A CASE REPORT ON QUALITY CONTROL IN CONCRETE CONSTRUCTION

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ABSTRACT

With better understanding of cement hydration, and developments in the field of chemical and mineral admixtures, concrete construction has become more complicated and requires strict measures for quality control. In several countries, including India, use of concrete mixed at site, often using primitive means of batching and construction is still quite common. This is especially true in building construction, where the volume of concrete involved is often small, and the job is carried out by smaller contractors.

This paper presents the results of some of the work carried out to highlight the importance of some of the aspects related to quality control in concrete construction. A survey was carried out using data from some building and industrial projects in the neighborhood. The results from a series of experiments carried out to study the implications of placing concrete through the reinforcement, in terms of the effect on its compressive strength, are also reported. It was found that the variations in the compressive strength values obtained in cases when strict measures for mixing, batching, etc. are not adopted, could be greater than those assumed in the codes. Further, it was found that there could be significant reduction in the compressive strength of concrete if it passes through congested reinforcement, on account of segregation and lack of proper vibration.

1. INTRODUCTION

Proper quality control at the stage of execution of a project is critical in ensuring durability. Though measures such as maintaining a certain water-cement ratio or cover thickness are often clearly given in codal and design provisions, they are expected to be physically implemented during construction by site engineers. Now, the extent of quality control actually exercised at site depends on the local conditions, available facilities and the skill and level of quality consciousness of the work force.

It is widely recognized that the compressive strength of concrete is the basic measure of quality control not only from the point of view of durability, but also to ensure structural integrity.

In this connection it needs to be borne in mind that (i) a certain amount of variation in the actual strength is expected and is taken in account by targeting a higher strength than the required characteristic strength of the concrete, (ii) the standard deviation in the compressive strength actually observed over time, can be used to better understand the extent of quality control, and, (iii) though specimens for quality control are cast using cubes or cylinders, and curing them under water, the conditions for the concrete in the actual structure are quite different. The real concrete 'falls through' reinforcing bars, which not only become a possible cause for segregation in concrete, but also make the task of adequate vibration very difficult.

This paper presents the results of some of the work carried out to highlight the importance of the some of these aspects in concrete construction [Krishnamurhty, 2002].

2. RESEARCH PROGRAMME

The scope and nature of the work was decided keeping in view the importance of the some of the above conditions, and an effort made to study,

(i) variation in compressive strength using data from nearby construction projects, and,
(ii) difference in concrete strength cast in the usual specimens, and that in a simulated beam, where the concrete was allowed to go through simulated reinforcement, and compacted using internal vibration to the extent possible.

3. VARIATIONS IN COMPRESSIVE STRENGTH IN PROJECTS

3.1 Background

Data with respect to cube strength of concrete over the duration of the project from 3 nearby construction sites was collected, and examined within the framework of specifications of the Bureau of Indian Standards [IS 10262, 1982; IS 456, 2000]. Whereas Project A involved construction of an industrial facility and concrete was often required to be cast in thin wall segments using complicated formwork layout, Projects B and C were essentially building constructions, involving casting of concrete in simple structural elements – footings, columns, beams and slabs. The concrete was mixed at site in all the cases, and the assumed standard deviation for determining mix proportions for these concrete is 4 MPa [IS 456, 2000].

3.2 Variations in compressive strength observed

A brief summary of the data collected in terms of the required grade of concrete, number of samples used, and statistical parameters as the mean and standard deviation, is given in Table 1. The 'real' characteristic strength is also shown in the table using a formulation of the kind $(\mu - k\sigma)$, on the basis of the actual values of the mean and standard deviation.

Table 1: Compressive strength data from three projects

Project	Nature	Data points	Char stre (MPa) *	Strength (MPa)		Coeff. Of variation
				Mean	Std dev	
A	Industrial	101	25 (30.1)	36.22	3.74	10.3
B	Building	23	20 (32.8)	38.13	3.27	8.6
C	Building	26	20 (26.2)	40.16	8.53	21.2

* *The 'real' values are given in the parenthesis following the design values.*

3.2.1 Project A

The variation in strength in Project A is shown in Figure 1. It can be seen that for the characteristic strength of 25 Mpa, the actual strength varies from about 28.0 Mpa to 43.7 Mpa, and the standard deviation is 3.74 Mpa. The figure also shows the lines for acceptability for the Indian standards, which are given as $max\ (f_{ck} + 0.825*\sigma, f_{ck} + 4.0)$. Figure 2 shows a normal distribution curve superimposed on the histogram for the compressive strength data.

3.2.2. Projects B and C

As mentioned above, these are basically building projects, and qualitatively speaking, the degree of quality control exercised was less stringent that used in Project A. This fact is amply demonstrated from the data given in Table 1, where in the case of Project C the standard deviations and variances are higher. In fact, the standard deviation in this project is higher than that given in the Indian standards for that grade of concrete, and also has the highest coefficient of variation. To that extent, it is clear that apart from the standard deviation, the coefficient of variation adds a different meaning to the extent of quality control practiced at site.

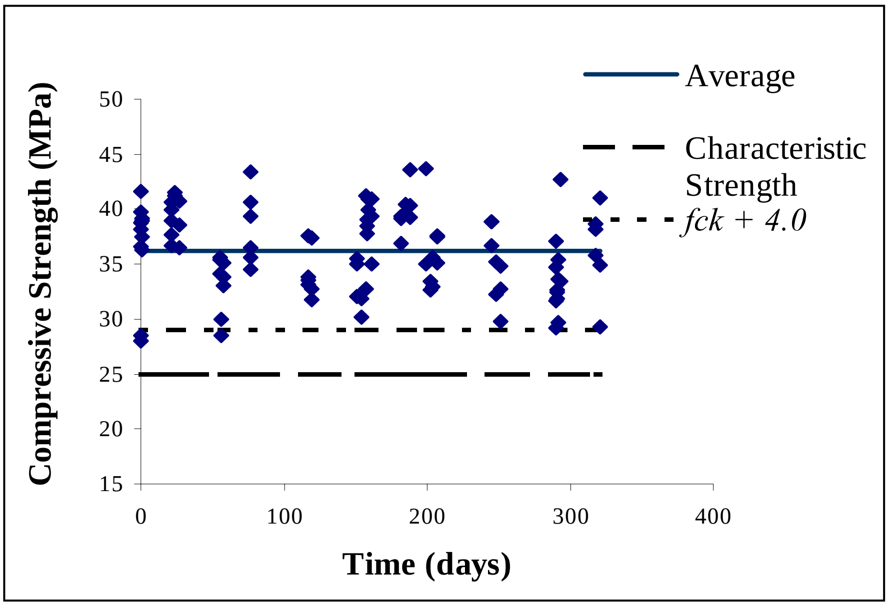

Figure 1: Observed variation in compressive strength and acceptance criteria

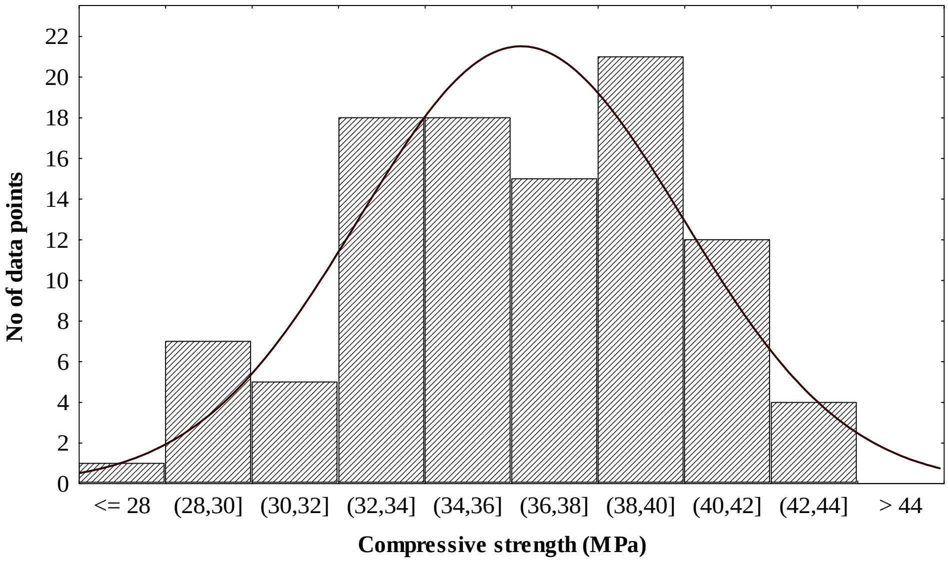

Figure 2: Normal distribution superimposed on compressive strength

3.3 Real characteristic strength

It can be seen from Table 1 that in spite of the high values of standard deviation, the actual characteristic strength is still far in excess of the required value, and therefore, appropriate corrections either in the proportions of the concrete or the design strength need to be made for economy of the project.

4. EFFECT OF PRESENCE OF REINFORCEMENT ON COMPRESSIVE STRENGTH

In a doubly reinforced RC beam, the reinforcement layer(s) at the top could impede proper placement and compaction of concrete. Provisions for clear spacing between bars notwithstanding, the situation is compounded by bad workmanship and need to provide laps, etc. Figure 3 shows a typical example of the reinforcement as per drawing, and that actually provided – the top reinforcement, which should be in two layers, is provided in a single layer and provisions for spacing between bars are obviously ignored.

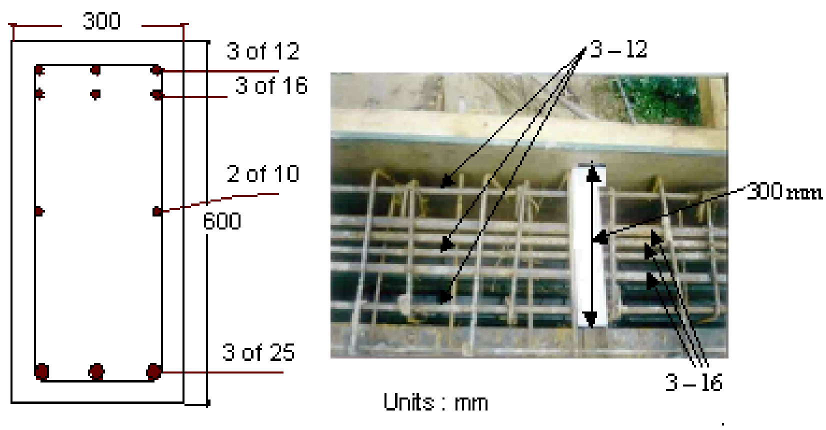

Figure 3: Design and actual placing of reinforcement in a beam

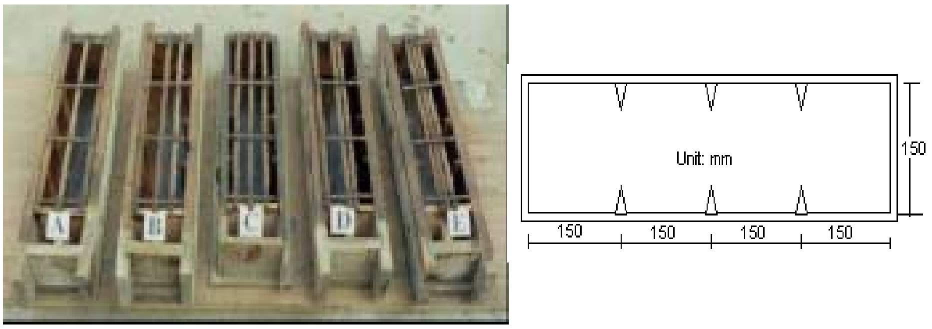

Figure 4: Formwork for prisms with bars on top and wedges on the sides

Now, it is clear that normal procedures of sampling concrete where cubes (or cylinders) are prepared with the concrete being cast and freely compacted do not necessarily reflect the ‘real’ concrete. This series of experiments was designed to better understand the effect, of the presence of reinforcement in the path of concrete on its compressive strength.

4.1 Experimental

Specially designed 600x150x150 mm prism molds as shown in Figure 4 were used. Concrete used to cast the prisms had to ‘negotiate’ through the ‘reinforcement’ fixed above the molds. The bars were subsequently removed to facilitate surface finishing. Four samples for determination of compressive strength were drawn from a single beam by cutting the hardened concrete. The spacing and layout of the bars at the top was varied to simulate the effect of different reinforcement spacing. Further, A, B, C, D, and E stand for cubes cast from prisms having the corresponding reinforcement meshes on top of the moulds, respectively. It may be noted that 3 bars of 16mm nominal diameter were used in all cases, and only the spacing between adjacent bars was varied in the five cases. A summary of the layout of the bars is given in Table 2. (Reference may be made to Figure 4 for better understanding.) For reference, other specimens – ‘N’ (normally cast cubes), and, ‘O’ (cubes obtained from prisms cast without any reinforcement on the top of the mould) were also tested. The study was carried out using separate sets of specimens cast in the laboratory and that at a neighboring construction site. In both cases the water-cement ratio of the concrete was kept at 50%.

To facilitate easy cutting/breaking of the beams to obtain specimens for compressive tests, protrusions were provided by nailing wooden wedges as shown in the sketch in Figure 4. The moulds were filled with concrete and compacted using needle vibrator to the extent possible. In cases where the vibrator could not be used, the concrete was compacted by hand using tamping rods.

Table 2: Spacing between adjacent bars in mm

A	B	C	D	E
51, 51	51, 22	21, 21	51, 0	0, 0

The specimens were covered with wet gunny bags to avoid loss of moisture from the surface for 24 hours, before being removed from the molds and being cured in water for 28 days. The beams were then cut into cubes of approximately 150 mm size using a rock cutting machine, and the specimens tested for compressive strength.

4.2 Results and discussion

Though the tests were carried out using four sets of specimens – two each being cast in the laboratory and the construction site, the discussion in this paper is based on two representative sets. Results obtained using specimens cast in the laboratory and at the construction site are given in Tables 3 and 4, respectively. It may be noted that though the following general observations can be made, a direct comparison, however, cannot be made since the proportions of concrete used in the two cases are different.

(a) the difference in the values observed between samples N and O, i.e. specimens obtained by cutting pieces from a beam without having any reinforcement at the top (N) and samples of standard cubes (O), is much less compared to that observed with respect to other cases. In other words, the strength of the normal cubes is quite close to that of cubes obtained from a beam cast without any impediment. This finding essentially validates the basic methodology followed in obtaining test specimens for compressive strength in this study.

(b) in both cases (Table3 and 4) the strength observed in all cases where the concrete was placed through the reinforcement (cases A through E) was substantially lower than that observed in specimens N or O. Also, the observed variation in terms of the ratio of the difference between the maximum and minimum values to the average, was very large.

Table 3: Results from specimens cast in the laboratory

Sl No	Strength in MPa							
	x_1	x_2	x_3	x_4	x_5	x_6	Range	Mean
N	43.11	45.25	45.01	43.64	45.01	46.96	43.11 - 46.96	45.04
O	41.13	44.92	45.17	-	-	-	41.13 - 45.17	43.15
A	43.30	37.13	26.55	28.69	-	-	26.55 - 43.30	36.00
B	38.29	36.32	30.21	32.39	-	-	30.21 - 38.29	35.34
C	32.80	29.68	31.98	27.96	-	-	27.96 - 32.80	30.38
D	33.10	31.19	35.03	37.59	-	-	31.19 - 37.59	35.35
E	41.55	40.74	39.75	41.11	-	-	39.75-41.55	41.33

Though it is difficult to relate the reduction in compressive strength to the spacing between the bars, which is related to the ease of placing and compaction, from the data cited here, the findings suggest that the reinforcing bars act as impediments to the placing and compaction of concrete, and lower the compressive strength, and could increase the extent of variability in strength from one place to another. Thus it is important that spacing between bars is carefully checked at the time of inspection of the reinforcement before the concrete is cast.

Table 4: Results from specimens cast at a construction site

Sl No	Strength in MPa							
	x_1	x_2	x_3	x_4	x_5	x_6	Range	Mean
N	39.78	40.46	38.28	39.15	39	42.06	38.28 - 42.06	40.92
O	38.73	40.69	41.19	-	-	-	38.73 - 41.19	39.96
A	26.55	35.11	33.21	30.66	-	-	26.55 - 35.11	28.605
B	26.82	27.81	29.36	26.45	-	-	26.45 - 29.36	26.635
C	35.43	35.77	37.74	32.38	-	-	32.38 - 37.74	33.905
D	30.04	36.93	27.54	31.42	-	-	27.54 - 36.93	30.73
E	27.05	34.47	36.72	31.89	-	-	27.05 - 36.72	29.47

5. CONCLUDING REMARKS

The strength of concrete placed in a structure could vary considerably depending upon the measures of quality control adopted. At times the standard deviations may be higher than those expected at the time of initiating project activities. In the present study it was found that though the standard deviations for two projects was within expected limits, that in the third was much higher.

Since there could be a considerable difference between the design and real characteristic strengths, economy in design and construction can be achieved only if appropriate mechanisms for corrections in the mix designs are actually used.

Evidence suggests that the presence of reinforcement hinders proper placing and compaction of concrete, even to the extent that causing reduction in compressive strength. This highlights the need for stringent control of reinforcement detailing, since specimens for normal quality control are cast where the concrete does not ‘negotiate’ the reinforcement.

The study points to a need to establish a system whereby contracting agencies are classified according not only the levels of jobs executed in the past, but also the levels of quality control achieved. Further, it appears that the coefficient of variation achieved at the site be considered as one of the means for assessing the degree of quality control.

ACKNOWLEDGEMENT

The authors also thank Mr. Santosh Kumar and Mr Rajeev Kumar of the Institute Works Department of the Indian Institute of Technology Kanpur, for their help in carrying out part of the work reported in this paper.

REFERENCES

Krishnamurthy, P. 2002 *A study on some issues relating to quality control in concrete construction*, M Tech thesis submitted to the Indian Institute of Technology, Kanpur, India

Bureau of Indian Standards, *Indian Standard 456-2000, Plain and reinforced concrete – code of practice*

Bureau of Indian Standards, *Indian Standard 10262- 1982, Recommended guidelines for concrete mix design*