INCOLD

CENTRAL BOARD OF IRRIGATION & POWER
ESTD. 1927
NEW DELHI

CLIMATE-RESILIENT DAMS AND HYDROPOWER INFRASTRUCTURE INTEGRATING ENVIRONMENTAL SUSTAINABILITY IN PLANNING AND DEVELOPMENT

CHALLENGES IN HYDRO PROJECTS: PLANNING THE RESTORATION OF RCC STRUCTURES - CASE STUDY OF TAPOVAN VISHNUGAD HYDRO POWER PROJECT

Vivek Gupta, *Dy. General Manager, NTPC Ltd.* **(INDIA)**

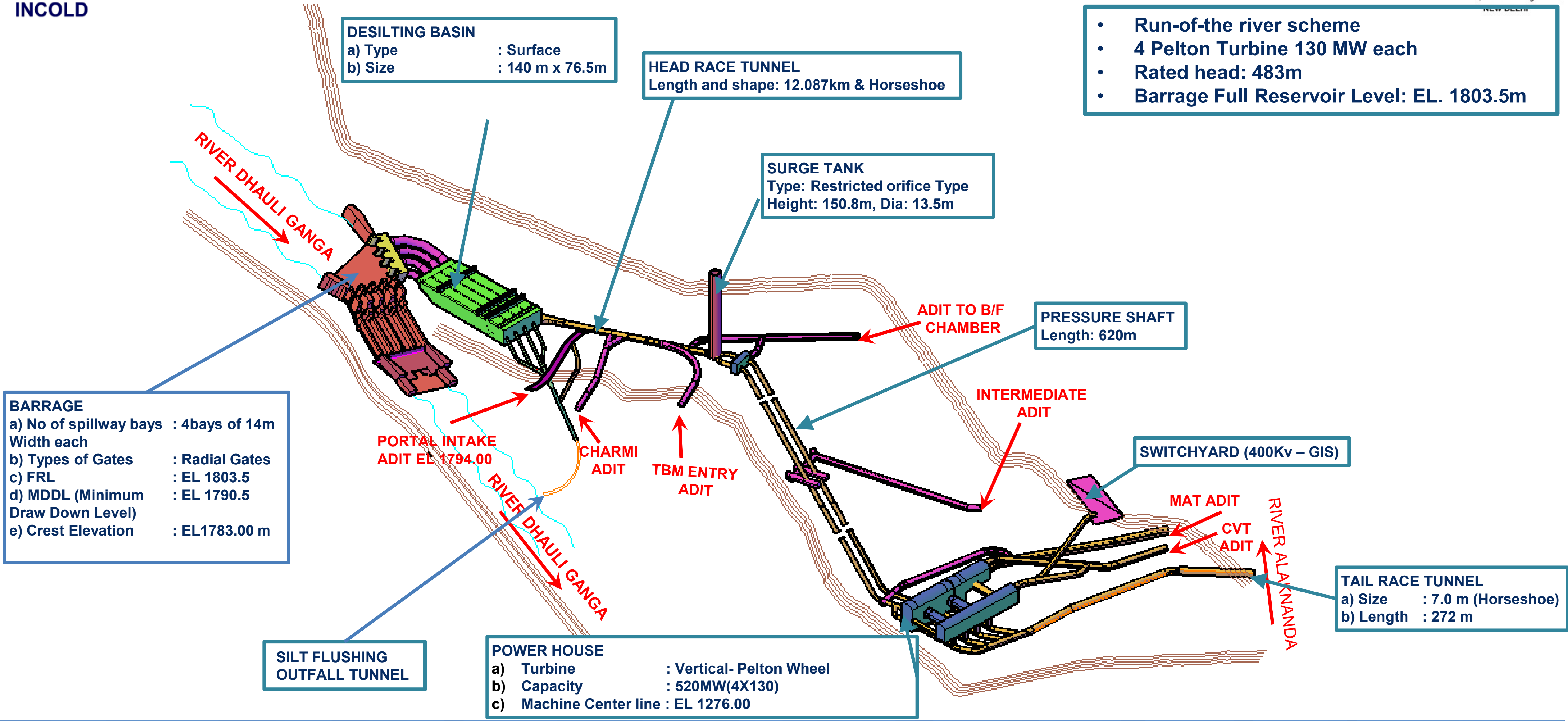
Dr. Anubhav, *Add. General Manager, NTPC Ltd.* **(INDIA)**

INTRODUCTION:

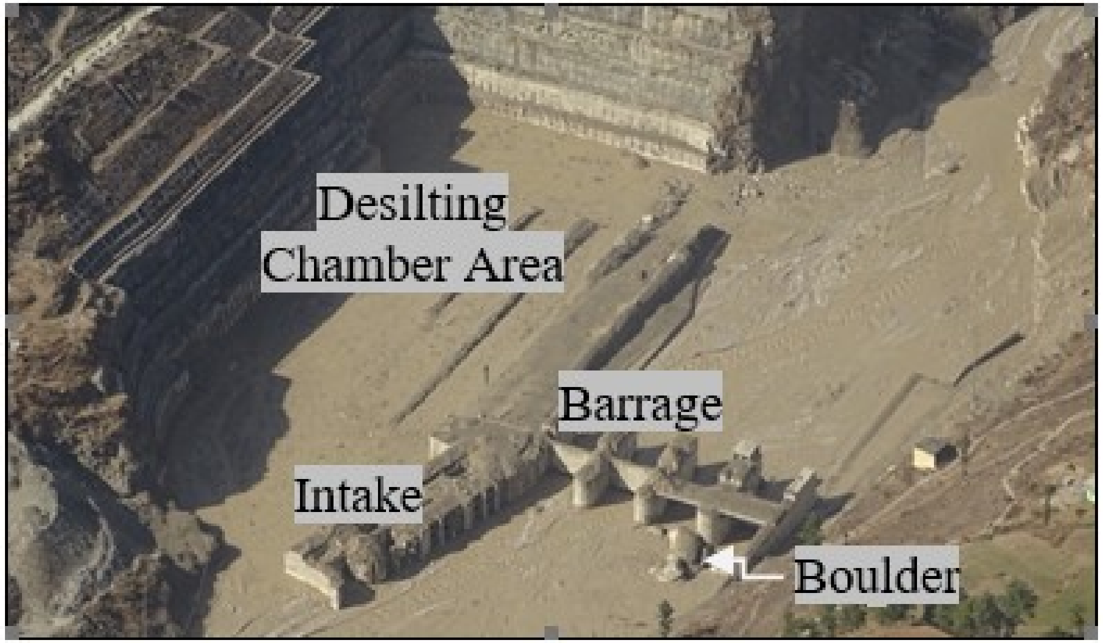
- Hydropower provides reliable, sustainable energy and stabilizes the grid alongside variable solar and wind power.
- Pumped storage hydropower is one of the most environment-friendly energy storage options.
- Hydropower development faces challenges of high cost, environmental and social concerns, difficult terrain, and climate change.
- Projects in hilly terrain must consider hazards such as landslides, GLOF, floods, and earthquakes.
- The 7 February 2021 Tapovan Vishnugad incident demonstrated the risk of unforeseen natural events.
- A glacial debris flow from Ronti Mountain caused severe damage to the Tapovan Vishnugad HPP Barrage complex , roads, and tunnel systems in the d/s..
- The paper mainly cover methodology to examine the impact of the event on restoration planning for damaged RCC structures of TVHPP.

PROJECT DESCRIPTION :

- Run-of-the river scheme
- 4 Pelton Turbine 130 MW each
- Rated head: 483m
- Barrage Full Reservoir Level: EL. 1803.5m



EFFECT OF INCIDENT ON PROJECT COMPONENTS



Barrage Complex Before & After Incident

EFFECT OF INCIDENT ON PROJECT COMPONENTS

Fig. 2. Barrage & Intake after Incident

INCOLD

EFFECT OF INCIDENT ON PROJECT COMPONENTS

- Glacial debris flow overtopped the Barrage at El. 1807.5 m, about 4 m above FRL (1803.5 m).
- Post-event, upstream riverbed level near the Barrage agraded by about 11 m.
- Around 18 m of debris was deposited downstream above the stilling basin.
- The Barrage structure suffered extensive damage.
- Breast wall at Bay 3 was washed away.
- Bridge deck at Bay 1 and Bay 2 washed away.
- Pier control room between Bay 1 and Bay 2 was severely damaged.
- Large boulders (5–15 m size) accumulated in front of Bay 3 and Bay 4.
- Heavy silt and debris accumulated over the intake structure.
- Trash rack columns of intake Bays 2 and 3 were severely damaged.
- Partially erected radial gates (Bays 1 to 3), hydraulic cylinders, tie flats, and trunnion bolts were washed away.

GENERAL APPROACH FOR CONDITION ASSESSMENT OF RCC STRUCTURES

- As a first step, alignment and structural integrity of the Barrage were assessed for restoration planning.
- Planning covered testing , repair methodology, and selection of repair materials for RCC structures.
- Detailed condition assessment was carried out in consultation with SERC, Chennai and CBRI, Roorkee.
- Structural strength, soundness, quality, and uniformity of concrete were evaluated.
- Both dimensional accuracy and structural strength were investigated to establish integrity of Barrage RCC structures.

Study on Alignment of Dam Structure

- Barrage alignment was checked against pre-incident position by surveying predefined layout points.
- Nineteen (19) points were surveyed and compared with construction drawing coordinates.
- Most points showed no deviation; only minor deviations of a few millimeters were observed at some locations.
- At eroded locations with exposed reinforcement, readings were taken using fixed steel plates.
- Survey results confirmed that the RCC barrage alignment remains undisturbed.

<u>**Details of Verified Survey Points at Barrage and Intake**</u>

INCOLD

NEW DELHI

Visual Inspection of the RCC Structure:

- Detailed visual inspection and documentation were carried out to assess overall structural condition.
- Concrete erosion and abrasion were observed in structures, with and without reinforcement exposure.
- Damage to the High-Performance Concrete at Barrage floor.
- Reinforcements were severely scrambled over the under-construction desilting chamber and intake structure.
- RCC columns at the intake entrance for trash rack installation showed bending and shear damage.
- Bridge deck over Bay #3 was laterally displaced by about 50 mm & Bridge deck at Bay 1 and Bay 2 washed away.
- Breast walls were severely affected by the incident with multiple flexural cracks .
- Breast wall at Bay #3 was completely sheared off.

Non-Destructive Tests and Partially Destructive Tests on the RCC Structure:

- Non-destructive testing (NDT) methods were used to assess concrete quality and integrity.
- UPV and rebound hammer tests were used together to minimize measurement errors.
- For “medium” quality concrete, strength assessment was supported by collateral data or core testing.

The following tests were conducted :

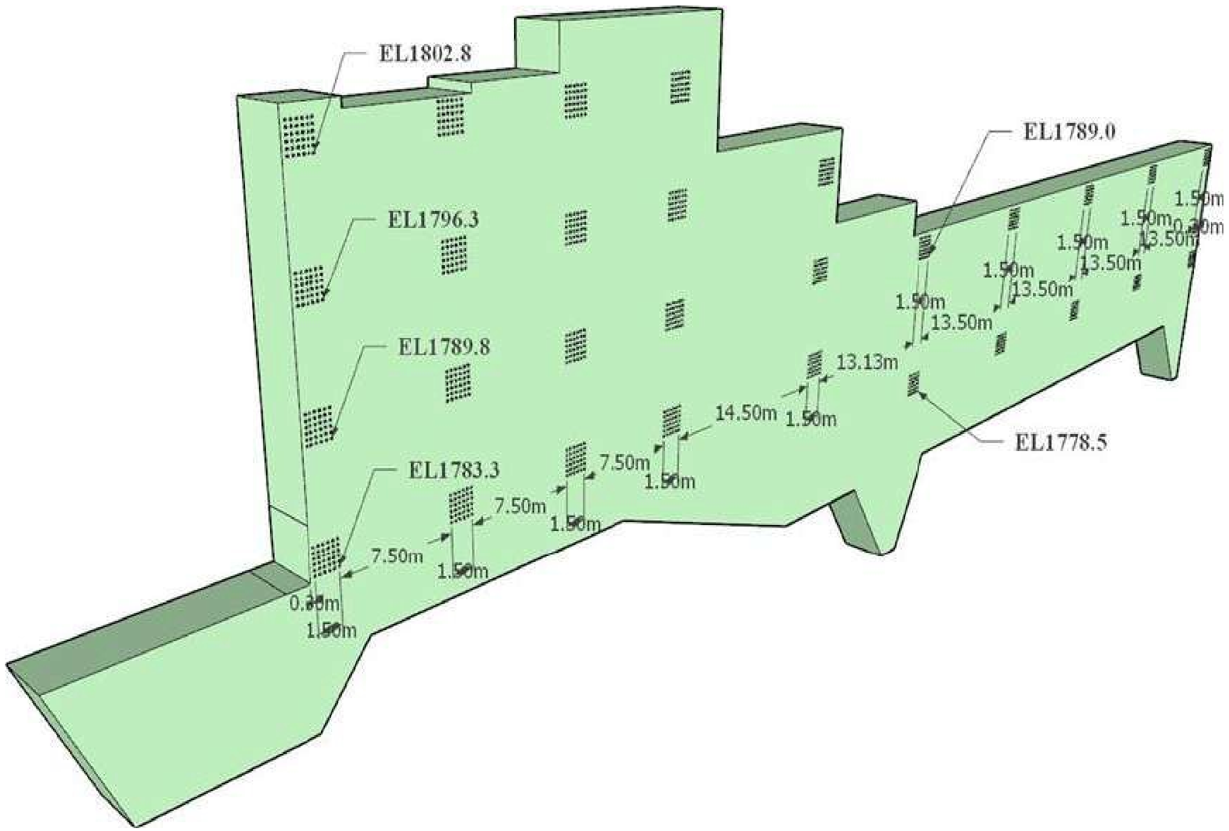
- Ultrasonic Pulse Velocity (UPV) test
- Rebound Hammer Number (RHN) test
- Low Strain Pile Integrity Test (PIT)
- GPR for concrete cover and rebar profiling
- Concrete core extraction

INCOLD

CENTRAL BOARD OF IRRIGATION & POWER ESTD. 1927 NEW DELHI

Ultrasonic Pulse Velocity Test (UPV)

- Measurement of Ultrasonic pulse velocity has been carried out in a systematic way of marking grid points on the concrete surface to 300 mm x 300 mm center to center spacing, both in vertically and horizontally directions (Fig. 4).
- The direct method of UPV test was carried out in accessible locations and in a few locations, the in-direct method of testing was done.
- Based on UPV, the Concrete quality present in the structure in terms of integrity was found satisfactory.



Typical Test locations showing grid points for UPV & RHT in Barrage

Rebound Hammer Tests

- A rebound hammer test was conducted at the same grid points where the ultrasonic pulse velocity (UPV) test was performed to ensure correlation of results.
- The rebound hammer testing was carried out in the horizontal direction in accordance with standard practice.
- Additional rebound hammer tests were performed on concrete cubes available at the site for comparative assessment.
- The rebound hammer test results at all tested locations were found to be within the acceptable range, indicating satisfactory surface hardness and uniformity of concrete.

Low Strain Pile Integrity Test

- Low Strain Pile Integrity Test (PIT) was used to assess continuity and integrity of pile-like structures
- PIT provides indication of defects such as cracks, necking, and section changes
- Test is quick, simple, and suitable for multiple locations
- Tests conducted at several locations in piers and breast walls.
- PIT results indicated satisfactory concrete integrity in Barrage piers.
- Concrete integrity suspected in breast walls where multiple cracks were present

Fig. 5. Typical Measurement of RHT, PIT & Rebar Profile using GPR

Ground Penetrating Radar (GPR) & Concrete Core Extraction

- Concrete cover is critical for durability of RCC structures.
- Ground Penetrating Radar (GPR) used to map rebar profile.
- GPR used to locate exact rebar positions to avoid cutting during concrete core extraction.
- Core samples collected randomly from various structures to assess concrete strength.
- Results corrected for h/d ratio and converted to equivalent cube strength.
- Acceptance checked as per IS 456:2000 criteria.
- Core test results confirmed concrete strength meets design requirements.

Concrete Core Extraction for Compressive Strength:

- Core samples collected randomly from various structures to assess concrete strength.
- GPR used to locate rebars and avoid cutting during coring.
- Results corrected for h/d ratio and converted to equivalent cube strength.
- Acceptance checked as per IS 456:2000 criteria.
- Core test results confirmed concrete strength meets design requirements.

Fig. 6. Typical Extraction of Concrete Core Samples from Barrage Pier

INCOLD

CENTRAL BOARD OF IRRIGATION & POWER ESTD. 1927 NEW DELHI

MAJOR FINDINGS:

- Visual inspection showed extensive damage and scrambling of dowel bars.
- Major components such as bridge deck, radial gates, and breast walls were washed away.
- NDT results indicate that the remaining dam structures are repairable.
- Appropriate repair procedures and methodologies were developed.
- Suitable repair materials and their specifications were identified.
- It is recommended to recheck breast wall concrete integrity using UPV testing after completion of grouting works.

General Considerations for Concrete Repair

- Durable repair requires a holistic approach covering material selection, surface preparation, application method, workmanship, and inspection.
- Compatibility of repair material with existing concrete is the most critical factor.
- Dimensional compatibility is essential to prevent cracking and premature failure.
- Repair material properties must be evaluated with respect to placement and service conditions.
- Geometry, access, temperature, and moisture during repair influence repair strategy.
- Service conditions such as temperature variation, chemical exposure, appearance, and design life must be considered.

INCOLD

ESTD. 1927 NEW DELHI

General Considerations for Concrete Repair (contd.)

- Repair materials should have properties close to the parent concrete.
- Excessively high-strength materials may cause high heat of hydration and drying shrinkage.
- Higher-strength materials are desirable for erosion-damaged zones.
- Modulus of elasticity should be comparable to ensure uniform load transfer.
- Higher thermal expansion of repair material can lead to cracking and delamination.
- Strong bond with existing concrete is essential; polymer bonding agents are preferred.
- Repair material should be shrinkage-controlled.

INCOLD

CENTRAL BOARD OF IRRIGATION & POWER
ESTD. 1927
NEW DELHI

Selection of Repair Material & Restoration Works:

Recommended repair and strengthening materials for the Barrage complex

- Epoxy resin bond coating
- Rebar rust remover
- Anti-corrosive coating for rebars
- Micro-concrete
- Chemical adhesive for rebar anchorage
- Epoxy grouting

Selection of Repair Material & Restoration Works (contd.):

Suggested repair and strengthening measures based on inspection and test results:

- Restore breast wall integrity using epoxy grouting.
- Extend reinforcement by drilling into parent concrete and fixing rebars with chemical grout.
- Rebuild concrete sections up to 100 mm thickness using micro-concrete.
- Re-cast damaged intake trash rack damaged columns with original concrete grade.
- Apply bond coat prior to placing new concrete or micro-concrete.
- Rebuild concrete up to 50 mm thickness using shotcrete.
- Fill cracks and voids by grouting.
- Restore severely damaged reinforcement using crimped/bolted couplers (IS:16172), Rebaring or K-welding (IS:9417).

CONCLUSIONS :

- Integrity testing and alignment survey planned after the incident
- NDT and partially destructive tests conducted on Barrage complex structures
- Alignment survey confirmed RCC structures were undisturbed
- Concrete integrity found satisfactory for Barrage, bridge decks, intake, and desilting structures
- Breast wall integrity found unsatisfactory
- All structures assessed as reparable
- Repair methodology and suitable materials finalized based on testing results

THANK YOU