Geotechnical Evaluation of the Unstable Slopes of Cabohill, near Rajbhavan, Panaji, Goa

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Abstract

Raj Bhavan, the official residence of His Excellency, the Governor of Goa, situated atop the Cabo hill promontory (El.40m) is over 400 years old. This NW-SE trending promontory is confined by Mandavi River in the North, and Zuari River in the South, both rivers flowing towards South and joining the Arabian Sea. The western and the north western slopes of this promontory adjacent to Raj Bhavan, facing the Arabian Sea have been experiencing continued distress since a few decades. Cracks have been developed on the pavements, floor of the verandah and also extending head ward retrogressively intercepting the corners of the back portion of the building of Raj Bhavan.

The Geotechnical evaluation of instability of slopes of Cabo hill, adjacent to Raj Bhavan, Goa includes the detailed investigation conducted at this site which includes surface geotechnical studies, geophysical surveys, subsurface exploration by drilling, insitu testing of the sub soil, testing of soil/ rock samples in various laboratories for determination of their properties, and finally suggesting various long term and short term remedial measures to stabilize the slopes in general and safeguarding the structure of Raj Bhavan in particular.

The area at the Raj Bhavan comprises mostly the laterites and lateritic soil. The parent rock is not traceable due to deep weathering. Depth of weathering is as high as 60m. The hard laterites (duricrusts) occupy the topmost part of Cabo hill and vary in thickness from 10 to 13.5 m. About 10 m wide medium grained dolerite dyke trending in NW-SE direction is exposed at the sea level.

The detail sub surface exploration includes drilling of 11 Nos. bore holes amounting to a total depth of 560.55m to establish the subsurface geological conditions. During the course of drilling, insitu testing were conducted by SPT methods and undisturbed samples were collected from the bore holes at sub surface levels representing different soil units for determination of their grain size distribution, specific gravity, bulk density, natural moisture content, porosity, compressive strength, C and Ø values etc. The critical slip circle of the distressed slopes adjoining the Raj Bhavan has been constructed on the basis of the existing geotechnical conditions and the engineering properties of the subsoil.

Keeping in mind the position of the slip circle, slope morphometry and the type, nature and the properties of the slope forming material, number of remedial measures to stabilize the distressed slope and suggestions for monitoring the slopes are recommended.

Introduction

Geotechnical investigations on the evaluation of instability of slopes of Cabo hill, adjacent to Raj Bhavan, Goa, which includes surface geotechnical studies, geophysical surveys, subsurface exploration by drilling, insitu testing of the sub soil, testing of soil/ rock samples in various laboratories for determination of their properties, and finally suggesting various long term and short term remedial measures to stabilize the slopes in general and safeguarding the structure of Raj Bhavan in particular. These investigations were undertaken at the request of Water Resources Department (WRD), Govt. of Goa.

This paper deals with the results of detailed investigations conducted at the site and suggesting various long term and short term

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measures to stabilize the slopes in general and safeguard the structure of Raj Bhavan in particular.

II. Geotechnical evaluation

A. Site characterisation

Raj Bhavan is situated on the western top on an elongated promontory trending in NW-SE direction bounded by Mandovi River in the North, Zuari River in the South and the Arabian Sea in the West. The slopes on all these three sides exhibit heterogeneous gradient. The area is marked by flat to slightly convex crest indicating a matured peneplain surface at Rl + 42m.

The regional geology of the area consists of the rocks of Dharwar Super Group representing actinolite-quartz schist, chlorite-sericite schist, quartzite, metabasalt, Greywacke/Arkosic wacke, ferruginous phyllites, silt-stone and shale intruded by dolerite dyke and vein quartz. The investigated area at Cabo hill comprises laterites and lateritic soil. The parent rock is not exposed due to deep weathering. Depth of weathering is as high as 60m As a result of drilling, fresh rock is found to occur at Rl-42m. These rocks generally strike in NNW-SSE direction with northerly dip varying from 35° to 70°.

In the study area, hard laterites (duricrust) occupy the topmost part of Cabo hill thickness of which varies from 10 to 13.5 m. This hard laterite exhibits sub-vertical and sub-horizontal joints. The near vertical steep escarpments of the upper part of the slopes in this area are controlled by these sub-vertical joints. A pile of dislodged blocks of laterites are accumulated on the mid slope as scree/debris. About 10 m wide medium grained dolerite dyke trending in NW-SE direction dyke with prominent vertical joints extends for about 50 m projecting on to the sea is exposed at the sea level.

The slope forming material on both the mid slope and the lower slopes consists of 2.5 to 5.00 m thick talus/ debris comprising of mainly the large blocks of hard laterite dislodged from the upper steep escarpment and the lateritic soils. The talus slope beneath

Photo : Cracks developed on the cladding wall with lateral shifting.

Photo : Old sea wall showing lateral shifting along the vertical cracks

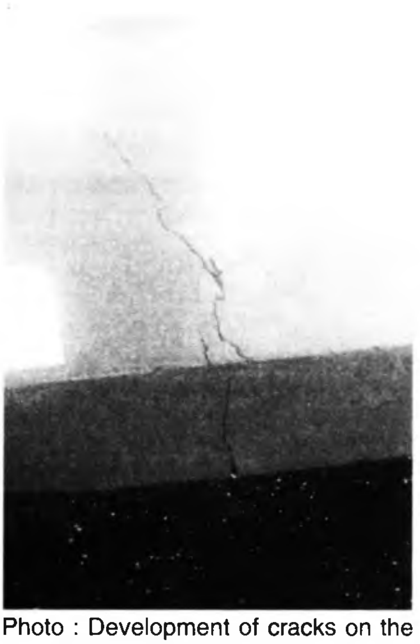


Photo : Development of cracks on the Verandah of Rajbhavan

the steep cliff is made up of loose aggregates of lateritic fragments, which are in process of progressive deterioration.

B. Failures/deformations associated with sliding/creeps

The western and the north western slopes of Cabo hill adjacent to Raj Bhavan, facing the Arabian Sea have been experiencing continued distress since a few decades. Cracks have been developed on the pavements, floor of the verandah and also extending head ward retrogressively intercepting the corners of the back portion of the building, Cracks on Parapet wall, Cracks on the western slope, Cracks on the slope protection structures, Cracks on the Sea wall. The available record indicates a section of northwestern slope of Cabo hill was subjected to severe sea erosion. This erosional phenomenon which has existed on the coast line adjacent to Raj Bhavan for the last 40 years has slightly increased since a decade. (Photograph).

C. Field investigations

The field investigations carried out in this area

Photo : Cracks on the slope protection structures

include topographic mapping on 1:200

scale using EDM, mapping of the surface features pertaining to the distressing slope, geophysical surveys using seismic and resistivity methods, subsurface explorations by drilling, insitu testing by SPT and collection of samples (both disturbed and undisturbed) from the boreholes for determination of various properties. Detailed account on all these field investigations carried out are as follows:

1) Topographic Mapping

The detail topographic map of unstable slopes of Cabo hill is determined by carrying out precise leveling and contours on 1:200 scale with one meter contour interval. Three prominent areas of distress viz. slide zone-1, slide, zone–il and slide zone-III are recorded on the sea side slope adjoining Rajbhavan.

Slide zone –I: This zone located NW of Raj Bhavan Palace and is found still active. The process of development of cracks both on the slope and the pavement was continuing head ward encroach the verandah of Raj Bhavan, thus creating concern regarding safety of the Raj Bhavan structure.

Slide zone-II: This zone situated NNW of Raj Bhavan. The crown of this slide is about 30 m away from the pavement of Raj Bhavan. Fresh cracks/subsidence is not reported in this zone subsequent to the treatments.

Slide zone-III: This zone located South West of Raj Bhavan and west of Grotto.

Though a deep and wide crack is seen cutting across the stair case leading to Grotto showing relative displacement of adjoining blocks, no significant development of cracks are seen in the slopes of this zone.

2) Geophysical Investigations

Geophysical investigations comprising resistivity and shallow seismic techniques and the limitations both in the terrain and the litho formational set up over the unstable slopes investigated, the geophysical traverses have indicated the following:

i. Influence of the sea water ingression/ seepage in to the adjacent sub soil up to a distance of about 20m from the coast line.

ii. Extension of the dyke from the sea side into the hill along the strike line.

iii. A relatively weak zone / disturbed zone situated in the middle portion of the unstable slope.

3) Exploration by Drilling

The sub surface exploration conducted in the slopes of Cabo hill and the top part by drilling adopting dry drilling techniques. The sub surface exploration details is as follows:

1. To establish the succession of the sub-soil/ rock below the ground level
2. To establish the bed rock profile at sub surface level.
3. To establish the existing ground water table at sub surface level.
4. To establish the critical slip circle/ line of rupture pertaining to the unstable slope.
5. To conduct insitu testing of typical sub soil units using Standard Penetration Test (SPT).
6. Collection of soil/ rock samples from cores at different levels for determination of their geotechnical properties.

On the basis of information collected during logging the boreholes, a comprehensive litho logical succession from top to bottom has been established as follows:

1. A thick layer of talus / lateritic debris and are made up of lateritic blocks /debris and soil (about 2.50 to 5.00 m thick)
2. Hard, laterite (duricrust) (about 11.50 m thick)
3. Stiff, Purplish/Reddish clayey laterite (Nodular) with pockets of grayish clayey/ laterite (about 5.00 to10.00 m in section line AA', in BB' section 6.00 to 15.00 m, where as in CC' section 7.00 m)
4. Creamy to purple clayey silt with pockets of fine sand/silty sand/grayish silty clay. (About 20.25m in section line AA', in BB' section 15.20 m, where as in CC' section 20.00 m thick)
5. Soft, weathered parent rock, which overlies the fresh bed rock (about 20.25 m in section AA' and in BB' section it is 15.0 m thick.
6. Bed rock consisting of Greywacke and Meta basalt.

These units are traversed by a 10 m wide NW-SE trending dolerite dyke

4) Laboratory studies

The laboratory studies of the different tests are as follows:

a) **Determination of Geotechnical properties of undisturbed samples:** Undisturbed samples were collected from the boreholes representing different soil units at sub surface levels for determination of their grain size distribution, specific gravity, bulk density, natural moisture content, porosity, compressive strength, C and Ø values etc.

b) **Mineralogy of the soil samples:** The X-ray analysis results study reveals that the silty sand unit (64% sand and 36% silt) comprises of major constituents like quartz and kaolinite with small amount of hematite and traces of muscovite.

The lateritic clay unit shows major constituents like kaolin, with quartz occurring in considerable amount and hematite and muscovite in small amount. Clayey laterite comprises quartz as a major constituent. The creamy to purplish clayey silt comprises kaolinite as major mineral with Quartz occurring considerably. Muscovite and hematite are less in amount. The decomposed/ weathered rock shows Kaolinite as the major mineral with quartz in small amount.

e) **In-situ testing:** In order to understand the insitu properties of the soil at sub surface conditions, Insitu testing was carried out in the boreholes by conducting Standard Penetration Tests (SPT).

The relative density of sub-soil units beneath the Cabo hill according to results of standard penetration tests are given as follows:

Geological Cross Section	Critical height(H)	Slope angle β	Depth at mid point (m) w.r.t the critical slip circle
AA'	36m	15º	18
BB'	35m	15-20º	15.50
CC	42m	20-30º	16

2) **Assessment of slope forming material/ sub surface geological condition:**

The sub-surface exploration has brought out almost an accurate picture of the subsurface geological condition of the unstable slope. They are shown on the geological cross sections AA', BB' and CC'.In these typical geological sections, various components including the hard duricrust, number of distinctive lateritic soils, zone of weathered rock, bedrock configuration/ profile, ground water table, critical slip circle/ the rupture zone, safety factor contours are put together to help interpretation of the unstable slopes.

Sl. No.	Sample description	Penetration resistance 'N' values	Relative Density
1	Silty sand	30	Medium
2	Clayey laterite (Nodular)	50	Dense
	Greyish lateritic clay		
3	Clayey silt	30-50	Medium - Dense
4	Weathered rock (Saprolite zone)	>50	Very Dense
5		>50	Very Dense

D. Inferences on stability analysis:

The stability analysis of the unstable slopes of Cabo hill was attempted by adopting mathematical computation (Swiss circle method). In this attempt, the critical circle was drawn on the basis of the "C" and "Ø" values of the existing slope forming material. In this, the crown of the critical circle emerges at the top of the western hill slope, at a distance of about 5 m behind the edge of the Raj Bhavan pavement and getting day lighted at the toe portion of the slope, slightly above the sea level. The interpreted results of the detailed investigation are as follows:

1) Geometry of the slides:

The geometry of the unstable slope adjacent to Raj Bhavan has been broadly worked out from the geological cross sections as follows:

Brief descriptions of the sequence of the formations encountered in the boreholes are discussed in the chapter drilling.

3) Critical Slip Circle/ Rupture plane:

To ascertain the existence, geometry, type and the nature of the rupture plane/ critical slip circle, along which, the destabilized mass has been creeping/ moving towards down slope. Detailed examination/ logging of the boreholes have shown the following features confirming the existence of the critical slip circle/ rupture zone.

a) Brecciation, crumbling and fragmentation of the laterite.

b) Appearance of integrated clay in the form of squeezed pulp.

c) Appearance of small pipe/linear cavity like structures in the clayey zone indicating free circulation of ground water.

d) Significant appearance of thin limonitic clay zone with in grey/ creamy silty clay.

On the basis of these evidences, the critical slip circle is ascertained and the position at sub surface levels are depicted in the geological sections drawn along AA', BB' and CC' lines. The position and the geometry of the rupture plane constructed on the basis of the sub surface geological evidences almost go hand in hand with the critical slip circle drawn earlier in the mention in the above chapter drawn on the basis of the mathematical model.

a) **Distress in the Top laterite crests (Duricrust):** The hard and competent media is resting over the soft and incompetent clayey soil and the contact surface between the upper duricrust and the lower clayey soil is gently dipping towards the free face, the individual blocks of the hard laterite on the crown start creeping outward as a result of continuous distress. In this process number of new crack developed in course of time and the old cracks get widened. This phenomenon has been observed prominently on the surface of the verandah adjacent to Raj Bhavan. Besides, there is a tilting of the main building of Raj Bhavan towards the edge of the crown of the steep slope indicating the gradual down ward creeping of the material. (photo)

b) **Mid slope:** The mid slope has heterogeneous slope angles covered with thick talus/ debris material. Insitu lateritic clay and silty clay substratum amounting to over 50m thickness underlies this debris material. The soft and saturated material lying above the critical slip circle has been undergoing creeping along this rupture plane, the effect of which has manifested on the ground in the form of development of number of cracks. The positions of these ground cracks (paleo-scars) were identified earlier. These cracks are now concealed while easening of the mid slope.

c) **Toe portion of the slope:** The toe portion of the slope in this study area has been under continuous threat by the onslaught of the sea waves leading to scouring and erosion of the shore line. In this area the curvature of critical slip circle passes through toe of the slope adjoining the sea. A continuous destabilization of the bottom support/ toe support of this unstable slope and a progressive creeping of the thick media lying above the critical slip circle has resulted in bottom upheaval, toe bulging etc. Due to this lateral thrust of the moving material, the sea wall constructed earlier is found cracked at many places with significant displacement of the laterite blocks of the sea wall. (Photo)

4) **Shear stress characteristics in sub-soil:** The sub soil units existing beneath the slopes of Cabo hill have been subjected to severe shear stresses for a longer period. Steeper slope angles at the higher reaches of the slope, incompatible with the shear parameters of the sub soil, excessive loading over the steep slope with continuous infiltration of the rain water and sewerage water of Raj Bhavan in to the unstable mass, at the crown, has made the slope forming material highly sensitive and susceptible for continuous distress mainly along the rupture zone.

a) **Gravitational stresses**

Computation of gravitational stress acting on the distressed media is considered one of the essential parameter while evaluating the stability of the slope. These gravitational forces, which are acting over the critical slip circle are directly proportional to the weight of the overlying sub soil units and are also influenced by the dip of the formation, which is about 10° towards free face. The probable magnitude of these forces (Rigidity ratio of vertical and lateral forces on the critical slip circle) has been evaluated by using the following geotechnical properties of the media.

Young's Modulus = 8,000 Kg/cm²

Poision's ratio = 0.27

Unit weight/unit volume = 2.33 kg/cm²

Rigidity factor 'K' = 0.27/ (1-0.27) = 0.35

In this particular case, the probable value of the rigidity factor 'K' is <1, indicating that the lateral component of the sub-soil unit exceeds the vertical component.

b) Ground water pressures

The position of ground water table beneath the unstable slope is established during drilling. The flow direction is almost parallel to slope and towards the Arabian Sea. As a result, the seepage pressures develop under such existing conditions have a considerable influence on the failure of the slope by increasing the effective shearing stresses on the critical surfaces and reducing the shearing resistance of the media.

c) Inherent physico-mechanical properties of the slope forming media

The field-cum laboratory studies of undisturbed samples collected from the boreholes have indicated a wide range of variations in their physico-mechanical properties. Some of the very important properties of the sub soil which are directly related with the slope instability analysis are given as follows:

i) Swelling properties of sub-soil units

The inherent swelling properties of the various sub-soil units have been computed by incorporating the determined plasticity indices (PI) Stiff clayey laterite Clayey silt Soft, weathered bed rock indicates PI is 10 to 40 and are having swelling capacity of medium to slightly higher in saprolite.

The sub soil of the destabilized slope beneath the Cabo hill shows medium swelling properties, due to the absence of prominent deleterious/ swelling clay mineral like montmorlinite. All samples analyzed chemically are in the area of 'kaolinite'.

ii) Geotechnical properties and shear strength parameters of sub-soil units

Geotechnical properties of various sub-soil units are tested. The important physico-mechanical properties, which influence the ultimate shear strength of soil includes porosity, void ratio and unit weight of sub-soil determined in natural state. Soil group (ISI), consistency index (Atterbergs limits).

III) Shear Strength Properties

5. Factor of Safety (SF)

The Factor of Safety (SF) for the unstable northwestern slopes of Cabo hills has been computed as per the standard incorporating the 'C' and Ø value of sub-soil units and the average segmental slope angle (b), as seen on the ground. The same is presented in table 5. Factor of safety contours are drawn over the geological section AA 'and BB ' lines as shown on plates 3 & 4. The normal spread of the influence of the factor of safety in relation to the variation in depth and the sub

Sl. No.	Sample description	Penetration resistance 'N' values (SPT)	Compressive strength Kg/Cm²	'C' Cohesion in Kg/Cm²	Friction angle Ø (in degree)	Shear resistance (s) (C+tanØ)
1	Silty sand	30	-	0.13	16	0.41
2	Clayey laterite (Nodular)	50	2.08	-	-	-
	Greyish lateritic clay					
3	Clayey silt	<50	2.12	0.13	5	0.21
	Soft, weathered bed rock					
4	(Saprolite zone)	>50	0.51-4.96	0.2	18	0.52
5		>50	0.5	0.02-0.16	6-16	0.81

soil has been broadly worked out and is tabulated as follows:

Level (RL in meters)	Safety factor (SF) (General)
EL 8.00m above the critical slip circle	<1 1.5
E.L 8.00m on the critical slip circle	>1.5
E.L 8.00m below the critical slip circle	

This indicates the relative improvements of the shear resistance properties of the sub soil unit with depth.

III. Causes for instability of slopes

The slopes on the western and north western part of the Raj Bhavan are found unstable as a result of the following causative factors:

1. More than 60 m thick, soft and incompetent soil strata on the slope lying between two competent media i.e. about 11m thick hard laterite (duricrust) on the top and the fresh bedrock at the bottom.
2. Natural slope angle comparatively on higher side compared to the C and Ø values of the subsoil of the slope.
3. Constant onslaught on the toe of the slope by the tidal waves of the sea causing continuing toe erosion/ scouring and subsequent downward creeping of the material.
4. Increase in structural load/weight on the disturbed mass by way of construction of structures thus increasing the stresses/gravitational forces on the disturbed mass.
5. Improper drainage by which the surface water is infiltrating into the disturbed mass decreasing its shear strength and encouraging the downward movement of the disturbed mass.

IV. Protective measures already provided and their effectiveness

A number of treatments have been provided by the Government of Goa, on the recommendation of different governmental and non-governmental agencies to protect the slopes as well as the building of Raj Bhavan. All these measures have failed to achieve the purpose in the long run. The cracks both on the pavement, the floor of the verandah and the wall of Raj Bhavan are increasing day by day posing a serious threat to the structure of Raj Bhavan.

The earlier protective measures provided to stabilize the cabohill slopes and are as follows:

1. Cladding wall with buttress, 2. Vertical piles with beam cap, 3. Sea wall on the toe part

4. Main catch water drain, 5. Weep holes, 6. Armor blocks, 7. Sewerage/ Septic tanks

Besides, grouting on lateritic horizon, micro piling in one spot was provided and is found not effective.

V. Recommended remedial measures

On the basis of the observed surface and subsurface geological conditions of the unstable slopes adjacent to Raj Bhavan, the insitu characteristics of the sub soil, their physico- mechanical properties relevant to the stability analysis of the slope, the position of the critical slip circle and the computed safety factor contours, various corrective and control measures to stabilize the slopes have been worked out to achieve the desired stability of the slope are:

1. Improving the mechanical behavior of the fractured hard laterite (duricrust) by appropriate anchoring.
2. Improving the shear resistance of the slope forming media in the middle slope by providing intermediate shear interceptors.
3. Strengthening the toe portion of the slope by effective slope and shore protection works.
4. Improving the draining systems to avoid development of excessive pore pressure in the slope forming media due to seepage of rain water.
5. Avoiding infiltration of surface water as

well as the waste water of Raj Bhavan into the destabilized media through tensional cracks.

6. Easening of the slope and resolving to growing of appropriate vegetation on the slope to improve stability of the loose material and give face lift to the beauty to the surroundings of Raj Bhavan.

The details of remedial measures suggested above are described as follows:

A) Upper part of the slope

The upper part of the slope comprising the hard laterite exhibits a very steep slope of about 9m high. This hard laterite is fractured and is undergoing a continuous process of distress, due to which, lot of cracks have developed on the parapet wall, pavement, verandah and the corner walls of Rajbhavan falling in the proximity of the unstable steep slope. At this condition, it is necessary to strengthen this media by appropriate anchoring, sealing of the cracks and providing effective subsurface drainage arrangements, which are described below.

a) Pre-stressed cable anchors

The basic aim of providing these pre-stressed anchors is to tie up the fractured hard lateritic media into almost a monolith and fix this media to the intact part of the duricrust. Apart from arresting further mobility of the distressed blocks, this method is also expected to arrest further development of any tensional cracks and subsequent distressing. The pre-stressed cable anchors are suggested in 4 rows from RL 38 to 32 with 2 meters distance and length 20, 17.5, 15and12.5m.The angle is 20° With 2 mts staggered cable anchors are to be designed considering the physico-mechanical parameters of the lateritic media:

The pull out pressure being applied in anchoring these cables should never exceed 70% of the fracture pressure of the media, suggested to test on trial basis at a selected place, before applying the same for the entire stretch of the steep slope. The cable anchors provided are to be utilized for injecting grout and making the anchored media monolithic. As an alternative, new intermediate holes of about 20m may be drilled with slight inclination into the hill and be used for providing consolidated grouting to the distressed hard lateritic media. A series of deep weep holes are to be provided at the last stage of the process, in between these anchors to dissipate the possible pore water pressure. These weep holes are to be drilled with an inclination of about 15° from the horizontal towards the free face of the slope. These holes are to be lined with perforated PVC pipes and are also being provided with the required graded filters. (Photo)

Photo : Prestressed cable anchoring at the top part of the slope

b) Intermediate shear interceptors at foot of the steep slope (Inclined bored piles with beam caps)

The foot of the steep upper slope are mechanically disintegrated huge blocks of hard laterite are creeping down wards over the rupture plane. These shear interceptors are also expected to serve as shear keys and provide the desired shear resistance to the creeping mass. In order to serve this purpose, two rows of inclined bored piles are suggested at the foot of the existing cladding wall. These are to be tied up on top by beam caps. (Photo)

c) Shifting of Sewerage/ Septic tanks

Two septic tanks (I & II) are located on the

Photo : Inclined bored piles with beam caps

crown of the unstable slope adjacent to Raj Bhavan, these tanks are located below the surface levels on the crest of the unstable slope. There is a possibility of seepage of the sewerage water from these tanks to the sensitive unstable slope making the media more amenable for further deterioration and an alternative location for having this septic tank was suggested.

d) Retaining of Rain water storage cisterns

The rain water storage tanks, it is found that these tanks do not contribute to the process of instability of the slopes.

e) Sealing of ground cracks

Number of cracks has developed at the crest part of the steep slope up to the walls of Raj Bhavan. These cracks are to seal by using suitable chemical binding agents.

B. Middle slope

Middle part of the slope is sensitive to progressive sliding/ creeping, the slope forming material comprises of a thick zone of incompetent soft lateritic clayey material lying above the critical slip circle and the slope is heterogeneous in its morphometry. This slope is to be treated with a series of remedial measures as follows:

a) Easening of slope and surface drainages

It is recommended to easen this sensitive midslope into terraces at different levels at 1:1.5 gradients by boulder sausages are to be provided with sufficient weep holes with a gradient towards the free face. The easening slope may be provided with sufficient lined contour drains.

b) Intermediate shear interceptors (Vertical bored piles with beam caps)

The shear interceptors are expected to serve as shear keys and provide the desired shear resistance to the creeping mass. In order to serve this purpose, one row of vertical bored piles at mid slope is suggested. These are to be tied up on top by beam caps. (Photo)

Photo : Vertical bored piles with beam caps in the midslope

c) Vertical Sand piles

A row of vertical sand piles is suggested on the mid slope at about RL.17m. to release the possible pore water/ ground water pressure from the slope forming media as the ground water table is at shallow depth. They are to be provided with perforated PVC pipes and to be filled with clean, coarse sand. (Photo)

d) Turfing / Terrace gardening over the easened/ treated slope

The slope, after providing all the recommended remedial measures has to be finally provided with turfing or gardening with deep rooting short height plants to maintain the stability of the slope effectively.

C. Toe part of the slope

The toe portion of the slope is a crucial part in the process of creeping of the slope forming material along the critical slip circle. A number of remedial measures have been recommended to strengthen the toe part and to avoid further effects of the onslaught of the mighty waves of the sea on the shore line.

a) Construction of retaining wall

A new alignment of retaining wall is recommended to give suitable resistance to the creeping mass. This retaining wall is suggested around RL.10m. The foundations of these retaining walls are to be taken at least 1.5m below the existing ground level. These retaining walls are also to be provided with effective weep holes and graded filtering. (photo)

b) Effective shore protection works

The shore protection works already carried out by providing a layer of Armour blocks all along the shore line of the unstable slope to protect the toe portion of the distressed slope are found insufficient as the level of the sea tides are extending beyond the outer limit of these armor blocks and the onslaught by the sea tides have caused continuous scouring of the bottom line of these protective measures. In light of the above situation, it is recommended to extend the armor blocks cladding along the effected shore line for at least another 2m height with the required standards. (Photo)

V. Recommendations for long term monitoring

These distressed slopes are to be monitored by the following methods to confirm the effective performance of these remedial measures provided to the slope.

1. Slope movement monitoring by electro-optic precise leveling instruments
2. Settlement observations by settlement gauges on the slopes.
3. Measurement of pore water pressure by installing a series of piezometers.
4. Monitoring of ground cracks by install cement 'tell tales' over these cracks.

Photo : Installation of settlement gauge, inclinometer and crack recorder

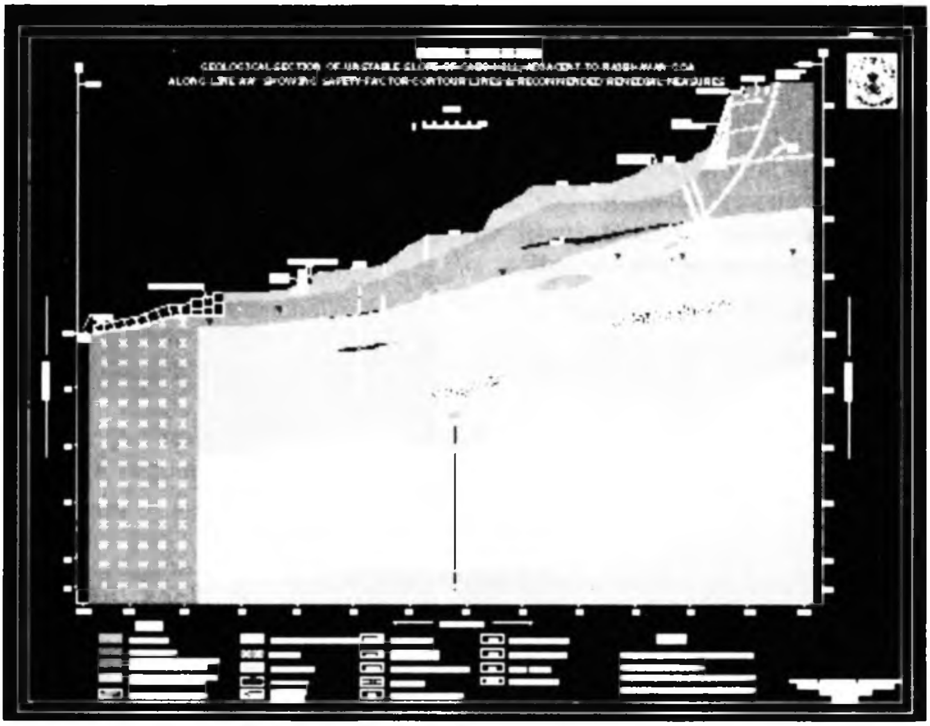
Photo : View of the Cabohill with protective measures

Conclusions

Detailed geotechnical investigations on the evaluation of instability of slopes of Cabo

hill, adjacent to Raj Bhavan, Goa, comprising surface geotechnical studies, geophysical surveys, subsurface exploration by drilling, insitu testing of the sub soil, testing of soil/rock samples for determination of their properties, and finally suggesting various long term and short term remedial measures to stabilize the slopes in general and safeguarding the structure of Raj Bhavan in particular.

The Geology of the area comprises laterites and lateritic soil. The parent rock does not outcrop due to deep weathering. The hard laterites (duricrusts) occupy the topmost part



of Cabo hill and slopes are occupied by lateric soil and clay. Medium grained dolerite dyke trending in NW-SE direction is exposed at the sea level. The subsurface exploration by drilling has established the subsurface geological conditions. During the course of drilling, insitu testing were conducted by SPT method. Samples collected from the boreholes at sub surface levels representing different soil units for determination of their grain size distribution, specific gravity, bulk density, natural moisture content, porosity, compressive strength, C and Ø values etc. The critical slip circle of the distressed slopes adjoining the Raj Bhavan has been constructed on the basis of the existing geotechnical conditions and the engineering properties of the subsoil.

Keeping in mind the position of the slip circle, slope morphometry and the type, nature and the properties of the slope forming material, the remedial measures suggested in the Upper part of the slope are a) Pre-stressed cable anchors. b) Intermediate shear interceptors (vertical bored piles with beam caps). c) Shifting of Sewerage/ Septic tanks. d) Retaining of rain water storage cisterns e) Sealing of ground cracks. In the Middle slope are a) Easening of slope and surface drainage. b) Intermediate shear interceptors (vertical bored piles with beam caps). c) Vertical Sand piles. d) Turfing/Terrace gardening over the easened/ treated slope. Toe part of the slope: a) Construction of retaining wall. b) Effective shore protection works. The long term monitoring measures suggested are Slope movement monitoring, Settlement observations, Measurement of pore water pressure and Monitoring of ground cracks.

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