Discussion Forum

Revalidating strength – Cementitious material – Water relationship for proportioning portland pozzalana cement concrete

Dear Sir,

This has reference to the the paper titled 'Revalidating Strength – Cementitious material – Water relationship for proportioning portland pozzalana cement concrete' by Dipesh Majumdar, Subhajit Saraswati, Partha Pratim Biswas and Subrato Chowdhury published in the July 2013 issue of The Indian Concrete Journal (Vol. 87, No. 7, pp. 50-53).

In this paper authors have studied the strength characteristics of fly ash based cement concrete designed based on the strength- cementitious material- water relationships developed for proportioning fly ash based concrete. They have discussed about the validity of the above relation by designed few mixes and studying their performances. The paper is well written and lots of experimental results were presented which according to the discusser will help the researchers working in this area. However the discusser would like to clarify few points on the proposed mix design and seeks some clarification about the results.

Strength of mortar is determined at w/c = 0.4. It means that the relation is characterized for this condition of mortar, which contains any cementitious materials (about 26 % of fly ash in this case). In addition no chemicals are added to the mortar as the flowablity of mortar at this w/c is quite sufficient. Concrete mixes are designed for various strengths namely 45/55/65 MPa at 28 days for which the established relations by one of the authors is used. Here the lower bound relation is considered for the design. On what basis this is selected is not clear. What is the order of variation of w/c when the other two relations are used? Give the w/c values for the mixes considered based on the three relations.

Here the water content is fixed at 155 liters. On what basis this water is fixed is not discussed in the paper. This depends on the range of workability required and the type of chemical admixtures used. The dosage of admixture is also important. Water can be further reduced or increased depending the range of workability and with this the amount of cement changes. Final mix proportions also changes leading to different strength and workability.[1,2] Authors should discuss on this aspect. For any one mix considered in the work, mere change in water content (and hence w/c) can produce any strength at that level of cement content. Only issue is to adjust the workability with suitable dosage of compatible plasticizer.[3-5] Kindly provide the details of admixture dosage and the workability results for better understanding.

The equations developed will lead to different strengths if the type and quality of aggregates are changed. In the present work the mixes have developed the target strengths for the type and quality of the aggregates used.

Is it valid for all types of coarse aggregates keeping the same fine aggregate for mortar and cement? This needs to be verified for generalization of the approach.

Another point for discussion is when the amount of fly ash is different. The strength of mortar will be less (or more) if the pozzolanic activity of fly ash is less (or more). The quality of fly ash is reflected in the mortar strength. The strength of this mortar and the corresponding w/c obtained from the authors' relation is the only criteria for designing concrete for any target strength. It means the type, quality, gradation, and interfacial bond (transition zone) are not coming in to picture at all in this approach. However, the discusser is of the opinion that with different types of coarse aggregates the concrete strengths will be different.[1, 2] This point may be discussed.

The type of cement used is such that the increase in 56 day strength in comparison with 28 day strength is not substantial. It is hardly 7%. Sometimes this much of increase in strength is possible with OPC itself. The discusser is of the opinion that waiting for another one month is not very advantages to get this small additional strength.

The discusser suggests one more possible approach to design the concrete for 56 day strength knowing the corresponding strength of mortar. For this, authors' results are used as follows.

For mortar the ratio of 56 day strength to 28 day strength = 60.9/57.0 x 100 = 106.8%. About 6% increase. Similarly the ratio of cement content for 60 MPa concrete at 56 days to 28 days is 409/382 x 100 = 107.1% (based on the first and the fifth results of Table 4). About 7% decrease. The ratio of w/c for 60MPa at 56 days to 28 day is 0.406/0.379 x 100 = 107.1%. About 7% increase. It means, for 56 day strength of concrete at any w/c ratio, decrease the cement by 7% (say x) or increase the w/c by 7% in the corresponding mix designed for 28 days, where x is the percentage increase in 56 day strength of mortar compared to its 28 day strength. Can this be generalized by conducting some more work? With this 56 day relations may not be required. Authors are requested to discuss on this in detail.

Lot of work has been reported in the literature on concrete mix design where unconventional aggregates and cementitious materials are used.[6] Many concrete mix design works carried out by the discusser is based on the generalized Abrams law using law of composite mechanics.[7-9] This method of concrete mix design is well established and the feasibility of the method is proved taking different types of aggregates. This method is quite satisfactory for the mix design where w/c ratio alone controls the design for all types of aggregates (normal to light weight). In addition the method is applicable for any type and combinations of cementations materials. Authors are informed to refer these papers where one trial mix design based on the aggregate characteristic strength and subsequent one (or two) design will give the required strength for all types and combinations of ingredients i.e. for any concrete. Workability can be adjusted varying the dosage of chemicals.

Though there exist different methods for concrete mix design, the proposed method has its own merits. From the point of utilization of pozzalanic materials, the work is quite encouraging. The use of fly ash or any mineral admixtures as a raw material in concrete should be highly encouraged.[10] The discusser congratulates the authors for taking such work when India is facing acute shortage of natural resources.

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(Continued on page 35)

Dear Sir,

This has reference to the the paper titled 'Revalidating Strength – Cementitious material – Water relationship for proportioning portland pozzalana cement concrete' by Dipesh Majumdar, Subhajit Saraswati, Partha Pratim Biswas and Subrato Chowdhury published in the July 2013 issue of The Indian Concrete Journal (Vol. 87, No. 7, pp. 50-53).

[1] The discussers appreciate the efforts by the authors to generate data to have a new look to the much established fact that higher w/c ratio means lower compressive strength of concrete (and vice versa) and the relationship was discovered by Abram in the beginning of last century. This was confirmed later on by many other scientists/engineers, including Bolomey in 1925. Cement strength was also recognised as an important influencing factor when Portland cements of several strengths were produced for various practical applications. Therefore, The discussers are happy to note that the cement strength (not the grade of cement) has been made as a part of the authors' relations between w/cm and fc'

[2] The authors have given following power relationships between w/cm, cement strength, f_{cem} , and strength of concrete, fc' :

$$f_{c28da} = 5.331 * f_{cem} * \exp [- 3.8607 * wcm] \quad .....(a1)$$

$$f_{c56d} = 4.9741 * f_{cem} * \exp [- 3.6623 * wcm] \quad .....(a2)$$

However, the discussers wish to point out that a simpler linear equation is feasible based on the already information available in the literature as shown below.

The following relationship for cement composites was suggested by Bolomey[1]:

$$fc = A * [(C/W)] + B \quad .....(1)$$

where, fc = compressive strength, C = cement content, W = water content, A and B are constants for given ingredients of concrete.

Above Equation (1) is shown to reduce practically to the following two equations[2]:

$$fc = A*[(C/W) - 0.5] \quad .....(2)$$

$$fc = A*[(C/W) + 0.5] \quad .....(3)$$

These two equations represent two ranges of concrete strengths and it is due to the often observed fact that a change in slope occurs at about w/c = 0.40, when C/W (cement-water ratio) is plotted against strength. However, it was found that the Equation (2) is useful for most of the present day concretes when an analysis was done by the discussers on test results available at CSIR-SERC[3] by the first discusser and also the extensive data published by Hansen[4]. Larrard also mentions this equation[5]. Therefore, Equation (2) can be generally used for cement composites. The value of constant 'A' can be found out for the given ingredients of concrete, by considering any mix with the known w/c ratio. Equation (2) can be written in the present case as :

$$fc = A*[(1/wcm) - 0.5] \quad .....(4)$$

where, (1/wcm) = 1/ (W/C) = C/W, W=Water content, C = Cement content

In above equation, the cement could be either Portland Pozzolana cement or Portland cement. Use of data from curves A to F of BIS publication SP:23(S&T) had led to following equation:[6,3]

$$fc = (0.39*f_{cem})*[(1/wcm) - 0.5] \quad \text{where, } f_{cem} = \text{cement strength} \quad .....(5)$$

This equation can be now written as:

$$fc = (K*f_{cem})*[(1/wcm) - 0.5] \quad .....(6)$$

where factor K is found for a test data for any wcm for a given set of ingredients and the factor A of Eqn (4) is now equal to $K*f_{cem}$. Then, Eqn (4) is written as:

$$K = fc / [f_{cem} * \{(1/wcm) - 0.5\}] \quad .....(7)$$

It may be noted that the values of both K and f_{cem} could be considered to depend upon the age at which cement and concrete strengths (for given set of concrete ingredients) are considered.

[3] For the authors' 28 days test data on the three mixes, viz., PPC 28/1/60, PPC 28/2/55, and PPC 28/3/45, the K value from Eqn (7) can be found using the data of mix PPC 28/2/55 as shown blow:

$$K = 57.1 / [57* \{(1/0.401) - 0.5\}] = 0.5 \quad .....(8)$$

Then, Eqn (6) for 28 days is written as

$$fc = (0.5*f_{cem})*[(1/wcm) - 0.5] \quad .....(9)$$

Eqn (9) is far simpler than the authors' Eqn (a1) of their paper. Using this Eqn (9), the following table is built where fc from Eqn (9) is entered as fc_{eqn} and fc from authors' paper is given as f_{test}:

Table D1 Computations for 28 days strengths

K	f_{cem}	wcm	fc_{eqn}	f_{test}	% Diff between fc_{eqn} and f_{test}
0.5	57	0.379	60.9	61.2	-0.4
0.5	57	0.401	56.8	57.1	-0.5
0.5	57	0.452	48.8	43.4	12.4

The above table shows that the prediction of strength is satisfactory since the difference between test and prediction is less than + or – 15% which is acceptable practically since there are so many parameters which actually affect the strength of a concrete, but, only here wcm and f_{cem} are used to estimate the strength.

[4] For the authors' 56 days test data on the mixes, PPC 56/1/70, PPC 56/1/55, and PPC 56/2/45, the K value using data from the mix PPC 56/2/55 works out to :

$$K=60.9 / [60.3* \{(1/0.55) - 0.5\}] = 0.5 \quad .....(10)$$

Then, Eqn (6) for the 56 days strength is

$$fc = (0.5*f_{cem})*[(1/wcm) - 0.5] \quad .....(11)$$

Eqn (11) is far simpler than the authors' Eqn (a2) of their paper. Using this Eqn (11), the following table can be built:

Table D2 Computations for 56 days strengths

K	f_{cem}	wcm	fc_{eqn}	f_{test}	% Diff between fc_{eqn} and f_{test}
0.5	60.9	0.365	68.2	69.3	-1.6
0.5	60.9	0.406	59.8	60.3	-0.9
0.5	60.9	0.455	51.7	50.4	2.6

The above table shows that the prediction of strength by Eqn (11) is satisfactory since the differences between test and prediction are far less than + or – 15% which is practically acceptable since there are so many parameters which actually affect the strength of a concrete, but, only here wcm and f_{cem} are used to estimate the strength

[5] From the above discussions and furthers computations in Table D3, the discussers observed that authors' Eqns (a1) and (a2) are essentially almost same. In this table, it is seen that both of these Eqns give almost same strength values if f_{cem} is same, even though the Eqns apparently seem to have different numerical constants embedded in them. Thus, if actual f_{cem} values at 28 and 56 days are used, any one of the authors' two equations can be used and then, apparently, one equation is adequate.

Table D3 Computations for typical values of wcm and f_{cem} for authors Eqns (a1) and (a2) where for f_{c28da}, Eqn (a1) is used and for f_{c56da}, Eqn (a2) is used.

f_{cem}	wcm	f_{c28da}	f_{c56a}	%Diff
45	0.38	55.3	55.7	0.6
45	0.40	51.2	51.7	1.0
45	0.42	47.4	48.1	1.4
45	0.45	42.2	43.1	2.0
45	0.50	34.8	35.9	3.0
45	0.55	28.7	29.9	4.1
55	0.38	67.6	68.0	0.6
55	0.40	62.6	63.2	1.0
55	0.42	57.9	58.8	1.4
55	0.45	51.6	52.6	2.0
55	0.50	42.5	43.8	3.0
55	0.55	35.1	36.5	4.1
60	0.38	73.8	74.2	0.6
60	0.40	68.3	69.0	1.0
60	0.42	63.2	64.1	1.4
60	0.45	56.3	57.4	2.0
60	0.50	46.4	47.8	3.0
60	0.55	38.3	39.8	4.1
65	0.38	79.9	80.4	0.6
65	0.40	74.0	74.7	1.0
65	0.42	68.5	69.4	1.4
65	0.45	61.0	62.2	2.0
65	0.50	50.3	51.8	3.0
65	0.55	41.5	43.1	4.1
			Max	4.1
			Min	0.6

[6] Further, it is seen that the discussers' Eqns (9) and (11) are again working out to be same, then, this fact can be used to develop a general formula to predict strength.

Then, Strength Estimation Eqn for both 28 and 56 days can be now given as:

$$fc = (0.5*f_{cem})*[(1/wcm) - 0.5] \quad .....(12)$$

where, the age at which f_{cem} is determined is related to the age at which the strength of concrete is required to be estimated.

[7] The following table shows that Eqn (12) is adequate practically to estimate the 28 day concrete strengths for cement strengths of 45 to 65 MPa for wcm values of 0.38 to 0.55:

Table D4 Comparison of authors' and discussers' equations for typical values of wcm and f_{cem} to compute 28 day strengths (f_{cem} is taken as 28 day cement strength)

f_{cem}	wcm	f_{cd}	f_{c28da}	%Diff
45	0.38	48.0	55.3	-13.3
45	0.40	45.0	51.2	-12.1
45	0.42	42.3	47.4	-10.7
45	0.45	38.8	42.2	-8.2
45	0.50	33.8	34.8	-3.0
45	0.55	29.7	28.7	3.4
55	0.38	58.6	67.6	-13.3
55	0.40	55.0	62.6	-12.1
55	0.42	51.7	57.9	-10.7
55	0.45	47.4	51.6	-8.2
55	0.50	41.3	42.5	-3.0
55	0.55	36.3	35.1	3.4
60	0.38	63.9	73.8	-13.3
60	0.40	60.0	68.3	-12.1
60	0.42	56.4	63.2	-10.7
60	0.45	51.7	56.3	-8.2
60	0.50	45.0	46.4	-3.0
60	0.55	39.5	38.3	3.4
65	0.38	69.3	79.9	-13.3
65	0.40	65.0	74.0	-12.1
65	0.42	61.1	68.5	-10.7
65	0.45	56.0	61.0	-8.2
65	0.50	48.8	50.3	-3.0
65	0.55	42.8	41.5	3.4
			Max	3.4
			Min	-13.3

Table D5 Comparison of authors' and discussers' equations for typical values of wcm and f_{cem} to compute 56 day strengths (f_{cem} is taken as 56 day cement strength)

f_{cem}	wcm	f_{cd}	f_{c56da}	%Diff
45	0.38	48.0	55.7	-13.8
45	0.40	45.0	51.7	-13.0
45	0.42	42.3	48.1	-12.0
45	0.45	38.8	43.1	-10.0
45	0.50	33.8	35.9	-5.9
45	0.55	29.7	29.9	-0.7
55	0.38	58.6	68.0	-13.8
55	0.40	55.0	63.2	-13.0
55	0.42	51.7	58.8	-12.0
55	0.45	47.4	52.6	-10.0
55	0.50	41.3	43.8	-5.9
55	0.55	36.3	36.5	-0.7
60	0.38	63.9	74.2	-13.8
60	0.40	60.0	69.0	-13.0
60	0.42	56.4	64.1	-12.0
60	0.45	51.7	57.4	-10.0
60	0.50	45.0	47.8	-5.9
60	0.55	39.5	39.8	-0.7
65	0.38	69.3	80.4	-13.8
65	0.40	65.0	74.7	-13.0
65	0.42	61.1	69.4	-12.0
65	0.45	56.0	62.2	-10.0
65	0.50	48.8	51.8	-5.9
65	0.55	42.8	43.1	-0.7
				-0.7
				-13.8

In above table, strength from discussers' Equation (12) is given as f_{cd} and that from following authors' equation as f_{c28da}:

$$f_{c28da}=5.331*f_{cem}*\exp [- 3.8607*wcm] \quad .....(13)$$

The difference between f_{c28da} and f_{cd} is computed by

$$\%Diff = 100*(f_{cd} - f_{c28da}) / f_{c28da} \quad .....(14)$$

[8] The following table shows that Eqn (12) is adequate practically to estimate the 56 day concrete strengths for cement strengths of 45 to 65 MPa for wcm values of 0.38 to 0.55:

In above table, strength from discussers' Equation (12) is given as f_{cd} and that from following authors' equation as f_{c56da}:

$$f_{c56d}=4.9741*f_{cem}*\exp [- 3.6623*wcm] \quad .....(15)$$

The difference between f_{c56da} and f_{cd} is computed by

$$\%Diff = 100*(f_{cd} - f_{c56da}) / f_{c56da} \quad .....(14)$$

[9] As seen above, Authors' equations for both 28 days and 56 days can be taken as same. There is no necessity for writing two separate equations for 28 day and 56

days; the increase in strength of concrete due to age can be accounted easily by considering the corresponding change in cement strength. This 'Same equation concept' can be also seen from the fact that the discussers' value of K in Eqns (8) and (10) were same, the common value being 0.50. Therefore, Eqn (12) can be taken as a practically useful empirical relationship between cement strength, f_{cem}, water-cement ratio, wcm, and concrete strength, fc.

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The authors' reply

Dear Sir,

This has reference to the letters from two ICJ readers. We express our deepest gratitude for the interest shown by these readers and for taking pains to provide many valuable inputs and advise. The scope of our paper was to identify from published literature, the relation of 'strength – cementitious materials – water' and to revalidate it using commercially available PPC as a cementitious material along with locally available concrete ingredients. Accordingly, the conclusion was limited to the working of PPC as cementitious materials, i.e. revalidations. The comments, advice and suggestions presented by the ICJ readers relate to the original paper ('Strength-Cementations Material-Water Relationship for Proportioning of Fly Ash Based Concrete', Subrato Chowdhury, and Prabir. C. Basu, ACI Materials Journal, Vol. 107, No. 4, July-August 2010, pp. 340-348.). The paper published in ACI, presents enough inputs, explanations, discussions on results and answers all the queries raised here. It would not be appropriate for us to reply to the queries raised by the readers regarding the paper published in another journal.

Thanking You,

Yours truly,

Dipesh Majumdar,
Subhajit Saraswati,
Partha Pratim Biswas
Subrato Chowdhury