Correction of a Lateritic Hill Slide in Goa

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ABSTRACT
A seven storey commercial building was constructed in Goa by creating a ground plot by cutting a hill, exposing 18 meter high slope, facing the West. A 3-meter high RCC retaining wall was constructed to protect toe of the slope. After a heavy monsoon season, the hill slope suddenly collapsed. It broke and distorted the toe-retaining wall, caused upheaval of road around the building and soil piled up against the building wall. Corrective steps included mapping geometry of slip plane and estimating soil properties by analyzing the slope stability. Remedial measures included a deep seated RCC toe-retaining wall, laterite-block masonry layer as slope face protection, creepers to protect exposed sandy face near the top and concrete drain beyond top edge. After 4 years, it was observed that corrective measures were performing satisfactorily."

Keyword: Hill Slide

1. INTRODUCTION
A 7-storeyed commercial building was constructed in a busy area of Madgaon Town. For this purpose, a large ground plot was created by cutting back a lateritic hill to the east of the building. The cutting had height of 18m on the East side with sloped faces on North and South sides. A 54m long and 3 m high RCC retaining wall was provided to protect toe of the slope. A 8- metre wide road separated main building and toe of the slope. (Fig.1)

Towards the end of a heavy monsoon season, the East side hill face suddenly collapsed and slid towards the building. This slide broke / distorted the toe retaining wall, caused 75 cm upheaval of the road and a large volume of lateritic soil piled up against the building walls. (Fig.2)

By the time the site was visited, there were just 4 months left before onset of the next monsoon. There, was no time to conduct detail soil investigation. Therefore, the soil properties were estimated by mapping the geometry of the slip surface and analyzing the slope stability.

Remedial measures were based on study of the soil properties, geometry of the cut and behaviour of typical lateritic soils. These included deeps- seated toe retaining wall, protective blanket on dispersive exposed soil surface, planting creepers to protect uppermost sandy zone and provision of drainage system.

These measures were completed before the onset of the monsoon. The site was visited for inspection after 9 years, and it was observed that the protection measures were performing satisfactorily.
2. SITE GEOLOGY

The site is located in a lateritic countryside. Typical laetrile profiles can be stated as (i) high level and (ii) low level. High level laterites are found on upper levels of the Western Ghats where rainfall is heavy and downward drainage is rapid. These result in development of thick, vesicular, hard laterite stone caps with underlying softer zones of weakly cemented sand, silt, and clay (called lithomarge).

Low level laterites are formed on low-lying hills, between the foot of the Western Ghats and the western sea-shore. In this zone, rainfall is relatively moderate and subsurface downward drainage is slow, even it may be upward in hot summer seasons.

Lateritic profile in this low-level zone typically consists of (a) thin top layers of hard laterite, followed by (b) weakly cemented (by iron oxides) red sand, (c) yellow / mottled coloured sandy silt/silt and (d) light yellow to white clay.

When the lateritic hills are cut, exposing the soil to direct rains, (a) top thin laterite crust may collapse due to loss of support from the underlying soil zones, (b) weakly cemented sand zone gets disintegrated by forces of the rain drops, (c) sandy silt/silt gets eroded, and / or (d) white clay zone is softened and can slump or flow out, due to water absorption.

The loss of clay strength triggers collapse of the overlaying soil zones. As a result, the soil slopes collapse by slip-circle mode or local shear.

3. SOIL PROPERTIES AT THE SITE

During the course of the remedial works, disturbed soil samples were collected from each of the zones and were tested for grain size distribution. Few block samples were also cut out from the exposed faces and tested for Density, NMC, Atterberg limits, strength and swelling. Representative results are as follows (Table 1).

![Table 1: Soil Properties](image)

<table>
<thead>
<tr>
<th>Zone</th>
<th>(b) Upper Reddish Sand</th>
<th>(c) Mottled Silty Sand/Silt</th>
<th>(d) Light Yellow White Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp. Gravity</td>
<td>2.83</td>
<td>2.7</td>
<td>2.58</td>
</tr>
<tr>
<td>Density</td>
<td>2.0</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Gravel</td>
<td>30</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>% sand</td>
<td>23</td>
<td>34</td>
<td>37</td>
</tr>
<tr>
<td>Silt+ clay</td>
<td>47</td>
<td>56</td>
<td>63</td>
</tr>
<tr>
<td>% Liquid Limit</td>
<td>45</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>% Plastic Limit</td>
<td>27</td>
<td>32</td>
<td>27</td>
</tr>
<tr>
<td>%NMC</td>
<td>14</td>
<td>21</td>
<td>27</td>
</tr>
<tr>
<td>a T/m²</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>φ Deg.</td>
<td>29</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>FSI %</td>
<td>-</td>
<td>46</td>
<td>71</td>
</tr>
</tbody>
</table>

Note: White clay (d) Contained Na-cation in pore water. Hence Dispersive. Ground water was not encountered even at RL (-) 4.0 m.
4. BACK - ANALYSIS OF THE FAILED SLOPE

Geometry of the failed slope was plotted from measurements in the field (Fig. 2).

Simplified approach was used to assess the soil parameters – i.e. same ‘C’ and ‘f’ values assumed along the entire slip circle.

Stability analysis programme for high embankments was used. Slip circles touching lowest elevations at R.L. (-) 1.5 to (-) 3.5 m, were analysed and gave minimum F.S., as follows.

<table>
<thead>
<tr>
<th>Elevation at Bottom</th>
<th>F.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-) 3.5 m</td>
<td>0.963</td>
</tr>
<tr>
<td>(-) 3.0 m</td>
<td>0.933</td>
</tr>
<tr>
<td>(-) 2.5 m</td>
<td>0.899</td>
</tr>
<tr>
<td>(-) 2.0 m</td>
<td>0.880</td>
</tr>
<tr>
<td>(-) 1.5 m</td>
<td>0.828</td>
</tr>
</tbody>
</table>

From these, F.S. value of 0.963 (i.e. close to 1.0) for bottom elevation of (-) 3.5 m was selected.

This gave ‘C’ value of 2.5 kg/cm$^2$ for density of 2.28 T/m$^3$

5. CORRECTIVE MEASURES

Measures for long term stability of the hill slope were worked out based on:

(i) Behaviour of the Lateritic soil profiles,
(ii) Effect of Rains, and its direction
(iii) Soil properties of the exposed slope and 4 m below the road level.
(iv) Construction facilities available at the site, to complete the works before end-May.

As a result, the following were adopted:

(a) Constructing a cellular RCC retaining wall, at toe of slope, with base at R.L. (-) 3.0 m (Fig 3).
(b) Protection of the exposed 45° soil slope, (from top of the retaining wall upto base of the Red sand layer) by a 0.5 m thick course of laterite block masonry, with down-sloping weep holes on 3 m x 3 m grid.
(c) Top vertical red sand layer - provide creepers on the exposed face to protect it from Impinging raindrops and surface flow of water.
(d) Beyond the top edge of the slope - provide vegetation cover.
(e) Drainage of surface water - provide laterite masonry as top cover, for the Toe Retaining wall, with a mild slope towards the building side.

REMARKS

a) The corrective measurement was designed without waiting for detail soil investigation.

b) All the works were carried out before of the monsoon

c) Locally available resources were used to minimize cost and time.

d) Site inspection after 9 years revealed that the protection measures were performing satisfactory.

REFERENCES

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