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Concrete Mix Design By Packing Density Method

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Abstract: *Packing density is new kind of mix design method used to design different types of concrete. To optimize the particle packing density of concrete, the particles should be selected to fill up the voids between large particles with smaller particles and so on, in order to obtain a dense and stiff particle structure. Higher degree of particle packing leads to minimum voids, maximum density and requirement of cement and water will be less. In this work the co-relation curves are developed for packing density method between compression strength and water cement ratio, paste content to reduce the time involved in trial to decide water cement ratio and paste content for a particular grade of concrete. Results obtained by packing density method are compared with IS code method. The optimum bulk density was obtained at proportion of 42% coarse aggregates (20mm downsize), 18% coarse aggregates (12.5mm downsize) and 40% fine aggregates. Large number of trial casting were carried out for each grade of concrete (i.e., M20, M25, M30, M35 and M40) with different water cement ratio and three paste contents in excess of void content. To finalise mix proportions using packing density method flow table tests were carried out to decide water cement ratio and paste content in excess of void content for each grade of concrete. The finalised mix proportion for each grade of concrete was used to cast the cube specimens for 7 days and 28 days curing age. The cube compressive strength results obtained by packing density and IS code method are nearly same. The co-relation curves were plotted for packing density results alone and also combining the results of packing density and IS code methods. The co-relation curves were plotted between compressive strength vs water cement ratio at 7 and 28 days curing age and compressive strength vs paste content at 7 and 28 days curing age. Very good co-relation is obtained with a co-relation co-efficient of 0.953 (minimum) to 0.998 (maximum). These curves can be used to decide the water cement ratio and paste content for the specified grade of concrete incase of packing density method thus reducing the material and time involved in trial testing.*

Keywords: *Bulk density, voids ratio, packing density, mix design, plotting***.**

I. Introduction

There are various methods of proportioning for various types of concrete. Packing density method of mix design is the only mix design method used for proportioning normal concrete, high strength concrete, no-fines concrete and self compacting concrete. No adequate literature is available on this method.

The subject of optimizing the concrete composition by selecting the right amounts of various particles has already aroused interest for more than a century. To optimize the particle packing density of concrete, the particles should be selected to fill up the voids between large particles with smaller particles and so on, in order to obtain a dense and stiff particle structure. Most of the early researchers, working on the packing of aggregates, proposed methods to design an ideal particle size distribution. Geometrically based particle packing models can help to predict the water demand of concrete, and thus the material properties.

The cement paste has to fill up the voids between aggregate particles and the “excess” paste will then disperse the aggregate particles to produce a thin coating of paste surrounding each aggregate for lubricating the concrete mix. In general, the higher the packing density of the aggregate, the smaller will be the volume of voids to be filled and larger will be the amount of paste in excess of void for lubrication.

In IS code method of mix design we have curves to decide the water cement ratio whereas in packing density method we don’t have such type of co-relation curves available. Here an attempt has made to develop co-relation curves between compressive strength of concrete versus water cement ratio and paste content versus Compressive strength. These co-relation curves help to reduce the trials and decide the water cement ratio and paste content for the given grade of concrete.

Wong and Kwan [1] used the ordinary Portland cement complying with BS 12:1996. Fennis and Walraven [3] used ordinary Portland cement and blast furnace slag cement. Wong and Kwan [2] used the aggregate particles smaller than 1.2mm for mortar and aggregate particles larger than 1.2mm for concrete mix. Kwan and Wong [2] used pulverised flyash as cementitious material complying with BS 3892: Part 1: 1982. Kwan and Wong[2] used the condensed silica fume complying with ASTM C 1240-03 as the cementitious material in their experiments. Kwan and Wong [2] in their studies used two types of superplasticisers a polycarboxylate based and cross linked polymer and naphthalene based formaldehyde condensate.

Kwan and Wong [2] measured the packing densities of cementitious materials containing ordinary Portland cement, pulverised fly ash and condensed silica fume. The results for non-blended materials revealed that the addition of a superplasticiser would always increase the packing densities of ordinary Portland cement and pulverised flyash, the addition of a polycarboxylate based superplasticiser could decrease the packing density of condensed silica fume.

Fennis and Walraven [3] studied on measuring the packing density to lower the cement content in concrete. It is described how centrifugal consolidation can be used to determine the packing density of powders. The method is assessed based on experimental data, calculations and polarization and fluorescence microscopy of the samples.

Kwan and Wong [1]proposed three tier system design. The mix design would be divided into three stages. At first stage the packing density of the cementitiious materials would determine the water demand, and at the second stage the aggregate particles smaller then 1.2mm would determine the paste demand and at third stage the aggregate particles larger then 1.2mm would determine the mortar demand.

Glavind and Pederson [5] studied that when selecting a concrete mix design, it is always desirable to compose the aggregates as densely as possible, i.e. with maximum packing. That minimises the necessary amount of binder which has to fill the cavities between the aggregates for a constant concrete workability. Apart from an obvious economic benefit, a minimum of binder in concrete results in less shrinkage and creep and a more dense and therefore probably a more durable and strong concrete type.

V.L. Kantha rao & S. Krishnamoorthy, [6] have studied the proportions required for least void content followed a linear trend fairly similar to what one would obtained from the theoretical gradings of fuller. An empirical equation has been fitted for this linear trend so that it can be used to determine the proportions of coarse and fine aggregate of least void contents.

Powers [7], in his studies on aggregate mixtures showed that the voids ratio of a binary particulate system would be minimum at a particular combination. Voids ratio (U) is defined as the ratio between the volume of voids (E) and the volume of solids (I-E) of a particulate system.

Kwan and Wong used the mini-slump cone test to check the fresh state properties in their experimental studies. Fennis and Walraven [2] carried out the centrifugal consolidation to check the workability. Kwan and Wong [4] obtained curve between voids ratio and water cement ratio for cementatious materials, where the ordinary Portland cement is blended with the pulverised fuel ash and condensed silica fume in different proportions.

From the above study it is observed that packing density mix design method is used to minimize voids to increase particle packing and to reduce the binder content. Very less information is available regarding co-relation between grade of concrete and water cementatious ratio, paste content, incase of packing density.

Materials

Ordinary Portland cement confirming to IS 12269-1987 [8] locally available river sand belonging to zone II of IS 383-1970 [9], was used. Locally available crushed aggregate of size 12.5 mm and 20 mm down size conforming to IS 383-1970 [9] were used in the preparation of concrete. Potable water was used in the present investigation for both casting and curing of the concrete. Superplasticizer complies with IS 9103:1999 [10] Sulphonated Napthelene based polymers is used. Bulk density and specific gravity test were carried out as per IS 2386(Part III)-1963 [11] and the test results are presented in Table 1.

Table 1: Bulk density and Specific gravity

Sl. No.	Materials	Bulk density Kg/m^3 (Compacted condition)	Bulk density Kg/m^3 (Loose condition)	Specific gravity
1	Fine aggregates	1600.133	1718.063	2.593
2	Coarse aggregate 12.5mm	1387.777	1542.222	2.937
3	Coarse aggregate 20mm	1525.555	1660.000	2.912

II. Design of Concrete Mix Using Packing Density Method

Determination of aggregate fractions

The packing density of aggregate mixture is defined as the solid volume in a unit total volume. The aim of obtaining packing density is to combine aggregate particles in order to minimize the porosity, which allows the use of least possible amount of binder.

Two size fractions of coarse aggregates were selected for the study i.e., 20mm and 12.5mm down size. The values of bulk density of the coarse aggregates (20mm and 12.5mm size) were first determined separately. The coarse aggregate 20mm and 12.5mm were mixed in different proportions by mass, such as 90:10, 80:20, 70:30 and 60:40 etc., and the bulk density of each mixture is determined. Addition of smaller size aggregate (12.5mm down size) increases the bulk density. However a stage is reached when the bulk density of coarse aggregate mixture, which instead of increasing, decreases again. The results of Bulk density of coarse aggregate fractions(20mm and 12.5mm) are plotted in Fig. 1.

Determination of Packing Density

The packing density of individual aggregate in a volume fraction of total aggregate or over all aggregate is determined from its maximum bulk density of mixture and specific gravity from the following relation.

$$\text{Packing density} = \frac{\text{Bulk density x weight fraction}}{\text{Specific gravity}}$$

Therefore total packing density of the mixture is sum of packing density of 20mm, 12.5mm and fine aggregate i.e., equal to the ratio of bulk density of mixture to specific gravity of individual aggregate (20mm : 12.5mm : fine aggregate). The value of specific gravity should be taken as average, if the values are differing in third decimal and if the values are differing in second decimal, the individual values should be taken for calculating packing density and voids content.

Determination of Voids Contents and Voids ratio

The voids content in percentage volume of aggregate or mixture of three aggregate is determined from its bulk density from the following relations.

$$\text{Voids content in percent volume} = \frac{\text{Specific gravity - Bulk density}}{\text{Specific gravity}} \text{ x } 100$$

From the Figures 1, 2 and 3 it is observed that the bulk density, packing density are maximum and voids ratio is minimum for 70 % of coarse aggregate (20mm) and 30 % of coarse aggregate (12.5mm) respectively.

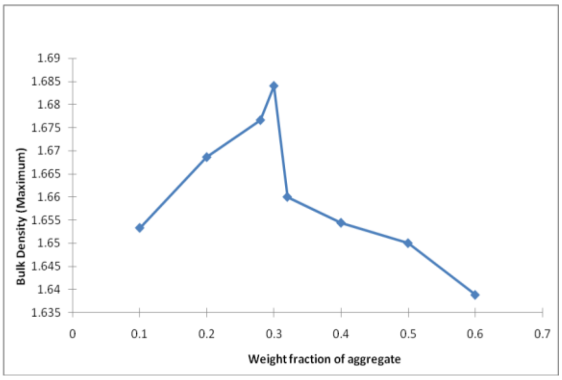

Fig 1: Maximum bulk density for 20mm and 12.5 mm aggregates

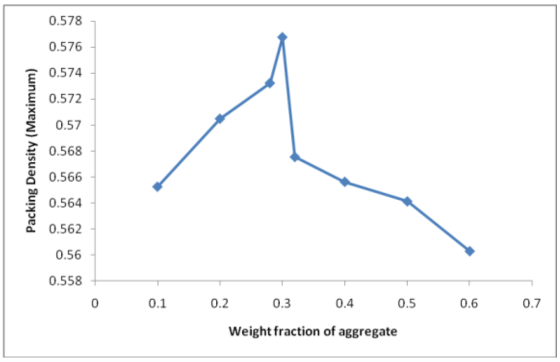

Fig 2: Maximum packing density for 20 mm and 12.5 mm aggregates

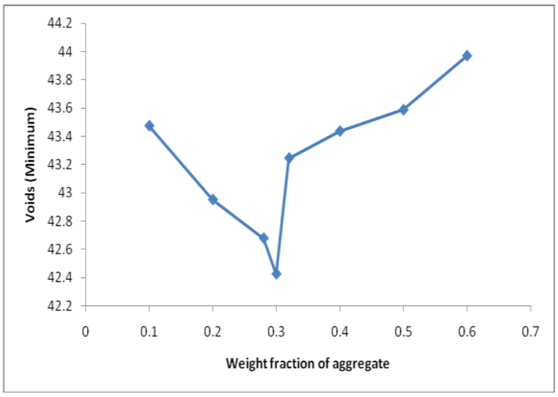

Fig 3: Minimum voids ratio for 20 mm and 12.5 mm aggregates

Increase in fine aggregate particles leads to decrease in void content thus increases the bulk density. The replacement of fine aggregates in the total coarse aggregates (20mm and 12.5mm down size in the proportion 70:30) in the ratio of 90 : 10, 80 : 20, 70 : 30, 60 : 40, 55 : 45. By increasing the finer content the bulk density increases up to a maximum extent after which it again reduces. Thus the proportion obtained for maximum bulk density is fixed as total coarse aggregates : fine aggregates i.e., 60 : 40. Total coarse aggregate proportion i.e., 20 mm : 12.5 mm is fixed as 70 : 30 as mentioned earlier. Therefore proportions of these aggregates i.e., coarse aggregates 20 mm : coarse aggregates 12.5 mm : fine aggregates is 42 : 18 : 40. The bulk density, packing density and voids ratio are plotted against the mass fraction of coarse aggregate are presented in the Figures 4, 5 and 6 respectively. From the Fig. 4, 5 and 6 maximum bulk density 2.007 gm/cc, maximum packing density 0.722 gm/cc and minimum voids content is 0.2866.

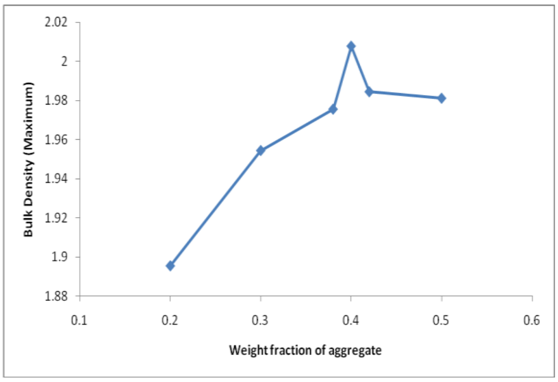

Fig 4: Maximum bulk density for 20 mm, 12.5 mm and fine aggregate

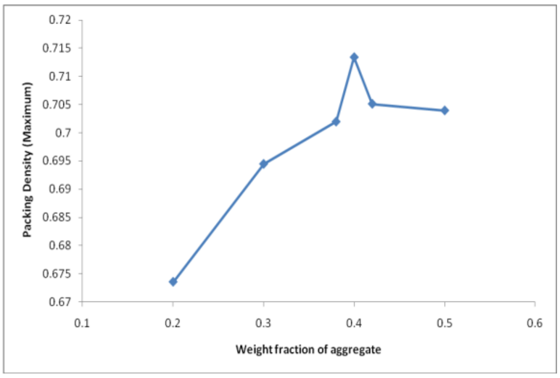

Fig 5: Maximum packing density for 20 mm, 12.5 mm and fine aggregate

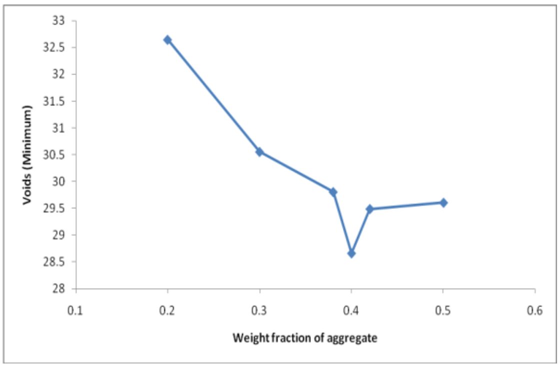

Fig 6: Minimum voids for 20 mm, 12.5 mm and fine aggregate

Using the above concept, design of concrete mix is carried out for M20, M25, M30, M35 and M40 concrete mixes. A detailed sample calculation for M20 grade of concrete is presented below. The ingredients of concrete for M20 grade were obtained for 5%, 10% and 15% in excess of paste content and water cement ratio 0.56 and 0.58 the values are presented in Table 2.

III. Mix Design for M20 Grade Concrete (Packing Density Method)

The calculations are presented in the following paragraph for bulk density, voids ratio and packing density.

(1) Bulk density of combined coarse aggregate 20mm and 12.5mm in the proportion 70:30.

$$\text{Bulk Density} = \frac{W_2 - W_1}{Volume\ of\ mould}$$

Where, W1 = empty weight of mould
W2 = weight of mould + aggregate filled

$$\text{Bulk density (maximum)} = \frac{35066 - 9800}{15000}$$

$$= 1.6840\ \text{gm / cm}^3$$

(2) Bulk density of three aggregates i.e., CA 20mm : CA 12.5mm : FA is 42 : 18 : 40. (coarse aggregate 20 mm : 12.5 mm i.e., 70 : 30 as fixed earlier).

$$\text{Bulk density (Maximum)} = \frac{39916 - 9800}{15000}$$

$$= 2.0077\ \text{gm / cm}^3$$

(3) Voids content:

$$\text{Voids content in percent volume} = \frac{2.8143 - 2.0077}{2.8143} x 100$$

$$= 28.660\ \%$$

(4) Packing density (P.D.):

$$\text{Packing density (maximum)} = \frac{Bulk\ density\ x\ weight\ fraction}{Specific\ gravity}$$

$$\text{Packing density of 20mm aggregates} = \frac{2.00778\, x\, 0.420}{2.9122}$$

$$= 0.2896\ \text{gm / cm}^3$$

Packing density of 12.5 mm aggregates = $\frac{2.0078\, x\, 0.180}{2.9376}$

= 0.1230 gm / cm³

Packing density of fine aggregates = $\frac{2.00778\, x\, 0.400}{2.5931}$

= 0.3097 gm / cm³

Total Packing Density = Packing Density of CA (20mm) + Packing Density of CA (12.5mm) + Packing Density of Fine Aggregate

PD = 0.7223 gm / cm³

This packing density value is fixed for further calculations.

Determination of Paste content for M20 Grade Concrete

Minimum paste content is sum of the void content in combined aggregate and excess paste over and above it to coat the aggregate particle. Meaning of minimum paste content can be explained as, a concrete mix containing minimum paste content should be cohesive, free from segregation and bleeding. Flow table test were carried out to decide the minimum paste contents required to form the workable mix for different W/C ratio and different paste content in excess of void content.

Voids content = 1 – 0.7223 = 0.2777

Assuming paste content as 10% in excess of void content, detailed calculations to obtain all the ingredients of concrete such as coarse aggregate 20mm, 12.5mm, fine aggregate, cement and water content is given below.

Paste content 10% in excess of void content

Paste content = 0.2777 + 0.1x 0.2777

= 0.3054

Volume of aggregates = 1 – 0.3054

= 0.6945 cc

Total solid volume of aggregates = $\frac{Weight\ fraction\ of\ 20mm}{Specific\ gravity} + \frac{Weight\ fraction\ of\ 12.5mm}{Specific\ gravity} + \frac{Weight\ fraction\ of\ fine\ aggregate}{Specific\ gravity}$

Total Solid volume of aggregates = $\frac{0.420}{2.9122} + \frac{0.180}{2.9376} + \frac{0.400}{2.5931}$

= 0.3598 cc

Weight of 20mm aggregates = $\frac{0.6945}{0.3598}\ x\ 0.420\ x\ 1000 = 810.7354\ Kg / Cum$

Weight of 12.5mm aggregates = $\frac{0.6945}{0.3598}\ x\ 0.180\ x\ 1000 = 347.4580\ Kg / Cum$

Weight of fine aggregates = $\frac{0.6945}{0.3598}\ x\ 0.400\ x\ 1000 = 722.1290\ Kg / Cum$

For M20 grade concrete keeping in mind the target mean strength suitable water-cement ratio is fixed as per trial mixes.

W/C ratio = 0.56; W = 0.56C

Total Paste = C + W = $\frac{C}{3.15} + \frac{0.56C}{1} = 0.8775C$

$$\text{Cement content} = \frac{0.3054}{0.8775}\ x\ 1000 = 348.1140\ Kg/Cum$$

Water content = 0.56 x 348.1140
= 194.9438 Kg/cum

Following the above procedure all the ingredients of concrete were obtained for 5%, 10% and 15% in excess of paste content and water cement ratio 0.56 and 0.58, the values are presented in Table 2.

Table 2: Trial mix proportions for M20 grade concrete

Grade of concrete	W/C ratio	Excess paste content (%)	Water content (Kg/m^3)	Cement content (Kg/m^3)	Wt. Of Fine aggregate (Kg/m^3)	Wt. Of 12 mm Coarse aggregate (Kg/m^3)	Wt. Of 20 mm Coarse aggregate (Kg/m^3)
M20	0.58	5	188.4416	324.8994	787.6736	354.4531	827.0573
			0.58	1	2.4243	1.0817	2.5455
	0.58	10	197.4151	340.3708	772.2352	347.5058	810.8469
			0.58	1	2.2688	1.0209	2.3822
	0.58	15	206.3885	355.8422	756.7967	340.5585	794.6366
			0.58	1	2.1268	0.9570	2.2331
	0.56	5	186.0907	332.3048	787.6736	354.4531	827.0573
			0.56	1	2.3703	1.0667	2.4889
	0.56	10	194.9522	348.1289	772.2352	347.5058	810.8469
			0.56	1	2.2182	0.9982	2.3292
	0.56	15	203.8136	363.9529	756.7967	340.5585	794.6366
			0.56	1	2.0794	0.9357	2.1834

To decide the paste content and water cement ratio among three paste content and two water cement ratios, using the above ingredients Flow Table tests were carried out. Flow Table test is carried out as per IS 1199-1959 [12]. Results of Flow table tests for M20 grade concrete indicated that water cement ratio 0.58 and all the three paste content (i.e., 5%, 10% and 15 %) and water cement ratio 0.56 with 5% paste content were rejected because of segregation and bleeding. Water cement ratio 0.56 with paste content of 10% and 15% in excess of void content resulted in good flow percent of 133 and 134 respectively without segregation and bleeding. For water cement ratio 0.56 in order to decide the paste content i.e., 10% and 15% in excess of void content, trial cube casting was carried out for 7 days cube compressive strength. The average compressive strength (3 cubes) obtained at the end of 7 days curing was 22.88 N/mm^2 and 23.666 N/mm^2 for 10% and 15% paste content respectively. Keeping economy in mind paste content of 10% for water cement ratio 0.56 was finalised for further casting.

Mix design is carried for M25, M30, M35 and M40 grade concrete as mentioned in mix design steps for M20 grade concrete. The value of packing density remains same irrespective of grade of concrete because coarse aggregate 20mm, 12.5mm and fine aggregate used is same for all grades of concrete.

Depending on grade of concrete paste content will vary, increases with increase in grade of concrete. Water cement ratio for different grades of concrete (M25, M30, M35 and M40) is fixed as per trial mixes. Paste contents for different grades of concrete were determined using flow table tests as mentioned earlier.

For individual grade of concrete finalised mix proportions are presented in Table 3.

Table 3: Finalised mix proportions designed by packing density method

Grade of concrete	W/C ratio	Excess paste content (%)	Water content (Kg/m^3)	Cement content (Kg/m^3)	Wt. Of Fine aggregate (Kg/m^3)	Wt. Of 12 mm Coarse aggregate (Kg/m^3)	Wt. Of 20 mm Coarse aggregate (Kg/m^3)
M20	0.56	10	194.9522	348.1289	772.2352	347.5058	810.8469
			0.56	1	2.2182	0.9982	2.3292
M25	0.54	15	201.1187	372.4420	756.7967	340.5585	794.6366
			0.54	1	2.0320	0.9144	2.1336
M30	0.50	20	203.8259	407.6518	741.3583	333.6112	778.4262
			0.50	1	1.8186	0.8184	1.9095
M35	0.48	25	208.9378	435.2871	725.9199	326.6639	762.2159
			0.48	1	1.6677	0.7505	1.7511
M40	0.44	30	209.7061	476.6047	710.4815	319.7167	746.0055
			0.44	1	1.4907	0.6708	1.5653

IV. Design of Concrete Mix Using IS Code Method

Mix design is also carried out using IS code 10262-2009 [13]. The objective of IS code method of mix design is to compare the ingredients of concrete (mix proportions) with the packing density method and also to compare the compressive strength at 28 days in these two cases and relevant observations were discussed.

Here also the final mix proportions were obtained for M20, M25, M30, M35 and M40 grade of concrete using IS method with different trial mix. The trial mix design for different grades of concrete was carried for different water cement ratios and workability is checked using Flow Table tests. Accepted trial mixes was further used to cast the trial cube specimens and were tested for compressive strength at the 7 days curing age. Observing the results of trial casting the appropriate mix is finalised. This finalised mix proportion is used for further casting.

Finalised mix proportions for different grades of concrete designed by IS code method is presented in Table 4.

Table 4: Finalised mix proportions designed by IS code method

Grade of concrete	W/C ratio	Water content (Kg/m^3)	Cement content (Kg/m^3)	Wt. Of Fine aggregate (Kg/m^3)	Wt. Of 12 mm Coarse aggregate (Kg/m^3)	Wt. Of 20 mm Coarse aggregate (Kg/m^3)
M20	0.55	192	349	669	609.7	609.7
		0.55	1	1.9169	1.7470	1.7470
M25	0.52	192	369.23	662.786	633.70	633.70
		0.52	1	1.7950	1.7162	1.7162
M30	0.48	197	410	646	617	617
		0.48	1	1.5756	1.5048	1.5048
M35	0.46	197	428	638	610.5	610.5
		0.46	1	1.4907	1.4264	1.4264
M40	0.42	197	469	625	598	598
		0.42	1	1.3326	1.2750	1.2750

V. Comparing the Mix Proportions and Compressive Strength

Finalized mix proportions for M20, M25, M30, M35 and M40 grade concrete using packing density and IS code method are presented in Table 3 and 4 respectively.

Using these finalized mix proportions for different grades of concrete final casting was carried out as mentioned in the following section.

In packing density method finalized mix proportions were used for final casting. Six cube specimens were cast (3 cube specimens for 7 days curing and 3 cube specimens for 28 days curing). Similarly, in IS method for each grade of concrete six cube specimens were cast (3 cube specimens for 7 days curing and 3 cube specimens for 28 days curing). Casting, curing and compressive strength testing procedure was followed according to IS 516-1959 [14].

The average test result of 3 cube specimens is considered for final test result. The results of final casting are presented in Table 5 and Table 6.

Table 5: Compressive strength of cube cast using packing density method

Grade of concrete	W/C ratio	Paste content	Strength of cube (Mpa) (7 days)	Strength of cube (Mpa) (28 days)
M20	0.56	10 %	22.8889	33.7037
M25	0.54	15 %	26.9629	38.7407
M30	0.5	20 %	30.3333	44.4444
M35	0.48	25 %	36.6667	50.6667
M40	0.44	30 %	40.8519	54.8048

Table 6: Compressive strength of cube cast using IS code method

Grade of concrete	W/C ratio	Strength of cube (Mpa) (7 days)	Strength of cube (Mpa) (28 days)
M20	0.55	22.6667	31.5555
M25	0.52	26.2222	37.7037
M30	0.48	31.8518	45.6296
M35	0.46	34.0741	48.8889
M40	0.42	38.2222	54.5184

VI. Results and Discussions

From the Tables 3 and 4, it is clear that fine aggregate particles are required more in case of packing density method compared to IS code method. Therefore, water and cement required in case of packing density method is more. In case of IS method coarse aggregate 20mm and 12.5mm down sizes are graded based on sieve analysis results but in case of packing density method aggregates quantity are decided based on actual packing of particles. Coarse aggregate particle 20mm downsize required will be more in case of packing density method compared to IS method. But both the methods have resulted in nearly same compressive strength at 28 days curing. Coarse aggregate particle may also contribute towards the strength along with bond. In case of packing density, finer aggregate particles required are more and paste required is also more. In this case contribution to the strength due to bond area may be more.

Too many trial calculations were involved for determining paste content and water cement ratio for designing any grade of concrete by packing density method. In addition to this number of trial tests such as flow table test and trial casting for compressive strength test are to be determined in order to arrive at water cement ratio and paste content for a particular grade of concrete. Well established co-relations were not available for packing density method to reduce the time and labour involved in this trial testing and casting. Therefore, here an attempt is made to develop these co-relations between compressive strength (for 7 days and 28 days curing age) and water cement ratio, paste content in excess of void content.

Data presented in Table 5 are represented in the form of figures. The data from Table 5 are considered to obtain the best fit equation through CURVE EXPERT 1.4. Fig. 7 represents compressive strength (7 days curing) vs water cement ratio for packing density data alone. Similarly Fig. 8 is a plot of compressive strength (7 days curing) vs water cement ratio including IS code and packing density method. Similar plots were obtained for 28 days curing age and they are represented in fig 9 (packing density alone) and fig. 10 (including both IS and packing density method). From fig 7 it is observed that a linear fit with a very good co-relation co-efficient i.e., 0.984 is obtained. Co-efficients a, b, standard error and co-efficient of co-relation for all the figures from 7 to 10 are presented in Table 7. From the table it is observed that a very good co-relation co-efficient is obtained for packing density alone at the curing age of 7 days and 28 days i.e., 0.984 and 0.988 respectively. Similarly good co-relation co-efficient is obtained for both the data (IS and packing density method) at 7 days and 28 days i.e., 0.953 and 0.961 respectively.

Fig 11 represents compressive strength vs paste content in excess of void content for the data of packing density alone at 7 days curing age and fig 12 represents compressive strength vs paste content in excess of void content for the data of including both IS code and packing density method at 7 days curing age. Similar plots were obtained for 28 days curing age and they are presented in fig 13 (packing density alone) and fig 14 (including both IS and packing density method). From fig 11 to 14 it is observed that a linear fit with very good co-relation co-efficient is obtained. From the Table 7 it is observed that a very good co-relation co-efficient is obtained for packing density alone at the curing age of 7 days and 28 days i.e., 0.995 and 0.998 respectively. Similarly good co-relation co-efficient is obtained for both the data (IS and packing density method) at 7 days and 28 days i.e., 0.988 and 0.994 respectively. However, the co-relations obtained are not generalised as the materials used for study are locally available materials.

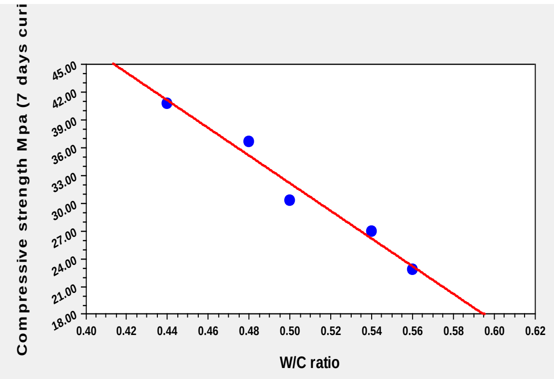

Fig 7: Packing density method at 7 days curing

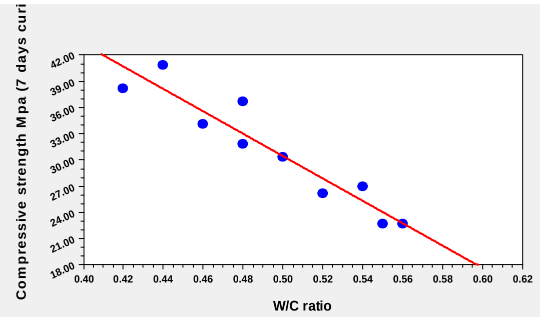

Fig 8: Packing density and IS code method at 7 days curing

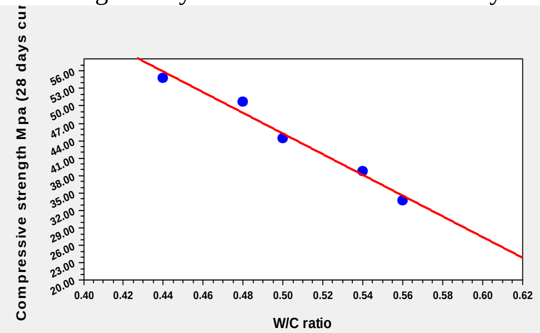

Fig 9: Packing density method at 28 days curing

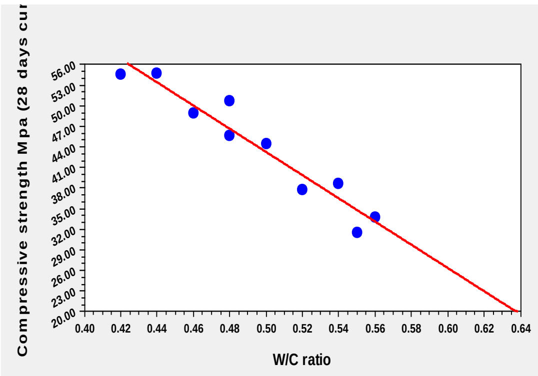

Fig 10: Packing density and IS code method at 28 days curing

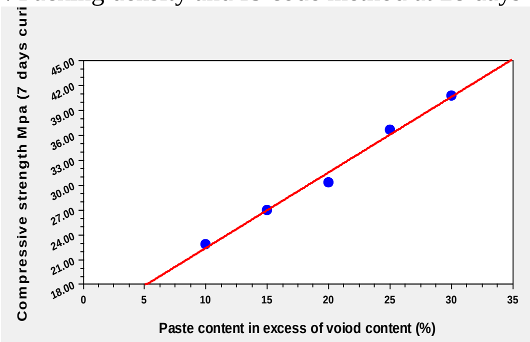

Fig 11: Packing density method at 7 days curing

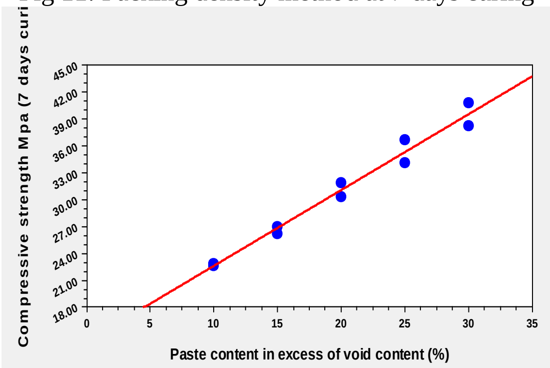

Fig 12: Packing density and IS code method at 7 days curing

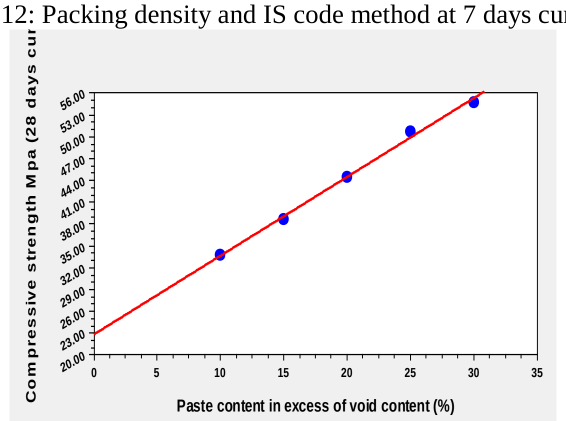

Fig 13: Packing density method at 28 days curing

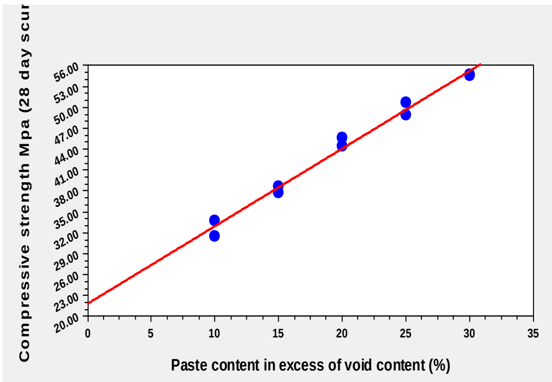

Fig 14: Packing density and IS code method at 28 days curing

Table 7: Equation co-efficients and co-relation co-efficients

Linear fit: y = a + bx						
Figure no.	Mix design method	Curing age	Co-efficients		Standard error (s)	Co-relation co-efficient(r)
			A	b		
Compressive strength (Mpa) vs Water cement ratio						
6.1	Packing density	7	1.069E+02	-1.495E+02	1.462	0.985
6.2	Packing density and IS code	7	9.439E+01	-1.279E+02	2.174	0.953
6.3	Packing density	28	1.340E+02	-1.775E+02	1.468	0.989
6.4	Packing density and IS code	28	1.278E+02	-1.691E+02	2.441	0.961
Compressive strength (Mpa) vs Paste content in excess of void content (%)						
6.5	Packing density	7	1.329E+01	9.126E-01	0.823	0.995
6.6	Packing density and IS code	7	1.416E+01	8.459E-01	1.028	0.988
6.7	Packing density	28	2.282E+01	1.083E+00	0.566	0.998
6.8	Packing density and IS code	28	2.182E+01	1.112E+00	1.001	0.994

VII. Conclusions

1. The packing density value will remain same irrespective of grade of concrete.
2. In packing density method, paste content in excess of void content will increase with the increase in grade of concrete.
3. In case of packing density method water cement ratio decreases with increase in grade of concrete.
4. In packing density too many trial calculations, trial tests and trial casting are to be done in order to arrive at water cement ratio and paste content for a particular grade of concrete. These co-relation curves helps to reduce the trials involved in determining the water cement ratio and paste content for the given grade of concrete.
5. The water and cement content for packing density and IS code method is nearly same for any particular grade of concrete.
6. The workability of concrete achieved is more in packing density method compared to IS code method for the same grade of concrete, as the water cement ratio is slightly higher in packing density method than IS code method.
7. The fine aggregate particles required are more in case of packing density method compared to IS code method. Therefore, water and cement required in case of packing density is more.
8. The fine aggregate and coarse aggregate 20mm down size required is more in packing density method and coarse aggregate 12.5mm down size required is more in IS method. But the cube compressive strength results at 7 days and 28 days curing age obtained by both the methods are nearly same.
9. Though the material quantities are different in both the methods, compressive strength achieved at 28 days by packing density and IS code methods are nearly same.

10. A very good correlation coefficient is obtained for the Co-relation curves with a minimum of 0.953 to maximum of 0.998.
11. Co-relation curves can be used to decide the water cement ratio and paste content in excess of void content for the given grade of concrete.

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