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Indian National Committee on Large Dams

INTERNATIONAL DAM SAFETY CONFERENCE

DRIP
Dam Rehabilitation & Improvement Project

Central Water Commission

REHABILITATION OF *GARARDA* EARTHEN DAM

Authors: Randhir Kumar Choudhary, *Deputy Director*
Ashwani Kumar Verma, *Deputy Director*

Central Water Commission, New Delhi (India)

10-12 October 2022 at Jaipur, Rajasthan (India)

SALIENT FEATURES

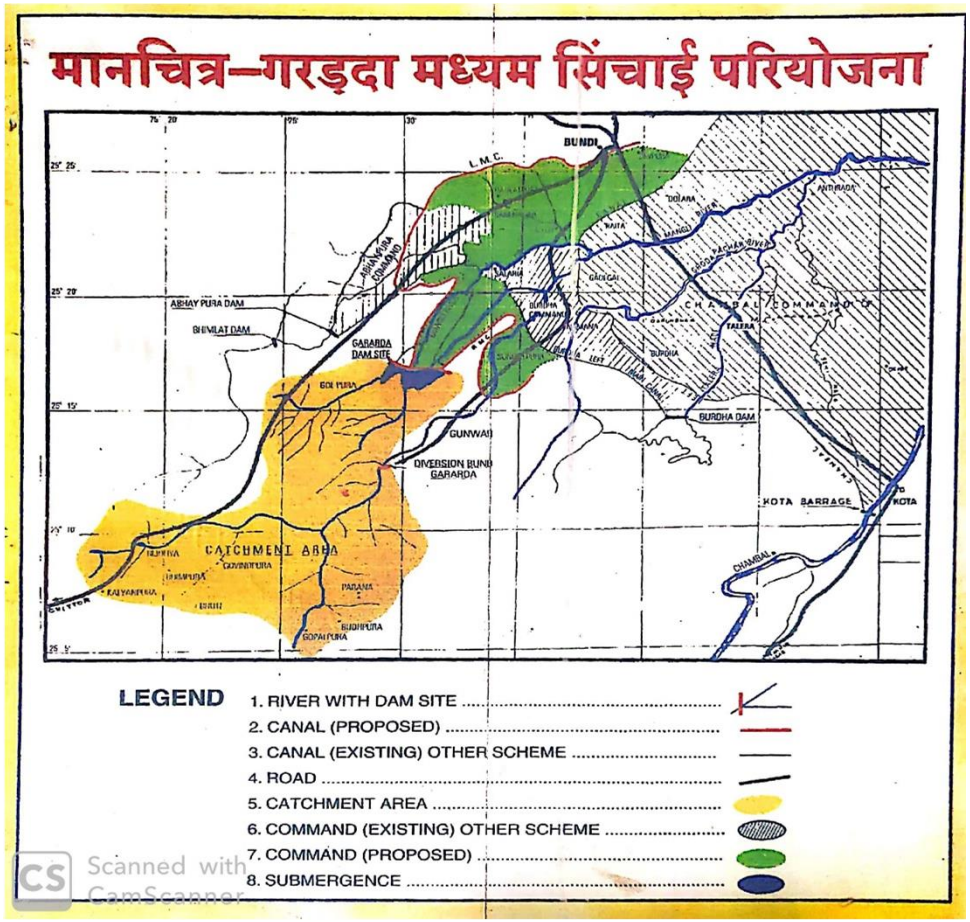
Length of Dam – 4271.0m

Maximum height – 32.0m

Storage Capacity – 42 MCM

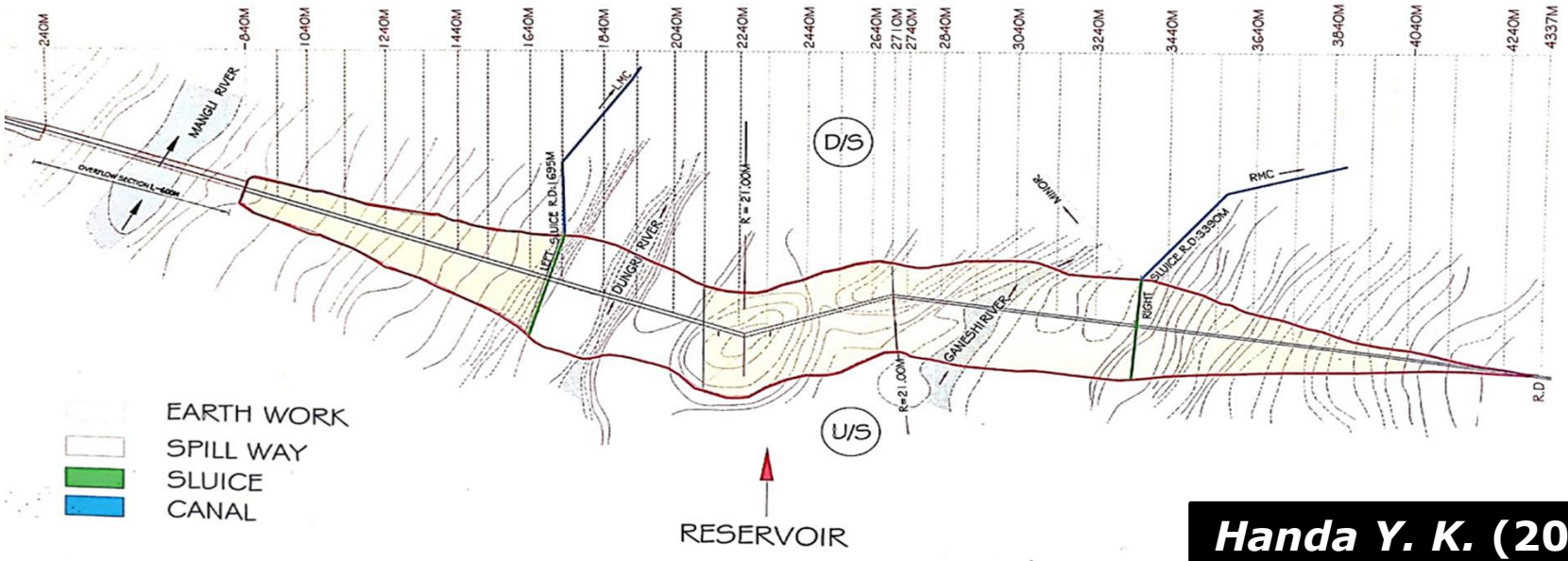
BENEFITS:

- ✓ to meet the increased agriculture production requirement by providing irrigation water to a **Gross Command Area (GCA) of 10492.0Ha** and
- ✓ **drinking water** requirement of **Bundi City**.



ABOUT THE PROJECT

***Gararda* Dam** was proposed to tap the discharge of three ***Chambal* basin** drainage channels, namely ***Mangli* River** towards the left end across which there is a spillway site**, *Dungri* River** in the middle and ***Ganeshi* River** at the right end of the Dam axis.



***Handa Y. K.* (2016)**

CHRONOLOGY

1996 64th TAC Meeting

2003 Construction Started

2009 Construction Completed

2010 March – Commissioned

2010 July – Reservoir Filling Commenced

Construction Works

- On completion of the dam, the reservoir filling commenced on July 26, 2010.
- **Due to heavy rain the catchment area, the water level in the reservoir quickly rose up to EL 291 m (just 4 m below FRL)**
- Subsequently, on ***August 15, 2010 at 4:30 am –***

the central portion of the dam across the Dungari River washed away from the closure section

BREACHED OF GARARDA EARTHEN DAM

On August 15, 2010 at 4:30 am, the central portion of the dam across the Dungari River washed away from the closure section

- **Flooding at least a dozen villages on the D/S and**
- **Causing major damages to crops.**
- **However, no casualties were reported.**

TOI *Jaipur News, (2010)*

REPORT OF THE ENQUIRY COMMITTEE

On August 15, 2010 at 4:30 am, the central portion of the dam across the Dungari River washed away from the closure section

- Subsequent to breach the state government **ordered an inquiry** *to ascertain the reasons and the circumstances behind the dam's breach*.

- The soil test results indicated that entire soil is of the single type which implies that a homogeneous section was constructed instead of a zoned section.

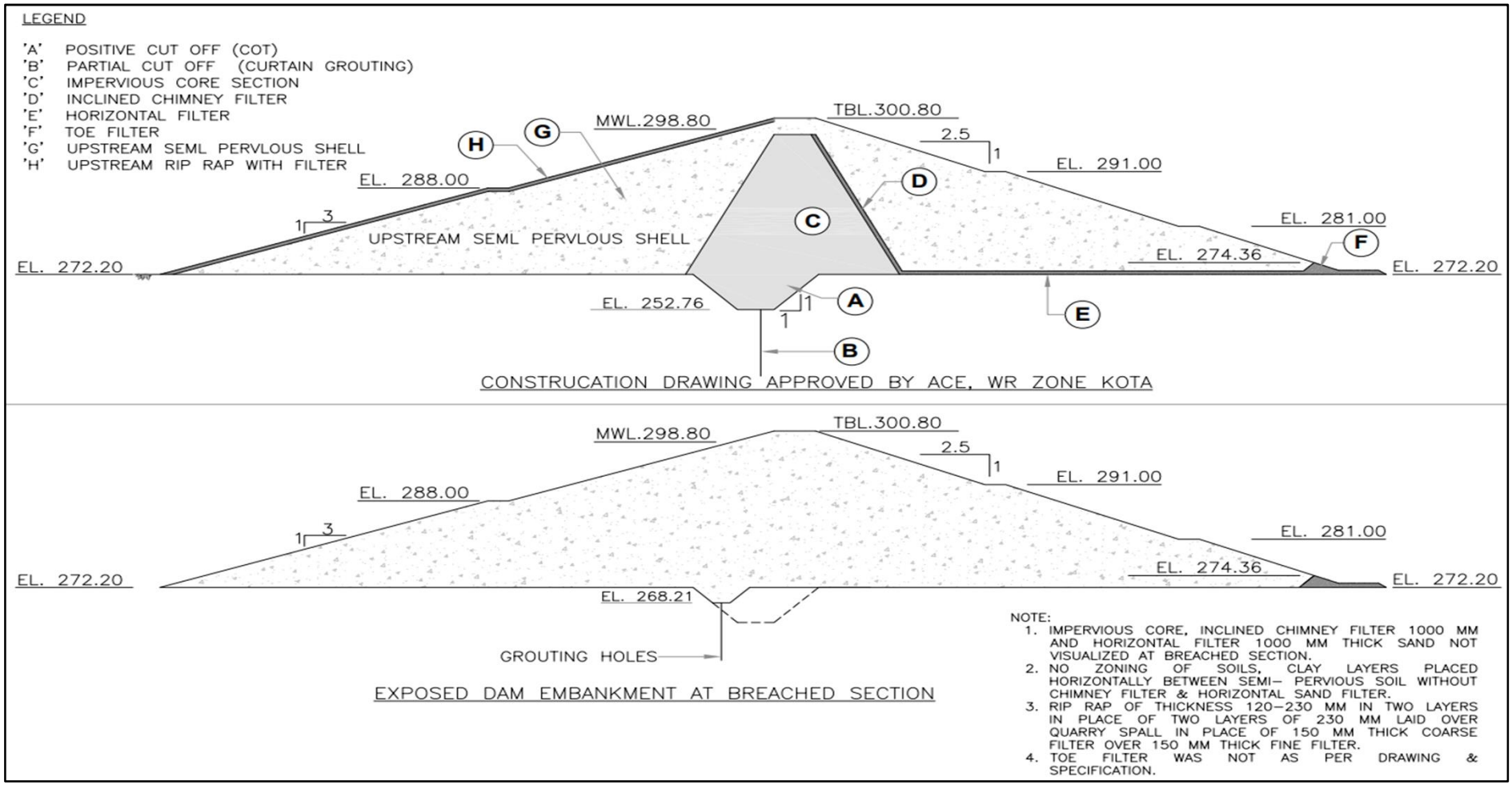
- The test results of filter material also shows that about 25-30% of the material is finer than 75 micron which means that proper filter material was not used rendering it ineffective

***CSMRS* Report (2011)**

From the information collected from official records, inquiry from staff & local people, based on visual inspection and from the results of soil testing it was inferred that the **decision** regarding reduction in the depth of Cut-of-Trench, depth of curtain grouting, and allowing quarry spoils in place of well-graded gravel **was taken anonymously by the site-engineer**.

***Handa Y. K.* (2016)**

DESIGNED AND EXECUTED CROSS SECTION



PROBLEM REFER TO CWC

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Construction Works

On August 15, 2010 at 4:30 am, the central portion of the dam across the Dungari River washed away from the closure section

- **Central water Commission (CWC) was requested to carry out detail investigations for ascertaining the reason of breaching of Gararda Dam and to advice on:**
  - ❑ **The totality of circumstances leading to breach of Dam;**
  - ❑ **Status of the Dam in other portion; and**
  - ❑ **Steps required to ensure the Dam safety in future.**

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Rehabilitation Works

- **2011-2015** – Investigations were done and Study Drawings were issued
- **2015-2017** – Design and Analysis were done and Construction Drawings were issued
- **2017** – Construction Works for Rehabilitation of dam Started
- **2020** – Deep cobble layer was noticed beneath unbreached portion
- **2022** – Rehabilitation completed and Reservoir Filling Commenced

RECONNAISSANCE: 2011–12

ABSTRACT OF CWC TEAM REPORT AFTER INSPECTION OF BREACHED DAM ON 01/10/2011

- The Gararda Dam was subjected to an uncontrolled filling. In absence of any arrangements to control the initial reservoir filling, it was not possible to undertake any effective remedial measure, in the event of any distress condition.

- Approval of geologists before covering the foundation and undertaking construction of the earth-dam was perhaps not taken. This is considered necessary in order to ensure satisfactory treatment of the rock foundations before undertaking dam construction.

- Adequate concern for dam safety was missing in construction as well as supervision of the works. It is understood that there were probably some compromises in quality of earthwork – especially on issues of construction, specification of dam materials, thickness and of lying of filters etc.

Four study drawings of earth dam for breached portion with the condition that final drawings for construction will be issued after receipt of the required data for which CSMRS was to carry out the soil test of the existing dam were issued to WRD, Rajasthan.

RECONNAISSANCE: 2015-16

The Joint Team Comprising Officials of CWC, CSMRS and WRD Rajasthan visited the existing dam both at the right portion and the left portion of the breached section.

Excessive weeds and shrubs growth with deep roots in the upstream and downstream slope were seen.

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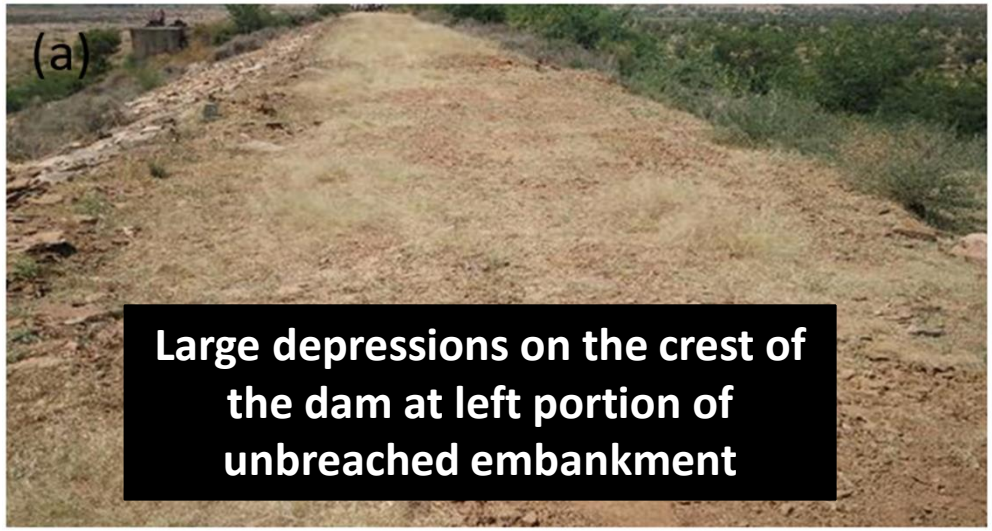
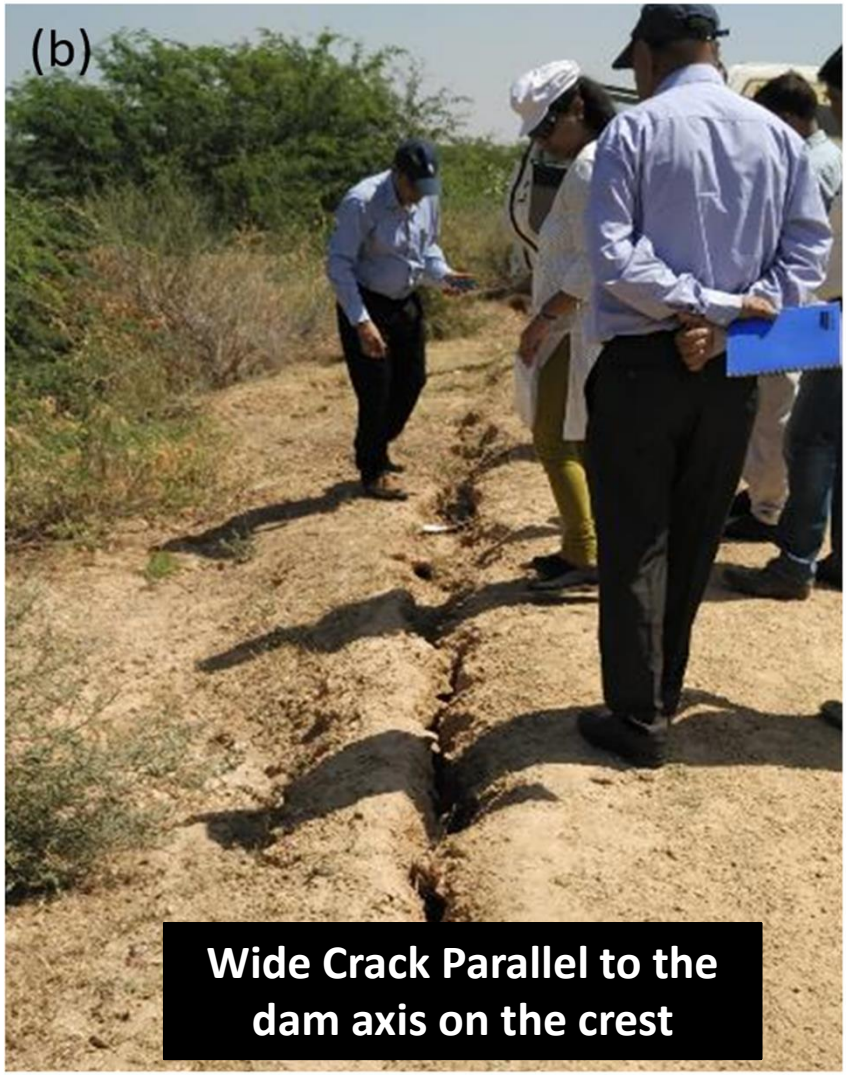




10-12 October 2022 at Jaipur, Rajasthan (India)

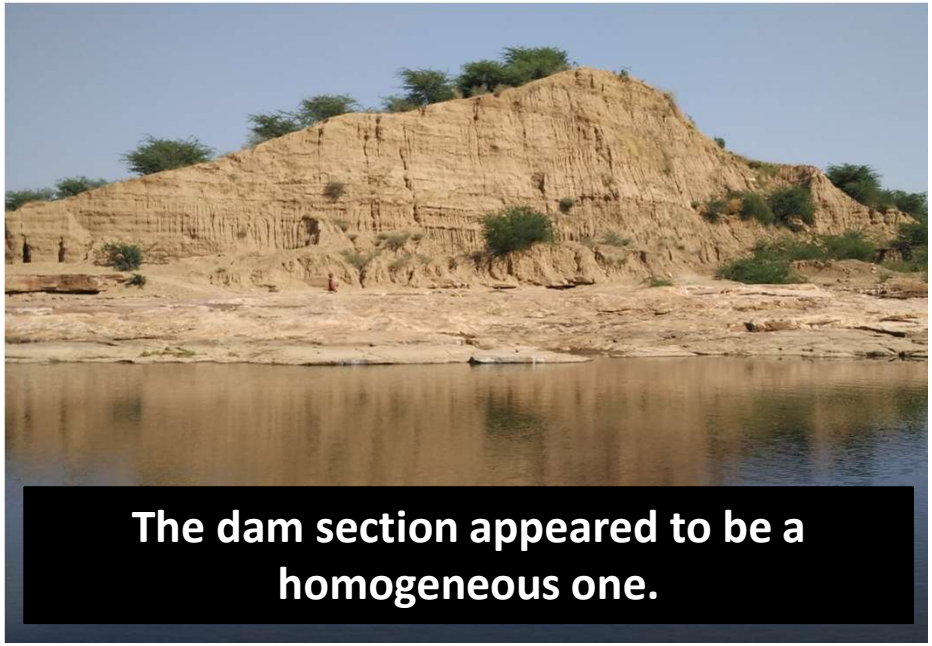
Deep rain cuts and gullies were observed on the D/S slope on entire dam body.

Localized slope failures were also found at some location on D/S slope.

Two wide vertical open joint parallel to flow of river at expose portion

Deep Holes on the crest of Dam

Settlement/Bulging of rip-rap in U/S side of dam was observed in entire length of earth dam

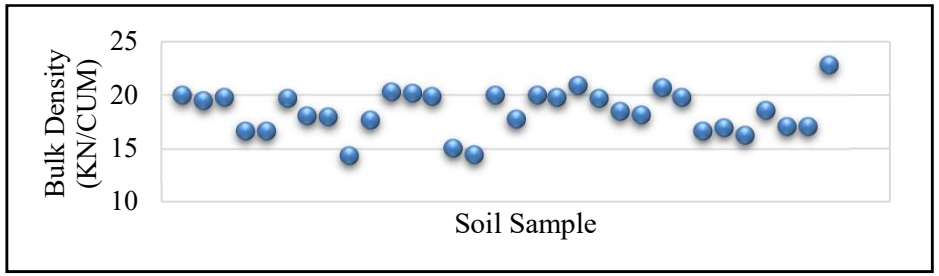


The dam section appeared to be a homogeneous one.

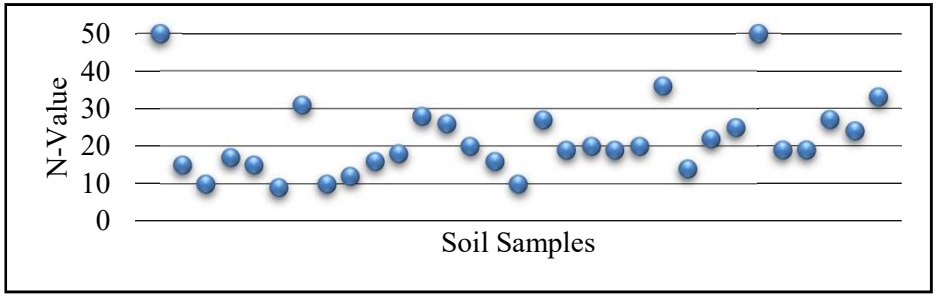
- The U/S slope was observed with very thin single layer stone pitching **without any filter**.

- There was **no clear evidence** for existence of any **filter** material, clay **core** and **cut-off** trench in the dam body as evident from exposed portion of breached section of dam.

GEOTECHNICAL INVESTIGATIONS BY CSMRS



In-situ wet Density



SPT (N) values

Triaxial Shear Tests

The result of triaxial tests indicated that **effective cohesion (c')** and effective values of **angle of shearing resistance (Φ')** for soil samples varies from **0.18-0.25 kg/sqcm** and **25° to 30°** respectively.

Consolidation Test

1D-Consolidation test results indicate that **the shell materials are likely to undergo low to medium compressibility depending upon the imposed stress levels**.

***CSMRS Report* (2015)**

***CSMRS Report* (2017)**

CHALLENGES

- There could be pockets/layers of low shear strength due to poor construction quality which might lead to large settlement.
- There could be uncertainty in soil properties as brief investigations showed high variability in in-situ parameters (like relative density).
- There had to ensure the continuous Seepage Barriers from FRL to sufficient depth below foundation level.
- Permeability values of clay core/shell material are inconsistent.
- There were no arrangements to control the rate of reservoir filling.
- Scarcity or non-availability of suitable filter material around the project site.
- The prolonged time gap could result in a differential settlement at the interface of breached and breached portion.

***Sibal S. K.* (2012)** **| *Handa Y. K.* (2016)** **| *Jain A.* (2018)**

FINITE ELEMENT ANALYSIS AT RD 2520m

The dam section at RD 2520 m was selected for analysis for two reasons:

- ✓ Firstly at his location drill hole was done from top of the dam to foundation level so it covers the **entire height of the dam** and
- ✓ Secondly **lowest bulk density** value was recorded at this section.

LOADS AND BOUNDARY CONDITION

- ❑ In 2D static analysis gravity forces i.e. body forces are considered while in dynamic analysis earthquake force (horizontal Earthquake coefficient as 0.068 and vertical coefficient as 0.045) were also considered for analysis.
- ❑ In 2D static analysis slope surface is allowed to move in all directions while rock foundation was restrained. Hydraulic boundary conditions were set as per flow conditions.

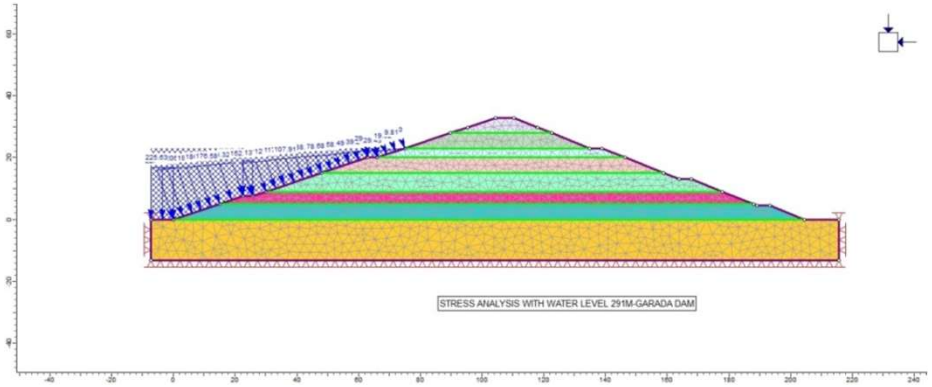
***Jain A.* (2018)**

MATERIAL PROPERSTIES USED FE IN ANALYSIS

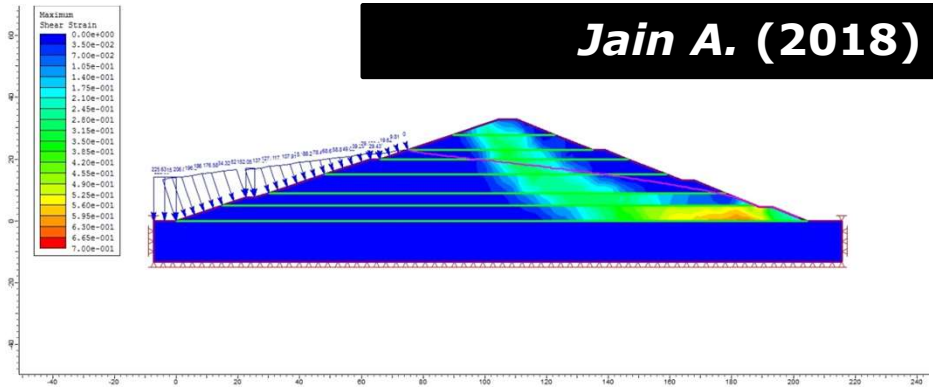
S. No.	Soil Layer as per Elevation	In situ Bulk Density (KN/cum)	(c') in KPa	(Φ') in Degree	Saturated permeability in cm/s
1	El300.8-El295.9	20.3	18	25	1×10^{-4}
2	El295.9-El291	19.9	18	25	1×10^{-4}
3	El291-El288	19.9	18	25	1×10^{-4}
4	El288-El283	15.1	18	25	1×10^{-4}
5	El283-El277	14.5	18	25	1×10^{-4}
6	El277-El273	20	18	25	1×10^{-4}
7	El273-El268	17.8	18	25	1×10^{-4}
8	Foundation Rock	27	500	35	1×10^{-5}

***Jain A.* (2018)**

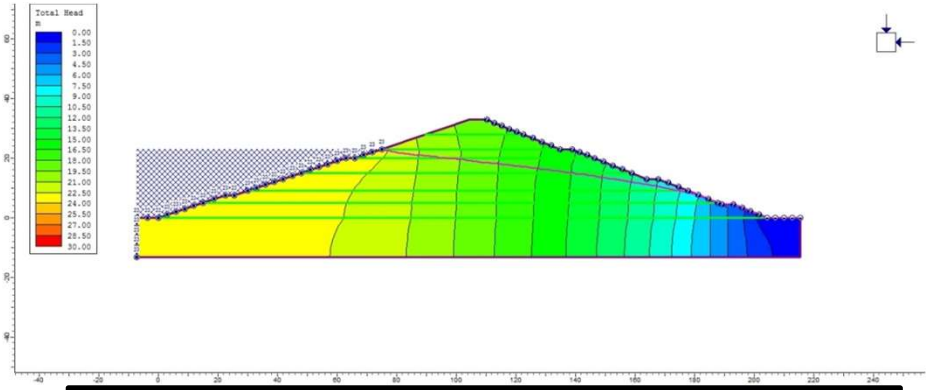
Jain A. (2018)



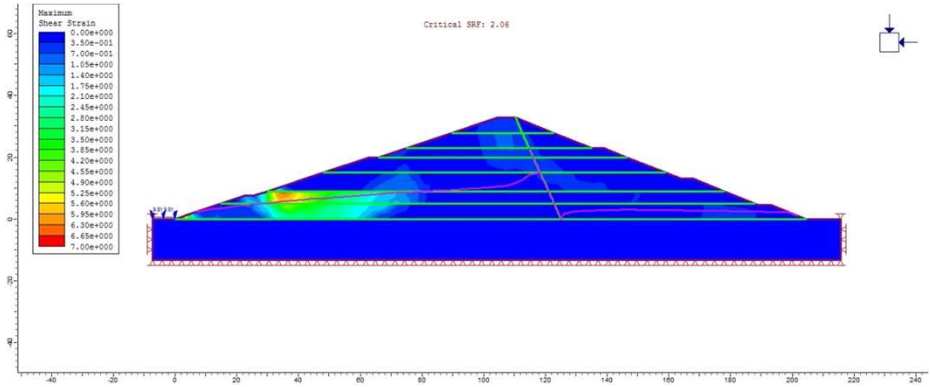
FE Model of Gararda Earth Dam Section with Water Head up to FRL



FE Analysis Results of Steady State Seepage Conditions.

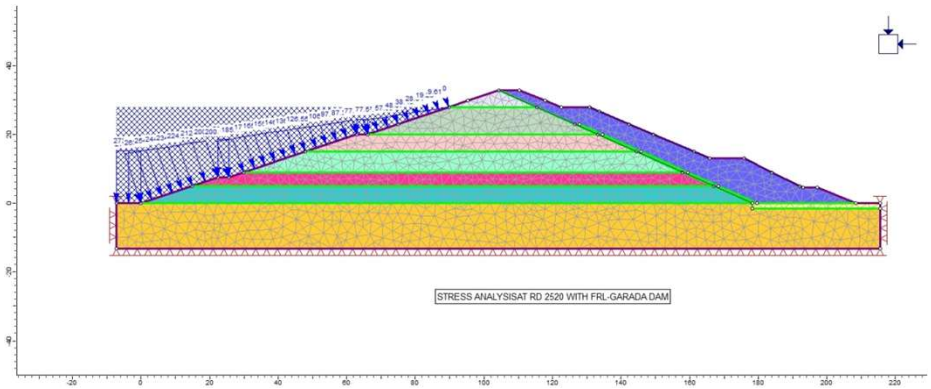


Seepage analysis is performed to estimate the phreatic line and hydraulic conditions

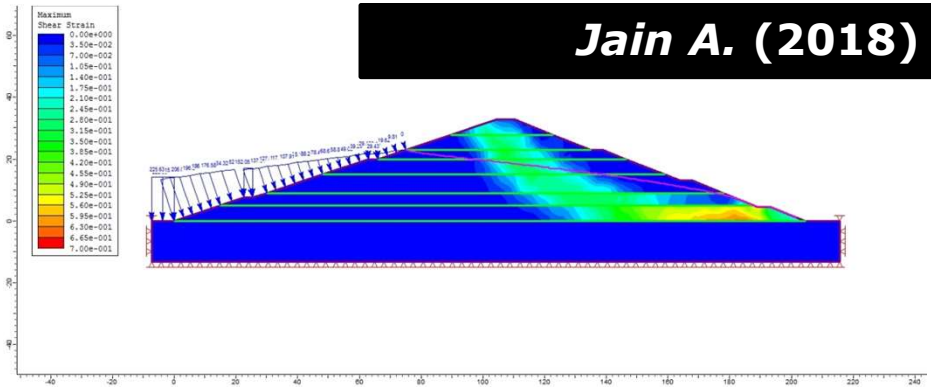


FE Analysis Results for Drawdown Conditions

Jain A. (2018)



FE Model of Modified Gararda Earth Dam Section



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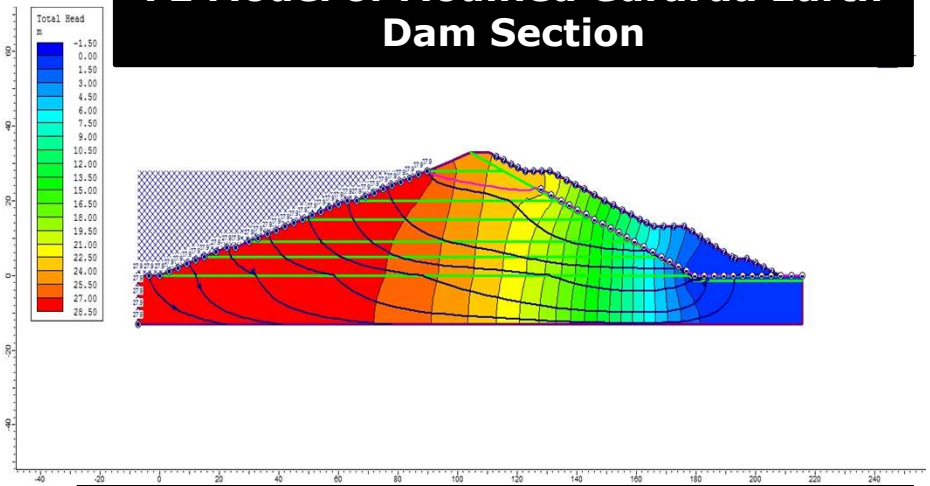

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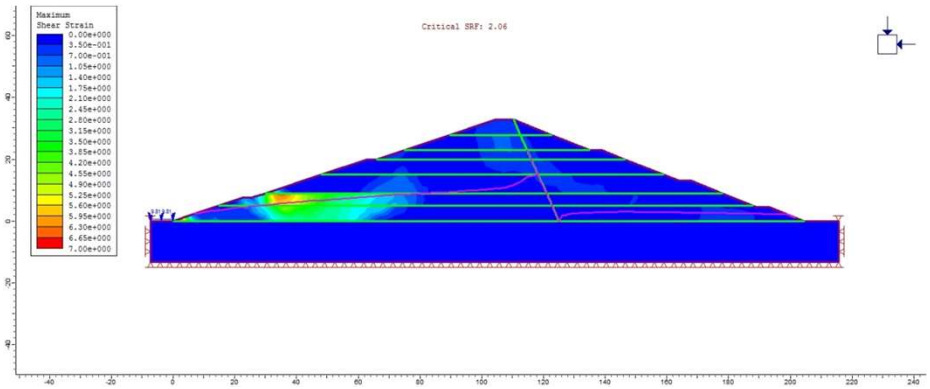
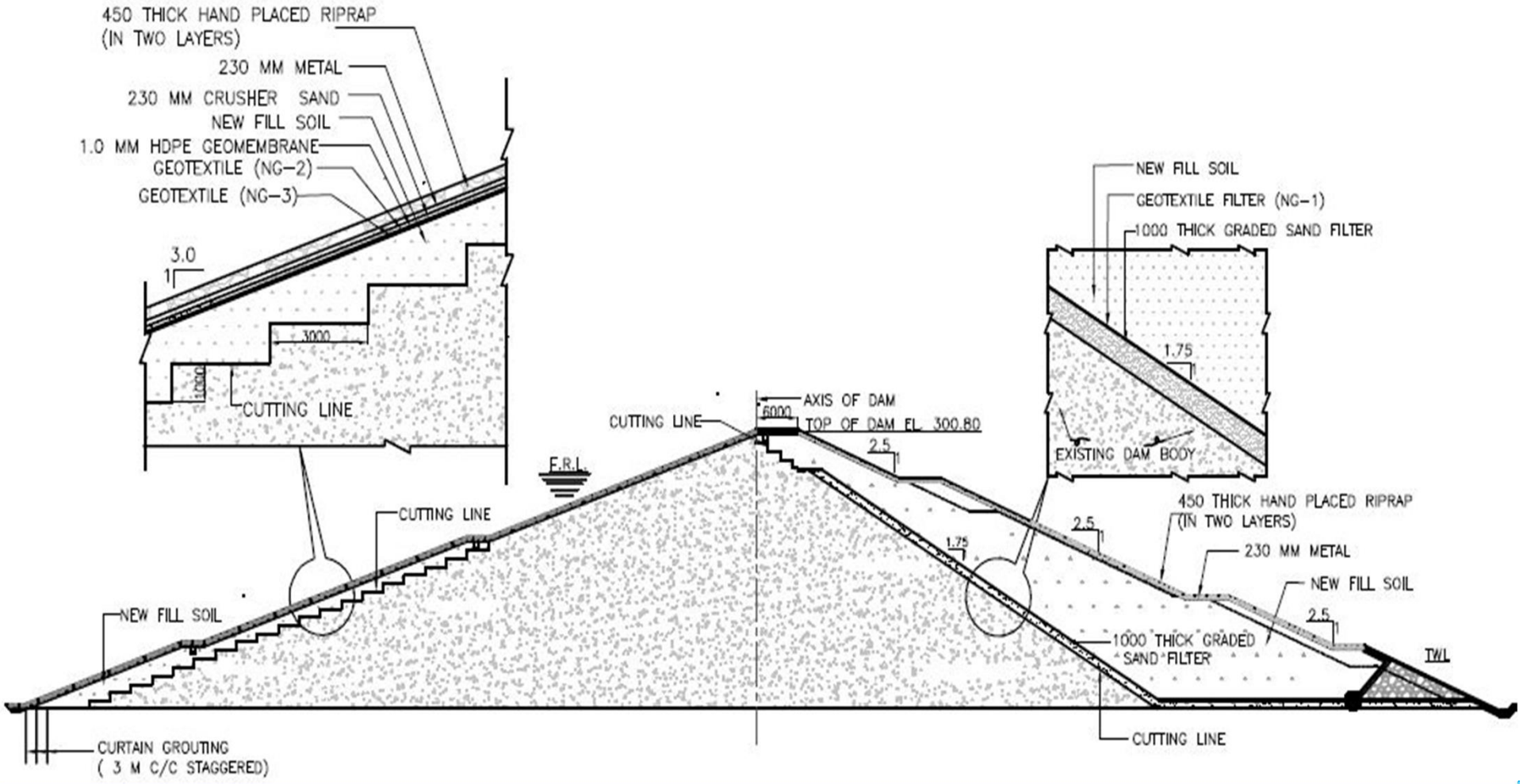
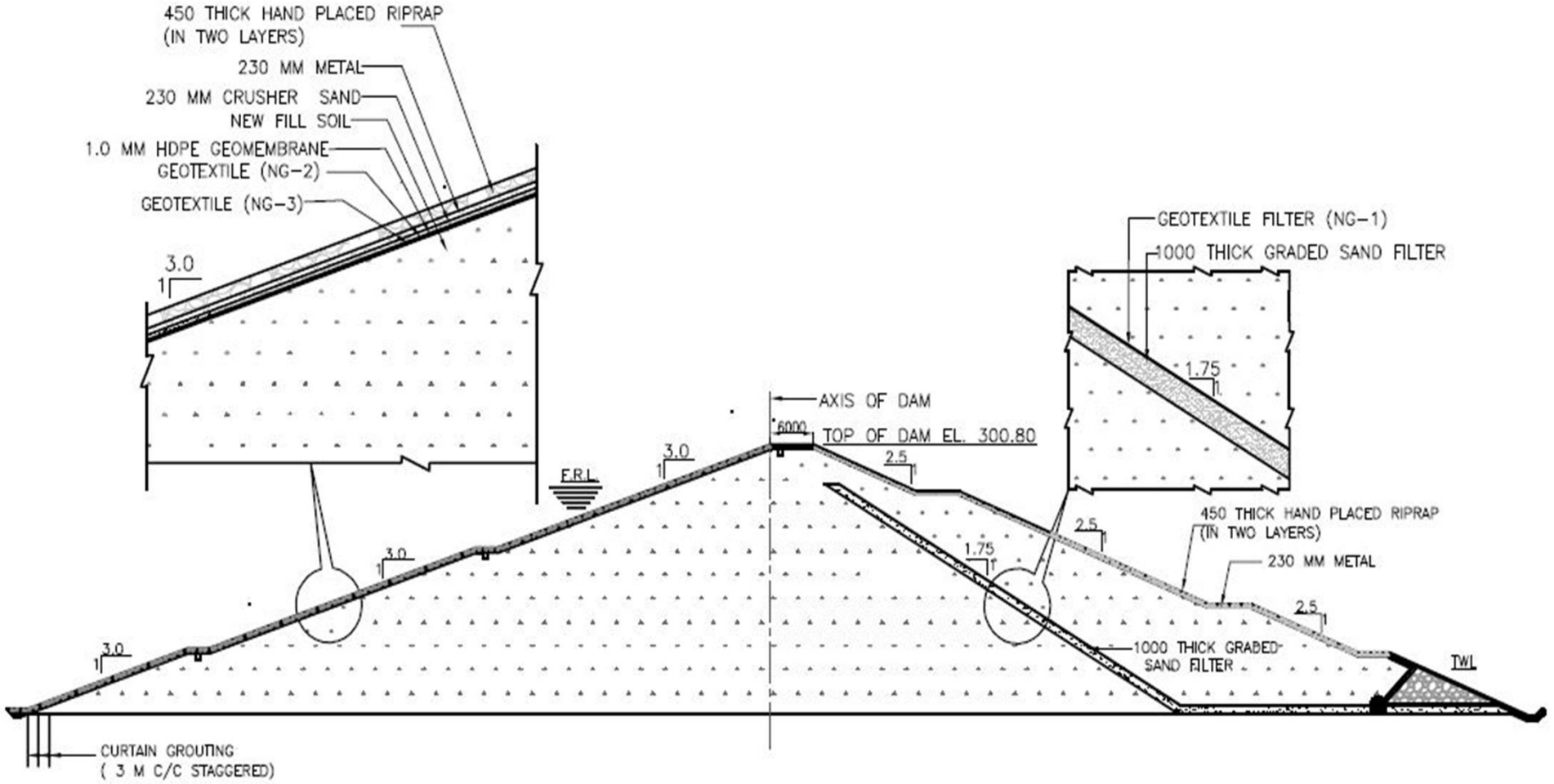


FE Analysis Results for Drawdown Conditions

Modified section for *UNBREACHED* portion



New section for *BREACHED* portion

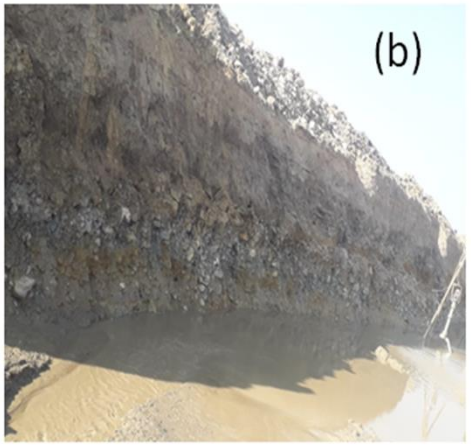


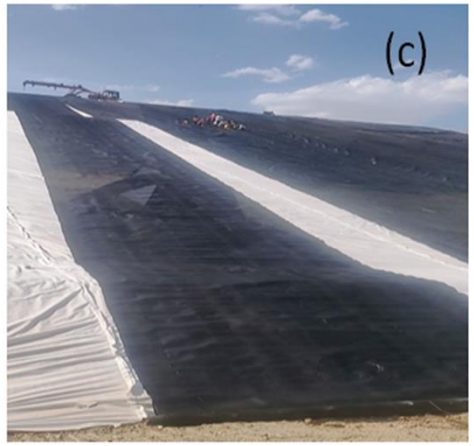
Physical properties of geotextiles used for R. works

Tests/Properties	Units	Method	NG-1	NG-2	NG-3
Mass per unit area	g/m^2	ENISO-9864	250	400	100-125
Wide width tensile strength	kN/m	ENISO-10319	15.5/18.5	265/32	6/7.5
Wide width elongation at break strength (MD/CD)	%	ENISO-10319	50/50	50/50	-
Puncture strength (CBR)	N	ENISO-12236	2300	4000	1000
Dynamic performance resistance-cone drop	mm	ENISO-13433	22	10	35
Permittivity/ flow rate	10^{-3} m/s	ENISO-11058	35	20	-
Apparent opening size (AOS)	mm	ENISO-12956	0.075	0.075	-

Rehabilitation Works at unbreached Sections

Rehabilitation Works at Breached Portion of Dam





a) The Cut-off Trench in the unbreached portion can be seen to be laid against the highly permeable cobble layer without filter protection

b) The cobble layer over which the unbreached section was founded

The portion of unbreached portion, founded over cobble layer, completely removed and laid as fresh dam section.

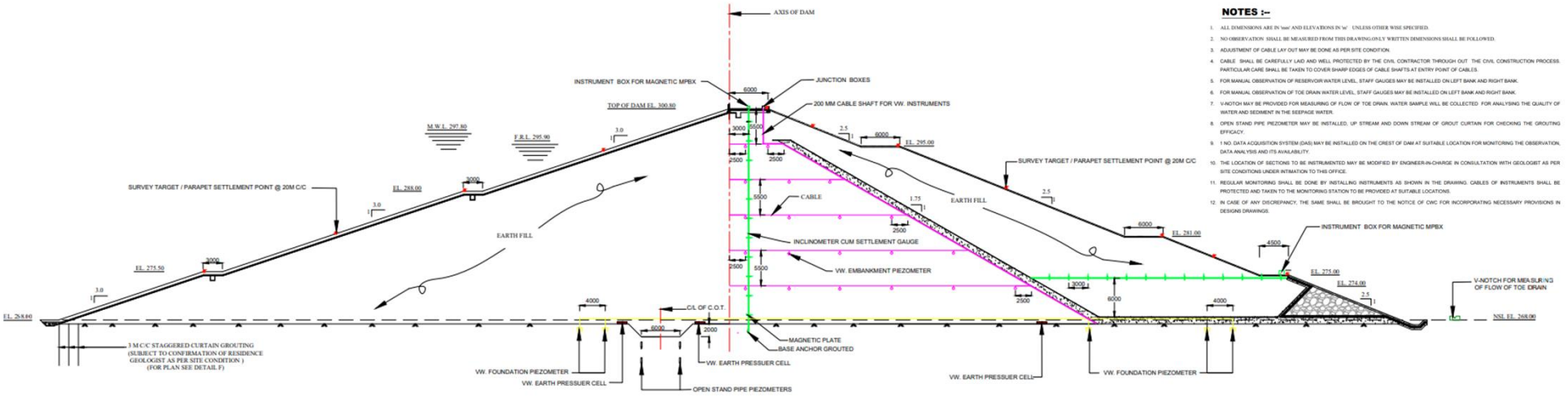
c) Laying of Geocomposite (Geotextile+Geomembrane+Geotextile) on u/s slope.

INSTRUMENTATION DETAILS

Various monitoring Instruments to measure/observe the dam behavior were installed in newly laid Embankment Section at **breached portion**.

INDEX

SYMBOL	CONVENTION	DESCRIPTION	TOTAL QTY
	OSPP	OPEN STAND PIPE PIEZOMETER	4 NO'S
	EPM	VW. EMBANKMENT PIEZOMETER	20NO'S
	FPM	VW. FOUNDATION PIEZOMETER	5 NO'S
	ST	SURVEY TARGET/SETTLEMENT POINT	AS REQD
	EPC	VW. EARTH PRESSUER CELL	3 NO'S
		V-NOTCH	AS REQD



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REHABILITATION COMPLETED

RESERVOIR FILLING COMMENCED

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LESSON LEARNED

- ✓ The most common causes of earth dam failures are piping in the dam body or foundation and overtopping. The quality control issues are the major cause for piping related failures.
- ✓ A proper planning on dam site selection, project layout, design and construction is essential for safety of dam.
- ✓ Geological investigations and laboratory testing should be considered an essential part of design.
- ✓ The dam foundation preparation and cleanup should be given due importance. Any laxity on this score can prove hazardous later on.
- ✓ As there are a large number of failures that have occurred during the first filling of dam, it is important to recognize the importance of filling of the reservoir slowly under fully controlled conditions and to have means available for lowering the water level rapidly if problems develop.

LESSON LEARNED

- ✓ It is fact that all the earth and rockfill dams are subject to seepage through the body of embankment, foundation and abutments. Seepage control is necessary to control excessive uplift pressure, instability of downstream slope, piping through body of embankment and/or foundation and erosion of material by migration into open joints of foundation or abutments.

- ✓ The filter on the downstream slope of COT is highly desirable especially for those COTs which are formed by excavating very permeable strata and can trigger particle migration and piping. This study shows that in the absence of downstream drainage filter, downstream slope of the existing dam is becoming seeping face.

- ✓ Further, during breach even existing dam section was subjected to sudden drawdown condition which has resulted in local slope failure in upstream face and settlements at the discrete location. The FEM analysis also depicts local slope failure near toe and first berm on the upstream slope.

LESSON LEARNED

- ✓ The existing dam section is modified by providing downstream 1.5 m thick horizontal and chimney filter and by providing geo-synthetic material on both u/s and d/s slopes.

- ✓ The geo-synthetic material would offer protection against piping during critical first filling of the reservoir and during the first few operating years when post construction settlement could be expected.

- ✓ Geosynthetics provide a lot of flexibility in design works, wherein their different functional capabilities such as seepage barrier, separation, filtration, drainage and reinforcement can be utilized effectively.

- ✓ In cases of non-availability of good quality of construction materials in vicinity of project sites, geosynthetics provide an excellent and sustainable alternative.

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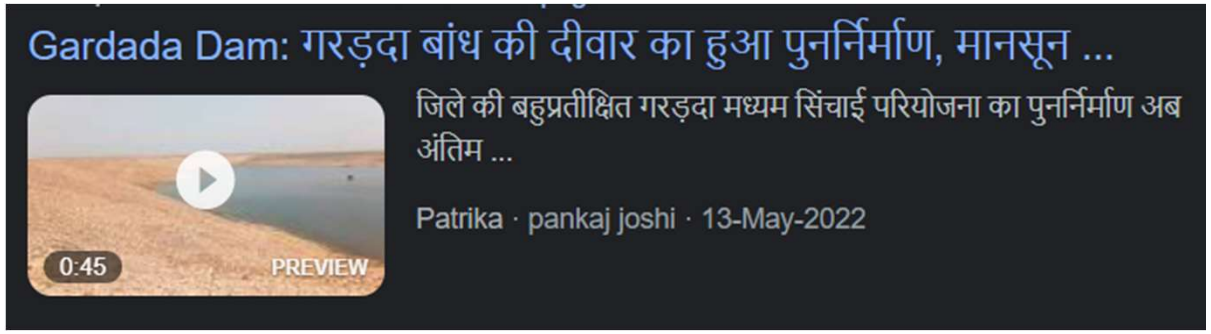
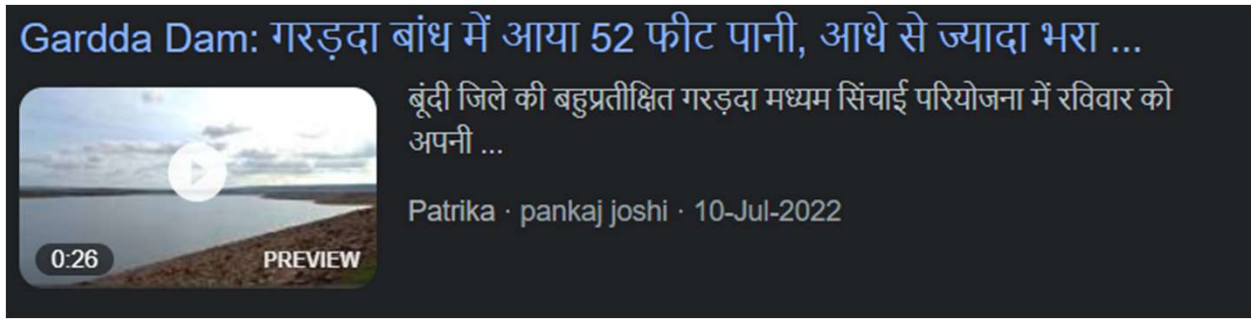
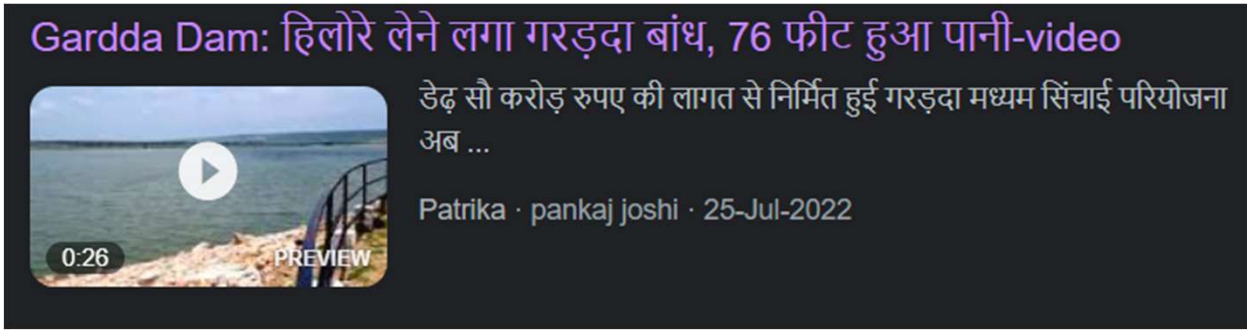


Thank You !





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