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Periodic Assessment and Long Term Durability Consideration of Drainage Galleries of Pandoh Dam, Himachal Pradesh, India using Non Destructive Test Method

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Abstract- **Interaction of concrete with the persistent prevailing environmental condition will alter its material properties and cause deterioration. There are various causes of distress in the concrete structure, such as improper construction practices, post-construction expansion due to Alkali-Aggregate Reaction (AAR), corrosion of reinforcement, non-homogeneity of concrete, development of cracks due to shrinkage and thermal stresses, aging, etc. Such phenomena are very common in various elements of the dam. Pandoh dam is an earth cum rockfill dam 76.2 m high from the deepest foundation level. The dam is 255 m long and 12.19 m wide at the top, with a concrete spillway located on river Beas near Mandi in Himachal Pradesh. This dam was constructed in the year 1977 for irrigation and hydropower. Part of a run-of-the-river power scheme, it diverts the waters of the Beas to the south-west through a 38 km long system of tunnels and channels. The water is used for power generation at the Dehar Power House before being discharged into the Sutlej River, connecting both rivers. The objective was to assess and monitor the in-situ quality of concrete in a drainage tunnel under a spillway and other galleries in the dam's body to study the effect of excessive sulfate content in the seepage water from drainage holes. In this regard, Non-Destructive Tests (NDT) were conducted on drainage galleries of a dam by using the Ultrasonic Pulse Velocity (UPV) method to assess the in-situ quality of concrete.**

Keywords*: *Concrete, Aging, diagnostic tool, ultrasonic pulse velocity, non-destructive testing.

I. INTRODUCTION

Pandoh dam was constructed on the river Beas near Mandi in Himachal Pradesh in 1977 for irrigation and hydropower. Pandoh dam comprises an earth cum rockfill dam of 76.2 m high from the deepest foundation level. The dam is 255 m long and 12.19 m wide at the top. The cross-section of the dam is shown in Figure 1.

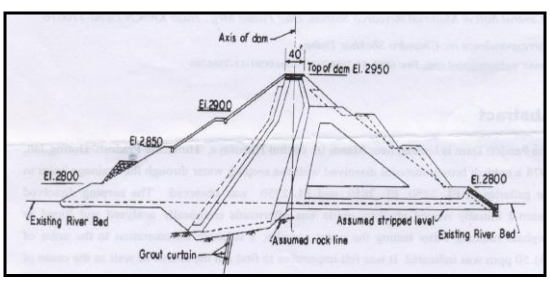

Figure 1.1: Cross-section of the dam

Figure 1.2: Arial view of Pandoh dam

The advances in concrete technology have paved the way to make the best use of locally available materials, judicious mix proportioning, and acceptable quality of materials to result in concrete satisfying the performance requirements. While the properties of the constituent materials are essential, the users are interested in the concrete itself having the desired properties. Concrete has to have satisfactory properties in the fresh and hardened state, while workability is the most important property for fresh concrete.

Cases of distress to structures under construction and in-service have posed a problem to engineers investigating such structures. The various application of non-destructive testing is an assessment of the overall quality and strength of concrete, diagnosis, categorization of distressed structures, ascertaining the existing condition of the concrete, checking of efficiency of repairs, and other time-dependent studies. Hence, the need is felt to test the concrete in a structure in-situ by non-destructive testing to evaluate its condition for taking appropriate remedial measures for rehabilitation and restoration. This paper mainly covers the non-destructive testing of concrete on drainage galleries of the dam by using the ultrasonic pulse velocity method.

II. PROGRAMME OF INVESTIGATION

The concrete faces in the drainage tunnel under the spillway and other galleries in the dam body were conducted for non-destructive tests using the Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT). The tests were carried out by using indirect and semi-direct pulse transmission methods. On each of two vertical concrete walls designated as the upstream face and downstream face of all the tunnels, the test points were marked at 30 cm horizontal spacing in two rows separated at 100 cm apart. Using the indirect method, measurements were taken horizontally with a path length of 30 cm. A thin layer of rich cement sand mortar was applied to each test point. Before each measurement, a thin layer of ordinary grease was applied to ensure proper acoustical coupling between the transducers and concrete surfaces. The tests were carried out on points marked in two rows on the upstream and downstream vertical concrete walls of the following three tunnels, which were placed at various elevations:

1. Drainage tunnel under flip bucket (Elevation 2750 ft.)

2. Drainage tunnel under spillway crest (Elevation 2850 ft.)

3. Drainage tunnel at left abutment (Elevation 2950ft.)

In addition, in drainage tunnel at elevation 2850 ft., measurements using semi-direct method were also taken at six corners designated as A, B, C, D, E & F.

III ULTRASONIC PULSE VELOCITY TEST

Basic principles of test

An electro-acoustical transducer in contact with one surface of the concrete under test generates pulses of longitudinal 'P' waves. A second transducer turns the vibrations pulse into an electrical signal after traveling a known path length (L) in the concrete. Electronic circuits allow the pulse's transit time (T) to be measured to be determined.

$V = L / T$ for direct transmission of pulse velocity

Where L = path length and T = time

Figure 3.1: Ultrasonic pulse velocity test equipment (Proceq, Model- PL 200) and its application on drainage gallery walls

Acceptance criteria

Ultrasonic pulse velocity tests have been employed extensively to evaluate the relative quality of in-situ concrete. It is a qualitative and relative test that does not provide the compressive strength of concrete. In general, high concrete pulse velocity readings indicate good quality.

Shocks in concrete caused by high discharge in the spillway through the gates affect ultrasonic pulse velocity readings in galleries. It is recommended to do this test during a lean period when there is either no or extremely low flow through the spillway. The following table lists the concrete quality evaluation criteria used in this study, which are recommended in IS 516 (Part 5/ Sec 1): 2018:

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

Pulse Velocity by cross probing, km/sec	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

IV DISCUSSION OF TEST RESULT

Drainage tunnel under flip bucket (Elevation 2750 ft.)

The ultrasonic pulse velocity measurements were performed on a drainage tunnel under a flip bucket at 201 test points with a 30 cm horizontal path length in two rows at a vertical distance of 100 cm on each of the upstream and downstream faces of the tunnel using an indirect method. It was observed that 171 (85.07 percent) of the 201 test locations indicated that concrete quality is excellent, while 30 (14.93 percent) test locations indicated that concrete quality is good. The overall quality of concrete is excellent.

Figure 4.1: View of NDT testing at drainage tunnel under flip bucket

Drainage tunnel under spillway crest (Elevation 2850 ft.)

In the drainage tunnel under the spillway crest, ultrasonic pulse velocity tests were conducted by indirect method at 332 test points with 30 cm horizontal path length in two rows at a vertical distance of 100 cm. Out of 332 test locations, 86 (25.90 percent) indicate that concrete quality is excellent, 232 (69.87 percent) indicate that concrete quality is good, 12 (3.61 percent) suggest that concrete quality is doubtful. The remaining 2 (0.6 percent) test locations indicate poor concrete quality. The overall quality of the concrete is good.

Figure 4.2: View of NDT testing at drainage tunnel under spillway crest

Concrete Wall from Block 168 to 174 under spillway crest (Elevation 2850 ft.)

The ultrasonic pulse velocity tests were performed on a concrete wall under the spillway crest using an indirect method at 152 test points with a 30 cm horizontal path length in two rows at a vertical distance of 100 cm. Out of 152 test locations, 35 (23.02 percent) indicate that concrete quality is excellent, 106 (69.73 percent) indicate that concrete quality is good, and 11 (7.23 percent) test locations indicate that concrete quality is doubtful. The overall quality of the concrete is good.

Figure 4.3: View of NDT testing at Concrete Wall from Block 168 to 174 under spillway crest

Corners designated in the Drainage tunnel under spillway crest (Elevation 2850 ft)

The semi-direct ultrasonic pulse velocity testing method was conducted on 36 test points (i.e., at six different corners identified as A, B, C, D, E, and F). Out of 36 test points, 13 (36.11 percent) indicate that concrete quality is excellent, 12 (33.33 percent) indicate that concrete quality is good, 9 (25 percent) indicate that concrete quality is doubtful. The remaining 2 (5.55 percent) test locations indicated poor concrete quality. The overall quality of the concrete is excellent.

Drainage tunnel at left abutment (Elevation 2950ft.)

Ultrasonic pulse velocity measurements were conducted on the left abutment of the drainage tunnel at 573 test points with a 30 cm horizontal path length in two rows at a vertical distance of 100 cm on each of the tunnel's upstream and downstream faces using an indirect method. Out of 573 test locations, 93 (16.23 percent) indicate that concrete quality is excellent, 436 (76.09 percent) indicate that concrete quality is good, 37 (6.45 percent) indicate that concrete quality is doubtful. The remaining 7 (1.22 percent) test locations indicate poor concrete quality. The overall quality of the concrete is good.

Corners designated in the Drainage tunnel under spillway crest (Elevation 2850 ft)

The semi-direct ultrasonic pulse velocity testing method was conducted on 36 test points (i.e., at six different corners identified as A, B, C, D, E, and F). Out of 36 test points, 13

(36.11 percent) indicate that concrete quality is excellent, 12 (33.33 percent) indicate that concrete quality is good, 9 (25 percent) indicate that concrete quality is doubtful. The remaining 2 (5.55 percent) test locations indicated poor concrete quality. The overall quality of the concrete is excellent.

Drainage tunnel at left abutment (Elevation 2950ft.)

Ultrasonic pulse velocity measurements were conducted on the left abutment of the drainage tunnel at 573 test points with a 30 cm horizontal path length in two rows at a vertical distance of 100 cm on each of the tunnel's upstream and downstream faces using an indirect method. Out of 573 test locations, 93 (16.23 percent) indicate that concrete quality is excellent, 436 (76.09 percent) indicate that concrete quality is good, 37 (6.45 percent) indicate that concrete quality is doubtful. The remaining 7 (1.22 percent) test locations indicate poor concrete quality. The overall quality of the concrete is good.

Figure 4.4: View of NDT testing at drainage tunnel at left abutment

Conclusion and recommendation

- The pulse velocity results were obtained for all the three Drainage and Grouting tunnels, viz. the tunnel under flip bucket at EL 2750 ft., the tunnel under spillway crest at EL 2850 ft., and the tunnel at left abutment at EL 2950 ft. In all, 1294 test locations were scanned using UPV test methods, and ***only 69 (5.33%) test locations (< 10%)*** were categorized under the doubtful category.
- In case of doubtful quality of concrete, additional tests shall have to be carried out to confirm the extent of deterioration the concrete has undergone according to **IS 516 (Part 5/ Sec 1): 2018**. The visual observations reveal that deterioration in the form of disruptions in concrete has taken place at fewer locations where conversion of monosulphate phases into ettringite phases is the primary cause of expansion and seepage. A significant volume increase accompanies this process is responsible for the internal stresses causing the cracking through which the seepage water entered the drainage and grouting galleries.
- Based on the UPV tests, the overall quality of in-situ concrete was observed to be good, and at those test points, wherever the quality of concrete was observed to be doubtful, it is suggested for continue monitoring of seepage water and determine dissolved Sulphate concentration.
- Apart from the above, assess the mineralogical content of leachate materials coming out along with seepage water. If the sulphate concentration exceeds the limit and the NDT test results indicate doubtful quality, extract a few cores from selective locations and determine their compressive strength and density to decide further action.
- Suppose spalling is observed in concrete exposing embedded reinforcement at doubtful locations, in that case, it is suggested to evaluate the extent of corrosion of reinforcement that has taken place in the entire area through the Half Cell Potentiometer.

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