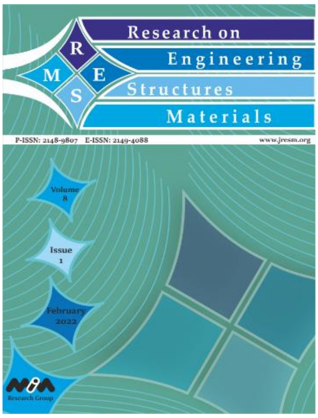
Research on Engineering Structures & Materials

journal homepage: http://www.jresm.org

Research Group



Effect of high ratio fly ash on roller compacted concrete for dam construction

P. N. Ojhaa, Brijesh Singh, Shivam Prakash, Pranay Singh, Manish K. Mandre, Suresh Kumar

Online Publication Date: 10 Feb 2022

URL: http://www.jresm.org/archive/resm2022.374ma1216.html

DOI: http://dx.doi.org/10.17515/resm2022.374ma1216

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article

Ojhaa PN, Prakash S, Singh P, Mandre MK, Kumar S. Effect of high ratio fly ash on roller compacted concrete for dam construction. *Res. Eng. Struct. Mater*., 2022; 8(2): 233-251.

Research on Engineering Structures & Materials
journal homepage: http://www.jresm.org

Research Article

Effect of high ratio fly ash on roller compacted concrete for dam construction

P. N. Ojha[a], Brijesh Singh[*b], Shivam Prakash[c], Pranay Singh[d], Manish K. Mandre[e], Suresh Kumar[f]

National Council for Cement and Building Materials, India

Article Info

Article history:
Received 16 Dec 2021
Revised 08 Feb 2022
Accepted 09 Feb 2022

Keywords:

Roller Compacted Concrete; Mass Concrete; Fly ash; Mechanical Property; Thermal Property

Abstract

One of the biggest advantages of Roller Compacted Concrete is faster and economic construction along with lesser heat generation. It is primarily used in mass concrete work like in Pavements, Ports and Dams. In this study the properties of Roller Compacted Concrete such as Vee-Bee density, Vee-Bee time, initial setting time, final setting time and compressive strength are studied for twelve mixes prepared using two types of fly ash sources, three cement sources and three admixture types. Furthermore, on one of the mixes with the least cement to fly ash ratio mechanical and thermal property related tests were performed. These tests include split tensile strength, direct tensile strength, modulus of elasticity, Poisson's ratio, apparent cohesion, angle of internal friction, specific heat of concrete by Transient Plane Source (TPS) method and Coefficient of Thermal expansion of Concrete. From the study it was found that compressive strength at 365 days is nearly two times that of 28 days. Also, there is negligible effect of adding admixture on compressive strength of roller compacted concrete. Current study shows that finer the fly ash, higher the compressive strength at later stage. The study on mechanical and thermal properties of Roller Compacted Concrete indicates that results are in line with Indian Standard Specification and Internationally reported values.

1. Introduction

Roller Compacted Concrete (RCC) refers to a special class of concrete which are compacted by a roller. To achieve this behavior, RCC in fresh state should be dry enough to resist the sinking of the roller. Also, it needs to be wet enough to be able to get compacted by the vibration of the roller. It is a zero-slump mix [1], which is placed using dump trucks and is compacted by the vibratory rollers [2]. Constituents of RCC mix are blended in a mixing plant to form a zero-slump heterogeneous mixture which resembles the consistency of a damp gravel. Apart from being economical RCC offers speed in construction, less or no use of formworks and leaves less environmental footprint due to reduced demand of cement [3]. It can be used for heavy-duty mass concrete application at ports, military installations, roadway and paving applications, dam constructions and many more.

In past years, urban areas have started preferring RCC for various applications [4]. Dams which are constructed using RCC assures great economy as compared to dams constructed using standard concrete [5], It gives a faster and cheaper method of mass concreting work [6]. RCC can be cast and compacted in layers, in this far better heat dissipation from the mass concrete can be achieved preventing thermal stresses and cracks. Also, in pavement construction it does not require dowels and light traffic can be allowed soon after placement. Placing of RCC [7] is a highly mechanized construction procedure where

*Corresponding author: brijeshsehwagiitr96@gmail.com
[a] orcid.org/0000-0003-1754-4488; [b] orcid.org/0000-0002-6512-1968; [c] orcid.org/0000-0002-6403-2306; [d] orcid.org/0000-0001-6169-9482; [e] orcid.org/0000-0002-0690-2510; [f] orcid.org/0000-0002-5049-856X
DOI: http://dx.doi.org/10.17515/resm2022.374ma1216

concrete is dumped from the trucks and then spread using bulldozers and then compacted using vibratory rollers. Compaction of RCC is similar to compaction of soil where compaction can be done in layers. Layer thickness of RCC depends on many factors like size of aggregates, compatibility of the concrete, roller capability, etc. [8].

RCC shows similar mechanical strength and other properties [9] as that of standard concrete. It comprises of same range of concrete mix materials as standard concrete with some variation. The mechanical strength of RCC is affected by the quality of aggregate and quantity of water [10]. The primary difference lies in the percentage of the constituents. RCC consists about 70-80 percent of aggregates by volume. Other constituents include cement in which fly ash or ground granulated blast furnace slag can be added. Admixtures like retarders can be added to increase the setting time of RCC. Fine aggregates in RCC are more than compared to standard concrete which can be seen as a difference between RCC and standard concrete [11]. More fine aggregates offer better packing and consolidation [12]. In RCC, consistency is measured using Vee-Bee method unlike slump test for standard concrete and compaction is done using rollers unlike vibrator for standard concrete. Proportioning of RCC mix is mainly done using either (i) Soil compaction approach, or (ii) Concrete engineering approach. In soil compaction approach optimum moisture content for highest dry density is calculated. Whereas, in concrete engineering approach, traditional approach with high cement paste content is followed. RCC mixing is performed in pug-mill, which is a very high energy mixing device. While mixing importance is given to control the moisture content. Increase in moisture content can make RCC too wet to get roller marks on compacted concrete.

Properties of RCC can be modified by the use of active mineral admixtures such as fly ash. Fly ash is made up of SiO_2 and $Al2O_3$ and has a lot of potential activity [13]. Morphological impact, pozzolanic effect, and micro aggregate effect are the three primary beneficial and noteworthy effects of adding fly ash [14]. The pozzolanic action of fly ash occurs when the mixed oxides of SiO_2 and Al_2O_3 in fly ash are activated by the $Ca(OH)_2$, which is the product of cement hydration, resulting in the formation of additional hydration gel. In some studies [15–18] the strength of roller-compacted concrete with high volume fly ash (HFRCC) was investigated, and it was discovered that: (1) HFRCC strength is weak at early ages, and the fly ash effect is modest or negative. (2) As HFRCC ages, its strength develops fast; in the meantime, the fly ash effect improves with time and becomes more useful to increasing flexural strength. (3) The influence of fly ash on HFRCC at a long curing age grows stronger as the quantity of fly ash increases.

Zhu, B. [19] presents the principles for temperature control of mass concrete RCC dams and suggest that since RCC contains more fly ash and less cement, the adiabatic temperature increase of RCC is smaller. Even yet, the increase in temperature produced by cement hydration is not too low since the significant amount of mixed fly ash would delay hydration heat dissipation. Also, since there is less cement in the RCC, it has less creep and extensibility, which implies it has less fracture resistance. Therefore, although RCC are less susceptible to temperature stresses and cracks than normal concrete, still temperature controlling and monitoring is essential for the mass concrete RCC dams.

Various past researchers have explored the properties of RCC made from slag and fly ash from the industries. Lam et al. [20] studied the Roller compacted concrete made of Elastic Arc Furnace (EAF) slag, a by-product of steel production. Using the Taguchi technique, the influence of variables in mixing percentage on the dry density of roller-compacted concrete pavement constructed of EAF slag aggregate and fly ash was primarily focused. According to the findings of this study, increasing the percentage of EAF slag as aggregate replacement increased dry density, however increasing the fly ash ratio as cement substitute decreased dry density. Lin et al. [21] evaluated the engineering properties of roller-compacted concrete containing Circulation Fluidized Bed Combustion Fly Ash (CFA). Circulation fluidized bed combustion (CFBC) technology is one of the emerging combustion technologies for electricity generation which produces CFA as a bi-product in huge quantity. Substitution of fine aggregate with CFA doesn't improves the compressive strength due to increased water demand, decreases the flexural strength, reduces the setting-time, absorption and unit weight, and increases the sulphate resistance of RCC.

Past studies have also evaluated the variation in properties of RCC based on composition of the mix. S.K. Rao et al. [22] conducted experimental study on Seven distinct Roller Compacted Concrete (RCC) combinations, with six different types of replacements (10%, 20%, 30%, 40%, 50%, and 60%) of Ground Granulated Blast Furnace Slag (GGBS). Study suggests that at the age of three days, replacing cement with six percentages of GGBS content lowered compressive strength, flexural strength, and splitting tensile strength, but at 7, 28, and 90 days, there was a constant and substantial improvement in strength. C. Settari et al. [23] investigate the mechanical characteristics and durability of roller compacted concrete (RCC) using various recycled asphalt pavement (RAP) sizes as a substitute for coarse and fine natural aggregate (NA). Based on experimental results, it was found that RCC with RAP shows a lower performance and it was suggested to limit the substitution of RAP to 50% on both fine and coarse aggregate. Chamroeun Chhorn and Seung-Woo Lee [24] conducted a study to determine the effect of aggregate gradation, water content, admixtures and time on consistency of RCC for pavement application. Based on the study authors found Poly Naphtalene Sulfonate (PNS) Superplasticizer to be very effective for lowering down vebe time and extending the duration of workable consistency for RCC. M.I. Abu-Khashaba et al. [5] explored the possibility of constructing Roller Compacted-Concrete dam using locally available Egyptian material to reduce cost and found satisfactory and encouraging results. Study also suggests that with increase in flya sh in the mix, ratio of 90 days to 30 days compressive strength also increases.

Recently, some of the computation based approach is also being used to evaluate the properties of RCC. To Establish the Compressive Strength of Roller Compacted Concrete Pavement, Ashrafian et al. [25] proposed an evolutionary-based approach called gene expression programming (GEP). The suggested equation-based models were found to be simple, resilient, and easy to use, and thus give novel compressive strength formulas for roller-compacted concrete pavement (RCCP). N.-t.-m. Lam et al. [26] proposes analytical methods for predicting the compressive strength of steel slag aggregate and fly ash in roller-compacted concrete pavement (RCCP). The study established and compared multiple regression analysis (MRA), artificial neural networks (ANN) and fuzzy logic (FL) based models. The MRA model was found to be less reliable whereas The ANN and FL models created reliable results in predicting the strength of RCCP made with EAF steel slag aggregate and fly ash.

In general, cementitious materials in Roller Compacted Concrete comprise of Portland cement and pozzolan. These materials should comply with standards specifications for their quality requirements. The binding property in concrete is mainly because of cementitious materials and hence, the selection of these materials affects the strength and heat generation in concrete mix [27]. Roller Compacted Concrete can be designed using any basic type of cement, though pozzolans are used as substitute of cement to reduce the cost, heat generation, CO2 emission and also to increase workability with setting time. Pozzolans can replace maximum fraction of cement in the mix as high as 70% [28].

Aggregate covers most of the volume of Roller Compacted Concrete mix and due to the large contribution in volume it affects the quality and properties of concrete whether it be hardened properties or fresh properties of concrete. In Roller Compacted Concrete fine and coarse aggregate are combined to get the required gradation. Coarse aggregates should be rigid enough to be able to resist the rollers compaction. The Nominal Maximum Size of Aggregate (NSMA) is generally capped at 50 mm to avoid segregation during transportation and compaction but with good quality control this size can be increased. Study shows that the cost saved by increasing the NSMA beyond 75mm is not that significant [29]. Aggregates should be tested for their physical properties before developing any Roller Compacted Concrete mix to conform the standard's specification.

In this study, properties of RCC such as Vee-Bee density, Vee-Bee time, initial setting time, final setting time and compressive strength were studied for twelve mixes prepared using different types of fly ash sources, cement and admixture. Furthermore, on two mixes mechanical and thermal property related tests were performed. These tests include split tensile strength, direct tensile strength, modulus of elasticity, Poisson's ratio, apparent cohesion, angle of internal friction, specific heat of concrete by Transient Plane Source (TPS) method and Coefficient of Thermal expansion of concrete.

2. Materials Used in RCC

This section gives the detail of various materials used in making of RCC in this study. These materials include the cementitious materials, water, aggregates and admixtures.

2.1. Water

Water conforming to the requirement same as standard concrete [29] was used for making the RCC mixes.

2.2. Admixtures

In the present study three types of retarders designated as A1, A2, A3 were used. The admixtures conform to the physical parameters and uniformity requirement as specified in IS 9103:1999[30].

2.3. Cementitious Materials

As cementitious material a mixture of Cement and Fly ash were used for making of RCC in the study. Three types of Cement of OPC43 Grade, designated as C1, C2 and C3 were used. The cement was tested for its physical properties which include Blain's fineness according to IS:4031(Pt-3):1999[31], setting time according to IS:4031(Pt-5):1988[32], soundness according to IS:4031(Pt-3):1988, compressive strength according to IS:4031(Pt-6):1988[33] and Chemical properties according to IS:4032(1985).[34]. The results of these tests are given below in Table 1. It was found that the physical and chemical test results conform to Indian Standards specification IS 269 :2015 [35].

Table 1. Physical and chemical test results of cement sample

Sl. No.	Properties	Results Obtained			IS Code Specifications IS 269: 2015
		C 1	C 2	C 3	
	PHYSICAL TEST				
1	Blain's fineness, m^2/kg	317	322	316	More than 225
2	Setting time, minutes				
	Initial	125	140	130	More than 30
	Final	185	195	185	Less than 600
3	Compressive strength, N/mm^2				
	3 days	33.5	29.5	28.5	More than 23
	7 days	44.0	38.0	36.5	More than 33
	28 days	54.0	52.5	50.0	Between 43 and 58
4	Specific Gravity	3.13	3.14	3.16	

Table 1 (Cont.). Physical and chemical test results of cement sample

	CHEMICAL TEST				
1	Loss on Ignition (% by mass)	4.43	2.13	2.66	Less than 5
2	Magnesium Oxide (% by mass)	3.55	1.78	1.96	Less than 6
3	Sulphuric Anhydride (% by mass)	2.66	1.54	2.19	Less than 6
4	Insoluble Residue (% by mass)	2.16	0.86	4.13	Less than 5
5	Chloride (% by mass)	0.012	0.007	0.009	Less than 0.1
6	Alkalies (% by mass) Sodium Oxide Pottasium Oxide Eq. as Na_2O	 0.02 0.40 0.28	 0.12 0.67 0.56	 0.04 0.43 0.32	Eq. Na_2O shall be less than 0.6 percent
7	Silica (% by mass)	19.69	19.87	22.83	Ratio of percentage of lime to percentage of silica, alumina and iron oxide when calculated by equation-1 shall be between 0.66 to 1.02. For C1=0.94 For C2=0.98 For C3=0.79
8	Iron Oxide (% by mass)	3.52	3.34	4.24	
9	Alumina (% by mass)	4.49	5.57	5.47	
10	Calcium Oxide (% by mass)	60.91	64.48	59.70	

$$(CaO-0.7SO_3)/(2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3) \quad (1)$$

Two types of fly ash designated as FA 1 & FA 2 which are available in eastern part of India were used to produce the mix trials. Fly ash were evaluated for their physical & chemical parameter as specified in IS: 3812-part 1[36]. The test results are given in Table 2. It was found that these results conform to Indian Standards specification IS: 3812-part 1 [36].

Table 2. Test results of fly ash sample

Sl No.	Properties	Results	
		FA 1	FA 2
	PHYSICAL		
1	Specific gravity	2.14	2.24
2	Fineness by Blaine (m^2/kg)	336	324
3	Soundness by Auto Clave Exp. (%)	0.03	0.04
4	Retention on 45µ IS Sieve by Wet Sieving (%)	22.3	29.0
5	Lime Reactivity (N/mm^2)	4.7	4.6
6	Compressive strength at 28 days as % of the strength of mortar cubes	86.2%	85.8%

Table 2 (Cont.). Test results of fly ash sample

	CHEMICAL		
1	Loss on Ignition (% by mass)	0.14	0.12
2	Magnesium Oxide (% by mass)	0.89	1.15
3	Total Sulphur (SO_3) (% by mass)	0.19	0.13
5	Chloride (% by mass)	0.002	0.002
6	Alkalies (% by mass)		
	Sodium Oxide	0.03	0.25
	Pottasium Oxide	0.74	1.66
	Eq. as Na_2O	0.52	1.34
7	Silica (% by mass)	59.95	62.27
8	Iron Oxide (% by mass)	7.69	7.70
9	Alumina (% by mass)	26.23	23.18
10	Calcium Oxide (% by mass)	1.97	1.86

2.4. Aggregates

Coarse aggregates with size in range of 4.75 mm to 40 mm were used for Roller Compacted Concrete mixes. These aggregates were differentiated into three size groups A40(20-40mm), A20(10-20mm) and A10(4.75-10mm) and were tested for their specific gravity according to IS:2386(Pt-3):1963[37], water absorption according to IS:2386(Pt-3):1963[37], sieve analysis according to IS:2386(Pt-1):1963[38], combined flakiness and elongation according to IS:2386(Pt-1):1963[39], crushing according to IS:2386(Pt-4):1963[40], impact according to IS:2386(Pt-4):1963[40], abrasion according to IS:2386(Pt-4):1963[40], deleterious material according to IS:2386(Pt-2):1963[41] and soundness according to IS:2386(Pt-5):1963[42]. The specific gravity of the aggregates is about 2.7 and water absorption lies between 0.4 and 0.6. Detailed result of these tests are tabulated in Table 3. The aggregate properties conform to the specifications of IS 383:2016 [43].

Table 3. Test results of coarse aggregate

Sl. No.	Properties	Result Obtained (A10)	Result Obtained (A20)	Result Obtained (A40)	Limits according to IS 383:2016
1	Specific gravity	2.7	2.68	2.66	2.1 to 3.2
2	Water absorption (%)	0.41	0.43	0.59	Less than 5
3	Abrasion Value %	28	16	17	Less than 30
4	Crushing value %	22	19	15	Less than 30
5	Impact value %	19	13	13	Less than 30
6	Combined Flakiness and Elongation Index %	31	29.9	36.7	Less than 40
7	Soundness (Na_2SO_4) %	0.46	0.16	0.05	Less than 10
8	Total deleterious materials % (except coal & lignite)	0.1	0.1	0.1	Less than 2

Fine aggregates were tested for their specific gravity as specified in IS: 2386 (Pt-3):1963 [44], water absorption as stipulated in IS: 2386(Pt-3):1963, Material finer than 75 microns according to IS: 2386(Pt-1):1963 [38] and sieve analysis as specified in IS: 2386(Pt-1):1963. Results of all the tests conform to the specification in IS: 383:2016 [43] and are tabulated in Table 4.

The overall combined grading curve for the aggregate blend is given in Figure 1. It shows that the combined grading lies between the specified limits given in ASTM C33 [45].

Table 4. Physical test results of fine aggregate sample

Sl No.	Test Carried out	Result Obtained	Limits according to IS383:2016
1	Specific gravity	2.66	2.1 to 3.2
2	Water absorption, %	0.80	Less than 5
3	Material finer than 75-micron, %	11.3	Less than 12

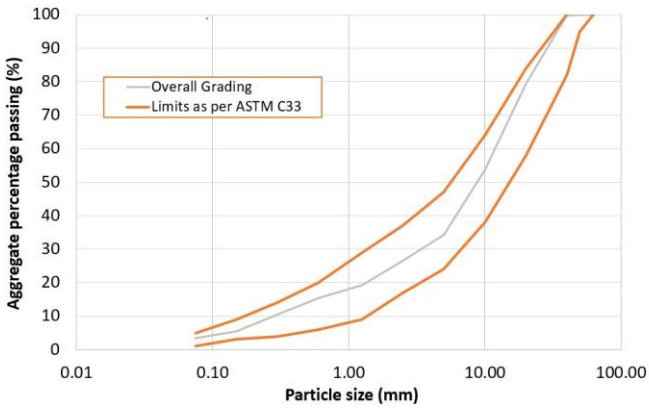


Fig. 1 Combined grading curve of aggregate ratio 20:22:28:30

3. Experimental Program

3.1. Admixture Dose and Setting Time

The setting time of concrete with admixture was determined by varying the doses of retarding chemical admixture with control mix. The setting time was determined by standard procedure of IS: 1199:2018(Part-7) [46] in which the standard needles were penetrated at different time intervals in the 4.75 mm sieved concrete. The initial and final setting time of concrete was calculated in respect of control mix and are tabulated in Table 5. It was seen that the setting time increases significantly when retarder was added as compared to that of concrete without a retarder (Control Mix).

Ingredients of control mix are as follows;

- Cement – 84 kg cum of OPC 43 (Cement 3)
- Qty. of fly ash used - 126 kg/cum
- Aggregate ratio 20:22:28:30 (A40:A20:A10:Fine Aggregate
- W/C Ratio – 0.57

Table 5. Initial and final setting time of control mix and concrete mixes

Chemical admixture	Dose of chemical admixture (% by wt. of Cementitious material)	Initial setting time of concrete (hh:mm)	Final setting time of concrete (hh:mm)
Control Mix	0.00%	06:40	10:30
A 1	0.35%	19:00	44:40
A 1	0.50%	45:30	74:40
A 2	0.35%	23:40	36:40
A 2	0.50%	24:00	34:10
A 3	0.35%	24:10	49:30
A 3	0.50%	44:45	72:00

3.2 Roller Compacted Concrete Mix Proportion

In this study, three fractions of coarse aggregates, i.e., 40mm, 20mm and 10 mm and one fine aggregate sample was taken. Different ratios of coarse and fine aggregates were blended and the compacted bulk densities were determined by following the procedure mentioned in IS: 2386 (Part III) [44]. The compacted bulk densities of various combinations of fine aggregates (Sand) to coarse aggregates (A40/A20/A10) were obtained. It was found that the compacted bulk density of aggregate ratio 20:22:28:30 was maximum. With the obtained maximum aggregate proportion (20:22:28:30), different RCC mixes were prepared using three types of cement, two sources of fly ash and three types of chemical admixtures. The RCC mix proportions are given in Table 6 (Column 1 to Column 15). Corrections were made in adding water to account for aggregate water absorption.

Table 6. Details of 12 roller compacted concrete trial mixes

Mix ID	Cement	Fly ash	Admixture Type	Total Cementitious content	Cement	Fly Ash
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	C 2	FA 2	A 1	190	66	124
2	C 1	FA 2	A 1	200	70	130
3	C 2	FA 1	A 3	210	70	140
4	C 3	FA 1	A 2	210	70	140
5	C 3	FA 1	A 1	210	70	140
6	C 1	FA 1	A 3	210	70	140
7	C 1	FA 1	A 2	210	70	140
8	C 1	FA 1	A 1	210	70	140
9	C 2	FA 2	A 2	210	74	136
10	C 2	FA 2	A 2	210	84	126
11	C 2	FA 2	A 2	240	84	156
12	C 2	FA 2	A 2	240	96	144

Table 6 (Cont). Details of 12 roller compacted concrete trial mixes

Mix ID	Cement / Fly ash	Water	Sand	40mm	20mm	10mm	W/C Ratio	Admixture (% by wt. of cementitious)
	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	0.53	108	652	434	481	617	0.57	0.35%
2	0.54	114	642	428	475	609	0.57	0.35%
3	0.50	114	637	424	470	603	0.54	0.35%
4	0.50	114	636	424	470	603	0.54	0.35%
5	0.50	114	637	424	470	603	0.54	0.35%
6	0.50	120	631	421	467	598	0.57	0.35%
7	0.50	114	636	424	470	603	0.54	0.35%
8	0.50	114	636	424	470	603	0.54	0.35%
9	0.54	119	636	424	470	603	0.57	0.50%
10	0.67	119	637	425	471	604	0.57	0.50%
11	0.54	119	627	418	463	594	0.5	0.50%
12	0.67	119	628	419	464	595	0.5	0.50%

Note: The RCC ingredient content mentioned above are in kg per m^3 of concrete.

4. Testing Programs and Results

4.1. Consistency and Density Using Vee-Bee Method

The consistency of this RCC mixes were measured according to IS: 1199 (Part 2)-2018 [47] using Modified Vee-Bee Consistometer. To determine the consistency of RCC Mixes, cylinder was filled with concrete in three layers and transparent acrylic disc was placed over it. The concrete mix was then vibrated to get the acrylic disc in full contact with cement paste. This test method provides a measure of the consistency of concrete having zero-slump or no measurable slump. Under the application of external vibration, the paste in the concrete rises to the surface. The consistency was measured as the time required for concrete to be consolidated by vibration in a cylindrical mould. The test results of Vee-Bee time are presented in Table 7.

4.2 Determination of Setting Time of Mixes

Initial Setting Time is the time elapsed after initial contact of cement and water, until the mortar (sieved from the concrete) acquires a penetration resistance of 3.5MPa. Final Setting Time is the time elapsed after the initial contact of cement and water, until the mortar (sieved from the concrete) acquires a penetration resistance of 27.6 MPa. The setting times for RCC were obtained using IS 1199 (Part 7):2018[46] and are tabulated in Table 7.

Table 7. Test results of Vee-Bee time, Vee-Bee Density and Setting time of Concrete

Mix ID	Vee-Bee time (s)	Vee-Bee Density (kg/m^3)	Setting Time (hh:mm)	
			Initial	Final
1	25	2397	25:30	40:00
2	14	2399	22:20	43:15
3	25	2363	24:00	40:10
4	23	2354	24:20	44:50
5	30	2339	26:00	46:00
6	15	2394	22:00	43:00
7	22	2393	22:00	38:40
8	24	2358	22:00	41:50
9	16	2430	27:00	39:00
10	12	2418	24:00	39:00
11	13	2426	22:00	39:00
12	11	2419	20:00	27:00

4.3. Compressive Strength

4.3.1. Casting and Curing of Cube Specimen

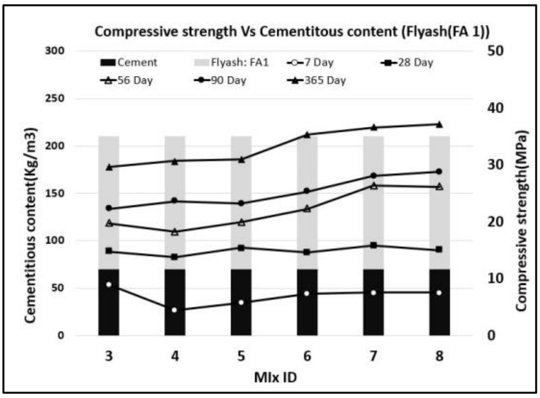
The 150 mm X 150mm X 150mm cubes were cast to determine the compressive strength of the concrete samples. The concrete in the cube mould was placed in three layers (each layer approx. 50mm) and was compacted using table vibrator keeping time of vibration 60±2 seconds for each layer. Before placing concrete in subsequent layer, previous layer was roughened using wire brush.

Fig. 2 Shows cast cube for one of the mix trial

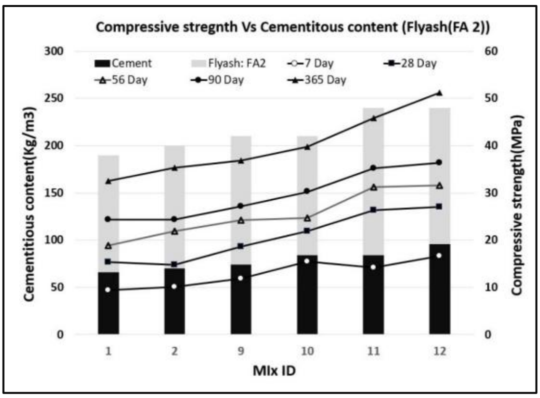
For Normal curing, the cube specimens were removed from the moulds after 72 hours of air curing at 27±2°C and RH±65%. After demoulding specimens were stored in water curing at 27±2°C and were taken out just prior to its testing at the required age. Cube specimens were tested for compressive strength at 7, 28, 56, 90 and 365 days for each trial mix according to the procedure given in IS: 516. The test results of compressive strength are presented in Figure 3.

In the figure, cementitious content and compressive strength are given on vertical axis while Mix ID on horizontal axis. It was observed in Figure 3(a) that for same cement content and fly ash content the compressive strength varies with change of cement type. The compressive strength was highest for Mix ID 8 while lowest for 3 which may be due to marginally higher compressive strength of cement 1 as compared to cement 2 which are used in Mix 8 and 3 respectively and can also be attributed to presence of performance improver which is getting reflected in insoluble residue value of cement (C1). It is also evident from compressive strength of Mix 8 & 7 and 5 & 4 that there is negligible effect of changing admixture type on strength. In figure 3(b) the compressive strength increases with increase of total cementitious content. From Mix 9 & 10 and 11 & 12 it is observed that increasing cement while keeping the total cementitious content same, increases the strength. It is also observed from Figure 3 that the 365 days compressive strength is approximately double of 28 days compressive strength.

Mardani et.al. [17] studied high fly ash ratio with cement to fly ash ratio of 0.67 and found compressive strength of 17.7, 31.8, 39.5, and 40.6 for 7, 28, 90, and 180 days. These values are comparable with findings particularly for mix ID 10 and 12, having cement to fly ash ratio of 0.67. Other mixes also show similar trend in their strength with age.



(a)



(b)

Fig. 3 Compressive strength at 7, 28, 56, 90, 365 days and cementitious content (a) Fly ash FA1 (b) Fly ash FA2

4.4 Mechanical and Thermal Properties Investigation

Mechanical properties such as Tensile strength, Modulus of Elasticity, Poisson's ratio, apparent cohesion, angle of internal friction, water permeability, specific heat and coefficient of thermal expansion were obtained for Mix ID 4. Keeping in view that strength requirement for dam construction is 25 N/mm^2 at 365 days, mix ID 4 was selected due to its lowest cement/fly ash ratio among all the mixes prepared, i.e., 0.50 and water/cement ratio of 0.54.

4.5. Split Tensile Strength, Modulus of Elasticity and Poisson Ratio

Cylindrical specimens of 150mm diameter and 300mm length were cast to determine Splitting Tensile Strength, Modulus of Elasticity (MOE) & Poisson Ratio and Direct Tensile Strength of concrete. The specimens were removed from the moulds after 3 days of casting. After demoulding, the specimens were kept in water at 27±2°C until the age of testing. The Split Tensile Strength, Modulus of Elasticity (MOE) & Poisson Ratio and Direct Tensile Strength were determined at the age of 28 days, 90 days and 180 days. Modulus of Elasticity (MOE) & Poisson Ratio was also done at 7 days. The test procedure as given in IS: 5816[48]/IS: 516[49] were followed to determine Split Tensile Strength. Modulus of Elasticity (MOE) & Poisson Ratio were tested according to ASTM C-469[50]. For testing of Direct Tensile Strength literature was referred [51]. The test results are presented in Table 8. Mardani et.al. [17] studied high fly ash ratio with cement to fly ash ratio of 0.67 and found split tensile strength of 3.87 at 180 days. These values are comparable with our findings for mix ID 4 with cement to fly ash ratio of 0.50.

4.5.1 Direct Tensile Strength Method

Cylindrical specimens of 150mm diameter and 300mm length were cast to determine Direct Tensile Strength of concrete. Direct Tensile Strength was determined at the age of 28 days, 90 days and 180 days. 2 cylinders, which were used for direct tension tests at each age, were taken out of the water one day prior to testing. After grinding both sides of each specimen, the specimens were dried for 12 hours and adhered to the steel plates with epoxy, as shown schematically in Figure 4. The epoxy was left for 12 hours to dry to improve bond quality between the concrete specimen and the steel plate in the test setup. Direct tensile cracking strength of cylinder specimens was measured using Universal Testing Machine (UTM). The test results are presented in Table 8.

Direct tensile strength at 180 days shows significant improvement than at 28 and 90 days suggesting the gain in tensile strength at later stage. The increase in modulus of elasticity of concrete made with Mix ID 4 from 28 days to 365 days is approximately 1.5 times whereas increase in compressive strength was approximately 2.2 times. The percentage of split tensile of concrete made with Mix ID 4 is approximately 14 percent of 28 days compressive strength whereas approximately 8 percent of 365 days compressive strength. The test results of split tensile strength are in line with ACI 363R-10 (ACI-2010) report which claims that for lower strength concrete, tensile strength may go upto 10 % of compressive strength; however, for higher strength it reduces to about 5 % of compressive strength [52, 53]. The ratio of direct tensile strength to split tensile strength of concrete at 28-, 90- and 180-days age varies between 0.63 to 0.73 with an average ratio of 0.67 which is in line with relationship reported in the literature [54]. The poisson's ratio values are lower than that of the standard value of 0.20 reported in codes and specification for normal strength concrete. This can be attributed to maximum size of aggregate in the mix (40 mm size).

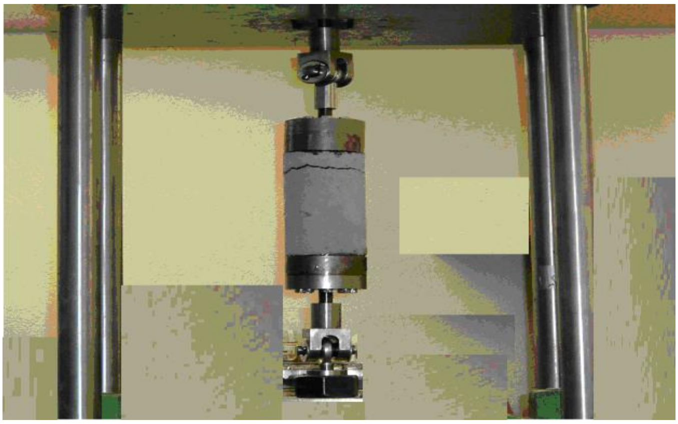


Fig. 4 Direct tension test conducted by the proposed test setup

Table 8. Test results of split tensile strength, direct tensile strength and modulus of elasticity (MOE) and poisson ratio

Mix ID	Age (Days)	Split Tensile Strength (N/mm^2)	Direct Tensile Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	Poisson's Ratio
4	7	-	-	9391	0.115
	28	1.52	1.115	19990	0.108
	90	1.93	1.199	25451	0.123
	180	2.51	1.745	30574	0.146

4.6. Apparent Cohesion and Angle of Internal Friction

Cylindrical specimens of 100mm diameter and 200mm length were cast to determine the Apparent Cohesion & Angle of Internal Friction of concrete. The specimens were removed from the moulds after 3 days of casting. After demoulding, the specimens were kept in water at 27±2°C. The Apparent Cohesion & Angle of Internal Friction was determined at age of 28, 90 and 180 days for Mix ID 4. The test procedure as given in IS: 13047 [55] were followed to determine Apparent Cohesion & Angle of Internal Friction. The test results of Apparent Cohesion & Angle of Internal Friction are presented in Table 9. Cohesion also shows the similar trend as tensile strength and shows a marginally higher value at later stage. No improvement was observed in angle of internal friction for RCC with age. The shear strength of concrete depends upon the cohesion and angle of internal friction. The general range of angle of internal friction as reported earlier [56] is between 30 to 65 degrees for RCC.

Table 9. Test results of apparent cohesion and angle of internal friction

Mix ID	Age in Days	Apparent Cohesion N/mm^2	Angle of Internal Friction Degree
4	28	4.17	39.30
	90	5.41	40.32
	180	5.71	38.83

4.7. Water Permeability

Cylindrical specimens of 150mm diameter and 150mm length were cast to determine the Water permeability of concrete. The specimens were removed from the moulds after 3 days of casting. After demoulding, the specimens were kept in water at 27±2^{o}C. The water permeability of concrete was determined at the age of 90 days for Mix ID 4 by following the test procedure given in IS: 516 (Part 2) [57] and it was found that the water permeability of the concrete was 70mm.

Past studies [58, 59] has indicated that the addition of high volume fly ash in the matrix leads to enhancement in its porosity and water absorption. Increasing porosity and water absorption with the addition of HVFA is one disadvantage of using this system. The hydration of cement fills the volume initially occupied by water thereby decreasing the overall porosity of systems. The pozzolanic activity of fly ash consumes portlandite and precipitates secondary CSH, without altering the porosity, but reducing the interconnectivity of the pore structure. Therefore, when HVFA addition is done in the concrete mix; the water cement ratio, cement to fly ash ratio, strength and durability requirements of the structure shall be considered for achieving desired concrete mix for the durable and safe structure.

4.8. Specific Heat of Concrete

Specific heat of concrete can be measured by steady state method or transient method. In this study, Transient Plane Source (TPS) method was used to determine the specific heat of concrete. This apparatus determines thermal properties based on hot disc method according to ISO 22007-2:2018 [60]. For determining specific heat of concrete, the specimen size was considered 300 mm ×300 mm × 100 mm. After demoulding, butyl sheet wrapping was done to prevent loss or gain of moisture in specimen. All the specimens were kept at a laboratory temperature of 27 ±2˚C and humidity more than 65%. Testing was conducted using TPS 500 as shown in Figure 5. The average specific heat of concrete at 7 days is 402.63 J/Kg/K and at 56 days is 368.59 J/kg /K. Specific heat for RCC in the study shows a much lower value than the specified values for normal concrete in IS 14591-1999 [61], i.e., 850 J/kg / ºC - 1050 J/Kg/ºC.

Fig. 5 Evaluation of thermal conductivity and specific heat of concrete

4.9. Coefficient of Thermal Expansion of Concrete

Prism specimens of 75mm X 75mm X 300mm length were cast to determine the coefficient of thermal expansion of concrete. The specimens were removed from the moulds after 3 days of casting. After demoulding, the specimens were kept in water at 27±2°C. The coefficient of thermal expansion of concrete was determined at 56 days. Mix ID 4 proportions were used for casting of specimens. The test procedure as given in CRD-C39-81 was followed to determine Co-efficient of thermal expansion of concrete. The test results show that average Coefficient of thermal expansion at 56-days was 1.276 x 10-5/°C which is in line with value (1.2 x 10-5/°C) specified by Indian standard IS456 -2000 for quartzite aggregate.

5. Conclusions

The study was performed to see the effect of various composition of materials of RCC on its properties. It was observed that average increase in compressive strength of RCC from 28 days to 365 days was twice, i.e. 365 days compressive strength was nearly two times 28 days. There was nearly no effect of adding different admixtures on 365 days compressive strength of concrete. The compressive strength of RCC mix increases with increase in total cementitious content, however cement to fly ash ratio is critical in achieving specified strength. Consistency in terms of Vee-Bee time is between 11 to 30 seconds for different mixes. Initial setting time is more than 20 hours and final setting time is as high as 46 hours for the mixes. Increase in setting time can be attributed to addition of retarder admixture.

The increase in modulus of elasticity of concrete made with Mix ID 4 from 28 days to 365 days is approximately 1.5 times whereas increase in compressive strength was approximately 2.2 times. The percentage of split tensile of concrete made with Mix ID 4 is approximately 14 percent of 28 days compressive strength whereas approximately 8 percent of 365 days compressive strength. The ratio of direct tensile strength to split tensile strength of concrete at 28-, 90- and 180-days age varies from 0.63 to 0.73 with an average ratio of 0.67. Cohesion also shows the similar trend as tensile strength and shows a marginally higher value at later stage. No improvement has been observed in angle of internal friction for RCC with age. The average specific heat of concrete at 7 days is 402.63 J/Kg/K and at 56 days is 368.59 J/Kg/K. Specific heat for RCC in the study shows a much lower values than the specified values for normal concrete in IS 14591-1999, i.e. 850 J/kg / ºC - 1050 J/kg /ºC for wide range of materials and conditions. The test results show that average Coefficient of thermal expansion at 56-days was 1.276 x 10-5/°C which is in line with value (1.2 x 10-5/°C) specified by Indian standard IS 456 -2000 for quartzite aggregate

References

[1] Al-Tameemi AA, Alkelabi EAM. Studying the influence of fiber reinforcement on the characteristics of roller compacted concrete used in airports with partial replacement of cement by cement kiln dust. In IOP Conference Series: Materials Science and Engineering, 2020. https://doi.org/10.1088/1757-899X/888/1/012011

[2] Shafigh P, Hashemi M, Nam BH, Koting S. Optimum moisture content in roller-compacted concrete pavement. International Journal of Pavement Engineering, 2020; 21:14. https://doi.org/10.1080/10298436.2019.1567919

[3] Warren T. Roller-compacted concrete dams: A brief history and their advantages. Dams and Reservoirs, 2012; 22:2. https://doi.org/10.1680/dare.12.00010

[4] Williams S. Construction of roller-compacted concrete pavement in the Fayetteville shale play area, Arkansas. Transportation Research Record. (2408) (2014). https://doi.org/10.3141/2408-06

[5] Abu-Khashaba MI, Adam I, El-Ashaal A. Investigating the possibility of constructing low cost roller compacted concrete dam. Alexandria Engineering Journal, 2014; 53:1 131-142. https://doi.org/10.1016/j.aej.2013.11.009

[6] Ashtankar VB, Chore HS. Development of design mix roller compacted concrete dam at Middle Vaitarana. Advances in concrete construction, 2014; 2:2. https://doi.org/10.12989/acc.2014.2.2.125

[7] Bayagoob KH, Bamaga SO. Construction of roller compacted concrete dams in hot arid regions. Materials, 2019; 12:19. https://doi.org/10.3390/ma12193064

[8] Filho JM, Paulon VA, Monteiro PJM, de Andrade WP, Dal Molin D. Development of laboratory device to simulate roller-compacted concrete placement. ACI Materials Journal, 2018; 105:2. https://doi.org/10.14359/19752

[9] Aghaeipour A, Madhkhan M. Mechanical properties and durability of roller compacted concrete pavement (RCCP)-a review. Road Materials and Pavement Design, 2020; 21:7. https://doi.org/10.1080/14680629.2019.1579754

[10] US Army Corps of Engineers. Standard Practice for Concrete for Civil Works Structures. Engineering Structures, 2000; 17:9.

[11] Arora VV, Singh B. Durability Studies on Prestressed Concrete made with Portland Pozzolana Cement, Indian Concrete Journal, 2016; 90:8.

[12] Harrington D, Abdo F, Adaska W, Hazaree C. Guide for Roller-Compacted Concrete Pavements. Institute for Transportation, Iowa state univerisity. (August) (2010).

[13] Rao SK, Sravana P, Rao TC. Experimental studies in Ultrasonic Pulse Velocity of roller compacted concrete pavement containing fly ash and M-sand. International Journal of Pavement Research and Technology, 2016; 9:4 289-301. https://doi.org/10.1016/j.ijprt.2016.08.003

[14] Arora V.V., Singh Brijesh, Patel Vikas, and Trivedi Amit, Evaluation of modulus of elasticity for normal and high strength concrete with granite and calc-granulite aggregate. Structural Concrete, 2021; 22: S1, Jan. https://doi.org/10.1002/suco.202000023

[15] Liu S, Li Q, Rao M, Wang L. Properties and microstructure of roller compacted concrete with high volume low quality fly ash. Medziagotyra, 2017; 23:3 2). https://doi.org/10.5755/j01.ms.23.3.16318

[16] Cao C, Sun W, Qin H. Analysis on strength and fly ash effect of roller-compacted concrete with high volume fly ash. Cement and Concrete Research, 2000; 30:1. https://doi.org/10.1016/S0008-8846(99)00203-3

[17] Mardani-Aghabaglou A, Ramyar K. Mechanical properties of high-volume fly ash roller compacted concrete designed by maximum density method. Construction and Building Materials. 38 (2013). https://doi.org/10.1016/j.conbuildmat.2012.07.109
[18] Adamu M, Mohammed BS, Shahir Liew M. Mechanical properties and performance of high volume fly ash roller compacted concrete containing crumb rubber and nano silica. Construction and Building Materials, 2018; 171. https://doi.org/10.1016/j.conbuildmat.2018.03.138
[19] Bofang Z. Key Principles for Temperature Control of Mass Concrete. In Thermal Stresses and Temperature Control of Mass Concrete, 2014. https://doi.org/10.1016/B978-0-12-407723-2.00023-3
[20] Lam MNT, Jaritngam S, Le DH. A Study on Mixing Proportion of Roller-Compacted Concrete Pavement Made of EAF Slag Aggregate and Fly Ash by Using Taguchi Method. In IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing, 2018. https://doi.org/10.1088/1755-1315/171/1/012048
[21] Lin WT, Lin KL, Chen K, Korniejenko K, Hebda M, Łach M. Circulation Fluidized Bed Combustion Fly Ash as Partial Replacement of Fine Aggregates in Roller Compacted Concrete. Materials, 2019; 12:24) 4204. https://doi.org/10.3390/ma12244204
[22] Rao SK, Sravana P, Rao TC. Abrasion resistance and mechanical properties of Roller Compacted Concrete with GGBS. Construction and Building Materials, 2016; 114: 925-933. https://doi.org/10.1016/j.conbuildmat.2016.04.004
[23] Settari C, Debieb F, Kadri EH, Boukendakdji O. Assessing the effects of recycled asphalt pavement materials on the performance of roller compacted concrete. Construction and Building Materials. 2015; 101: 617-621. https://doi.org/10.1016/j.conbuildmat.2015.10.039
[24] Chhorn C, Lee SW. Consistency control of roller-compacted concrete for pavement. KSCE Journal of Civil Engineering, 2017; 21:5 1757-1763. https://doi.org/10.1007/s12205-016-0820-y
[25] Ashrafian A, Gandomi AH, Rezaie-Balf M, Emadi M. An evolutionary approach to formulate the compressive strength of roller compacted concrete pavement. Measurement: Journal of the International Measurement Confederation. 152, 2020. https://doi.org/10.1016/j.measurement.2019.107309
[26] Lam NTM, Nguyen DL, Le DH. Predicting compressive strength of roller-compacted concrete pavement containing steel slag aggregate and fly ash. International Journal of Pavement Engineering, 2020. https://doi.org/10.1080/10298436.2020.1766688
[27] Kokubu K, Anzaki Y. State of the Art Report on Roller Compacted Concrete Pavements. Concrete Journal, 1989; 27:5. https://doi.org/10.3151/coj1975.27.5_22
[28] Services SA. Sika Roller-Compacted Concrete Dams Handbook,2019.
[29] 325 ACIC. Abstract of: State-of-the-Art Report on Roller Compacted Concrete Pavements. ACI Materials Journal. 91(5).
[30] IS 9103: 1999, Specification for Concrete Admixtures BIS. Bureau of Indian Standards, New Delhi. (1999).
[31] IS 4031- Part III. Methods of physical tests for hydraulic cement: Determination of soundness. (1988).
[32] IS 4031- Part V. Methods of physical tests for hydraulic cement. Part V- Determination of initial and final setting times. Bureau of Indian Standards, New Delhi. (1988).
[33] IS 4031- Part VI. Methods of physical tests for hydraulic cement. Part VI- Determination of compressive strength of hydraulic cement (Other than masonry cement). (1988).
[34] IS-4032 1985. Method of chemical analysis of hydraulic cement, (1985).
[35] Bureau of Indian Standards. Ordinary Portland Cement - Specification (Sixth Revision). IS 269: 2015 (Reaffirmed Year: 2020). (2020).
[36] IS 3812(part-1):2003. Indian Standard Pulverized Fuel Ash- Specification. Bureau of Indian Standards, New Delhi, India. 3812(October) (2003).

[37] Bureau of Indian Standard. Method of Test for aggregate for concrete. IS: 2386 (Part III) - 1963. (1963).
[38] IS 2386- Part I. IS: 2386 (Part I)-1963- Indian Method of test for aggregate for concrete. Part I - Particle size and shape. Indian Standards. (1963).
[39] Bureau of Indian Standards (BIS). IS: 2386 (Part I)-1963- Indian Method of test for aggregate for concrete. Part I - Particle size and shape. Indian Standards. (1963).
[40] IS 2386 - Part IV. Methods of test for Aggregates for Concrete, part 4: Mechanical properties. Bureau of Indian Standards, New Delhi. (1963).
[41] Bureau of Indian Standards (BIS). IS: 2386 (Part II) - 1963: Methods of test for aggregates for concrete. Indian Standards. (1963).
[42] Bureau of Indian Standards (BIS). IS 2386-5 (1963): Methods of Test for Aggregates for Concrete, Part V: Soundness. Bureau of Indian Standards (BIS).
[43] Bureau of Indian Standards. Coarse and Fine Aggregate for Concrete - Specification (Third Revision). IS 383-2016. (2016).
[44] Bureau of Indian Standards. Methods of test for aggregates for concrete Part 3 Specific gravity, density, voids, absorption and bulking. IS 2386: Part 3: 1963 (Reaffirmed Year: 2021).
[45] ASTM. Standard Specification for Concrete Aggregates. ASTM C33-01 DOI: 101520/C0033-01.
[46] Bureau of Indian Standards (BIS). IS 1199: Part 7: 2018 Fresh Concrete - Methods of Sampling, Testing and Analysis Part 7 Determination of Setting Time of Concrete by Penetration Resistance (First Revision).
[47] Bureau of Indian Standards (BIS). IS 1199: Part 2: 2018 Fresh Concrete - Methods of Sampling, Testing and Analysis Part 2 Determination of Consistency of Fresh Concrete (First Revision).
[48] Bureau of Indian Standards (BIS). IS 5816: 1999 (1 Revision) Splitting tensile strength of concrete - Method of test (First Revision).
[49] IS 516:2014. Method of Tests for Strength of Concrete. IS: 516 - 1959 (Reaffirmed 2004). (2004).
[50] American Society for Testing and Materials. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (ASTM C 469). (2014).
[51] Kim JJ, Reda Taha M. Experimental and numerical evaluation of direct tension test for cylindrical concrete specimens. Advances in Civil Engineering, 201. https://doi.org/10.1155/2014/156926
[52] Singh B, Arora VV, Patel V. Study on stress strain characteristics of high strength concrete. Indian Concrete Journal, 2018; 92:6 37-43.
[53] Arora VV, Singh B, Patel V, Daniel YN, Mohapatra BN. Stress-Strain Behaviour and Performance Evaluation of High Strength Steel Fibre Reinforced Concrete. Indian Concrete Journal, 2019; 93:12 54-61.
[54] Malkawi AIH, Mutasher S. A direct tensile strength for Roller Compacted (RCC) gravity dams. In Roller Compacted Concrete Dams, Berga et al. (eds) © 2003 Taylor & Francis Group, London, ISBN 90 5809 564 9.
[55] Bureau of Indian Standards. Method for determination of strength of rock materials in triaxial compression. IS 13047: 1991 (Reaffirmed Year: 2021).
[56] Schrader EK. Shear Strength and Lift Joint Quality of RCC. International Journal on Hydropower & Dams. 6(1): 46-55 (2002).
[57] Bureau of Indian Standards (BIS). IS 516: Part 2: Sec 1: 2018 Hardened Concrete - Methods of Test Part 2 Properties of Hardened Concrete other than Strength Section 1 Density of Hardened Concrete and Depth of Water Penetration Under Pressure (First Revision).
[58] Filho JH, Medeiros MD, Pereira E, Helene P, Isaia GC. High-volume fly ash concrete with and without hydrated lime: chloride diffusion coefficient from accelerated test. Journal

of materials in civil engineering, 2013; 25:3 411-418. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000596
[59] Arora VV, Singh B. Use of Fly Ash Concrete and Recycled Concrete Aggregates-A Cost Effective Solution and Durable Option for Construction of Concrete Roads. Indian Concrete Journal, 2017; 91:1.
[60] International Organization for Standardization. Iso 22007-2. Plastics-Determination of thermal conductivity and thermal diffusivity-Part 2. 2008 (2008).
[61] Bureau of Indian Standards. Temperature Control of Mass Concrete for Dams - Guideline. IS 14591: 1999 (Reaffirmed Year: 2020). (2020).