Strengthening of Reservoir Embankments

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Abstract. This paper is a case study of breach of embankment of 12 Lakh m3 capacity raw water reservoirs, situated in Gujarat, India. Three reservoirs were constructed within a cellulose fibre plant to provide water for the plant and the colony. The embankment of one of these reservoirs along with mid embankment was breached, resulted in minor losses to the property. The root cause analysis of the reservoir breach has been carried out and rectification measures have been suggested after a detailed analysis. Slope Stability and seepage analysis have been carried out by Geoslope software. All the safety measures were taken care for design and the same have been implemented at site during execution.
Keywords: Embankment; Raw water reservoir; Rectification; Slope stability; Seepage analysis; Geoslope

1 Introduction

1.1 Raw water reservoir

A raw water reservoir is an artificial lake or pond to store water. This also allows particles and silts to settle out. This can be built by excavating existing ground and then constructing embankment.

1.2 Embankment

Embankment is a structure raised above the immediately surrounding land to redirect or prevent flooding by a river, lake or sea or to retain water.

1.3 Homogenous Embankment Dam

An embankment dam composed of single type of material.

1.4 Large Dam

A dam exceeding 15 m in height above deepest river bed level and a dam between 10 and 15 m height provided volume of earthwork exceeds 0•75 million m^3 and storage exceeds 1 million m^3 or the maximum flood discharge exceed 2000 cumecs.

1.5 Small Dam

A dam not satisfying the criteria of a large dam.

1.6 Basic Design Requirements

The basic requirements for design of embankment dam are to ensure:

Safety against overtopping

The freeboard should be sufficient to prevent overtopping by waves and should take into account the settlement of the embankment and foundation. Free board for wave run up on slope shall be provided in accordance with the provisions contained in IS 10635 [2].

Stability Analysis

The slopes of the embankment shall be stable under all loading conditions. They should also be flat enough so as not to impose excessive stresses on foundation.

Extensive investigations of the foundation soil and borrow area soil were required to be carried out and the design of the embankment dam was carried out in accordance with IS 7894 [1].

2 Case Study

2.1 Location

Three raw water earthen reservoirs separated with bunds were constructed in the state of Gujarat, serving fibre factory and the ancillary purposes of the colony. The combined capacity of the three reservoirs is around 12 Lakh cum.

2.2 Details of Reservoirs

All the three reservoirs were built in various phases during 2000 to 2016 and the details are given below:

Table 1-Details of reservoirs

Slr. No:	Description	Year of Construction	Total Depth of reservoir (m)	Height of Embankment (m)	Storage capacity (cum lakh)
1	Reservoir -1	2000	6.5	5	3
2	Reservoir -2	2005	6.5	5	1
3	Raising of height of 1&2 by 2 meters	2010	8.5	7	2
4	Reservoir no: 3	2011	8.5	7	3
5	Raising of height of 1, 2&3 by 2 meters	2016	10.5	9	3

The southern embankment of reservoir-3 and intermediate embankment between reservoirs-2&3 was breached on 10th December 2016. Three embankments were constructed and raised during different years.

Fig. 1. Some photos of breached portion of embankment

3 Analysis

3.1 Stability Analysis

Slope stability analysis has been conducted with relevant design conditions as mentioned in IS 7894 [1] based upon the geotechnical investigations. Stability analysis of the embankment has been carried out using SLOPE/W software of Geoslope package. Earth embankments shall be safe and stable during all phases of construction and operation of the reservoir.

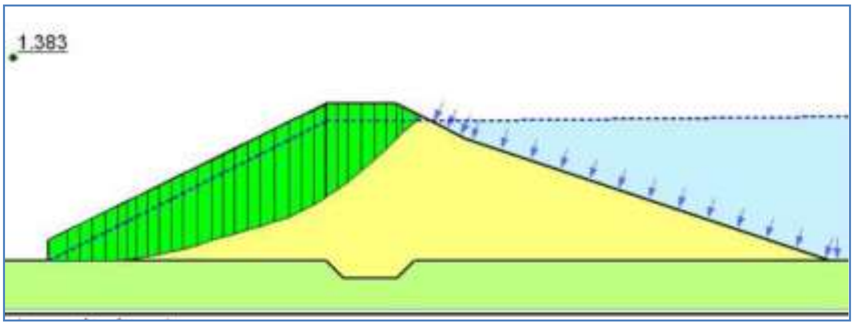

Fig. 2. Typical slope stability analysis conducted using SLOPE/W software

Analysis has been performed for the most critical combination of external forces, which are likely to occur in practice. The factor of safety calculated for the stability analysis is more than the codal requirements.

3.2 Seepage analysis

Seepage analysis of the embankment has been carried out using SEEP/W software of Geoslope package, based on Finite Element Method. The amount of water seeping through and under the embankments has been estimated by using the theory of flow through porous media. All the embankments have been constructed without any provisions for an internal drainage zone. The evaluation of seepage through the embankments is crucial since a critical uncontrolled seepage that develops during the filling of reservoir to its Full Reservoir Level (FRL) can destabilize the structure to a total structural failure.

The visually confirmed seepage conditions to be avoided are:

- the exit of the phreatic surface on the downstream slope of the dam development of hydrostatic heads sufficient to create in the area downstream of the dam erode materials by the phenomenon as “piping”
- localized concentrations of seepage along conduits or through previous zones

Quantity of seepage, exit gradient and maximum velocity are to be evaluated for checking the stability of embankments against seepage.

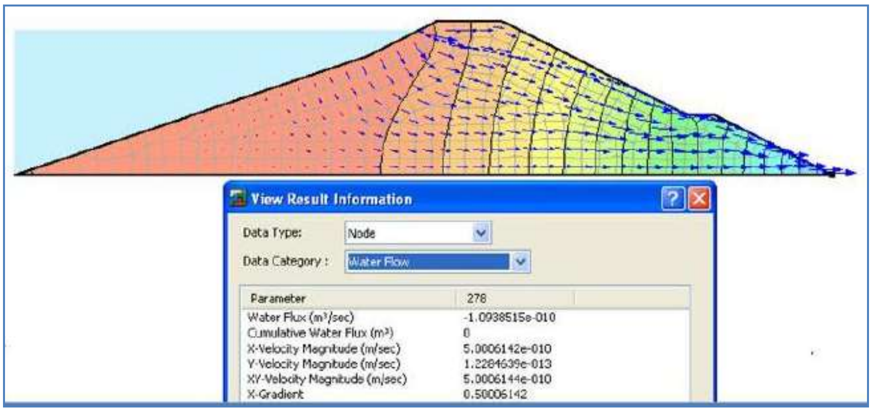

Fig 3- Typical seepage analysis conducted using SLOPE/W software

3.3 Freeboard Analysis

Free board for reservoir has been calculated as per IS 10635 [2]. The following factors are considered for the estimation of free board.

i. Effective fetch length
ii. Wave characteristics, particularly wave height and wave length
iii. Height of wind set-up above the still water level adopted as freeboard reference elevation
iv. Slope of the dam and roughness of the pitching

Fetch length of 0.4 km and wind speed of 44 m/s have been considered in analysis.

4 Root cause analysis

4.1 General

The construction of reservoir up to height of 10.5 m was completed on 1st December 2016. The filling of reservoir was commenced on 4th December 2016 after the construction was certified. Water filling was completed on 9th December 2016 up to a height of 10.0m leaving a freeboard of 500mm only. Seepage was noticed from the southern side of the reservoir-3 on 10th December. Some temporary measures were taken by site engineers but seepage was not arrested. This further led to the breach of embankment at midnight on the same day. The water flow resulted in the inundation of the nearby areas and minor losses to property. Subsequently, intermediate bund between reservoirs-2&3 failed.

4.2 Causes of Failure

The various causes of failure of reservoir embankments may be classified as:
a) Hydraulic failure
b) Seepage failure
c) Structural failure

Hydraulic Failure

Hydraulic failure accounts for over 40% of earth dam failure and may be due to one or more of the following:
i) By overtopping: This aspect needs to be addressed by providing sufficient free-board above the maximum water level. Water was filled up to a height leaving a free-board of 500mm from the top of embankment. The final layer of 2m embankment was constructed not in monolithic with the bottom layer. The water started coming from the top, which was not having enough strength to resist the water pressure and the body of dam subsequently failed.
ii). Erosion of downstream toe: The present failure started and triggered from the upstream face and this reason is not valid in the present case.
iii) Erosion of upstream surface: Erosion of the upstream surface was impossible as protected by concrete lining and this cannot be the reason for reservoir breach.
iv). Erosion of downstream face by gully formation: During heavy rains, the flowing rainwater over the downstream face can erode the surface, creating gullies, which could lead to failure. The present failure triggered from the upstream face and erosion of downstream face by gully formation shall take sufficient time. So, this has not been found to be the reason for failure of embankment.

Seepage Failure

Seepage is one of the main reasons for reservoir embankment failure. If the magnitude is within design limits, stability of the embankments will not be affected.
In our present case, foundation and embankment are highly impermeable to an extent of $1e^{-9}$m/s. Hence piping through foundation would not occur. When the downstream toe of embankments becomes saturated and starts being eroded, the process of failure due to sloughing starts. This also needs sufficient time to develop.
From the above observations, it can be concluded that reservoir breach in Dec. 2016 was not due to seepage.

Structural Failure:

Structural failure is mainly due to shear failure causing slide along the slopes. The failure may be due to:

i) Slide in embankment: This might happen when there is a sudden drawdown, due to development of extremely high pore pressures, which decreases the shearing strength of the soil. The mid embankments between reservoirs-2&3 failed due to this reason.
ii) Foundation slide: Since the foundation is having sufficient bearing capacity, the breach was not occurred due this reason.
iii) Faulty construction and poor maintenance: Compaction was done at water content less than Optimum Moisture Content (OMC). Soils compacted in less than optimum water content; have a certain skeleton strength composed by suction effect between soil particles. This skeleton strength readily disappears by wetting (saturation) during the filling of the reservoir, which results in large settlement also in differential settlement and opening cracks. During filling of water in the reservoir, seepage started from the top layer. The fill material at the top layer might not have sufficient strength and overtopping was triggered due to this.

4.3 Analysis of rectified embankments

Considering the studies, existing embankments have been modified by reducing the top width and modifying to a milder slope, provision of retaining wall, revised free board and effective drainage system. Analysis has been carried out on the rectified embankment sections for critical cases. The factor of safety calculated for the stability analysis is more than the codal requirements. Seepage quantity and flow velocity has been determined, as bare minimum and phreatic line has been modified not to exit along the downstream failure. Factor of safety against piping failure has been estimated and found to be greater than 3.

5 Reservoir Strengthening Measures

Based on the above analyses, strengthening measures suggested are given below:

Upstream face

- On the breach portion on the southern side of reservoir 3, concrete lining with construction joints to be provided after preparation of surface and plate compaction.

Downstream face

- Erosion of the downstream slope to be prevented by providing grass turfing. Down stream surface should be properly maintained; all cuts (if any) filled on time and surface well grassed
- Where turfing cannot grow on downstream slope of embankment, for proper growth of turfing selected soil layer may be provided or alternatively 300 mm thick hand placed riprap without filter layers may be provided
- Grass turfing shall consist of the furnishing and laying of live grass of perennial turf on downstream slope.

- Stone pitching with 1:3 cement mortar is to be provided at the slope in vicinity to an office building. Intermediate tie beams of size 200mmx300mm shall be provid ed at very 3m c/c in both directions.

Toe

- On the southern embankment near the breached area and on eastern embankment where there is a space restriction, 2m high RCC retaining wall/Gabion wall is recommended at the toe.
- Toe drains are to be provided all along the periphery details.

Top of embankments

- Cracks of the top layer shall be filled with bentonite slurry with 50mm dia. 2m long holes at 3m spacing
- Compaction using plate compactors with adequate sprinkling of water after soil sta bilization
- Interlocking pavement blocks to be provided with underlying 75mm thick sand layer and 100 thick Granular sub base (GSB)
- Top level of all embankments to be maintained uniformly at same level before pavement work commences

Mid embankments

- Loose materials in the breached portion shall be removed up to hard soil and comp acted using plate compactor. Sides of the breached portion to be trimmed to a slope of 1V:3H and to be protected using 125 thick concrete lining on the sides and bot tom to avoid further erosion. If unprotected, this will lead to uncontrolled seepage along the direction of the embankment on northern side, which may further breach.

Freeboard

- Freeboard of 1.5m is to be provided for the reservoir during its operation at Full Reservoir Level (FRL)
- A parapet wall of height 0.5 m is also proposed on the inner periphery of the emb ankment

6 Conclusions

This case study explains the root cause analysis conducted for breaching of reservoir embankments. Overtopping failure, which is a prominent cause of reservoir breach, shall be prevented by sufficient free board in reservoir. The embankment was raised in different years and the ultimate lifting was executed without proper compaction. Due to this, embankments were overtopped and subsequently breached. Construction joints shall be sealed properly to make the upstream face waterproof and watertight. Downstream face shall be protected from erosion and rainwater cuts.

7 References

1. IS 7894, Code of practice for stability analysis of earth dams
2. IS 10635, Freeboard requirements in embankment dams - Guidelines