Concrete mix proportioning

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With the use of chemical and mineral admixtures in concrete, one would expect that the concrete mix design procedure as given in IS 10262 will need changes. Experimental data from different construction sites indicate that the existing relationships between water-cement ratios and 28-day compressive strengths of concrete for two grades of ordinary Portland cement (43 and 53 grades) as given in IS 10262 can still be used to estimate the water-cementitious materials ratios for the target 28-day compressive strengths of concrete using Portland slag cement, Portland pozzolana cement or concrete containing ordinary Portland cement plus ground granulated blast furnace slag (ggbs) or flyash, and a superplasticiser. This indicates that the mineral admixtures, that is, flyash and ground granulated blast furnace are contributing to the strength-development process at 28 days, similar to that by OPC in concrete. Regarding sand and water contents, suggestions to modify existing guidelines of IS 10262 have been made for superplasticised concrete mixes. Concrete mix design for very high-strength concrete (M80 and above) using silica fume and a PC based superplasticiser needs special considerations, and the trial mix approach is best for selecting mix proportions for such high-strength concrete.

There are many methods of concrete mix design. But the British or American methods will not be applicable for our country, as the specific relationships constituting figures and tables are based on their materials. The IS 10262 recommends procedure for designing concrete mixes for general types of construction using the concreting materials normally available[1]. The procedure was developed in 1982 based on the experiments carried out at the National Council for Cement and Building Materials (NCBM), New Delhi. The method is primarily based on the basic assumption that the compressive strength of concrete is governed generally, by the water-cement ratio. The recent development of using chemical and mineral admixtures in concrete has not alterted the applicability of the age-old Abram's water-cement ratio 'law', and the compressive strength of concrete is governed by the water-cementitious materials ratio used in concrete. The cementitious materials include cement (OPC, PPC and PSC) and mineral admixtures, like, flyash, ggbs and silica fume.

In this paper, an attempt has been made to highlight that in the procedure of concrete mix design, the water-cement (or water-cementitious materials) ratio must be selected from an established relationship between this and the 28-day compressive strength of concrete and that for superplasticised

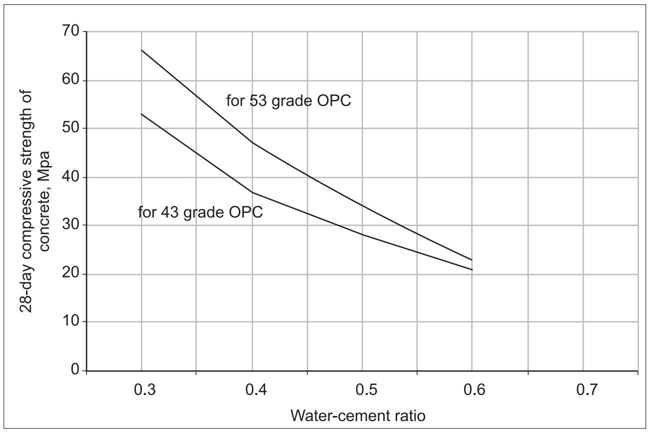

Fig 1 Typical relationship between water-cement ratio versus 28-day compressive strength of concrete (as per IS 10262)

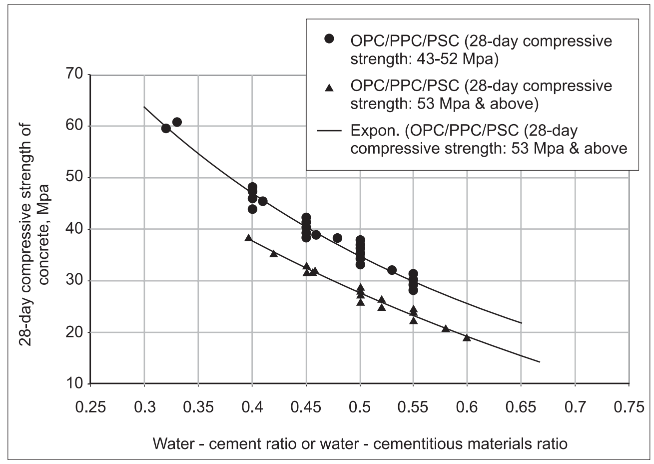

Fig 2 Typical relationship between water-cement ratio or water-cementitious material ratio versus 28-day compressive strength of concrete

and mineral admixtured concrete, such relationship could also be established. While the quantity of flyash in concrete can be decided based on its quality, that of ggbs can be decided based on the durability requirement at the site.

Existing relationship between water-cement ratio and 28-day compressive strength of concrete using OPC and no chemical or mineral admixture

The relationship between water-cement ratio and 28-day compressive strength of concrete as given in *Fig* 2 of IS 10262 need extrapolation of curves for higher grades of concrete, that is, M40, M45, M50 and M55, because the target 28-day compressive strengths of concrete will be higher for these grades. The curve D (for 28-day compressive strength of cement = 46.6 – 51.5 N/mm^2) and curve F (for 28-day compressive strength of cement = 56.4 – 61.3 N/mm^2) of *Fig* 2 of IS 10262 correspond broadly to the two grades of OPC, that is, 43-grade and 53-grade, respectively. These two curves (with extrapolation) have been shown in *Fig* 1.

Concrete mix design data using OPC and superplasticiser

Data on concrete mixes using 43-grade and 53-grade OPC and superplasticisers obtained from various construction sites, like, flyover projects of Delhi Development Authority, PWD Delhi, CPWD constructions, NTPC constructions, Delhi Metro project, etc. and the same are plotted in *Fig* 2 for comparison with the existing relationships given in IS 10262.

Concrete mix data using Portland slag cement, Portland pozzolana cement or concrete containing ggbs, flyash and superplaticiser

The ground granulated blast furnace slag conforming to to IS 12089 and flyash conforming to IS 3812 are permitted to be used as mineral admixtures in concrete and as part replacement of OPC[3,4]. The 28-day compressive strength of concrete will depend on the quality and quantity of these mineral admixtures in the concrete mix and the concrete curing temperature.

Concrete mix data corresponding to various grades of concrete viz. M15, M20, M25 and M30 with OPC (43 grade) and 55 percent ggbs and M40 and M45 with OPC (53 grade) and 60 and 70 percent ggbs and a superplasticiser have been plotted in *Fig* 2.[5,6,7,8,9,10] Also included in the same figure is concrete mix data with OPC (43 and 53 grades) containing 23, 28 and 35 percent of flyash which conformed to IS 3812 (Part 1) and a superplasticiser.

Table 1: Approximate sand and water contents#

Nominal maximum size of aggregate, mm	*Water content per cubic metre of concrete, kg**		*Sand as percent of total aggregate by absolute volume*
	Normal concrete	*Superplasticised concrete*	
10	208	175	40
20	186	160	37
40	165	145	33

#per cubic metre of concrete for grades upto M 35 (w/c = 0.60, workability : 0.80 C.F. (25 mm slump), crushed rock coarse aggregate and fine aggregate conforming to grading Zone II)

*water content corresponding to saturated surface dry aggregate

Table 2: Approximate sand and water contents#

Nominal maximum size of aggregate, mm	*Water content per cubic metre of concrete, kg**		*Sand as per cent of total aggregate by absolute volume*
	Normal concrete	*Superplasticised concrete*	
10	200	170	33
20	180	155	30

#per cubic metre of concrete for grades above M 35 (w/c = 0.35, workability : 0.80 C.F. (25 mm slump), crushed rock coarse aggregate and fine aggregate conforming to grading Zone II)

*water content corresponding to saturated surface dry aggregate

Table 3 : Adjustment of values in water content and sand percentage for other conditions

Change in condition	*Adjustment required in*	
	Water content	*Percent sand in total aggregate, percent*
For sand conforming to grading Zone I, Zone III or Zone IV of Table 4 of IS 383	0	+ 3.0 for Zone I – 1.5 for Zone III – 3.0 for Zone IV
Increase or decrease in the value of C.F by 0.1 or ±25 mm slump	± 5 percent	0
Each 0.05 increase or decrease in water-cement ratio	0	± 1
For rounded aggregate	– 15 kg/m^3	- 7

It is observed that the best fitted curve lines drawn through these experimental data points are almost the same curve lines of *Fig* 1. In other words, the relationship of *Fig* 1 (reproduced from *Fig* 2 of IS 10262) between water-cement ratio and 28-day compressive strength of concrete are still valid, and can be used for designing superplasticised concrete mixes with 43 and 53 grades of OPC. In other words, *Fig 2* can be used to decide the water cementitious material ratio for superplasticised concrete mixes, using PPC or PSC or (OPC + flyash) or (OPC + ggbs), for the target 28-day compressive strength of concrete.

Once the water-cement ratio or water-cementitious material ratio is decided for the target 28-day compressive strength of concrete from *Fig* 2, the sand and water contents per cubic metre of concrete can be decided using *Tables* 1, 2 and 3, depending on the grade of concrete, workability requirement, type and maximum size of aggregate and grading of fine aggregate. These tables (with modifications) are based on the work carried out at the National Council for Cement and Building Materials, and contain suggestions for superplasticised concrete mixes[2].

Quantities of ingredients

Once the water-cement ratio or the water-cementitious material ratio is determined, the water content of concrete can be decided based on workability requirement and maximum size of aggregate. The percentage of flyash or ggbs being decided before hand, based on the quality and durability requirement at the site. The cement and flyash or ggbs contents of the concrete mix are then calculated. The percentage of fine aggregate is decided based on its grading and the maximum size aggregate. The quantities of individual constituents are then calculated by the absolute volume method, using specific gravity values of the constituent materials and considering the entrapped air content of concrete as expected in normal non-air entrained concrete, typically 1 percent for 40 mm maximum size of aggregate, 2 percent for 20 mm maximum size of aggregate and 3 percent for 10 to 12 mm maximum size of aggregate. The air content in concrete (which is present even in fully compacted concrete) must be considered while calculating the quantities of the ingredients in concrete, by absolute volume method.

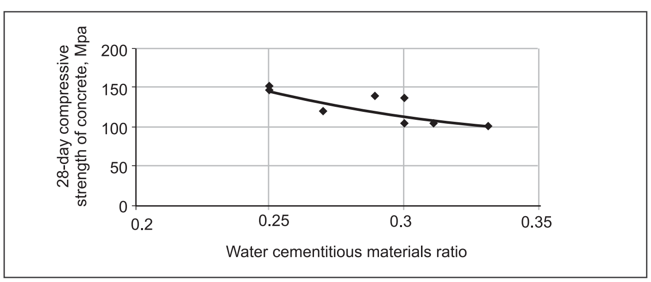

Fig 3 Typical water-cementitious materials ratio versus 28-day compressive strength of very high strength concrete[11]

Concrete mix design for very high-strength concrete

In very high-strength concrete (compressive strength >80 MPa), Abram's water-cement ratio 'law' is not valid strictly, because the water-cementitious material ratios are very low. The role of water-cement ratio is not prominent in such concretes. *Fig* 3 is a typical plot of water-cementitious material ratio versus 28-day compressive strength of concrete based on data from Canada, USA and France[11]. These high-strength concretes had water-cementitious material ratios in the range of 0.25 to 0.33. The water-cementitious material ratios versus 28-day compressive strength of concrete indicates that there exists a continuum of the relationship between the two parameters in the range indicated. It is noteworthy that such concretes contain about 30 to 40 percent of mixing water compared to normal strength concrete without high range water reducing admixture. By using a polycarboxylate based superplasticiser the water content in the case of high strength concrete is reduced to about 130 to 140 lit/m^{3}of concrete.

For normal strength concrete, the cement contents are typically in the range of 300- 450 kg/m^3 of concretes, whereas for very high-strength concrete, the content of cementitious materials (cement + silica fume + flyash / blast furnace slag) is in the range of 500 to 650 kg/m^3 of concrete.

There is no formal mix design method for such high-strength concretes. According to Canadian Portland Cement Association, the trial mix approach is best for selecting mix proportions for such high-strength concretes.[12]

Discussion

All the relationships between water-cement ratio and 28-day compressive strength of concrete given in *Fig* 2 of IS 10262 : 1982 (6 curves : A, B, C, D, E and F) need not be used for concrete mix design purposes. Only curve D (applicable for 43 grade OPC) and curve F (applicable for 53 grade of OPC) can be used since these two strength levels of cement are now predominant in the Indian market. The water-cement ratio of concrete must be selected from established relationships between water-cement ratios and 28-day compressive strengths of concrete. The water-cement ratio cannot be decided from experience.

It is established with a large number of experimental data that these two curves (for concrete without any admixture, as mentioned in the Recommended Guidelines IS 10262:1982) need not be discarded as they are valid for concrete using OPC/PPC/PSC/(OPC + flyash)/(OPC + ggbs) and a superplasticiser. The relationship between water-cement ratios or water-cementitious materials ratios and 28-day compressive strengths of concrete as developed from experimental data can be used for normal concrete mixes using superplasticisers and mineral admixtures (flyash or ggbs) for mix design. The concrete mix design is generally carried out for 28-day compressive strength of concrete. At this age the contribution of flyash and in strength development is similar to that of OPC. The relationships between water-cement ratios and 28-day compressive strengths of concrete for strength levels 43-52 MPa and > 53 MPa are also satisfactory for concrete containing superplasticisers and mineral admixtures, like flyash and ggbs.The mineral admixture silica fume however contributes much more to the strengthdevelopment process and therefore for very high-strength concrete (28-day compressive strength of concrete > 80 MPa) containing PC-based superplasticiser (high-range water-reducing admixture water reduction being of the order of 30-40 percent) and silica fume, the above relationships cannot be used for selecting water-cementitious materials ratio.

Conclusion

Relationships between water-cement ratios or water-cementitious materials ratios and 28-day compressive strength of concrete have been arrived at based on experimental data from different construction sites. Such concrete contains OPC or PPC or PSC or (OPC + flyash) or (OPC + ggbs) and a superplasticiser. These relationships however are for two levels of 28-day compressive strengths of cement, viz. 43-52 MPa, and greater than 53 MPa. It is observed that these relationships are almost same as given in IS 10262 for two grades of OPC (43-grade and 53-grade). This indicates that the mineral admixtures, like flyash and ggbs contribute to the strength development process at 28-days, similar to that of OPC in concrete. This reinforces the observations made by an independent approach using generalised Abram's Law for multi component cementing materials[13]. The relationships can thus be used for selecting water-cementitious materials ratio for the target 28-day compressive strength of concrete containing flyash or ggbs and a superplasticiser. These relationships however cannot be used for very high-strength concrete that is, for concrete having 28-day compressive strength above 80 MPa, using silica fume and a PC-based superplasticiser. The trial mix approach is best for selecting mix proportions for such high strength concrete.

References

1. ______ *Indian standard recommended guidelines for concrete mix design,* IS 10262 : 1982, Bureau of Indian Standards, New Delhi

2. Maiti, S.C., Wason, R.C., Kumar, Suresh and Chaturvedi, A.K., Concrete mix design – Suggestions for modifying existing guidelines, *Proceedings of the Seventh NCBM International Seminar on Cement and Building Materials,* November 2000, pp. VIII B-8 to VIII B-13.

3. ______*Indian standard specification for granulated slag for the manufacture of portland slag cement*, IS 12089, Bureau of Indian Standards, New Delhi

4. ______*Indian standard specification for pulverised fuel ash-part 1 : for use as pozzolana in cement, cement mortar and concrete*, IS 3812 (Part 1) : 2003, Bureau of Indian Standards, New Delhi

5. ______*Studies on characteristics of concrete made with Portland Slag Cements*, *Unpublished Report*, December 2000, National Council for Cement and Building Materials, New Delhi

6. Prasad, G.V.K. and Lokesh Babu, L.V.R., Use of ground granulated blast furnace slag (GGBS) for durable concrete, *Proceedings of the Fifth International conference on concrete technology for developing countries*, Vol. 1, 17-19 November 1999, New Delhi, pp. II-12 to II-22.

7. Nataraja, M.C., Reddy, B.M.R., Bhavanishankar, S. and Etigi, Y.B.B., Mix design and some properties of cement concrete containing ground granulated blast furnace slag, *Proceedings of the second international symposium on concrete technology for sustainable development with emphasis on infrastructure*, 27 February - 3 March, 2005, Hyderabad, India, pp. 491-499

8. Maiti, S.C. and Jain, N.K., Mix proportioning of superplasticed flyash concrete, *Proceedings of the Fifth International conference on concrete technology for developing countries*, Vol. 2, 1999, New Delhi, pp. VI-106 to VI-113.

9. Kamal, Nayan, Blended cement concrete in Delhi Metro Rail Project, *Proceedings of the second International symposium on concrete technology for sustainable development with emphasis on infrastructure*, February 27 – March 3, 2005, Hyderabad, pp. 397-408.

10. Shetty, M.S., Muenz, K. and Gall, N., Delhi Metro : Quality control of concrete for underground section. *The Indian Concrete Journal*, April 2005, Vol. 79, No. 4, pp. 11-21

11. Maiti, S.C., Mix proportioning of high-performance concrete, *New Building Materials and Construction World*, September 2004, pp. 62-63

12. Mindess, S., Materials Selection Proportioning and Quality Control, High performance concretes and applications, Edward Arnold, London, 1994, pp. 1-25.

13. Nagaraj, T.S., Generalised Abram's Law for multi-component cementing materials, International Conference in Civil Engineering (ICCE - 2001), Indian Institute of Science, Bangalore, 2001.

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