Slope stability analyses at Agumbe Ghat section NH-169A with and without slope protection

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Abstract: Slopes along the highways in hilly areas are more prone to landslides and rockfalls. Slope failure predominantly occurs during monsoon and traffic gets interrupted. Slope stability analysis is carried out to lessen the adverse effects of landslides and slope failures. One of the dangerous Ghat section in Karnataka is Agumbe Ghat. It has totally 14 hair pin bends. The work is focussed on slope stability carried out between 7th and 8th bend of Agumbe Ghat section which passes through NH-169A. The work reveals the analysis of slope stability with and without anchors. Slope catastrophes can be determined through suitable measurement of slope stability. Soil samples at the terrain are collected and tested in laboratory for important soil parameters. The bore log data has been collected and relevant data has been used for the analysis. The software used for analysis is GEO5 which helps to verify slope stability for critical circular or polygonal slip surfaces. Profile co-ordinate points have been surveyed and slope details have been collected from Google Earth, and were used to plot 7th bend profile. This paper gives insight regarding the set of anchors and effects on shear stresses along failure plain and stabilizing the slope effectively. Stability analysis were carried out by finding Factor of safety before and after adding anchors. It is found that the anchors increased the stability of slopes from 1.35 to 1.56.

Keywords: Slope stability, Shear stresses, Critical slip surface, Slope protection, anchors.

1. Introduction
One of the high-altitude villages in southwest Indian state of Karnataka is Agumbe. The hills consist of igneous rocks embedded in loose gravelly soil. Agumbe Ghat connects major cities like Thrithahalli, Udupi, Bhatkal, Kundapur and Mangalore. The Agumbe Ghat section is about 8.8 kms in length and 643 m of drop elevation. The existing alignment of Agumbe section passes through hilly/ mountainous terrain. The highway runs entirely inside Someshwara wildlife sanctuary. It is also a major attraction and is a tourism spot. Agumbe Hill Ranges have the historical backdrop of events and repeated landslides. To evaluate the stability of slopes at the site under examination, an assessment of geotechnical properties of the slopesubstance in the field has been viewed as essential. Landslide is an overall term used to depict the downslope development of soil, rock, and natural materials under the impacts of gravity and furthermore the landform that outcomes from such development. Landslide mishaps in Agumbe slope has influenced altogether the typical existence of the individuals connected in different regards.

There are many factors which cause landslides at slope regions, which even actually cause distress at highway pavements. In reference, a newspaper article in Times of India dated 28 June, 2018, a massive landslide had occurred which was followed by road accident at 7th bend of Agumbe Ghat section. The retaining structure also collapsed due this catastrophe. Around 10m of retaining wall collapsed along
with foundation. Due to heavy rainfall the repair works could not been taken up immediately. Many mishaps are taking place at the same stretch during monsoon season but not all events are reported. The highways at this section are always in danger. Carrying out slope stability analysis at this region was of greater importance especially during monsoons.

2. Literature Review
Kundu et. al. (2015) studied the stability analyses of landslide prone areas and made a GIS model to predict the landslide. The study was conducted at Ganesh Ganga watershed and susceptible landslide zonation are carried out [1]. The accuracy of the model has been evaluated using frequency ratio and success rate method. It was 85% accurate in predicting landslides.
Mir (2014) carried out research work on the role of Geosynthetics in preventing landslides. In his work he proved that geosynthetics takes less time in implementation as compared to conventional alternatives. Solutions are economically viable and sustainable [3]. In this study, an attempt has been made to utilize the available lightweight and sustainable material without affecting the earth's natural resources for the sustainable development in the region.
Ramli. et. al. (2013) carried out research to study the resistance of gabions against lateral movement by means of interlocking configuration instead of the conventional stack and pair system [5]. The research concluded that interlocking design exhibits better structural integrity than conventional box-gabions.
Lee et. al. (2002) described the physical characteristics of landslides and the statistical relations of landslide frequency with the physical parameters contributing to the initiation of landslides on Lantau Island in Hong Kong [2]. The results of this study demonstrate that slope instability can be effectively modeled by using GIS technology and logistic multiple regression analysis.

3. Slope Stability Analysis
Slope stability examination is performed to evaluate the protected structure of human-made or natural slopes (for example dikes, street cuts, open-pit mining, landfills and so on). The factor of safety for slope stability analysis is usually defined as the ratio of the ultimate shear strength divided by the mobilized shear stress at emerging failure [6]. There are several ways in formulating the factor of safety F. The most common formulation for F assumes the factor of safety to be constant along the slip surface, and it is defined with respect to the force or moment equilibrium [4]. The factor of safety should be more than 1.5 to confirm that slope is stable. If the slope is not found safe than the methods to make it stable must be carried out.
Geotechnical programming bundle GEO5 is intended to tackle different geotechnical issues. In this paper GEO-5 tool is used in measuring factor of safety of the given slope. Slope stability is chosen as the categorized tool under GEO-5. Analysis for slope without any slope protection and by using anchors is done.

4. Study area
The Agumbe hill ranges which form the present study area is bounded by 13° 15' to 13° 40' N latitudes and 75° 00' and 75° 15' E longitudes and falls in Survey of India Topo Sheets 480/2, 480/3. The area forms a part of Shimoga and Udupi districts of Karnataka state covering about 1150 sq.km of Malnad region. National Highway NH-169A passes through the Ghat section near Agumbe and is popular as "Agumbe Ghat" and it is shown in Figure. 1. The Agumbe Ghat section has 14 hairpin bends which makes it one of the dangerous Ghat sections in Karnataka. At 7th hair pin bend the radius of the curve is 3.5m which is smallest of all the curve radius, resulting in problematic maneuvering of vehicle. Through site and geological investigation, it is also found that slope is highly instable especially during monsoons. The sites selected for analysis is between 7th and 8th hair pin bend for this study. It is 3.5kms away from the Agumbe town and it is 474m above than the mean sea level. 13°49” 513” N and 75°07”36” E is the longitude and longitude of 7th bend.
4.1 Soil and Rock test of Agumbe Ghat Section

In the Table 1 the properties of soil and rock is described. In this paper all the parameters of the soil about 5 m depth are tested and at greater depths soil data is obtained from Bore log data collected from National highway Phase 2 report of DPR project from Thirthahalli to Udupi.

### Table 1. Properties of a soil/ rock present in terrain

| Material           | Angle of internal friction \((\Phi_{\text{eff}})\) | Cohesion \((C_{\text{eff}})\) | Unit weight \((\gamma)\) | Stress state | Soil / Rock Classification as per Method IS-1498 |
|--------------------|---------------------------------|-------------------|-----------------|--------------|---------------------------------|
| Brown sandy soil   | 16                              | 37.26 kPa         | 18.82 kN/m\(^3\) | effective    | Siliceous clayey soil            |
| Rock               | 30                              | 10000 kPa         | 25.39 kN/m\(^3\) | effective    | Weathered rock                  |
| Subgrade soil      | 35                              | 90.00 kPa         | 18.00 kN/m\(^3\) | effective    | Sandy soil                      |

**Figure 1. Location map of Agumbe**

5. Methodology

The bend chosen is between 7\(^{th}\) and 8\(^{th}\) hairpin curve as it is more prone to landslides and also is considered to be unstable if it is not protected. After detailed investigation the site the next step was to check feasibility. Reconnaissance survey is carried out to find out the slope cross sectional points. Google earth is chosen in order to verify coordinates points required to mark interface points in GEO-5. Google earth is profoundly an effective tool to find out slope angles and height of slope. Soil parameters is further updated into the software from conducted test results. Triaxial tests are conducted to get cohesion and angle of internal friction values. The soil is analyzed for 90% saturation considering that condition is worse during monsoon season. Water table at critical depth is mentioned while analyzing. The stability analysis is carried out using GEO-5 software demo version. Factor of safety is calculated using 5 different methods using same software. The 5 methods used in the stability analysis are Bishop method, Fellenius method, Janbu method, Spencer method and Morgenstern -Price method.

Chainages point of 7\(^{th}\) and 8\(^{th}\) points are 37.900 to 38.200 and 38.300km to 34.400 km respectively. The highest elevation point is 486m and lowest point is 474m MSL. The 7\(^{th}\) bend has the radius of
curvature about 4.5m and 8th bend has the curvature of about 3.50m. Due to this low curvature maneuvering of vehicle is a difficult job which indeed seeks for widening of road. To increase the width of road it is important to have stable slope. Therefore, slope stability analysis has been carried out.

5.1 **Slope stability Analysis without protection.**

The first phase in analysing the slope is to mark the coordinate points. The terrain interface points must be added in the system. In the Table 2 all the interface points are added in the Geo 5 software. There are four layers of interface points. These lines are drawn to visualize the depth of different soils and rocks in the Agumbe Ghat terrain.

| Table 2. Interface location of the slope |
|----------------------------------------|
| Interface No. | Coordination of Interface points (m) |
| x | z | x | z | x | z |
| 1. | 0.00 | 19.66 | 5.57 | 19.87 | 8.29 | 17.64 |
| | 8.57 | 15.13 | 10.24 | 13.03 | 12.54 | 10.59 |
| | 13.52 | 8.71 | 16.38 | 7.45 | 18.06 | 7.10 |
| | 19.58 | 5.10 | | | | |
| 2. | 0.00 | 10.20 | 6.28 | 7.93 | 9.42 | 5.06 |
| | 12.47 | 5.49 | 17.68 | 5.19 | 19.58 | 5.10 |
| | 30.00 | 4.51 | | | | |
| 3. | 19.58 | 5.10 | 19.77 | 3.63 | 20.64 | 3.41 |
| | 23.70 | 3.28 | 26.43 | 3.05 | 30.00 | 3.14 |
| 4. | 0.00 | 3.92 | 2.86 | 3.57 | 6.89 | 2.26 |
| | 9.77 | 1.91 | 12.30 | 1.30 | 18.49 | 0.10 |
| | 20.41 | 0.17 | 24.25 | 0.45 | 27.65 | 0.45 |
| | 30.00 | 0.43 | | | | |

The next phase is to assign the soil data. The soil parameters are considered from the bore hole data. After assigning data it is important to define boundary for the particular soil. For each layer the material of soil and their parameters is allotted and the details are shown in Table 3.

| Table 3 Assigning soil properties |
|-----------------------------------|
| Interface No. | Coordination of Interface points (m) | Assigned Soil |
| x | z | x | z | x | z | |
| 1. | 0.00 | 19.66 | 5.57 | 19.87 | 8.29 | 17.64 | Brown sandy clay |
| | 8.57 | 15.13 | 10.24 | 13.03 | 12.54 | 10.59 |
| | 13.52 | 8.71 | 16.38 | 7.45 | 18.06 | 7.10 |
| | 19.58 | 5.10 | | | | |
| 2. | 0.00 | 10.20 | 6.28 | 7.93 | 9.42 | 5.06 | Subgrade soil |
| | 12.47 | 5.49 | 17.68 | 5.19 | 19.58 | 5.10 |
| | 30.00 | 4.51 | | | | |
Third phase is to assign the surcharge load which will be applied from vehicles. As per IRC classification vehicle load with variable action is added. Table 4 gives the details of surcharge application.

Table 4. Surcharge applied on terrain

| No. | Type | Type of action | Location | Origin | Length | Slope | Magnitude (kN/m²) |
|-----|------|----------------|----------|--------|--------|-------|------------------|
| 1   | Strip| Variable      | On terrain | x=1.00 | l=2.50 | 0     | 9.80             |
| 2   | Strip| Variable      | On terrain | x=2.00 | l=2.50 | 0     | 9.80             |

It is important to add details of water table specified within the slope bed. It influences the analysis in two different ways. First when computing the weight of a soil block and second when determining the shear forces. It acts like a piezometric line passing at certain levels. The level is considered as per Central ground water board for the similar elevation at a nearby place. As it is a hilly terrain the water level may change. In the Table 5 ground water co-ordinate points are mentioned.

Table 5. Water table location

| No. | Water table location | Coordinates of GWT points(m) |
|-----|----------------------|------------------------------|
| 1   | [Diagram of water table] | x | z | x | z |
|     |                       | 0.00 | 13.52 | 2.96 | 11.57 |
|     |                       | 6.05 | 7.94 | 10.24 | 4.03 |
|     |                       | 13.03 | 2.29 | 16.52 | 0.47 |
|     |                       | 16.66 | 0.12 | 24.62 | 0.58 |
|     |                       | 30.00 | 0.65 |     |     |

Defining circular slip surface is utmost important. The circular slip surface is specified in terms of 3 points: two points on the ground surface and one inside the soil body. Each point on the surface has one degree of freedom while the internal point has two degrees of freedom. The slip surface is defined in terms of four self-determining parameters. The slip surface is first defined by optimizing it to critical slip surface. After critical surface is obtained later it is used as standard for all the methods. The Table 6 speaks about parameters involved in defining circular slip surfaces.
Table 6. Parameters adopted in circular slip surface

| Centre: x = 17.78m | Angles: α₁ = -79.64 (°) | Radius: R = 17.87m | Analysis of the slip surface without optimization |
|-------------------|------------------------|-------------------|--------------------------------------------------|

A critical slope surface occurs when a combination of soil and slope factors create a high-budding-for-slope face failure and subsequent erosion. Over-steepened freshly peevd or disturbed slopes are considered critical when resistance to surface erosion is low and sheer and strength resistance tolerances are exceeded. The possible slope face failure of the slope can compound with inadequate slope face compaction under super saturated conditions. The complete slope with all the layer is shown in the Figure 2 below.

![Figure 2. Slope diagram without slope protection](image)

5.2 Slope stability Analysis with anchors.
To make the slope stable the anchorages are later secured to slope. Anchors are selected from Rembco Geotechnical company. The anchor consists of steel Tandon and it is grouted into a pre-drilled hole in soil. Anchors which are having force capacity of 100KN are used for this stabilization. However, the tensile crack is not considered. In the Table no.7 location of anchors in the terrain and their parameters are shown.

Table 7 Anchor Parameters

| Sl. No | Origin x(m) | Origin z(m) | Free length l(m) | Root Length l₁(m) | Slope α(°) | Anchor spacing b(m) | Force F(kN) |
|--------|-------------|-------------|------------------|-------------------|------------|---------------------|-------------|
| 1      | 16.77       | 7.37        | 7                | 0.50              | 165.00     | 2.00                | 100         |
| 2      | 13.18       | 9.37        | 7                | 0.50              | 165.00     | 2.00                | 100         |
| 3      | 13.97       | 8.51        | 7                | 0.50              | 165.00     | 2.00                | 100         |
| 4      | 14.72       | 8.16        | 7                | 0.50              | 165.00     | 2.00                | 100         |
| 5      | 15.29       | 7.93        | 7                | 0.50              | 165.00     | 2.00                | 100         |
Figure 3 shows the analysis of cross section of slope which is inserted with anchorages.

![Anchorages compiled slope of Agumbe Ghat](image)

**Figure 3.** Anchorages compiled slope of Agumbe Ghat

### 6. Result and Discussions

The analyses for the slope at Agumbe Ghat 7th hairpin bend were carried out. Factor of safety for all the 5 methods were analyzed. In the first case slope stability was analyzed without adding the anchors. It was found that factor of safety was less than 1.5 and were found to be unstable. Figure 4 represents that FOS is less and it is not acceptable. Slopes might tend to fail if they are not protected.

![Slope stability verification (all methods)](image)

**Figure 4.** FOS values for slope without anchorage

In the second case, slope stability was analyzed by adding slope protection measure like anchors. It was found that factor of safety increased to a value more than 1.5. Figure 5 represents that FOS is more than the limit and it is acceptable. Slope is protected against sliding with the inclusion of anchors.
Figure 5. FOS values for the slope with anchors

Table 8 represents the comparison of FOS with and without the inclusion of anchors are involved. In this comparison table we can predominantly notice the increment in resisting moment which increase factor of safety.

| Factor of safety | Without slope protection | With anchorages |
|------------------|--------------------------|-----------------|
| Bishop           | 1.35                     | 1.56            |
| Fellenius        | 1.32                     | 1.52            |
| Janbu            | 1.40                     | 1.74            |
| Spencer          | 1.36                     | 1.70            |
| Morgenstern-Price| 1.47                     | 1.80            |

7. Conclusion

Taking Bishop's analysis as a main consideration following conclusions have been drawn:

- Factor of safety of instable slopes is 1.35
- Factor of safety of the slope when it is protected with anchorages is 1.56 which is 21% more safer than unstable slope
- Increase in the shear strength is high during monsoon season, which is the key factor for landslide and road blockage during rainy season.
- Shear failure in the soil layer also happen due to lose of suction during monsoon.

8. References

[1] Kundu, S., Saha, A. K., Sharma, D. C. & Pant, C. C., 2015. Remote sensing and GIS- based statistical landslide susceptibility zonation. International Journal of Geotechnical Engineering, p. 697-709(41(3)).
[2] Lee, F. C. & F, D. C., 2002. Landslide characteristics and slope instability modeling using GIS. Elsevier Journal- Geomorphology, 42(213-228), p. 16.
[3] Mir, B. A., 2014. Geosynthetics applications in highway construction in J.K: sustainable
infrastructure development. *I-manager's Journal on Structural Engineering*, Volume 314.

[4] V, K. Murti., P, Y. S. & Dias, N., 2010. *Stabilization slope for hill road at Chorla Ghat*. Mumbai, Indian Geotechnical Conference.

[5] Ramli, M., Karasu, T.J. R & Dawood, E.T. 2013. *The stability of gabion walls for earth retaining Structure*. Switzerland, Alexandria Engineering Journal, 52(4). 705-710.

[6] Mohammedi, C., 2015. Slope stability analysis report. *Research gate*, Technical Report DOI No: 10.13140/RG.2.2.12503.42405.