SLOPE STABILITY ANALYSIS AND DESIGN USING NUMERICAL TECHNIQUES: A CASE STUDY

[a] Ahsan Javed*, [b] Naveed Ahmed, [c] Babar Khan

a: Department of Civil Engineering, UET, Taxila, Pakistan, ahsanbhatti798@gmail.com
b: Department of Civil Engineering, UET, Taxila, Pakistan, naveed.uet28@gmail.com
c: BK Consultants (Pvt) Limited, Islamabad, Pakistan, ino@bkconsultants.com.pk
* Corresponding author: Email ID: ahsanbhatti798@gmail.com

Abstract- This case study analyses kilometer 28th of Islamabad-Murree Dual Carriage Way (IDMC) also known as National Highway (N-75) of Pakistan for its stability. The slope has high gradient, irregular shape and no vegetation cover which makes this slope susceptible to failure. The slope was analyzed with software Rocscience Slide 6.0. Based on the analysis, it was found that slope has a low factor of safety and might be unsafe. The slope was then designed using active design method. For analysis, different numerical methods i.e. Bishop's method, Janbu method simplified, Janbu method modified and Spencer method were used. Various types of supports were used individually and in combination to design the slope. Three different models were designed and analyzed having improved factor of safety from each other. From all the models, one model was finalized and declared as safest models having factor of safety greater than 2.0

Keywords- Slope Stability, Rocscience Slide 6.0, Active Design, National Highway-75 (N75).

1 Introduction

Landsliding can have significant and wide-ranging effects on both natural and human systems. Some of the effects of landsliding include loss of life and property damage, disruption of transportation networks, damage to natural habitats, soil erosion and sedimentation, flooding, economic impacts. [1] A slope fails when the driving forces overcome the resistive forces acting in the slope strata. In order to analyze the slopes for its stability, several methods have been introduced and modified over time. However, each of these methods is dependent on a number of factors i.e., type of slope, working approach, equilibrium type & assumptions. [2] Reviewing all these factors, the accuracy of one method can outperform the other.

Murree road is located near a tectonically active region of the Earth where mass movements like rock fall, rockslides and slumps cause adverse economic loss through disruption of travelling on roads. [3] Rainfall has seriously affected Islamabad Murree Dual-Carraige Way (N75) over the past few years. [4] Based on the results of a study, it can be concluded that the failure of the landslides along the Murree-Kohala road was activated by the reduction of shear strength of the slide material due to the increase in percentage of saturation, which reduced the effective normal stress along the slip surface. [3] There are major environmental impacts of landslide in Himalayan region. [5] Sohaib Naseer analyzed the slope using Limit Equilibrium and Finite Element Method using Rocscience Slide 6.0 and concluded that LE method overestimates the safety factor as compared to FE method. [6] This study was conducted in Dahr, ElBaidar – Lebanon Geometry ad visual analysis is shown in Fig. 1 (a) & (b).

In general, LE methods are used for slope stability analysis by the practicing engineers and professionals, however, similar studies show the vigorous nature of FE approach. In general, the LE and FE methods used in this study provide fairly consistent FOS. [7] LE method, being more practiced, will be used in analysis of this slope. A landslide occurred in a slope near Dahr Elbaidar in Lebanon during roads excavation work was suggested to be stabilized by means of active support system, i.e., reinforcement such as piles and nails. [8] We will be using active support system for the designing of the slope.

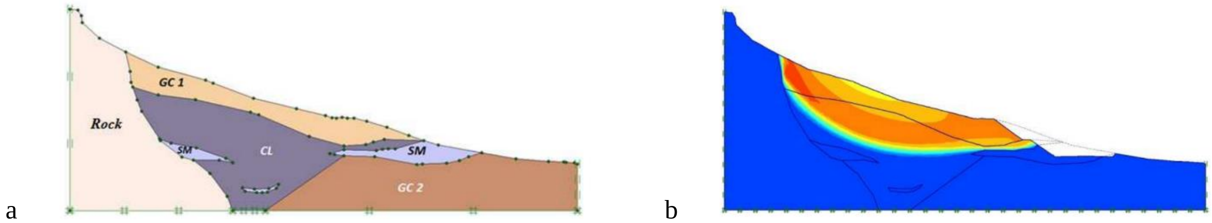


Fig 1. (a) Geometry of Slope (b) Analysis of Slope FS 2.07

Subject slope i.e., kilometer 28 of National Highway is a critical slope. It has a very steep slope at an angle of 79.69 degrees with no vegetation cover. The toe part of the slope does not have natural backfill to hold the slope. This slope has a long history of failure in the past. [9] The geographical/topographical location, seismic activity and high rainfall has been a major cause of failure of the slope. There are various software used for the analysis and design of the slopes using limit equilibrium approach [10]. We will be using Slide 6.0 in this paper due to its convenient visual representation and accurate FOS calculation. [11]

2 Research Methodology

For subject case study, boreholes were drilled at different location of the slope and samples were tested in the lab to acquire the physical properties of the slope. All the physical testing and data collection by done in collaboration with B.K Consultants. Once the soil parameters are determined, the slope is modeled with Rocscience 6.0, the slope is first analyzed for its minimum factor of safety. Based on the results, the slope is designed using active design method. Various ground improvement techniques are used with respect to support members to achieve the safest, economical, and practical model. For analysis of designed slope, Bishop's method, Janbu Method – simplified, Janbu Method – corrected and spencer method are used.

3 Experimental Analysis

The slope under study is located at kilometer 28th of Islamabad Murree National Highway (N-75). It does not have any vegetation cover and high slope gradient of 79.60 degree. Tension cracks has also developed on the road. (*Fig. 2.d*) The base of slope consists of Rock material; it has rocky soil strata on top of it mentioned as failure envelope in (*Fig. 3.a*) A distributed load of 20 kN/m2 is taken as live load of traffic. This highway falls in between Murree and Islamabad having seismic zone 3 and seismic load has been applied accordingly i.e., 0.2 g horizontal and 0.1 g vertical. The slope of failure envelope is steep, and toe also does not lie on a proper slope angle or solid base, which makes it prone to failure.

Fig. 2 (a), (b), (c), (d) shows top, right side, left side and road view (with tension crack) of slope

The current geometry of the slope is shown in *Figure 2*. The slope will be analyzed for its stability using four different methods of analysis. Based on the results of Factor of Safety, the slope will be designed to achieve the safest model.

3.1 Analysis of Slope

Based on the parameters of the slope, the data was input in the software and analysed for its stability. For analysis of slope, the non-circular slip surface method was used. The properties of the materials are given as under Table 1 & 2.

Table 1: Properties of Rock

Rock		
Unit Weight	20	kN/m3
Unconfined Compressive Strength	12000	kPa
Water Surface	None	

The Properties of identified failure envelope is given in Table 2.

Table 2: Properties of Failure Envelope

Failure Envelope		
Unit Weight	19	kN/m3
Cohesion	50	kPa
Phi	30	degrees

The visual analysis of the slope is shown in *Fig. 3 (b)* along with the results of the same using four different approaches in *Table 3.* A filter on all the slip surfaces in applied to show only layers with FOS below 2.0.

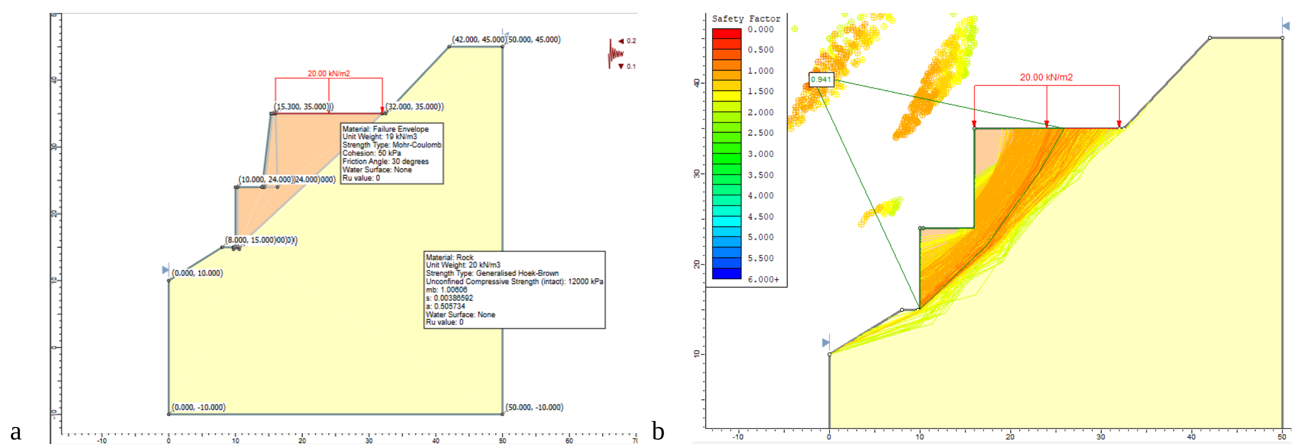


Fig 3. (a) Slope structure and coordinates (b) Analysis of Original Slope

The Table 3 shows the results of analysis of slope using four different approaches.

Table 3: Results for Analysis of Slope

Global Minimums SF			
Bishop simplified	Janbu simplified	Janbu corrected	Spencer
0.923121	0.919315	0.940862	0.952144

In *Fig 3. (b)* all yellow and brown layers are visible having FOS below 1.5. Based on these results, it is found that the slope has low factor of safety and is unsafe. It needs to be redesigned using different ground improvement techniques.

3.2 Model 1: Active Design of Slope

In model-1 of active design of slope, as shown in *Fig. 4* a retaining wall of specifications given below is introduced along the steep angle of slope, in order to counter the steep angle impacts on its strength. The properties of retaining wall used are given in the *Table. 4* below.

Table. 4. Properties of Ground Anchors

Retaining Wall		
Unit Weight	20	kN/m3
Cohesion	30	kPa
Phi	35	degrees

3.3 Model 2: Active Design of Slope

In model-2 of active design of slope, as shown in *Fig. 4 (a)*, grouted tie backs are introduced which act as ground anchors. Specifications of ground anchors are given in *Table 5*. Both retaining wall and ground anchors act in combination to increase the overall strength of the slope.

Table. 5. Properties of Ground Anchors

Ground Anchor		
Support Type	Grouted Tie Backs	
Tensile Strength	750	kN/m
Plate Capacity	750	kN/m
Pullout Strength		
Adhesion	15	kPa
Friction Angle	35	degrees

3.4 Model 3: Active Design of Slope

In model-3 of active design of slope, as shown in *Fig 4 (b)* micropiles are added in the model. The lower portion of the slope seems too steep, in order to support the toe, micropiles maybe introduced to further increase the strength of the slope. Specifications of ground anchors are given in *Table 6*. Retaining wall, ground anchors and micropiles act in combination to increase the overall strength of the slope.

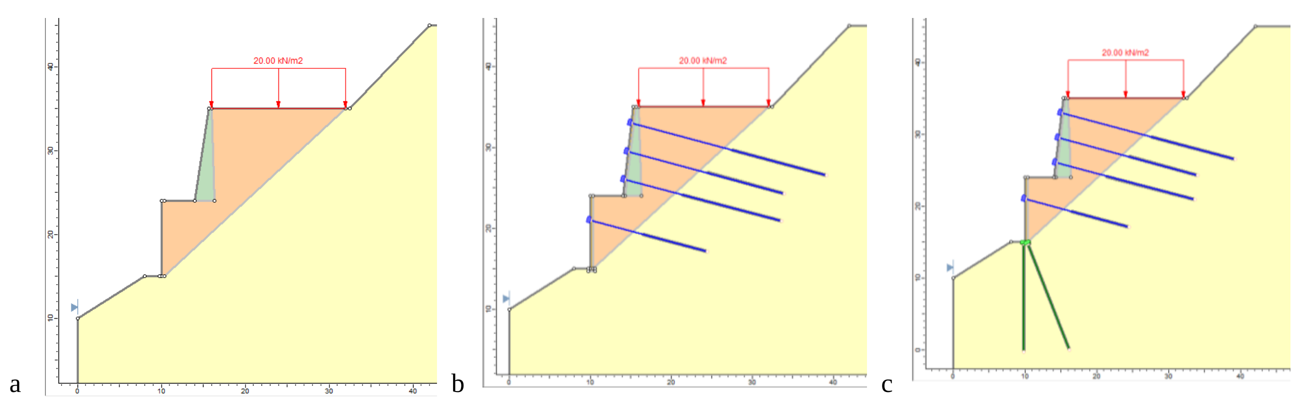


Fig 4. (a)Model 1: Existing Slope with Retaining Wall (b) Model 2: Existing Slope with retaining wall and ground anchors (c) Model 3: Existing Slope with retaining wall, ground anchors and micropiles

The properties of the micropiles are given in the Table 6.

Table.6. Properties of micropiles

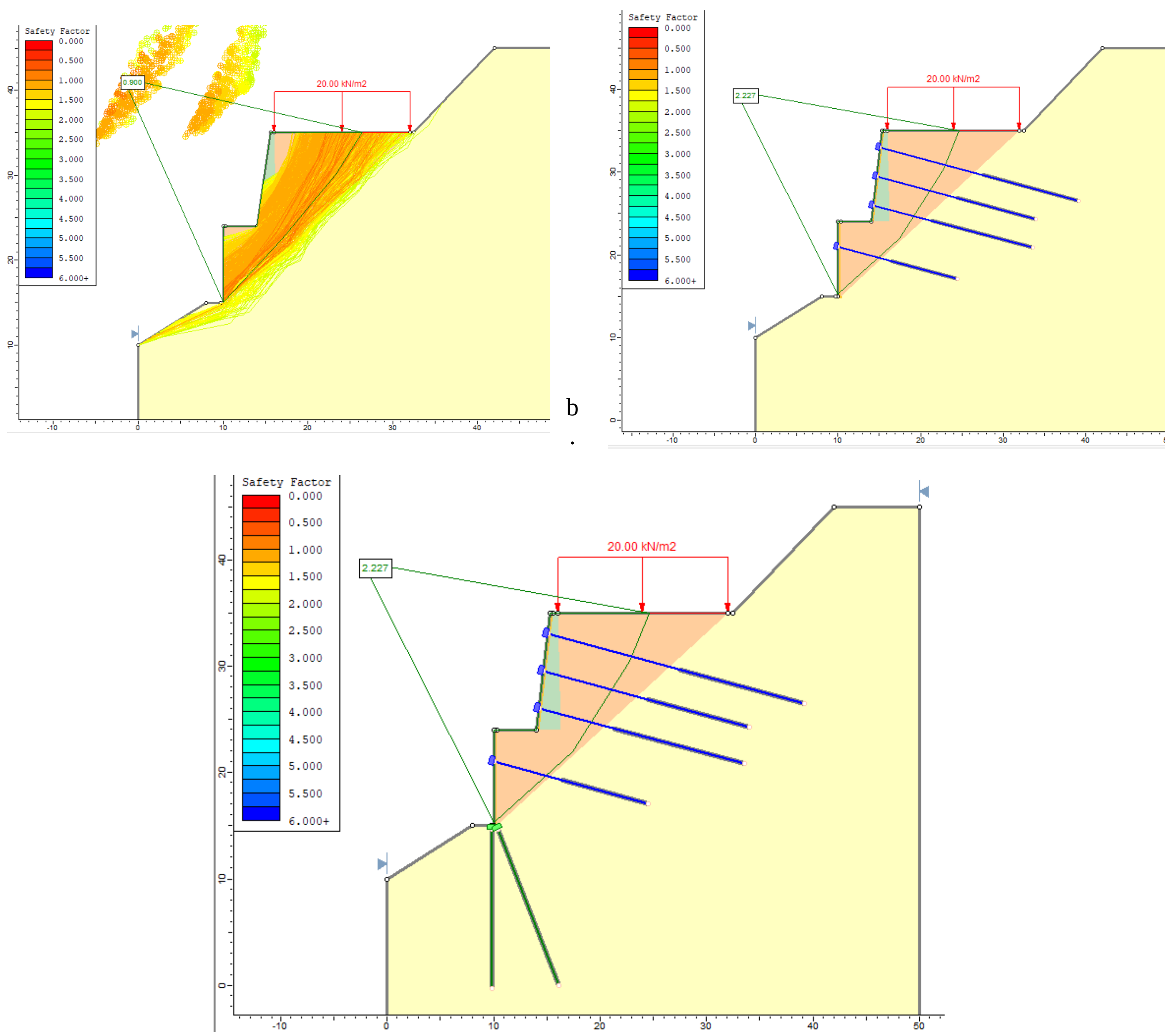
Micropiles		
Pile Shear Strength	30	kN
Out of place spacing	1.5	m
Force Direction	Parallel to surface	

4 Results

Al the models were analyzed using Rocscience Slide 6.0. The visual analysis of models 1, 2 & 3 is shown in the *Fig 5 (a), (b) & (c).* A filter on all the slip surfaces in applied to show only layers with FOS below 2.0.

It can be seen in Model 1: *Fig 5 (a)*, all the yellow and brown layers have FOS below 1.5 and was unsafe. Based on these results, Model 2: *Fig 5 (b)* was designed, which on application of filter shows that no layer has FOS below 2.0 and has Global minimum SF of 2.35. However, the toe of the slope has a steep angle of slope resting on it. Model 3: *Fig 5 (c)* was designed to support the toes of the slope. It can be seen in *Table 7*, that SF using spencer method has improved from 2.60 to 2.62.

a.



c.

Fig 5. Analysis of (a) Model 1 (b) Model 2 (c) Model 3

Table 7. SF against Model 1

Global Minimums SF				
Model no.	**Bishop simplified**	**Janbu simplified**	**Janbu corrected**	**Spencer**
Model 1	0.898475	0.880255	0.900295	0.946555
Model 2	2.35709	2.15056	2.22677	2.60895
Model 3	2.35709	2.15056	2.22677	2.62366

5 Conclusions

In most of the slope cases at Islamabad Murree Dual Carraige Way (N-75), active design method is used for stability of slope. In the same way, active design method is used in this case. Active design method is most effective in stability design of the slopes which are already prone to failure because active design method acts to reduce the driving forces acting in a slope mass.

In this particular case, the slope is located in high rain fall and seismically active zone of Pakistan. The steep angle of slope, topography and rainfall conditions of area has reduced the strength of the slope. Using the active deign approach and ground improvement techniques used in the design mentioned above, the strength of the slope can be improved with better slope structure and factor of safety.

Following the slope stabilization techniques used in this paper, the strength of the subject slope can be improved but findings in this research are site specific and are only applicable to this slope. For other slopes, new analysis should be carried out and based on the results the design should be made.

Acknowledgment

The authors would like to thank every person/department who helped thorough out the research work, particularly BK Consultants. They provided all the services during site visits and data collection. They also provided the manpower, and the software used in the analysis i.e., Slide software 6.0. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

References

[1] A. N. KHAN, IMPACT OF LANDSLIDE HAZARDS ON HOUSING AND RELATED SOCIO-ECONOMIC.

[2] A. Pourkhosravani, "A Review of Current Methods for Slope Stability Evaluation," *Electronic Journal of Geotechnical Engineering ER,* vol. 16.

[3] F. F. K. M. H. e. a. Ali, "Influence of Saturation on Rainfall Generated Landslides in Shale along Murree-Kohala Road, Pakistan," *JOURNAL GEOLOGICAL SOCIETY OF INDIA,* 2016.

[4] K. A. C. A. e. a. Atta-ur-Rahman, "Causes and extent of environmental impacts of landslide hazard in the Himalayan region: a case study of Murree, Pakistan," *Natural Hazards,* 2010.

[5] A. Khan, "Causes and extent of environmental impacts of landslide hazard in the Himalayan region: A case study of Murree, Pakistan," *Natural Hazards,* 2011.

[6] A. Fawaz, "Slope Stability Analysis Using Numerical Modelling," *American Journal of Civil Engineering,* 2014.

[7] S. Naseer, STABILITY ANALYSIS OF SLOPES USING LIMIT EQUILIBRIUM AND FINITE ELEMENT METHODS.

[8] E. F. Salmi, "Slope stability assessment using both empirical and numerical methods: a case study," *Bulletin of Engineering Geology and the Environment,* 2014.

[9] M. Akram, "Geotechnical evaluation of rock cut slopes using basic Rock Mass Rating (RMRbasic), Slope Mass Rating (SMR) and Kinematic Analysis along Islamabad Muzaffarabad Dual Carriageway (IMDC), Pakistan," *Journal of Biodiversity and Environmental Sciences,* 2018.

[10] S. Inumula, "Stability analysis of a deep highwall slope using numerical modelling and statistical approach—a case study," *Arabian Journal of Geosciences,* 2021.

[11] G. You, Probabilistic slope stability analysis of open pit mine using Slide 6.0, 2016.