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Remedial Measures to Seepage and Instability Aspect of a Dam Near Bombay

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SYNOPSIS: The paper describes the distress caused to a minor earth dam constructed at a high elevation in a mountainous area to conserve water. The distress related to instability of the dam and also due to high percolation underneath the dam coupled with formation of piping. The remedial measures taken to rectify instability and reduce percolation are described in this paper.

INTRODUCTION

In India western ghats, a mountain chain runs parallel to west coast of India, starting from a few kilometers north of Bombay and go right upto Cape Comerin, covering a distance of 1500 km to 2000 km. These mountain ranges have elevation ranging from 1000 m to 4000 m. The rainfall varies from 2000 mm to 4000 mm that too during monsoon season. The rock formations are mostly of basaltic origin locally known as deccan trap. The mountain ranges are highly folded, faulted and jointed. The joints are present right upto a depth of 20 m to 40 m.

There are a large number of locations in these mountain ranges which are ideal for storing water at high elevations.

During recent years a large number of human settlements are getting established in such locations. To provide water for such settlements, reservoirs having capacity of 200 TCM to 300 TCM are constructed.

To develop a social welfare centre a tank having a storage capacity of 227.53 TCM was constructed at Kune, in Poona district, in western ghats. The main gorge and the upstream storage area is formed due to the presence of around 3 to 4 hills. Water is collected from a catchment of around 0.75 sq.km through 2 to 3 streams which converge at the gorge and join the main valley, after a vertical drop of 100 m.

A zoned rolled filled earth dam of height 15.9 m. and length 77 m. was constructed to store water. A waste weir was constructed by blasting the weathered rock, and is located at a distance of around 7 m. from the dam on the right flank. It was unlined.

During the first filling of the dam in the year 1984, the authorities noticed heavy seepage on the down stream side of the dam. They also observed subsidance and heaving on a portion of the down stream part of the dam close to the right flank. The tank was getting depleted at a rate of around 11 cm. perday.

The authorities approached the authors to study the causes of the distress and suggest the remedial measures to be adopted. A systematic study was conducted through visual observations when the reservoir was empty and also by conducting appropriate subsurface investigations. Based on these studies various remedial measures were adopted. The efficasy of the remedial measures adopted was evaluated during the subsequent fillings of the dam. The paper describes the above aspects.

LOCATION

The tank is located at Kune, in the state of Maharashtra. The latitude and longitude of location are 19°46'0'' north and 73°24'0'' east respectively. Location at which the tank is constructed is on the top of western ghats surrounded by highly folded, weathered and jointed hills and mountain features. It may be observed from the countour map given in Fig.1, that the dippression is formed by folding of almost 3 to 4 hills. A small valley in between the two hills provides an outlet for the water to drain into the main valley through a steep vertical drop. The underlying rock mass is made up of various types of basaltic rocks. The heavily jointed terrain is subjected to high degree or hydro thermal weathering of rock mass. The top 2 m. to 5 m. of over burden consists of murrum containing various amount of boulders, gravel and fine grained material. This is a typical tropical soil. On the basis of vegetation one can expect highly weathered fractured rock interspersed with murrum of thickness 10 m. to 12 m. As this site is close to a mountain fall one can expect jointing to reach a depth almost of the order of 40 m. or more.

An examination of the countour map indicates that the jointing and fracturing may converge at the main gorge. This may lead to collection of percolated water from subsurface at that point and may act as an outlet channel.

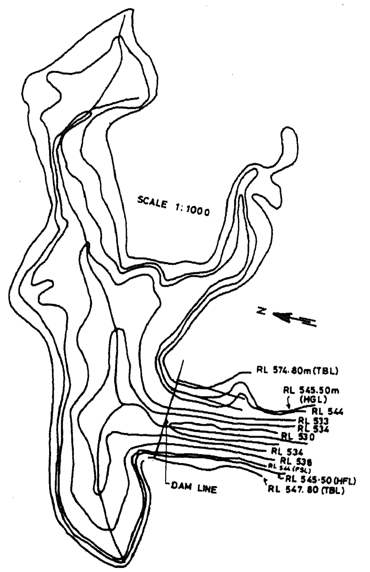

Fig. 1 Contour Map of the Dam Site

BROAD FEATURES OF THE SCHEME

Nature of the catchment	: ghat type
Catchment area	: 0.75 sq.km.
Average rainfall	: 3587.35 mm.
Total yield available	: 2690.51 TCM
Total storage capacity	: 227.53 TCM
Storage yield	: 211.75 TCM
Storage due to borrow area	: 15.78 TCM
Levels of the dam	
Lowest base level	: RL 530.01 m.
FSL	: RL 543.00 m.
HFL	: RL 544.50 m.
TBL	: 77.00 m.

SALIENT FEATURES OF THE DAM

The dam is a zoned rolled filled earth dam. The salient features of the dam are given below. See Fig.2 and 3.

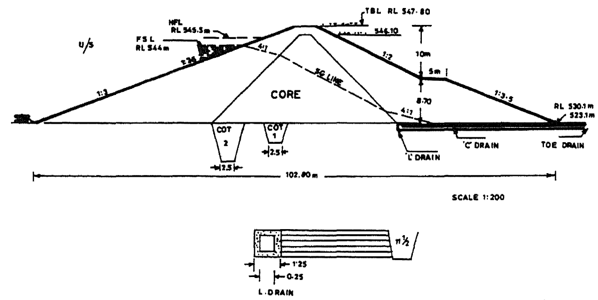

Fig. 3 Cross Section of the Zoned Dam.

The dam lies between	: ch 36 and ch 113
Deepest portion of the gorge lies between	: ch 70 and ch 75
Upstream slope	: 1:3 upto RL 537.8; 1:2.5 from RL 537.8 to TBL
Down stream slope	: 1:2.5 between RL 530.10 and RL 537.8; 1:2 between RL 537.8 and RL 547.8

Berm of width 5 m. is provided on the down stream side at RL 537.8

Central core :

Top width of core : 2 m.
Slope of u/s and d/s side : 1:1

Cut off trench :

Two cut off trenches are provided whose width is 2.6 m. and depth 3.6 m. Rock toe is provided on the d/s side.

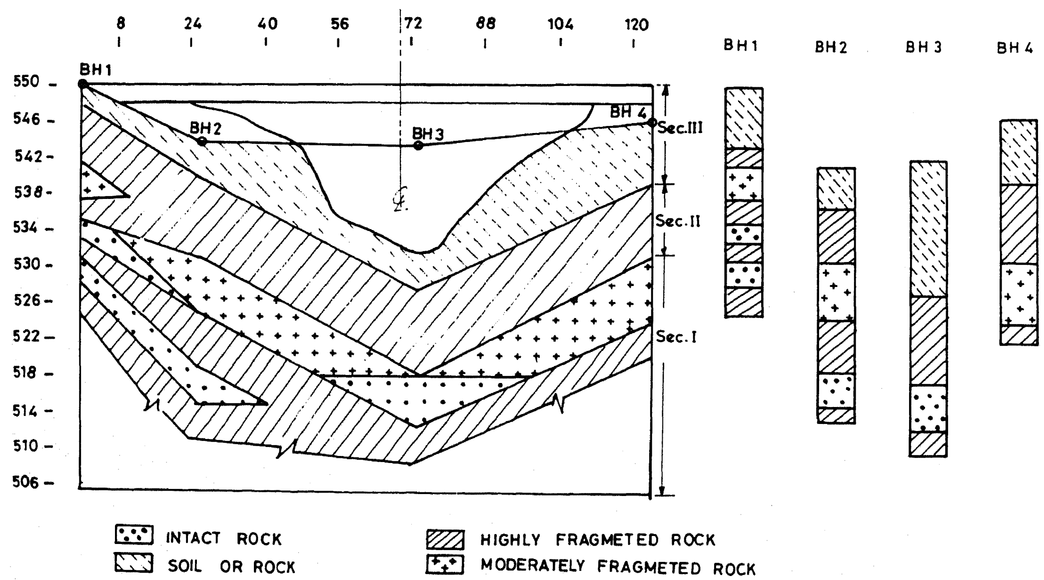

Fig. 2 Subsurface Section Along the Dam Axis

Rip rap :
30 cm. to 40 cm. boulders are placed on up-stream as well as down stream sides.

Density of hearting material : 1.29 gm/cc
Density of casing material : 1.80 gm/cc

Filter :
Longitudinal drain and cross drains are provided on the down stream side.

WASTE WEIR

The major portion of the waste weir passess through rocky strata. For construction in rocky strata blasting methods were adopted. The waste weir was left without lining and sides and bottom are highly jointed. The distance between the waste weir and the dam is around 5 m. to 7 m. The bottom of the waste weir is 10 m. wide corresponds to FSL (RL 544).

NATURE OF DISTRESS

During first filling of the dam two kinds of distresses were encountered. One related to stability aspect and the second related to the percolation aspect. The percolation aspect in turn may also be responsible for instability of the dam and the flanks. As a first step immediately after the whole water in the tank had got completely depleted, in the middle of February 1984, a thorough visual inspection of storage area, dam and the waste weir was conducted.

Reservoir Area

The whole area consisted of highly weathered soil mass followed by highly fractured and jointed basalt. See Fig.2. Such a condition of reservoir may give rise to high degree of subsurface percolation. It was also observed that a big piping had appeared close to the waste weir and was cutting across underneath the dam and was opening up down stream at RL 536. Further examination revealed that 2 to 3 streams which are passing through the reservoir area converge into goose neck and join the main valley. The location of the piping coinsides with the course of the stream. It is presumed that the cut off trenches are above the bed of the streams which are filled up with sand and gravel. See Fig.5. It is also observed that considerable distress has taken place on the right flank due to blasting operation during the construction of waste weir. This can lead to heavy percolation through the right flank when the dam would be full.

Instability of Dam

The portion on the down stream of the dam enclosed between RL 538 and RL 542 and between chainage 40 and 68 showed subsidence and heave indicating potential possibility of slide. In addition a subsidence of around 30 cms was observed on the top of the dam towards d/s side between chainage 45 and 55.

The dam section used here is a standard section adopted in these regions for minor dam construction. These sections are stable when they are constructed by compacting the locally available murrum to maximum standard proctor density with a variation of ± 5%.

Fig. 4 Nature of Basin.

Fig. 5 Stream Feeding the Reservoir.

Subsurface Investigation

To understand the causes of heavy seepage it was considered necessary to take around 4 boreholes along the dam axis. See Fig.2. With the help of 4 borehole logs a subsurface profile is developed to indicate the strate containing murrum, highly crushed fragmented rock and intact rock etc. It can be seen from the section that on the right flank murrum deposit is encountered upto RL 536 and at the centre of the dam it is upto RL 527.5. Near borehole 4 the murrum zone ends at RL 539. Below the murrum zone around 8 m. to 10 m. of thick fragmented crushed rock zone is encountered. On the left flank the rock strata encountered is moderately fragmented rock as shown in Fig.2. On the basis of subsurface section coupled with surface observations in the storage area it can be concluded that even after the dam is constructed almost all the water can percolate out at a high rate through the subsurface underneath the dam. The average thickness of crushed rock and murrum overburden would be around 18 m. Approximate computations show that the coefficient permeability K value would be 2.2×10^{-2} cm/sec. for average strata. However, the coefficient of permeability for fractured zone would be 4×10^{-1} cm/sec.

In the present case it is clear that the percolation is not only through the subsurface but also through the right flank.

Embedment

Inadequate embedment of right and left flanks of earth dam into the original natural ground has added to further seepage losses and also to instability of the dam itself. Weakening of the right flank due to construction activities in the waste weir has further contributed to high seepage and to instability to flanks and the dam. See Fig.4.

Steep Gorge

Because of narrow steep gorge 3 diamensional instability is induced into the earth dam. As such conventional analysis indicate that the dam should be stable under normal conditions.

Piping

In adequate cut off, untreated subsurface, and followed by storing of tank has resulted into high internal subsurface erosion and formation of pipes. See Fig.6.

Fig.6 Piping

REMEDIAL MEASURES

Based on the visual observations of the reservoir area, dam, flanks, waste weir and the subsurface profiles, following remedial measures were adopted in stages to rectify the defects in stages as the time available for implimenting the remedial measures was hardly 2 to 3 months. The remedial measures adopted for improving the stability of the dam and reducing the percolation are given below :

i) Preventing the d/s slide with shear barriers using reinforcement
ii) Adoption of curtain grouting
iii) u/s dam protection
iv) Treatment of reservoir area with impervious material
v) Lining of the waste weir

Stability of d/s Side

Specially with respect to the stability of dam on the d/s side, there was a need to take immediate rectification measures. The measures taken with respect to stability are described below. With the help of zone of subsidence and heave a probable circular potential plane of failure was adopted for analysis. The computed value of the activating force turns out to be 4 tonns/m. width. It was considered prudent to provide shear connectors to take the whole activating force (4T/m. width) as the portion was already in the process of sliding. The method adopted consisted of providing 3 rows of shear connectors with the spacing as shown in Fig.7 and Fig.8.

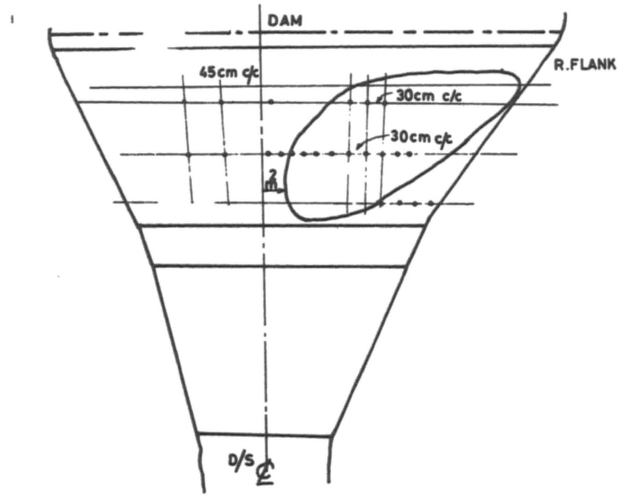

Fig. 7 d/s Face

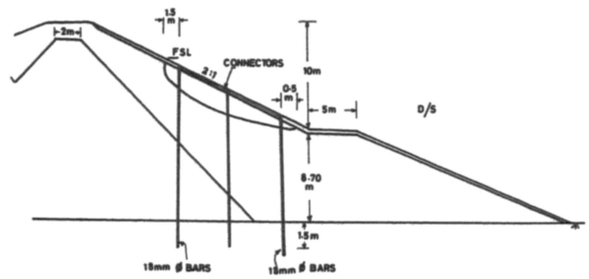

Fig. 8 d/s Section

Construction

Minimum number of rip rap stones were removed at the location where the shear reinforcement were to be inserted. Pnumatic drill was used to drill a 2.5 cm. diameter hole upto a depth of 1.5 m. into the original ground through the body of the dam. Care was taken to see that the surrounding rocks are not disturbed. After the drilling was completed 16 mm. diameter steel bars were inserted into the hole upto the desired depth. The remaining cavity of the whole was filled with cement slurry of 1 in 15 consistancy. The 3 rows of bars were inter connected with 6 mm. diameter bars at the surface of the soil layer. Immediately after these rods are placed in position the rip rap was reinstated.

Grouting Procedure

As the pressure due to water is around 1.5 kg/cm^2 it was necessary to use a thick mix 1:6 to 1:8. The cement bentonite ratio was 60%: 40%. The grout mix was injected at 2 kg/cm^2 and was raised up 4.5 to 6 kg/cm^2 before termination between RL 505 and RL 520. See Fig.9.

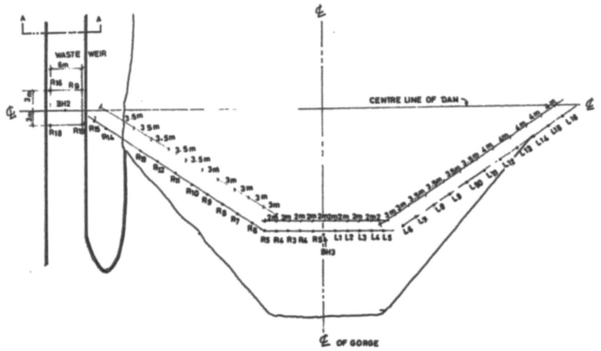

Fig. 9 Grouting Plan.

The second stage of grouting was between RL 525 and RL 520. The grout mix used was 1:8 to 1:9. The initial pressure was 1.5 kg/cm^2 to 2.5 kg/cm^2 and was raised to 3.5 kg/cm^2 before termination.

The grouting in the weathered zone was done very carefully without increasing the pressure equal to the height of the dam.

The amount of grout consumption interms of cement bags turned out to be more than 90 bags per hole between the waste weir and chainnage 50 as compared to 2 to 5 bags per grout hole on the left flank. The above procedure was implimented only after the reservoir got emptied. The piping portion was plugged with cement concrete.

u/s Face

To prevent heavy percolation through the upstream face the rip rap was completely removed. The whole area was covered with impervious, double ply polypropeline sheets passing over the top of the dam to around 1/2 m. on d/s face from the top. The tip rap was reinstated and was pointed with cement forter. The same method was used in the inclined portion on either side of the dam.

Basin

Asphaltic treatment was adopted to prevent seepage of water. The method consisted of scraping the area, placing 2 cm. to 3 cm. thick grated metal and lightly compacting it. 70-80 penetration asphalt was spread at the rate of 5% of the weight of the aggregate. Choke stone was spread and was lightly rolled. Subsequently a thin layer of asphalt was spread on the top and was covered with stone dust. Only some critical part of the basin could be treated before the rains during 1984. This helped considerably in reducing the percolation as observed during the filling of the dam. See Fig.10. When the dam was completely filled suddenly a pipe appeared increasing the percolation. Subsequently it was observed that the pipe got started on the upper reaches of one of the stream. See Fig.10. With the help of asphaltic treatment and grouting the percolation was reduced to the extend of 10^{-4} to 10^{-5} cm/sec. However, as the basin is small and the demand of water is high it was decided to adopt gunniting and sodium silicate treatment to treat the basin to prevent percolation. The streams were treated by gunniting to a considerable distance from the reservoir area.

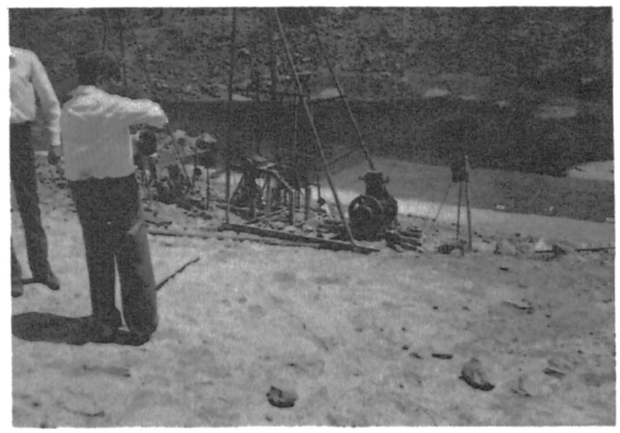

Fig. 10 View Showing Basin Asphaltic Treatment and Grouting.

Waste Weir

Waste weir was lined with bricks and was properly plastered. Polythene sheets were used below and around the brick lining to prevent water from percolating. The gap between the brick lining and undulated surface of the blasted waste weir wall was filled up with soil. See Fig. 11, Fig.12, Fig.13 and Fig.14.

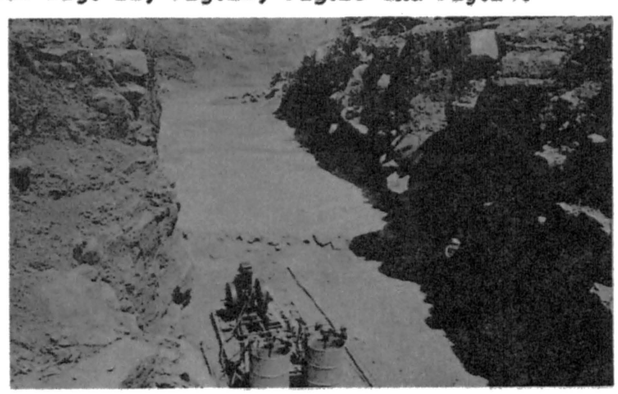

Fig. 11 Waste Weir Prior to Lining.

PERFORMANCE

Stability

During the last 2 filling the dam has not shown any distress and is stable. See Fig.15.

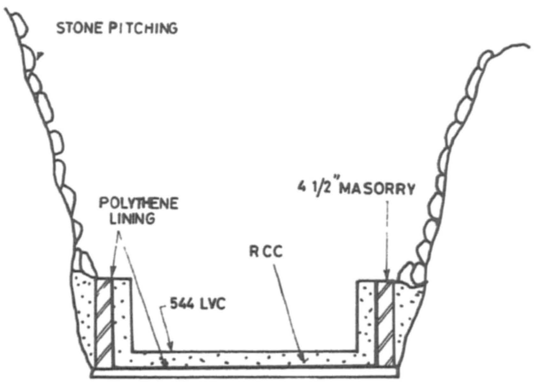

Fig. 12 Cross Section Showing Lining.

Fig. 13 View of Waste Weir After Lining.

Fig. 14 Pointing of the Dam Rip Rap and Gunniting.

Percolation

The treatment has reduced percolation to a reasonable degree. The problem of preventing the formation of piping has been done with treating the streams to a considerable distance from the reservoir area.

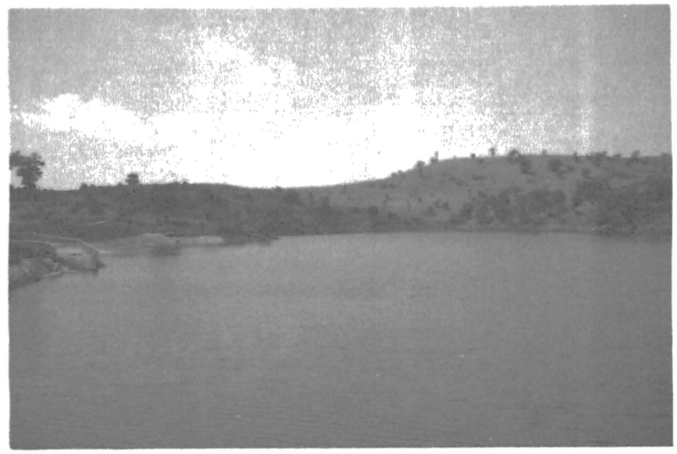

Fig. 15 Reservoir - Filledup

SUMMARY AND CONCLUSION

However, minor may be a dam it is necessary to construct it by adopting all well laid scientific and engineering procedures. Recification of a dam or a reservoir would add to considerable expenditure. The remedial measures adopted in the present case with respect to the stability of the dam are found to be quite satisfactory. The basin treatment with impervious material can be considered as a satisfactory solution to reduce percolation from the floor of the basin.

It is necessary to treat the streams to prevent percolation and formation of piping.

It is possible to develop cheaper basin treatment methods and also construction of stable minor dams to store water at higher elevation in mountainous area.

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