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Case Study on Fracture Treatment in Dam Foundation

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ABSTRACT: This case study presents Investigation, Structural Analysis and further Treatment of a fracture encountered in the foundation of a dam. The concrete gravity dam in subject is 38m high above deepest foundation level. This dam is approx. 400m long with 21 number blocks with 15 NOF blocks. In the geological mapping of the dam foundation, shear crack/ fracture (suspected fault) of thickness 10-30 cm reported to be stretching in 5 blocks. Based on field investigations and FEM modelling treatment was proposed and executed.

KEYWORDS: Dam Foundation, Fracture, Shear crack, Investigation, Treatment.

I. INTRODUCTION

This case study presents investigation, structural analysis and further treatment of a fracture zone encountered in the foundation of a dam. The concrete gravity dam is 38m high above deepest foundation level. This dam is approx. 400m long with 21 number blocks with 15 NOF blocks.

Storage of the reservoir of this dam shall be utilized for supply of water for irrigation, drinking purpose and Thermal Power Projects. This project lies in seismic zone II and had no history of major earthquakes.

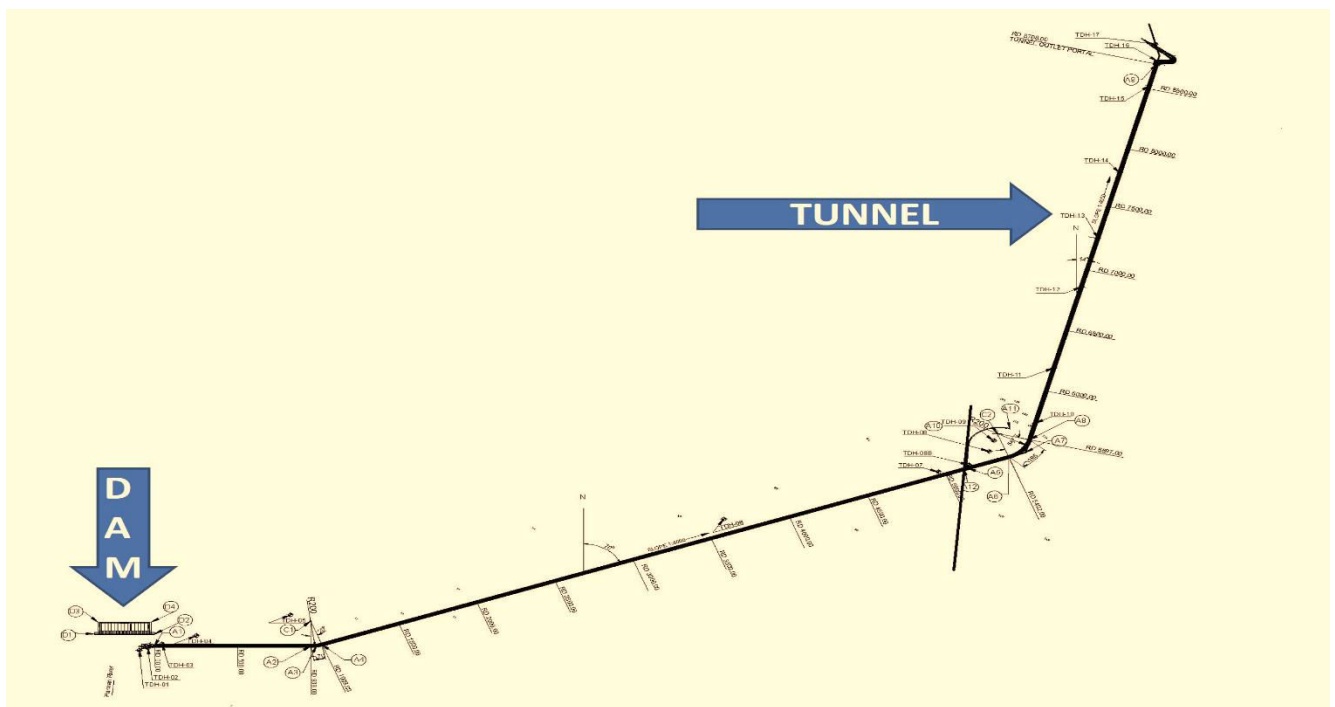


Figure 1: Layout of Project

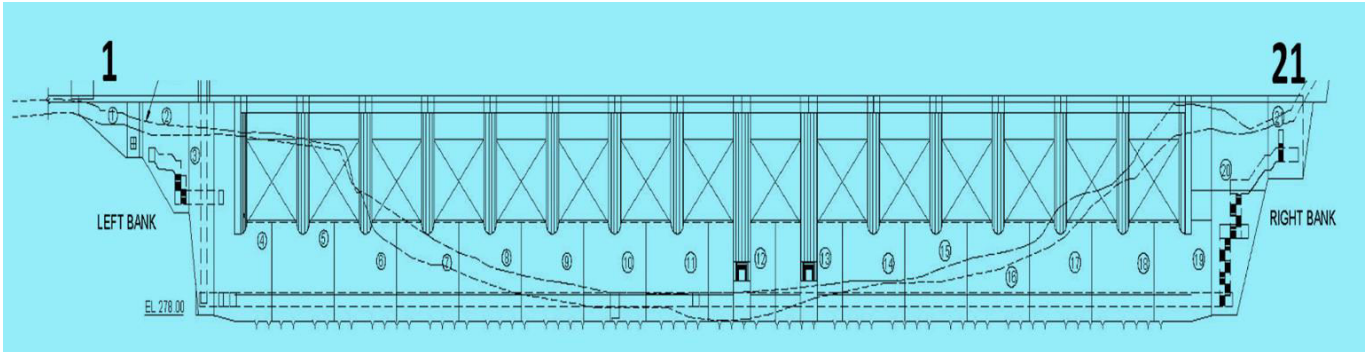


Figure 2: Upstream Elevation of Dam

II. THE PROBLEM

The geological mapping of all the dam block foundation was carried out and recorded the geological features including discontinuity patterns. In the geological mapping of the dam foundation, shear crack/ fracture (suspected fault) of thickness 10-30 cm reported to be stretching in 5 blocks. This crack was trending N75°W to S75°E direction with sub-vertical dip and crossing upstream to downstream of the dam. It was interpreted that the rock blocks on either side of the crack plane can move in any direction, so it was recommended to treat this zone with necessary treatment before taking up the concreting.



Figure 3: Fracture/ Shear Crack in Dam foundation

THE GEOLOGY

The foundation exposed was hard, compact, grey colour, fresh to slightly weathered massive ortho-quartzite rock. Due to river erosion, the top of the ortho-quartzite got smoothen showing weavy surface and showed cross bedding structure at places. Ortho-quartzite beds are sub-horizontal in nature and strikes in N20° to 30°W- S20° to 30° E/05°-15° towards southwest (towards upstream). Thickness of beds varies from 2 cm to 50 cm in vertical section upstream direction. The strike of beds is askew to the dam axis and dips in upstream direction. Apart from bedding joint, the rock mass is beset with the following prominent sets of joints. These are J2:N30° to 40°E – S30° to 40°W/80° Northwest to sub-vertical and J3: N20° to 60°W – S20° to 60°E/85° towards northeast to sub-vertical.

The crack in the foundation was trending in N75°W to S75°E direction with sub-vertical dip. A 10-30cm crushed rock material along with fractured rock fragments was present within this crack plane. A 5-7 cm crushed gouge (yellow color silt and sand material along with fractured rock pieces) was present within this plane.

No visible vertical displacement is observed in the vertical scarp faces however minor shearing & crushing along the crack zone were observed at places. As per opinion of the geologist, the fault in the absence of any visible displacement may not be considered as Active Fault (Slemmons and McKinney, 1977)^[1] and is most likely to be a shear zone along the axial plane joints.

III. INVESTIGATIONS AND STUDIES

Two inclined bore holes at 45° were recommended to explore the nature and extent of the shear crack. The holes were drilled to approx. 80m depth and permeability tests were carried out. Although the existence of crack was reported at varied depths, but the permeability could be ascertain approximately 2 Lugeon, which showed tight joints near the crack zone. The thickness of crack was reported in the range of 10-80 cm.

Further investigation of the shear crack was proposed by site specific seismic study. However, during initial visit of a team of senior geologists suggested that based on observations it indicated that the fault may not be active fault and further potential seismicity can be ascertained by the field tests.

Geophysical test was conducted at six profiles which were transverse to the surface exposure to the fracture line and data acquired by Seismic refraction method, Electrical resistivity tomography and Multi-Channel Analysis of Surface Waves (MASW).

Seismic refraction method

Elastic waves are initiated at a point at or near the ground surface and to determine at a number of other positions the arrival times of the seismic energy that has traveled along discontinuities and totally refracted back to the surface. It consists of recording the time taken for and artificially provoked surface vibration.

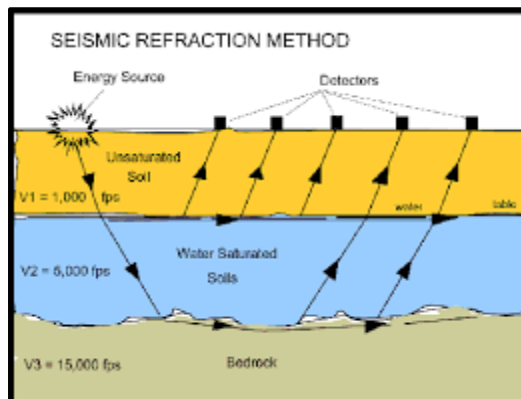


Figure 4: Diagram showing thory of Seismic Refraction Survey



Electrical resistivity tomography

Data for electrical currents travel along pathways in the most conductive material is collected with multi electrode.

Table 1 Resistivity of some common rocks

MATERIAL CONDUCTIVITY	RESISTIVITY (Ohm.m)
Igneous and Metamorphic rocks	
Granite	$5 \times 10^3 - 10^6$
Basalt	$10^3 - 10^6$
Slate	$6 \times 10^2 - 4 \times 10^7$
Marble	$10^2 - 2.5 \times 10^8$
Quartzite	$10^2 - 2 \times 10^8$
Sedimentary rocks	
Sandstone	$8 - 4 \times 10^3$
Shale	$20 - 2 \times 10^3$
Limestone	$50 - 4 \times 10^2$
Soil and water	
Clay	1-100
Alluvium	10-800
Fresh ground water	10-100

MASW

Shear wave are measured at multiple locations and a 3 dimensional map of shear wave velocity constructed and deviations in shear wave velocities can identify voids, and other features of subsurface like mechanical properties such as shear strength and internal structures.

A fair quality MASW data was analysed by SeisImager SW software. Average shear wave velocity at 30m depth is commonly known as Vs30 and is a controlling parameter for site classification according to the Building Seismic Safety Council (BSSC 2003). The NEHRP classification based on Vs30 is given below: -

Table 2 National Earthquake Hazard Reduction Program (NEHRP) site classes (BSSC, 2003)

SITE CLASSIFICATION	DESCRIPTION	AVERAGE SHEAR WAVE VELOCITY up to 30m (Vs30) m/s
A	Very hard rock	>1500
B	Rock	$760 < V_{s30} < 1500$
C	Very hard oil and soft rock	$360 < V_{s30} < 760$
D	Hard soil (sand, clay and gravel)	$180 < V_{s30} < 360$
E	Soft clay of thickness about H in site profiles	$V_{s30} < 180$
F	Soils requiring site-specific evaluations	-

Conclusion of Investigations

The fault line was not categorized as active or potentially active as the area lies in low seismic risk zone (II), the fracture line confined in small length and was too short to have potential seismic activity or risk and no such other feature on either side.

The outcome of geophysical investigation (ERT, MASW and SRT) did not supported the magnitude of fault given by physical observations of boreholes. As per output of geophysical investigations, there was very hard and impermeable rock beyond 20m found to be present. However, the permeability values reported less than 2 Lugeon in bore hole study very well supported by the study in ERT, MASW and SRT establishing the rock mass in foundation as hard and compact in nature.

The two-dimensional mapping of shear wave velocity from MASW survey indicated the presence of anomalous velocity zone in very negligible width within or within the vicinity of fracture at the surface, which is extended at a

maximum depth of 20m.

Based on investigations and analysis, the concrete dam was recommended to be safe over the fracture after adopting the remedial measures. A suitable designed raft of 3m width over the fracture was recommended to cater the stresses of the fault/ fracture zone.

Further a Finite Element Modelling (FEM) analysis was recommended to ascertain the suitability of the reinforcement for the tensile stresses generated in the vicinity of the raft.

FEM Analysis

FEM analysis of dam blocks was carried out in MIDAS FEA software by creating a 3D finite element model. Induced stresses in terms of major principal stresses in bottom face of dam mass concrete was considered to evaluate the suitability of proposed reinforcement. Based on FEM analysis, negligible tensile stresses found to be induced in the founding level of dam blocks, hence no reinforcement was required.

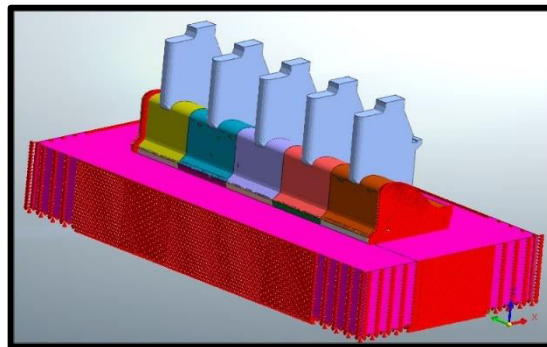


Figure 5: Diagram showing FEM model of dam blocks

IV. TREATMENT PROPOSED

Based on the investigations and structural analysis following treatment was proposed: -

- Grouting in the fracture zone to ensure permeability less than 2 Lugeon.
- Dental treatment after grouting by removing the material in a trapezoidal shape of 2.6m (w) x 0.5m (d) with side slope 1:1.
- Placement of anti-shrink concrete with reinforcement T25 Φ @ 200 c/c at top & bottom + 6L - T16 Φ @ 200 c/c.
- Contact grouting after concreting.

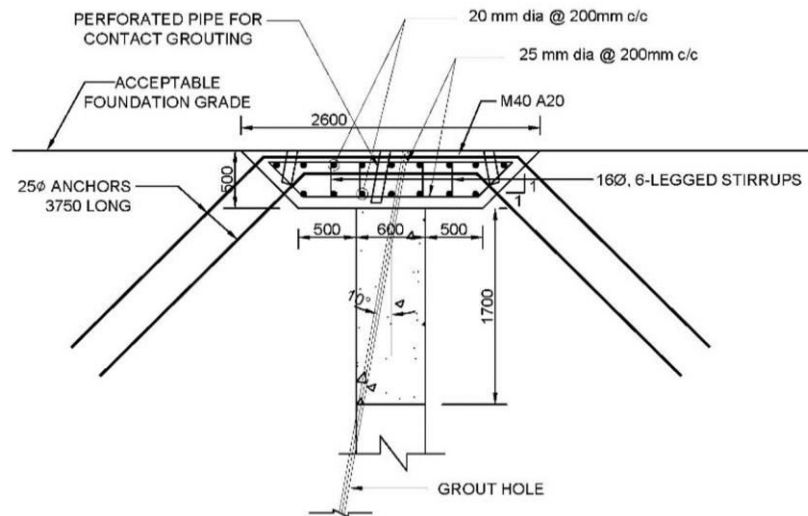


Figure 6: Sketch showing proposed treatment

V. CONCLUSION

In the geological mapping of the dam foundation, shear crack/ fracture (suspected fault) of thickness 10-30 cm reported to be stretching in 5 blocks of the dam. The investigation of the fracture was carried out by drilling holes, geophysical studies by using ERT, MSAW and SRT methods. The studies showed that the suspected fault is not a fault and dam can be placed over foundation by suitable treatment.

Recommendations of the study were further designed structurally by using MIDAS FEA software. Based on the analysis results, the treatment of fracture was carried out at site.

REFERENCES

- [1] Slemmons, David B. and McKinney, Roy, 1977, Definition of Active Fault: In U.S. Army Engineer Waterways Experiment Station, Soils and Pavements Laboratory, 24p.
- [2] Geological reports of the Project



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