Structural Assesment Of Concrete Strength For Ageing Konar Dam, Jharkhand, India

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***Abstract*— Interactions of concrete with persistentprevailing environmental conditions will alter its material properties and cause deteriorations. Such phenomenon is very common in various elements of dams. Konar dam is an earthen dam with concrete spillway built across the Konar river (23.9411° N, 85.7750° E) in Hazaribag district of Jharkhand, India.**

It is 3,549 m long and 49 m high dam with 110 m long concrete spillway.The project was commissioned in 1955. Besides providing irrigation facilities to 45,000 hectares of agricultural land, it supplies clean water to the thermal power plant located at Bokaro. Observation of horizontal cracks of 2-4 mm width extending continuously all along the upstream as well as downstream facesin the galleries from one end to other necessitated evaluation of the quality of concrete with regard to its strength and other associated properties. For initial broad spectrum diagnosis and overall assessment of the status of concrete,ultrasonic pulse velocity technique was adopted. Based on the test observations,locations for extraction of cores for further investigationswere identified on upstream as well as downstream faces of galleries.

This paper presents the outcome of various investigations that were carried out for structural assessment of different grades of concrete used in the dam.

***Index Terms*— Concrete, Ageing, Diagnostic Tool, Ultrasonic,Non-Destructive.**

I. INTRODUCTION

Konar dam is an earthen dam with concrete spillway built across the Konar River (23.9411° N, 85.7750°E) in Hazaribag district of Jharkhand, India (Fig. 1).

Fig. 1 Location of the Project

It is 3,549 m long and 49 m high dam with 110 m long concrete spillway. The project was commissioned in 1955. It has gross storage capacity of 337 million cubic meters and live storage capacity of 276 million cubic meters. Besides providing irrigation facilities to 45,000 hectares of agricultural land, it supplies clean water to the thermal power plant located at Bokaro.

Three grades of concrete classified as Grade A, Grade B and Grade C have been adopted in the construction of the dam. Grade A corresponds to Mass Concrete in the core portion whose maximum aggregate size was 150 mm whereas Grade B was adopted in the crown and side walls in each of the galleries and on the Spillway portion whose maximum aggregate size was 75 mm. Grade B concrete was richer than Grade A and their 28 days compressive strength recorded during the construction phase was 15 MPa (2100 psi) for Grade A and 18 MPa (2700 psi) for Grade B concrete. Grade C concrete was adopted on top of the dam for deck slab.

Observation of horizontal cracks of 2-4 mm width extending continuously all along the upstream as well as downstream face in the galleries from one end to other. Wider crack widths were prominent on the downstream face. There was a reduction in crack widths in other two galleries viz., Access Gallery (middle) and Drainage Gallery (bottom). Leaching of white material was also observed at few places on the face of the gallery. It necessitated evaluation of the quality of concrete with regard to its strength and other associated properties viz., density, permeability etc. in the galleries of the dam where cracks were predominant. Qualitative assessment of the in-situ concrete in all the galleries through non-destructive ultrasonic pulse velocity (UPV) test [1] was carried out for selection of locations for extraction of concrete cores along the walls, mass concrete along the bottom pathway (invert portion) and the blocks in the galleries where dampness and leaching were observed. Test for determining UPV, density, pH, permeability and compressive strength of cores were carried out in the laboratory. This paper presents the outcome of these investigations for structural assessment of different grades of concrete used in the dam.

II. TESTING PROGRAMME

The general investigation work of structural assessment of in-situ concrete of Konar dam, Jharkhand was carried out in two stages.

- **Field Investigation**
- Investigation of concrete walls inside all the three galleries were scanned using Ultrasonic Pulse Velocity testing machine for qualitative analysis of wet and dry

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concrete as well as location of points for extraction of concrete cores.

- Extraction of concrete cores from the walls of all three inspection galleries covering both dry and damp areas of both the upstream and downstream walls in the galleries where Grade B concrete has been used. Extraction of a few representative mass concrete core samples (Grade A concrete) was carried out from the invert (underneath the pathway) in each of the galleries.

➢ **Laboratory Investigation**

The extracted representative concrete cylindrical samples were subjected to following laboratory investigations for assessing its in-situ engineering properties.

- Laboratory assessment of in-situ Pulse velocity
- Core Density,
- Compressive strength
- Modulus of Elasticity
- Split Tensile strength
- Rapid chloride permeability
- Residual pH

III. MATERIALS AND METHODS

➢ **Ultrasonic Pulse Velocity test (UPV)**

Through an indirect transmission mode in the field tests and direct transmission mode on the cores UPV was measured by a commercially available Portable Ultrasound Non-destructive Digital Indicator Tester (PUNDIT) with an associated transducer pair. The nominal frequency of the transducers used for testing concrete sections is 54 kHz. The principle of ultrasonic pulse velocity measurement involves sending a longitudinalwave pulse into concrete by an electro-acoustical transducer and measuring the travel time for thepulse to propagate through the concrete. The pulse is generated by a transmitter and received by a similar type of receiver in contact with the other surface. The concrete surface was prepared for a proper acoustic coupling by applying grease. Light pressure was applied to ensure firm contact of the transducers against the concrete surface. Knowing the path length (L), the measured travel time between the transducers (T) is used to calculate the pulse velocity (V) using the formula

$$V = L/T$$

Based on the UPV, the in-situ Quality of concrete is assessed as per Table 1

Table 1: Velocity Criterion for Concrete Quality Grading as per IS 13311 (Part I), 1992

Pulse Velocity (km/sec)	General condition of concrete
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.50	Medium
Below 3.0	Doubtful*

Based on in-situ UPV test results, concrete cores were extracted in the top inspection gallery, middle access gallery and bottom drainage gallery. Details are given inTable2

Sample No	Block No	RL (ft)	Location of Extraction	Remarks
Top Inspection Gallery				
1	5	1340	Invert (Below the pathway)	Grade A concrete
2	6	1340	Invert (Below the pathway)	Grade A concrete
3	7	1343.3	Downstream face	Grade B concrete
4	10	1340	Invert (Below the pathway)	Grade A concrete
5	11	1342.7	Downstream face	Grade B concrete
6	14	1342.5	Downstream face	Grade B concrete
7	15	1342.8	Downstream face	Grade B concrete
8	16	1343.3	Downstream face	Grade B concrete
9	17	1343.1	Downstream face	Grade B concrete
10	18	1342.5	Downstream face	Grade B concrete
11	20	1342.9	Downstream face	Grade B concrete
Middle Access Gallery				
1	8	1299.1	Upstream face	Grade B concrete
2	9	1298.3	Upstream face	Grade B concrete
3	10	1298.4	Downstream face	Grade B concrete
4	10	1298.6	Upstream face	Grade B concrete
5	11	1298.2	Downstream face	Grade B concrete
6	11	1298.3	Upstream face	Grade B concrete
7	12	1299.1	Upstream face	Grade B concrete
8	13	1299.1	Upstream face	Grade B concrete
9	14	1299.1	Upstream face	Grade B concrete
10	15	1295	Invert (Below the pathway)	Grade A concrete
11	16	1295	Invert (Below the pathway)	Grade A concrete
12	16	1295	Invert (Below the pathway)	Grade A concrete
Bottom Drainage Gallery				
1	6	1259	Invert (Below the pathway)	Grade A concrete
2	8	1260.5	Upstream face	Grade B concrete
3	8	1259	Invert (Below the pathway)	Grade A concrete
4	9	1263.5	Downstream face	Grade B concrete
5	9	1259	Invert (Below the pathway)	Grade A concrete
6	12	1263.1	Upstream face	Grade B concrete
7	13	1262.7	Upstream face	Grade B concrete
8	14	1262.9	Upstream face	Grade B concrete
9	15	1262	Upstream face	Grade B concrete
10	16	1262.6	Upstream face	Grade B concrete
11	18	1262.3	Upstream face	Grade B concrete
12	19	1262.5	Upstream face	Grade B concrete

Table 2: Details of Concrete Core samples extracted from Galleries of Konar Dam

➢ **Compressive Strength, Density and Modulus of Elasticity**

Cylindrical concrete cores of different sizes depending on the maximum particle size were extracted from pre located points of all the three galleries and were tested for evaluation of their

in-situ Equivalent Cube Compressive Strength as per the procedure given in IS: 516-1959(Reaffirmed 2004). Before testing for compressive strength,density of cores was evaluated. Necessary correction factor 'K' was incorporated for those cores whose length to diameter ratio was less than 2.0. Few cores were tested for Modulus of Elasticity as per IS: 516-1959(Reaffirmed 2004).

- **Split Tensile strength**

Split strength tests were carried out as per IS 5816:1999 (Reaffirmed 2004) on representative concrete core samples. Concrete core samples were subjected to split tensile strength tests after keeping the specimens in water for 24 hours before testing. The load was applied at a nominal rate of 1.4 N/mm^2 until failure. The splitting tensile strength f_{ct} of the specimen was calculated using the formula as given below:

$$f_{ct} = 2P/(\pi l d)$$

Where,
P = max load in N applied to the specimen
l = Length of the specimen in mm
d = diameter of the specimen in mm

- **Rapid Chloride Permeation Test (RCPT)**

In the ASTM C1202 test, a water-saturated, 50-mm thick, 100-mm diameter concrete specimen issubjected to a 60 V applied DC voltage for 6 hours using the apparatus as shown in Fig 2

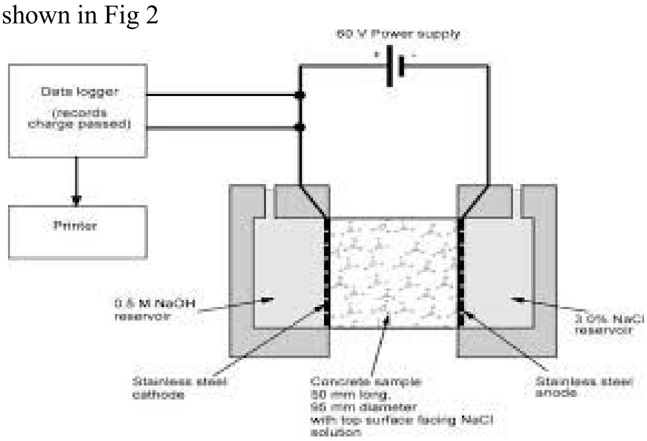

Fig. 2 RCPT Apparatus

In one reservoir is a 3.0 % NaCl solution and in the other reservoir is a 0.3 M NaOHsolution. The total charge passed is determined and this is used to rate the concrete according to the criteria included as Table 3.

Table 3: Ratings of chloride permeability of concrete according to RCPT

Charge Passed (C)	Chloride Permeability	Typical Concrete Type
> 4000	High	High w/c ratio (> 0.60) Conventional PC concrete
2000-4000	Moderate	Moderate w/c ratio (0.40 – 0.50) Conventional PC concrete
1000 – 2000	Low	Low w/c ratio (< 0.40) Conventional PC concrete
100 - 1000	Very Low	Latex modified concrete
<100	Negligible	Polymer impregnated concrete

Being 6 decades old dam, due importance was given to assess the permeability of mass concrete of the existing dam through latest technology of assessing the potential of chloride ion penetration in concrete. In all 4 sets of concrete cores containing 2 samples in each set were tested for assessing the permeation potential of chloride ions in to the concrete using Rapid Chloride Permeability Test equipment. Test procedures laid down in ASTM C 1202 was adopted.

IV. RESULTS AND DISCUSSIONS

- **Density of Concrete Cores**

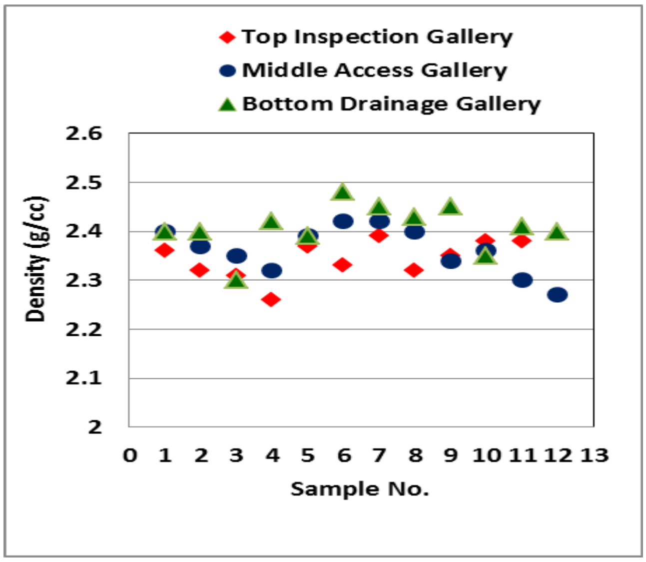

Fig 3 Results of Density Test on the core samples from three galleries

Results of the density test are presented in Fig 3 which shows that the density of the extracted cores in all the three galleries is found to be above 2.27 gm/cc.

- **Ultrasonic Pulse Velocity test (UPV) on Concrete Cores [5, 6]**

Results of the UPV test are presented in Fig 4 which shows UPV of Grade A and grade B concrete cores in all the three galleries indicates Good to Excellent Grade Quality as per IS: 13311 part-I.

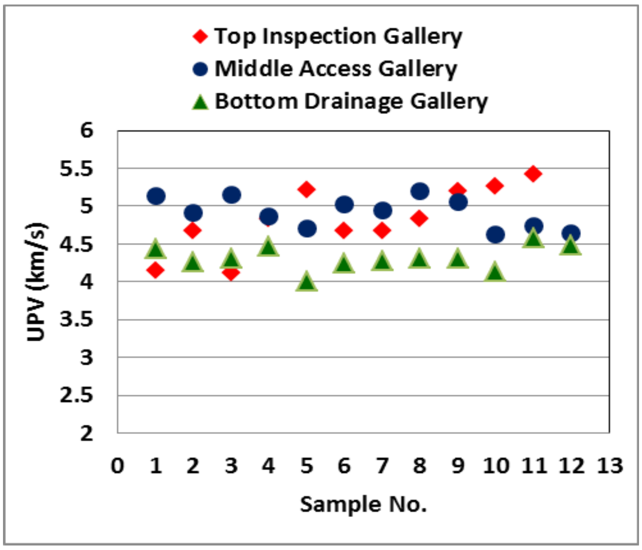

Fig 4 Results of UPV Test on the core samples from three galleries

➢ **Compressive Strength of Concrete Cores**

Results of the compressive strength test are presented in Fig 5 which shows that the existing in-situ strength of mass concrete is very well above the design strength which was 15 N/mm^2 for Grade A concrete and 18 N/mm^{2}for Grade B concrete in all the three galleries.

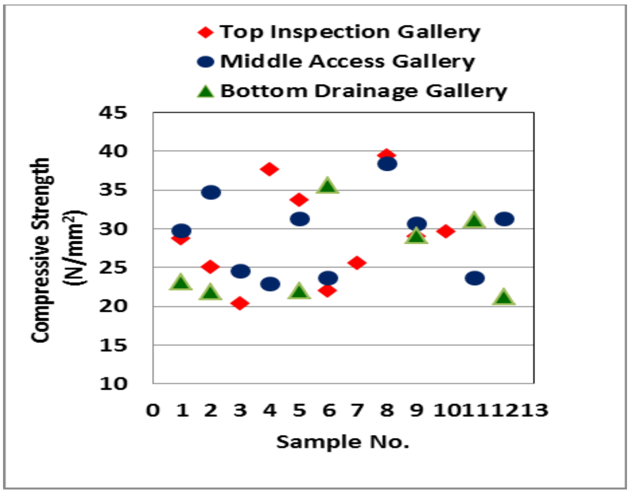

Fig 5 Results of Compressive Strength test on the core samples from three galleries

➢ **Modulus of Elasticity test results of core samples[2]**

The results of Modulus of Elasticity test on extracted core samples are presented in Table 4

➢ **Split Tensile strength Test results of core samples**

The results of Split Tensile strength test on extracted core samples are presented in Table 5

➢ **Rapid Chloride Permeability Test results of core samples[3]**

The results of RCPT on extracted core samples are presented in Table 6.

In the access gallery, the total current passed through the concrete cores during the process of chloride ion permeation in to the Grade A Concrete (mass concrete in invert) indicate Moderate Permeability which implies conventional good quality plain cement concrete with moderate w/c ratio between 0.40 – 0.50 while for Grade B Concrete (Crown portion of all galleries & Spillway) indicate Moderate (w/c ratio 0.40 -0.50) to high Permeability (w/c ratio > 0.60).

In the drainage gallery the total current passed through the first set of concrete cores (extracted from block 6) during the process of chloride ion permeation in to the concrete indicate Low to Moderate Permeability. Low permeability implies good quality plain cement concrete made with w/c ratio less than 0.40 while Moderate Permeability implies conventional good quality plain cement concrete made with w/c ratio between 0.40 – 0.50. Concrete cores (extracted from block 8) indicate Moderate to High Permeability. Moderate Permeability implies conventional good quality plain cement concrete made with w/c ratio between 0.40 – 0.50 and w/c ratio > 0.60 is categorised under high permeability range.

Table 4 Results of Modulus of Elasticity test

Sample No. & Block No.	Pulse Velocity (km/sec)	Equivalent cube compressive strength (MPa)	Static Modulus of Elasticity (MPa)	Grade of concrete
16/9, 13	5.09	21.25	2.08×10^4	B*
16/10, 13	4.78	26.22	2.06×10^4	B*
16/15, 14	4.12	12.28	1.98×10^4	B*
16/17, 14	3.98	37.53	2.05×10^4	B*
16/32, 16	5.04	38.72	2.37×10^4	B*
16/35, 16	4.46	19.83	1.95×10^4	B*

Table 5 Results of Split Tensile strength test

Sample No. & Block No.	Split Tensile Strength (MPa)	Density (g/cc)	Quality of Concrete (based on UPV)
16/2, 13	2.47	2.43	Excellent
16/7, 13	2.63	2.36	Excellent
16/18, 14	3.30	2.41	Excellent
16/29, 16	2.64	2.39	Excellent
16/30, 16	1.53	2.36	Excellent
16/34, 16	3.13	2.38	Excellent

Table 6Resultsof RCPT

Sample No.	Dia. (mm)	Height (mm)	Concrete Grade	Current Passed (Coulombs)	Permeability
Access Gallery					
1	101	50	B	3722 C	Moderate
				5363 C	High
10	101	50	A	3383 C	Moderate
				3845 C	Moderate
Drainage Gallery					
1	100	50	A	2402 C	Moderate
				1672 C	Low
3	100	51	A	4577 C	High
				2541 C	Moderate

- **pH of concrete samples**
  The results of pH of the concrete samples are presented in Table 7. The results indicate alkaline nature of the samples.

Table 7: Results of pH of concrete

Sample No	Concrete Grade	pH	Remarks
Inspection Gallery			
3	B	12.12	Alkaline
Access Gallery			
5	B	11.91	Alkaline
6	B	11.90	Alkaline
Drainage Gallery			
1	A	11.98	Alkaline
2	B	11.94	Alkaline

- **Alkali content in in-situ concrete**

All the concrete cores that were extracted from all the three galleries were thoroughly inspected for any visible cracks especially on aggregate in the matrix before being taken for conducting other laboratory investigations. Visible observations indicated that none of the concrete cores extracted from all the three galleries showed any symptoms related to initiation of cracks on aggregate in the matrix due to alkali aggregate reaction. In order to confirm further, available total alkali content as Na_2O was determined for a few representative in-situ concrete cores extracted from the galleries. The results of same are presented in Table 8

Table 8: Results of Total available Alkali as percent of Na_2O in the concrete

Sample No.	Conc. Grade	Na as Na_2O % by mass	K as Na_2O % by mass	Total Alkali (as Na_2O % by mass)	Remarks
Inspection Gallery					
2	A	0.20	0.29	0.49	Within permissible limit as per IS: 456 (2000)
3	B	0.23	0.31	0.54	
Access Gallery					
5	B	0.18	0.21	0.39	Within permissible limit as per IS: 456 (2000)
6	B	0.11	0.17	0.28	
Drainage Gallery					
2	B	0.15	0.36	0.51	Within permissible limit as per IS: 456 (2000)

The Total alkali content as Na_2O in all the concrete samples were below 0.6 % which reconfirm that in-situ concrete is not likely to be affected by alkali aggregate reaction.

V. Conclusions

Based on the detailed laboratory investigations for evaluation of in-situ mass concrete, the following conclusions can be drawn.

- Quality of 6 decade old in-situ concrete of both Grade A (Mass concrete) and Grade B (Concrete in crown and side walls of the three galleries) from the point of compressive strength are well above the design strength.
- Modulus of elasticity of in-situ concrete in general is agreeable with the range as evaluated from the empirical formula given in IS456:2000 [4].
- Split Tensile Strength of in-situ concrete in general is closer to the value as determined from the empirical formula given in IS456:2000.
- Permeability of inner concrete of both Grade A and GradeB concrete are in general, fall under moderate category (conventional plain cement concrete made with w/c ratio between 0.40 – 0.50).
- Aggregates in the matrix of concrete cores did not show any sign of distress due to alkali silica reaction.

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