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Behaviour of Inginimitiya Embankment Dam

T. Sivapatham
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SYNOPSIS

The prominent component of the Inginimitiya Reservoir Project is the Inginimitiya Dam. This dam with a maximum height of 58 ft is essentially a homogeneous earthfill embankment except for the slope protection, filter and drainage arrangement. The cut-off for the foundation seepage and the provisions made in the design for seepage control are described in this paper.

The reservoir when partially impounded for the first time in 1983 "boiling" (bubbling with fines heaving up) was observed on the downstream at different locations close to the toe of the embankment between chainages 71 and 75. This reach when investigated revealed the presence of an impermeable residual soil layer on the ground surface. The material in the entire foundation of the dam up to bed rock is insitu weathered rock material which is heterogeneous in nature.

The analysis of the problem and the remedial measures adopted are discussed in detail. The performance of the embankment dam in 1984 and 1985 after the remedial measures were adopted is found to be satisfactory.

1. INTRODUCTION

The Inginimitiya Reservoir Project is situated in the North Western Province of Sri Lanka. The Embankment dam is the prominent component of the project. The dam is constructed across Mi-Oya and is 2 miles 4,690 ft long with a maximum height of 58 ft at the river.

Several dam sites were investigated and the present one was ultimately chosen as the most suitable site from considerations such as geology, storage capacity and the availability of foundation rock at the location of the spillway.

Water balance studies for irrigation of 6300 acres under the Project dictated the full supply level of 202 ft M.S.L. The dam top elevation was fixed at 212 ft M.S.L. allowing for the flood lift, wave height, wave ride up, etc.

In view of the availability of homogeneous and suitable embankment materials (all residual soils) in the vicinity of the dam site and the foundation conditions encountered along the dam axis, a homogeneous embankment dam was chosen to close this wide valley. This type of dam was found to be both economically feasible and technically sound.

2. DESIGN FEATURES OF DAM

The plan and longitudinal section of the dam axis are shown in Fig. 1. The typical design embankment section is shown in Fig. 2.

The width of the dam crest was chosen as 20 ft to facilitate vehicular traffic. The upstream and downstream slopes were chosen to be 1 on 2.5 and 1 on 2 respectively. The upstream slope was protected with rip-rap to prevent erosion by wave action. The downstream was provided with turf to prevent surface erosion by rain water. Sufficient freeboard was provided by keeping the dam top elevation at 212 ft M.S.L. to prevent overtopping of the embankment dam during floods. Due to the availability of a large quantity of decomposed rock materials from spill tail canal excavation it was decided to use this material on the downstream slope as shown in Fig. 2.

The average properties of the fill materials used for the construction of the embankment are shown in Table 1 (Nos. 1 & 2).

Since the foundation rock along the dam axis exists at greater depths (45 ft below bed level at the river) as shown in Fig. 1, only partial cut off was provided by taking the core trench to a depth of one-third the dam height. Generally the material encountered at the bottom of the core trench at this level was fairly
hard decomposed rock materials. Because of partial cut off, special attention was given to the downstream drainage arrangements during the design stage. The filters on the downstream included a horizontal sand blanket, a larger rock-toe filter and toe drain.

3. BEHAVIOUR OF THE DAM

The dam was completed in 1983 except for the construction of the toe drain in certain reaches and it was partially impounded in late 1983 by the help of a coffer dam across the spillway which was not completed at that time. After the water reached a maximum level of around 194. ft M.S.L. (full supply level being 202 ft M.S.L.) "boiling" (bubbling with fines heaving up) was observed on the downstream of the embankment close to the toe at many locations between chainages 71 and 75 and the downstream area in this reach was in a "quick condition". This "quick condition" or "boiling" was not observed anywhere outside this reach of the dam. The material that came out of the "boils" were very fine silty sand-clay mixture which was decomposed rock materials. It is believed that the seepage path is below the bottom of the core trench which is about 26 ft below ground level. The dam height in this reach is around 42 ft.

Immediate remedial measures were attempted by reducing the water level by discharging water through the sluice and cutting a relief trench at the toe and filling with sand. Since the downstream area was in a "quick condition" the latter operation was found to be difficult. Fortunately the inflow into the reservoir reduced and the water level was gradually lowered. Hence there were no damages caused to the bund.

Sub-surface investigations were carried out in the reach from chainages 71 to 75 in the downstream toe area. Auger holes were dug and the soil samples were tested and classified. The material is basically a residual soil. The typical results of tests on samples in this reach are shown in Table 1 (Nos 3 & 4).

Fig. 1. - Plan and Longitudinal Section of Dam Axis
4. ANALYSIS OF THE PROBLEM

The investigations revealed the following:

(i) The downstream area in the reach from chainage 71 to 75 was covered with a soil of very low coefficient of permeability.

(ii) When the reservoir water level was at 191.6 ft M.S.L. the piezometric level at the downstream toe was at 170.0 ft M.S.L. which is the same as the average ground level in the reach from chainage 71 to 75.

(iii) The bed rock is 42 ft below ground level and 16 ft below bottom of the core trench in the reach from chainage 71 to 75.

The seepage flow is confined only to this 16 ft between the bottom of the core trench and the bed rock.

The presence of impervious soil in the downstream area was likely to have prevented free exit of seepage water with high exit gradients and thus exerted large seepage forces on the downstream which caused "boils" (bubbling with fines heaving up) at different locations in the downstream area.

The material below the foundation of the embankment is in situ weathered rock (residual soils) with bedding planes which characterise the parent rock. In this heterogeneous material...

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**Table 1.** Average Results of Embankment materials and typical results on samples between chainages 71 and 75.

<table>
<thead>
<tr>
<th>No.</th>
<th>SAMPLE</th>
<th>Unified Soil Classification</th>
<th>Liquid Limit</th>
<th>Plasticity Index</th>
<th>Specific Gravity</th>
<th>Mechanical Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Fill Material</td>
<td>SC</td>
<td>21</td>
<td>30</td>
<td>16 22 14 14 28 06</td>
<td>100 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14.2 112.5 1150 22.5</td>
</tr>
<tr>
<td>2.</td>
<td>Decomposed Rock Material</td>
<td>SC</td>
<td>19</td>
<td>17</td>
<td>12 23 22 31 04 04</td>
<td>98 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Ground Surface on Downstream</td>
<td>SC</td>
<td>17</td>
<td>8</td>
<td>2.60 08 21 35 30 04 02</td>
<td>98 39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Material from Locations where</td>
<td>SC</td>
<td>17</td>
<td>70</td>
<td>2.64 16 28 32 22 02</td>
<td>100 44</td>
</tr>
<tr>
<td></td>
<td>&quot;boiling&quot; occurred</td>
<td></td>
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</tbody>
</table>
the locations of lines of least resistance against subsurface erosion and the hydraulic gradients required to produce a continuous channel along these lines depend only on geological details. This cannot be deterrnind by any theoretical methods, Terzagaphi & Peck (1968).

It is seen from Fig. 1 that in the reach from chainage 71 to 75 the distance between the bottom of the core trench and the bed rock is the smallest (16 ft) when compared to all other sections along the entire length of the embankment. Therefore, there would have been a concentration of seepage flow which probably would have produced continuous channels along lines of least resistance against internal erosion. The "boiling" observed may also be attributed to this internal erosion.

5. PERMANENT REMEDIAL MEASURES

A seepage analysis was carried out by sketching a flownet, Harr (1962), using the following conditions as applicable to the site.

(i) The worst condition during floods with the reservoir water level at 204 ft MSL.
(ii) The seepage through the foundation takes place within a 42 ft thick soil stratum which overlies bed rock with 16 ft thick soil stratum between the bottom of core trench and bed rock.
(iii) 5 ft thick top impervious layer extending to a distance of 100 ft from downstream toe of dam.

From the flownet, the uplift pressures were calculated and the loads required to balance the uplift pressures with a factor of safety of 2.5 were computed.

Materials from the spill tail canal excavation which were in spoil dumps were used over a sand layer as stabilising fill to produce the loads required. As an additional safety measure a relief trench was excavated along the length of the dam close to the toe as possible and filled with sand. This sand was made continuous with the horizontal sand layer below the stabilising fill. Wrap-around toe drains and lead-away drains constituted the drainage for the area. The details of these arrangements are shown in Fig. 3.

Elsewhere along the downstream where this phenomenon of "boiling" was not observed and where the toe drain had not been constructed relief wells of 6 inch diameter filled with sand to a depth of about 10 ft at 10 ft intervals were provided below the bottom of the toe drain at locations where impervious material was encountered during the excavation for the construction of the toe drain. This is also shown in Fig. 3.

The remedial measures were completed in 1984. The reservoir was impounded in 1984 and in 1985 it was spilling with water level in the reservoir rising above 202 ft M.S.L. The "boiling" was not observed and the entire downstream area was safe with no visible signs of a "quick condition."

Fig. 3 - Downstream Remedial Measures
6. CONCLUSIONS

The causes for the occurrence of the 'boils' on the downstream portion of the embankment in the reach from chainage 71 to 75 may be attributed to the following:

(i) The presence of impervious soil in the downstream toe area which was subjected to high exit gradients.

(ii) Concentration of seepage flow in the heterogeneous foundation material which produced continuous channels along lines of least resistance against internal erosion.

It is concluded that the remedial measures adopted are adequate for the satisfactory performance of the embankment.

7. ACKNOWLEDGEMENT

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8. REFERENCES:
