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EFFECT OF RE-VIBRATION ON COMPRESSIVE STRENGTH OF CONCRETE

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Abstract

The present work is aimed at studying the effect of re-vibration on the compressive strength of concrete using 53 grade Ordinary Portland Cement, with wide range of w/c ratios varying from 0.35 to 0.7 and with more number of re-vibration time lag intervals ranging from ½ hour to four hours. The effect of re-vibration on the density of concrete is also studied. The results have shown that the compressive strength of the concrete with various w/c ratios have increased up to certain time lag interval i.e. within the initial setting time (IST) and decreased thereafter. The percentage increase in the compressive strength also nearly followed the above trend.

Keywords: Compressive strength; initial setting time; re-vibration; timelag intervals; water cement ratio; cost analysis.

1. Introduction

Insufficient vibration of concrete may result in defects, such as honey combing and voids leading to reduction in strength and performance. Since early days many civil engineers are of the opinion that partially set concrete should not be disturbed. Strong belief has been there that any disturbance to concrete, like re-vibration in the initial hardening stage makes the concrete deteriorate and loose its strength. The opinion is reflected in such standard requirements as the limited period of time permissible between the mixing and placing of concrete and by the limiting of time between pouring of successive batches. Although this opinion still prevails throughout the profession, there are few dissenting views on the subject which forms the nucleus of an entirely new school of thought. Yet for years, some engineers have, upon occasion, found it necessary to disturb the hardening process, often with no apparent detrimental effects upon the properties of the finished job. This has happened when the delivery of concrete to a partially complete pouring has been some how delayed, thus presenting the problem of avoiding cold joints. In many such instances, the problem has been over come by having workmen tamp and agitate the surface of the concrete, often for several hours, until the fresh concrete has arrived. The practice has often been quite successful, in direct contradiction to the traditional opinion concerning the hardening process. Re-vibration technique has advantages in obtaining water tight concrete in the building of concrete tankers and dry docks. The technique was adopted in order to release the water which is generally trapped beneath horizontal reinforcing bars; and not only was this achieved by the disturbance of the hydration process, but also many of the properties of the concrete appear to be actually improved by the re-vibration. The Bureau of Reclamation, in the 6th edition of its concrete manual stated that Re-vibration is beneficial rather than detrimental, provided that the concrete is again brought to a plastic condition. The manual further stated that the Revibration may be accomplished by immersion- type vibrators, by form vibration, or by transmission of vibration through the reinforcement system. In the light of the apparent contradiction between general traditional opinion researchers, Sawyer and Lee [1], Vollick [2], Sheshadri and Rama Rao [3] and Everard.and Bhagat [4] conducted some experimental investigations. These research works agreed with one another in showing an increase in the compressive strength with re-vibration. But, the results were only qualitative in nature. The present work is aimed at quantifying the results covering a time lag ranging from ½ hour to 4 hours for concretes with different w/c ratios.

2. Mechanism of Re-Vibration of Concrete

Re-vibration of concrete is the process of again vibrating the placed concrete intentionally and systematically, sometime after its consolidation is completed. A properly executed re-vibration results in improved concrete quality, i.e., increased strengths and bond, better impermeability, reduction in shrinkage and creep, reduction in surface and other voids as well as cracks in the fresh concrete and so on. Re–vibration can be done usually at any time as long as the running internal vibrator can sink by its own weight in to the concrete or when the external vibrator or vibrating table can liquefy the concrete momentarily. The usually accepted stiffness limit for re-vibration is when the penetration resistance of the standard steel needle specified in ASTM C 403 , Ref. [5] reaches the value of 3.5 N/mm^2. Re-vibrating concrete momentarily liquefies the concrete again. The primary chemical process that occurs in the first two hours after concrete is placed is the formation of calcium hydroxide which typically makes to 15% to 25% of Ordinary Portland Cement concrete. The other major product of hydration is calcium silicate hydrate, which usually makes up about 50% of OPC concrete and gives the concrete its hardness and durability. When re-vibration occurs after the initial set, it breaks down some of the calcium hydroxide that has already been formed, which allows freshly placed concrete adjacent to the re-vibrated concrete to join with it, rather than introducing a construction joint and it again becomes a monolithic concrete structure.

3. Experimental Program

It was proposed to study the effect of re -vibration with a time lag on compressive strength of concrete for different w/c ratios. Concrete of five different strengths based on five different w/c ratios (0.35, 0.5, 0.55, 0.6, 0.7) were used to cover the rich and lean mixes. The time lag used for the study was 4 hours (with ½ hourly intervals). Thus for each w/c ratio, 27 numbers of 15 cm cubes were cast representing 3 cubes for each test for 9 time lag intervals namely, 0 hr, ½ hr, 1 hr, 1½ hr, 2 hr, 2½ hr, 3 hr, 3½ hr and 4 hr. In all a total of 135 cube specimens were cast and tested.

3.1 Materials used

53 -Grade cement was used. The type of cement was ordinary Portland cement confirming to IS -12269 -1987, Ref. [6]. Details of the other characteristics of cement are shown in Table 1. The fine aggregate used was river sand with a maximum size of 4.75 and confirming to zone-II as detailed in Table 2. The coarse aggregate used was locally available with a maximum size of 20 mm. The grading curve was chosen in such a way that it was within the four continuous grading curves for combined aggregate as per IS-383 , Ref. [7]. Details of the coarse aggregate used are presented in Table 3. Potable water was used for mixing and curing purposes.

Table 1. Characteristics of cement (53Grade)

S. No	Particulars of test	Result	Specifications as per IS: 12269
1	Standard consistency (% by weight)	29.0	
2	Setting Time in minutes		
	(a) Initial (b) Final	160 (2hrs 40min) 285 (4hrs 45min)	30 Minimum 600 Maximum
3	Compressive Strength in N/mm^2 at the age of		
	a) 3 days	28	27 Minimum
	b) 7 days	39	37 Minimum
	c) 28 days	56	53 Minimum
4	Specific Gravity	3.12	
5	Fineness in cm^2/gm	2673	2250 Minimum

Table 2. Characteristics of fine aggregate

S. No	Sieve Size	% Passing	Specifications for zone II as per IS:383
1. Sieve Analysis	10.0 mm	100	100
	4.75 mm	99	90–100
	2.36 mm	97	75–100
	1.18 mm	68	55–90
	600 micron	48	35–59
	300 micron	14	8–30
	150 micron	0	0–10
2	Specific Gravity	2.62	
3	Materials Finer than 75 micron	1.50	3 Maximum
4	Loose Density in Kg/m^3	1600	
5	Fineness, Modulus	2.74	

Table 3. Characteristics of coarse aggregate

S. No	Sieve Size	% Passing	Specifications as per IS:383
1. Sieve Analysis	40.0	100	100
	20.00	96	95–100
	10.00	39	25–55
	4.75	5	0–10
2	Crushing Value in %	26	
3	Impact Value in %	26	
4	Los Angeles Abrasion Value in %	32	
5	Specific Gravity	2.64	
6	Loose Density in Kg/m^3	1400	
7	Fineness Modulus	6.6	

The mixes were designed as per IS:10262, Ref. [8] and the mixes thus obtained are presented in Table 4.

Table 4. Characteristics of the concrete mixes

S. No	**Chapter 2 Particulars**	**Water / Cement Ratio**				
		0.35	**0.50**	**0.55**	**0.60**	**0.70**
1.	Mix proportion by weight (C: FA:CA)	1:0.88:1.65	1:1.50:2.80	1:1.71:3.20	1:1.92:3.59	1:2.44:4.57
2.	Materials per m^3 of concrete in Kg					
	Water	210	200	197	195	186
	Cement	600	400	358	325	266
	Fine Aggregate	530	598	613	624	650
	Coarse aggregate	991	1118	1147	1168	1216
3.	Slump in mm	60	55	60	65	60
4.	28 days compressive strength in N/mm^2	46.6	44.2	41.4	36.5	29.9
5.	Number of Cubes cast	27	27	27	27	27

3.2 Casting and testing

Cube specimens of 150mm x 150mm x 150mm were cast as per the standard procedure. For casting the specimens, Benford's 3cft electrically operated concrete mixer was used for mixing concrete. Westerwork's 6′ × 3′ balanced vibrating table with 3000 rpm was used for initial vibration (Figure 1) and 1″ dia and 15″ length pin vibrator with 2880 rpm was used for re-vibration of concrete (Figure 2). The slump and compaction factor values were evaluated as per IS-1199, Ref. [9]. The compression strength of the specimens at the end of 28 Days of curing was tested using Avery's 250 T Universal Testing Machine under strain rate control.

Figure 1. Details of initial vibration of concrete

Figure 2. Details of re-vibration of concrete

4. Results and Discussions

The compressive strengths of concrete for different time lag intervals of re-vibration for different w/c ratios are given in Table 5. A comparative study of compressive strength for different w/c ratios is also shown in the same table and plotted in Figure.3. A comparative study of maximum percentage increase in compressive strength for various time lag intervals for different w/c ratios can be obtained from Table 5. The percentage increase in compressive strength thus obtained is plotted against time lag interval for different w/c ratios as shown in Figure. 4. From the Figure it can be noticed that the percentage increase in compressive strength increases with the time lag interval of re-vibration up to a certain time lag interval i.e. before the initial setting time (IST) of cement and decreases their after. The maximum percentage increase in compressive strength varies from 27% to 31.4% and the optimum time lag interval varies from 1 hour to 2½ hours depending on the w/c ratios as shown in Table 6. It can be observed from the Table that the optimum time lag interval of re–vibration for different w/c ratios is lower than the initial setting time (i.e. 160 minutes) of the cement used. From Table 6 the average value of maximum percentage increase in compressive strength for lean mixes with higher water cement ratios 0.6 and 0.7 is 30% and that for the rich mixes with low and medium water cement ratios 0.35, 0.5, 0.55 is about 27.8%. It can be observed from Table 5 and Figure.3 that the compressive strength of the concrete with w/c ratios from 0.35 to 0.6 at the time lag intervals up to 4 hours is higher than the compressive Strength of concrete without re-vibration. Whereas, the compressive strength of concrete with w/c ratio of 0.7 is higher than that without re-vibration only up to a time lag interval of 2½ hours, after which it is falling below the value of non-re-vibrated concrete. The density of concrete for different time lag intervals of re-vibration, for different w/c ratios are given in Table 7 and plotted against time lag interval for different w/c ratios is shown in Figure 5. From the Figure it may be observed that there is an increase in density of concrete on re-vibration. The nature of the plots is the same as that of % increase in compressive strength versus time lag interval. Even though there is a decrease in density after a certain time lag the density was never less than 2400kg/m^3 in any case.

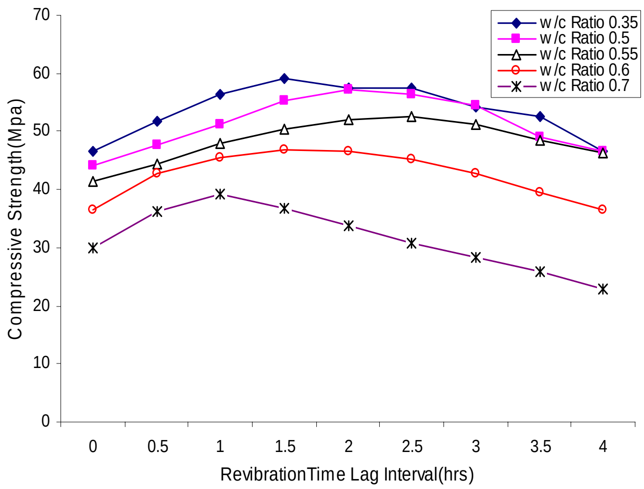

Figure 3. Compressive strength versus re-vibration time lag

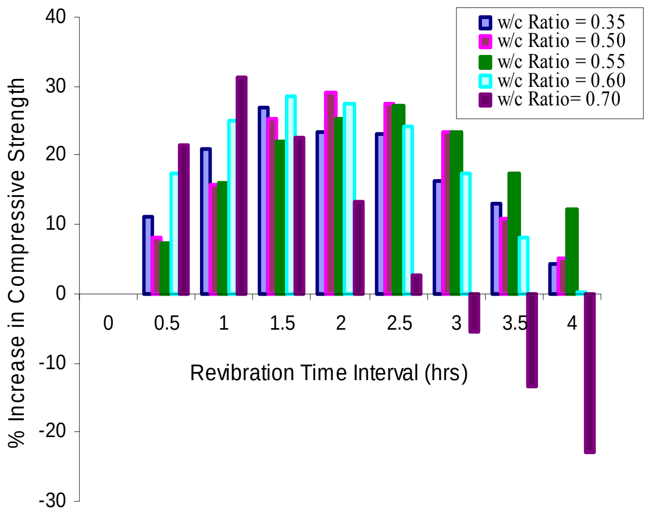

Figure 4. % Increase in compressive strength versus re-vibration time

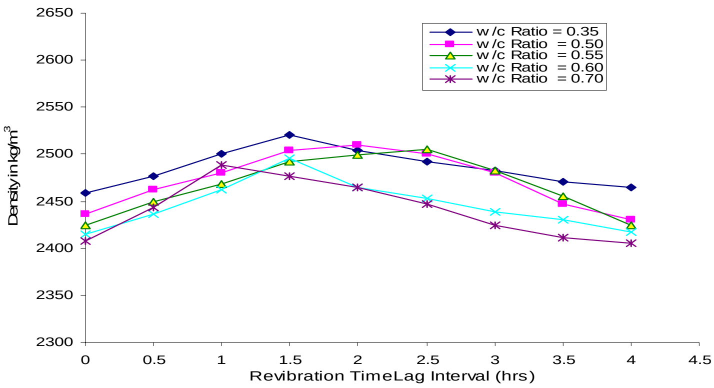

Figure 5. Density versus re-vibration time lag interval for different water cement ratios

Table 5. Compressive strength of concrete on re-vibration

S. No	w/c ratio	Compressive strength in N/mm^2								
		Time Lag interval in Hours								
		0	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
1	0.35	46.6	51.8	56.3	59.2	57.5	57.4	54.2	52.7	46.7
2	0.50	44.2	47.8	51.2	55.4	57.1	56.4	54.6	49.0	46.5
3	0.55	41.4	44.4	48.0	50.5	51.9	52.7	51.1	48.6	46.4
4	0.60	36.5	42.8	45.6	46.9	46.6	45.3	42.8	39.5	36.6
5	0.70	29.9	36.3	39.3	36.7	33.9	30.7	28.2	25.9	23.0

Table 6. Increase in compressive strength and optimum time lag interval for different w/c ratios

S. No	w/c ratio	Maximum % increase in compressive strength	Optimum time lag interval in hours
1	0.35	27.0	1.5
2	0.50	29.1	2.0
3	0.55	27.3	2.5
4	0.60	28.5	1.5
5	0.70	31.4	1.0

Table 7. Density of concrete on re-vibration

w/c	Time Lag Interval in Hours	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
0.35	Density in Kg/m^3	2459	2477	2500	2521	2504	2492	2483	2471	2465
0.5	Density in Kg/m^3	2436	2462	2480	2504	2510	2501	2480	2447	2430
0.55	Density in Kg/m^3	2424	2450	2468	2492	2499	2505	2483	2456	2424
0.60	Density in Kg/m^3	2415	2436	2462	2496	2465	2453	2439	2430	2418
0.70	Density in Kg/m^3	2408	2444	2489	2477	2465	2447	2424	2412	2406

6. Economy of the Problem

The technique of re-vibration, if applied in the field will ensure comparatively higher strength, thus ensuring higher partial safety factors for the materials. On the other hand leaner mix, if re-vibrated will have the same strength as that of the richer mix without re-vibration, thus ensuring economy in construction. From Table 5, it can be observed that a concrete mix with w/c ratio of 0.5, without re–vibration attained a 28 days compressive strength of 44.2 N/mm^2. A concrete mix with w/c ratio of 0.6, with re-vibration at time lag interval of 1½ hours, attained maximum 28 days compressive strength of 46.9 N/mm^2. A typical example to explain the cost economics is worked out below (Tables 8 and 9).

Table 8. Cost of one m^3 of 0.5 w/c ratio mix

Material	Weight in kg	Quantity	Rate($)	Per	Amount($)*
Cement	400	8 Bags	5	Bag	40
Fine Aggregate	598	0.355 m^3	150	8.12 m^3	6.56
Coarse Aggregate	1118	0.764 m^3	70	5.42 m^3	9.87
			Total or say		56.43 56.5 $

Table 9. Cost of one m^3 of 0.6 w/c ratio mix

Material	Weight in Kg	Quantity	Rate ($)	Per	Amount($)*
Cement	325	6.5 Bags	5	Bag	32.50
Fine Aggregate	624	0.374 m^3	150	8.12m^3	6.91
Coarse Aggregate	1168	0.793 m^3	70	5.42 m^3	10.24
			Total or say		49.65 50$

The amounts are worked out as per Indian market and converted to Dollars.

5. Conclusions

The following conclusions are drawn based on the results of tests performed

1. Re-vibration resulted in enhancement of compressive strength when carried out within the initial setting time (IST) confirming that good vibration within the IST increases compressive strength. The maximum % increase in workable mix range is 31.4%.
2. Compressive strength is found to reduce if re-vibration is carried out after the IST and before final setting time (FST) irrespective of the mix and water cement ratio. The percentage increase in compressive strength increases with the time lag interval of re-vibration up to certain time lag interval depending on the mix and water cement ratio and there after, decreases. The increase may be due to re-arrangement of coarse aggregate and mortar in the concrete under the plastic condition.
3. The average value of maximum percentage increase in compressive strength for lean mixes is slightly higher than the same value for rich mixes.
4. Lean mixes seem to have detrimental effect due to re-vibration after certain time lag interval.
5. The maximum compressive strength is obtained for the time lag interval at which the concrete has maximum density.

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