Discussion Forum

Reproportioning concrete mixtures for rapid production of precast units

The authors — H.L. Girish Raje Urs, M.C. Nataraja and T.S. Nagaraj — have presented an important paper on reproportioning of concrete mixes in the April 2006 issue of the *Journal* (pp. 40-44). The paper is well written. The following points are offered for consideration by the authors as well as readers of the *Journal.*

(i) The authors mention under the paragraph on 'Gel-space ratio' that 'Even in fully hydrated condition, there would be some gel pores and some capillary pores left, but in lesser amount.' It may be noted here that gel pores are generated as a result of hydration of cement when calcium-silicate-hydrate (C-S-H) gel of very high specific area is formed and gel porosity of hydrated cement portion is about 28 percent[1]. Capillary pores are the spaces generated by water used for mixing. It is generally believed that capillary pores tend to be negligible (zero) when full hydration occurs at a w/c ratio of around 0.38[2]. For any w/c ratio less than 0.38, full hydration is not possible due to lack of space available for hydration products to occupy and a part of cement always remains unhydrated. Thus, in a well cured cement paste, capillary pores may or may not be present depending upon parameters such as w/c ratio, curing methodology and age[2].

(ii) The authors have used ACI 211 for mix proportioning calculations. This requires the information on fineness modulus of sand and bulk density of coarse aggregate (CA). The authors may provide this information for the benefit of readers.

(iii) The proportion of different ingredients of the initial mix having w/c ratio = 0.50 as arrived at by the authors are: cement = 380 kg/m^3, sand = 745 kg/m^3, CA =945 kg/m^3, water = 190 kg/m^3. The sum of these contents is 2260 kg/m^3, and this is much less than commonly observed concrete densities which could be in the range of 2350 to 2500 kg/m^3. Even for w/c ratio of 0.38, the values of ingredients, viz, cement= 500 kg/m^3, sand=657 kg/m^3, CA=945 kg/m^3, water=190 kg/m^3, give the density of only 2292 kg/m^3. Thus, for such low water-cement ratio of 0.35, this density value appears to be low especially when the specific gravities of cement, sand, and CA given in the paper are of normal values. The authors may inform the readers whether any measurements were made for fresh concrete densities and explain how these contents were arrived at. It may be noted here that the weights of cubes, varying from 7.95 to 8.22 kg, give the densities in the range of about 2360 to 2440 kg/m^3, which falls within commonly-observed and reported values of densities of concrete.

(iv) Under the title, 'Analysis of results', the authors attempt to connect the reduction in strengths with the decrease in weight of cubes due to deficient curing. It is well known that weight of concrete is not very sensitive to compressive strengths. This is particularly true at higher strength levels of concrete. A small change in w/c ratio at lower values of w/c ratio may significantly increase the compressive strength; but, this might not involve in corresponding degree of increase in densities. This is clearly seen from the commonly known, w/c ratio versus strength curves of concrete. Rather than the porosity itself, the actual pore size distribution seems to influence more the strength[3]. In the present case, almost similar levels of weights of cubes at 3 and 28 days in *Table* 2 of the paper shows the strengths of 26 and 51.6 MPa, respectively. This means about two-fold increase in strength has been achieved without much change in weights of cubes. The writers feel that estimation of degree of hydration by measurement of non-evaporable water content of concrete would have given a better quantification of deficient curing.

(v) Under paragraph on 'Re-proportioning method', the equation suggested is:

$$S = S_{0.5}\ [-0.2 + 0.6\frac{c}{w}\ ] \qquad ...(1)$$

Table 4: Computations for verifying utility of equation of this discussion

Curing, days				*Unit contents of ingredients*				*Density, kg/m*^{3}	*wc*	*S MPa*	*A*	S_{eqn} *MPa*	*Diffe-rence, percent*	*Ref wc for 'A'* (wc_{ref})
Mould	*Water*	*Air*	*Total*	*Cem-ent*	*Sand*	*CA*	*Water*							
1	0	6	7	380	745	945	190	2260	0.50	29.0	19.33	29	0.0	0.50
1	0	6	7	500	657	945	190	2292	0.38	39.4		41.2	4.6	
1	0	6	7	500	657	945	190	2292	0.38	39.4	18.485	39.4	0.0	0.38
1	0	6	7	380	745	945	190	2260	0.50	29.0		27.7	-4.4	
1	0	27	28	440	707	945	190	2282	0.43	53.0	29.18	53	0.0	0.43
1	0	27	28	380	745	945	190	2260	0.50	43.2		43.7	1.3	
1	0	27	28	380	745	945	190	2260	0.50	43.2	28.8	43.2	0.0	0.50
1	0	27	28	440	707	945	190	2282	0.43	53.0		52.3	-1.3	

Note: (i) S_{eqn} = A((1/wc)-0.5), *wc* = water-cement ratio *(ii)* $A = S_{Ref}/(cw_{Ref} - 0.5) = S_{Ref}/((1/wc_{Ref}) - 0.5)$
(iii) Difference, percent = $100(S_{eqn} - S)/S$, *(iv)* Table Nos 1 to 3 are in the original paper

The above can be re-written as:

$$S = A\left(\frac{c}{w} - 0.33\right) \qquad ...(2)$$

where, $A = 0.6S_{0.5}$ = Constant value

Equation (2) is a modified version of following Bolomey equation[4]:

$$S = A\left(\frac{c}{w}\right) + B \qquad ...(3)$$

Equation (3) has been shown to be practically reduced to the following two equations[5], — each equation corresponding to a separate range of w/c ratios:

$$S = A\left[\frac{c}{w} - 0.5\right] \qquad ...(4)$$

$$S = A\left[\frac{c}{w} + 0.5\right] \qquad ...(5)$$

The above two equations are due to change in slope that occurs at about w/c = 0.40, when c/w is plotted against strength. This fact is discussed by the authors also in their earlier publications. However, the writers have found that the equation (4) is useful for most of the present-day concretes when an analysis was done on test results available at the writers' laboratory and also the extensive data published by Hansen[6,7]. Larrard also mentions this equation in his famous book on 'Concrete mix proportioning – A scientific approach'[8]. Therefore, the equation (4) can be generally used for re-proportioning. The value of constant 'A' can be found out for the given concrete ingredients by considering a concrete mix of any w/c ratio (and the authors' suggestion of 0.50 as this reference w/c can also be considered). To clarify this, the compressive strengths for the same type of curing mentioned by the authors, but at different w/c ratios were used as shown below.

Table 4 given above shows that the equation (4) is valid when reference w/c ratio is either 0.50 or 0.38 for calculation of 'A' in case of 7-day strength (1 day in mould followed by 6 days of air curing). Similarly, the equation (4) is valid when reference w/c ratio is either 0.43 or 0.50 for calculation of 'A' in case of 28-day strength (1 day in mould followed by 27 days of air curing). The difference between predicted value and actually observed compressive strength is in the range of –1.3 to 4.6 percent which can be taken as negligible for practical considerations.

It would be more appropriate if the value of 'A' is obtained by test results on two or more w/c ratios instead of a single value. When a single w/c ratio is used to find 'A', it is suggested that more number of cubes (say 20 and above), instead of the conventional three may be used to avoid any bias on the determination of value of 'A'.

(vi) The authors have presented a method of estimating the reduced w/c ratio required for a concrete with deficient curing when it has to attain the strength of water-cured specimens. However, this approach gives importance to strength characteristics of concrete which is not rational since durability is also a parameter to be attained in any concrete and this can be attained by curing only. Thus, instead of trying to adjust the w/c ratio for concrete with deficient curing, it would be prudent to find the reasons for deficient curing and these reasons can be addressed suitably. It should be noted here that a concrete with low w/c ratio but having deficient curing could have lower durability than the concrete with higher w/c ratio having proper curing; this could be attributed to differences in microstructures of the two concretes

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The authors thank the discussers for their interest in the paper. The following are the point-wise replies. The numbers indicate the points raised by the discussers.

(i) The capillary porosity of the cement paste depends both on the water-cement ratio of the mix and on the degree of hydration. In addition, the type of cement also influences the degree of hydration achieved at a given age. As mentioned by the discussers, at a water-cement ratio higher than about 0.38, the volume of the gel is not sufficient to fill all the space available to it so that there will be some volume of capillary pores left even after complete hydration. However, the hydration increases the solid content of the paste and in mature and dense paste, the capillaries get blocked by gel. The absence of continuous capillaries is due to a combination of factors such as use of suitable water-cement ratio and sufficient long period of hydration during moist curing as reported by Neville. However, in the present investigation, the strength attained at 28 days is reported and this not the maximum strength as hydration is not fully over. In addition, the concrete cubes were deficiently cured. The amount of gel produced increases with the progress of hydration and hence the volume of gel pores also increases. As full hydration is not over theoretically in the concrete cubes (for most concretes with OPC, hydration is practically over by 28 days), the authors feels that there would be some gel pores and capillary pores left.

(ii) The fineness modulus of sand and the dry-rodded density of coarse aggregate corresponding to

Table 5: Concrete failure without aggregate crushing[10]

Size, mm	*CA, kg/cm³*	*Cement content, kg/m³*	*CF*	*7-day strength, MPa*	*28-day strength, MPa*
40-25	1209	414	0.84	41	56
25 and down	1107	486	0.86	34	46
12.5 and down	858	529	0.84	29	38

Note: Aggregate strength = 112 MPa, Water-cement ratio = 0.35, that is, for same cement mortar matrix strength.

saturated and surface dry condition were 2.91 and 1,567 kg/m³, respectively. The sand used was somewhat coarse.

(iii) The yield of concrete generally varied from 2,300 to 2,340 kg/m³. Yes, the values obtained in the present investigation were slightly lower than the usual values observed, but were not exceptional. However, the calculations of mix details were found to be okay and the same have been reported in the M.Tech. thesis of one of the junior authors. No analysis of the fresh concrete was made in this investigation.

(iv) The strength of concrete mainly depends on the w/c ratio, the porosity of paste, strength and porosity of aggregates, and to a lesser extent, on other factors such as weight of concrete cubes as mixes were deficiently cured. Here, the authors have not analysed in detail the exact reasons for reduction in strength due to deficient curing and one possible reason could be the weight of cubes as observed in the experiment which indirectly reflects loss of water due to deficient curing. Yes, we do agree that some sophisticated measurements (for example, non-evaporable water content of concrete as mentioned by the discussers) could have been done. No such measurements were made due to lack of availability of such instruments.

(v) It appears that there has been some misunderstanding regarding the use of generalised Abrams' law in re-proportioning of the mixes[9]. The generalisation advanced clearly states that the equations generated are phenomenological in nature. This has been elaborated in detail in the paragraph on page 41 under 'Reproportioning method'. The strength $S_{0.5}$ is not a constant. This value has to be determined for a given set of materials (cement or cementitious materials, size and specific surface area and other characteristics of aggregates) or even when any one of the ingredient changes. This enables to take into account the synergy between different interacting and non-interacting ingredients at the age considered. Since this is not a constant considering $A = 0.6S_{0.5}$ = Constant value in equation (2) — which is a modified version of the Bolomey's equation $(S = A\ (c/w) + B)$ — is tenable in a very restricted sense. It can be seen that as the aggregate size decreases the strength also decreases considerably even at the same water-cement ratio, *Table* 5.

Further, the expression $S/S_{0.5}$ is an indirect reflection of the microstructure of the constituent cement mortar matrix. As discussers have suggested that if 'A' can be found out for a given set of ingredients using the strength at w/c ratio of 0.50 then one can as well use the authors' equation itself than equation (4) suggested by the discussers, for analysis and assessment of strength. It is interesting to note that the potential of generalised Abrams' law is such that it could be used even for proportioning of concrete mixtures with discrete fibres[11]. The authors fail to understand the distinct advantages of transforming the generalised Abram's equation into modified form of Bolomey's equations for re-proportioning concrete mixtures. The potential and application of equations relating to generalised Abrams' law have been demonstrated amply in the investigation reported and in many other situations in proportioning of concrete mixtures.

(vi) Authors do agree that continuous moist curing always helps in attaining good durability. The idea behind this investigation was only to compensate the loss of strength for deficient curing (as in case of concrete blocks where certain low levels of strengths are needed). Here, the emphasis was only on strength, wherein a technical feasibility to attain the needed strength in spite of deficient curing was demonstrated. As mentioned by authors under 'Limitations of the study' in their technical paper itself, one should be very careful about the quality of concrete as a result of deficient curing which would have an adverse affect on durability. Thus, the proposed method may not be applicable for structural concrete where durability is one of the key criterion rather than the compressive strength alone.

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