1
Introduction

1.1. GENERAL

Concrete is one of the main materials of construction utilized in modern civil engineering works. It is used and studied closely by civil engineers. Other materials used in civil engineering constructions like steel, plastic, aluminium etc. have definite physical and strength properties and can not be varied, but the properties of concrete are largely depending upon type of material used, their properties, method of mixing, placing, curing etc.

No single building material has enabled civil engineers and architects to design and build structural forms that are functionally suitable and aesthetically pleasing, except for concrete, plain, reinforced or prestressed. In order to provide strength, stability and durability in construction, trends indicate that the primacy of concrete as a building material in the decades to come is not likely to be threatened despite the changing habits and needs of humanity or challenged by non-conventional building materials. This is because of the continuous improvement in the performance of concrete as a structural material, brought about through scientific research on its constituents and properties. For example concrete with a compressive strength of 100N/mm^2 is quite feasible, whilst concretes with high strengths of the order of 400 N/mm^2 are envisaged for the none too distant future.

Construction of today's civil engineering structures without using concrete are beyond imagination, rather structures are constructed using concrete as the only constructional material. The use of concrete in modern practice probably dates from 1950 as a rediscovery material in the form of cement concrete, after the production of Portland cement. The Romans as the master builders of the olden days used kind of concrete 'Structure Caementicia' which they made from the Pozzuolana cement mixed with broken fragments of stones and tiles.

They placed this material into timber forms; the marks of which can still be seen in places, and they even used pumice as aggregate when light-weight concrete was needed. The great dome of the Pantheon and other vaulted roofs testify to their skill in the use of this early concrete, lacking only reinforcing steel to make it the counterpart of the used today.

Concrete is a heterogeneous material produced by mixing some cementing material with strength giving material, further to make it workable for handling, moulding and placing some lubricating material is added. Such a concrete produced is named by its cementing material like cement concrete, lime concrete, bitumen concrete etc. The modern material cement concrete is obtained by mixing cement as cementing material, coarse aggregate, or metal or crushed rock as strength giving material and water as lubricating material. The cement along with water form cement paste which binds coarse aggregate to produce concrete which is a heterogeneous compound. This concrete is light and contains voids which reduce its actual strength. These voids actually increase intensity on coarse aggregate through covering cement paste joining these particles of coarse aggregate. Breaking of cement film causes concrete failure. To avoid this, these spaces or voids are required to be filled by some inactive material which is of course sand. It does not affect the quality of concrete and hence called as inert material. Thus, cement concrete is obtained by mixing cement, sand as an inert material and coarse aggregate by crushing rock mass.

This concrete is quite strong and durable. Cement concrete as such is quite strong in compression but weak in tension. The size of coarse aggregate, specific gravity of material, grading, quality of material etc are various factors which affect the quality of concrete. Despite the number of factors that determine the final character of concrete, the aggregate is 70% by volume and probably 80% by weight, consists of the coarse aggregate used. Hence, most of the properties of concrete are based on quality of aggregate used. Further the present practice is to improve work ability and to reduce its bleeding. Admixtures also affect the various other properties of concrete.

Hence, these ingredients of concrete when mixed thoroughly produce fresh wet concrete which is put in forms. Once the concrete is hardened, form work is removed and hardened concrete becomes a structural part of the construction. The proportion of these gradients depends on various factors. The main job of civil engineer is to use these materials such that the final product must be strong enough to resist stresses and the cost of construction must be minimum.

Admixture is also one of the important constituent of concrete. As on today, hardly and concrete is prepared without using some kind of admixture. It has become an integral part of concrete. Thus todays concrete is called as a mixture of cement, sand, coarse aggregate, water and admixture.

1.2. CONCRETE

Concrete referred as plain concrete is a material obtained by cementing together with the inert materials such as sand, gravel, crushed rock or some other suitable material which is hard and durable. It possesses the distinguishing property to harden under water. A diagrammatic representation is as shown in the Fig. 1.1.

Concrete is one of the main materials of construction utilized in modern civil engineering works. It is perhaps, that which should be most closely studied by civil engineers. The quality of a given piece of timber can not be varied, and steel also has definite properties when supplied for use; but the quality and strength of concrete are under the control of the engineer in charge of construction. Further the quality of given concrete can be varied even by using its main constituent cement, sand, coarse aggregate and water in different proportion, method of mixing; curing etc.

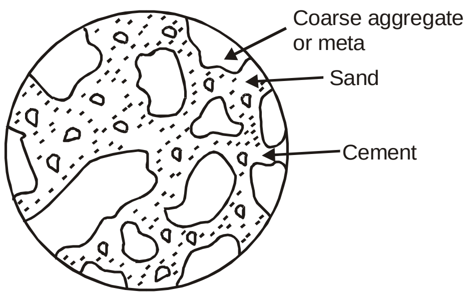

Fig. 1.1. Diagram of structure of plain concrete.

The use of concrete in modern practice probably dates from about 1850; but only after the development of modern Portland cement produced in 1845 by *Isaac Johnson*.

The fame of the Romans as the master builders of olden days is due in no small measure to their use of a kind of concrete, 'Structure caementicia', which they made from the puzzuolana cement, mixed with broken fragments of stone and tile. They placed the material in timber forms, the marks of which can still be seen in places; and they even used pumice as aggregate when light weight concrete was needed. The great dome of the Panthoeon and other vaulted roofs testify to their skill in the use of this early concrete, lacking only reinforcing steel to make it the counterpart of that used today.

The term concrete is synonymous to a 'Solid' material. In building industry it means a hard and solid material made from a mixture of cement, water and aggregates. The strength, durability and other characteristics of concrete depend upon the properties of its ingredients, the proportion of mix, the method of compaction and other controls. Hardened concrete may be considered as an artificial stone in which the voids of larger particles (coarse aggregates) are filled by the smaller particles (fine aggregates) and the voids of fine aggregates are filled with cement. Cement in addition to filling the voids of fine aggregates also acts as a binder. Set and hardened concrete is strong in compression but weak in tension. Situation in which tensile stresses are developed, concrete strengthened by steel bars forming composite construction is termed as R.C.C. (Reinforced Cement Concrete). Sometimes the tensile stresses are taken care of by introducing compressive stresses in the concrete so that the initial compression neutralises the tensile stresses. Such a construction is known as 'Prestressed Cement Concrete Construction'.

1.3. IMPORTANCE OF CONCRETE

Concrete is by far the most widely used man-made construction material and studies indicate that it will continue to be so in the years and decades to come. Such versatility of concrete is due to the fact that from the common ingredients, namely, cement, aggregate and water (and nowadays admixtures also), it is possible to tailor the properties of concrete so as to meet the demands of any particular situation. It has found use in nearly all types of construction—from highways, bridges, dams, chimneys, towers, canal linings, to the most beautiful and artistic of buildings. With the addition of steel reinforcement to supply the needed tensile strength, it has become the foremost structural material.

Concrete technology has progressed and evolved with the times and with new discoveries. In the latter part of the 19th century, concrete was ordinarily placed nearly dry and compacted with heavy tampers. There was practically no reinforcement used at that time. In the early part with the development of reinforced concrete, very wet mixes become popular and much of the concrete was literally poured into the forms and had neither good strength nor durability. This practice continued until investigations began to emphasize the importance of using scientifically designed mix proportions to produce a uniform concrete of improved workability, strength and durability. It is now possible to produce concrete satisfying the performance requirements by making use of locally available material through judicious mix proportioning and proper workmanship.

Even though the properties of the ingredients of concrete are important individually, the concrete users are now interested in the concrete itself having desired properties. In the true sense, concrete is thus the real building material rather than its ingredients like cement and aggregates, which are only intermediate products. This concept of treating concrete as an entity is symbolised with the progress of ready-mixed concrete industry, where the consumer can specify the concrete of his needs without bothering about the ingredients ; and further in precast concrete industry where the consumer obtains the finished structural components satisfying the performance requirements.

1.4. MAKING GOOD CONCRETE

Improved practices and techniques have added greatly to our ability to produce good concrete, and engineers are in close agreement on the practical needs for producing it. They recognize that in addition to proper ingredients, a modern formula for successful concrete production would include common sense, good judgement and vigilance.

There is still some concrete which, through carelessness or ignorance in the manufacture and placement, fails to give the service that can be expected. It is the responsibility of those in charge of construction work to make sure that concrete is of uniformly good quality. The extra effort and care required to achieve this objective are small in relation to the benefits. Good engineering dictates acceptance of only the best when the best is procurable at no greater cost. This axiom is especially true of concrete, for the best costs usually no more than the mediocre. All that is required to achieve the best is an understanding of the basic principles of making good concrete and close attention to proved practices during construction.

1.5. GRADING OF CONCRETE

Concrete is graded according to its compressive strength. The various concrete grades are shown in Table 1.1. In this classification of concrete mix; letter M refers to the mix and the number to the specified characteristic compressive strength of 150 mm. cube at 28 days expressed in N/mm^2. The characteristic strength is defined as the strength of concrete below which not more than 5% of the test results are expected to fall. M5 M7.5 grades are generally used for lean concrete bases and simple foundations for masonry walls. Grades M15 and M20 are used for normal reinforced concrete works. M25, M30 and M35 are used as high strength concrete mixes. Grades lower than M40 can not be used in pre-tensioned prestressed concrete and lower than M30 cannot be used in post tensioned concrete.

Table 1.1. Grades of Concrete

Designation	*Mix proportion*	*Characteristic compressive strength in N/mm^2*
M5	—	5
M7.5	—	7.5
M10	1 : 3 : 6	10
M15	1 : 2 : 4	15
M20	1 : 1½ : 3 tentetive else designed	20
M25	1 : 1 : 2	25
M30	Designed	30
M35	Designed	35
M40	Designed	40
M45	Designed	45
M50	Designed	50
M55	Designed	55
M60	Designed	60

Normal concrete can be a nominal concrete or 'designed concrete' depending upon whether the proportions of ingredients are prespecified (nominal concrete) or have to be worked out depending upon the service requirements. In special situations, concrete can be classified in many other ways : by its density (for example, lightweight, normal weight or heavy weight concrete), workability (for example, flowing or pumpable concretes) or its durability in specific environment (for example, sulphate-resisting concrete, refractory concrete).

Table 1.2. Standard Applications.

Classification	*Grade*	*Applications*
Ordinary	M10	PCC (Plain Cement Concrete) e.g., levelling course, bedding for footing, concrete roads, etc.
	M15	PCC e.g., Levelling course, bedding for footing, concrete roads, etc.
	M20	RCC (Reinforced Cement Concrete) e.g., slabs, beams coloumns, footings, etc. (for mild exposure)
Standard	M25	RCC (Reinforcement Cement Concrete) e.g., slabs, beams coloumns, footings etc.
	M30	RCC e.g., slabs, beams, coloumns, footing, etc.
	M35	RCC e.g., slabs, beams, coloumns, footing, etc.
	M40	RCC e.g., pre-stressed concrete, slabs, beams, coloumns, footing, etc.
	M45	RCC e.g., runways, concrete roads, prestressed concrete girders, RCC coloumns, prestressed beams.
	M50	RCC e.g., runway, concrete roads, prestressed concrete girders, RCC coloumn, prestressed beams.
	M55	RCC e.g., prestressed concrete cirders and piers
High strength	M60-M80 and more	RCC work where high compressive strength is required such as high rise buildings, long span bridges, ultra-thin white topping etc. and constructions in aggressive environment e.g., spillways of dams coastal construction.

The utility of grading of concrete is that it gives concrete an identifying number, enabling the engineer to decide the grade of concrete required for each part of the work and determine the suitable limitations on the constituent materials and mix proportions. The use of cube strength at 28 days for specifying the grade designation has arisen out of convenience as major part of the long-term strength of concrete made with normally used cements which is attained at this age. However, when special cements, such as high alumina cement, are used, the strength development at earlier ages may also have to be specified.

1.6. ADVANTAGES AND DISADVANTAGES OF CONCRETE

1.6.1. Advantages

The advantages of using concrete are :

1. It is quite strong; durable and fire proof.
2. It is further economical in long run compared to other materials; requires less maintenance if used properly.
3. It can be moulded to any shape and size for architectural and decorative purposes.
4. It is quite strong in compression and along with steel as reinforcing material to resist tension, concrete has unlimited structural uses. These two materials have approximately same co-efficient expansion, and develop very good bond with each other.
5. Concrete can be used as grouting material to fill up cracks.

6. It can be pumped hence places where spaces for material storages are not available; it can be transported by means of pipe line.

1.6.2. Disadvantages

In general, it has hardly any disadvantage if constructed properly; further some deficiencies can be overtaken by using some admixtures. Following are the disadvantages of concrete.

(*i*) It has low tensile strength hence surface cracks develop which lead water to penetrate and cause corrosion of steel, but this drawback can be minimised by using steel bars and meshes.

(*ii*) It shrinks on drying and expands on wetting. Provision of expansion joints is made which minimizes it. Concrete further expands and contracts, hence expansion joints provided take care of it.

(*iii*) Concrete subjected to sustained loads causes creep.

(*iv*) Concrete cannot be made impervious hence water soluble salts cause efflorescence which gives bad appearance to concrete. This further reduces life of electric fittings etc.

(*v*) Concrete is liable to sulphate attack and alkalies attacks hence deteriorates and disintegrates with respect to time.

(*vi*) This is brittle material.

Uses : Probably in todays time; none of the structures can be built without using concrete. It is used for almost all items of building works. It is further used for construction of dams, bridges, bunkers; silos, retaining walls ; water tanks, shells, domes etc. Further concrete is also used for grouting works. Present trend of construction of doors and window frames of concrete is also becoming common. It is also used for precast construction works of jallies; railway sleepers; floor decks etc.

1.7. PROPERTIES OF CONCRETE

The characteristics and properties of concrete depend on many factors. The characteristics of concrete should be considered in relation to the quality required to final product for specific construction. Ingredients used, their relative quality and quantity, amount of water, manner in which these ingredients are mixed, placed, curned, etc. are various factors which affect the quality of concrete. Tempreature during mixing, placing and curing also affect on characteristics of concrete.

In general concrete is very strong in compression. It is brittle and hard. A plain concrete has little usable tensile strength, it is reinforced by mild steel bars when subjected to tensile stress. Following are the main properties of concrete which must be taken into consideration while designing a mix or proportion of concrete ingredients.

Concrete is prepared by mixing concrete ingredients and placing this wet concrete into forms. This concrete is cured till it attains its specific strength. Hence studies of properties of concrete can be held under two different conditons:

1. When concrete is still in plastic stage, *i.e.,* wet concrete or fresh concrete.
2. When the concrete has become hard, *i.e.*, hardened concrete.

For an Engineer, the properties of hardened concrete are of only importance, but these properties depend mainly on workability of concrete, *i.e.,* property of plastic concrete before it is placed in position. The various properties of concrete are dealt in detail. Various tests performed to ascertain properties are also dealt with properties.

The main constituents of concrete are cement, fine aggregates and coarse aggregates and it is usual to specify a particular concrete by the proportion (by weight) of these constituents. Thus 1 : 2 : 4 concrete stands for the particular concrete prepared by mixing cement, sand and broken stones in the proportion of 1 : 2 : 4. However by specifying this proportion, the property of this concrete, is not completely specified as there are a number of variables which influence the quality of concrete. These variables may be summarised as below:

(*i*) *Water*—its ratio in term of cement known as water cement ration, and its quality.

(*ii*) *Aggregate*—quality of fine and coarse aggregates; their size and grading.

(*iii*) *Method of compaction and other quality controls.* However, inspite of all the above variables, there is one single property of concrete namely its crushing strength, which can invariably be used as the basis for evaluation of any concrete.

The important properties of concrete are :

1. Permissible stresses :
   (*i*) Compressive strength in bending (*ii*) Direct compressive strength
   (*iii*) Diagonal tension (Permissible stress in shear meassured as diagonal tension)
   (*iv*) Local bond stress
   (*v*) Average bond stress
   (*vi*) Bearing pressure.
2. Workability
3. Durability
4. Creep
5. Shrinkage
6. Fire resistance
7. Segregation
8. Modulus of Elasticity and Modular ratio.

The above properties are briefly described below :

1. Permissible stresses. Concrete when hardened, supposed to take various stresses like compression, impact etc. Reinforcing bars are introduced in concrete to resist bending and shear stresses. Concrete is very strong in compression but weak in tension; as such steel bars are introduced to take tension, bending, shear stress, torsion, etc. Fibres are also mixed in concrete to prevent surface cracks during drying.

2. Workability. Workability of concrete is a measure by means of which plastic concrete can be placed and compacted in form easily.

3. Durability. Durability and strength of concrete normally go together. In other words higher the compressive strength of the concrete more durable it will be. The various factors which affect the durability are:

(*i*) Mix of the concrete (Proportion of its constituents)

(*ii*) Quality of fine and coarse aggregates. (It is presumed that the cement used satisfies the IS tests)

(*iii*) Water cement ratio, (*iv*) Compaction and curing

4. Creep. Creep is the strain in the direction of loading which a material undergoes when it is subjected to prolonged loading. It is time-dependent phenomenon and the strain due to this effect is additional to the elastic strain caused due to instantaneous strain.

The various factors which influence creep in concrete are :

(*i*) Age of the concrete at the application of stress.

(*ii*) Magnitude of the strain.

(*iii*) Nature of the stress and its duration.

(*iv*) Water cement ratio and strength of concrete.

(*v*) Properties and proportion of fine and coarse aggregates in relation to cement.

In R.C.C. structures, the effect of creep is redistribution of stresses between steel and concrete resulting in additional stresses being developed in steel.

The total creep strain during any specific period is assumed for all practical purposes, to be the creep strain due to a sustained stress equal to the average of stresses at the beginning and end of the period.

The loss of prestress due to creep of concrete under load shall be determined for all the permanently applied loads including the prestress.

The creep loss due to live load stresses, erection stresses and other stresses of short duration may be ignored. The loss of prestress due to creep of concrete is obtained as the product of modulus of elasticity of the prestressing steel and the ultimate creep strain of concrete fibre integrated along the line of centre of gravity of the prestressing steel over its entire length.

The total creep strain during any specific period is assumed for all practical purposes, to be the creep strain due to sustained stress equal to the average of stresses at the beginning and end of the period.

5. Shirnkage. When concrete sets and hardens it shrinks. The amount of shrinkage varies from 0.02 to 0.10% depending on a number of factors which affect the quality of the finished concrete product but primarily on the water cement ratio employed in the preparation of the concrete. Shrinkage of concrete can therefore be considerably reduced by keeping smallest w.c. ratio and using denser mix.

Shrinkage of concrete results in its cracking. The size of these cracks is kept small by providing nominal network or reinforcement. It results in the concrete gripping the reinforcement and developing the desired bond.

The loss of prestress due to shrinkage of concrete is the product of the modulus of elasticity of steel and shrinkage strain of steel.

6. Fire Resistance. The fire resistance property of concrete is due to the following :

(*i*) Water combined in a chemical state. (*ii*) Presence of pores.

The chemically combined water is removed at the temperature above 300°C. At this elevated temperature however, the insulation property of concrete increases.

The fire resistant property is also influenced by the quality of the coarse aggregate. For example broken brick aggregate concrete is better fire resistant than broken stone aggregate.

In the case of R.C.C. however, the rise in temperature result in lowering of the strength of the concrete because of transfer of heat through the steel. For this reason R.C.C. work should be given adequate cover of plain concrete.

7. Segregation. There is always a danger of the components of cement concrete mix getting segregated because till such time as the concrete sets and hardens the bond between the consituents does not develop. The following conditions accelerate segregation.

(*i*) Water mix.

(*ii*) Large size coarse aggregate *i.e.*, (MSA) maximum size of aggregate.

(*iii*) Coarser grading.

Thus it is seen that whereas from the consideration of surface area, the fineness of fine aggregate has to be restricted, from the consideration of risk of separation, the upper size of coarse aggregate has also to be restricted.

The liability to segregate depends upon the cohesiveness of the mix and this depends in the increase on the specific surface of the aggregate and cement combined.

Under the following situations it becomes necessary to increase the proportion of fines and hence the cohesiveness of the mix.

(*i*) Lean mix. (*ii*) Wet mix.

(*iii*) Conditions under which handling promotes segregation.

(*iv*) Mould or reinforcement contains sharp corners.

(*v*) Comparatively large maximum aggregate.

(*vi*) When concrete is to be pumped.

(*vii*) Rough textured aggregate.

(*viii*) Concrete underwater.

8. Modulus of Elasticity and Modular Ratio. Loading tests show that in the initial stages stresses are proportional to strains. With the increase in stresses there is increase in the strain. The other factors which effect the modulus of elasticity of concrete are:

(*i*) Strength of concrete. (*ii*) Age of concrete.

(*iii*) Moisture content of conrete. (*iv*) Type of aggregates.

For the purpose of design however, the modulus of elasticity of concrete for a concrete of specified strength is taken as constant and is equal to E_s/m, where m is the modular ratio between steel and concrete.

Module of Elasticity, $E_c = 5700\ \sqrt{f_{ck}}$ N/mm^2

where E_c = Short term elastic modulus of elasticity in N/mm^2 and f_{ck} is the characteristic cube strength of concrete in N/mm^2.

1.8. USES OF CONCRETE AS BUILDING MATERIAL

As building material concrete is used in the following cases :

1. Foundations

(*i*) Foundation of all types of structures.

(*ii*) Caissons. (*iii*) Cofferdams.

(*iv*) Well foundations. (*v*) Pile foundations.

2. Superstructure

(*i*) Walls and pillars (*ii*) D.P.C.

(*iii*) Flooring. (*iv*) Lintels.

(*v*) Slabs and beams. (*vi*) Roofing.

3. Construction of R.C.C. and Prestressed Concrete Bridges

4. Bunkers and silos **5.** Shell Structures

6. Water Tanks **7.** Retaining Walls

8. Dams

1.9. INGREDIENTS OF CONCRETE

Ingredients of concrete can broadly be classified under the following two categories:

1. Cement and 2. Aggregates.

1. Cement. Cements are broadly classified into the following :

(*i*) Portland
(*ii*) High alumina
(*iii*) Super sulphate
(*iv*) Special cement such as masonry
(*v*) Trief
(*vi*) Expansive
(*vii*) Oil well cement.

The main constituents of portland cement are lime (60 to 67%) Silica 17 to 25% and Alumina 3 to 8%.

The properties of portland cement are governed mainly by the fineness of grinding and the relative proportions of the three principal active compounds. Other cements derive their particular properties through the addition of certain materials desired to give the required effect.

2. Aggregates. Aggregates may be classified according to their petrological characteristics and can be divided into the following :

(*i*) Heavy weight
(*ii*) Nominal weight
(*iii*) Light weight

Natural   Artificial

The aggregates can also be classified according to their particle shape into the following:

(*i*) Rounded
(*ii*) Irregular
(*iii*) Angular
(*iv*) Flaky

According to their surface texture they may be divided into:

(*i*) Glassy
(*ii*) Smooth
(*iii*) Granular
(*iv*) Rough
(*v*) Crystalline
(*vi*) Honey-combed
(*vii*) Porous.

Sawdust and wood shavings have also been used as aggregates but in such a case precaution has to be taken to counteract the effect of soluble carbohydrates which most timbers contain.

In specific cases asbestos in the farm of chrysotile has been used as an aggregate.

Furnace clinker can form satisfactory aggregate if suitable precautions are taken.

In localities where natural aggregates are not available light weight aggregates are extensively used. The chief light weight aggregates are :

(*i*) Foamed slag
(*ii*) Expanded shales
(*iii*) Slates
(*iv*) Clays.

1.10. PERCENTAGE STRENGTH OF CONCRETE AT VARIOUS AGES

The strength of concrete increases with age due to curing. Table 1.3 shows the strength of concrete at different ages in comparison with the strength at 28 days.

The gain in compressive strength above that at 28 days is about 25% after 3 months, 56% after 6 months, 75% after one year and 100 percent after 3 years provided the curing is done. This is all theoretical, hence concrete never reaches its 100% strength.

Table 1.3.

Age in days	*Strength percent of 28 days*
1	16%
3	40%
7	65%
14	90%
28	99%

Concrete should be cured under temperature and moisture conditions most favourable to a normal gain in strength to prevent formations and cracking which may be due to intensive dewatering and contraction. Precautions must be taken against mechanical damage to the fresh concrete. During the warm season, open surface of concrete (floor or deck surface) should be protected against direct insolation and the action of wind with matting, wet saw, dust, polymer films.

Freashly placed concrete should be protected against mechanical damage, and care should be taken to ensure the strength and the stability of construction.

1.11. STRUCTURAL PROPERTIES OF CONCRETE

The behaviour of hardened concrete largely depends upon its structural proportion. The important structural properties are as given below :

1. Crushing strength of concrete.
2. Tensile strength of concrete.
3. Flexural strength of concrete.
4. Modulus of Elasticity & poisons ratio.

Besides the above Shrinkage, Creep, Thermal conductivity, Resistance to wear, Resistance to Weather, Impermeability etc. are some of the other structural properties.

The structural properties of concrete are largely governed by four factors :

(*a*) Water/cement ratio.

(*b*) The quality & characteristics of cement.

(*c*) Degree of compaction, and

(*d*) The age of concrete.

In general, the water cement ratio required for sound workability varies from 0.4 to 0.5. As the water cement ratio is increased there is fall in the strength of concrete. The importance of quality and characteristics of cement are well recognised. The degree of compaction decides the compactness of the concrete mass. As regards the age of concrete it is well known that as the age of concrete increases there is a gain in the strength. The rate of gain of strength is high in the initial stages and as age goes on increasing the rate of gain reduces though there is always a gain in strength except after a certain limit which is due to the deterioration of the concrete.

Crushing Strength of Concrete. It is well known that concrete has a very poor strength in tension as compared to the same in compression. In many design procedures the tensile strength of concrete is neglected and only the compressive strength is accounted for the design. It is also possible to have a general idea about the tensile and flexural strength of concrete from the knowledge of compressive strength. The method of testing concrete is comparatively very simple and hence it is very common to test the concrete in compression.

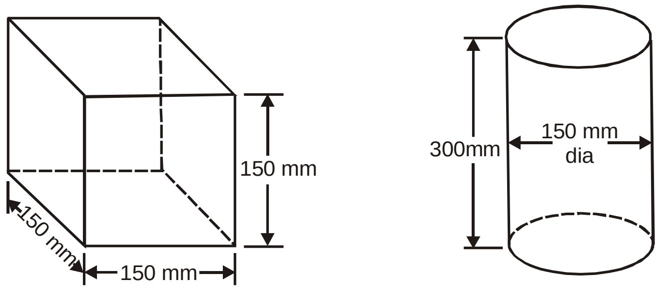

Fig. 1.2(*a, b*) Various shapes and sizes of specimen used for compression strength test.

The compressive strength obtained for a concrete, with same water cement ratio, same aggregate cement ratio, same cement, same aggregate and with same degree of compaction, varies with the rate and shape of the specimen used for the test.

The various shapes used for preparation of specimen are cubes, cylinders and prisms. The cubes may be of 100 mm size or 150 mm size, cylinders may have a diameter of 100 mm or 150 mm or 200 mm and a height diameter ratio of 2 of the base.

Durability and strength are the two main properties : Strength is most important test, as it is generally the basic of conclusions regarding the qualities of end product. High strength concrete is usually good concrete. If excessive cement is used to get high strength, keeping water cement ratio low, there may be excessive shrinkage and hair cracking.

Testing of compressive strength of concrete. The compressive strength of concrete is one of the most important and useful properties of concrete. This single property of concrete usually represents an overall picture of the quality of concrete. It is qualitative measure of other properties.

The compressive strength of concrete is the maximum load per unit area sustained by a concrete specimen before failure under compression. Although the compression test on concrete is easy to carry out, the test results are difficult to interpret in terms of actual strength which is influenced by many factors. Many of the important properties of concrete like the modulus of elasticity, resistance to shrinkage, creep and durability improve with the increase in compressive strength.

A major portion of the structural concrete used is proportioned to have a strength of 15 to 25 N/mm^2 at 28 days. High strength concrete used in prestressed works is designed to have a 28 days compressive strength of 35 to 50 N/mm^2. The compressive strength of mass concrete may be as low as 7.5 to 15 N/mm^2, while that of dry lean concrete only 3.5 to 7.1 N/mm^2.

At present different types of specimens are used to determine the compressive strength of concrete in different countries. The common types of specimens used being cube and cylinders. For crushing strength test cubes are used in U.K., Germany, India and many other European countries. Cylinders are used in U.S.A., Canada, Australia, and New Zealand.

The ratio of cylinder to cube strength depends primarily on the level of strength of concrete and is found to be higher for high strength concrete. The cylindrical strength may be taken as equal to 75 to 80% of the cube strength for concrete of a crushing strength of 15.0 N/mm^2. The ratio of cylinder to cube strength approaches almost unity for very high strength concrete having a 28 days strength of 70 N/mm^2.

1.12. PERMEABILITY OF CONCRETE

Penetration of concrete by materials in solution may adversely affect its durability. For example, when $Ca(OH)_2$ is being leached out or an aggressive attack by liquid takes place. Specially in the case of R.C.C. entry of water and air results in the corrosion of steel. Since this leads to an increase in the volume of the steel, cracking and spalling of the concrete cover may well follow.

Both the cement paste and aggregate contains pores. In addition, the concrete as a whole contains voids due to improper compaction. These voids can be reduced by vibration.

The cement paste envelopes the aggregate, contains pores. In addition the concrete as a whole contains voids due to improper compaction. These voids can be reduced by vibration. The pores in the cement paste are made up of cement gel 28% and capillary pores (0 to 40%). The latter depends on water cement ratio.

Though the cement gel has a porosity of 28%, its permeability is only 7×10^{-14} cm/sec. This is due to extremely fine texture of hardened cement paste. The cement paste as a whole is 20 to 100 times more permeable than the cement paste. Therefore in a properly compacted concrete, permeability is controlled by capillary pores in the cement paste. The coefficient of permeability of the capillary pores can be reduced to a greater extent by w/c ratio.

The higher permeability of concrete is due to the following reasons:

1. Due to long term drying, micro cracks form in concrete, causes deterioration of concrete due to weathering effect, these cracks also develop due to structural stresses.
2. Unequal thermal stresses cause rupture of bond between concrete constituents.
3. Air is entrapped in concrete due to poor compaction of concrete, this causes environment to have undue defects in concrete.
4. Various other reasons cause volume change of concrete, hence permeability of concrete is affected.

The permeability of concrete can be reduced by :

1. Reducing water cement ratio to optimum value.
2. Compacting concrete thoroughly but not in excess.
3. Using pozzolanic material.
4. Use of air entrained concrete upto certain level *i.e.,* upto maximum reduced permeability. Excess air should be avoided.
5. Using dense aggregate.

Permeability of concrete of good quality is so low that permeability test is rearely required. However the test is conducted when concrete is required for containing highly volatile liquids and light fraction petroleum which are very penetrative. Further, in mass concrete work as in concrete dams where concrete is subjected to very high hydrostatic pressures and lean air concrete having 3 or even 2½ bags per cu.m of concrete have been used, permeability of concrete needs to be examined.

1.13. DURABILITY OF CONCRETE

Although the methods of strength calculations for engineering structures have been rather thoroughly elaborated, the ways in which stone materials are acted upon by various physical and chemical weathering agents need further investigations. A profound study of the special problems involved in weathering has been associated with an extensive investigation of the behaviour of concrete in any climatic zone. The failure of concrete is usually related to the action of water on it. If concrete is not saturated with water systematically, its failure at temperatures below zero is precluded, since concrete will not suffer multiple freezing and thawing, no chemical corrosion of the fabricated stone will occur due to lime being washed out of it, or for instance, decay due to formation of new chemical compounds which back cementing properties. The formation of chemical compounds of a volume exceeding that of its components, etc. Besides water, concrete and aggregate are acted upon by other weathering agents. The weathering of cement concrete is identical to the weathering of aggregate. It results in a loss of bond between newly formed particles of the concrete and between the stone particles of aggregates in concrete.

This is defined as the ability of the material to withstand the effects of its environment. The durability of concrete depends on its resistance to deterioration and the environment in which it is placed. The resistance of concrete to weathering, chemical attack, frost and fire depends largely upon its quality and constituent materials. Susceptibility of corrosion of the steel is governed by the cover provided and the permeability of concrete. The cube crushing strength is not only the reliable guide to the quality and durability of concrete, it must also have an adequated cement content and a low water cement ratio. One of the main cement characteristics influencing the durability of any concrete is its permeability. With strong dense aggregate, a suitably low permeability is achieved by having a sufficiently low water cement ratio, by ensuring as thorough compaction of the concrete as possible and by ensuring sufficient hydration of cement through proper curing method. Therefore, for given aggregate, the cement content should be sufficient to provide adequate workability with the means available.

In construction, the durability of concrete may be inter penetrated as :

1. Chemical attack.
2. Physical stress, and
3. Mechanical assault.

Chemical attack is usually encountered as aggressive ground water, particularly sulphate, polluted air and spillage of reactive liquids.

Physical stresses are principally frost action and shrinkage and temperature stresses.

Mechanical damage can result from abrasion or impact or from excessive loading.

The other internal causes are the alkali aggregate reaction, volume changes due to the differences in thermal properties of aggregate and cement paste, and permeability of the concrete. Deterioration of concrete is rarely due to one cause, it is due to combination of more than one.

1.14. GOOD CONCRETE

It is difficult to give a precise definition of "Good Concrete". However in general it can be stated that good concrete is one which can satisfy certain standards in fresh state, while being transported from mixer to actual site, placed and compacted to and achieves equal strength after getting in hardened state.

As far as hardened state is concerned, it is generally specified as 28 days characteristic strength of concrete cube/cylinder. It should be noted that the compressive strength obtained from standard tests using cubes/cylinders prepared and cured under certain conditions is not the actual strength of concrete in the structural member. It is common practice that a period of 28 days is specified as standard curing duration. It should be noted here that this duration is only from the point of view standardization and it should be changed keeping in mind the requirement of different projects and working conditions, type of materials used and structure in consideration.

1.15. MIXING GOOD CONCRETE

During manufacture of concrete following points must be considered for good concrete.

1. Fresh cement should be used. Cement starts losing its strength if stored for more than 6 months.
2. Well graded aggregate free from all impurities should be used.
3. During batching, moisture content of aggregate must be taken into consideration.
4. Concrete must be mixed in mixer. It should be mixed thoroughly.
5. Water added should be free from all impurities. Minimum quantity of water for maintaining required workability should be used.
6. During transportation, it should be seen that concrete has not become dry. There should be no segregation during transportation of concrete.
7. Concrete should be placed at its final position before setting starts.
8. Concrete should be compacted properly either by hand or by vibrator.
9. It should be finished after its little stiffining.
10. It should be cured properly for at least 10 days.
11. Formwork used should be rigid, water tight and smooth.

REVIEW QUESTIONS

1. What do you mean by M15 grade concrete?
2. What is the proportion of various constituents of M10 grade concrete?
3. What is concrete?
4. Where can we use M10 grade concrete?
5. What are different grades of concrete?