GOVERNMENT POLYTECHNIC

BHUBANESWAR-23

DEPARTMENT OF CIVIL ENGINEERING

LECTURE NOTES

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Subject code/Name -Th-4, Concrete Technology

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Chapter-1

1.0: Concrete as a construction material

Components of Concrete

Components of concrete are cement, sand, aggregates and water. Mixture of Portland cement and water is called as paste. So, concrete can be called as a mixture of paste, sand and aggregates. Sometimes rocks are used instead of aggregates.

The cement paste coats the surface of the fine and coarse aggregates when mixed thoroughly and binds them. Soon after mixing the components, hydration reaction starts which provides strength and a rock solid concrete is obtained.

Grade of Concrete

Grade of concrete denotes its strength required for construction. For example, M30 grade signifies that compressive strength required for construction is 30MPa. The first letter in grade "M" is the mix and 30 is the required strength in MPa.

Based on various lab tests, grade of concrete is presented in Mix Proportions. For example, for M30 grade, the mix proportion can be 1:1:2, where 1 is the ratio of cement, 1 is the ratio of sand and 2 is the ratio of coarse aggregate based on volume or weight of materials.

The strength is measured with concrete cube or cylinders by civil engineers at construction site. Cube or cylinders are made during casting of structural member and after hardening it is cured for 28 days. Then compressive strength test is conducted to find the strength.

Regular grades of concrete are M15, M20, M25 etc. For plain cement concrete works, generally M15 is used. For reinforced concrete construction minimum M20 grade of concrete are used.

Concrete Grade	**Mix Ratio**	**Compressive Strength**	
		MPa (N/mm^2)	**psi**
Normal Grade of Concrete			
M5	1 : 5 : 10	5 MPa	725 psi
M7.5	1 : 4 : 8	7.5 MPa	1087 psi
M10	1 : 3 : 6	10 MPa	1450 psi
M15	1 : 2 : 4	15 MPa	2175 psi

M20	1 : 1.5 : 3	20 MPa	2900 psi
Standard Grade of Concrete			
M25	1 : 1 : 2	25 MPa	3625 psi
M30	Design Mix	30 MPa	4350 psi
M35	Design Mix	35 MPa	5075 psi

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M15	1 : 2 : 4	15 MPa	2175 psi
M20	1 : 1.5 : 3	20 MPa	2900 psi
Standard Grade of Concrete			
M25	1 : 1 : 2	25 MPa	3625 psi
M30	Design Mix	30 MPa	4350 psi
M35	Design Mix	35 MPa	5075 psi
M40	Design Mix	40 MPa	5800 psi
M45	Design Mix	45 MPa	6525 psi
High Strength Concrete Grades			
M50	Design Mix	50 MPa	7250 psi
M55	Design Mix	55 MPa	7975 psi
M60	Design Mix	60 MPa	8700 psi
M65	Design Mix	65 MPa	9425 psi
M70	Design Mix	70 MPa	10150 psi

Advantages of concrete

The following are the advantages of concrete :

1. Availability of concrete ingredients easily.
2. Easy handling and moulding of concrete into any shape.
3. Easy transportation from the place of mixing to place of casting before initial set takes place.
4. Ability to pump/spray to fill into cracks and lining of tunnels.
5. When reinforced, all types of the structures are made possible from an ordinary lintel to massive fly overs.
6. Monolithic character gives better appearance and much I rigidity to the structure.
7. The property of concrete to possess high compressive strength, makes a concrete structure more economical than that of steel structure.

Disadvantages of Concrete

The following are the disadvantages of concrete:

1. Due to low tensile strength, concrete is required to be reinforced to avoid cracks.
2. In long structures expansion joints are required to be provided if there is large temperature variance in the area.
3. Construction joints are provided to avoid cracks due to drying shrinkage and moisture-expansion.
4. Soluble salts in concrete cause efflorescence if moisture reacts with them.
5. Concrete made with ordinary Portland cement, gets integrated in the presence of alkalies, sulfates etc.
6. Sustained loads develop creep in structures.

Chapter-2

2.0: CEMENT

Portland Cement

Concrete is made by portland cement, water and aggregates. Portland cement is a hydraulic cement that hardens in water to form a water-resistant compound. The hydration products act as binder to hold the aggregates together to form concrete. The name Portland cement comes from the fact that the colour and quality of the resulting concrete are similar to Portland stone, a kind of limestone found in England.

Manufacture of Portland cement

Portland cement is made by blending the appropriate mixture of limestone and clay or shale together and by heating them at 1450^0 c in a rotary kiln. The sequence of operations is shown in following figure. The preliminary steps are a variety of blending and crushing operations. The raw feed must have a uniform composition and be a size fine enough so that reactions among the components can complete in the kiln. Subsequently, the burned clinker is ground with gypsum to form the familiar grey powder known as Portland cement.

The raw materials used for manufacturing Portland cement are limestone, clay and Iron ore. a) Limestone ($CaCO_3$) is mainly providing calcium in the form of calcium oxide (CaO)

$$CaCo_3(1000^0c) \rightarrow CaO + Co_2$$

b) Clay is mainly providing silicates (SiO_2) together with small amounts of Al_2O_3 +Fe_2O_3

$$\text{Clay } (1450^0C) \rightarrow SiO_2 + Al_2O_3 + Fe_2O_3 + H_2O$$

c) Iron ore and Bauxite are providing additional aluminium and iron oxide (Fe2O3) which help the formation of calcium silicates at low temperature. They are incorporated into the raw mix.

d) The clinker is pulverized to small sizes (< 75 µm). 3-5% of gypsum (calcium sulphate) is added to control setting and hardening.

The majority particle size of cement is from 2 to 50 µm. A plot of typical particle size distribution is given below. (Note: "Blaine" refers to a test to measure particle size in terms of surface area/mass)

Chemical composition

a) Abbreviation:

$CaO = C$, $SiO_2 = S$, $Al_2O_3 = A$; $Fe_2O_3 = F$, $Ca(OH)_2 = CH$,

$H_2O = H$, SO_3 = (sulphur trioxide) S

Thus we can write 3 CaO = C_3 and 2 $CaO^0SiO_2 = C_2S$.

b) Major compounds:

Compound	Oxide composition	colour	Common name	Weight percentage
Tricalcium Silicate	C3S	white	Alite	50%
Dicalcium Silicate	C2S	white	Belite	25%
Tricalcium Aluminate	C3A	white/grey	---	12%
Tetracalcium Aluminoferrite	C4AF	black	Ferrite	8%

Since the primary constituents of Portland cement are calcium silicate, we can define Portland cement as a material which combine CaO SiO_2 in such a proportion that the resulting calcium silicate will react with water at room temperature and under normal pressure.

c) Minor components of Portland cement

The most important minor components are gypsum, MgO, and alkali sulphates. Gypsum ($2CaSO_4{}^0 2H_2O$) is an important component added to avoid flash set. Alkalies (MgO, Na_2O, K_2O) can increase pH value up to 13.5 which is good for reinforcing steel protection. However, for some aggregates, such a high alkaline environment can cause alkali aggregate reaction problem.

Hydration

The setting and hardening of concrete are the result of chemical and physical processes that take place between Portland cement and water, i.e. hydration. To understand the properties and behaviour of cement and concrete some knowledge of the chemistry of hydration is necessary.

A) Hydration reactions of pure cement compounds

The chemical reactions describing the hydration of the cement are complex. One approach is to study the hydration of the individual compounds separately. This assumes that the hydration of each compound takes place independently of the others.

I. Calcium silicates

Hydration of the two calcium silicates gives similar chemical products, differing only in the amount of calcium hydroxide formed, the heat released, and reaction rate.

$2\,C_3S + 7\,H \rightarrow C_3S_2H_4 + 3\,CH$ $2\,C_2S + 5\,H \rightarrow C_3S_2H_4 + CH$

The principal hydration product is $C_3S_2H_4$, calcium silicate hydrate, or C-S-H (non-stoichiometric). This product is not a well-defined compound. The formula $C_3S_2H_4$ is only an approximate description. It has amorphous structure making up of poorly organized layers and is called glue gel binder. C-S-H is believed to be the material governing concrete strength. Another product is CH - $Ca(OH)_2$, calcium hydroxide. This product is a hexagonal crystal often forming stacks of plates. CH can bring the pH value to over 12 and it is good for corrosion protection of steel.

II. Tricalcium aluminate

Without gypsum, C3A reacts very rapidly with water:

$$C_3A + 6\ H \rightarrow C_3AH_6$$

The reaction is so fast that it results in flash set, which is the immediate stiffening after mixing, making proper placing, compacting and finishing impossible.

With gypsum, the primary initial reaction of C_3A with water is :

$$C_3A + 3\ (C\ S\ H_2) + 26\ H \rightarrow C_6A\ S_3H_{32}$$

The 6-calcium aluminate trisulfate-32-hydrate is usually called ettringite. The formation of ettringite slows down the hydration of C_3A by creating a diffusion barrier around C_3A. Flash set is thus avoided. Even with gypsum, the formation of ettringite occurs faster than the hydration of the calcium silicates. It therefore contributes to the initial stiffening, setting and early strength development. In normal cement mixes, the ettringite is not stable and will further react to form monosulphate ($C_4A\ S\ H_{18}$).

B) Kinetics and Reactivities

The rate of hydration during the first few days is in the order of $C_3A > C_3S > C_3AF > C_2S$.

Their reactivities can be observed in the following figures.

C) Calorimetric curve of Portland cement

A typical calorimetric curve of Portland cement is shown in the following figure. The second heat peaks of both C_3S and C_3A can generally be distinguished, although their order of occurrence can be reversed.

From the figure, five stages can be easily identified. Since C_3S is a dominating component in cement, the five stages above can be explained using the reaction process of C_3S by the following table.

On first contact with water, calcium ions and hydroxide ions are rapidly released from the surface of each C_3S grain; the pH values rises to over 12 within a few minutes. This hydrolysis slows down quickly but continues throughout the induction period. The induction (dormant) period is caused by the need to achieve a certain concentration of ions in solution before crystal nuclei are formed for the hydration products to grow from. At the end of dormant period, CH starts to crystallize from solution with the concomitant formation of C-S-H and the reaction of C_3S again proceeds rapidly (the third stage begin). CH crystallizes from solution, while C-S-H develops from the surface of C_3S and forms a coating covering the grain. As hydration continues, the thickness of the hydrate layer increases and forms a barrier through which water must flow to reach the unhydrated C_3S and through which ions must diffuse to reach the growing crystals. Eventually, movement through the C-S-H layer determines the rate of reaction. The process becomes diffusion controlled.

D) Setting and Hydration

Initial set of cement corresponds closely to the end of the induction period, 2-4 hours after mixing. Initial set indicates the beginning of forming of gel or beginning of solidification. It represents approximately the time at which fresh concrete can no longer be properly mixed, placed or compacted. The final set occurs 5-10 hours after mixing, within the acceleration period. It represents approximately the time after which strength develops at a significant rate.

In practice, initial and final set are determined in a rather arbitrary manner with the penetration test. While the determination of initial and the final set has engineering significance, there is no fundamental change in hydration process for these two different set conditions.

Types of Portland cements

According to ASTM standard, there are five basic types of Portland cement.

Type I Regular cement, general use, called OPC

Type II Moderate sulphate resistance, moderate heat of hydration, $C_3A < 7\%$

Type III With increased amount of C_3S, High early strength

Type IV Low heat

Type V High sulphate resistance (Note: sulphates can react with $C_4A\ S\ H_{18}$ to from an expansive product. By reducing the C_3A content, there will be less $C_4A\ S\ H_{18}$ formed in the hardened paste)

Their typical chemical composition is given in the following table:

From the above table, we can evaluate the behaviour of each type of cement and provide the standard in selecting different cement types. The following figures show the strength and temperature rise for the different types of cement.

These graphs provide the basic justification in selecting the cement for engineering application. For instance, for massive concrete structure, hydration heat is an important consideration because excessive temperature increase (to above 50-60^{0}C) will cause expansion and cracking. Hence, type IV cement should be the first candidate and Type III should not be used. For a foundation exposed to groundwater with high concentration of sulphates, high sulphate resistance is needed. Thus, type V should be selected. If high early strength is needed, type III will be the best choice. But, generally, type I is the most popular cement used for civil engineering.

Porosity of hardened cement paste and the role of water

Knowledge of porosity is very useful since porosity has a strong influence on strength and durability. In hardened cement paste, there are several types of porosity, trapped or entrained air (0.1 to several mm in size), capillary pores (0.01 to a few microns) existing in the space between hydration products, and gel pores (several nanometres or below) within the layered structure of the C-S-H. The capillary pores have a large effect on the strength and permeability of the hardened paste itself. Of course, the presence of air bubbles can also affect strength.

From experiments, the porosity within the gel for all normally hydrated cements is the same, with a value of 0.26. The total volume of hydration products (cement gel) is given by

$$Vg = 0.68\alpha \text{ cm}^3\text{/g of original cement}$$

Where, α represents the degree of hydration.

The capillary porosity can be calculated by

$$Pc = (w/c) - 0.36\alpha \text{ cm}^3\text{/g of original cement}$$

Where, w is the original weight of water and c is the weight of cement and w/c is the water-cement ratio. It can be seen that with increase of w/c, the capillary pores increase.

The gel / space ratio (X) is defined as

$$X = \frac{\text{volume of gel (including gel pores)}}{\text{of gel + volume of capillary pores}}$$

$$= \frac{0.68\alpha}{0.32\alpha + w/c}$$

The minimum w/c ratio for complete hydration is usually assumed to be 0.36 to 0.42. It should be indicated that complete hydration is not essential to attain a high ultimate strength. For pastes of low w/c ratio, residual unhydrated cement will remain.

To satisfy workability requirements, the water added in the mix is usually more than that needed for the chemical reaction. Part of the water is used up in the chemical reaction. The remaining is either held by the C -S-H gel or stored in the capillary pore. Most capillary water is free water (far away from the pore surface). On drying, they will be removed, but the loss of free water has little effect on concrete. Loss of adsorbed water on surfaces and those in the gel will, however, lead to shrinkage. Movement of adsorbed and gel water under load is a cause of creeping in concrete

Basic tests of Portland cement

a) Fineness (= surface area / weight): This test determines the average size of cement grains. The typical value of fineness is 350 m2 / kg. Fineness controls the rate and completeness of hydration. The finer a cement, the more rapidly it reacts, the higher the rate of heat evolution and the higher the early strength. I III V Fineness (m2 / kg) 350 450 350 f'c 1-day (MPa) 6.9 13.8 6.2

b) Normal consistency test: This test is to determine the water required to achieve a desired plasticity state (called normal consistency) of cement paste. It is obtained with the Vicat apparatus by measuring the penetration of a loaded needle.

c) Time of setting: This test is to determine the time required for cement paste to harden. Initial set cannot be too early due to the requirement of mixing,

conveying, placing and casting. Final set cannot be too late owing to the requirement of strength development. Time of setting is measured by Vicat apparatus. Initial setting time is defined as the time at which the needle penetrates 25 mm into cement paste. Final setting time is the time at which the needle does not sink visibly into the cement paste.

d) Soundness: Unsoundness in cement paste refers to excessive volume change after setting. Unsoundness in cement is caused by the slow hydration of MgO or free lime. Their reactions are $MgO + H2O = Mg(OH)2$ and $CaO + H2O = Ca(OH)2$. Another factor that can cause unsoundness is the delayed formation of ettringite after cement and concrete have hardened. The pressure from crystal growth will lead to cracking and damage. The soundness of the cement must be tested by accelerated methods. An example is the Le Chatelier test (BS 4550). This test is to measure the potential for volumetric change of cement paste. Another method is called Autoclave Expansion test (ASTM C151) which use an autoclave to increase the temperature to accelerate the process.

e) Strength: The strength of cement is measured on mortar specimens made of cement and standard sand (silica). Compression test is carried out on a 2" cube with S/C ratio of 2.75:1 and w/c ratio of 0.485 for Portland cements. The specimens are tested wet, using a loading rate at which the specimen will fail in 20 to 80 s. The direct tensile test is carried out on a specimen shaped like a dumbbell. The load is applied through specifically designed grips. Flexural strength is measured on a 40 x 40 x 160 mm prism beam test under a centre-point bending.

f) Heat of hydration test: (BS 4550: Part 3: Section 3.8 and ASTM C186). Cement hydration is a heat releasing process. The heat of hydration is usually defined as the amount of heat evolved during the setting and hardening at a given temperature measured in J/g. The experiment is called heat of solution method. Basically, the heat of solution of dry cement is compared to the heats of solution of separate portion of the cement that have been partially hydrated for 7 and 28 days. The heat of hydration is then the difference between the heats of solution of dry and partially hydrated cements for the appropriate hydration period. This test is usually done on Type II and IV cements only, because they are used when heat of hydration is an important concern. Excessive heating may lead to cracking in massive concrete construction.

g) Other experiments: Including sulphate expansion and air content of mortar.

h) Cement S. G and U. W.: The S.G. for most types of cements is 3.15, and UW is 1000-1600 kg/m^3.

Chapter-3

Aggregates

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stonelike 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. The most popular use of aggregates is to form Portland cement concrete. Approximately three-fourths of the volume of Portland cement concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should have an important effect on the properties of both the fresh and hardened products. As another important application, aggregates are used in asphalt cement concrete in which they occupy 90% or more of the total volume. Once again, aggregates can largely influence the composite properties due to its large volume fraction.

Classification of Aggregate

Aggregates can be divided into several categories according to different criteria.

a) In accordance with size:

Coarse aggregate: Aggregates predominately retained on the No. 4 (4.75 mm) sieve. For mass concrete, the maximum size can be as large as 150 mm.

Fine aggregate (sand): Aggregates passing No.4 (4.75 mm) sieve and predominately retained on the No. 200 (75 μm) sieve.

b) In accordance with sources:

Natural aggregates: This kind of aggregate is taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Some examples in this category are sand, crushed limestone, and gravel.

Manufactured (synthetic) aggregates: This is a kind of man-made materials produced as a main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregate (e.g. expanded perlite), and heavy weight aggregates (e.g. iron ore or crushed steel).

c) In accordance with unit weight:

Light weight aggregate: The unit weight of aggregate is less than 1120kg/m3. The corresponding concrete has a bulk density less than 1800kg/m3. (cinder, blast-furnace slag, volcanic pumice).

Normal weight aggregate: The aggregate has unit weight of 1520-1680kg/m3. The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m3.

Heavy weight aggregate: The unit weight is greater than 2100 kg/m3. The bulk density of the corresponding concrete is greater than 3200 kg/m3. A typical example is magnesite limonite, a heavy iron ore. Heavy weight concrete is used in special structures such as radiation shields.

d)In accordance with origin:

Igneous rock Aggregate:

- Hard, tough and dense.
- Massive structures: crystalline, glassy or both depending on the rate at which they are cooled during formation.
- Acidic or basic: percentage of silica content.
- Light or dark coloured.
- Chemically active: react with alkalis.

Sedimentary rock Aggregates:

- Igneous or metamorphic rocks subjected to weathering agencies.
- Decompose, fragmentise, transport and deposit deep beneath ocean bed are cemented together.
- Can be flaky.
- Range from soft-hard, porous-dense, light-heavy.
- Suitability decided by: degree of consolidation, type of cementation, thickness of layer and contamination.

Metamorphic rock Aggregate:

- Rocks subjected to high temperature and pressure.
- Economic factor into consideration.
- Least overall expense.

e) Particle shape:

• Rounded Aggregate: Good workability, low water demand, poor bond

• Angular Aggregate: Increased water demand, good bond

• Flaky Aggregate: Aggregate stacks give workability problems

• Elongated Aggregate: May lack cohesion and require increased fines

• Irregular Aggregate: Fair workability, low water demand. Irregular shape with rounded edges.

• Angularity number (IS:2386-Part 1-1963): The concept of angularity number was suggested by Shergold. It gives a qualitative representation of shape of aggregate. In angularity number test, a quantity of single sized aggregate is filled into metal cylinder of 3 litres capacity. Then the aggregate is compacted in a standard manner and the percentage of void found out. If the void content of the aggregate is 33% the angularity of such aggregate is considered 0. If the void is 44%, the angularity number of such aggregate is considered 11.

• Importance of Angularity Number:

- The normal aggregate which are suitable for making concrete may have angularity number anything from 0 to 11.
- Angularity number 0 represents the most practicable rounded aggregate
- Angularity number 11 indicates the most angular aggregate that could be used for making concrete.

• Angularity Index:

- Suggested by Murdock for expressing shape of aggregate.
- Angularity index = fA = + 1.0 Where, fH is the angularity number.

f) Texture:

- It depends on hardness, grain size, pore structure, structure of the rock and degree to which forces acting on the particle surface have smoothened or roughened it. As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume.

Strength of Aggregates

• When the cement paste is of good quality & its bond with the aggregate is satisfactory, then the mechanical properties of rock or aggregate will influence the strength of concrete. • The test for strength of aggregate is required to be made in the following situations: i. For production of high strength & ultra -high strength concrete. ii. When contemplating to use aggregates manufacture from weathered rocks. iii. Aggregates manufactured by industrial process.

Deletrious Substance in Aggregate

1. Organic Impurities

- Organic impurities interfere with the hydration reaction.
- Frequently, it is found in sand and consists of products of decay of vegetable matter.
- Organic matter may be removed from sand by washing.
- Colorimetric test recommended by ASTM C 40-92 can be used to determine aggregate organic content.
- The colorimetric test does not show the adverse effect of the organic impurity since high organic content does not necessarily mean that the aggregate is not fit for use in concrete.
- For this reason, strength test on mortar with questionable sand as per ASTM C 87-90 is recommended.
- This strength has to be compared with the strength of mortar with washed sand

2. Clay

- Clay may coat the surface of aggregates which impair bond strength between aggregate and cement paste. Consequently, it adversely affecting the strength and durability of concrete
- it is necessary to control the amount of clay in aggregate
- Since no test is available to determine separately the clay content, the limits of fine materials are prescribed in terms of the percentage of material passing sieve No. 200.

3. Silt and crusher dust

- Silt and dust, owing to their fineness, increase the surface area and therefore increase the amount of water necessary to wet all the particles in the mix.
- Impair wear resistance
- Reduce durability
- They may result popouts
- It is necessary to control the amount of silt and fine dust in aggregate.
- Since no test is available to determine separately the silt and dust, the limits of fine materials are prescribed in terms of the percentage of material passing sieve No. 200

4. Salts

- Salts are present in certain types of aggregates such as Sand from seashore, sand and Coarse aggregate dredged from the sea or a river estuary, and desert sand.
- Salts coming through aggregates cause reinforcement corrosion and also absorb moisture from the air and cause efflorescence.
- The BS 882:1992 limits on the chloride ion content of aggregate by mass, expressed as a percentage of the mass of total aggregate.

5. Unsound Particles

- Two major classes of unsound particles are materials fail to maintain their integrity, and substances lead to disruptive expansion on freezing or even on exposure to water.

- Shale, particles with low density, clay lumps, wood, coal, mica, gypsum, and iron pyrites are examples of unsound particles.
- Unsound particles if present in large quantities (over 2 to 5% of the mass of the aggregate) may adversely affect the strength of concrete.
- These materials should not be allowed in concrete which is exposed to abrasion.
- Mica is very effective in reducing strength (15% reduction in 28-d f'c with 5% mica).
- Gypsum and iron pyrites are mainly responsible for expansion of concrete

6. Alkali- Aggregate Reactions

- Reaction between alkali from cement and silica or carbonate from aggregate is called "alkali- aggregate reaction".
- The most common reaction is that between the active silica constituents of the aggregate and that alkalis in cement, called as "alkali-silica reaction"
- Another type of the alkali-aggregate reaction is that between dolomitic limestone aggregates, containing carbonate, and alkalis in cement, called as "alkali-carbonate reaction".
- Both types of the reactions cause deterioration of concrete, mainly cracking.
- The reactive forms of silica opal (amorphous, i.e. shapeless), Chalcedony (cryptocrystalline fibrous), and tridymite (crystalline).
- The gel formation on the surface of aggregate particles destroys the bond between the aggregate and cement paste.
- The swelling nature of the gel exerts internal pressure and eventually lead to expansion, cracking and disruption of the hydrated cement paste.
- In case of alkali-carbonate reaction also, gel is formed, which upon swelling cause expansion of concrete.
- Gel is formed around the active aggregate particles, causing cracking within rims and leads to a network of cracks and loss of bond between the aggregate and the cement paste.

FINENESS MODULUS OF AGGREGATE

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 of Sand

DETERMINATION 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.
- Fineness modulus of different type of sand is as per given below.

Type of Sand	Fineness Modulus Range
Fine Sand	2.2 – 2.6
Medium Sand	2.6 – 2.9
Coarse Sand	2.9 – 3.2

- Generally sand having fineness modulus more than 3.2 is not used for making good concrete.
- Fineness modulus can also be used to combine two aggregate to get the desirable grading.

HOW TO DETERMINE FINENESS MODULUS?

Following procedure is adopted to calculate fineness modulus of aggregate.

PROCEDURE

- Sieve the aggregate using the appropriate sieves (80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron & 150 micron)
- Record the weight of aggregate retained on each sieve.
- Calculate the cumulative weight of aggregate retained on each sieve.
- Calculate the cumulative percentage of aggregate retained.
- Add the cumulative weight of aggregate retained and divide the sum by 100. This value is termed as fineness modulus

Grading of Aggregates:

The grading should be such that it could give a reasonable workability with minimum segregation. Segregation is very important in the production of good concrete. A workable mixture which could produce a strong and economical concrete will result in honey combed, weak, undurable and variable end product if segregation takes place.

The process of calculation of the proportions of aggregates of different sizes to achieve the desired grading comes within the scope of mix design. Here properties of some good grading curves have been discussed. Usually aggregate available locally or within an economic distance has to be used.

Grading of Fine and Coarse Aggregates:

For all important works coarse and fine aggregates are batched separately, hence their grading should be known and controlled.The grading curve of any fine aggregate falling wholly within the limits of any one zone is considered suitable.

A tolerance of total amount of 5% on certain sieves is permitted, but the aggregate should not be finer than the exact limits of the finest grading or coarser than the coarset grading. In case of crushed stone 20% is allowed to pass the 150 micron test sieve in all zones.

Sand (fine aggregate) falling into any zone can be generally used in concrete, although under some circumstances the suitability of a given sand may depend on the grading and shape of the coarse aggregate.

The suitability of the fine sand of zone 4 for use in reinforced concrete should be tested. For sands, the sand content of the mix should be low whose greater part is smaller than 60C micron. In general, finer the grading of the fine aggregate, higher should be the coarse/fine aggregate ratio. Typical values are shown in Table 4.23.

Table 4.23. Ratio of fine and coarse aggregate

S. No.	*Maximum size of coarse aggregate in mm*	*Coarse/fine aggregate ratio for sand of zone*			
		1	2	3	4
1.	10.0	1 : 1	1 : 1.5	1 : 2	1 : 3.0
2.	19.0	1 : 1.5	1 : 2	1 : 3	1 : 3.5
3.	38.0	1 : 2	1 : 3	1 : 3.5	—

On the other hand the coarse sand of zone I produces a harsh mix and a high content of sand may be necessary for higher workability. This sand is more suitable for rich mixes or for use in concrete of low workability.

Zone II represents medium sand, generally suitable for the standard 1:2 fine to coarse mix, when the maximum size of coarse aggregate is 20 mm. The choice of correct proportion is particularly important as the grading of the sand approaches the fine outer limit of zone 4 or the coarse outer limit of zone I. It is worth noting that if proportioned correctly, fine sand can be utilized with success and its use is economical as it is available locally in desired quantity.

Chapter-4

WATER

Quality of water for mixing and curing

Generally, quality of water for construction works are same as drinking water. This is to ensure that the water is reasonably free from such impurities as suspended solids, organic matter and dissolved salts, which may adversely affect the properties of the concrete, especially the setting, hardening, strength, durability, pit value, etc.

The water shall be clean and shall not contain sugar, molasses or gur or their derivatives, or sewage, oils, organic substances.

If the quality of water to be used for mixing is in doubt, cubes of 75 mm in cement mortar 1:3 mix with distilled water and with the water in question shall be made separately. The latter type of cubes should attain 90% of the 7 days' strength obtained in cubes with same quantity of distilled water.

Alternatively, the water shall be tested in an approved Laboratory for its use in preparing concrete / mortar.

The water quality for construction shall be tested or monitored regularly, as it affects the overall strength of concrete. For plain and reinforced cement concrete permissible limits for solids shall be as follows:

Type of Solid in water	**Permissible Limits for Construction**
Organic matter	200 mg/l
Inorganic matter	3000 mg/l
Sulphates (SO4)	500 mg/l
Chlorides (Cl)	a) 1000 mg/l for RCC work and, b) 2000 mg/l for PCC work
Suspended matter	2000 mg/l

Limits of Alkalinity:

To neutralize 200 ml of sample should not require more than 10 ml of 0.1 normal HCI using methyl orange as an indicator.

Limits of Acidity:

To neutralize 200 ml sample of water should not require more than 2 m of 0.1 normal NaOH (Caustic soda). The pH value of water shall generally be not less than 6.

Chapter-5

Admixtures

Functions of Admixture

As explained above, admixtures are added to modify concrete properties. Major functions and advantages of using admixtures are detailed below.

- To improve workability of fresh concrete
- To improve durability by entrainment of air
- To reduce the water required
- To accelerate setting & hardening & thus to produce high early strength
- To aid curing
- To impart water repellent / water proofing property
- To cause dispersion of the cement particles when mixed with water
- To retard setting
- To improve wear resistance (hardness)
- To offset / reduce shrinkage during setting & hardening
- To cause expansion of concrete and automatic prestressing of steel
- To aerate mortar / concrete to produce a light-weight product
- To impart colour to concrete
- To offset or reduce some chemical reaction
- To reduce bleeding
- To reduce the evolution of heat

Admixtures are those ingredients in concrete other than portland cement, water, and aggregates that are added to the mixture immediately before or during mixing.

Admixtures can be classified by function as follows:

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers

9. Alkali-silica reactivity inhibitors

10. Colouring admixtures

11. Miscellaneous admixtures such as workability, bonding, dampproofing, permeability reducing, grouting, gas forming, anti-washout, foaming, and pumping admixtures.

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.

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.

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.

Air-entraining admixtures Air-entraining admixtures cause small stable bubbles of air to form uniformly through a concrete mix. The bubbles are mostly below 1 mm diameter with a high proportion below 0.3 mm. The benefits of entraining air in the concrete include increased resistance to freeze-thaw degradation, increased cohesion (resulting in less bleed and segregation) and improved compaction in low-workability mixes.

Concrete should be workable, finishable, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by resorting to admixtures (except air-entraining admixtures when needed).

The major reasons for using admixtures

1. To reduce the cost of concrete construction

2. To achieve certain properties in concrete more effectively than by other means

3. To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions

4. To overcome certain emergencies during concreting operations

Chapter-6

Properties of fresh concrete

There are two sets of criteria that we must consider when making concrete;

1) Long-term requirements of hardened concrete, such as, strength, durability, and volume stability,

2) Short-term requirements, like workability. However, these two requirements are not necessarily complementary.

For fresh concrete to be acceptable, it should:

1. Be easily mixed and transported.

2. Be uniform throughout a given batch and between batches.

3. Be of a consistency so that it can fill completely the forms for which it was designed.

4. Have the ability to be compacted without excessive loss of energy.

5. Not segregate during placing and consolidation.

6. Have good finishing characteristics.

Workability

All the characteristics above describe many different aspects of concrete behavior. The term workability is used to represent all the qualities mentioned. Workability is often defined in terms of the amount of mechanical energy, or work, required to fully compact concrete without segregation. This is important since the final strength is a function of compaction.

For a very dilute suspension of solids in liquids, this relationship holds true. However, for large volumes of suspended solids, like concrete, the Newtonian model does not work. Concrete has an initial shear strength that must be exceeded before it will flow.

A third type of viscous behaviour is called thixotropic, where the apparent viscosity decreases with shear stress. Concrete will exhibit thixotropic characteristics.

Factors Affecting Workability

- **Water Content of the Mix --** This is the single most important fact or governing workability of concrete. A group of particles requires a certain amount of water. Water is absorbed on the particle surface, in the volumes between particles, and provides "lubrication" to help the particles move past one another more easily. Therefore, finer particles, necessary for plastic behaviour, require more water. Some side-effects of increased water are loss of strength and possible segregation.

- **Influence of Aggregate Mix Proportions --** Increasing the proportion of aggregates relative to the cement will decrease the workability of the concrete. Also, any additional fines will require more cement in the mix. An "over sanded" mix will be permeable and less economical. A concrete deficient of fines will be difficult to finish and prone to segregation.
- **Aggregate Properties --** The ratio of coarse/fine aggregate is not the only factor affecting workability. The gradation and particle size of sands are important. Shape and texture of aggregate will also affect workability. Spherical shaped particles will not have the interaction problems associated with more angular particles. Also, spherical shapes have a low surface/volume ratio, therefore, less cement will be required to coat each particle and more will be available to contribute to the workability of the concrete. Aggregate which is porous will absorb more water leaving less to provide workability. It is important to distinguish between total water content, which includes absorbed water, and free water which is available for improving workability.
- **Time and Temperature** -- In general, increasing temperature will cause an increase in the rate of hydration and evaporation. Both of these effects lead to a loss of workability.
- **Loss of Workability --** Workability will decrease with time due to several factors; continued slow hydration of C3S and C3A during dormant period, loss of water through evaporation and absorption, increased particle interaction due to the formation of hydration products on the particle surface. Loss of workability is measured as "slump loss" with time.
- **Cement Characteristics** -- Cement characteristics are less important than aggregate properties in determining workability. However, the increased fineness of rapid-hardening cements will result in rapid hydration and increased water requirements, both of which reduce workability.
- **Admixtures --** In general, air-entraining, water-reducing, and set-retarding admixtures will all improve workability. However, some chemical admixtures will react differently with cements and aggregates and may result in reduced workability.

Segregation and Bleeding

Segregation :

Segregation refers to a separation of the components of fresh concrete, resulting in a nonuniform mix. This can be seen as a separation of coarse aggregate from the mortar, caused from either the settling of heavy aggregate to the bottom or the separation of the aggregate from the mix due to improper placement.

Some factors that increase segregation are:

1. Larger maximum particle size (25mm) and proportion of the larger particles.

2. High specific gravity of coarse aggregate.

3. Decrease in the amount of fine particles.

4. Particle shape and texture.

5. Water/cement ratio.

Good handling and placement techniques are most important in prevention of segregation.

Bleeding :

Bleeding is defined as the appearance of water on the surface of concrete after it has consolidated but before it is set. Since mixing water is the lightest component of the concrete, this is a special form of segregation. Bleeding is generally the result of aggregates settling into the mix and releasing their mixing water. Some bleeding is normal for good concrete.

However, if bleeding becomes too localized, channels will form resulting in "craters". The upper layers will become too rich in cement with a high w/c ratio causing a weak, porous structure. Salt may crystalize on the surface which will affect bonding with additional lifts of concrete. This formation should always be removed by brushing and washing the surface. Also, water pockets may form under large aggregates and reinforcing bars reducing the bond.

Bleeding may be reduced by:

1. Increasing cement fineness.

2. Increasing the rate of hydration.

3. Using air-entraining admixtures.

4. Reducing the water content.

Measurement of Workability

Workability, a term applied to many concrete properties, can be adequately measured by three characteristics:

1. Compatibility, the ease with which the concrete can be compacted and air void removed.

2. Mobility, ease with which concrete can flow into forms and around reinforcement.

3. Stability, ability for concrete to remain stable and homogeneous during handling and vibration without excessive segregation.

Different empirical measurements of workability have been developed over the years. None of these tests measure workability in terms of the fundamental properties of concrete. However, the following tests have been developed:

- **Subjective Assessment --** The oldest way of measuring workability based on the judgement and experience of the engineer. Unfortunately, different people see things, in this case concrete, differently.
- **Slump Test --** The oldest, most widely used test for determining workability. The device is a hollow cone-shaped mould. The mould is filled in three layers of each volume. Each layer is rodded with a 16mm steel rod 25 times. The mould is then lifted away and the change in the height of the concrete is measured against the mould. The slump test is a measure of the resistance of concrete to flow under its own weight.

  There are three classifications of slump; "true" slump, shear slump, and collapse slump. True

  slump is a general reduction in height of the mass without any breaking up. Shear slump indicates a lack of cohesion, tends to occur in harsh mixes. This type of result implies the concrete is not suitable for placement. Collapse slump generally indicates a very wet mix. With different aggregates or mix properties, the same slump can be measured for very different concretes.

- **Compaction Test --** Concrete strength is proportional to its relative density. A test to determine the compaction factor was developed in 1947. It involves dropping a volume of concrete from one hopper to another and measuring the volume of concrete in the final hopper to that of a fully compacted volume. This test is difficult to run in the field and is not practical for large aggregates (over 1 in.).
- **Flow Test --** Measures a concretes ability to flow under vibration and provides information on its tendency to segregate. There are a number of tests available but none are recognized by ASTM. However, the flow table test described for mortar flows is occasionally used.
- **Remoulding Test --** Developed to measure the work required to cause concrete not only to flow but also to conform to a new shape.
- **Vebe Test -** A standard slump cone is cast, the mould removed, and a transparent disk placed on top of the cone. The sample is then vibrated till the disk is completely covered with mortar. The time required for this is called the Vebe time.
- **Thaulow Drop Table -** Similar to the Vebe test except a cylinder of concrete is remoulded on a drop table. The number of drops to achieve this remoulding is counted.
- **Penetration Test --** A measure of the penetration of some indenter into concrete. Only the Kelly ball penetration test is included in the ASTM Standards. The Kelly ball penetration test measures the penetration of a 30 lb. hemisphere into fresh concrete. This test can be performed on concrete in a buggy, open truck, or in form if they are not too narrow. It can be compared to the slump test for a measure of concrete consistency.

Setting of Concrete

Setting is defined as the onset of rigidity in fresh concrete. Hardening is the development of useable and measurable strength; setting precedes hardening. Both are gradual changes controlled by hydration. Fresh concrete will lose measurable slump before initial set and measurable strength will be achieved after final set.

Setting is controlled by the hydration of C3S. The period of good workability is during the dormant period, (stage 2). Initial set corresponds to the beginning of stage 3, a period of rapid hydration. Final set is the midpoint of this acceleration phase. A rapid increase in temperature is associated with stage 3 hydration, with a maximum rate at final set.

If large amounts of ettringite rapidly form from C3A hydration, the setting times will be reduced. Cements with high percentages of C3A, such as expansive or set-regulated cements, are entirely controlled by ettringite formation.

Chapter-7

Hardened Concrete

Strength of hardened concrete

Strength is defined as the ability of a material to resist stress without failure. The failure of concrete is due to cracking. Under direct tension, concrete failure is due to the propagation of a single major crack. In compression, failure involves the propagation of a large number of cracks, leading to a mode of disintegration commonly referred to as 'crushing'. The strength is the property generally specified in construction design and quality control, for the following reasons:

(1) It is relatively easy to measure, and

(2) Other properties are related to the strength and can be deduced from strength data.

The 28-day compressive strength of concrete determined by a standard uniaxial compression test is accepted universally as a general index of concrete strength.

Compressive strength and corresponding tests

(a) Failure mechanism

a. At about 25-30% of the ultimate strength, random cracking (usually in transition zone around large aggregates) are observed

b. At about 50% of ultimate strength, cracks grow stably from transition zone into paste. Also, microcracks start to develop in the paste.

c. At about 75% of the ultimate strength, paste cracks and bond cracks start to join together, forming major cracks. The major cracks keep growing while smaller cracks tend to close.

d. At the ultimate load, failure occurs when the major cracks link up along the vertical direction and split the specimen

The development of the vertical cracks results in expansion of concrete in the lateral directions. If concrete is confined (i.e., it is not allow to expand freely in the lateral directions), growth of the vertical cracks will be resisted. The strength is hence increased, together with an increase in failure strain. In the design of concrete columns, steel stirrups are placed around the vertical reinforcing steel. They serve to prevent the lateral displacement of the interior concrete and hence increase the concrete strength. In composite construction (steel + reinforced concrete), steel tubes are often used to encase reinforced concrete columns. The tube is very effective in providing the confinement.

The above figure illustrates the case when the concrete member is under ideal uniaxial loading. In reality, when we are running a compressive test, friction exists at the top and bottom surfaces of a concrete specimen, to prevent the lateral movement of the specimen. As a result, confining stresses are generated around the two ends of the specimen. If the specimen has a low aspect ratio (in terms of height vs width), such as a cube (aspect ratio = 1.0), the confining stresses will increase the apparent strength of the material. For a cylinder with aspect ratio beyond 2.0, the confining effect is not too significant at the middle of the specimen (where failure occurs). The strength obtained from a cylinder is hence closer to the actual uniaxial strength of concrete. Note that in a cylinder test, the cracks propagate vertically in the middle of the specimen. When they get close to the ends, due to the confining stresses, they propagate in an inclined direction, leading to the formation of two cones at the ends.

(b) Specimen for compressive strength determination

The cube specimen is popular in U.K. and Europe while the cylinder specimen is commonly used in the U.S.

i. Cube specimen

BS 1881: Part 108: 1983. Filling in 3 layers with 50 mm for each layer (2 layers for 100 mm cube). Strokes 35 times for 150 mm cube and 25 times for 100 mm cube. Curing at 20±5 0 C and 90% relative humility.

ii. Cylinder specimen

ASTM C470-81. Standard cylinder size is 150 x 300 mm. Curing condition is temperature of 23±1.7 0 C and moist condition. Grinding or capping is needed to provide level and smooth compression surface.

(c) Factors influencing experiment results

(i) End condition. Due to influence of platen restraint, cube's apparent strength is about 1.15 times of cylinders. In assessing report on concrete strength, it is IMPORTANT to know which type of specimen has been employed.

(ii) Loading rate. The faster the load rate, the higher the ultimate load obtained. The standard load rate is 0.15 -0.34 MPa / s for ASTM and 0.2-0.4 MPa/s for BS.

(iii) Size effect: The probability of having larger defects (such as voids and cracks) increases with size. Thus smaller size specimen will give higher apparent strength. Standard specimen size is mentioned above. Test results for small size specimen needs to be modified.

Tensile strength and corresponding tests

(a) Failure mechanism

a. Random crack development (microcracks usually form at transition zone)

b. Localization of microcracks

c. Major crack propagation

It is important to notice that cracks form and propagate a lot easier in tension than in compression. The tensile strength is hence much lower than the compressive strength. An empirical relation between f t and f c is given by: f t = 0.615 (f c) 0.5 (for 21 MPa < f c < 83 MPa) Substituting numerical values for f c , f t is found to be around 7 to 13% of the compressive strength, with a lower f t /f c ratio for higher concrete strength. In the above formula, f c is obtained from the direct compression of cylinders while f t is measured with the splitting tensile test, to be described below.

(b)Direct tension test methods

Direct tension tests of concrete are seldom carried out because it is very difficult to control. Also, perfect alignment is difficult to ensure and the specimen holding devices introduce secondary stress that cannot be ignored. In practice, it is common to carry out the splitting tensile test or flexural test.

(c) Indirect tension test (split cylinder test or Brazilian test) BS 1881: Part 117:1983. Specimen 150 x 300 mm cylinder. Loading rate 0.02 to 0.04 MPa/s ASTM C496-71: Specimen 150 x 300 mm cylinder. Loading rate 0.011 to 0.023 MPa/s

The splitting test is carried out by applying compression loads along two axial lines that are diametrically opposite. This test is based on the following observation from elastic analysis. Under vertical loading acting on the two ends of the vertical diametrical line, uniform tension is introduced along the central part of the specimen. .

Flexural strength and corresponding tests

BS 1881: Part 118: 1983. Flexural test. 150 x 150 x 750 mm or 100 x 100 x 500 (Max. size of aggregate is less than 25 mm). The arrangement for modulus of rupture is shown in the above figure. From Mechanics of Materials, we know that the maximum tension stress should occur at the bottom of the constant moment region. The

However, according to British Standards, once fracture occurs outside of the constant moment zone, the test result should be discarded.

Although the modulus of rupture is a kind of tensile strength, it is much higher than the results obtained from a direct tension test. This is because concrete can still carry stress after a crack is formed. The maximum load in a bending test does not correspond to the start of cracking, but correspond to a situation when the crack has propagated. The stress distribution along the vertical section through the crack is no longer varying in a linear manner. The above equations are therefore not exact.

Dimensional stability--Shrinkage and creep

Dimensional stability of a construction material refers to its dimensional change over a long period of time. If the change is so small that it will not cause any structural problems, the material is dimensionally stable. For concrete, drying shrinkage and creep are two phenomena that compromise its dimensional stability.

Shrinkage and creep are often discussed together because they are both governed by the deformation of hydrated cement paste within concrete. The aggregate in concrete does not shrink or creep, and they serve to restrain the deformation.

Drying shrinkage

After concrete has been cured and begins to dry, the excessive water that has not reacted with the cement will begin to migrate from the interior of the concrete mass to the surface. As the moisture evaporates, the concrete volume shrinks. The loss of moisture from the concrete varies with distance from the surface. The shortening per unit length associated with the reduction in volume due to moisture loss is termed the shrinkage. Shrinkage is sensitive to the relative humidity. For higher relative humidity, there is less evaporation and hence reduced shrinkage. When concrete is exposed to 100% relative humidity or submerged in water, it will actually swell slightly.

Shrinkage can create stress inside concrete. Because concrete adjacent to the surface of a member dries more rapidly than the interior, shrinkage strains are initially larger near the surface than in the interior. As a result of the differential shrinkage, a set of internal self-balancing forces, i.e. compression in the interior and tension on the outside, is set up.

In additional to the self-balancing stresses set up by differential shrinkage, the overall shrinkage creates stresses if members are restrained in the direction along which shrinkage occurs. If the tensile stress induced by restrained shrinkage exceeds the tensile strength of concrete, cracking will take place in the restrained structural element. If shrinkage cracks are not properly controlled, they permit the passage of water, expose steel reinforcements to the atmosphere, reduce shear strength of the member and are bad for appearance of the structure. Shrinkage cracking is often controlled with the incorporation of sufficient reinforcing steel, or the provision of joints to allow movement. After drying shrinkage occurs, if the concrete member is allowed to absorb water, only part of the shrinkage is reversible. This is because water is lost from the capillary pores, the gel pores (i.e., the pore within the C-S-H), as well as the space between the C-S-H layers. The water lost from the capillary and gel pores can be easily replenished. However, once water is lost from the interlayer space, the bond between the layers becomes stronger as they get closer to one another. On wetting, it is more difficult for water to re-enter. As a result, part of the shrinkage is irreversible.

The magnitude of the ultimate shrinkage is primarily a function of initial water content of the concrete and the relative humidity of the surrounding environment. For the same w/c ratio, with increasing aggregate content, shrinkage is reduced. For concrete with fixed aggregate/cement ratio, as the w/c ratio increases, the cement becomes more porous and can hold more water. Its ultimate shrinkage is hence also higher. If a stiffer aggregate is used, shrinkage is reduced. The shrinkage strain, ε sh , is time dependent. Approximately 90% of the ultimate shrinkage occurs during the first year.

Both the rate at which shrinkage occurs and the magnitude of the total shrinkage increase as the ratio of surface to volume increases. This is because the larger the surface area, the more rapidly moisture can evaporate.

Based on a number of local investigations in Hong Kong, the value of shrinkage strain (after one year) for plain concrete members appears to lie between 0.0004 and 0.0007 (although value as high as 0.0009 has been reported). For reinforced concrete members, the shrinkage strain values are reduced, as reinforcement is helpful in reducing shrinkage.

Creep

Creep is defined as the time-dependent deformation under a constant load. Water movement under stress is a major mechanism leading to creeping of concrete. As a result, factors affecting shrinkage also affect creep in a similar way. Besides moisture movement, there is evidence that creep may also be due to time-dependent formation and propagation of microcracks, as well as microstructural adjustment under high stresses (where stress concentration exists). These mechanisms, together with water loss from the gel interlayer, lead to irreversible creep. Creeping develops rapidly at the beginning and gradually decreases with time. Approximately 75% of ultimate creep occurs during the first year. The ultimate creep strain (after 20 years) can be 3-6 times the elastic strain.

Creep can influence reinforced concrete in the following aspects.

i). Due to the delayed effects of creep, the long-term deflection of a beam can be 2-3 times larger than the initial deflection.

ii). Creeping results in the reduction of stress in pre-stressed concrete which can lead to increased cracking and deflection under service load.

iii). In a R.C column supporting a constant load, creep can cause the initial stress in the steel to double or triple with time because steel is non-creeping and thus take over the force reduced in concrete due to creep.

Creep is significantly influenced by the stress level. For concrete stress less than 50% of its strength, creep is linear with stress. In this case, the burger's body, which is a combination of Maxwell and Kelvin models, is a reasonable representation of creep behaviour. For stress more than 50% of the strength, the creep is a nonlinear function of stress, and linear viscoelastic models are no longer applicable. For stress level higher than 75-80% of strength, creep rupture can occur. It is therefore very important to keep in mind that in the design of concrete column, 0.8 f c is taken to be the strength limit.

Factors affecting Creep of concrete

a) w/c ratio: The higher the w/c ratio, the higher is the creep.

b) Aggregate stiffness (elastic modulus): The stiffer the aggregate, the smaller the creep.

c) Aggregate fraction: higher aggregate fraction leads to reduced creep.

d) Theoretical thickness: The theoretical thickness is defined as the ratio of section area to the semiperimeter in contact with the atmosphere. Higher the theoretical thickness, smaller the creep and shrinkage.

e) Temperature: with increasing temperature, both the rate of creep and the ultimate creep increase. This is due to the increase in diffusion rate with temperature, as well as the removal of more water at a higher temperature.

f) Humidity: with higher humidity in the air, there is less exchange of moisture between the concrete and the surrounding environment. The amount of creep is hence reduced.

g) Age of concrete at loading: The creep strain at a given time after the application of loading is lower if loading is applied to concrete at a higher age. For example, if the same loading is applied to 14 day and 56 day concrete (of the same mix), and creep strain is measured at 28 and 70 days respectively (i.e., 14 days after load application), the 56 day concrete is found to creep less. This is because the hydration reaction has progressed to a greater extent in the 56 day concrete. With less capillary pores to hold water, creep is reduced.

Chapter-8

Concrete Mix Design

INTRODUCTION

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass.

Factors to be considered for mix design

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.

- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

Types of Concrete Mix Design

Concrete mix design can be done by the two ways namely

1. Nominal concrete mix
2. Designed concrete mix

1. Nominal Concrete Mix

Nominal concrete mix are low grade concrete mixes which are used for small and unimportant works. In this method, fine aggregate quantity is fixed irrespective of cement and coarse aggregate proportions. Hence, the quality of concrete mix will be varied and required strength may not be obtained.

In Nominal mix design water-cement ratio also not specified. Grades of concrete M20 and below are prepared by the Nominal mix design. For higher grade designed concrete mix is preferred.

Fig 1 : Nominal Mix Concrete

2. Designed Concrete Mix

The designed concrete mix does not contain any specified ranges in proportions. The design is done according to the requirements of concrete strength. So, we can achieve the desirable properties of concrete either it is in fresh stage or in hardened stage.

The fresh concrete properties like workability, setting time and hardened concrete properties like compressive strength, durability etc. are attained surely by this method. Use of additives like admixtures, retarders etc. other than basic ingredients are used to improve the properties of mix.

Fig 2 :Designed Mix Concrete

Using design concrete mix, one can design various grades of concrete from as low as M10 grade to higher grades such as M80, M100 can also be prepared. The workability requirements of each mix can also meet using this method from zero slump to the 150 mm slump. Each mix prepared is tested in laboratory after hardening to verify whether it meet the requirement or not.

Advantages of Concrete Mix Design

The advantages of concrete mix design are as follows

1. Required Proportions of Each ingredient
2. Quality Concrete Mix
3. Economical Concrete Mix
4. Best Use of Locally Available Material
5. Desired Properties of Mix

1. Desired Proportions of Each ingredient

The main aim of the concrete mix design is to find out the desired proportion of each ingredients which are cement, coarse aggregate, fine aggregate, water etc. to obtain the required properties of resulting mix.

Fig 3 :Concrete Ingredients

2. Quality Concrete Mix

Each ingredient used in the concrete mix design is tested for its quality. The aggregates with good strength, shape, specific gravity and free from organic content are used. The water used also is of good quality generally potable water is used.

Concrete with good quality improves its properties such as strength, durability etc. The design mix which is prepared from suitable ingredients in respective proportions itself improves the concrete properties.

The concrete mix prepared is tested using compressive strength machines, tensile strength machines in the form of concrete cubes and cylinders. Hence, recommended grade of concrete can be obtained using concrete mix design.

3. Economical Concrete Mix

Normally For making concrete in nominal mix, cement is used more than the other materials to get more strength which effects the cost of the project. It also increases the heat of hydration and causes shrinkage cracks in concrete.

But using concrete mix design, concrete of required strength can be designed with accurate quantity of cement. It saves the cost of the project and economical concrete mix will be obtained and also prevents the formation shrinkage cracks by lowering heat of hydration.

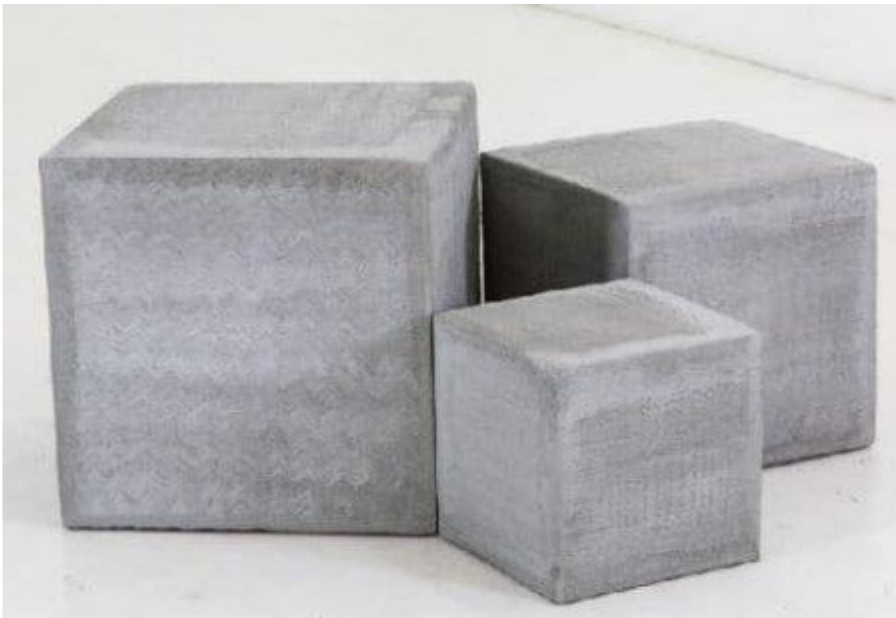


Fig 4 :Concrete Cubes

4. Best Use of Locally Available Material

Concrete mix design allow the use of locally available material such as coarse aggregates, fine aggregates etc. only if it is of good quality. This will reduce the cost of project and will also encourage rapid construction.

5. Desired Properties of Mix

The concrete obtained through mix design contain desired properties like workability, durability, setting time, strength, impermeability etc. The design is processed by considering some important factors like water cement ratio, gradation of aggregates etc.

Depending upon on the construction conditions or requirement, admixtures are used to improve the properties of concrete. Designed concrete mix fulfills the durability requirement of structure against several environmental effects and serves good throughout its functional life. Different cements available can also be used depending upon the requirement.

Proportioning of concrete mix :

Proportioning of concrete is the process of selecting quantity of cement, sand, coarse aggregate and water in concrete to obtain desired strength and quality.
The proportions of coarse aggregate, cement and water should be such that the resulting concrete has the following properties:

1. When concrete is fresh, it should have enough workability so that it can be placed in the formwork economically.
2. The concrete must possess maximum density or in the other words, it should be strongest and most water-tight.
3. The cost of materials and labour required to form concrete should be minimum.

The determination of the proportions of cement, aggregates and water to obtain the required strengths shall be made as follows:

a) By designing the concrete mix, such concrete shall be called design mix concrete, or

b) By adopting nominal mix, such concrete shall be called nominal mix concrete.

- Design mix concrete is preferred to nominal mix.
- Concrete of each grade shall be analysed separately to determine its standard deviation.

Standard Deviation $S = \sqrt{\frac{\sum \Delta^2}{n-1}}$

Where, Δ = deviation of the individual test strength from the average strength of n samples.

n = Number of sample test results.

Methods of Proportioning Concrete

Arbitrary Method of Proportioning Concrete

The general expression for the proportions of cement, sand and coarse aggregate is 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

$$R = \frac{P_2 - P}{P - P_1} \times 100$$

Where, P = desired fineness modulus for a concrete mix of fine and coarse aggregates.

P_1 = fineness modulus of fine aggregate

P_2 = fineness modulus of coarse aggregate.

Minimum Void Method
(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:
(Not very Popular)

$$P = 100\left(\frac{d}{D}\right)^{1/2}$$

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

Chapter-9

Production of Concrete

Batching

Batching is the process of measuring concrete mix ingredients either by volume or by mass and introducing them into the mixture. Traditionally batching is done by volume but most specifications require that batching be done by mass rather than volume. Percentage of accuracy for measurement of concrete materials as follows.

Cement:

When the quantity of cement to be batched exceeds 30% of scale capacity, the measuring accuracy should be within 1% of required mass. If measuring quantity is less than 30% i.e. for smaller batches then the measuring accuracy should be within 4% of the required quantity.

Aggregates:

If the measurement is more than 30% of the scale capacity then the measuring accuracy should be within 1%. If measurement is less than 30% then the measuring accuracy should be within less than 3%.

Water:

Water is measured in volumetric quantity as 1 litre = 1kg. In case of water, the measuring accuracy should be within 1%.

Admixtures:

For mineral admixtures same accuracy as that required for cement. For chemical admixtures same accuracy as that required for water. Mineral admixtures accuracy is same as that of cement because it is used as partial replacement of cement. As chemical admixtures are liquid or added to water therefore its accuracy is same as that of water.

Mixing

The mixing operation consists of rotation or stirring, the objective being to coat the surface the all aggregate particles with cement paste, and to blind all the ingredients of the concrete into a uniform mass; this uniformity must not be disturbed by the process of discharging from the mixer.

Batch mixer

The usual type of mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer. There are four types of batch mixer.

Tilting drum mixer:

A tilting drum mixer is one whose drum in which mixing take place is tilted for discharging. The drum is conical or bowl shaped with internal vanes, and the discharge is rapid and unsegregated so that these mixers are suitable for mixes of low workability and for those containing large size aggregate.

Non tilting drum mixer:

A non tilting drum is one in which the axis of the mixer is always horizontal, and discharge take place by inserting a chute into the drum or by reversing the direction or rotation of drum. Because of slow rate of discharge, some segregation may occur.

Pan type mixer:

A pan type mixer is a forced–action mixer, as distinct from drum mixer which relies on the free fall of the concrete inside the drum. The pan mixer consist of a circular pan rotating about its axis with one or two stars paddles rotating about vertical axis of pan.

Dual drum mixer:

A dual drum is sometimes used in highway construction. Here there are two drums in series, concrete being mixed part of the time in one and then transferred to the other for the remainder of the mixing time before discharging.

Continuous mixers:

These are fed automatically by a continuous weigh-batching system.

Charging the mixer:

There are no general rules on the order of feeding the ingredients into the mixer as this depend on the properties of the mixer and mix. Usually a small quantity of water is fed first, followed by all the solids materials. If possible greater part of the water should also be fed during the same time, the remainder being added after the solids. However, when using very dry mixes in drum mixers it is necessary to feed the coarse aggregate just after the small initial water feed in order to ensure that the aggregate surface is sufficiently wetted.

Uniformity of Mixing

In any mixer, it is essential that a sufficient interchange of materials occurs between parts of the chamber, so that a uniform concrete is produced. The efficiency of the mixer can be measured by the variability of the samples from the mix. ASTM prescribes samples to be taken from about points 1/6 and 5/6 of the discharge of the batch and the difference in the properties of the two samples should not exceed any of the following:

1. Density of concrete 1 lb/ft^3

2. Air content 1%

3. Slump 1" when average is less than 4"

4. 1.5" when average is less than 4 to 6"

4. % of aggregate retained on 4 No. sieve 6%

5. Compressive strength 7 day, 3 cylinders 7.5%

Mixing time:

It is important to know the minimum mixing time necessary to produce a concrete of uniform composition, and of reliable strength.

The mixing time or period should be measured from time all the cementing materials and aggregates are in mixer drum till taking out the concrete. Mixing time depends on the type and size of mixer, on the speed of rotation, and on the quality of blending of ingredients during charging of the mixer. Generally, a mixing time of less than 1 to 1.25 minutes produces appreciable non-uniformity in composition and a significant lower strength; mixing beyond 2 minutes causes no significant improvement in these properties.

Table: Recommended minimum mixing times

Capacity of mixer (yd^3)	Mixing time (Minutes)
Up to 1	1
2	1.25
3	1.5
4	1.75
5	2
6	2.25
10	3.25

Prolong mixing:

If mixing take place over a long period, evaporation of water from the mix can occur, with a consequent decrease in workability and an increase in strength. A secondary effect is that of grinding of the aggregate, particularly if soft; the grading thus becomes finer and the workability lower. In case of air entrained concrete, prolong mixing reduces the air content.

Ready mixed concrete:

If instead of being batched and mixed on site, concrete is delivered for placing from a central plant. It is referred to as ready-mixed or pre-mixed concrete. This type of concrete is used extensively abroad as it offers numerous advantages in comparison with other methods of manufacture:

1. Close quality control of batching which reduces the variability of the desired properties of hardened concrete.

2. Use on congested sites or in highway construction where there is little space for a mixing plant and aggregate stockpiles;

3. Use of agitator trucks to ensure care in transportation, thus prevention segregation and maintaining workability

4. Convenience when small quantities of concrete or intermittent placing is required.

There are two categories of ready-mixed concrete: central-mixed and transit mixed or truck mixed. In the first category, mixing is done in a central plant and then concrete is transported in an agitator truck. In the second category, the materials are batched at a central plant but are mixed in a truck.

Transporting Concrete

Transporting the concrete mix is defined as the transferring of concrete from the mixing plant to the construction site. Keep in mind that not all concrete is mixed on the actual construction site and could require some significant travel. This is most common for ready-mixed concretes. The main objective in transporting concrete is to ensure that the water-cement ratio, slump or consistency, air content, and homogeneity are not modified from their intended states.

Important Factors in Choosing Transportation

There are many elements of transporting that need to be considered in order to ensure that a mix does not change its state as specified in the contract. The two key goals when transporting concrete from the mixing plant to the construction site are to prevent segregation and to not reduce the workability of the mix. This transportation process must be well thought out and organized efficiently. As a general rule of thumb, thirty to sixty minutes of transportation are acceptable on small jobs. At a central or portable ready-mix plant, concrete should be discharged from a truck mixer or agitator truck within two hours. If non-agitating transporting equipment is used, this time is reduced to one hour. All delays must be avoided in order prevent honeycombing, as shown in Figure 1, or cold joints.

Many factors determine which type of transportation is most suitable. Type and constituents of the concrete mix, size and type of construction, topography, weather conditions (i.e. temperature, humidity, wind speed), location of the batch plant, and cost are all taken into consideration when choosing a mode of transport for your concrete. If you choose the wrong mode of transportation, your concrete could be segregated, which would in effect, make it useless. Therefore it is essential that adequate thought be given to the type of transportation you actually need.

Categories of Transportation

There are many modes of transportation as shown below:

1. Wheelbarrow or motorized buggy

2. Truck mixer

3. Bucket or steel skip

4. Chute

5. Belt conveyor

6. Concrete pump

7. Pneumatic placer

Concrete Placing and Compaction of Concrete

The operation of placing and compaction are interdependent and are carried out simultaneously. They are most important for the purpose of ensuring the requirements of strength, im permeability and durability of hardened concrete in the actual structure. As for as placing is concerned, the main objective is to deposit the concrete as close as possible to its final position so that segregation is avoided and the concrete can be fully compacted. The aim of good concrete placing can be stated quite simply.

It is to get the concrete into position at a speed, and in a condition, that allow it to be compacted properly.

To achieve proper placing following rules should be kept in mind:

1. The concrete should be placed in uniform layers, not in large heaps or sloping layers.

2. The thickness of the layer should be compatible with the method of vibration so that entrapped air can be removed from the bottom of each layer.

3. The rate of placing and of compaction should be equal. If you proceed too slowly, the mix could stiffen so that it is no longer sufficiently workable. On no account should water ever be added to concrete that is setting. On the other hand, if you go too quickly, you might race ahead of the compacting gang, making it impossible for them to do their job properly.

4. Each layer should be fully compacted before placing the next one, and each subsequent layer should be placed whilst the underlying layer is still plastic so that monolithic construction is achieved

5. Collision between concrete and formwork or reinforcement should be avoided.

6. For deep sections, a long down pipe ensures accuracy of location of concrete and minimum segregation.

7. You must be able to see that the placing is proceeding correctly, so lighting should be available for large, deep sections, and thin walls and columns.

Compaction

Once the concrete has been placed, it is ready to be compacted. The purpose of compaction is to get rid of the air voids that are trapped in loose concrete.

Why is compaction of concrete necessary?

It is important to compact the concrete fully because:

- Air voids reduce the strength of the concrete. For every 1% of entrapped air, the strength falls by somewhere between 5 and 7%. This means that concrete containing a mere 5% air voids due to incomplete compaction can lose as much as one third of its strength.
- Air voids increase concrete's permeability. That in turn reduces its durability. If the concrete is not dense and impermeable, it will not be watertight. It will be less able to withstand aggressive iquids and its exposed surfaces will weather badly.
- Moisture and air are more likely to penetrate to the reinforcement causing it to rust.
- Air voids impair contact between the mix and reinforcement (and, indeed, any other embedded metals). The required bond will not be achieved and the reinforced member will not be as strong as it should be.
- Air voids produce blemishes on struck surfaces. For instance, blowholes and honeycombing might occur.

Summing up, fully compacted concrete is dense, strong and durable; badly compacted concrete will be porous, weak and prone to rapid deterioration. Sooner or later it will have to be repaired or replaced. It pays, therefore, to do the job properly in the first place. Stiff mixes contain far more air than workable ones. That is one of the reasons why a low-slump concrete requires more compactive effort than one with a higher slump – the compaction needs to continue for a longer time, or more equipment has to be used.

Even air-entrained concrete needs to be compacted to get rid of entrapped air voids. The difference between air voids and entrained air bubbles should be noted at this stage. The air bubbles that are entrained are relatively small and spherical in shape, increase the workability of the mix, reduce bleeding, and increase frost resistance. Entrapped air on the other hand tends to be irregular in shape and is detrimental to the strength of the mix. It is to remove this air that the concrete must be properly compacted. There is little danger that compaction will remove the minute air bubbles that have been deliberately entrained, since they are so stable.

Methods of Compaction of concrete

Vibration:

To compact concrete you apply energy to it so that the mix becomes more fluid. Air trapped in it can then rise to the top and escape. As a result, the concrete becomes consolidated, and you are left with a good dense material that will, after proper curing, develop its full strength and durability. Vibration is the next and quickest method of supplying the energy. Manual techniques such as rodding are only suitable for smaller projects. Various types of vibrator are available for use on site.

Poker Vibrators

The poker, or immersion, vibrator is the most popular of the appliances used for compacting concrete. This is because it works directly in the concrete and can be moved around easily.

Sizes:

Pokers with diameters ranging from 25 to 75mm are readily available, and these are suitable for most reinforced concrete work. Larger pokers are available - with diameters up to 150mm - but these are for mass concrete in heavy civil engineering.

Radius of action:

When a poker vibrator is operating, it will be effective over a circle centred on the poker. The distance from the poker to the edge of the circle is known as the radius of action. However, the actual effectiveness of any poker depends on the workability of the concrete and the characteristics of the vibrator itself. As a general rule, the bigger the poker and the higher its amplitude, the greater will be the radius of action. It is better to judge from your own observations, as work proceeds on site, the effective radius of the poker you are operating on the concrete you are compacting.

The length of time it takes for a poker vibrator to compact concrete fully depends on:

1. The workability of the concrete: the less workable the mix, the longer it must be vibrated.

2. The energy put in by the vibrator: bigger vibrators do the job faster.

3. The depth of the concrete: thick sections take longer.

CURING OF CONCRETE

There are various methods of curing. The adoption of a particular method will depend upon the nature of work and the climatic conditions. The following methods of curing of concrete are generally adopted.

- Shading concrete work
- Covering concrete surfaces with hessian or gunny bags
- Sprinkling of water
- Ponding method
- Membrane curing
- Steam curing

1. SHADING OF CONCRETE WORK

The object of shading concrete work is to prevent the evaporation of water from the surface even before setting. This is adopted mainly in case of large concrete surfaces such as road slabs. This is essential in dry weather to protect the concrete from heat, direct sun rays and wind. It also protects the surface from rain. In cold weather shading helps in preserving the heat of hydration of cement thereby preventing freezing of concrete under mild frost conditions. Shading may be achieved by using canvas stretched on frames. This method has a limited application only.

2. COVERING CONCRETE SURFACES WITH HESSIAN OR GUNNY BAGS

This is a widely used method of curing, particularly for structural concrete. Thus exposed surface of concrete is prevented from drying out by covering it with hessian, canvas or empty cement bags. The covering over vertical and sloping surfaces should be secured properly. These are periodically wetted. The interval of wetting will depend upon the rate of evaporation of water. It should be ensured that the surface of concrete is not allowed to dry even for a short time during the curing period. Special arrangements for keeping the surface wet must be made at nights and on holidays.

3. SPRINKLING OF WATER

Sprinkling of water continuously on the concrete surface provides an efficient curing. It is mostly used for curing floor slabs. The concrete should be allowed to set sufficiently before sprinkling is started. The spray can be obtained from a perforated plastic box. On small jobs sprinkling of water may be done by hand. Vertical and sloping surfaces can be kept continuously wet by sprinkling water on top surfaces and allowing it to run down between the forms and the concrete. For this method of curing the water requirement is higher.

4. PONDING METHOD

This is the best method of curing. It is suitable for curing horizontal surfaces such as floors, roof slabs, road and air field pavements. The horizontal top surfaces of beams can also be ponded. After placing the concrete, its exposed surface is first covered with moist hessian or canvas. After 24 hours, these covers are removed and small ponds of clay or sand are built across and along the pavements. The area is thus divided into a number of rectangles. The water is filled between the ponds. The filling of water in these ponds is done twice or thrice a day, depending upon the atmospheric conditions. Though this method is very efficient, the water requirement is very heavy. Ponds easily break and water flows out. After curing it is difficult to clean the clay.

5. MEMBRANE CURING

The method of curing described above come under the category of moist curing. Another method of curing is to cover the wetted concrete surface by a layer of water proof material, which is kept in contact with the concrete surface of seven days. This method of curing is termed as membrane curing. A membrane will prevent the evaporation of water from the concrete. The membrane can be either in solid or liquid form. They are also known as sealing compounds. Bituminised water proof papers, wax emulsions, bitumen emulsions and plastic films are the common types of membrane used. Whenever bitumen is applied over the surface for curing, it should be done only after 24 hours curing with gunny bags. The surface is allowed to dry out so that loose water is not visible and then the liquid asphalt sprayed throughout. The moisture in the concrete is thus preserved. It is quite enough for curing.

This method of curing does not need constant supervision. It is adopted with advantage at places where water is not available in sufficient quantity for wet curing. This method of curing is not efficient as compared with wet curing because rate of hydration is less. Moreover the strength of concrete cured by any membrane is less than the concrete which is moist cured. When membrane is damaged the curing is badly affected.

6. STEAM CURING

Steam curing and hot water curing is sometimes adopted. With these methods of curing, the strength development of concrete is very rapid. These methods can best be used in pre cast concrete work. In steam curing the temperature of steam should be restricted to a maximum of 75°C as in the absence of proper humidity (about 90%) the concrete may dry too soon. In case of hot water curing, temperature may be raised to any limit, ay 100°C.

At this temperature, the development of strength is about 70% of 28 days strength after 4 to 5 hours. In both cases, the temperature should be fully controlled to avoid non-uniformity. The concrete should be prevented from rapid drying and cooling which would form cracks.

Chapter-10

INSPECTION AND QUALITY CONTROL

INTRODUCTION

Inspection is needed for maintaining quality in a construction project. Different aspects of quality are to be considered. Different types of inspection and quality control procedures may apply to different materials. An engineer should be conversant with all these procedures.

Objectives

After studying this unit, you should be able to

- understand the need of inspections and quality control in construction projects,
- understand different aspects of quality control,
- know about principles of inspection, and
- appreciate what different considerations are required for quality control of different materials.

NEED FOR INSPECTION AND QUALITY CONTROL

Every operation is connected with the quality of the product. In the case of construction the quality of construction is to be maintained as per project specifications. It is important that quality requirements be satisfied and production schedules are met. The satisfaction of the owner of the project is mainly derived by the quality of the work.

Stiff competition in the national and international level of construction sector demands a high quality oriented attitude of engineers. However, the management is required to achieve the satisfaction of the owner by completing the project within the cost constraints for the project. Both of these things are dependent on properly integrating quality development, quality maintenance and quality improvement in construction. The integration of all these three aspects can be achieved through a sound quality control system.

Quality

Quality is a relative term and is used with reference to the end use of the product. In the context of the construction field, this end product is what we construct. Sometimes quality is defined as the fitness of any constructed facility or structure for use at the most economical level.

As there may be difference in the perception of quality of an object, we have to specify the quality in a clear term. As mentioned above, quality may sometimes mean as the fitness for use. Sometimes it may be interpreted in terms of conforming to requirements. For example, a tourist building must be planned so that people staying inside it must feel its aesthetic appeal or beauty. If it does not conform to this requirement some people may term it not conforming (or matching) to the requirements.

Sometimes quality may be interpreted in terms of grade or degree of excellence for some structures. The quality of construction of a project is also dependent on the quality of several other parameters.

Quality of a constructed facility may be verified based on some instincts or factors. These may be considered as follows :

- Aesthetics
- Strength
- Durability
- Safety
- Economy
- Maintainability
- Reliability
- Degree of satisfaction of the end user
- Versatility of use for many purposes

Quality of Design

Quality of design of a construction is concerned with the specifications which have to be conformed with. A good quality of design must ensure consistent performance of the facility for the entire life span of the facility. The design of the facility should be done in such a way that all possible modes of failures are considered and appropriate inputs are ingrained in the design to take care of them.

Quality design is a continuous process which results in good evaluation of an end product. Design features which are essential for a project are necessary to be considered. For example, a road without design features such as camber, superelevation or provision of side drains is not going to be evaluated as a good construction. Objectives of the owner for the construction of a structure, cost considerations, environmental considerations, etc. are some of the factors which may affect the design of a structure and hence its quality.

Conforming to Quality

Conforming to quality means the quality of the product/construction to be of a required order. It is essential so that the construction goes on as per the satisfaction of the owner. Use of proper quality of materials, proper work sequences, proper types of equipment and inspections from time to time are 101 Inspection and Quality Control factors which should be considered. It is to note that a higher quality of design increases the cost but a higher quality of conformity with the design saves the investment.

Quality of Performance

It is connected with how well the constructed facility gives its performance. It depends on both the quality of design and the quality of conformance. It may be easily understood that even a best design may not be able to provide us with something which is going to be the best in terms of performance if the quality of conformance is poor. The reverse is also true. A proper quality of conformance also can not provide a good quality of constructed facility if the quality of design of the facility is not good.

Characteristics of Quality

Quality of a particular object, such as a car, a book or a building, may be assessed by some parameters which are physical or chemical in nature. Sometimes the criteria may be abstract such as aesthetics or beauty of an object. These parameters are used to define the quality of an object.

Quality characteristics may be defined in terms of parameters which may be of the following types :

- Technical parameters – length, viscosity, etc.
- Psychological parameters – taste, beauty, etc.
- Time parameters – speed, life span, etc.
- Contractual parameters – safety, reliability, etc.
- Ethical parameters – honesty, integrity, nature, etc.

These characteristics may be measurable or non-measurable. This may be another criterion for classifying those parameters which may assess quality. Quality control may be defined as a procedure by which we compare the actual quality of an object with the intended quality. If the actual quality is different from the intended one, especially if it is less, we have to take corrective actions. The intended quality is defined by some characteristics. The same characteristics of the actual object are measured. When these characteristics are compared, we can have an idea of whether the actual quality of the object is acceptable.

Quality control may be termed also as a systematic control of those factors which define the quality of an object. For example, we know that the strength of a structural member, such as a column, is dependent on the quality of materials which are used to construct that column. We shall have to control the quality of materials to control the quality of column. Quality control includes all such procedures, tools, specifications and the system of norms & specifications which are used to control the quality of an object.

Quality control is generally costly. We have to train people for making inspections, assessing quality of objects with the help of instruments which are sometimes purchase or hired on rent. Time also is spent on inspections. Inspections may sometimes affect the progress of work. Sometimes, we may have to dismantle some construction or part of construction which may be a drain on the resources of an organization. The cost of quality assurance should be considered and it should be the practice on the part of the contractor to establish high quality standards.

Sometimes disputes may be there because of decisions made during Construction Management inspections which have to be sorted out. Getting these disputes amicably resolved also may sometimes be time consuming and costly. There are some benefits of maintaining quality in the construction. These may be expressed as below :

- Increase in efficiency because of quality consciousness
- Reduction of scrap due to less number of items being rejected
- Easy identification of construction faults
- Decrease in cost in the long run due to benefits of quality control
- Creating quality consciousness in workers

Norms and guidelines are made for the quality specifications to be followed. For civil engineering construction, a variety of codes have been drafted by Bureau of Indian Standards, New Delhi.

PRINCIPLES OF INSPECTION

Inspection means the checking of material or product at various stages of manufacture or construction of an object. It is done with respect to some pre-defined parameters and it tries to detect the faulty nature of the object. When we inspect something, we try to see the past history of construction and try to learn from our past experiences. Faulty objects are sorted out and are rejected. For example, those structural members, whose construction has been faulty, may be dismantled and reconstructed.

There may be different aspects which may be followed. For example, the quality of a beam specimen may be faulty because the concrete in that beam may not be of the chosen grade. It may be considered faulty if the detailing of reinforcement (i.e. how the reinforcement is to be placed in the beam) also is faulty. Such beam members would be discarded, dismantled and reconstructed. Inspection should not be confused with quality control. Inspection is a way or method of maintaining the quality of the object being constructed or produced.

Controlling the quality is what is termed as quality control. Quality control is a wide term which involves inspections at various stages of construction. Basically, when we consider the quality control of some object, we always have some future object in mind and we try to find out the ways as to how to control the quality of that object, to be produced in future. This is why, the quality control people are provided with instructions prior to the production or construction of some object or some building. Inspections give us needed inputs to control quality. If the quality of an object is found to be not as per expectations, we have to take remedial steps. Inspections check the quality of past constructions and quality control norms or specifications are provided for the future constructions.

Inspection is an act of checking the objects or items, sorting out and finding out the faulty item. Quality control is a broad term which includes inspection as an activity out of a number of activities carried out for the purpose. Inspections are carried out using precise equipment and instruments. These devices or tools are used to measure those characteristics which define the quality of an object. Using such devices, we can ascertain the quality of past constructions and judge if those objects, which were constructed, were as per accepted norms and 103 Inspection and Quality Control specifications. Inspection is mainly carried out by people who are responsible for it. They must know the norms and specifications, characteristics to be measured and should know how to use different devices and tools to examine the quality of a construction. For inspecting the quality of construction, non-destructive test procedures have been established. In such procedures, which are termed as NDT procedures, we can test the quality of construction without deforming a structural element.

MAJOR ITEMS IN CONSTRUCTION JOB REQUIRING QUALITY CONTROL

To understand the aspect of quality control in construction, it has to appreciate that construction industry is somewhat different from other manufacturing industries. The objects created or constructed in this sector are most of the times unique in the sense that the structures are never the same or the exact replica of one another. Two buildings, two bridges, two roads may be chosen at random and in each case we would find that there are differences or variations.

There are certain considerations which should be kept in mind when we consider quality control in civil engineering construction.

Quality of construction is dependent, to a great extent, on

- The quality of materials which are used in construction
- The expertise of workers
- The technology adopted in construction
- Number, type and quality of inspections
- Quality consciousness of people
- Funds available for construction and quality control
- Time available for quality control procedures
- Existence of norms and guidelines for assessing quality of construction of a particular type
- Experience and expertise of inspectors
- Quality of design
- Nature of the construction project

We can see that some activities in a construction work may be of a repetitive nature. Some activities are taken up only for some times. Concrete mix making may be a routine affair at a construction site. We can understand that quality control norms may be different when we compare two materials out of which one is a factory made item and the other one is a site made material. It may be the case of some steel channel section and the concrete mix. We should be more concerned for the quality control exercised for the making of materials which are manufactured at the site. This is due to the reason that illiterate workers may not know the correct manner of doing something in a right way. For some materials, we have to be extra vigilant for quality as these materials may be very important for supplying strength to the construction. If the quality of concrete is not good, we can not expect a good quality of construction.

Quality of construction materials should be good. Guidelines should be followed in the assessment of quality of these materials. Some common materials which are used for construction are given below :

- Cement
- Fine and coarse aggregates
- Chemical admixtures
- Timber
- Steel
- Soil of a site
- Bricks and stones

Standard guidelines, formed by standard codes, are available. These guidelines supply us with the tests conducted to assess the quality of these materials. Tests should be conducted on these materials and faulty materials should not be used.

Quality of construction procedures and processes adopted also should be considered in the context of quality control.

STAGES OF INSPECTION AND QUALITY CONTROL

Specifications for quality are available in Indian standards formulated by Bureau of Indian Standards, New Delhi. Different types of construction works are dealt with in different ways and different tests to assess their different quality characteristics are available. In different types of construction works or jobs different stages may be recognized. For example, if we wish to make a reinforced concrete beam structural member, we have to go through different stages such as providing supports to the form work, making of form work, cutting or reinforced bars for the beam, putting the reinforcement in the formwork, mixing of concrete, pouring of concrete in the formwork, vibrating concrete, curing concrete, etc. There are different types of guidelines to oversee each stage so that the quality of the beam is of a right type. We should appreciate that it shall be difficult to maintain the overall quality if quality is not maintained in some of these stages. We have to monitor quality of each and every stage to get the required quality of the concrete member.

Salient points are given below regarding different stages and quality control aspects required to be considered in some general construction operations.

Earth Work

Stages

- Measurement of dimensions in different directions in terms of height, width and length
- Excavation of soil
- Determination of soil properties
- Compacting soil

Quality Control Considerations

- Accurate measurements with precise instruments
- Use of good equipment
- Use of standard procedures for testing of soil
- Use of equipment for compaction

Masonry

Stages

- Measurement of dimensions in different directions in terms of height, width and length
- Construction of masonry
- Curing of masonry work

Quality Control Considerations

- Use of good quality materials
- Use of right construction procedures and correct bonds
- Employment of people with experience and expertise
- Adequate curing of masonry

Reinforced Cement Concrete (RCC)

Stages

- Measurement of dimensions in different directions in terms of height, width and length
- Creation and installation of formwork
- Provision of reinforcement
- Mixing of concrete
- Casting of concrete
- Curing of concrete

Quality Control Considerations

- Use of good quality materials
- Use of right construction procedures
- Employment of people with experience and expertise
- Correct detailing of reinforcement
- Adequate curing of concrete

Sanitary and Water Supply Services

Stages

- Measurement of dimensions in different directions in terms of length as well as area covered
- Procurement of sanitary and water supply items
- Installation of these items correctly
- Testing of these items

Quality Control Considerations

- Use of good quality materials and items
- Use of right construction procedures
- Employment of people with experience and expertise

Electrical Services

Stages

- Measurement of dimensions in different directions in terms of length as well as area covered
- Procurement of items
- Installation of these items correctly
- Testing of these items Quality

Control Considerations

- Use of good quality materials and items
- Use of right connection procedures
- Employment of people with experience and expertise

Chapter-11

SPECIAL CONCRETE

Ready Mixed Concrete (RMC)?

Ready Mixed Concrete is a tailor – made 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.

Types of Ready Mixed Concrete

There are three types of ready mix concrete (RMC) depending upon the mixing of the various ingredients as given below:

- Transit mixed concrete
- Shrink mixed concrete
- Central mixed concrete

1. Transit mixed concrete

It is also called dry batched concrete because all the basic ingredients including water are charged directly into the truck mixer. The mixer drum is revolved fast at charging speed during the loading of the material and after that it continues rotating at a normal agitating speed. In this type of ready mix concrete, also three types of variations are possible as given below:

Concrete mixed at job site

While being transported towards the destination, the drum is revolved at a slow or agitating speed of 2 rpm, but after reaching the site just before discharging the material, it is revolved at maximum speed of 12 to 15 rpm for nearly 70 to 100 revolution for ensuring homogeneous mixing.

Concrete mixed in transit

The drum speed is kept medium during the transit time, i.e. approximately 8 rpm for about 70 revolutions. After 70 revolutions, it is slowed down to agitating speed of 2 rpm till discharging the concrete.

Concrete mixed in the yard

The drum is turned at high-speed of 12 to 15 rpm for about 50 revolutions in the yard itself. The concrete is then agitated slowly during transit time.

2. Shrink mixed concrete

The concrete is partially mixed in the plant mixer and then balance mixing is done in the truck mounted drum mixer during transit time. The amount of mixing in transit mixer depends upon the extent of mixing done in the central mixing plant. Tests should be conducted to establish the requirement of mixing the drum mixer.

3. Central-mixed concrete

It is also called central batching plant where the concrete is thoroughly mixed before loading into the truck mixer. Sometimes the plant is also referred as wet-batch or pre-mix plants. While transporting the concrete, the truck mixer acts as agitator only. Sometimes, when workability requirement is low or the lead is less, non-agitating units or dump trucks can also be used.

Advantages of Ready Mixed Concrete

1. Quality concrete is obtained as a ready-mix concrete mix plant make use of sophisticated equipment and consistent methods. There is strict control over the testing of materials, process parameters and continuous monitoring of key practices during the manufacture.Poor control on the input materials, batching and mixing methods in the case of site mix concrete is solved in a ready-mix concrete method.
2. Speed in the construction practices followed in ready mix concrete plant is followed continuously by having mechanised operations. The output obtained from a site mix concrete plant using a 8/12 mixer is 4 to 5 metric cubes per hour which is 30-60 metric cubes per hour in a ready mix concrete plant.
3. Better handling and proper mixing practice will help to reduce the consumption of cement by 10 – 12%. Use of admixtures and other cementitious materials will help to reduce the amount of cement.
4. The concrete mixed is used with high versatility. It is placed by following best concrete placing methods.
5. Cement is saved and the dust caused is reduced as ready mix concrete make use of bulk concrete instead of bags of cement.
6. Cement saving will conserve the energy and the resources.
7. Less consumption result in less production of cement hence less environmental pollution.
8. More durable structure is obtained thus increasing the service life and saving the life cycle costs.
9. Ready mix concrete manufacture have less dependency on human labours hence the chances of human errors is reduced. This will also reduce the dependency on intensive labours.
10. Small or large quantities of concrete as per the specification is delivered timely at the site.
11. This demands no space for storing the raw materials at site. There is no delay due to site based batching plant erection/ dismantling; no equipment to hire; no depreciation of costs.
12. Petrol and diesel consumed is less thus noise and air pollution is reduced.

Disadvantages of Ready Mixed Concrete

1. The transit time from the time of preparation of concrete to the delivery site, will result in loss of workability. This will demand for additional water or admixtures to maintain the workability as per the specification. At site, the QA/QC engineer are supposed to check the workability through slump test before using it for construction.
2. Traffic during the transit of concrete can result in setting of concrete. This will hence require addition of admixtures to delay the setting period. But unexpected traffic is a great problem.
3. The formwork and placing arrangement must be prepared in advance in large area as the concrete can be bought in larger amounts.

High performance concrete (HPC)

The composition of high performance concrete (HPC) are almost same as those of Conventional Cement Concretes(CCC). But, because of lower Water Cement Ratio, presence of Pozzolans and chemical admixtures etc., the HPCs usually have many features which distinguish them from CCCs.

From practical considerations, in concrete constructions, apart from the final strength, the rate of development of strength is also very important. The High performance concrete usually contains both pozzolanic and chemical admixtures. Hence, the rate of hydration of cement and the rate of strength development in HPC is quite different from that of conventional cement concrete(CCC).

The **proportioning (or mix design)** of normal strength concretes is based primarily on the w/c ratio 'law' first proposed by Abrams in 1918. For **high strength concretes**, however, all the components of the concrete mixture are pushed to their limits. Therefore, it is necessary to pay careful attention to all aspects of concrete production, i.e., **selection of materials, mix design, handling and placing**.

The proportioning (mix design) of High Performance concrete consists of three interrelated steps :

1) **Selection of suitable ingredients** – cement, supplementary cementing materials (SCM),aggregates, water and chemical admixtures.
2) **Determination of relative quantities of these materials** in order to produce, as economically as possible, a concrete that has the rheological properties, strength and durability.
3) **Careful quality control** of every phase of the concrete making process.

COMPOSITION OF HPC

The most common **composition of high performance concrete** as supplementing cementitious materials or **mineral admixtures** are:

1. Silica Fume

2. Fly Ash

3. GGBFS(Ground granulated blast furnace slag)

1. Silica Fume in HPC

Silica fume is a waste by-product of the production of silicon and silicon alloys. Silica fume is available in different forms, of which the most commonly used now is in a densified form. In developed countries it is already available readily blended with cement.

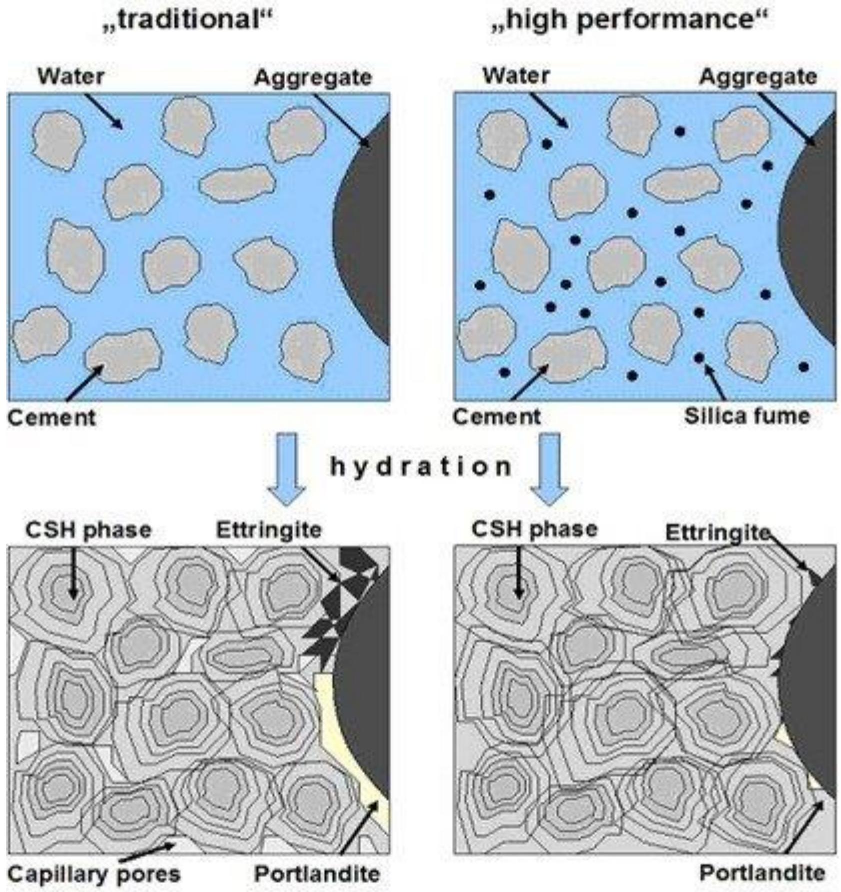
It is possible to make high strength concrete without silica fume, at compressive strength of upto 98 Mpa. Beyond that strength level however, silica fume becomes essential. With silica fume it is easier to make HPC for strengths between 63-98 Mpa.

2. Fly Ash in HPC

Fly Ash of course, been used extensively in concrete for many years. Fly ash is , unfortunately, much more variable than silica fumes in both their physical and chemical characteristics. Most fly ashes will result in strengths of not more than 70 Mpa. Therefore for higher strengths, silica fume must be used in conjunction with fly ash.

For high strength concrete, fly ash is used at dosage rates of about 15 % of cement content.

3. Ground granulated blast furnace slag (GGBFS) in HPC:
Slags are suitable for use in high strength concrete at dosage rates between 15-30 %. However, for very high strengths, in excess of 98Mpa, it is necessary to use the slag in conjunction with silica fumes.



Key Features of High Performance Concrete (HPC)

- Compressive strength > 80 MPa ,even upto 800 MPa
- Water-binder ratio =0.25-0.35 ,therefore very little free water
- Reduced flocculation of cement grains
- Wide range of grain sizes
- Densified cement paste
- No bleeding – homogeneous mix
- Less capillary porosity
- Discontinuous pores
- Stronger transition zone at the interface between cement paste and aggregate
- Low free lime content
- Endogenous shrinkage

- Powerful confinement of aggregates
- Little micro-cracking until about 65-70% of fck
- Smooth fracture surface

Silica Fume Concrete

CHARACTERISTICS OF SILICA FUME

1. Physical Properties

- Diameter is about 0.1 micron to 0.2 micron
- Surface area about 30,000 m^2/kg
- Density varies from 150 to 700 kg/m^3
- When its density is about 550 kg/m^3 it is the best suited as concrete additive

2. Chemical Composition

- Contains more than 90 percent silicon dioxide
- Other constituents are carbon, sulphur and oxides of aluminium, iron, calcium, magnesium, sodium and potassium

PROPERTIES OF SILICA FUME CONCRETE

1. Properties of Fresh Concrete

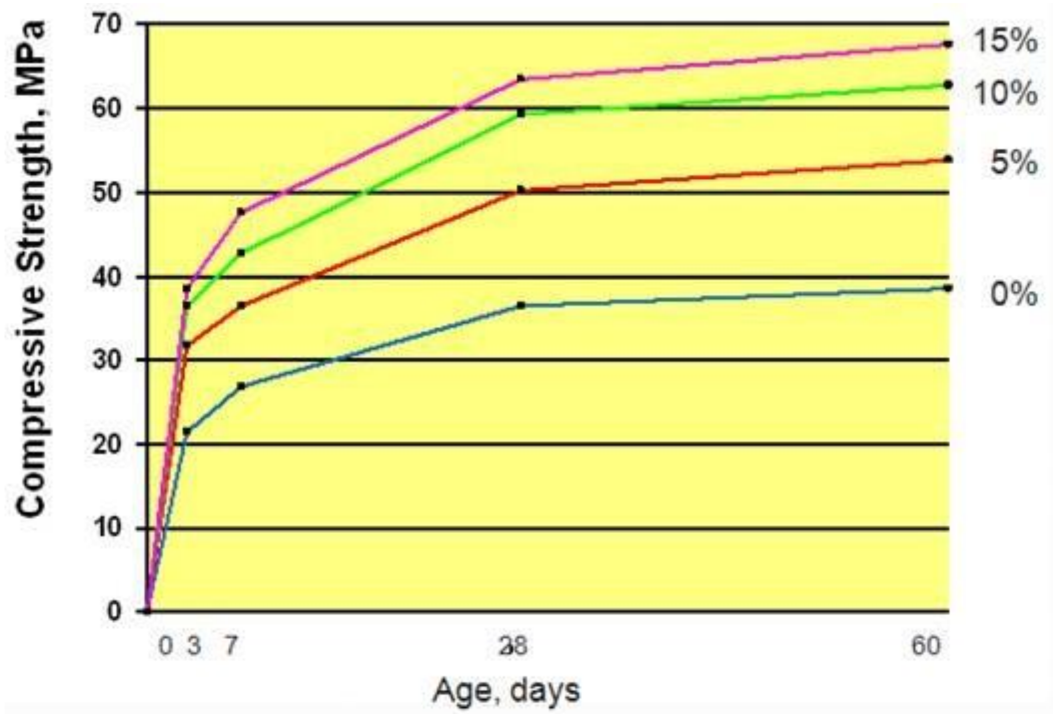
- Too much silica fumes cause the concrete to become sticky and thus reduces the workability
- Silica fume addition up to 15% by weight of cement does not result in any loss of workability
- Silica fume concrete, due to larger surface area of fine particle requires higher water content for same workability than ordinary concrete

2 Properties of Hardened Concrete

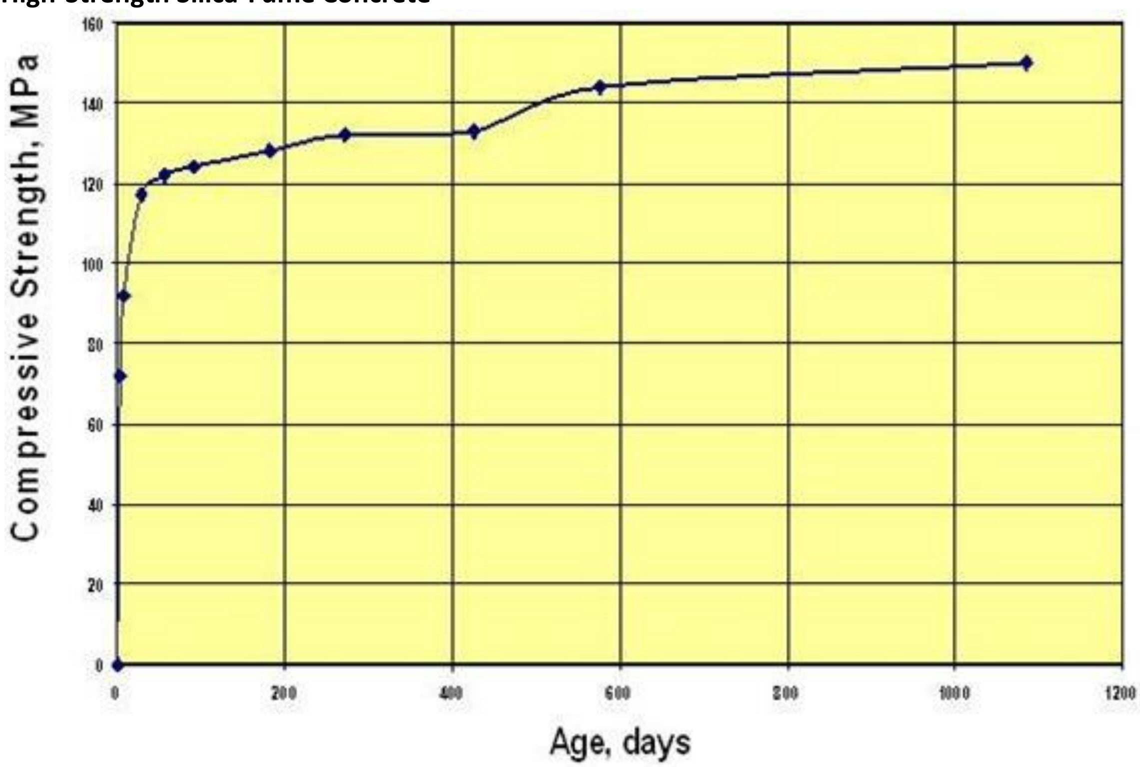
A Compressive Strength

- There is a marked increase in compressive strength, with the use of silica fume.

Silica-Fume Concrete: Typical Strengths

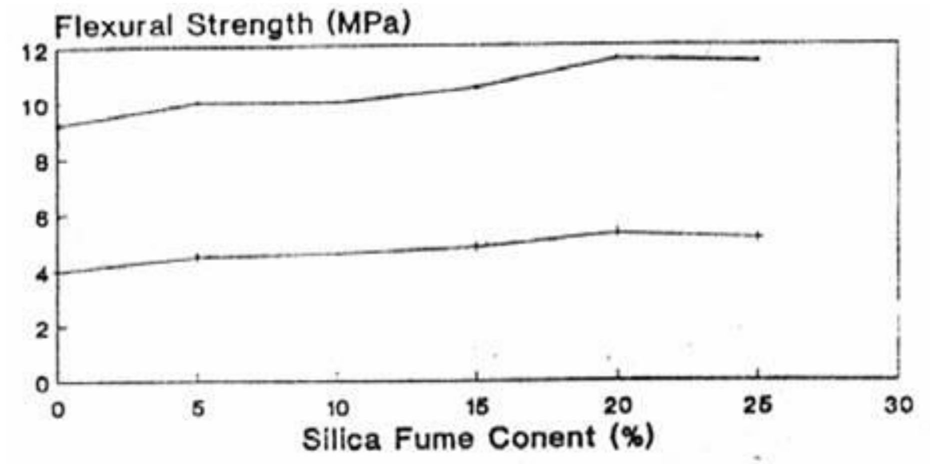


High-Strength Silica-Fume Concrete



Flexural Strength

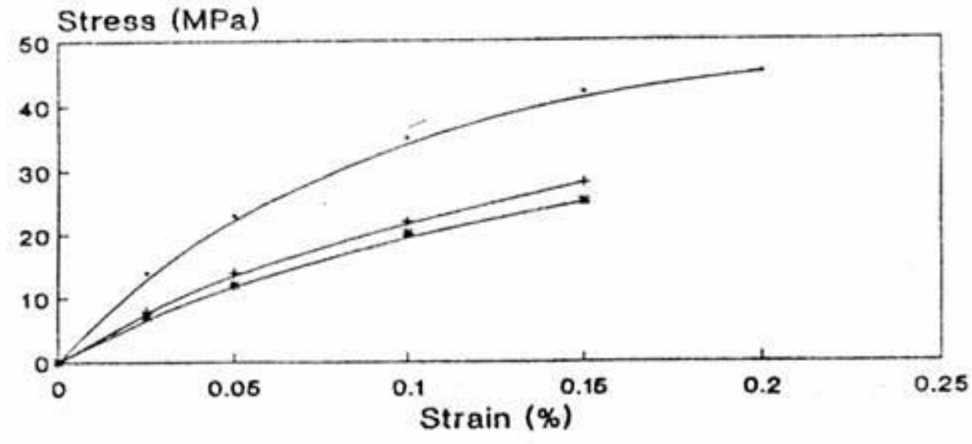
- Silica fume concrete has a gain in flexural strength from 5th to 20th days
- Upon filling the voids, silica fume densifies the mix, this increases the tensile strength of concrete and hence there is a increase in flexural strength



Flexural Strength of Silica Fume Concrete

Elastic Modulus

For silica fume concrete the strain at failure was more or less equal to that of ordinary concrete. This means that the modulus of elasticity is substantially higher than that of normal concrete



Stress Strain Curves for Silica Fume Concrete

DURABILITY OF SILICA FUME CONCRETE

Resistance to Chemical Attack

Silica fume checks sulphate attack by:

a) Being very fine, it reduces permeability and the entry of sulphate ions.

b) By consuming the calcium hydroxide in course of pozzolanic action, it checks conversion of mono-sulphoaluminate into ettringite.

Resistance against Acidic Environment

a) Silica fume reacts with lime present in paste matrix. Lime is considered as a dangerous compound, as it reacts with various chemicals causing expansion.

b) Silica fume mortar has a better pore structure which vastly reduces permeability.

c) Addition of silica fume as a partial replacement of cement reduces C3A content of the paste. C3A is seemed to react with acids causing expensive products.

ADVANTAGES

- Silica fume improves the properties of fresh and hardened concrete

- Fresh concrete made with silica fume is more cohesive
- Silica fume reduces segregation and bleeding
- Silica fume improves the durability of concrete
- Lack of bleeding allows a more efficient finishing process

PROBLEMS WITH THE USE OF SILICA FUME

- Availability
- Handling problem
- Cost

APPLICATIONS

- Silica Fume is now widely used for high strength structures

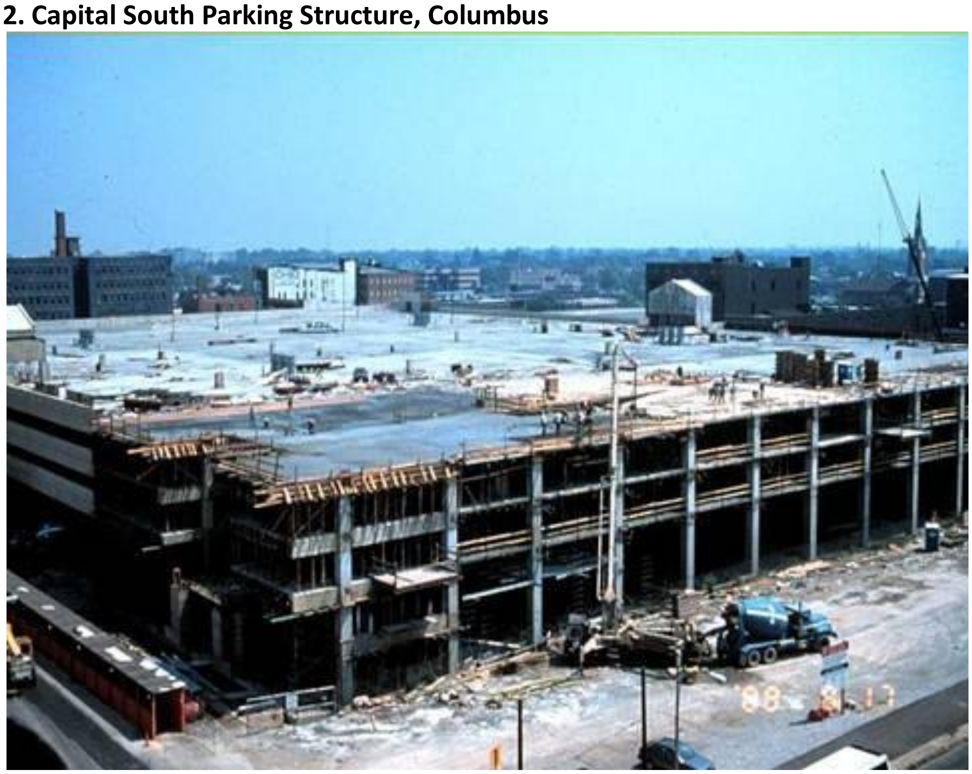
Examples

1. Key Bank Tower, Cleveland.

High-strength (83 MPa), high-modulus (47 GPa) concrete columns were specified at the corners of this structure to stiffen against wind sway.

The concrete for this structure contained a combination of Portland cement, blast furnace slag, and silica fume. The water-cementitious materials ratio was 0.24. A combination of chemical admixtures was used to produce a minimum slump of 250 mm.

2. Capital South Parking Structure, Columbus

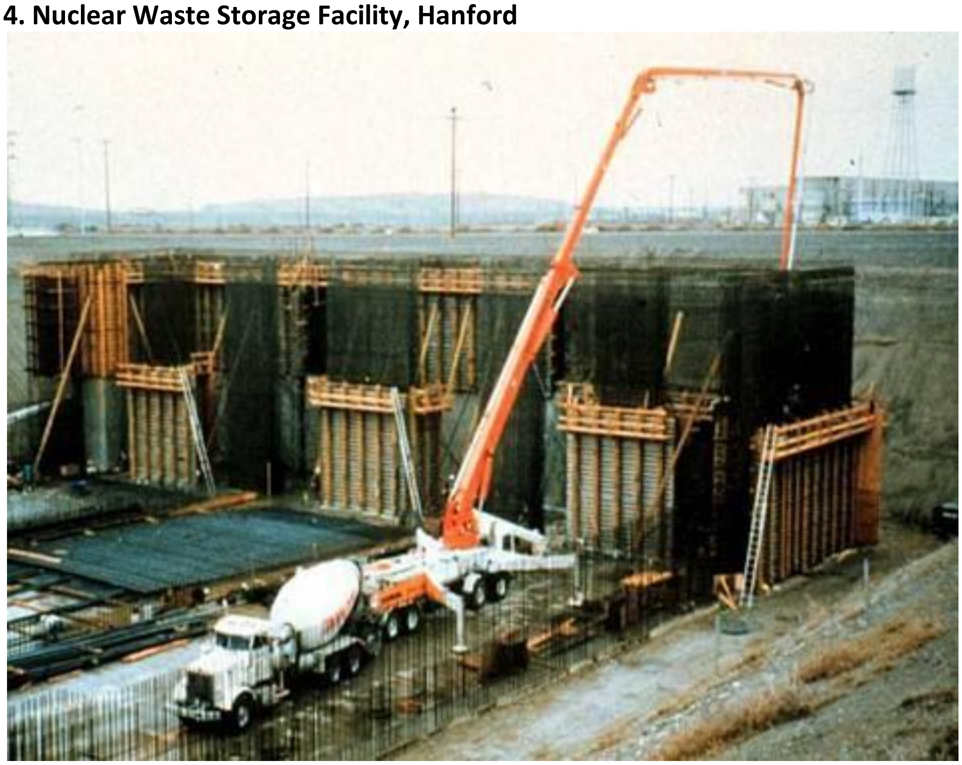


Designers of parking structures have specified low-permeability silica-fume concrete to slow the entry of chloride ions from deicing salts. A project using silica-fume concrete in a parking structure is described in the projects portion of this post.

3. Kinzua Dam, Western Pennsylvania

Kinzua Dam is located on the Allegheny River in western Pennsylvania. This structure is owned by the Corps of Engineers.

4. Nuclear Waste Storage Facility, Hanford



On this project silica fume was added primarily to enhance constructability. The exterior concrete walls in this structure are 4.5 ft (1.4 m) thick. To prevent thermally induced cracking, the designer specified very tight control over the maximum temperature rise allowed in the concrete. To meet the requirements for concrete temperature, the contractor elected to use a Class F fly ash in the concrete. While the fly ash did help to reduce temperature development, the early strength gain characteristics of the concrete were such that form removal was delayed. Addition of silica fume to the concrete provided additional early strength to facilitate form removal on a satisfactory schedule.

SHOTCRETE (OR GROUTED CONCRETE)

The concrete in which mortar or concrete is pneumatically projected at high velocity on the backup surface is known as shotcrete or gunite. It is also known as spray concrete as the force of jet impacting on the surface compacts it so as to make itself supporting.

This type of concrete has no special properties as compared to normal concrete placed under similar conditions.

ADVANTAGES OF SHOTCRETE CONCRETE

- Shotcrete concrete layers are very strong.
- These types of concrete do not need construction or expansion joints.
- It can be evenly applied on uneven surfaces and can be applied from a distance.

LIMITATION OF SHOTCRETE CONCRETE

- It has high cost. Its lining is less durable than ordinary concrete lining of the same thickness.

USE OF SHOTCRETE CONCRETE

- Thin and lightly reinforced sections likes curtain walls etc.
- Shell or folded roofs.
- Lining of tunnels, canals etc, protective covering for soft dock
- Stabilizing rock slopes
- Encasing steel
- Repair of old building and disintegrated leaking lining etc.

GUNITING

The guniting is the most effective process of repairing concrete work which has been damaged due to inferior work or other reasons. It is also used for providing an impervious layer.

The gunite is a mixture of cement and sand, the usual proportion being 1:3. A cement gun is used to deposit this mixture on the concrete surface under a pressure of about 20 to 30 N/cm^2.

PROCEDURE OF GUNITING

The cement is mixed with slightly moist sand and then necessary water is added as the mixture comes out from the cement gun. A regulating valve is provided to regulate the quantity of water.

The surface to be treated is cleaned and washed. The nozzle of gun is generally kept at a distance of about 750 mm to 850 mm from the surface to be treated and the velocity of nozzle varies from 120 to 160 m/sec.

ADVANTAGES OF GUNITING

Following are the advantages of guniting

- The high compressive strength is obtained. Strength of about 56 to 70 n/mm^2 at 28 days is generally obtained.
- The high impermeability is achieved.
- The repairs are carried out in any situation in a short time.

Chapter-12

Deterioration of Concrete and its Preventation

Different types of defects in concrete structures can be cracking, crazing,blistering, delamination, dusting, curling, efflorescence, scaling and spalling. These defects can be due to various reasons or causes.

Causes for Defects in Concrete Structures

Causes of defects in concrete structures can be broadly categorized as:

1. Structural deficiency resulting from errors in design, loading criteria, unexpected overloading, etc.

2. Structural deficiency due to construction defects.

3. Damage due to fire, floods, earthquakes, cyclones etc.

4. Damage due to chemical attack.

5. Damage due to marine environments.

6. Damage due to abrasion of granular materials.

7. Movement of concrete due to physical characteristics.

Structural Defects due to Design and Detailing

In such case, the design is required to be reviewed in detail and remedial measures worked out by the design team. Once this is done the methods of carrying out the remedial measures will be similar to those arising out of other defects.

Structural Deficiency due to Construction Defects

Defective construction methods form the largest segment of source of distress to the beams. Such defects can be broadly subdivided as follows:

1. Defects due to the quality of raw materials.

2. Non adoption of designed concrete mix.

3. Use of defective construction plant for producing, transporting, and placing the concrete.

4. Defective workmanship.

5. Inadequate quality detailing.

It is very necessary to choose the right type of cement for the concrete going into the structure under consideration. Ordinary Portland cement is the most common of all cements. Provided the quality of cement conforms to the relevant standard specifications, at the time of use, normally no problem is encountered in respect of ordinary Portland cement.

Where the concrete is exposed to aggressive environment, it may be necessary to use special cements, such as, sulphate resisting Portland cement, blast furnace slag cement, low C 3 A cement.

The quality of aggregates, particularly in respect of alkali-aggregate reaction, needs to be taken into account, fortunately cases of defects /failures attributed to alkali aggregate reaction in India are very rare.

The use of water containing salt for making concrete can also contribute to deterioration of the concrete.

The design of concrete mix can be satisfactorily carried out using a wide variety of aggregates. A reasonable continuity of grading of aggregates should be ensured.

Excessive use of water in the concrete mix is the largest single source of weakness.

The accuracy of weighing the various components is very much dependent on the quality of the weigh batching system, available. Spring loaded dials of the weigh batchers contribute toward$ excessive variability in the quality of weigh-batched concrete in India. Other contributory factors that add to bad workmanship include segregation, improper placement, inadequate or excessive vibration leakage of mortar through shuttering joints, inadequate concrete cover, in sufficient curing etc.

Proper detailing of reinforcement, including adequate cover is essential to ensure successful placement of concrete. Bad detailing results in congestion of reinforcement to such an extent that concrete just cannot be placed and compacted properly, even if the concrete is workable.

Detailing of reinforcement should be based on a proper appreciation of how the concrete placement and compaction is going to be carried out.

Other factors leading to poor design detailings

1. Re-entrant corners.

2. Abrupt changes in section.

3. Inadequate joint detailing.

4. Deflection limits.

5. Poorly detailed drips and scuppers.

6. Inadequate or improper drainage.

7. Poor detailing of expansion joints.

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.

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.

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.

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.

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.

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.

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.

8. Scaling and Spalling

Scaling and spalling, in both the cases concrete surface gets deteriorated and flaking of concrete occurs. The main cause for this type of cases is penetration of water through concrete surface. This makes steel gets corroded and spalling or scaling may occurs.

Some other causes are use of non-air entrained concrete mix, inadequate curing and use of lo strength concrete etc. This type of defects can be prevented by, using well designed concrete mixes, by adding air entrainment admixtures, proper finishing and curing, providing good slope to drain water coming on to the surface etc.

Causes Of Corrosion In Reinforcement Steel

Corrosion of the steel reinforcement bars may occur due to localized failure of the passive film on the steel by chloride ions or a general failure of the passivity by neutralisation of the concrete due to reaction with carbon dioxide from the atmosphere. 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. Effect of Corrosion in Reinforcement When the steel bars start corroding, the reinforced concrete member gradually begins deteriorating going through the following stages:

- **Formation of white patches –** Atmospheric carbon dioxide reacts with calcium hydroxide present in the cement paste forming calcium carbonate. This calcium carbonate is carried by moisture and deposited onto the concrete surface forming white patches.
- **Brown patches along reinforcement –** When the steel bars start corroding, a layer of iron oxide is formed on it. This iron oxide also gets carried to the surface of the concrete by moisture.
- **Formation of cracks –** The products of corrosion occupy a greater volume than the original material. Hence they exert pressure on the concrete and crack it. With more corrosion occurring, more and wider cracks are formed.
- **Spalling of concrete cover** – Due to loss of the bond between concrete and steel, the concrete starts forming multiple layers of scales and peels off. The steel bars also get reduced in size.
- S**napping of bars** – Due to reduction in the size of the steel bars, they finally snap. Also, there is a considerable reduction in the size of the main bars.
- **Buckling of bars –** Spalling of the concrete cover and snapping of bars lead to buckling of the main bars. This bulges the concrete in that regionand eventually the whole structure collapses.

Prevention of Corrosion in Reinforcement:

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

- **Adequate 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
- **Employing 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 as excessive water may damage the steel bars.
- **Proper Compaction:** Concrete must be sufficiently compacted such that no air voids or air pockets are present in it.

- **Using FBEC Bars:** Fusion Bonded Epoxy Coating (FBEC) is 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, which forms a protective coating. They are thermoset polymer coatings because application of heat will not melt the coating. Apart from rebars, it also has wide application in pipeline construction.
- **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.
- **The Rapid Chloride Permeability Test (RCPT):** This test is 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 ofthe concrete.
- **Use of Migratory Corrosion Inhibitors:** These are to be used in the concrete mix or 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-13

Repair technology for concrete structure

There are various techniques available for repair and rehabilitation of concrete structure for failure and defects in concrete. These techniques and materials for repair of concrete is described.

Concrete is the most widely used and versatile construction material possessing several advantages over steel and other construction materials. However very often one come across with some defects in concrete. The defects may manifest themselves in the form of cracks, spalling of concrete, exposure of reinforcement, excessive deflections or other signs of distress.

On many occasions, corrosion of reinforcement may trigger off cracking and spalling of concrete, coupled with deterioration in the strength of the structure. Such situations call for repairs of affected zones and sometimes for the replacement of the entire structure.

Causes for Failures or Defects in Concrete Structures

The following are the major causes for failures of concrete structures:

- Structural deficiency arising out of faulty design and detailing as well as wrong assumptions in the loading criteria.
- Structural deficiency due to defects in construction, use of inferior and substandard materials, poor workmanship, and negligence in quality control and supervision.
- Damages caused due to fire, floods, earthquakes, etc.
- Chemical deterioration and marine environments.
- Damages caused due to abrasion, wear and tear, impact, dampness etc.
- Movement of concrete caused due to settlement of foundation, thermal expansion etc.

Identification of Failures and Defects in Concrete Structures

A correct diagnosis establishing the cause, nature and extent of damage, and the weakness or deterioration caused in the structure is very essential, since a faulty diagnosis may lead to improper selection of materials and repair techniques leading to the failure of the repaired zone again. It may also be necessary that the serviceability of the structure is checked after carrying out the necessary repairs.

Need for Repair and Rehabilitation of Concrete Structure

The need of structural repairs can arise from any of the following:

- Faulty design of the structure
- Improper execution and bad workmanship
- Extreme weathering and environmental conditions
- High degree of chemical attack
- Ageing of the structure

Techniques for Repairs and Rehabilitation of Concrete Structure

The technique to be adopted for repair or restoration of the structure depends on the cause, extent and nature of damage, the function and importance of the structure, availability of suitable materials and facilities for carrying out repair, and a thorough knowledge of the long-term behavior of the materials used for the repair work.

Depending upon the requirement, the repairing technique may be of a superficial (cosmetic) nature or, in some cases, may involve the replacement of part or whole of the structure.

The repairing techniques can be classified into three major groups:

1. Injection into cracks, voids or honey-combed areas.
2. Surface treatment
3. Removal and replacing of defective or damaged material / area.

A variety of new materials have been developed for the repair and restoration of damaged structures by following any one of the above methods. These are briefly described below.

Materials for Repairs and Rehabilitation of Concrete Structure

Cement, Cement Grouts, etc.

In most cases, the repair material may be cement-based, since cement is the only active ingredient in concrete. Dry pack consisting of rich cement concrete or cement grouting may be suitable for sealing damaged areas and cracked portions.

Spraying of concrete or cement sand grout by means of high pressure nozzles, usually termed as 'shotcrete' or 'guiniting', respectively, may prove effective in many cases where a large surface area is to be repaired. The guiniting or shotcrete may be carried out with or without the use of steel reinforcing mesh or steel fibers.

Resin based Repairs of Concrete

The resins normally used are from epoxide, polyester, acrylic or polythene families. The application of resins for repair work requires a thorough understanding of their chemical and physical properties and their performance in the structure, particularly with the passage of time and under unfriendly environs.

Epoxy resin systems find application in civil engineering works such as grouting of cracks, repairs of eroded concrete structures, emergency repairs of bridges, aqueducts, chemically corroded columns and beams.

Generally, resin materials are used in repair and restoration work where properties such as, high strength (hence thin sections), excellent adhesion (hence small patches), quicker curing (hence saving in time), and high chemical resistance are required. One of the most commonly adopted resins is from epoxide. A brief description of the properties and applications of epoxy based resins is given below.

Epoxy Resins for Concrete Repair

The resin mortar may be obtained by adding fillers such as coarse sand or calcined bauxite grit. The chemical reaction begins as soon as the resin and hardener are combined. Most combinations have a pot-life between 30 and 60 minutes. They develop excellent strength and adhesive properties and are resistant to many chemicals besides possessing good water proofing.

Epoxy resin when cured with different hardeners offer wide range of properties. Once cured, they form irreversible system (thermosetting).

The characteristic properties of cured epoxy resin systems repair and rehabilitation of concrete structure are

- High adhesive strength to almost all materials
- Low shrinkage during curing
- Exceptional dimensional stability
- Natural gap filling properties
- Thermosetting (does not melt)
- Resistance to most chemicals and environments
- Ability to cure in wet conditions and underwater (for selected grades)
- Ease of application

Procedure of epoxy resin grouting

- Locating the cracks
- Cleaning of the cracked surface
- Drilling and fixing of nozzles for grouting at suitable intervals with epoxy putty
- Grouting of epoxy mixture with the help of the grout pump
- Sealing of nozzles through which grouting is done

A grout vessel essentially consists of a pressure vessel (to withstand 10 – 15 kg/cm^2 pressure) with inlet and outlet for resin mixture, pressure gauge, connection for compressed air with regulator for pressure grouting.
A pre-mixed resin + hardener is filled in the grouting vessel and through the nozzle the activated resin is pumped in the cracks. When cracks get filled in, the grouting is carried in the next nozzle and so on till all the cracks are filled in.

When cured, the epoxy resin improves the load carrying capacity of the cracked structure.

Bonding Old to New Concrete

Epoxy resin with a special polyamide hardener combination is successfully used for bonding old to new concrete.

The process consists of —

- Removal of all loose and damaged concrete using mechanical means or water jet
- Surface to be dried
- A suitable epoxy resin [unmodified solvent less epoxy resin + polyamide hardener (special grade)] is applied with stiff nylon brush

- The fresh concrete should be poured when epoxy coating has become just tack free
- Care should be taken not to completely dry the coating.

Epoxy resins are a not primary construction material. A judicious use of these resins is required in view of the high cost of these resins. The resins should be used in emergencies.

Properties of epoxy resin systems can be advantageously exploited, when other materials cannot be used due to strength or other considerations. Epoxy resins are finding many new applications in pressing conditions such as underwater repairs of dams, ships, etc. Many new applications will be found using epoxy and other synthetic resins in future.

Polymer Concrete Composites

Most of the deficiencies found in ordinary structural concrete are removed using polymer concrete composites either in the form of a surface coating over the structure or by impregnating it into the structure.

Polymer concrete composites are relatively new developments and have been used in structural applications since 1950. They possess very high strengths and are more durable and resistant to most chemicals and acids.

There are three types of polymer concrete composites, namely polymer impregnated concretes (PIC), polymer concretes (PC), and polymer cement concretes or polymer modified concretes (PCC or PMC). In PICs the monomers (usually styrene, methyl-methacrylate (MMA), polymethyl methacrylate (PMMA), etc.) are impregnated into the pore system of the hardened concrete, thereby filling up the pores and making them impermeable and resistant to chemical attack; In PCs the polymer is the sole binder in lieu of cement and water. In PCCs and PMC s, a polymeric additive (latex or pre-polymer) is added to the normal cement composite during the mixing stage itself.

All the three types of polymer concrete composites are useful for carrying out repairs and restoration work in damaged structures. The use of these composites for post-distress and post-failure applications is steadily increasing because of their superior durability, excellent bond to parent concrete structure, superior abrasion and wear-resistant properties, a high degree of resistance to chemicals like chlorides and acids, and their very low water absorption. Repairs of cracks can be easily carried out by injecting the polymer concrete damaged by corrosion of reinforcement can be chipped off and replaced by polymer concrete.

Sealants

Many commercial sealants are available for sealing of cracks in concrete structures. Joint sealants should ensure structural integrity and serviceability. They should also serve as protection against the passage of harmful liquids, gases, and other undesirable substance which would impair the quality of concrete. In the case of repair of a cracked surface, the cracks are first enlarged along their exposed face and are pointed up with the sealants.

Surface Treatment to Concrete

The durability of the concrete can also be increased particularly on the surface by applications of different materials which make it waterproof, hardened and resistant to chemical attack.

Some of the commonly used surface treatments are:

- Sodium silicate, magnesium or zinc fluoride

- Drying oils like Tung or Linseed oil
- Chlorinated rubber paints and neoprene paints
- Epoxy paints
- Silican Fluoride treatment

The surface of the hardened and dry concrete can be made abrasion resistant and less dust generating by application of solutions of sodium silicate, magnesium or zinc sulphates or silico fluorides. Drying oil like tung oil or linseed oil can be used. Alternatively, carborundum or fused alumina or finely divided iron aluminum chloride preparations may be added in the surface layer while placing the fresh concrete.

Floor paints also provide reasonable durability if the traffic on floor is not heavy. Paints containing synthetic resins particularly polyurethanes or epoxies or chlorinated rubber provide greater resistance to wear. They also protect against solutions of salts and dilute acids.

Sodium silicate and silico fluoride applications provide protection against mild conditions of attack by aqueous solutions or organic liquids. Bitumen and coal tar gives protection against insects and borers. Some plastic materials, rubber latex glass fiber coatings and PVC linings have also been successfully employed to improve durability of concrete.

Steel Fiber Reinforced Concrete

Use of small diameter steel fibers in concrete has been found to improve several properties of concrete and particularly its tensile strength and impact and wear resistance. One of the uses of steel fiber reinforced concrete (SFRC) is in the area of repairs and restoration of concrete structures.

The damaged portions of a concrete structure can be removed and can be made good by placing of SFRC to the sides and bottom of damaged structures by guiniting or shotcrete techniques. Because of its improved wear and tear and abrasion resistance, SFRC has been successfully employed for the repair of industrial floors and bridge decks with or without the use of polymer concrete.

Other Materials for Repair and Rehabilitation of Concrete

There are several other materials which can also be used for repairs of certain structures. For repairs to existing foundations, special chemical grouts have been developed which will ensure the compaction of the soil below and provides protection to the reinforcing steel in the foundations. Superplastized fiber reinforced concrete has been used in carrying out repairs to machine foundations and underground structures.

Certain chemicals and surface coatings marketed under brand names are said to seal the cracks in structures like water tanks and afford sufficient protection to the steel from corrosion. Special paints (latex or bitumen based) have also been developed for applying to the concrete surface or to the bars for making them resistant to aggressive environs.

With the increasing number of cases of damages being observed on structures built in the past, repairs and rehabilitation of such structures have assumed greater importance. Some of the techniques and materials found useful to reinstate some affected structures.

Table below shows the materials generally recommended for repair of concrete structures. Epoxy resins and concrete composites show high potential as promising repair materials.

Timely detection of deficiencies in concrete and steel of an existing structure and execution of immediate remedial measures will prevent further deterioration of the structure and will result in huge savings in the maintenance cost.

The old dictum, 'prevention is better than cure' is applicable to concrete structures, both at the time of constructing the structures and at a time when the structure has shown signs of initial distress.

Materials for Repair of Concrete

Repair Operation	**Material**	**Comments**
Sealing of fine cracks	Epoxy resins	– Good bonding properties even in the presence of moisture
Sealing of large cracks and joints	Portland cement Mortar Polymer mortar Putties and caulks	– Well – compacted – Good bonding properties – Based on synthetic polymers and tars
General sealing of surface	Synthetic polymers and asphalt coatings	
Localized patching of surfaces	– Concrete or mortar using Portland cement – Rapid-setting cements – Polymer resins; epoxies; polyesters	– Calcium aluminate and regulated-set cements – Good bonding
Repair Operation	**Material**	**Comments**
Overlays and shotcrete	– Portland cement concrete – Steel fiber reinforced concrete – Latex modified concrete – Polymer concrete – Asphaltic concrete	– Quick-setting admixtures – Resistance to cracking – Good bonding