INCOLD
Indian National Committee on Large Dams

INTERNATIONAL DAM SAFETY CONFERENCE

Dam Rehabilitation & Improvement Project

Central Water Commission

DEALING WITH LARGE LATERAL FORCES DUE TO CREEPING SLOPE

A CASE STUDY OF SHONGTONG KARCHAM HEP (450 MW), HP

Authors:

N. S. Shekhawat, Director, Central Water Commission

M.S. Harshitha, Deputy Director, Central Water Commission

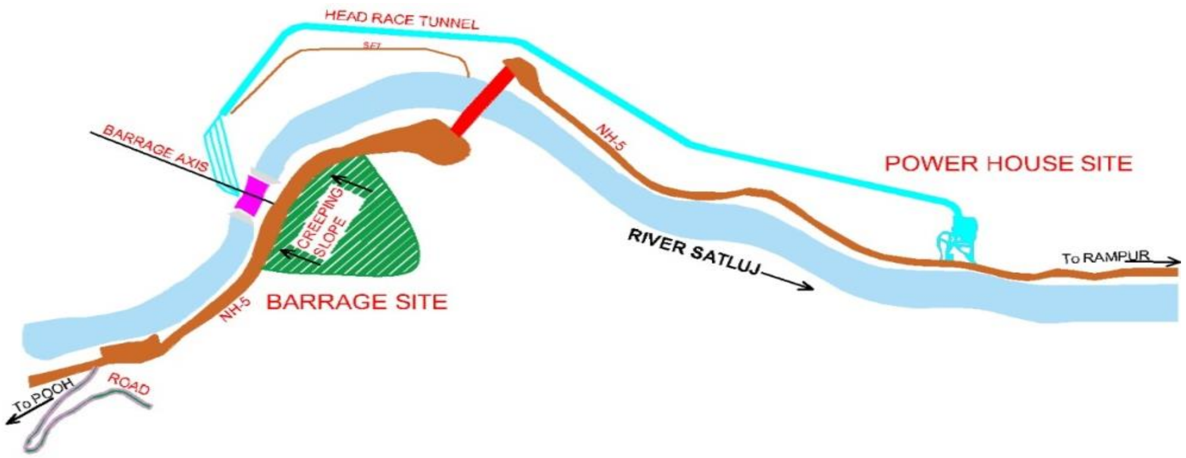
Amir Suhail, Assistant Director, Central Water Commission

CONTENT

- INTRODUCTION
- PROBLEM STATEMENT
    - CREEPING OF RIGHT BANK SLOPE AT BARRAGE AXIS
- CONCEPT OF DEALING THE LARGE CREEPING FORCES THROUGH STRUCTURE ITSELF
- OBSERVATIONAL APPROACH OVER THE CONVENTIONAL ONE
- DEVISING SUITABLE STRUCTURAL ARRANGEMENTS AND ARRIVING AT CONCEPT DESIGN
- ADOPTED STRUCTURAL AND NON-STRUCTURAL INTERVENTIONS
- CONCLUSIONS

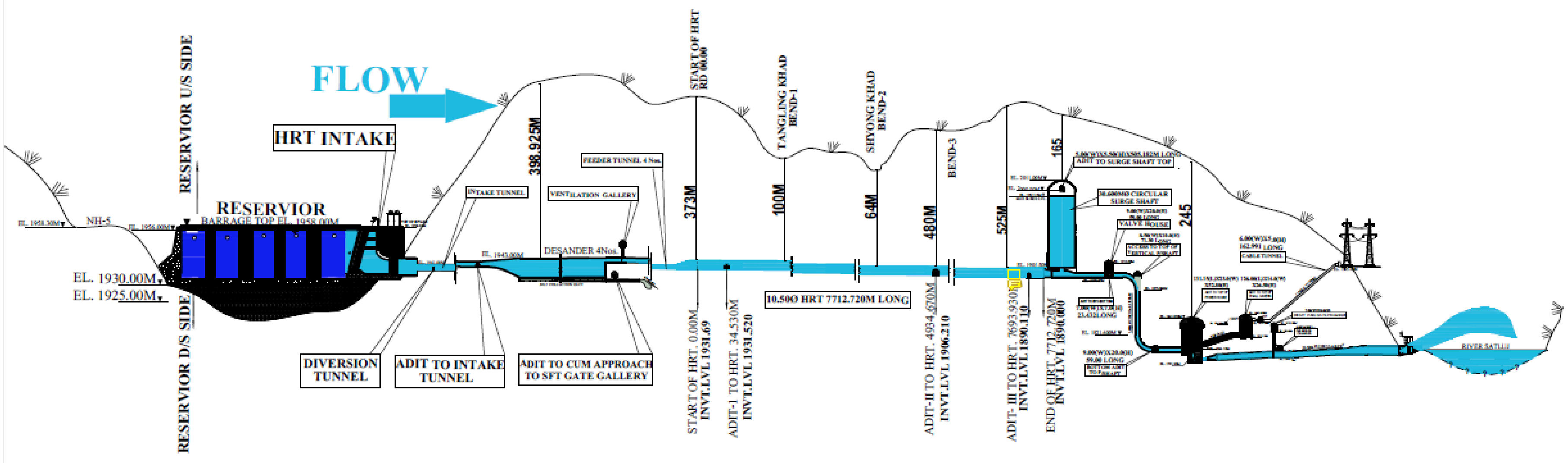
Introduction

- Shongtong Karcham Hydroelectric project is a run-of-river project being executed by M/s HPPCL on River Satluj in Kinnaur district of Himachal Pradesh
- Diversion Structure has been envisaged as a Barrage
- The diverted water is to be conveyed through a 7.7 km long and 10.5m finished diameter Head Race Tunnel (HRT).
- The project envisages Underground De-silting Basin and an Underground Surge Shaft
- An Underground Powerhouse having 3 vertical axis Francis Turbines of 450 MW installed capacity is envisaged

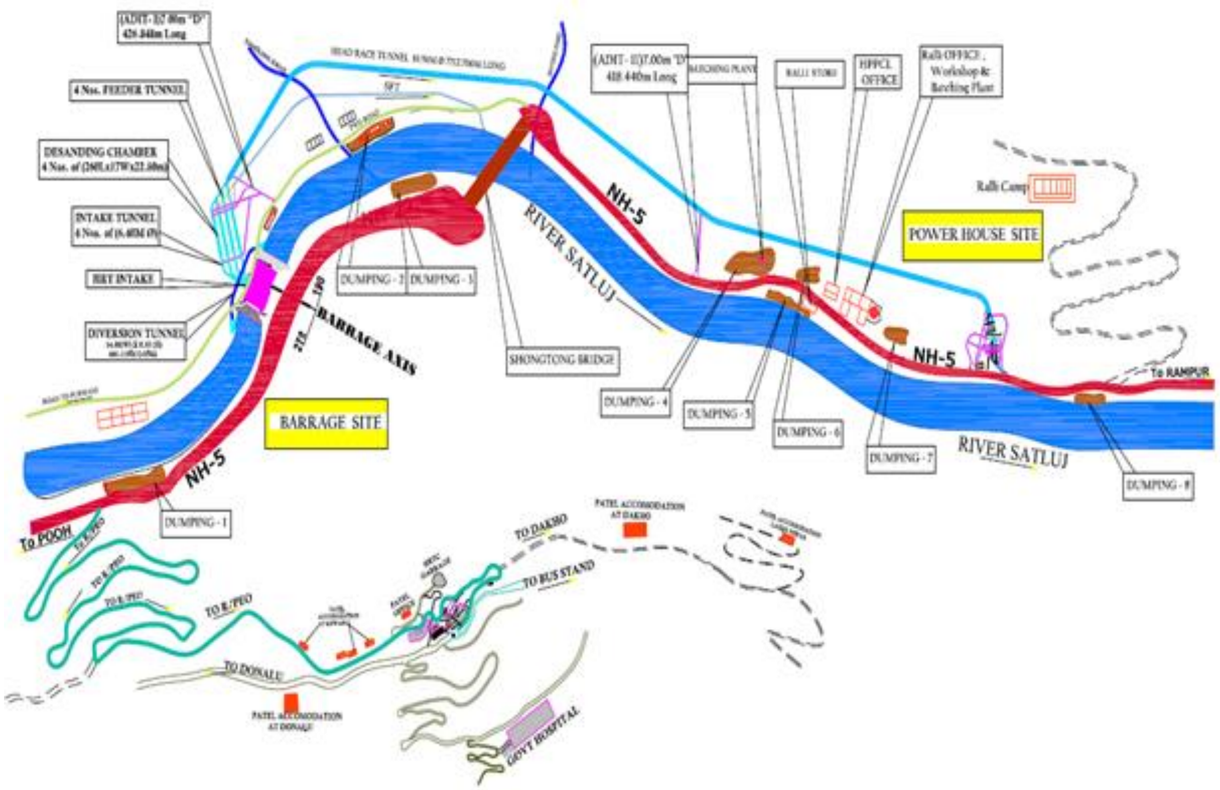


Creeping on the right bank slope of the barrage posed serious challenges in taking up the construction of the barrage.

L- Section through Water conductor System



CONSTRUCTION STATUS OF THE PROJECT



- River diversion works (Diversion Tunnel, U/s & D/s Coffer Dams) have been completed and river is already diverted
- Excavation of Feeder Tunnel is completed
- Excavation of De-silting Chambers is in progress
- HRT excavation is in progress with heading excavation is completed & benching excavation is in progress
- Excavation of Surge Shaft has been completed
- The excavation of Transformer Hall Cavern has been completed and Power House Cavern is also near completion

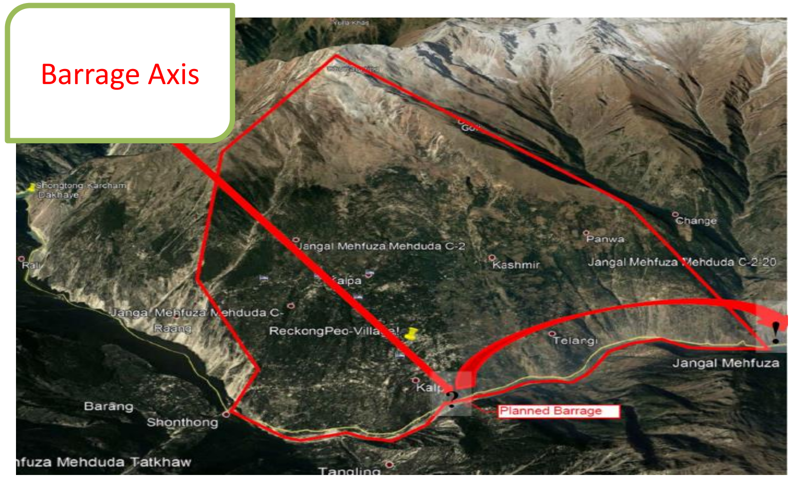
PROBLEM STATEMENT

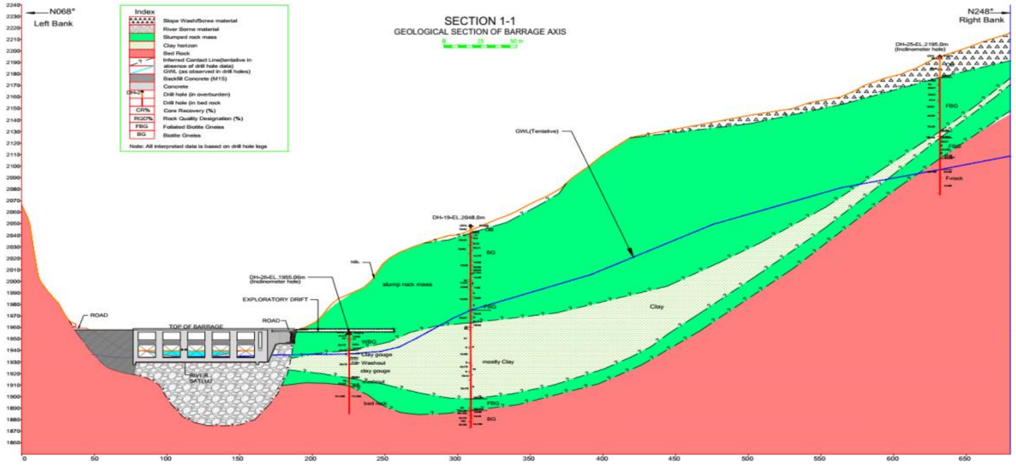
Geology of Right Bank Slope

As per Detailed Project Report (DPR):

- The right abutment is covered with thick slope wash deposits and slumped rock mass up to NH-5 and fluvial deposits & slope wash below it
- However, few isolated rock exposures are observed on right bank upstream u/s of Barrage axis at road level and above
- No concern and measures regarding stabilization of right bank slope have been addressed at DPR stage.

CREEPING RIGHT BANK SLOPE AT BARRAGE AXIS





Extent of The Creeping Slope:

- The slide mass is more than 1km wide at the top and flares to 3km at the river edge
- Slide mass is estimated around 80 m deep near toe and for higher reaches the its depth may exceed 200 m

CREEPING OF RIGHT BANK SLOPE AT BARRAGE AXIS

To define the creeping/sliding rate(s) and the extent and size of the moving slope mass the detailed geotechnical investigations of Right Bank is done by HPPCL, which includes but not limited to

- Boreholes, Exploratory drift, electrical tomography, laboratory tests
- Photo documentation of slope by remote sensing method (by LIDAR)
- Surface movement monitoring (SMM) i.e. high precise satellite based measurements by Airbus
- Inclinometer measurements by 5 inclinometers at different locations

Inclinometer DH-25, Barrage axis at El. 2195

Period	Observation (days)	Displacements (mm)	Displacement Rate (mm/month)	Displacement Rate (mm/year)
1.3.18-16.7.18	138	25	5.4	66.1
16.7.18-15.7.19	365	11	0.9	11.0
1.3.18-15.7.19	**503**	**36**	**2.2**	**26.2**
15.7.19-9.12.19	148	21	4.3	51.8
1.3.18-9.12.19	**651**	**57**	**2.6**	**32.0**

Inclinometer DP-101C, D/S of stilling basin, at El. 1952

Period	Observation (days)	Displacements (mm)	Displacement Rate (mm/month)	Displacement Rate (mm/year)
1.3.18-16.7.18	138	80	17.4	211.6
16.7.18-15.7.19	365	6	0.5	6.0
1.3.18-15.7.19	**503**	**86**	**5.2**	**62.4**
15.7.19-9.12.19	148	67	13.6	165.2
1.3.18-9.12.19	**651**	**153**	**7.1**	**85.8**

Period	Observation (days)	Displacements (mm)	Displacement Rate (mm/month)	Displacement Rate (mm/year)
1.3.18-16.7.18	138	30	6.5	79.3
16.7.18-15.7.19	365	26	2.1	26.0
1.3.18-15.7.19	**503**	**56**	**3.4**	**40.6**
15.7.19-9.12.19	148	30	6.1	74.0
1.3.18-9.12.19	**651**	**86**	**4.0**	**48.2**

Inclinometer DH-26, Barrage axis, El.1954

Period	Observation (days)	Displacements (mm)	Displacement Rate (mm/month)	Displacement Rate (mm/year)
1.3.18-16.7.18	138	35	7.6	92.6
16.7.18-15.7.19	365	40	3.3	40.0
1.3.18-15.7.19	**503**	**75**	**4.5**	**54.4**
15.7.19-9.12.19	148	35	7.1	86.3
1.3.18-9.12.19	**651**	**110**	**5.1**	**61.7**

Inclinometer DP-106C, U/S of intake area, El.1958

Period	Observation (days)	Displacements (mm)	Displacement Rate (mm/month)	Displacement Rate (mm/year)
1.3.18-16.7.18	138	10	2.2	26.4
16.7.18-15.7.19	365	27	2.2	27.0
1.3.18-15.7.19	**503**	**37**	**2.2**	**26.8**
15.7.19-9.12.19	148	10	2.0	24.7
1.3.18-9.12.19	**651**	**47**	**2.2**	**26.4**

Inclinometer DP-108C, far upstream, El.1962

Alternatives explored by HPPCL to deal with the Creeping Issue:

1. Shifting of barrage complex upstream made this alternative economical unviable due to
   1. Connecting/altering the already constructed water conductor system
   2. Changes in operational conditions of the project
2. L-shaped right bank stabilization wall with deep (~55m) anchorage onto a rock which got ruled out on account of structural competency
3. Usage of a heavy set of soil anchors/cable anchors for slope stabilization which again got ruled out due to uncertainty in its competency to stabilize such large slope
4. Redesigning of barrage complex to sustain the creeping force and to transfer these loads onto competent left bank

After deliberating the pros and cons of each of the alternatives and seeing the uncertainty in quantifying the creeping forces; an observational method for a suitably modified alternative was finally adopted

CONCEPT DESIGN TO DEAL THE CREEPING FORCES THROUGH STRUCTURE ITSELF

OBSERVATIONAL APPROACH OVER THE CONVENTIONAL ONE

- The observational approach is generally applied when the magnitude of force acting on the structure is uncertain and the conservative assumptions leads to unreasonably high structural costs
- In observational approach certain mitigation measures are planned during the design phase to implement in the structures. These measures do not necessarily cover the worst case; hence the effect of the measures must be monitored after completion of the works
- In case the observed behavior of the structure is not at par with the envisaged one, the additional predefined mitigation measures will be required

Observational Approach

APPROACH ADOPTED

Involved Panel of Experts (PoE) from diverse fields

Major questions answered :

- *Necessity/cost-effectiveness of a full proof remedy?*
- *Extent to which the uncertain creep forces need to be addressed?*

Evolved over time (2018-2020)

HPPCL agreed to adopt the **Observational Method**

Step 1
Estimate/predict creeping force

Step 2
Devise/design structural measures before completion of project

Step 3
Prepare mitigation plans for future

Estimation of Creeping Forces

Methodologies adopted to estimate the creep load for the concept design:

Analytical methods for assessing creep

- Brandl & Dalmatiner: The method is on the assumption that deep-seated sliding planes are forced by stabilization structure to be rearranged within the following months and years after completion of the structure. The sliding/failure plane tends to move upward after getting resistance from the structure and eventually comes over and above the structure over time, provided the structure is designed to show rigidity.
- Rheological considerations: The effect of the toe cutting and thereafter resistance required to bring the creep velocity to its original value is studied.

Results of Design Creep Load Summary Calculated by Different Design Approaches for Barrage and Stilling Basin

Design Philosophy	Structural Component (MN/m)		Remarks
	Barrage	Stilling Basin	
Earth Pressure at Rest	7.1	7.1	Considering the angle of internal friction, ϕ = 35^0
Brandl Approach	12.9	12.9	Assuming rigid wall
Toe Resistance	3.29	6.37	Considering the angle of internal friction, ϕ = 35^0
Rheological Approach	3.85	12.0	Assessed creep rate before and after excavation : (a) Barrage and apron area: 48mm/yr and 73.4mm/yr (b) Stilling basin: 86mm/yr and 324mm/yr
Design Creep Force	**17.5**	**19.4**	With factor of Safety (1.35 & 1.5 respectively)

- The resistance forces obtained from Rheological calculations are comparatively less than that obtained using Brandl theory
- Max pressure from above is considered for the design
- Factor of Safety further applied for barrage and stilling basin is 1.35 and 1.5 respectively

Estimation of Creeping Forces

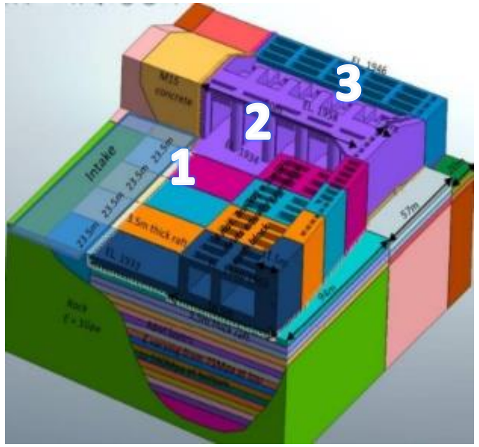
Parameter	Upstream Apron Area	Barrage	Stilling Basin
Un-Factored Design creep load E_b(MN/m)	12.9 – 15.5	12.9	12.9
F1	1.2	1.35	1.5
Factored Design creep load E_d(MN/m)	-	17.5	19.4
Factored Design creep pressure ρ_h(E_d/H)(kPa)	**220-700 (Trapezoidal)**	**630 (Uniform)**	**690 (Uniform)**

Devising suitable Structural Arrangements and arriving at The Concept Design

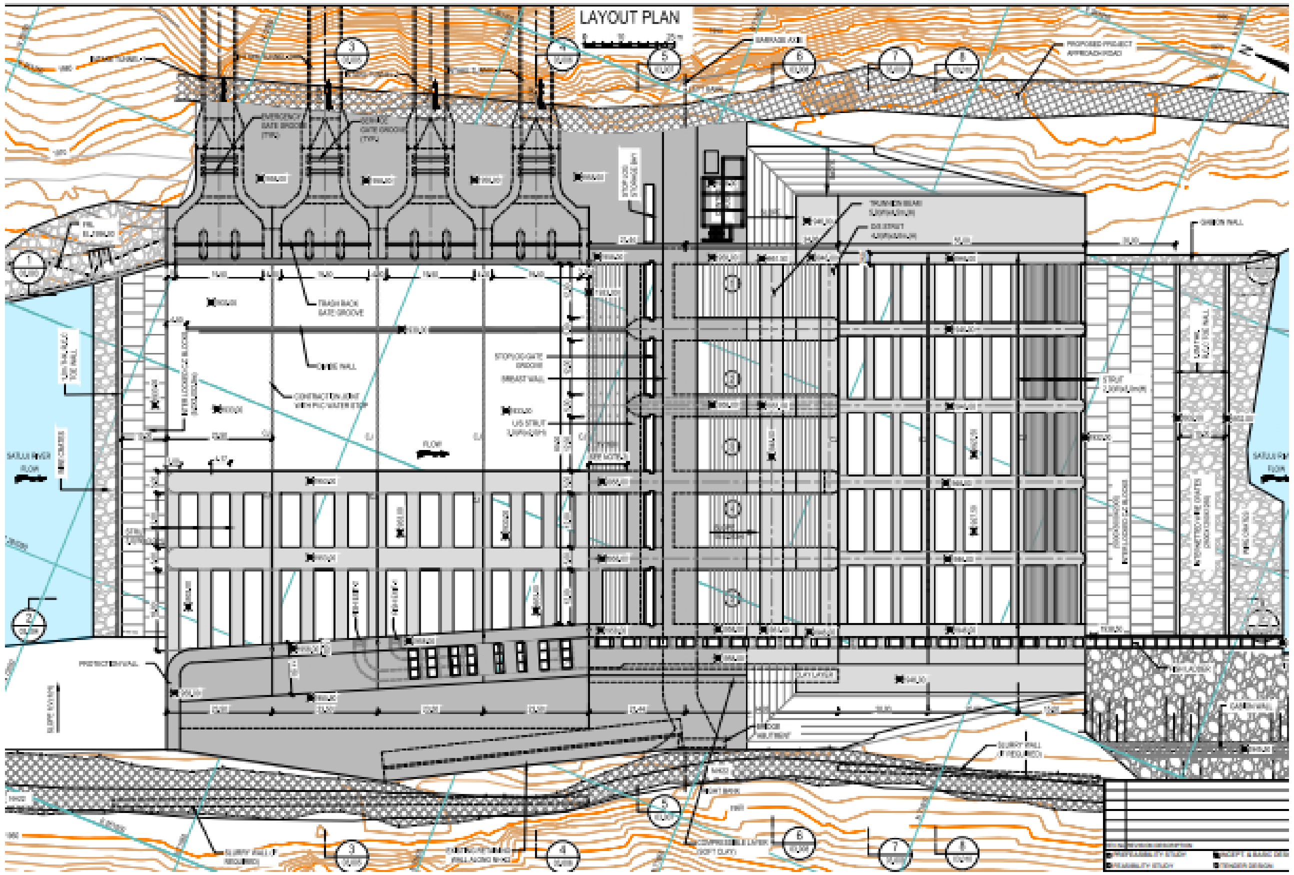
- Modification in the existing structural arrangements of barrage components to make them capable of safely transferring such large creep forces
  - To the left bank
  - To the Foundation
  - To ensure minimum interference in the hydraulics of the flow
- With the design approach and forces in hand, numerical analysis of the barrage complex was carried out in 3 parts using MIDAS FEA-NX. 3D model of barrage complex along with foundation rock mass was developed.

Description of FEM models

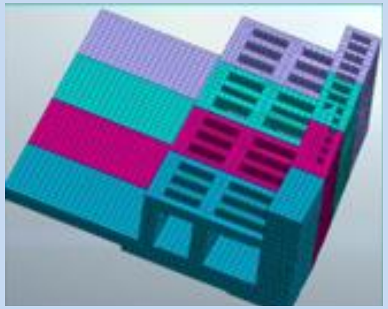
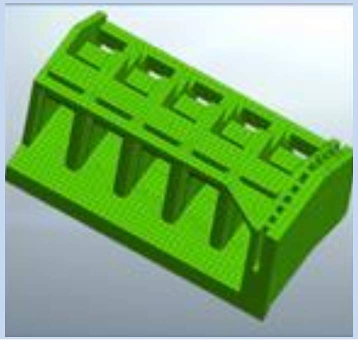
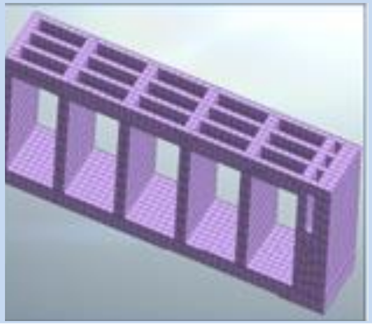
Three separate FEM models each for the apron floor (1), barrage (2) and stilling basin (3) with the corresponding foundation were developed and analyzed. Foundation for each part was modelled as per the geometry of the river profile and soil mass parameters in those regions (modelled in segments with varying moduli of elasticity along the depth). Interface elements between raft and foundation were defined using normal and stiffness parameters estimated between barrage and the overburden material (alluvium). Various loads considered were pressure loads (hydrostatic load, creep and uplift), point/concentrated load (to model gate structures) and seismic load.



Adopted Structural Interventions



Devising suitable Structural Arrangements and arriving at The Concept Design

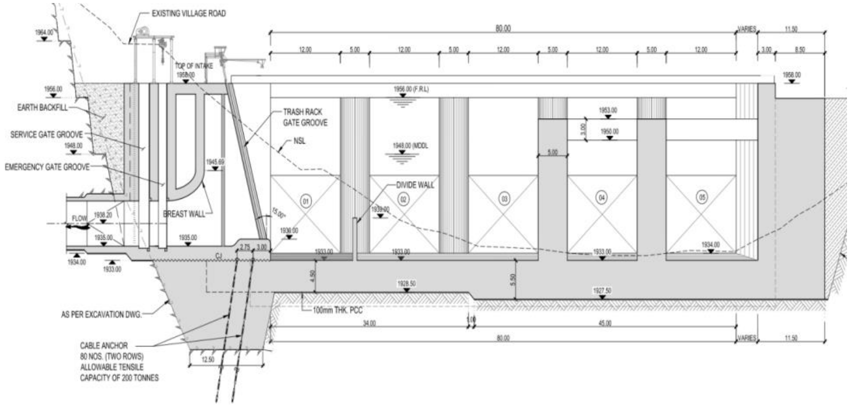
Load combinations analyzed		
1. Apron Floor (Intake area)	2. Barrage Structure	3. Stilling Basin Structure
		
a. End of construction: Self-weight + creep pressure b. Normal operation with uplift + creep pressure c. Normal operation with uplift + creep pressure+ Seismic d. End of construction: Self-weight e. Normal operation without uplift + creep pressure f. (Besides above, sudden drawdown condition for silt flushing operation is checked for u/s apron-intake area)	a. End of construction: Self-weight + creep pressure b. Normal operation with uplift + creep pressure c. Normal operation with uplift + creep pressure+ Seismic d. End of construction: Self-weight e. Normal operation without uplift + creep pressure	a. End of construction: Self-weight + creep pressure b. Normal Operation+ creep pressure + uplift c. Normal Operation+ creep pressure + uplift + Seismic d. End of construction: Self-weight

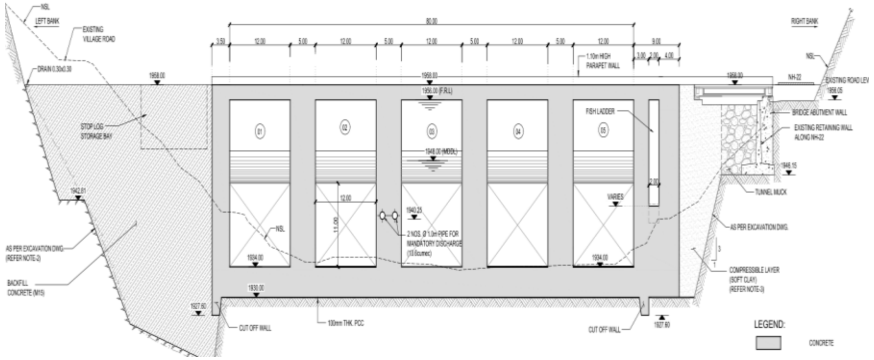
Adopted Structural and Non-Structural Interventions

Structural Interventions in Barrage Complex

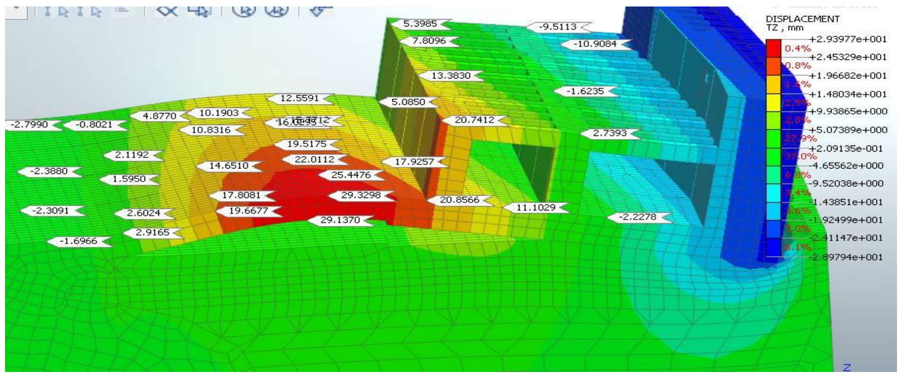
- Semi-gravity wall in the right bank is proposed as the primary retaining structure against the creep forces
- Divide walls of bay no 4 & 5 is extended upstream in Intake area
- Floor thickness of apron floor is substantially increased
- Right bank semi-gravity wall along with struts, divide wall and floor raft acts as box structure
- The increased weight of these divide walls turn out to be supportive against uplift forces during sudden drawdown
- Cable anchors are proposed to counter the uplift forces on power intake during sudden drawdown
- Introduction of concrete (continuous) struts (2mx3m) in the form of breast wall, monolithic trunnion beam and monolithic bridge over spillway piers spanning across the barrage and stilling basin structures proposed without affecting the hydraulics
- Backfill concrete of minimum M15 grade is proposed to support the transfer of loads between the structures and the rocks

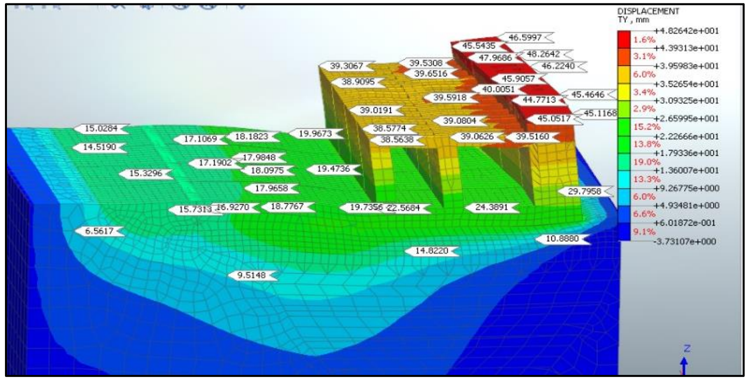
Adopted Structural Interventions





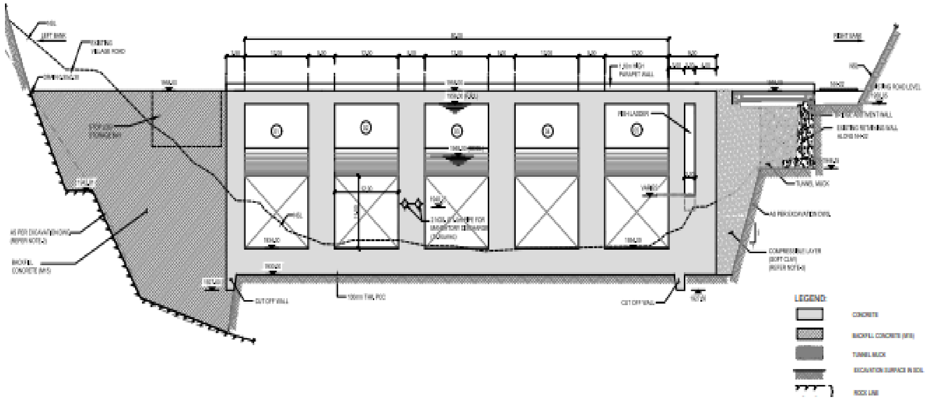
Cross section of Apron and Barrage area showing proposed structural and non-structural measures

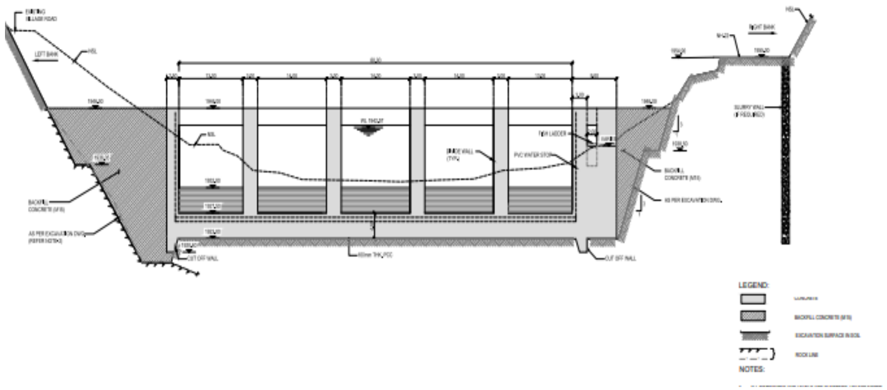




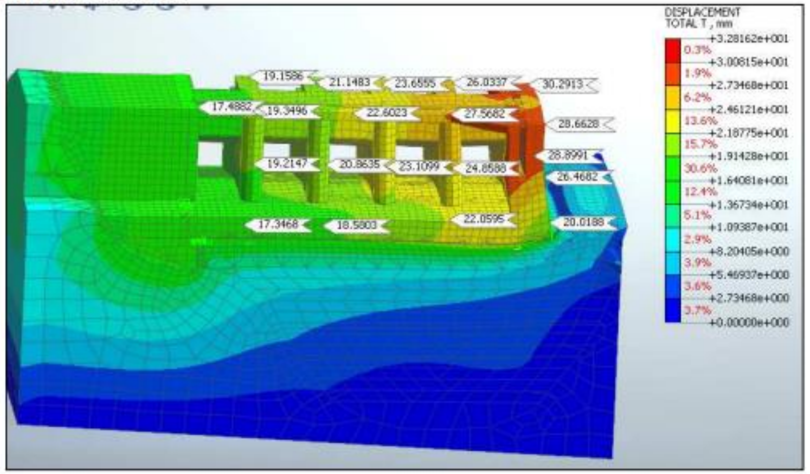
Vertical and lateral deformation in Apron area

Adopted Structural Interventions

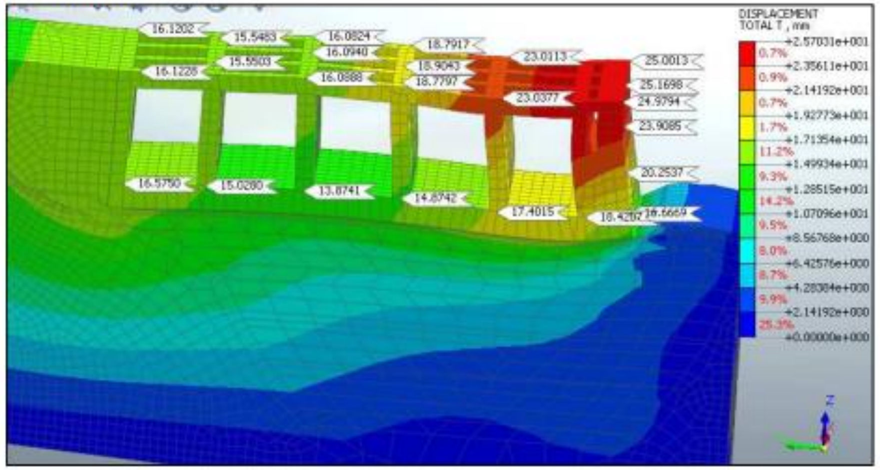




Resultant deflection



Resultant deflection

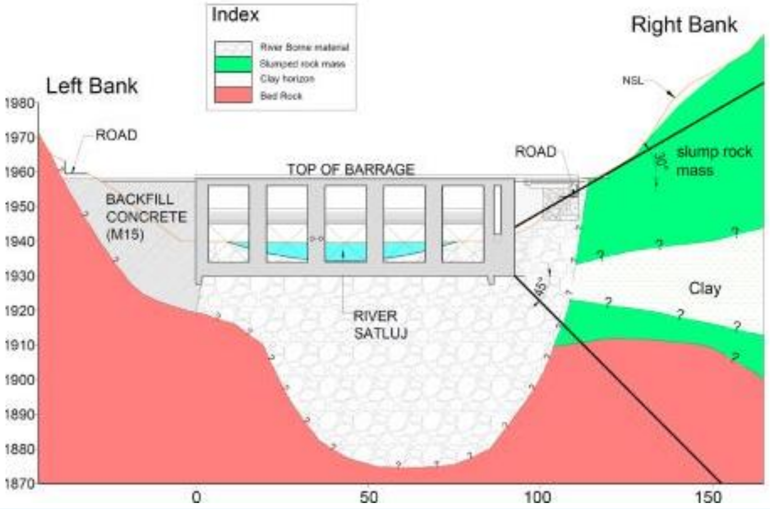


Resultant Deflection in Barrage and Stilling Basin Structures

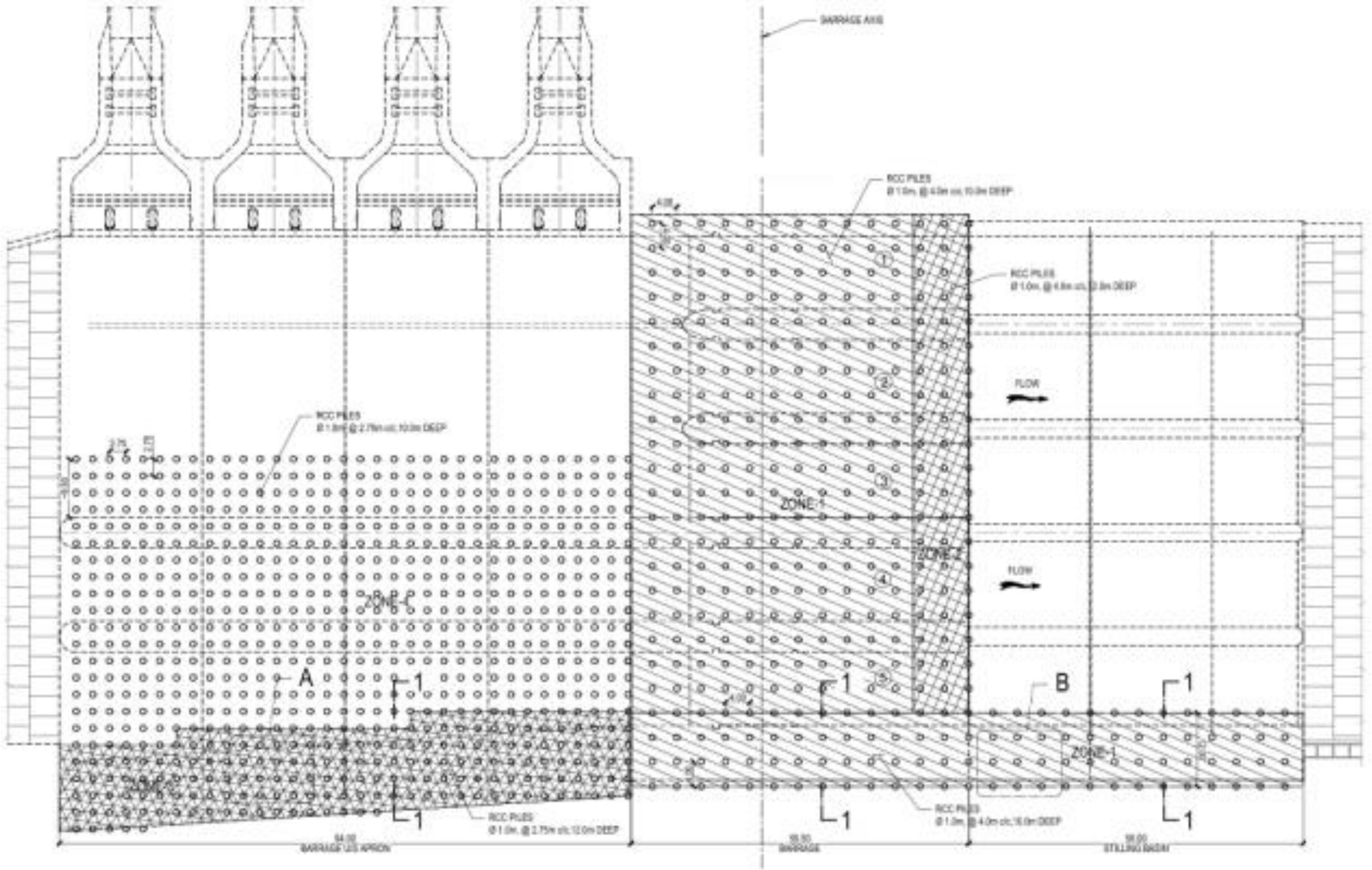
Adopted Structural Interventions

Structural Interventions in foundation and ground improvement

- Results of numerical analysis reflected that the adopted structural form transfers the lateral loads to left bank partially and a portion of this load is transferred through the foundation in regions that are to the right side of barrage complex.
- Due to the **low safe bearing capacity (SBC~20ton/m^2)** of river-borne material at the barrage site following foundation/ground improvement measures were suggested:
    - ❑ Skin friction piles in intake area, barrage and stilling basin
    - ❑ Friction piles in right bank area of the entire barrage complex
- Cement soil bedding layer proposed after excavation of riverbed material up to a depth of 1 m is proposed
- Use of mechanically compacted graded riverbed material is proposed after replacement of 2 to 3 m thick layer of foundation stratum
- Consolidation grouting of RBM foundation strips proposed with cement grout by confinement of strip with concrete cut-off

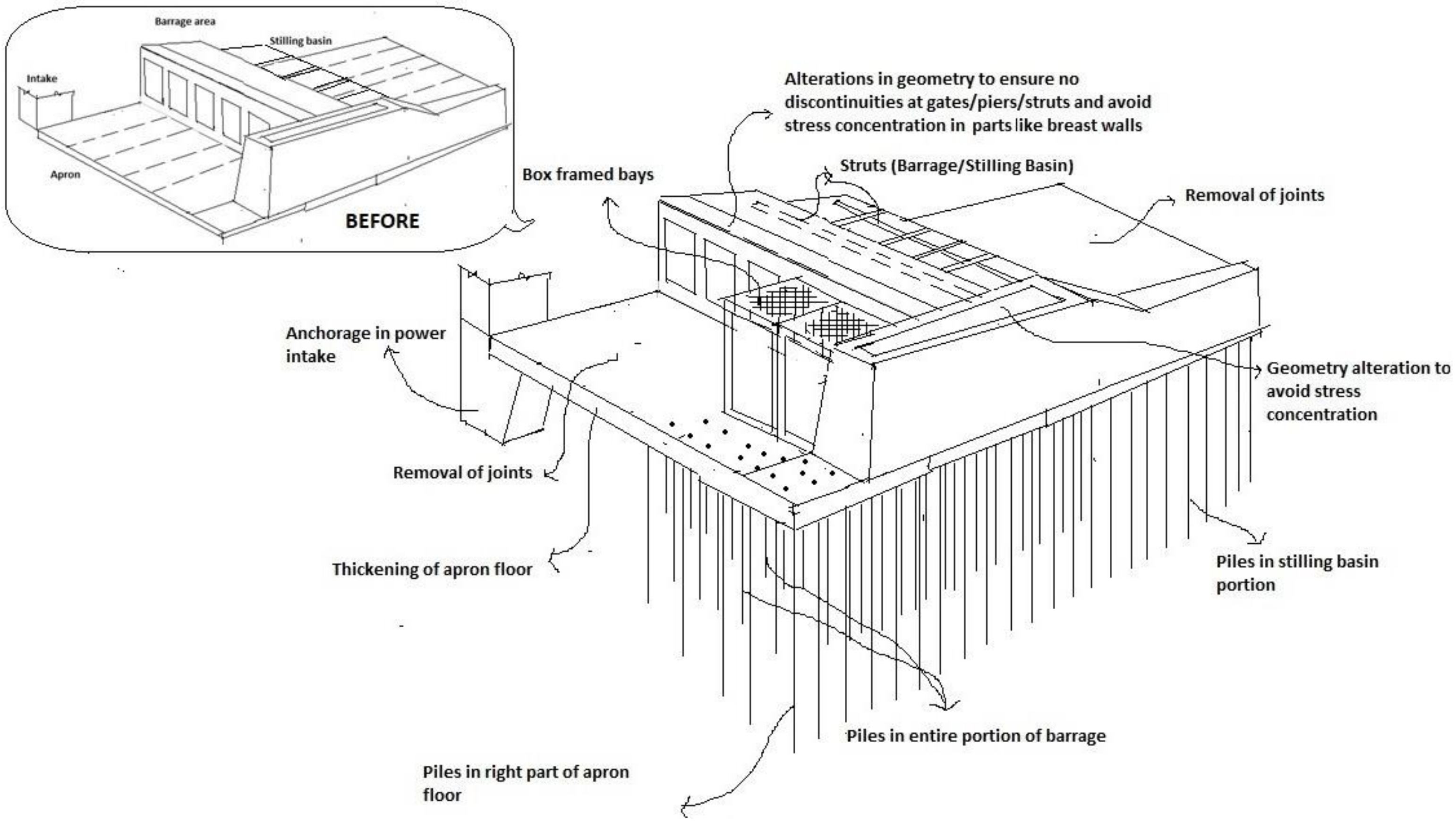


Adopted Structural Interventions



Layout of foundation (friction piles) suggested for barrage complex

Adopted Structural Interventions

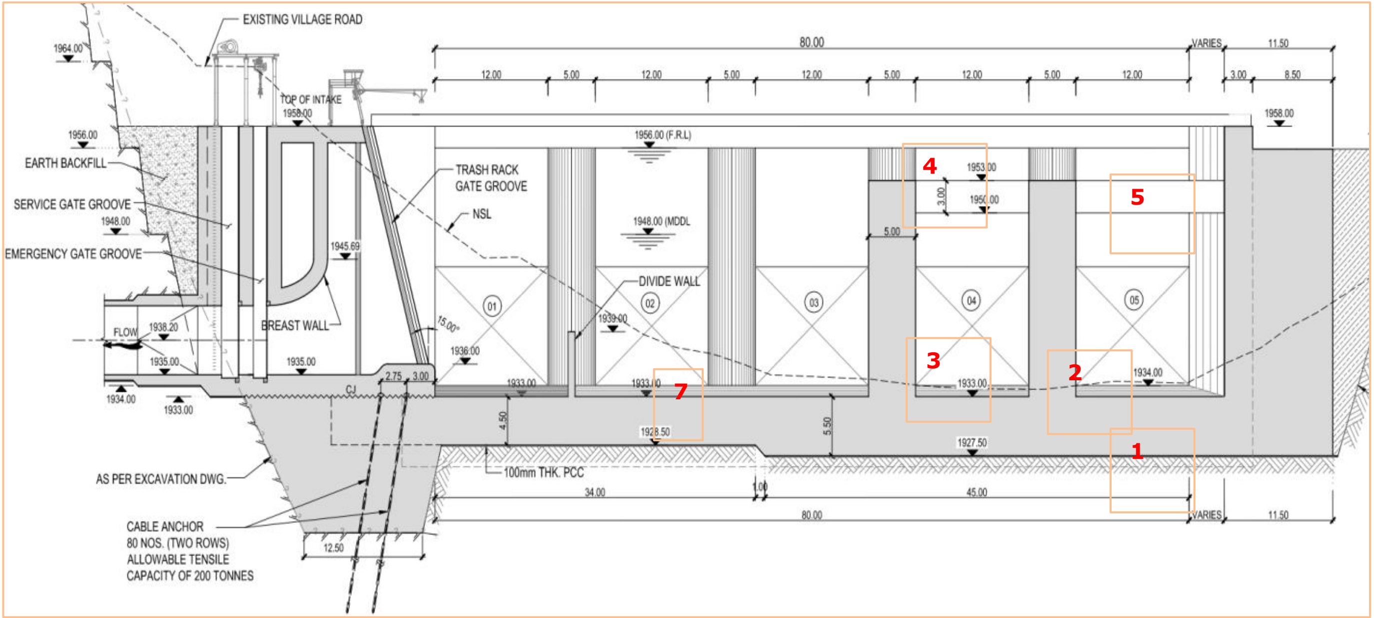


Schematic of the structural form of barrage complex finally adopted

Non-Structural Interventions- Continuous Observation

Non-structural measures

- Construction of an observation block at the right bank to monitor creeping, if any, for 6-12 months which will be integrated into the barrage complex later on
- Pre-defined points for instrumentation in areas of intake, barrage and stilling basin (as shown below in red) identified for monitoring as part of the observational approach



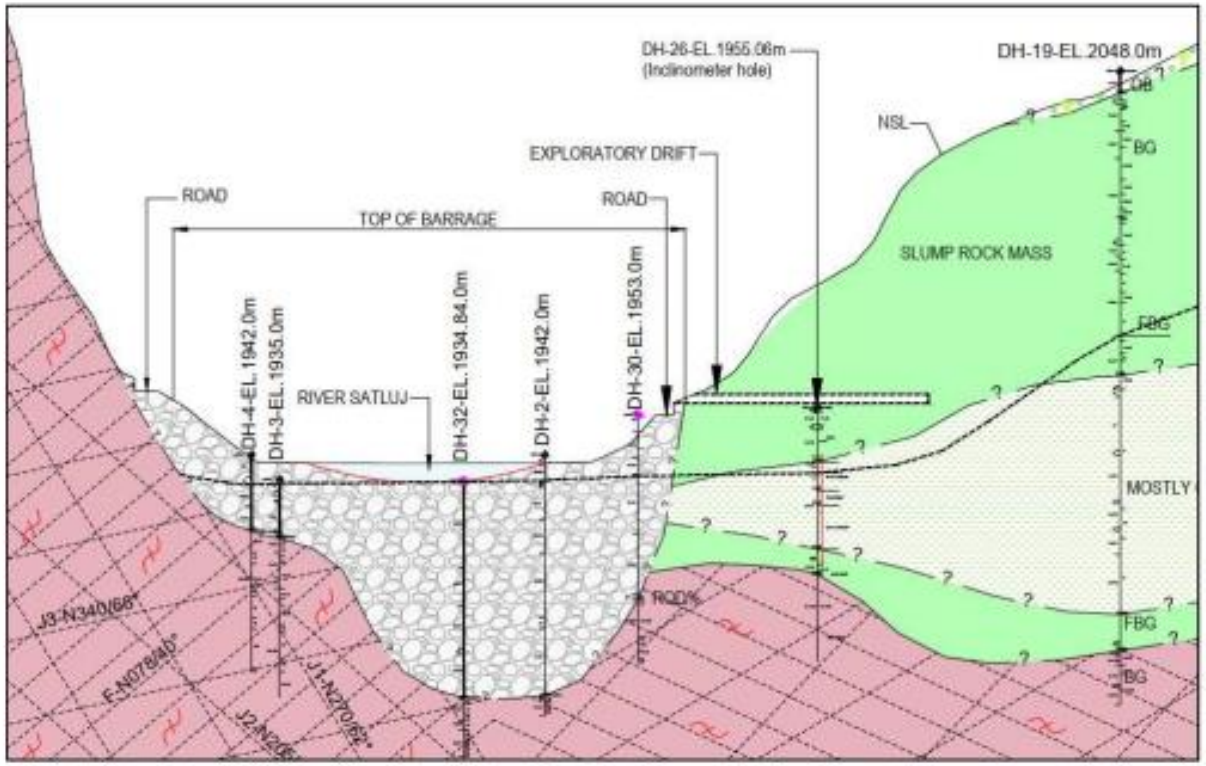
Suggested Non-Structural Interventions

1. Provision of a compressible soft clay backfills behind the earth retaining structures to allow for some additional deformations (and hence reduction in creep load)
2. Provisions of additional mitigation measures for future in case of unexpected behavior of the structures (excessive displacements, overstressing etc.) is observed
   I. Placing of prestressed anchors
   II. Strengthening of the concrete structures
   III. Implementation of slurry trench walls between the structures and the hillside, etc.

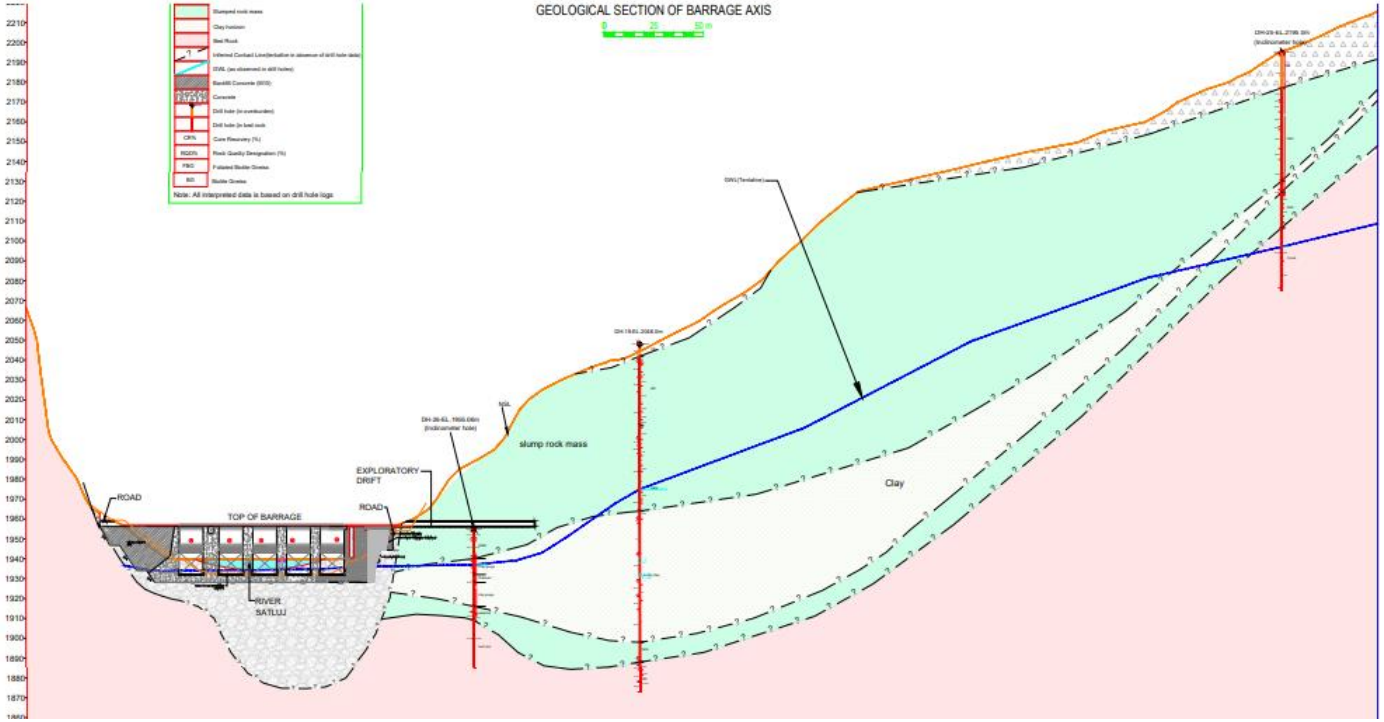
CONCLUSIONS

1. Conventionally designed barrage (which was not designed for any lateral load) is now capable to withstand lateral forces of the order of 17-19MN/m
2. The observational approach (A mix of structural and non-structural measures) is recommended
3. A stiffer barrage complex with the addition of continuous struts, divider walls, attached gravity walls and continuous/thicker floors, etc. has finally been arrived at
4. Structural forms for different components of the barrage complex to transfer heavy creeping force from the creeping right bank to the competent left bank have been recommended
5. Foundation improvement methods are also devised and recommended for the otherwise less competent foundation strata
6. Construction methodology and monitoring measures to suit the adopted observational approach are recommended
7. Alternative so developed is believed to lead to faster commissioning of the project

Thank you !



As per geophysical report conducted at site, following modulus of elasticities are obtained:


GEOLOGICAL SECTION OF BARRAGE AXIS
Note: All interpreted data is based on drill hole logs
slump rock mass
Clay
EXPLORATORY DRIFT
ROAD
TOP OF BARRAGE
ROAD
RIVER SATLUJ