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Investigation of in-situ strength of concrete in an old concrete dam for its repair and maintenance

M Raja, S K Dwivedi, U S Vidyarthi, C.B.Sarma

Abstract - **This paper presents the concrete condition assessment of an inspection gallery, access gallery, and drainage gallery of old dam. Minor degradation and water seepage were observed in a few places of galleries, particularly from the top surfaces of the galleries. This investigation was carried out to obtain the concrete properties needed to assess the strength and quality of concrete. The method of evaluation of the strength of the old dam is carried out by using ultrasonic pulse velocity (UPV) measurements and core compressive strength. The gallery concrete surface was recommended for repair and waterproofing based on the results.**

Key words- Ultrasonic Pulse Velocity (UPV), Compressive Strength, Density

1. BACKGROUND

Inside the dam body, the size of galleries is about 1.2 m wide and 2.1 m high. This old dam is an earthen dam with concrete spillway length of around 110 meters. The primary objective of this gallery is to provide access to the interior of the dam for inspection, monitor the dam's stability and functionality during the post-construction phase, and perform any necessary remedial work. Figure 1 shows a sketch of the layout of the dam body, which includes all the galleries. According to the available facts from the construction records, these galleries were built using two grades of concrete (Grade A and B). The concrete strength of Grade A and B is about 15 MPa and 18 MPa, respectively.

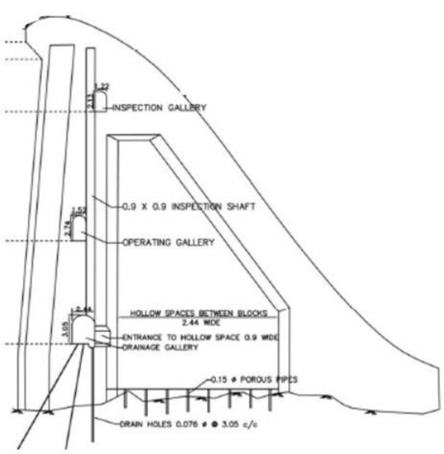


Figure1. Layout of Dam

2. *Strategy for Investigation*

Due to structural challenges, the project authorities were very cautious about the extraction of cores from these galleries. They permitted to extract the minimum number of cores possible from each gallery. Moreover, the project authorities realized that a comprehensive stability analysis of the dam should be done using mathematical modeling based on the evaluated core compressive strength. During the present investigation, Thirty-five cores were collected from various locations of the three galleries presented in Table1. The cracks on the concrete surface of the gallery were also seen in few places. Rationalizing the data obtained (pulse velocity, density, and core compressive strength) is often tricky.

Table 1 : Details cores extracted from various locations of the gallery

Location	No. of Cores extracted	No. of tested for		
		Density	Pulse Velocity	Compressive strength
Inspection Gallery	11	11	11	10
Access Gallery	12	12	12	10
Drainage Gallery	12	12	12	7

3.0 Tests on cores

(A) Pulse Velocity:

The test apparatus comprises a pulse generator and transmitter for producing and introducing a wave pulse into concrete and a receiver for sensing the arrival of the pulse and accurately measuring the time it takes for the pulse to travel through the concrete. The equipment can be linked to an oscilloscope or other display device for displaying the time of travel for a known distance. Figure 2 illustrates a schematic diagram. IS 516, Part 4 contains a detailed description of the test method.

Ultrasonic testing units are portable and available all over the world. The equipment is lightweight, easy to use, and may consist of a rechargeable battery and charging unit. Pulse times of up to 6500 micro-seconds may usually be detected with 0.1micro-second resolution. The measured travel time is displayed prominently. The instrument consists of two transducers, one for transmitting the ultrasonic pulse and the other for receiving it. Concrete is often tested using transducers with frequencies ranging from 24 to 100 kHz. For specific applications, transducer sets with different resonant frequencies available: high-frequency transducers (above 100 kHz) are used for small specimens, short path lengths, or high-strength concrete, whereas low-frequency transducers (below 24 kHz) are used for larger specimens, longer path lengths, or concrete with the larger size aggregate. These transducers primarily generate compression waves at a single frequency, the majority of the wave energy directed along the normal axis of the transducer face. Figure 3 shows regularly used equipment.

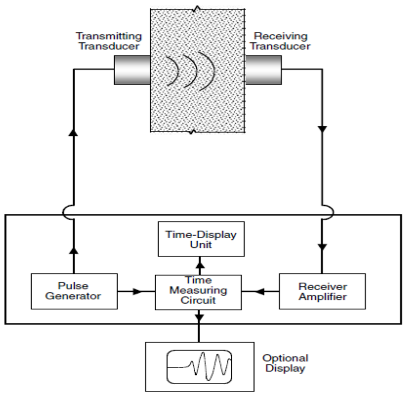


Figure 2 and 3: Schematic diagram and equipment

The extracted cores from three galleries were dried to a temperature of 50°C in the oven after cutting the drilled core to an acceptable size. The UPV measurements on thirty-five cores were conducted by placing the transducers (24 kHz) directly on opposite faces of the core, according to IS 516 (Part 5/Sec 1). The pulse velocity measurement was performed with a commercially available PUNDIT 200 Touch Screen (Portable Ultrasonic Non-destructive Digital Indicating Tester) equipment which M/s Proceq, Switzerland, developed. Before measurement, the length of each core is fed to the UPV machine, which displays the pulse velocity (v) directly using the in-built programmed expression:

$$V = \frac{L}{t} \qquad \text{[Eq.1]}$$

Where

V= Pulse Velocity, km/s
L= Length of the core in meter and
t= Transit time in seconds

Table 2 shows the statistical summary of pulse velocity results and complete results were presented in Figure 1, 2 and 3 for the cores collected from the inspection gallery, access gallery, and drainage gallery. The approximate concrete quality can be evaluated using the velocity criterion, as shown in Table 3, which meets the IS 516 (Part 5/Sec 1) guidelines. All the cores' measured mean pulse velocity from various locations fell into the "good to excellent" grading category.

Table 2: Statistical Summary of pulse velocity of concrete

Location	Max	Min	No. Cores	Average
Inspection Gallery	5.42	4.12	11	4.82
Access Gallery	5.20	4.63	12	4.90
Drainage Gallery	4.58	4.00	12	4.31

Table 3: Velocity Criterion for Concrete Quality Grading as per IS 516 (Part 5/Sec 1):2018

Average Value of Pulse Velocity by Cross Probing in km/s	Concrete Quality Grading
Above 4.40	Excellent
3.75 to 4.40	Good
3.00 to 3.75	Doubtful#
Below 3.00	Poor

In case of "Doubtful it may be necessary to carry out further tests

(B) Density:

By measuring three pairs of measurements at right angles, at the half and quarter points of the length of the core, the core dimensions, such as average core diameter and average length, were determined to an accuracy of 0.01 mm. The mass of cores was also measured to be within 0.1 percent of the specimen's mass. The core density was calculated using Eq. 2, as shown below. Table 4 shows the statistical summary of density results and complete results were presented in Figure 1,2,and 3 for the cores collected from the inspection gallery, access gallery, and drainage gallery. According to the results, the calculated mean density is approximately within the range of normal concrete.

$$Density = \frac{Mass\ in\ kg}{Volume\ in\ m^3} \qquad \text{[Eq. 2]}$$

Table 4: Statistical Summary of density of concrete

Location	Max	Min	No. Cores	Average
Inspection Gallery	2.39	2.26	11	2.34
Access Gallery	2.42	2.27	12	2.36
Drainage Gallery	2.48	2.30	12	2.41

(C) Compressive Strength:

The compressive strength of twenty seven cores collected from various locations of the galleries were tested as per the procedure described in IS 516. Before testing the cores, the core samples were prepared to an acceptable tolerance level as described in IS 516 (Part 4) for the sample surface flatness, perpendicularity, parallelism, and straightness. After that, these cores were conditioned by soaking in water for 40 to 48 hours at 27±3°C temperature. These soaked cores were taken out from the water, and they were wiped and brought to a saturated state on the surface. These cores were carefully placed central axis of the compression testing machine platen (as per IS 14858). Continuous stress of 14 N/mm^2/min is applied on these cores until the core specimen breaks down.

$$f_{ck(Cube)} = 1.25 * (CF)_{l/d} * f_{ck,cylinder} \quad \text{[Eq. 3]}$$

Where $f_{ck(Cube)}$ = Equivalent Cube compressive strength in *MPa*

$f_{ck,cylinder} = \frac{P}{A}$ (P = Load at failure in N & A = Area in mm^2)

$(CF)_{l/d}$ = Correction Factor for l/d (l = length of the core in mm and d = diamter in mm)

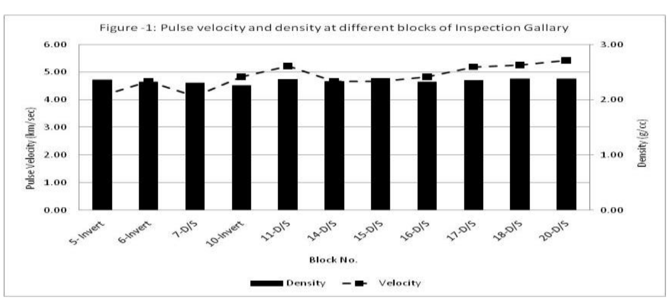
Table 5 shows the statistical summary of core compressive strength results and complete results were presented in Figure 4,5 and 6 for the cores collected from the inspection gallery, access gallery, and drainage gallery.

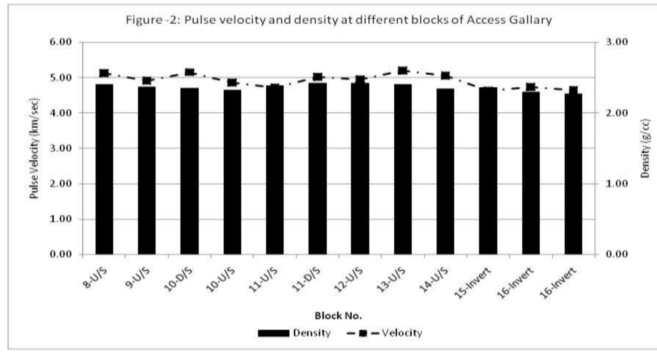
Table 5: Statistical Summary of core compressive strength of concrete

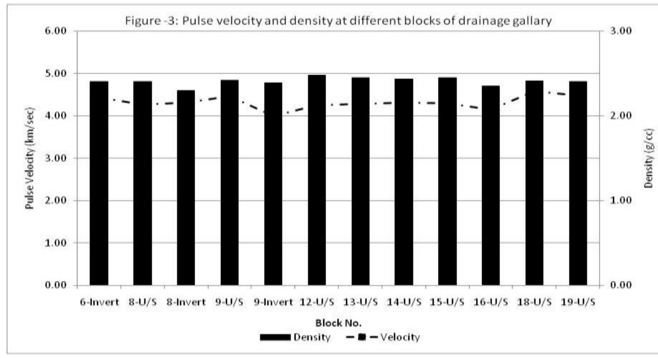
Location	Max	Min	No. Cores	Average
Inspection Gallery	39.39	20.38	10	29.11
Access Gallery	38.43	22.92	10	29.02
Drainage Gallery	35.66	21.23	7	26.85

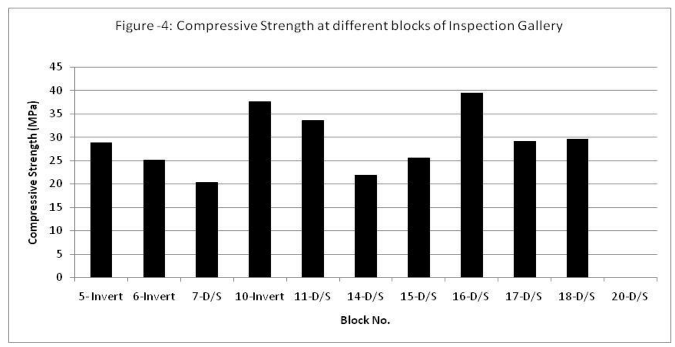
Conclusions:

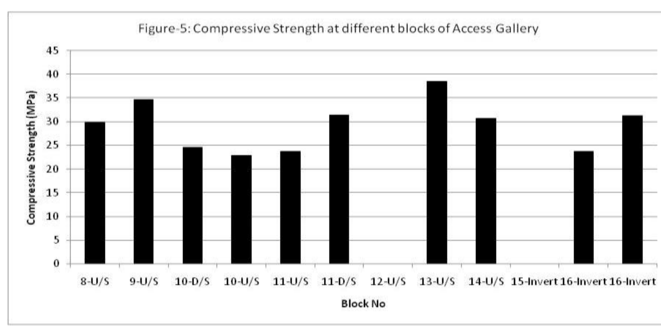
1. The compressive strength of all cores was above the designed strength.
2. Pulse velocity of all cores falling in good to excellent as per IS 516.
3. The density of all cores is near to the density of normal concrete.
4. Few durability tests, such as permeability tests, a rapid chloride penetration test, etc., are recommended for a clear understanding of structural quality.
5. Extensive investigations are necessary before repairing and rehabilitating old dam structures, which involve huge funding, even with the available results recommended for repair and waterproofing of galleries surface.

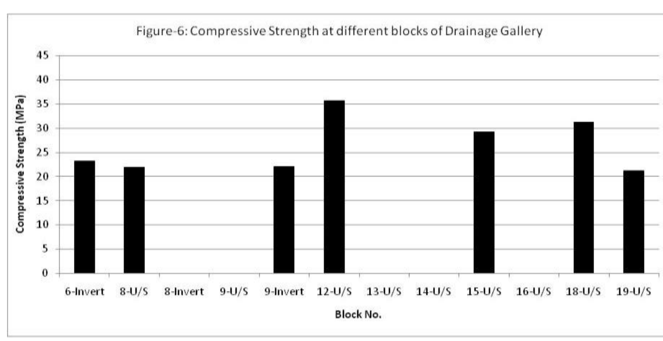












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M Raja, S K Dwivedi, U S Vidyarthi, C.B.Sarma CSMRS, New Delhi