International Journal of Engineering & Technology, 7 (3.29) (2018) 524-528

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Geotechnical and geological investigation of landslide in western GHAT of Maharashtra, India

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Abstract

The problem of the landslide is severe in Western ghat of Maharashtra mostly due to the topography, human interference, heavy rainfall etc. Upland region of Deccan Volcanic Provinces (DVP) is considered as a most vulnerable region for landslides activity in the Maharashtra state of India. The area shows thick flows of the Deccan Trap basalt of Upper Cretaceous to Eocene age. State Highway -70 is the lifeline of the Pune District and Raigarh District of Konkan. The part of the highway between Bhor and Mahad is highly landslide prone and frequently blocked during the rainy season. Considering the importance of SH-70, landslide susceptibility zonation studies along SH-70 between Bhor and Mahad were carried out. The landslide susceptibility study gives an overall idea of the stability condition of the slopes of the hill so it can be used for planning any further construction activity and remedial measures. A detailed exploration was carried out along the road section started from Bhor city, and it extended up to the Mahad, in Konkan region. Paper discusses the geological, geotechnical investigation of the area. The remedial measures are suggested to minimize the severity of landslide.

Keywords: *Deccan Trap; Geotechnical; Konkan; Landslide; Western Ghat.*

1. Introduction

The `landslide' is the downward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds, whereas others may take hours, weeks, or even longer time to develop. Landslide is a natural phenomenon and causes damage to property and loss of life. It is an isolated process which individually may not be large in size but can occur with high frequency [1]. According to Dai and Lee [2], landslide also known as landslip is a geological phenomenon that includes a wide range of ground movements. According to Schidegger [3], landslides are the chance, that reasonably stable condition may opaque abruptly. Guzetti et al. [4] preferred the definition to include the area, volume, and speed of the expected landslides. Fellenius [5] introduced the Ordinary or Swedish method of slices for analysis of stability of the slope. The slope failures noted along the highway in the Ghat section invariably fall in the rock- fall and rock topple group as per Varnes [6], classification. Landslide hazard is defined as the probability of occurrence of landslides within a specific period of time and within a given area [7]. According to Scheidegger [8], it is the probability that a reasonably stable condition may change abruptly. Guzzetti et al. [9] preferred the definition to include the area, volume, and velocity of the expected landslide. Sharma [10] emphasized that a complete hazard assessment and mapping should be based on where and how large a landslide will occur. Landslide is a natural disaster, which commonly occurs on natural slopes as well as cut slopes of ghat roads in a hilly area, causing losses to human life and properties [11], [12]. The occurrence of landslides in mountainous regions is subjected to influence of different causative factors and are triggered by rainfall, earthquake shaking, water level change, storm waves and rapid stream erosion etc. [13], [14]. In addition, the anthropogenic activities on hill slope such as the construction of roads, urban expansion, deforestation, and changes on land use practices increase the landslide occurrences [15]. The discrimination and mitigation of landslide-prone areas in a region are essential for future planning and developmental activities. Mhaske and Choudhury [16] have developed a methodology for preparation of soil liquefaction susceptibility map of the entire Mumbai city during an earthquake using GIS. It is necessary to develop landslide hazard zonation by using modern techniques which can help the planners and decision makers to take the quick decision.

2. Study area

The study area is a part of Sahyadri Uplands, which is present between Konkan Coastal Belt bounded to the Arabian Sea in the West and shield - plateau region in the east. It is next to the Bhor, a southwestern boundary of Pune District. The proposed study area is located in Bhor region of Pune district of Maharashtra along SH-70. The area under investigation falls in the Survey of India toposheet no. E43H12 (47F/12), E43H16 (47F/16) between latitudes 18° 00’ 00’’ N to 18°15’00’’ N and longitudes 73° 30’ 00’’E to 73°52’30”E. An increasing socio-economic interaction between the Konkan Coastal belt and Plateau region has resulted in increase in the density, the lines of communication, by traversing through the Ghat section, which is highly susceptible for mass movement especially in rainy season. Such activity some at local and regional scale produce large- scale hazard along the ghat sec-

tion roads resulting, highway traffic jam takes place [17]. Fig. 1 shows the location Map of the study area.

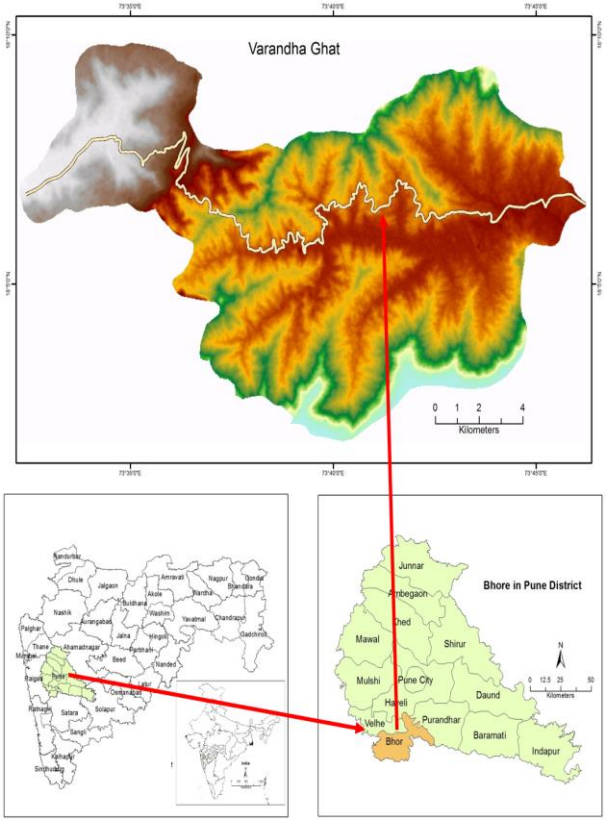

Fig. 1: Location Map of the Study Area.

Lithologically, these volcanic igneous rocks are massive, sometime presence of empty cavities / filled gas cavities with secondary minerals, and fine textured. The flows are of two types of characters, i.e. nonvesicular - compact basalt flows are thick, regular, and extensive and show plain tops and bottoms. While, the amygdaloidal basalt flows are thin, irregular, less extensive, chaotic flows and absence of plain tops and bottoms. These individual flows are separated by thin, bands of red / green tachylitic basalt. When they exposed to the atmosphere, they rapidly give a response to the weathering action and get converted into small fragments, resemble like baked soil and after some period, the baked soil starts to convert into fine-textured clay. At places, the rock shows different divisional planes, viz. columnar (vertical), sheet (horizontal) and irregular (both consistent and inconsistent) type. The block type of joint is comparatively less. These joints are open at the surface at the top. During every rainy season, fine developed loose sediments and gaps between two blocks were washing out. In this way, the gaps between two blocks get increased and such blocks become unsupported. In this way, they started to dislodge, in the form of mass movement activity in this area. This formation covers nearly 85% part of Maharashtra state and hence the continuous area of the plateau has rocks of trap formation [18].

The climate of the study region is of a tropical monsoon type nd it observes variations during the year. The vicinity of the Sahyadri to the Arabian Sea controls the coastal climate to a narrow strip on the west coast of Konkan that stands in sharp contrast to the continental climate over the entire region. Naturally, the windward slopes of Sahyadri and its crest gets sufficient rainfall while to the eastward of Ghat section, rainfall decreases rapidly over a short distance. The study reveals significant changes in seasonal and annual rainfall in Nira river basin of Maharashtra, Central India during past 104 years. The increasing trends are detected in annual rainfall at 10% significance level for the Akluj and Bhor stations. The analysis shows that larger anthropogenic trends are embedded in the climate data in the baseline period. The climatic changes taking place after 1960 might have affected the rainfall pattern in the basin which needs further investigations [19].

3. Methodology

The exploration was carried out to find out the past history and present conditions of the Varandah Ghat section, i.e. along the Maharashtra State Highway-70 on the Deccan plateau which cut the Sahyadri escarpments along its route line. These factors include, lithology, texture, slope, the rate of weathering, the intensity of rainfall, climatic variations, geomorphology, and tectonic activity, which leads to the mass movements. Soil samples were collected from different locations along the Verandha ghat section for testing. Geotechnical tests were conducted on soil samples as per Indian Standard specifications. The stability of existing slope was obtained by calculating the factor of safety of the slope. The study is carried out with the help of available literature, topographic maps and goggle images of the study area. Based on this work various thematic maps such as place, geology, drainage, slope, land-use and land-cover maps were studied.

The data used from Survey of India Toposheet no. E43H12, E43H16 on the scale of 1:50000. ASTER- USGS derived 30-meter-resolution digital elevation models of study area. The topographical map was geo-referenced in the GIS environment and the Varandha Ghat road, landslide locations were digitized using the ArcGIS software (version10.1). Landsat 8 image is used to classify land use and land cover of study area. Landsat 8- Panchromatic (12/02/2015) multispectral images have been applied. During this survey the factors studied are Initial point of the survey and their RL,Details of the each locality, Position (Latitude-Longitude), Elevation details of each locality, Degree of the slope, Type of vegetation, Types of rock, Texture and structure present in the rock, Details of the previous records of the mass movement of the area, Recording of the panoramic view of the mass movement by using camera, Drawing of the stratigraphic section and Rate of weathering of the flows of different varieties of basalt. Flowchart of the methodology is shown in Fig. 2.

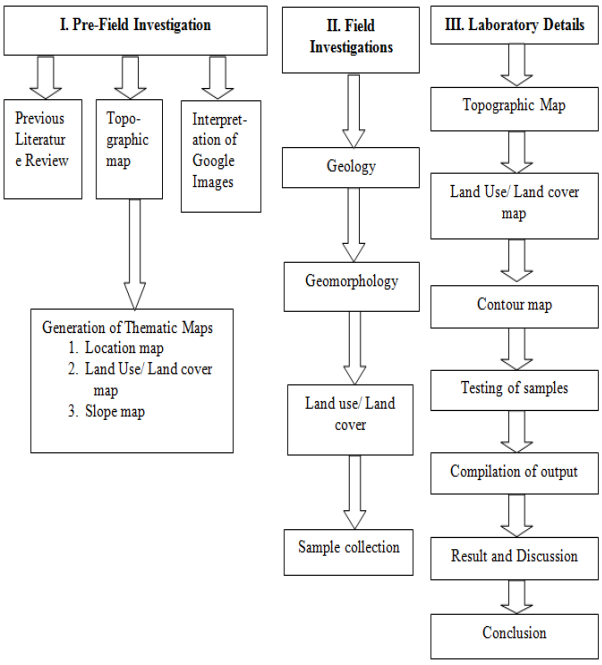

Fig. 2: Flowchart of the Methodology.

4. Exploration details

Mostly, during the rainy season, the roads in these areas are blocked due to mass movement activity along the Ghat section. By knowing the importance of the area, a detailed field exploration is

carried out along the Bhor-Mahad Highway, During the survey, each important earlier mass
movement locations along the left and right side of the road are systematically met and mapping is carried out with the help GPS (Garmin E-Trex-30). Their details, such as nature, type, extension, dimension, causes of mass movements, etc. observations are carried out. The details of the field exploration are given in Table-1.

Table 1: Details of Field Observations

Site No.	Site Name	Latitude/Longitude/Elevation	Slope/ Height/Length	Type of Vegetation	Type of Rock	Previous Landslide	Type of Joint	Type of Flow	Weathering condition	Chances of landslide
1	Kondri Bus Stop	N 18˚06' 32" E 73˚ 41' 09" Ele.-733 m	S-85°H-20mL-17m	Scanty	Compact Basalt	Yes	Irregular Joint	Compact Basalt	Low Moderately weathered	High
2	Ramdas Swami vidhyalaya	N 18˚06' 26" E 73˚ 41' 54" Ele.-743 m	S-80°H-22mL-27m	Scanty	Compact Basalt	Yes	Irregular Joint	Compact Basalt	Fresh	Medium
3	Venupri - Near bridge	N 18˚06' 47" E 73˚ 42' 01" Ele.-721 m	S-60°H-10mL-25m	Moderately dense	Red Tachylatic Basalt	Yes	Irregular Joint	Red Tachylatic Basalt	Highly weathered	Very High
4	Venupuri-Near Bus Stop	N 18˚06' 25" E 73˚ 42'11" Ele.-741 m	S-85°H-7mL-17m	Moderately dense	Vascular basalt with zeolitic lava matrix	Yes	Sheet Joint and Irregular Joint	Vascular Basalt with zeolitic lava matrix	Highly weathered Moderately weathered	High
5	Ayush Garden before irdoshi	N 18˚06' 42" E 73˚ 40' 55" Ele.-743 m	S-80° H-15m L-125m	Moderately dense	Red Tachylatic Basalt, Compact Basalt	Yes , Creep	Irregular Joint	Red Tachylatic Basalt, Compact Basalt	Highly weathered	Medium
6	Near bridge Hirdoshi	N 18˚07' 02" E 73˚ 40' 39" Ele.-705 m	S-75° H-15m L-25m	Moderately dense	Red Tachylatic Basalt	Yes	Vertical columnar joint	Compact Tachylatic Basalt	Fresh	Very High
7	Near bridge Hirdoshi	N 18˚07' 00" E 73˚ 40' 36" Ele.-705 m	S-85°H-25mL-125m	Dense	Red Tachylatic Basalt	Yes	Irregular Joint	Red Tachylatic Basalt	Moderately weathered	High
8	Near bridge Hirdoshi	N 18˚06' 58" E 73˚ 40' 35" Ele.-701 m	S-85° H-15m L-50m	Moderately dense	Compact Basalt	Yes	Vertical and Sheet Joint	Compact Basalt	Highly weathered	High
9	Near bridge Hirdoshi	N 18˚06' 53" E 73˚ 40' 34" Ele.-696 m	S-85° H-15m L-25m	Moderately dense	Red Tachylatic Basalt, Compact Basalt	Yes	Columnar Jointed	Red Tachylatic Basalt, Compact Basalt	Highly weathered	High
10	Near bridge Hirdoshi	N 18˚06' 48" E 73˚ 40' 36" Ele.-733 m	S-85° H-1m L-20m	Moderately dense	Compact Basalt	Yes	Irregular Joint	Compact Basalt	Highly weathered	High

5. Causes and remedial measures

The causes of the landslide are given below.

i) High-Intensity Rainfall: This area comes under the high rainfall zone. The high-intensity rainfall causes the drainage problem and results in a landslide.
ii) Construction activities: The instability of the hillsides was due to the construction activities, which are often done without careful analysis.
iii) Soil: The area covers with reddish brown soil, which is loose and easily flows after saturation. Due to continuous heavy rainfall, the soil becomes more vulnerable for landslide as the depth of loose soil varies from shallow to moderate. After saturation, the shear strength reduces and a landslide occurs.
iv) Deforestation: Deforestation is the major factor in a landslide all over the world. Trees protect the soil erosion, reinforce soil and increase the stability.

The remedial measures are required to avoid landslide, which may be site-specific.

i) Construction of Retaining walls: Retaining wall gives the stability to an unstable slope. Retaining walls can be strengthened by adding tiebacks and buttressing beams. Buttressing beams are placed at an angle down the slope of the piles to prevent the piles from toppling or tilting.
ii) Preservation of Vegetation: Vegetation, trees, and bushes can minimize the amount of water infiltrating into the soil, slow the erosion caused by surface-water flow, and remove water from the soil.
iii) New Construction: Before starting new construction, we should take expert consultation of geologists, environmentalist and geological survey of India.
iv) Continuous contour trenches: It should be constructed along the stiff slope areas.
v) As the total part of the Ghat section is rocky escarpment of Sahyadri hill ranges and covered with thin moderate vegetative cover therefore, there is need of plantation of trees along the ghat section road.
vi) Geosynthetic net should be provided on the highly jointed /deeply weathered portion of the surface to avoid the sliding of the fragment of rocks.
vii) Like the Konkan railway, Raskha dhaga' should be provided in the sensitive portion for easy alarm.
viii) Patrolling in the weaker section of ghat section is required during the rainy season.
ix) Removal of soft soil: Soft soil can be removed and replaced with stronger materials, such as silty or sandy soils
x) To prevent the traffic during the heavy rainfall along this ghat section.
xi) Awareness in the mind of people from Bhor portal and Konkan portal.

xii) Berms / Step like terraces should construct to restrict the movement and quick in-situ deposition of loose-transferred sediments.
xiii) In case of highly jointed and fractured rock cliffs along the roadside, they should be stabilized by giving bolting - netting -grouting treatment.
xiv) To avoid the movements of loose sediments towards highway trackside, guard wall should be constructed parallel to the road along the difficult, movement prone terrain area.
xv) Improving surface and subsurface drainage: Surface water should be diverted away from the landslide-prone region by channeling water in a lined drainage ditch to the base of the slope.

Observations and discussions

Geotechnical investigation and slope stability analysis was carried out to determine the existing stability of the slope. The soil samples were collected from different sites and
tested in the laboratory for particle size analysis, Proctor Density Test and Direct Shear Test. Particle size analysis has shown that a large number of total fines were present in some of the samples which may be due to particle crushing and breakdown as a result of sliding activity and weathering process. To determine the optimum moisture content (OMC) and maximum dry density (MDD) Proctor tests were also carried out in the laboratory. Direct shear test was carried out under the unsaturated condition to determine the cohesion and friction of the material. Samples were prepared at OMC on the Proctor mould. The most common slope stability analysis is the limit equilibrium analysis in which a ratio between the static stabilizing force and de-stabilizing force is computed and conventionally designated as a factor of safety. In such a method as long as the factor of safety so computed remains more than unity the slope is believed to be in stable condition. The overall slope of the landslide is from 60° to 85° and Factor of Safety under the static condition without pore pressure was found to be 0.46 to 2.04. The Factor of Safety for such steep slopes under the static condition without pore pressure turns out to be around 1. Further, with the rise in pore pressure the factor of safety value turns out to be marginally more than unity indicating the marginal stability of the slope. Hence it could be said that during intense rains limited slips are expected on these local steep portions of the slope. The material removed due to local slips may get deposited into the drain causing partially blockade of the flow. The slope material has considerable silts and the permeability was found to be of the order of 10-6 cm/sec. As a result due to heavy rain continued for a couple of days it is expected that pore pressure on the slope may rise and could trigger the local slips. The value of factor of safety is less than 1 for all samples except samples of site 2. This indicates that the slope is not stable and preventive measures are essential to avoid the landslide. The majority area is covered with Red Tachylatic Basalt which undergoes weathering speedily and the strength of it reduces considerably. During rain the wetting process results into the decrease in shear strength of weathered and weak rock and it results into landslide. The properties of soil are shown in Table 2.

Land Use/ Cover play an important role in environmental assessments and issues. Mapping of land cover is important for global monitoring studies, resource management, and planning activities. This map is divided in 4 categories which are as follows: Barren Land is of 59.62% of total study area. Vegetation is 34.89% of total study area. Water is covered 5.48% of total study area. Land use Map of Varandha Ghat is shown in Fig. 3.

a) Digital Elevation Model (DEM) is a digital representation of topography, i.e. an elevation map. In this map height of each terrain is calculated in "meters above sea level" and different class of height is shown in different colour. Faint Green colour shows the lowest of 23 to 459 meters above sea level. While the highest class in white colour is 1,110 to 1,418 meter above sea level. Most of the Verandha Ghat road area covered under the 460 m to 869 m height of the terrain.

Most of the landslides are spotted in this area. Digital Elevation Model of Varandha Ghat as shown in Fig. 4.

Table 2: Properties of Soil

Description	Site- 1	Site-2	Site-3	Site-4	Site - 5	Site- 6
Field Density- Dry (kN/m^3)	11.25	11.90	11.35	11.82	11.76	7.65
Field Density- Bulk (kN/m^3)	12.07	12.60	12.10	12.20	12.23	7.91
Specific Gravity	2.31	2.51	2.41	2.48	2.30	2.36
Liquid Limit (%)	36.10	34.20	33.34	37.20	33.50	36.60
Plastic Limit (%)	21.20	19.30	22.20	24.10	25.00	20.30
O.M.C. (%)	17.10	15.80	14.40	13.90	17.10	18.00
M.D.D. (kN/m^3)	13.70	14.20	13.00	13.40	13.60	11.90
Coefficient of Curvature	2.80	2.00	2.30	2.60	2.60	1.70
Uniformity Coefficient	7.61	9..52	8.10	7.10	10.60	8.10
Direct Shear Test - ϕ°	35.7	38.83	34.10	33.20	36.55	36.23
Direct Shear Test-C kPa	26.33	35.83	25.44	26.10	27.61	10.56
Angle in degrees	5°	30°	5°	10°	10°	15°
Factor of Safety	0.82	2.04	0.78	0.93	0.94	0.46
Rock Type	Vascular basalt with zeolatic lava matrix	Red Tachylatic Basalt	Compact Basalt	Compact Basalt	Red Tachylatic Basalt	Red Tachylatic Basalt
Chances of Landslides	High	Medium	Medium	Medium	Medium	Very high
Present Condition	Highly weathered	Highly weathered	Moderately weathered	Moderately weathered	Highly weathered	Fresh

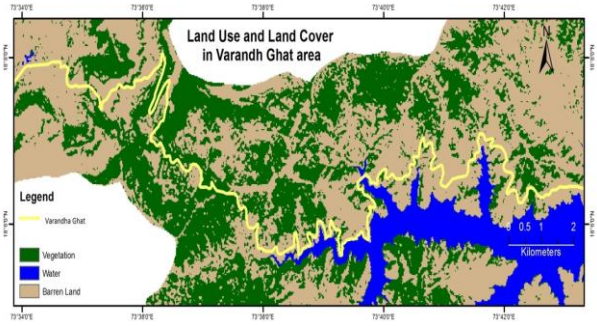

Fig. 3: Land use Map of Varandha Ghat.

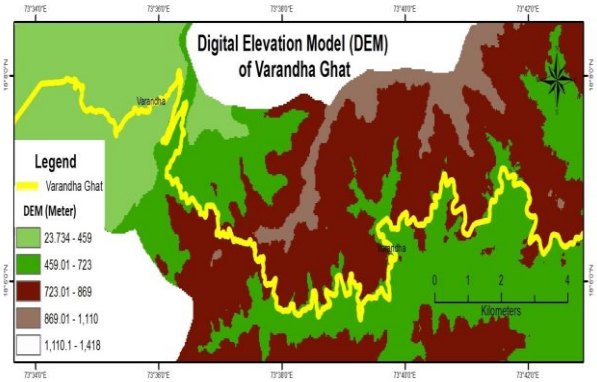

Fig. 4: Digital Elevation Model of Varandha Ghat.

6. Conclusion

The total topography of the slope is such that the drain flowing almost through the middle of the slope can carry considerable debris. However, the overall condition of the
slope is such that it may not fail unless there is some major triggering factor. The human settlement at the foot of hill slope may get affected in the eventually of slide due to rain. Especially, during the rainy season, along the Bhor-Mahad State highway faces number of mass movement incidents such as rock fall, landslides and creep movements through which big blocks, rubbles, soil mixed boulders slides and spread along the road, affected the road traffic jam problems, causes large scale damages road constructions and human lives. Through this shortcut way, which connecting upper Plateau region and Konkan Coastal Belt, vehicle carries huge traffic like thousands of passengers and goods. The highway has deep cut along its route with mostly untreated, unsafe slopes and presence extreme climatic conditions. Another
important is that a lot of construction activities day to day are going on in the hilly terrain, which is partially responsible to cause the jerk in the rock along the road cutting section. Such activities help for the movements of loose material towards the sloppy area. For the prevention of such mass movements, there is need of ground improvement techniques for the stability of slopes. As it is a highly vulnerable region especially in a rainy season as per as the mass movements are concerned. The slope material has considerable silts and the permeability was found to be of the order of 10-6 cm/sec. As a result due to heavy rain continued for a couple of days it is expected that pore pressure on the slope may rise and could trigger the local slip. The material dislodged due to local slips may get deposited into the drain making partially blockage of the flow. Under such condition the subsequent damage downstream of the slope will be even larger.

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