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Slope Stabilization for Malshej Ghat

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Abstract - *Highway side hill slopes are exposed to environmental and atmospheric condition, like deforestation, cycles of freezing and thawing weather, heavy storms etc. Over time, these weather conditions can influence slope stability together with other factors like geological formations, slope angle and groundwater conditions. These factors contribute towards causing slope failures that are hazards to highway structures and therefore the traveling public. There are various types of slope failures.*

Key Words: Deforestation; Freezing and thawing weather; Geological Formation; Slope failures; Slope stability.

1. INTRODUCTION

The Malshej Ghat is the key link to connect Konkan Area of Thane, Kalyan to upper plateau of Deccan in Pune district. Owing to its importance as a popular tourist destination and part of NH 222, it has tremendous traffic load and is vulnerable to landslide hazard pose serious problems during rainy seasons. In 2013, this area experienced huge rock fall and blocked the road for few days with loss of life and damage to the properties.

Landslides are short-lived phenomenon, which may cause extraordinary landscape changes and destruction of life and property. Landslides within the strict sense denote the rapid movement of sliding earth material, separated from the underlying stationary a part of the slope by a precise plane of separation to slope failure, under the influence of gravity. Varnes (1981) estimated that in the period from 1971 to 1974, nearly 600 people per annum were killed worldwide by slope failures. In last three decades, many researchers have worked on landslide hazard and risk zoning employing a style of approaches. Keeping national highway operational, minimizing the economic loss to the exchequer and safeguarding the general public interests, adoption of slope stabilization techniques rather becomes an important tool. A correct planning for demarcating landslide prone areas/segments within the entire route, delineating the grounds of slopes failure and adoption of speedy mitigation and mitigation measures along the route become paramount.

2. STUDY AREA LOCATION

Malshej Ghat, a nearly fifteen kilometers long lofty ghat road is a part of an important road link between Mumbai (via Kalyan- Murbad) and Ahmednagar a district place located due northeast of Pune Although this road was earlier classified under "State Highway" category, recently its status has been upgraded to National Highway (NH No. 222) as shown in figure 1. Besides serving as an important part of the NH 222, the Malshej Ghat area also attracts large number of tourists in the monsoon period as it offers one of the most picturesque view of the Western Ghat escarpment and the neighboring "Inner Konkan plain The Maharashtra Tourism Development Corporation (MTDC) run tourist bungalow, located at the plate edge of the Western Ghat plateau looking over scenic Inner Konkan plain is an important landmark of the area. During monsoon, this road section experiences minor and major incidences of landslides at number of places. They not only cause traffic disruption but also act as a constant threat to the commuters. Over the years, a few fatal accidents causing either deaths or serious injuries due to landslides (mainly rock fall) were reported in last few years.

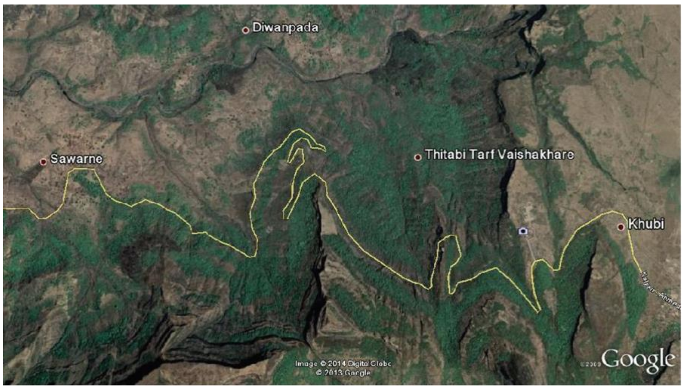


Figure -1: Study Area Location **-** Malshej Ghat

3. DATA COLLECTION

Stability of Slope is "the heart" of embankment along the road. Pit slope monitoring is an important undertaking requiring collection of structural data for geotechnical characterization and stability analysis. In this paper, photogrammetry is applied to capture images for processing. The data available for the assessment were limited to those collected through geological mapping and field observations.

3.1 Physical Properties of Rocks

1) Density

Density is defined as mass per unit volume of the rock. Depending on the requirement, the density may be expressed as dry density, bulk density or saturated density. Dry density refers to the mass per unit volume when the rock mass is completely dry, i.e., when the bulk spaces containing only air. Bulk density refers to the mass per unit volume under normal conditions, which implies that the rock mass may contain some liquid and some air in its pore spaces. Saturated density refers to the mass per unit volume when the rock mass is fully saturated. Density of a rock can be measured by using a hand specimen as well as using crushed gravel sized grains of the rock.

Dry density is calculated by using following equation (ISRM, 1977).

$\rho_d = (W_{dry} \times \rho_{fluid}) / (W_{sat} - W_{sub})$

Where,

ρ dry density, ρfluid density, W_{dry} weight of dry samples

W_{sat} -weight of saturated sample, W_{sub} = weight of sample in fluid.

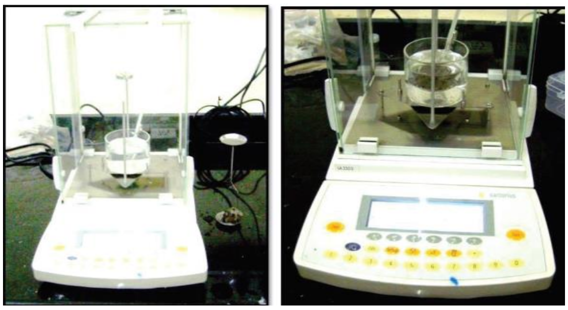


Figure 2 Setup for determination of density of rock samples

2) Water Absorption

Water absorption is amount of water socked by sample for a given time. It is expressed in term of percentage. The water absorption of core sample is given in table 1.1 and calculated using equation 2. Water Absorption = $\{(W_{sat} - W_{dry}) / W_{dry}\} \times 100$

3) Porosity

Porosity is the percentage of void space ma rock. It is defined as the ratio of the volume of the voids or pore space divided by the total volume. It is written as either a decimal fraction between 0 and 1 or as a percentage between 0 to 100%. The porosity has been estimated as per ISRM standards (ISRM, 1977). The porosity of core samples given in table 1.1 and calculated using following equation.

Porosity (In percentage) = $\{(W_{sat} - W_{dry}) / (W_{sat} - W_{sub})\} \times 100$

Table 1.1: Density, water absorption and porosity of core samples

S.N	Sample	Density		Water Absorption		Porosity	
1	MG01	2.65	Mean=2.64 Min=2.59 Max=2.71	1.6	Mean=2.23 Min=1.81 Max=2.77	4.25	Mean=5.88 Min=4.89 Max=7.17
2		2.64		1.72		4.54	
3		2.67		1.49		3.99	
4		2.59		2.25		5.82	
5		2.56		2.16		5.54	
6		2.68		2.06		5.34	
7	MG02	2.69	Mean=2.62 Min=2.56 Max=2.67	2.06	Mean=1.88 Min=0.93 Max=2.42	5.54	Mean=4.95 Min=3.99 Max=5.82
8		2.68		2.22		5.96	
9		2.71		1.81		4.89	
10		2.59		2.47		6.04	
11		2.59		2.77		7.17	
12		2.59		2.05		5.31	
13	MG03	2.54	Mean=2.59 Min=2.54 Max=2.68	2.42	Mean=1.92 Min=0.93 Max=2.42	6.14	Mean=4.95 Min=2.49 Max=6.14
14		2.55		2.39		6.1	
15		2.68		0.93		2.49	
16		2.55		2.21		5.65	
17		2.58		1.71		4.41	
18		2.62		1.89		4.94	
19	MG04	2.71	Mean=2.70 Min=2.67 Max=2.72	2.02	Mean=2.32 Min=1.84 Max=3.61	5.48	Mean=6.26 Min=5.00 Max=9.62
20		2.72		2.14		5.82	
21		2.72		1.84		5	
22		2.7		2.13		5.76	
23		2.7		2.16		5.84	
24		2.67		3.61		9.62	

4) Uniaxial Compressive Strength (UCS), Dry and Saturated

The uniaxial compression test is most direct means of determining rock strength. In this test, cylindrical rock specimens are tested in compression without lateral confinement. The test specimen should be a rock cylinder of length-to-width ratio (H/D) in the range of 2 to 2.5 with specimen must maintain full contact with the loading platens. If core samples ends are not flat then the application of load will be on a lesser area and the sample will fail at an early load. The load should be applied at the rate of 0.5-1.0 MPa/sec for uniform distribution flat, smooth and parallel ends cut perpendicular to the cylinder axis (ISRM 1978). The specimen is kept between two loading platens of a compression testing machine (UTM). Therefore, zero stress in the sample. Strength depends upon the rate of loading also.

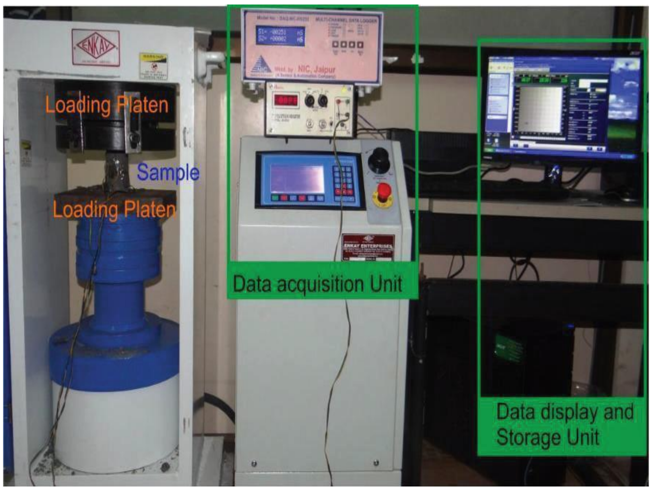


Figure 3 UTM setup for determination of UCS (Left)

The unconfined compressive strength of the specimen is calculated by dividing the maximum load at failure by the sample cross-sectional area Table 1.2.

6c= F/A

Where,

6c = Unconfined compressive strength (KgF/cm^2 or N/mm^2).
F= Maximum Failure Load (kN), and

A= Cross-sectional area of the core sample (cm^2).

Table 1.2 Dry and saturated uniaxial compressive strength (UCS)

S.N.	Sample	UCS (MPa)		% Reduction
		Dry	Saturated	
1	MG01	29.38	28.28	3.74
2	MG02	36.45	25.31	30.56
3	MG03	24.29	18.46	24

5) Tensile Strength (Dry and Saturated)

The tensile strength of a material is defined as the maximum tensile stress which a material is capable of developing. In nature, rock mass is rarely subjected to direct tension, but it undergoes tensile stress. Rocks become weaker under the tension. It has been found that the rock possesses tensile strength which is about 10% of its compressive strength.

The direct tensile strength testing is difficult to perform and generally expensive for routine applications. Also it often is prone to give low results due to the effects of existing micro-fractures and other rock defects. Therefore, an indirect method, the Brazilian disk test, is most commonly used to determine the tensile strength of rocks as per ISRM suggested method (ISRM, 1978) Figure 3.

Figure 3: Tensile strength setup

In Brazilian cage test, a circular disk specimen is used with a thickness to diameter ratio (L/D) of between 0.5 and 0.75 The load is applied across the sample diameter as shown in Figure 3. This specimen is placed in loading platens of the UTM. The rate of loading is normally 22 MPa (21 57MPa). The test may be stress controlled or strain controlled. The tensile strength Table 1.3 is calculated by the following formula

6t=2p/πdt

Where,

6t= Tensile strength (MPa),

P=Failure load (kN),

D=Diameter of the specimen (cm), and

T=Thickness of the specimen (cm).

Table 1.3: Tensile strength of core sample in dry and saturated condition

S.N.	Sample	Tensile strength (MPa)	
		Dry	Saturated
1	MG01	12.78	10.24
		12.23	7.37
2	MG02	7.19	7.75
		6.37	8.19
3	MG03	9.37	5.67
4	MG04	10.26	
		9.68	

6) Point Load Index

In the point load test, the tensile strength is measured indirectly by loading the rock specimen between two conical, or point shaped, platens. Test specimens may be cores or irregular lumps of rock Core samples can be tested both diametrically and axially Figure 4. For crystalline rocks, the point load strength indices normally vary between 5 and 20 MPa (54 mm cores) Weak rocks have indices lower than 1 MPa. The point load anisotropy index (the ratio between maximum and minimum point load strength index) may reach values of 5 or higher in highly anisotropic rocks such as shales and schists. Since PLI is not directly used in prediction models. It can be used qualitatively to estimate rock strength and the degree of anisotropy. The point load index of various samples is tabulated in Table 1.4.

The point load strength index (Is) is calculated as:

$Is=P/De^2$

Where,

P= Failure load (N),

D= Distance between platen tips (m)

$De^2= D^2$for diametrical test, or = 4A/ for axial, block and lump test.

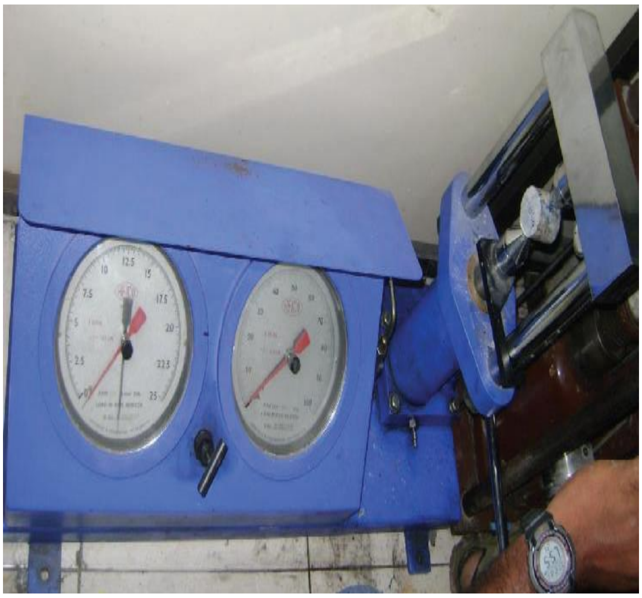


Figure 4: Point load index determination setup

Table 1.4: Point load index of various samples

S.N	Sample	Point load index Mpa
1	MG01	4.99
2		6.11
3		3.97
4	MG02	4.57
5		2.83
6		4.08
7	MG03	4.01
8		3.93
9		4.54
10	MG04	5
11		3.02

7) Elastic properties of the rock samples

Elastic properties of intact rock are measured while carrying out of uniaxial compressive test by measuring deformation as function of stress. It is common to measure for both axial and diametric strain. The average modulus over the linear elastic segment of the stress-strain curve has been considered. The Youngs modulus Poisson's ratio, bulk modulus and shear modulus were calculated with the help of load-deformation curve obtained from the universal testing system machine. The results of elastic properties are given in Table 1.5.

Table 1.5: Elastic properties of samples

S.N.	Sample	Youngs Modulus E, (MPa)	
		Dry	Saturated
1	MG01	32.07	18.20
2	MG02	18.84	11.44
3	MG03	42.16	33.16

3.2 Geo-mechanical properties of soils

1) Grain size analysis of soils

The gram size analysis of six samples were prepared and analysed according to methods mentioned in D6913-04 (ASTM, 2009), Sieve size and cumulative passing of each samples Table 2.1 to 2.6 and Figure 5 to 10 respectively.

Table 2.1: Sieve analysis for sample no. 01

ASTM	Weight (gm)	Cumulative Retain (%)	Cumulative Passing (%)
5	375.14	62.63	37.37
16	148.19	87.36	12.64
25	22.76	91.16	8.84
45	13.23	93.37	6.63
80	9.41	94.94	5.06
120	5.25	95.82	4.18
200	8.11	97.17	2.83
270	15.5	99.76	0.24

ASTM	Weight (gm)	Cumulative Retain (%)	Cumulative Passing (%)
PAN	1.43	100	0

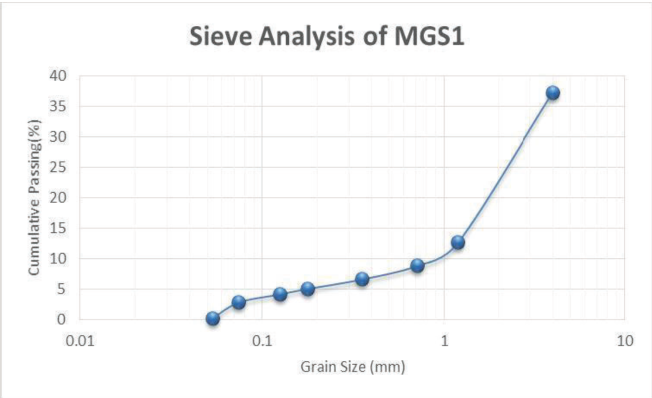


Figure 5 Cumulative Passing vs grain size for soil sample 01

Table 2.2 Sieve Analysis for example no. 02

ASTM	Weight (gm)	Cumulative Retain (%)	Cumulative Passing (%)
5	213.92	35.98	64.02
16	232.12	75.01	24.99
25	40.25	81.78	18.22
45	33.42	87.4	12.6
80	24.41	91.51	8.49
120	11.56	93.45	6.55
200	12.98	95.63	4.37
270	24.72	99.79	0.21
PAN	1.24	100	0

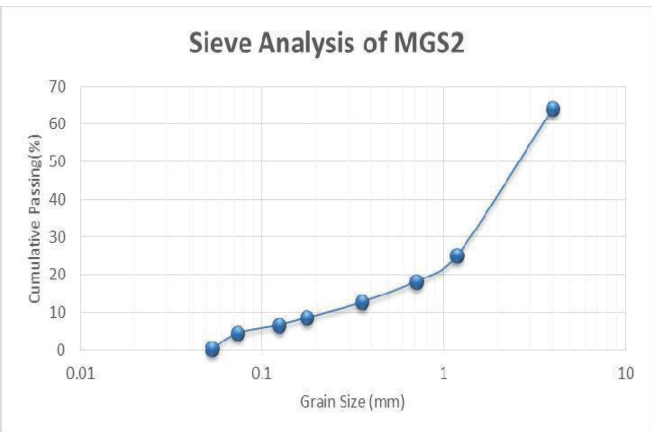


Figure 6 Cumulative Passing vs grain size for soil sample 02

Table 2.3 Sieve Analysis for example no. 03

ASTM	Weight (gm)	Cumulative Retain (%)	Cumulative Passing (%)
5	248.24	40.77	59.23
16	132.32	62.50	37.50
25	38.02	68.74	31.26
45	46.17	76.33	23.67
80	40.17	82.92	17.08
120	22.70	86.65	13.35
200	6.61	87.74	12.26
270	60.30	97.64	2.36
PAN	14.37	100.00	0.00

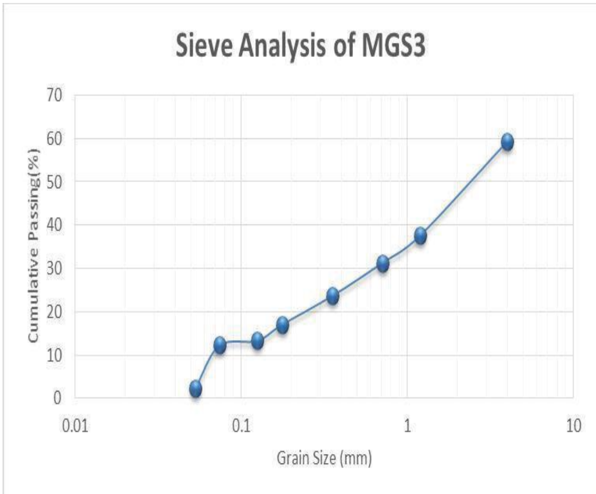


Figure 7 Cumulative Passing vs. grain size for soil sample 03

Table 2.4:Sieve analysis for sample no. 05

ASTM	Weight (gm)	Cumulative retain (%)	Cumulative passing (%)
5	327.27	53.17	46.83
16	186.49	83.47	16.53
25	29.29	88.23	1 1.77
45	21.87	91.79	8.21
80	14.76	94.18	5.82
120	7.79	95.45	4.55
200	9.16	96.94	3.06

270	18.37	99.92	0.08
PAN	0.48	100.00	0.00

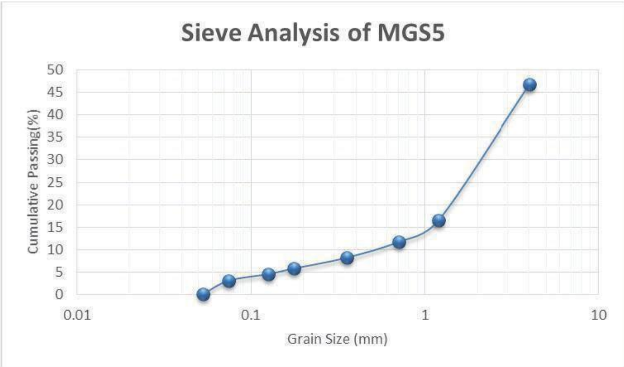


Figure 8:Cumulative passing vs. grain size for soil sample 05

Table 2.5: Sieve analysis for sample no. 06

ASTM	Weight (gm)	Cumulative retain (%)	Cumulative passing (%)
5	349.67	49.21	50.79
16	202.67	77.73	22.27
25	34.29	82.55	17.45
45	31.57	86.99	13.01
80	27.39	90.85	9.15
120	13.74	92.78	7.22
200	18.19	95.34	4.66
270	32.34	99.89	0.11
PAN	0.76	100.00	0.00

Figure 9: Cumulative passing vs grain size for soil sample 06

Table 2.6: Sieve analysis for sample no. 07

ASTM	Weight (gm)	Cumulative retain (%)	Cumulative passing (%)
5	99.16	17.25	82.75
16	263.41	63.07	36.93
25	49.23	71.63	28.37
45	39.11	78.43	21.57
80	30.68	83.77	16.23
120	18.99	87.07	12.93
200	25.10	91.44	8.56
270	47.43	99.69	0.31
PAN	1.78	100.00	0.00

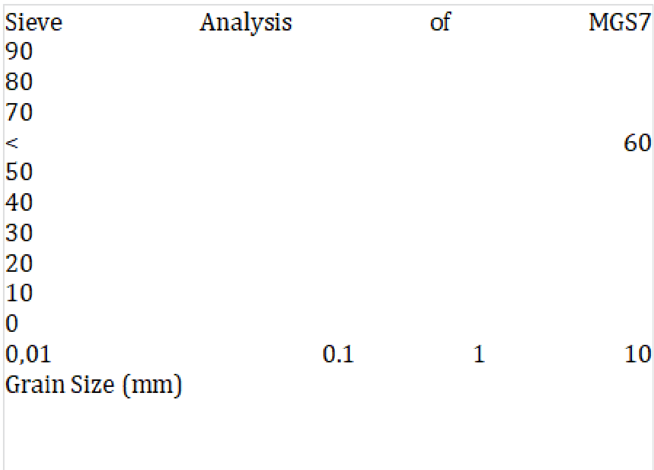
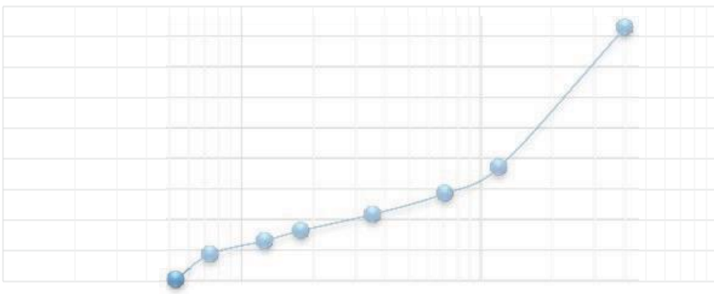


Figure 10: Cumulative passing vs grain size for soil sample 07



3.3 Slope Stabilization

Slope stability analysis is a static or dynamic, analytical, or empirical method to evaluate the stability of earth and rock-fill dams, embankments, excavated slopes, and natural slopes in soil and rock. Slope stability refers to the condition of inclined soil or rock slopes to withstand or undergo movement. The stability condition of slopes is a subject of study and research in soil mechanics, geotechnical engineering, and engineering geology. Analyses are generally aimed at understanding the causes of an occurred slope failure, or the factors that can potentially trigger a slope movement, resulting in a landslide, as well as, at preventing the initiation of such movement, slowing it down or arresting it through mitigation countermeasures. The stability of a slope is essentially controlled by the ratio between the available shear strength and the acting shear stress, which can be expressed in terms of a safety factor if these quantities are integrated over a potential (or actual) sliding surface. A slope can be globally stable if the safety factor, computed along any potential sliding surface running from the top of the slope to its toe, is always larger than 1. The smallest value of the safety factor will be taken as representing the global stability condition of the slope.

The slopes will be classified into two types namely, the infinite slopes and finite slopes. An infinite slope is that the sort of slope that's very large in extent within which the characteristics of the soil will remain the identical at the identical depths specified the slip surface is a plane parallel to the surface of the slope. On the opposite hand, a finite slope is that the form of slope that's limited in extent during which the properties of the soil won't be the identical at the identical depths such the slip surface is a curve. Such slope will undergo several failures associated with the instability of slopes. Many of the slope failures are related to the increasing amount of the water ingress during heavy rainfall and flood.

The surface of the earth is a complex and dynamic system constantly subject to modification through physical interactions and processes. Landslides, erosion flows and other soil movements along slopes are some of the processes that modify the landscape (Hansen, 1984). Slope processes such as these are referred to as mass movements. They involve outward or downward movement of soils along slopes under the influence of gravity.

4 DATA ANALYSIS AND RESULT

4.1 The hazardous locations identified for various cases of study area.

Figure 11. Case 1 Typical locations on existing road where PCC and RCC retaining walls can be proposed on valley side

Figure 12. Case 2 Typical locations on existing road where Gabion wall can be proposed.

Figure 13. Case 3 Typical locations on existing road where RCC Retaining wall can be proposed.

Figure 14. Case 4 The slope downhill is to be protected for further deterioration. The risk involved is of washing away the road all sudden.

4.2 **Analysis-** (in terms of costing)

There are 4 cases have been studies for the hazardous locations on the existing road malshej ghat. These are detailed below.

Case no. 1 -

1. cutting the slope to natural sustainable slope.

Costly as it requires excavation and disposal of debris to the safe disposal place. So also it requires acquisition of land in forest area.

2. use of gabion wall along the hill face.

As the boulders are not available, boulders need to be brought on site from out side. So also the base width required for gabion wall is around 1.5 to 2 meters which is not available on site. So not a workable option

3. Use of retaining wall

This will be most suitable action. PCC retaining wall with adequate weep holes shall be provided along the hillside.

Case no. 2 –

1. Here we see a typical soil boulders matrix .

The option of cutting the slope to the natural sustainable slope will not be possible due to this matrix.

2. The provision of concrete retaining wall.

Here the height to be retained is more than 7 to 8 meters .Therefore, provision of concrete retaining wall may not be economical.

3. The provision of gabion wall .

This will prove to be the economical as the boulders are readily available. The height to be retained is between 7 to 8 for which gabion walls are most suited.

4. Soil nailing and mesh.

Since this is heterogeneous mass of soil and boulder matrix ,this treatment will not prove to be effective.

Case no. 3 -

The slope downhill is to be protected for further deterioration. The risk involved is of washing away the road all sudden.

1. The option to construct a gabion wall. However, looking at the site conditions, the base support needed for gabion wall will not be available at valley side.

So, this option is ruled out

So also, option of constructing solid PCC wall is also ruled out as width of base for such walls is more and site cannot accommodate this width to give the stability.

2. The only option left is to construct the RCC retaining wall by providing anchorages at bottom. The section is slender, and it will provide maximum width for carriageway which is very much needed.

Case no. 4 -

This is a typical case where soil mass is separated in vertical discontinuity with respect to rock mass. Here a chance of sudden landslide, particularly in monsoon is predominant.

1. Here the width of soil mass ,is about 6 to 7 meters and height is about 8 to 10 meters so provision of gabion wall is suited to this site. The required base width is also available and required bench width for every step is also available.

2. The option of providing PCC retaining wall will not be economical by considering the huge quantity of concrete required for it.

3. The option of providing soil nailing and net will also be uneconomical as the area to be protected and retained is relatively small. The area is easily accessible for other treatments. For such a small quantity, soil nailing is not advisable.

Table -4.1: Costs requirement for various cases.

Case/ Options	Case -1	Case-2	Case-3	Case-4
Cutting the Slope to Natural Slope	40.08	-	-	-
Provision of Gabion Wall	16.73	22.64	60.94	0.81
Provision of PCC Retaining Wall	14.89	25.10	93.84	3.228
Provision of RCC Retaining wall	-	-	50.69	-
Provision of Soil Nailing and Mesh	-	44.85	-	4.67

Remark Feasibility	Provision of PCC Retaining Wall	Provision of Gabion Wall	Provision of RCC Retaining wall	Provision of Gabion Wall

*All costs are in INR Lakhs

5 CONCLUSIONS

The current research aims at assessing the mitigation of slope stabilization in Malshej Ghat. Slope Stabilisation, particularly in Malshej Ghat, is a long time challenge to keep this important National Highway in safe and traffic worthy condition. Every year, specifically in Monsoon season, there are quite a few incidents of Landslides and Rock falls causing injuries, sometimes fatal and disruption of traffic.

It is seen that from the analysis of various provisions for the different cases that have some pros and cons related to them .Here we analysed four cases where slope stabilisation measures are to be adopted. The treatments were provision of Gabion walls ,cutting the slope to natural slope, Provision of PCC walls, Provision of RCC walls, provision of Soil nailing and Mesh . Out of these treatments, most suitable treatments for each case were selected and detailed design and cost analysis is done. By giving due consideration to cost and site specific constraints ,for Case number 1,2 and 4,we can conclude that Gabion walls or PCC walls are the cheapest solution for slope stabilisation where height to be retained is limited to 8 to 9 meters and wherever space for base width of such wall is available on site. RCC walls are effective where space available for base is limited and wall is to be provided on valley side. Soil nailing and mesh can be effectively provided where soil mass is of uniform texture and of sufficient quantity.

While finalising various measures for slope stabilisation, we shall carefully study the reasons of slope failure as well as type of soil, type of texture of soil mass, height and position of soil mass in threat. So that, the best suited treatment for that particular location and most economical treatment can be recommended for a particular problem.

It is observed that RCC retaining walls are most suited to be constructed on Valley side where steep slope are existing and small space for base of wall is available. The lowest construction cost for case no. 1 and case no. 3 is Rs 14.89 Lakhs and Rs. 50.69 Lakhs respectively if retaining wall is proposed whereas lowest construction cost for case no. 2 and case no. 4 is Rs 22.64 Lakhs and Rs. 0.81 Lakhs respectively if Gabion wall is proposed. Soil nailing is recommended where integral and homogeneous soil mass is in threatening condition to collapse. This treatment is not suited for Soil Boulder Matrix type of mass. Sometimes, due to stratification, layer of soil mass is resting at a height over layer of Rock mass, then Soil nailing along with mesh shall be provided.

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