable opening over time, adapting to movements, with minimum width of approximately 0.2 mm or (ii) acrylic gel resins, a very elastic material with an extremely reduced viscosity (similar to water), having ideal properties to penetrate structures voids, they can be injected in cracks thinner than 0.05 mm. Acrylic resins application is common in the use of injection curtains technics as a repair solution to other waterproofing systems or as preventive waterproofing in retaining walls in underground structures.

Microcement grouts

Microcement grouts are not flexible and, consequently, they do not adjust to structures movements. These materials can be used in injection works to repair structural cracks (wider than 0.5 mm), but are usually used in structural joints treatment. Therefore, microcements are not products with a high demand for common cracks injections, because their penetrability and mechanical characteristics are lower than those of epoxy resin products.

Injection equipment

The appropriate selection of injection equipment is the second key factor for the injection systems success . The pumps and packers depend on the injections materials, the injection pressure and the concrete quality in the cracks surround.

Injection pumps

There are two injection pumps technologies: (i) Single-component and (ii) bi-component. Singlecomponents pumps can be manual, pneumatic (compressed air) or electrical. In this type of pumps, the product composed by two components (resin + hardener) is mixed beforehand, being deposited into a container. The product work time begins after components are mixed, and that it is necessary to implement the complete volume mix inside the indicated pot life in the Product Technical Data Sheet. Bi-component pumps are usually pneumatic (delivery of compressed air) and have two storage containers, each one being filled with a part of product (usually part "A", mix of pre-dosed liquid resin and hardener and part "B" with a mix of an accelerator and water). The two components product mix is only made in the injection moment, in the pump head, when components are pumped, and products pot life begins counting when two parts are mixed.

3.2.2 Injection packers

Two types of injection packers can also be distinguished: (i) surface packers and (ii) mechanical packers. Surface packers (Fig. 1) are plastic or metal filling valves that are installed above the cracks, at structures surface. These packers are commonly used epoxy resins injections when a structural reinforcement is necessary [7] and in cases where it is not recommended to drill the concrete [15]. There are also simple cylindrical packers, similar to surface packers but without the circular injector basis and that are placed manually inside the crack.

References: book **Concrete Technology (M.L Gambhir)**

M.S Setty (Concrete technology)