CHAPTER THREE

Concrete

Concrete is a product obtained artificially by hardening of the mixture of: binding material (cement), fine aggregate (sand), coarse aggregate (gravel), Admixtures in some cases, and water, in predetermined proportions. Since concrete is made from different materials which form different parts, it is known as a composite material.

Concrete is a workable plastic mixture of cement, aggregate & water which can be cast in to any desired shape or convenient size. Concrete when set and cured resemble stone in weight, hardness, brightness & strength.

The property of concrete varies depending on the quality of the constituent, proportion of the concrete mix, quality of the workmanship & curing. In concrete each and every aggregate must be completely surrounded by the paste of cement. The paste binds the aggregate together and forms a solid mass. The pastes usually occupy 25 - 35% of the volume of the concrete.

In concrete mixes, the ingredients should be so proportioned that the resulting concrete has the following properties. When freshly mixed it should be workable enough for economical and easy and uniform placement, but not excessively fluid. When hardened it should poses strength and durability adequate to the purpose for which it is intended. It involves minimum cost consistent with acceptable quality

The chemical reaction takes place rapidly of first with considerable amount of water lost and then slowly for a long period under favorable conditions.

3.1. Materials for Concrete.

3.1.1 Water:

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement paste, the quantity & quality of water is required to be looked very carefully.

Generally water used for drinking is suitable for making good concrete. In general water to be used in concrete should be free of Sugar, Carbonates & bicarbonates of sodium & potassium, Chlorides & Sulphides, Salts of manganese, tin, zinc, copper & lead, Silt & suspended particles. And Algae with some permissible amount.

The use of sea water for mixing concrete lead to corrosion of reinforcement. Therefore, it should be avoided. the best way to find out whether a particular source of water is suitable for concrete making or not, is to make concrete with this water & compare its 7 days and 28 days strength with cubes made with distilled water.

Impurities in mixing water may cause abnormal setting time, Decreased strength, Volume changes Efflorescence, Corrosion of reinforcement.

Water has two functions in concrete mix

i) It reacts chemically with cement.

ii) It lubricates all other materials & makes the concrete workable.

Cement used in concrete mix needs less than 30% by wt. of water for its hydration process. However, because of the dual function of water, concrete containing such a small amount would be very dry and very difficult **to fully compact**. The quantity of water used in concrete mix has; therefore, to be sufficient to fully satisfy both functions, for this reason water used in concrete mix is usually much greater than 30% of the cement wt.

The total amount of water required per unit volume of fresh concrete depends on:

- The desired consistency
- The maximum size, particle shape, and grading of aggregate
- The water reducing or air entraining admixtures.

3.1.2. Cement

3.1.3 Aggregates

Aggregates are the most important constituent on concrete. They give body to the concrete, reduce shrinkage, and effect economy. The fact that aggregate occupy 65 - 75 percent of the volume of concrete, their impact on various mixes and properties of concrete is considerable.

Therefore, in choosing the aggregate, attention should be given to four general requirements.

a) Economy of the mixture b) Potential strength of hardened mass

c) Probable durability of the concrete structure d) Workability when fresh

The Function of the aggregate is to form the inert mineral filler material which the cement paste binds together and Reduce the volume changes resulting from the setting and hardening process and from moisture changes in the paste

3.1.3.1 Classification of aggregates

Aggregates can be classified as normal wt. aggregate, light wt aggregate and heavy wt.aggregate according to their wt. Aggregates can be further classified as natural aggregate and Artificial Aggregate based on their source.

Natural:

Sand, gravel, crushed rock (granite, quartzes, basalt, sand stone)

Artificial:

Broken Brick, air cooled slag

Aggregate can also be classified on the basis of the size of the aggregate as coarse aggregate (bigger than about 4.75mm in diameter).and fine aggregate below 4.75mm.

3.1.3.2. Source of aggregate:

Almost all natural aggregate materials originate from bed rocks. There are three kinds of rocks, namely igneous, sedimentary & metamorphic. Most igneous rocks made highly satisfactory concrete aggregate. The quality of aggregate desired from sedimentary rocks will vary in quality depending up on the cementing material and the pressure under which these rocks are originally compacted. Some siliceous sand stones and lime stones have proved to be good concrete aggregate.

Metamorphic rocks such as quartzes, snless have been used for production of good concrete aggregate. But mica shall not be used as concrete aggregate.

Many properties of aggregate namely, chemical & mineralogical composition, specific gravity, hardness, strength, physical and chemical stability, pore structure, etc depend mostly on the quality of the parent rock. But there are some properties such as size and shapes which are important so far as concrete making is concerned which have relation with the parent rock.

The most part of Ethiopia sand is obtained from river beds while coarse aggregate is prepared from crushed rock & sold as crushed stone aggregate.

3.1.3.3 Gradation of Aggregate.

One of the important properties of aggregate used for concrete is the gradation of particles. A suitable gradation of the combined aggregate in a concrete mix is essential in order to secure good workability and to secure economy in the use of cement. For mixes of given consistency & cement content a well graded mixture produces a stronger concrete than a harsh or poorly graded one, since less water is required to get the required workability.

The grading (particle size distribution) of aggregate is determined by sieve analysis, which is usually made by shaking the material through a series of sieves (BS or ASTM) or screens, nested in order with the smallest on the bottom.

BS	3"	11/2"	3/4"	3/8"	3/16"	No 7	No 14	No 25	No 52	No 100		
ASTM	3"	2"	11/2"	1"	3/4"	No 4	No 8	No 16	No 30	No 50	No100	No200

Fineness Modulus (FM):- The FM is an empirical factor obtained by adding the total percentage of an aggregate sample retained on each of a specified series of sieves and dividing the sum by 100. It is used as an index to the finesse or coarseness and uniformity of aggregate supplied, but it is not an indication of the grading, since there could be an infinite number of gratings which will produce a given F.M. which will produce a given F.M. In calculating the F. M. The intermediate sieves No. 200, 1/2 ' 1' and 2" ASTM sieves should be omitted.

Example: Sieve analysis of fine aggregate

Total wt. of sand to be taken for sieve analysis is soon

Sieve size	wt. retained	percent retained	cumulative period Retained	Cumulative percent passing

3/8"	0	0	0	100
No 4	2	0.4	0.4	99.67
No 8	29	5.8	6.2	93.8
No 16	133	26.6	32.8	67.2
No 30	140	28.0	60.8	39.2
No 50	147	29.4	90.2	9.8
No 100	39	7.8	98.0	2.0
No 200	8	1.6	99.6	0.4
Rest	8	0.4		0
Sum	506	100	100	FM = 288.4/100 = 2.88

Percent retained % $= \frac{wt\ .\ retained}{Total\ wt}\ x\ 100$

Cumulative percent coarser (retained) % = the commutative sum of the percent retained.

Commutative percent passing % = 100 - commutative percent coarser.

Example:2 Sieve analysis of coarse aggregate.

wt. of C.A. to be taken for sieve analysis depends on the maximum size of aggregate (ASTM).

N.B. The maximum size of aggregate is defined by the largest sieve through which at least 90% of the aggregate passes.

Sieve size (ASTM)	wt. retained (gm)	Percent retained	com. per retained	Com per. passing
3"				100
2"				100
11/2"				100
1"	1444	18	18	82

3/4"	4350	54	72	28
1/2"	1423	18	90	10
3/8"	550	7	97	3
No 4	223	3	100	-
No 8	-	-	100	-
No 16	-	-	100	-
No 30	-	-	100	-
No 50	-	-	100	-
No 100	-	-	100	-
No 200	-	-	100	-
Sum	8000	100	769	

$$FM = \frac{769}{100} = 7.69$$

Combined Aggregate:- Some times aggregate available at sites may not be of specified or desirable grading in such case two or more aggregate from different sources may be combined to get the desired grading. Often mixing of available CA in appropriate percentage may produce desirable gradients. But some times two or more fraction of C.A. is mixed first and the combined C.A. is mixed with F.A. to obtain the desired grading.

Grading requirements: The maximum size and grading are important factors to be considered because they affect:

a) The relative volume occupied by the aggregate (i.e. the relative proportions), hence the economy in producing concrete.

b) The surface area of the aggregate which determine the amount of water necessary to wet all the solids.

c) The workability of the mixture

d) The tendency to segregation.

e) Porosity and shrinkage.

This means that from the point of view of selecting proportions (mix design), it is important to have a well graded CA and FA with maximum possible size. For the above reason, national standards specify grading limits for coarse, tine and combined aggregate (Refer table 8.8, 8.9 and 8.12).

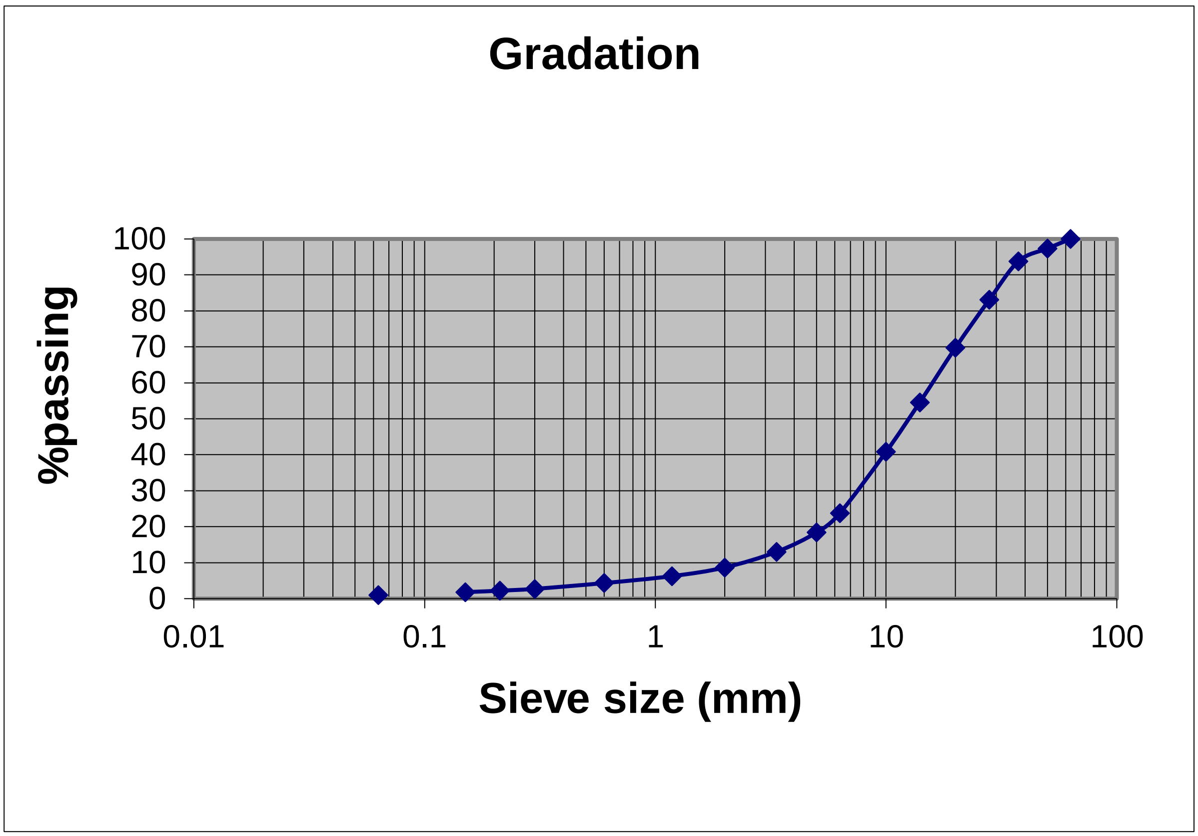
In addition the FA should not have more than 45% retained b/n any two consecutive sieves and the FM. should not be less than 2 or more than 3.5 with tolerance ± 0.2.

Grading chart: The result obtained as percentage passing or percent coarser can be shown graphically in grading charts. The chart consists of sieve opening in the horizontal axis and percent passing or percent coarser in the vertical scale.

GRADATION

Sieve size (mm)	Weight of sieve(gm)	Weight of sieve+soil(gm)	Weight of retained(gm)	Percentage retained	Cumulative % retained	Percentage passing
63	0	0	0	0.00	0	100.00
50	0	247	247	2.66	2.66	97.34
37.5	1718.9	2047.3	328.4	3.54	6.20	93.80
28	1726.7	2721.3	994.6	10.71	16.91	83.09
20	1626	2859.8	1233.8	13.29	30.20	69.80
14	1353.9	2765.9	1412	15.21	45.42	54.58
10	1318.7	2598.3	1279.6	13.78	59.20	40.80
6.3	1347	2929.7	1582.7	17.05	76.25	23.75
5	1377	1873.4	496.4	5.35	81.60	18.40
3.35	1319	1820.2	501.2	5.40	87.00	13.00
2	374.1	776.7	402.6	4.34	91.34	8.66

1.18	389.6	613.5	223.9	2.41	93.75	6.25
0.6	351.9	531	179.1	1.93	95.68	4.32
0.3	319.4	468.5	149.1	1.61	97.28	2.72
0.212	305.4	352.1	46.7	0.50	97.79	2.21
0.15	298.1	335.5	37.4	0.40	98.19	1.81
0.063	255.9	329.7	73.8	0.80	98.98	1.02
Pan	315.4	409.7	94.3	1.02	100.00	0.00



3.1.3.4. Quality of Aggregates

An aggregate for concrete must be clean, sound, hard and strong and durable. Harmful substances which may present in aggregate may be classified as follows.

a) Substance causing an adverse chemical reaction.

E.g. organic materials such as loam, humus, sugar, etc.

b) Substances which undergo disruptive expansion example, shale, colloidal silica (chert), iron Oxide etc …

c) Clay and surface coatings

- Dust increase water requirement and clay prevents good bond between cement paste and Aggregate.

d) Particles having an unduly flat oven elongated shape (offsets workability).

e) Structurally soft or weak particles.

- Give lower strength and increase drying, shrinkage, abrasssion.

Reactive aggregate: the alkalis No_2O in some cement react with certain minerals present in the aggregate and course disruption of concrete.

Numerous tests have shown Opaline silica to be a serious of tender other known reactive substances are chalcedy, tridymite, critubolic zeolite, rhyolite, decites and as desires.

The extremely fine fraction of aggregate materials are commonly classified as silt and clay and should not permitted in large amounts because of their tendency to increase the water requirements of a mix and thus contribute to decrease strength or durability.

3.1.3.5 SPECIFIC GRAVITY & UNIT WT OF AGGREGATE.

Specific gravity:- The specific gravity of a substance is the ratio between the wt of the substance and that of the same volume of water. This definition assumes that the substance is solid through out. But aggregate usually contain pores and hence the specific gravity has to be carefully defined.

i. ABSOLUTE SP.GR:- It is the ratio of the mass of a unit volume of material to the mass of the same volume of gas free distilled water.

ii. APPARENT SP.GR.:- is the various of the wt air of a materials of a given volume solid matter plus impermeable pores or voids to the wt. in air of an equal volume of distilled water.

App. sp.gr = A/A-C

iii. Bulk Sp. GR:- is defined as the ratio of the wt in air of a given volume of a permeable material (including both its permeable & impermeable voids) to the wt in air of equal volume of water.

Bulk sp.gr = A/B - C

On saturated surface any basis the bulk specific gravity is defined as in ratio of the wt. in air of permeable material in a saturated surface dry (SSD) condition to the wt in air of an equal volume of water.

Where A = wt. of the over dry sample in air

B = wt of SSD sample in air

C = wt of saturated sample in water.

In the computation of quantities for concrete mixes it is the specific gravity the SSD aggregate that is always used.

When the sample is tested in separate size fractions the average value for bulk specific gravity can be computed as the weighted average of the values as computed in the above equations using the following equations.

$$G = \frac{1}{\frac{P_1}{100G_1} + \frac{P_2}{100G_2} + ... + \frac{P_n}{100G_n}}$$

Where G = Average specific gravity

G_1, G_2 ………… G_n = appropriate sp.gr. values for each size fractions.

P_1 , P_2 ……….P_n wt percentage of each size fraction present in the original sample.

The bulk specific gravity for fine aggregate can be determined using pycnometer on the basis of wt of saturated surface dry aggregate as follows.

Bulk specific gravity (SSD) = A/B+A-C.

Where A = wt . of SSD sample (usually 500g)

B = wt of pycnometer filled with water (g)

C = wt. of pycnometer with specimen and water to calibration mark. g.

Average specific gravity of rocks varies from 2.5 - 2.9.

UNIT - WT (BULK DENSITY):- The unit wt of aggregate is the wt. of a unit volume of aggregate usually stated in kg/m^3. It is helpful in batching by volume.

VOIDS:- The term void (w.r.t. amass of aggregate) refers to the space between the gross overall, volume of the aggregate mass & the space occupied by the particles alone.

$$Percentage\ of\ voids\ \frac{Solid\ unit\ wt - unit\ wt}{Solid\ unit\ wt}\ x\ 100$$

Solid Unit wt:- is the specific gravity of a material in metric unit (kg/m^3)

- Useful in calculating solid void of aggregate.

Eg:- unit wt = 1680 Kg/m^3

sp.gr = 2.65

$$Voids\ (\%) = \frac{2.65 x 100 - 1680}{2.65 x 1000}\ x\ 100$$

= 36.6 %

For a given specific gravity the greater the unit wt the smaller the percentage of voids, and hence the better the gradation of the particles.

$$Solid\ volume = \frac{Weight}{Solid\ unit\ wt}$$

The unit wt of aggregate is influenced by the specific gravity of the particles, the moisture condition of the aggregate and the compactness of the mass.

General unit wt of some natural aggregate.

Sand	1520 - 1680 Kg/m^3		
Gravel	1280 - 1440	"	Compacted unit wt.
Crushed stone	4250 - 1400	"	

The unit wt. of aggregate may vary a considerable range, depending up on the type, grading and the source of the material. Aggregate made of blast furnace slag may range in unit wt from 960 kg/m^3 to 1360kg/m. The unit wt of Ethiopian pumice is about 200 kg/m^3.

3.1.3.6. ABSORPTION & MOISTURE CONTENT

*Some of the aggregate are pores and absorptive. Poro*sity & absorption of aggregate will affect water cement ratio and hence the workability of the concrete. The porosity of aggregate is also affect the durability of concrete. When the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

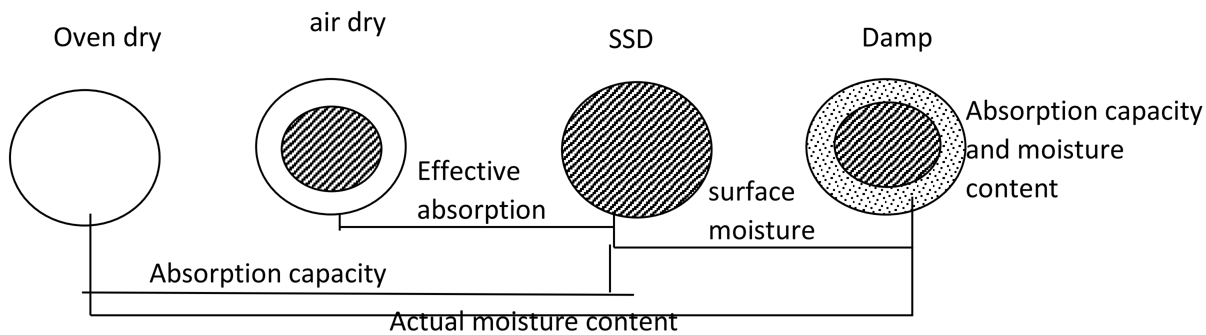
Aggregate to moisture content, the various states in which an aggregate moisture exist are

1. OVEN DRY: all moisture, external and internal driven off, usually by heating at 100-110^{o}c

2. AIR DRY: No surface moisture on particles, some internal moisture, but particles are not saturated.

3. SATURATED SURFACE DRY: no free or surface moisture on the particles, but all void between the particles is fill with water.

4. DAMP OR WET: Saturated and with free or surface moisture on particles.



5. ABSORPTION CAPACITY:- The total internal moisture content of an aggregate in SSD condition.

Absorption capacity % = $\frac{SDD - Oven\ dry\ wt}{Ovendry\ wt}\ x\,100$

6. EFFECTIVE ABSORPTION:- The amount of water required to bring an aggregate from the air dry condition to SDD.

Effective absorption (%) = $\frac{SDD\ wt - air\ dry\ wt}{Oven\ dry\ wt}\ x\,100$

Surface (free) moisture (%) = $\frac{Damp\ wt - SDD}{SDD}\ x\,100$

It should be noted that if the aggregate are dry they absorb water from the mixing water and they affect the workability, and on the other hand, if an aggregate contains surface moisture they contribute extra water to the mix and their increase w/C ratio. Hence adjustment on the quantities of the materials have to be made based on SSD condition of the aggregate since of this state the aggregate will neither absorb nor contribute water to the mix.

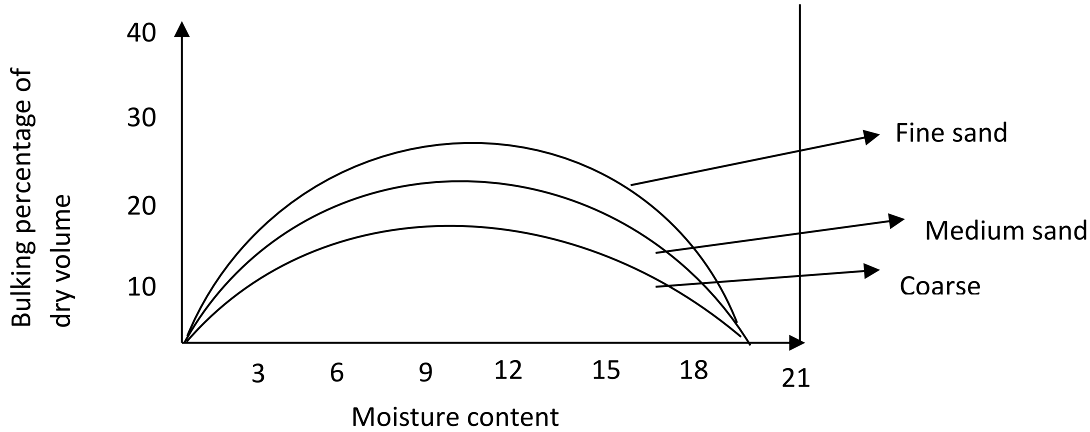
In the case of weight batching, determination of free moisture content of the aggregate is necessary & correction of w/C ratio to be affected on this regard,

but when volume batching is adapted, the determination of moisture content of the fine aggregate does not become necessary but the cons equate batching of sand & correction of volume of sand to give allowance for balking is necessary.

1.1.3.7. BULKING OF SAND

In the aggregate free moisture holds the particles a part and present then from adjusting themselves. to occupy a minimum volume, hence they may result a marked decrease in wt of aggregate in a given measured volume and measure in the percentage of voids. These phenomena known as "bulking".

The bulking increases with the increase in moisture content up to a certain limit and beyond that the further increase in moisture content results in the decrease in the volume and at a moisture



content representing saturation pt. the fine aggregate shows bulking.

Coarse aggregate also bulks but the bulking is so little that it is always neglected the extent of bulking can be estimated by a simple field test. A sample of moisture fine aggregate is filled in to a measuring cylinder note down the level say m, pour water in to the measuring cylinder and completing inundate the sand and shake it . Since the volume of the saturated sand is the same as that of the dry sand; the inundated completely offsets the bulking effect Note down the level of the sand say h_2. Then h_1 - h_2 shows the bulking of the sample under rest.

Percentage of bulking = (r/o) $\frac{h_1 - h_2}{h_2} x\ 100$

Mostly, mix proportions by volume given specifications are based on dry sand - Hence, if the specified quantity is followed, and moist sand is used, the mix will contain less sand (and more cement) than interested, and it will be harsh and difficult to work. There fore whenever volume batching is used, bulking of moisture sand has to be allowed for by increasing its total volume. In this case the volume of sand obtained from the proportions in the saturated state, is multiplied by the bulking factor.

Bulking factor $1 + \frac{h_1 - h_2}{h_2} = h_1/h_2$

3.1.3.8. TEST ON AGGREGATES

1) Sieve analysis
2) Unit wt. determinate is
3) Specific gravity
4) Absorption test
5) Determination dust or clay content
6) Organic impurities of sand
7) Soundness
8. Abrasion test (Los Angeles abrasion)

- Abrasion is the resistance to wear.

3.1.4. ADMIXTURES

Admixtures are defined as materials other than cement, water & aggregate that is used as an ingredient of concrete and is added to the batch immediately before or during mixing.

This day's concrete is being used for so many purposes in different conditions in these conditions ordinary concrete may fail to exhibit the required quality or durability or workability. In much cases admixtures is used to modify the property of the ordinary concrete. So as to make it most suitable for any conditions. As per the report of ACI committee 212 admixtures have been classified into 15 groups according to the type of materials consisting the admixtures, use. The some groups are listed below.

1. Air entraining agents
2. Pozzolona
3. Accelerators
4. Retarders
5. Air determining a gents
6. Air determining agents
7. Alkali aggregate expansion inhibitors
8. Damp proofing & permeability
9. Workability agents.
10. Grouting agency
11. Corrosion in habiting agents.
12. Bonding agents
13. Fungicidal, germicidal & in sectional agents

3.2. FRESH CONCRETE

Fresh concrete or plastic concrete is a freshly mixed material which can be molded in to any shape. The relative quantities of cement, aggregate and wall mixed together control the properties in wet state as well as in hardened state.

3.2.1 PROPERTIES OF FRESH CONCRETE

1. WORKABILITY:- is the property of fresh mixed concrete which determines the easy and homogeneity with which it can be mixed, Placed, compacted and furnish and serve the purpose it is intended for when hardened.

2. CONSISTANCY:- is a general term to indicate he degree of fluidity or the degree of mobility of the freshly mixed concrete.

A concrete which has a high consistence and which is a more mobile, need not be of right workability for a particular job, every job regimes a particular workability.

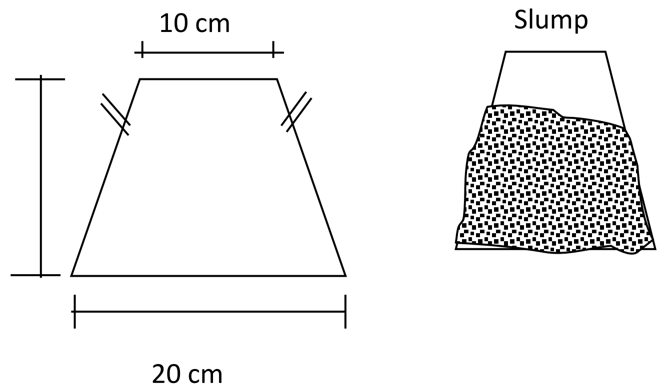
A plastic consistence is neither stiff and crumble mix, nor too fluid & water mix. A stiff mix has a tendency to crumble and segregate; on the other hand a fluid mix has a tendency to flow & segregate. But concrete of plastic consistency neither crumbles nor segregates. Therefore, to obtain a concrete of suitable consistency water should be added very carefully.

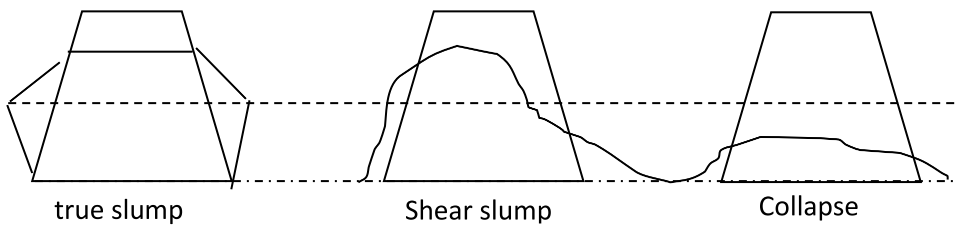
The following are factors that affect workability and consistency of fresh concrete.

* Water content * size, shape & textures of aggregate
* use of admixture.
* Mix proportions * grading of aggregate (maximum influence)

Among the methods for checking the consistency of fresh concrete, the slump test is the most commonly used and can be employed both in the laboratory and at site work.

There are three patterns of slump.





SEGEREGATION: - Can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogenous mixture.

BLEEDING:- The tendency of water to rise in freshly placed concrete when the solids settle through the body of water is called bleeding. It results from the inability of constituent materials to hold all the mixing water as the relatively heavy solids settle.

The rising water tends to carry with it many fine properties which weakness the top portion.

3.2.2. BATCHING:- Prior to the mixing of ingredients it is essential to measure the materials accurately to ensure the right proportions. The concrete may be batched either by weight or by volume.

- When concrete is batched by volume there is always variation between one batch & another. This is due to the fact that the quantities of solid materials in a container very much depend on its degree of compaction, more over volume of most sand in a loose solution weight much less than the same volume of dry compacted sand. Because of this batch, wt batching is prefer than volume batch especially on important works, however, because it is simple & convenient volume batching is used at most construction sites.

- ❖ Cement is always measured by wt. Generally, for each batch mix, one bag of cement (50kg) is used. The volume of one bag of cement is taken as 35 lit.
- ❖ Gauge boxes are used for measuring the fine coarse aggregate whenever volume batching is adapted correction for the effect of bulking should be made when the fine aggregate is moist.
- ❖ Water is usually measured by volume in a calibrated tank or by means of flow tile watermeters.

3.2.3 CONCRETE MIXING

Through mixing of materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colors & consistency. There are two methods adapted for mixing concrete

a) Hand mixing

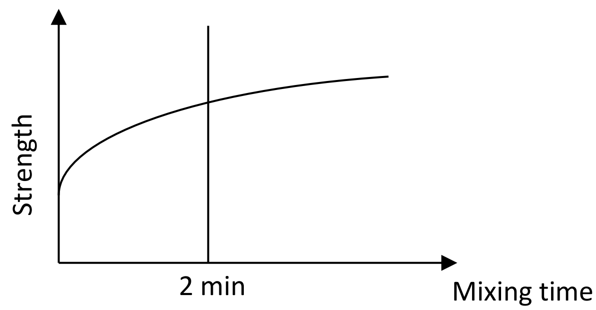
b) Machine mixing

Hand mixing is practiced for small scale unimportant concrete works. As the mixing can not be through & efficient, It is desirable to add 10% more cement to compensate the inferior concrete produced by this method.

- ❖ Machine mixing obviously gives better and uniform mixes than hand mixing and because of this reason, it is generally recommended. There are different types of concrete mixers such as, Tilting drum mixer, non-tilting drum type, pan mixer type, truck mixer, plant mixer etc …

It is seen from experiment that the strength of concrete will increase with increasing time of mixing, but for mixing time beyond 2 min, the important in compressive strength is not very significant.

The minimum mixing time recommend by US. bureau of reclamation, after all ingredients,



except the last of the water, are in the mixer is as follows.

Capacity of mixer (cu.m)	**Time of mixing (min)**
1.5	1.5
2.3	2.2
3.0	2.5
4.5	3.0

3.2.4. CONCRETE CONVEYING

Depending up on the type of work & equipment, various methods employed to transport fresh concrete from the mixer to the site where it is caste. This include the use of wheel borrows carts, chutes, dump, buckets, truck mixers, Belt conveyers etc.

It is important that the concrete be handled with out segregation of the constituent materials, the condition which may easily occur.

3.2.5. PLACING OF CONCRETE

Concrete is a plastic material when fresh and it needs form molds until it sets& harden. The forms are made from timber or steel. Before placing the concrete, the forms and subscribe should be cleaned moisten especially in hot weather. When wooden form have been exposed to the sand or some time, it may be necessary to saturate the wood to tighten the joints. In order to prevent the concrete from the adhering to the surface; forms should be thoroughly oiled when concrete to be placed on a hardened concrete, a few mm thick layer of material is necessary to prevent formation of stone pockets & secure tight joints. The mould should be made from concrete mix to be cost but without its coarse aggregate.

Concrete should be placed as soon as possible, in no case more than 30 min after mixing period. It should be deposited in layers usually hot exceeding 25cm. Each layer should be compacted before the next layer is placed.

Rein forcing steel should be clean & free from loose or harden mortar. Rein forcing bar surface must never be oiled.

3.2.6. COMPACTION

Compaction of concrete is a process adapted for expelling the entrap air from the concrete & to achieve max density which leads to higher strength. Compaction is done by hand by vibrator. When compacting by hand, the concrete should be loaded, tamped & so as to make it settle thoroughly everywhere in the forms & produce a density mass. The use of vibrator which enables stiffer mix by compaction has two possible advantages compared to hand compaction.

I. Much stronger concrete can be produced for given cement content by reducing the water Content & therefore water cement ratio.

II. The same strength can be produced with less cement.

3.3. HARDEND CONCRETE

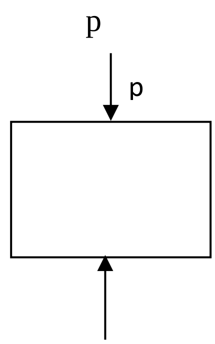
3.3.1. Strength & Properties of hardened concrete.

The strength & Properties of concrete depends on the following factors.

1. Quantity of the binding materials & aggregate.
2. Size, grading & proportioning of ingredients.
3. W/C ratio & consistency.
4. Quality of work man ship.
5. Method of mixing & measuring adapted.
6. Method of consolidation of concrete.
7. Site condition & temperature.
8. Method of curing.

Concrete should be tested for crashing (comp) strength, After 28 days curing.

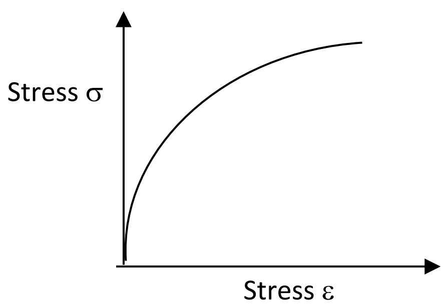
For testing, 15cm cube or cylinders of 15cm diameter, 30cm high are used the cube test generally give 25% high values than the cylinder test. Strength of concrete test specimen decrease in increase in size.



$\sigma \quad \frac{\rho}{\Delta}$ P= Crushing load.

A= sectional area.

The stress -strain characteristics of concrete is shown in the fig. below.



$$\Sigma = \frac{\Delta h}{h}$$

h = original height

Δh=deformation

Concrete is relatively strong in compression and weak in tension. In forced concrete members, little dependence is placed on tensile strength of concrete. Since steel reinforcing bars are provided to resist all tensile force. However, tensile stresses are likely to develop in concrete due to dry shrinkage & rusting of steel reinforcement (temperature gradients & many other reasons) there fore, the knowledge of tensile strength of concrete is of importance.

DIRECT MEASUREMENT OF TENSILE strength of concrete is difficult therefore, indirect tests such as the flexural test and cylinder splitting tests are used. In the flexural test the specimen may be subjected to center pt loading or 3rd point loading. In both cases the modulus of rupture (extreme fibers stress in bending) is calculated in flexural form.

The standard size of specimen are 15 x 15 x 20 cm. Alternately, if the largest nominal size of the aggregate does not exceed 20 mm, specimens 10 x 10 x 50cm may be used.

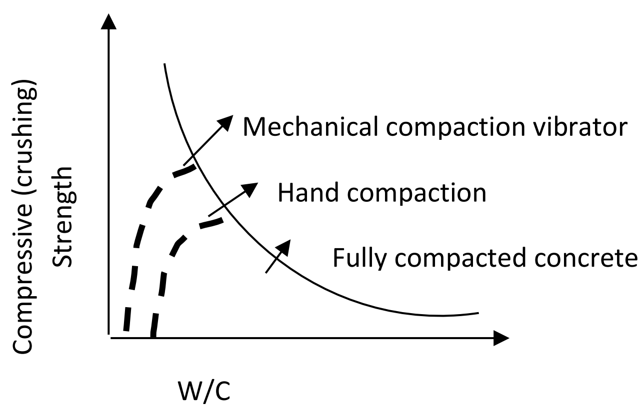
3.3.2 CURING OF CONCRETE

The strength of concrete increases considerably by general chemical action of cement in setting & for which after casting, concrete demands water to attain its strength. The process of supplying water to concrete after casting is called **"CURING".** When the initial setting of concrete is complete it should be kept moist at least for four weeks. Curing also helps to prevent formation of surface cracks, due to quick loss of water while the concrete is fresh & wet.

Vertical surfaces may be kept moist by sprinkling and horizontal surface may be kept damp either by storing water on surface, or by placing wet straws, wet sand or etc …., over the surface.

3.3.3. W/C RATIO & DEGREE OF COMPACTION.

The strength of concrete at a given age & cured at prescribed temperature depend on two factors:
* W/C ratio
* Degree of compaction



W/C ratio determines the porosity of the hardened cement past.

Both W/C ratio & degree of compaction affect the volume of voids in concrete.

The quantity of water used in the mixture has, therefore great influence on the strength of concrete.

Definition Abrams established that when concrete is fully compacted strength may be taken to be inversely proportional to W/C ratio.

3.3.4 SHRINKAGE OF CONCRETE.

Shrinkage of concrete takes place when it sets & hardness. It should be kept minimum by curing concrete under wet condition.

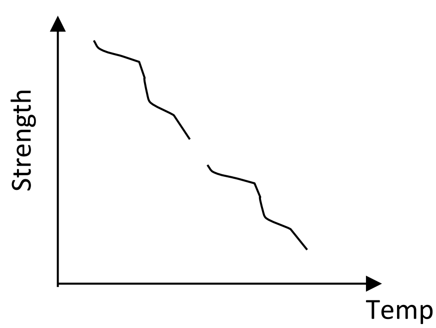
Unnecessary stresses are developed due to shrinkage and it may take place even over along period of times due to carbonation.

Carbonation shrinkage probably caused by dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place . As the new product is less in volume than the produce replace, shrinkage takes place.

1.3.5. EFFECT OF TEMPRATURE

Concrete expands & contracts with change in temperature which results in setting un necessary stresses in concrete.

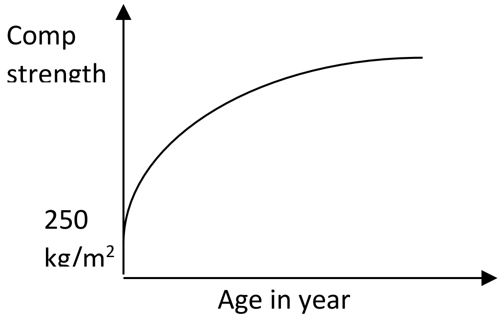
With increase in temperature; stress in concrete gradually reduces.



3.3.6. STRENGTH OF CONCRETE WITH AGE

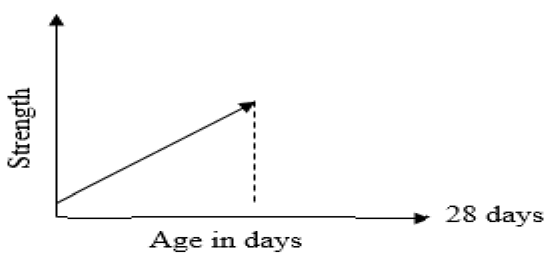
The design of most of concrete structures is done on the base of 28 days strength.

i.e. the design is made such that the design load may be applied after 28 days from the date of



casting.

It has been observed that even after a month concrete attains strength gradually with age. The strength of concrete is about 130% after three months, about 150% after one year & 155% after 10 years.



Thus, you find that no appreciable change in strength occurs beyond 1 year.

3.3.7. DURABILITY OF CONCRETE

In practice, concrete is designed & constructed in order to build permanent structures.

However, at times, its services markedly reduced by the disintegrating effect of either the environment to which it is exposed or by internal cause within its mass.

The resistance of concrete to the effect of whether, to salt, to chemical attack, to mechanical damage resulting from abrasion or impact are the different aspects of of durability of concrete . A concrete which withstands the conditions it is intended for, with out deteriorating over along period of time is said to be durable.

3.4. MIX DESIGN

Mix design can be defined as the process of selecting suitable ingredients of concrete & determining their relative proportions with the object of producing concrete of certain minimum strength and durability and as economical as possible.

One of ultimate aim of studying the varies properties of the materials of concrete, plastic concrete & harden concrete to in able the concrete technology to design a concrete mix for a particular strength.

Design of concrete mix needs not only the knowledge of material properties of concrete in plastic condition; it also needs wider knowledge of experiencing concrete.

Among the various methods of mix properties the following will be dissolved here after.

a) TRIAL method of proportioning.

b) ARBITRARY Methods of proportioning.

c) ACI method of mix design.

A) TRIAL METHOD OF PROPTIONING.

This method is based on abrasion law, i.e, the strength of concrete depends up on the net ratio of the mixing water to the cement.

Steps:-

1. Select W/C ratio from strength - W/C curve (table 8.23)
2. Measure the cement (about 3kg for Lab. trial) and the corresponding area of water.
3. Mix by hand in a pan to form paste.
4. Make the aggregate surface saturated dry condition (SSD) & measure known quantities from each of aggregate say "M"kg of fine aggregate and "N" kg of coarse aggregate.
5. The aggregate are mixed with intermittent mixing until it brought to the desired consistency.

The coarse aggregate is the 1st aggregate to be added.

Then the sand is added continuously till enough mortar is produced to fill the space between piece of coarse aggregate.

6. When the batch is satisfactory the remaining aggregate in the containers are weight and by the difference the amount used in the batch is computed.
7. Then the cubes should be prepared from the mix for 7 day & 28 days compression test.

Examples:

Given: Compressive strength of 25 Mpa. Plastic consistency

Required: Design the mix calculate the quantities per one bag of cement.

SOLUTION

1. W/C: 0.62
2. Cement: 3kg

   Water =3 x 0.62 = 1.86 kg.
3. Mix (form a paste).
4. Suppose 10kg of sand and 12kg of C.A. are available.
5. Suppose 4 kg sand and 3 kg of C. A are left in the container

   C. A. 12 - 3 = 9kg

   F. A. 10 - 4 = 6kg
6. Proportions

   C: FA: CA

   3: 6: 9 = 1: 2: 3 by wt.

The quantities per one bag of cement.

50: 100: 150

B) ARBITRARY PROPORTIONS

The arbitrary proportions have been established by experience, but this method of proportioning doesn't secure concrete of certain strength because the mount of W/C ratio is not defined.

In Arbitrary proportioning strength is rapidly contributed by varying each content.

Such as - rich mix 1:1:2

- Lean mix 1:3:6

Example: 2

Given a concrete mix in which the proportions of cement to fine aggregate to coarse aggregate are 1: 2: 3 by wt. and using a W/C of 0.60 by wt.

Calculate:

a) The yield (The amount of concrete per one bag of cement)

b) The cement factors (cement content in bags per one meter cube of concrete)

c) The materials per cubic meter of concrete.

Given data:

S.p.gr of cement = 3.15

S.p.gr pf FA = 2.65

S.P.gr CA = 2.65

Solution: wt. proportions per sack are

50:100:150

The volume of one bag batch

Solid volume

- Absolute volume of cement $= 50/3.15 x 1000\ 15.87 liters$
- Volume of water = 50 x 0.6 = 30 liters
- Absolute volume of FA $= {}^{100}\!/_{2.65} = 37.74 litre.$

- Absolute volume CA = $\dfrac{150/2.650 = 56.601H.}{140.21\,lit.}$

a) Yield = 140.21 liter = 0.144m^3.

b) Cement factor = 1/0.1404 = **7.14 bags**

c) Materials per cubic meter of concrete.

Cement	= 7.14 bags	= 375 kg/m^3
Fine aggregate	= 2 x 375	= 714 kg/m^3
Coarse aggregate	= 3 x 375	= 1077 kg/m^3
Water	= 0.6 x 375	= 2.15 kg/m^3.

Example:3

Given: C: FA: CA: 1: 2: 3 by volume

W/C = 0.85 by volume.

Required. a) The yield

b) Cement factor

c) material per cubic meter of concrete

Take: Unit wt of FA = 1700 kg/m^3

Unit wt of CA = 1400 kg/m^3

Sp. gr of cement = 3.15

Sp.gr of FA & CA = 2.65

Volume of one bag (sack) of cement = 35 liter.

Solution:

The proportions by volume per one bag of cement.

35: 70: 105

The volume of one bag batch

- abs. volume of cement = 50/3.15 = 15.8 liter
- abs. vol. of $FA = W / solid unit wt = \frac{volume x unit wt FA}{solid unit wt}$

$$= \frac{70 x 1700}{2.65 x 1000} = 44.90 lit$$

- abs. vol. of CA $\frac{105 x 1400}{2.65 x 100} = 55.47 litre$

❖ Volume of water $=0.85x35=\frac{29.75litre}{\underline{\underline{145.99litre}}}$

a) Yield = 145.99 litre = 0.146 m^3.

b) Cement factor = $1/_{0.146} = 6.85 bags/m^3$

c) materials per m^3 of concrete.

Cement	= 6.89 bags	= 240 liter
FA	= 2 x 240	= 480 liter
CA	= 3 x 240	= 720 liter
Water	= 0.85 x 240	= 204 liter

ACI - method of mix Design.

Procedure

1. Data to be collected.
   i) Fines modulus of selected FA.
   ii) Unit wt. of dry roaded CA
   iii) Sp.gr of CA and FA
   iv) Absorption characteristics of both CA and FA
   v) Sp.gr cement (3.15)

2. From the minimum strength specified estimate the average design strength (table 8.27)
3. Specify the minimum cement content (table 8.27)
4. Choice of clump (table 8.21 or table 8.28)
5. Determine the max. Size of CA.
6. Estimate mixing water, and air content (table 8.28)
7. Select W/C (table 8.23) based on strength or (table 8.24) based on requirement for durability.
8. Calculate the cement content and compare with step 3 ⇒ take what ever is larger.
9. Estimate the bulk volume of dry rodded as per unit volume of concrete (table 8.25)

10. Calculate wt. of CA. per m^3 of concrete

W_{CA} = bulk vol. x bulk density

11. Calculate the solid volume of CA in one m^3 of concrete

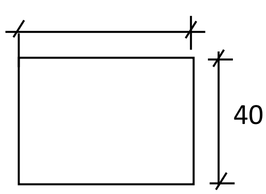
V_{CA}: W_{CA}/1000.sp.gr

12. Similarly the solid volume of cement/water and volume of air is calculated in one m^3.
13. Solid volume of sand is then calculated by subtracting from the data volume of concrete the solid volume of cement, CA, water & entraps air or if the wt of concrete per unit volume is assumed or can be estimated from experience (table 8.26), the rigged wt. of FA is the difference between the wt of fresh one and the total wt of the other ingredients.
14. Adjustments for aggregate moisture.
15. Trial batch adjustments. The calculated mix proportions should be checked by means of trial batch.

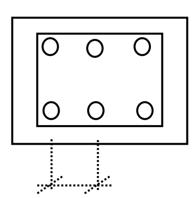
Maximum size of aggregate recommended for various types of construction.

Type of element	Dimensions of section (cm)			
	10-15	15-20	20-35	35-75
	Maximum size of aggregate (mm)			
Un reinforced or light reinforced foundations or slabs	25-40	40	40-50	50
Reinforced foundations or slab, un rein forced or lightly reinforced walls or columns.	20-25	25	25-40	40
Reinforced columns, beams, walls hollow block slabs	15-20	20-25	25-30	30

N.B:. Maximum size should not be larger than 1/5 of minimum dimensions of section or larger than 3/4 of minimum clear spacing b/n reinforcing bars.



1/5 x 25 = 5 cm



Example:-

20 cm square reinforced concrete columns have to be cast in the interior of a building. Reinforcement & ϕ 12 mm bars and nominal strength of concrete 200 kg/cm^2. Prepare a mix design assuming class of control good.

Solution:

Step - 1- Data

i) FM of sand = 2.4

ii) Dry rodded unit wt C.A: 1600 kg/m^3

iii) Specific gravity of C.A. : 2.6

Specific gravity of F.A. = 2.65

iv) Absorption Capacity of C.A. = 0.56

Free moisture in sand = 3.12%

v) Specific gravity of cement = 3.15

Step - 2- Minimum strength (For mix design)

Average strength = 1.2 x 200 = 240 kg/m^2.

Step - 3 - Minimum cement context (table 8.27) = 240 kg/m^3.

The space between two reinforcing bars = clear spacing

Step - 4 - $\dfrac{Choice\ of\ \ slump}{Lightly\ re\text{inf}\ orced\,(row-2)}$ = 75 cm

Step - 5 - maximum size of Aggregate = 25

Step - 6 - Mixing water = 185 lit / m^3

air content = 10 lit/m^3

Step - 7 - W/C (8.23) = 0.64 based strength

Step - 8 - Cement content $= \dfrac{mixingwater}{W/C} = 185/0.64 = 289\,kg/m^3$

Step - 9 - bulk volume of dry rodded C.A. per unit volume of concrete (8-25 = 0.71)

Step - 10 - Wt of C.A. = 0.71 x 1600 = 1136 kg.

Step - 11 - Solid volume of C.A. = 1136/2.6 x 1000

Step - 12 - Solid volume of cement = 289/3.15 = 92.0 lit/m^3.

" " water = 185 lit/m^3

" " air = 10 lit/m^3.

= 724 lit/m^3.

Step - 13 - Solid volume of sand = 1000 - (437 + 92 + 185 + 10)

Based on volume = 276 lit/m^3.

Wt of F.A. = 0.276 x 2.65 x 1000 = 732 kg/m^3.

	Volume (lit)	**wt (kg)**
Air	10	-
Cement	92	289
Water	185	185
C.A.	437	1136
F.A.	276	732
	1000 lit	**2342 kg/m^3**

Or based on wt. (8.26)

The wt of concrete per unit volume = 2375 kg/m^3

wt of F.A. = 2375 - (1136 + 289 + 181) = 765 kg/m^3

	wt (kg)	**Volume (lit)**
Air	0	10
Cement	289	92
Water	185	185
F.A.	765	289
C.A.	1136	437
	2375 lit	**1013 kg/m^3**

Step - 14- Adjustments for Aggregate moisture

- C.A. absorbs 0.5/100 x 1136 (wt.of C.A.) = 5.68 kg of mixing water

- Sand supplies 9/100 x 732 (wt.of. sand = 29.28 kg) of H_2o to the mixing water. Therefore, the estimated requirement for added water.

= 185 + 568 - 29.28 = **161.4** lit.

Therefore, the estimated batch wt for cubic meter of concrete are

Water (free)	161 lit
Cement	289 kg
C.A. = 1136 - 5.8	1130 kg
F.A. = 732 + 29.28	761 kg

Step - 15 - Trial batch" a trial batch of 30 lit. Concrete is prepared for trial mix

Water = 0.03 x 161 = 4.83 kg

Cement = 0.03 x 289 = 8.67kg

C.A. = 0.03 x 1130 = 33.90 kg

F.A. = 0.03 x 761 = 22.83 kg

TABLES FOR ACI CONCRETE MIX DESIN

Table 1. Estimated Average Strength for Concrete

Compressive strength 28 days (M pa)	Water / cement ratio (by mass)	
	Non-air entrained	***Air entrained***
45	0.38	-
40	0.42	-
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52

20	0.69	0.60
15	0.79	0.71

*Values are estimated average strength for concrete containing not more than percentage of air shown in table 3. For constant water/cement ratio, the strength of concrete is reduced as the air content is measured. **Strength is based on 15x30cm cylinders moist-cured 28 days at 25± 1.7 ^{o}C** in accordance with section 9(b) of ASTM C31 for making and curing concrete compressive and flexure test specimen in the field. Cube strength will be higher by approximately 20^{o}C. Relationship assume size of aggregate about 20 to 30mm, for a given source, strength produced by a given water/cement ratio will increase as maximum size decrease.

Table 2. Fine aggregate as a percentage of total aggregate

W/c	Max. agg. size (mm)	Fineness modulus		
		2.5	2.7	2.9
0.4	10	50%	52%	54%
	20	35	37	39
	40	29	31	33
0.5	10	53	55	57
	20	38	40	42
	40	32	34	36
0.6	10	54	56	58
	20	40	42	44
	40	33	35	37
0.7	10	55	57	59
	20	41	43	45
	40	34	36	38

Table 3. Recommended slumps for various types of constructions

Types of construction	Slump (cm)	
	***Max.**	**Min.**
Reinforced foundations, walls and footings	8	2
Plain footings, cassoins and substructure walls	8	2
Beams and reinforced walls	10	2
Building columns	10	2
Pavements and slabs	8	2
Heavy mass concrete	8	2

* may be increased by 2cm for methods of consolidation other than vibration

Table 4. Approximate mixing water requirements for different slumps and maximum sizes of aggregates.

Slump (cm)	**Water kg/m3 of concrete for indicated max. sizes of agg. in mm ***							
	10	12.5	20	25	40	50+	70+	150+
	Non –Air entrained concrete							
3- 10	205	200	185	180	160	155	145	125
8- 10	225	215	200	195	175	170	160	140
15-18	240	230	210	205	185	180	170	--
Approx. amount of entrapped air in non entrained conc(%)	3	25	2	15	1	0.5	0.3	0.2
	Air entrained concrete							
3 to 5	180	175	165	160	145	140	135	120
8 to 10	215	205	190	185	170	165	160	--
Recommended average total air content (%)	8	7	6	5	4.5	4	3.5	3

* These quantities of mixing water for use in computing cement factors for trial batches. They are maxima for reasonably well shaped angular course agg graded with in limit of accepted specifications.

+ The slump values for concrete containing agg larger than 40mm are based on slump tests after removal of larger than 40mm by wet screening.

Table 5. Maximum permissible water cement ratios for concrete in severe Exposure

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing	Structure exposed to sea water or surfaces
Thin sections (railing curbs, sills, ledges, ornamental work) and sections with less than 3cm cover over steel	0.45	0.40¥
All other structures	0.50	0.45¥

* Based on the report on ACI committee 201 "Durability of concrete in severe previously cited concrete should also be air entrained"

¥ If sulphate-resisting cement (type II or Type V of ASTMC 150) is used permissibly water-cement ratio may be increased by 0.50.

Table 6. <u>Volume of coarse Aggregate per unit Volume of concrete</u>

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete fo different fineness modulus			
	2.4	2.6	2.8	3.0
10		0.50	0.46	0.44
12.5		0.59	0.55	0.53
20		0.66	0.62	0.60
25		0.71	0.67	0.65
40		0.76	0.72	0.70
50		0.78	0.74	0.72
70		0.81	0.77	0.75

150	0.87	0.83	0.81

- Volumes are based on aggregate in dry rodded condition as described in ASTEC29 for unit weight of aggregate.

These volumes are selected empirical relationship to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for pavement construction they may be increased about 10%. For more workable concrete, such as required may be required when placement is to be by pumping, they may be reduced up to10%.

Table 7. First Estimate of Weight of Fresh Concrete.

Maximum size of aggregate, mm	First estimate of concrete weight, Kg/m^3	
	Non-air entrained concrete	Air- entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Table 8. Requirement for Concrete cast under different control condition

Class of Control	Good	Fair	Poor
1) Requirements for material			
Cement	Weight		Volume
Batching	1% accuracy	2% accuracy	Leveled boxes

Water Batching	Measuring tank or 1% accuracy	Flow type meter 3 % accuracy	Estimated visually
Aggregate Quality and batching		Standard at least 2 fractions	
	Washed and screed at least 3 fractions weight	Weight 3% accuracy or volume gauge boxes	Volume, gauge boxes, boxes, wheel barrows
2. Control of mixes, placing, compaction	Under full supervision of an inspector experienced in concrete technology. Continuous of adjustment of mixes by a field laboratory.	By an experienced foremen with knowledge in good concrete. Adjustment of mixes when visible changes in size and moisture content of aggregate occur, when consistency of concrete changes.	No special supervision. Amount of mixing water adjusted visually by mix man when consistency of concrete changes.
3. Method of compaction	By vibration	By hand or vibration	By hand
4. Requirement for average strength at 28 days expressed in % of nominal strength.			
Mix design	120%	135%	150%
Field acceptance	115%	125%	140%
5. Minimum cement* content for reinforced concrete Kg/m$^{3.}$			
Unexposed to weather	240	260	280
Exposed	260	280	300

- This standard includes a separate minimum limit on cement in addition on cement in addition to requirements for strength and durability the mixture must be based on whichever criterion leads to a larger amount of cement.

Table 9. Approximate requirements of mixing water (W_0) for different types of

structures and maximum sizes of aggregates.

Types of cements	Methods of compaction	Max. Slump consistency	Water (lit/m^3 concrete) for indicated maximum size of angular course aggregate and natural.					
			15	20	25	30	40	50
Un reinforced or lightly reinforced foundations or slabs	By hand	Plastic, 10mm	215	200	195	190	180	170
	Vibrator	Stiff, 5mm	195	180	175	170	160	150
Reinforced foundations or slabs, un reinforced or slightly reinforced walls or columns	By hand	Plastic flowing, 12.5mm	225	210	205	200	190	-
	Vibrator	Plastic stiff, 75mm	205	190	185	180	170	-
Reinforced columns, beams, walls, hollow block slabs	By hand	Flowing, 18mm	235	220	215	210	200	-
	Vibrator	Plastic, 10mm	225	200	195	190	180	-
Note: 1) For rounded aggregate like pebble etc. reduce 10% 2) For reinforced concrete with water reducing admixtures or entrained concrete reduce 5 to 10% 3) For manufactured sand (sharp angular) add 5 to 10 % 4) For type V cement reduce 5%								
Approximate amount of entrapped air (Ao) in normal concrete (liter)			20	15	10	10	9	-
Recommended max. entrained air (A_o) (liter)			45	40	35	30	30	-

Table 10. Maximum size of aggregate recommended for various types of constructions

Type of element	Dimensions of sections (cm)			
	10-15	15-20	20-35	35-75
Un reinforced or slightly reinforced foundations or slabs	Maximum size of aggregate (mm)			
	25-40	40	40-50	50
Reinforced foundations or slabs, un reinforced or lightly reinforced walls or columns	20-25	25	25-40	40
Reinforced beams, columns, walls, hollow block slabs	15-20	20-25	25-30	30

N.B. Maximum size should not be greater than 1/5 of minimum dimensions of sections or larger than ¾ of minimum clear spacing between reinforcing bars.

3.7 Mortar

Mortar is the name given to a mixture of sand or similar inert particles with cementing materials and water, and which has the capacity of hardening in to a rock like mass.

Mortar = Cement + Sand + H_2O

Uses: - as a binding material in brick and stone masonry.

-for plastering of walls

-for making concrete

-to transfer load from brick to bricks or masonry to masonry

Mortar mixes:

Lime mortar = Lime + Sand + H_2O = Mortar------ (Traditional)

-Has good workability

-Economical

Cement mortar= Cement + Sand + H_2O = Mortar

- Develops strength rapidly
- Stronger than lime mortar
- Expensive than lime mortar

Compo Mortar =Cement + Lime + Sand + H_2O

- has increased workability

- is relatively cheaper than cement mortar

Properties of Mortar:

Depend on: -Properties of cementiceous material

-ratio of cementiceous material

-grading and quality of sand

-water cement ratio, etc

1. Workability

For the same proportions, lime-sand mortar has a better workability than cement-sand mortar. How ever, cement produces higher strength than lime

In order to increase workability of cement-sand mortars, especially when they are lean mixes (i.e. containing less amount of cement); plasticizers & air-entraining agents are used.

2. Strength

- Affected by factors like: -quality of ingredients

  -their proportions

  -the curing method and age, etc.
- for the same proportions lime-sand mixes gives weaker mortar than cement-sand mix. this is due mainly to two factors:
  1. Cement gives stronger paste than lime
  2. Cement gives a better bond b/n the paste & the sand grains

- The gradation of sand particles highly affects the strength of mortar. From lab tests, it is found that for the same proportion of sand and cement, coarse sand gives more compressive, tension, shear and bending strengths than medium and *fine sands .But, the* strength increases as the cement content increases.

- High amount of mixing water reduces strength and density of mortar .reduction in strength is higher in earlier ages.
- Strength of mortar increases with time. The rate of gaining of strength is higher initially and slows down gradually. Approximately after a year it attains its full strength. This is because
  -In cement mortar---Hydration of cement occurs slowly
  -In Lime mortar-----Absorption of co_2 occurs slowly

3. Water tightness

In damp conditions:

- Cement should be used in the mortar b/c of its hydraulic property
- The mix should be rich and dense
- Smaller water cement ratio shall be used.

Mixing:

- by hand or
- using mechanical mixers