Jurnal Kejuruteraan SI 4(1) 2021: 101-107
https://doi.org/10.17576/jkukm-2021-si4(1)-13

Preliminary Investigation of the Effect of Surcharge Load and Distance on Non-Homogenous Man-Made Slope

(Penyiasatan Awal Kesan Beban Tambakan dan Jarak Terhadap Kestabilan Cerun Tak Homogen Buatan Manusia)

Jestin Jelani[a,*], Syahmi Baharudin[b], Maidiana Othman[a], Mohd Nazrin Mohd Daud[a], Aina Syahirah Ahmad Ishak[b] & Muhamad Azani Yahya[a]

[a]*Department of Civil Engineering, Faculty of Engineering, National Defense University of Malaysia, Sg. Besi Camp, Kuala Lumpur, Malaysia*
[b]*Royal Engineering Regiment, Malaysia Armed Forces, Kuala Lumpur, Malaysia*

**Corresponding author: jestin@upnm.edu.my*

Received 25 February 2021, Received in revised form 2 April 2021
Accepted 30 August 2021, Available online 30 September 2021

ABSTRACT

Slope failure is a natural disaster that involves the movement of ground and rock under the influence of gravity. There are several factors influencing slope stability, including the excessive surcharge load imposed on the top of the slope. This study performs slope stability analysis to evaluate the performance of a non-homogenous man-made slope constructed on the UPNM campus. The methodology of this research comprises two parts. The first part is laboratory test, and the second part is simulation work. The laboratory tests conducted to determine the soil properties are sieve analysis, permeability test, and direct shear test. The limit equilibrium method using the SlopeW software is employed to determine the effect of imposing a gradually increasing surcharge load on the man-made slope from a varying distance. The value of Factor of Safety (FOS) and critical slip surface formation obtained using SlopeW were used to determine the maximum load carrying-capacity before failure. The results showed that the FOS decreased with an increasing surcharge load. However, the FOS increased as the distance of the load increase. Further analysis was carried out to enhance the stability of the slope. By reducing 40% of slope height, the stability of slope is increased to 44%. It is also suggested that no activity or development should be carried out on the slope crest to prevent slope failure occurrence in the future.

Keywords: Slope stability; factor of safety; critical slip surface; SlopeW

ABSTRAK

Kegagalan cerun adalah bencana alam yang melibatkan pergerakan tanah dan batu di bawah pengaruh graviti. Terdapat beberapa faktor yang mempengaruhi kestabilan cerun, termasuk beban tambakan berlebihan yang dikenakan di atas cerun. Dalam kajian ini, analisis kestabilan cerun dilakukan untuk menilai prestasi cerun tak homogen buatan manusia yang dibina di dalam kampus UPNM. Kaedah penyelidikan ini merangkumi dua bahagian. Bahagian pertama adalah ujian makmal dan bahagian kedua adalah kerja simulasi. Ujian makmal yang dilakukan untuk menentukan sifat tanah adalah analisis saringan, ujian kebolehtelapan, dan ujian ricih langsung. Kaedah keseimbangan had melalui perisian SlopeW digunakan untuk menentukan kesan dikenakan beban tambakan yang meningkat secara beransur-ansur dari beberapa jarak berbeza ke atas cerun buatan manusia. Nilai Faktor Keselamatan (FOS) dan pembentukan permukaan gelincir genting yang diperoleh menggunakan SlopeW digunakan untuk menentukan keupayaan menanggung beban sebelum kegagalan. Hasil kajian menunjukkan bahawa FOS menurun dengan peningkatan beban tambakan. Walau bagaimanapun, FOS meningkat apabila jarak beban meningkat. Analisis lebih lanjut dilakukan untuk meningkatkan kestabilan cerun. Dengan mengurangkan 40% ketinggian cerun, kestabilan cerun meningkat kepada 44%. Disarankan juga agar tidak ada kegiatan atau pembangunan yang dilakukan di atas cerun untuk mencegah terjadinya kegagalan cerun di masa depan.

Kata kunci: Kestabilan cerun; faktor keselamatan; permukaan gelincir genting; SlopeW

INTRODUCTION

Slope stability assessment remains a challenge to geotechnical engineers and researchers even though many previous studies have investigated slope stability. Among the factors influencing slope stability are the complexity of slope-forming materials, geological factors, hydrological factors, human activities, and others. Surcharge load has a considerable effect on slope stability as it adds gravitational force to the soil that may cause the landslide (Azzmi et al. 2011; Paul & Kumar 1997). This condition prevails when many multi-story structures, bridge abutment, and residential or commercial structures are constructed close to the edge of the slope crest. Therefore, there is a need to determine the stability of a slope imposed with a surcharge load.

Generally, the stability of a slope is measured using a Factor of Safety (FOS) that is computed as the ratio of shear strength over shear stress in the soil. This ratio is given by Equation (1), where S_S is soil shear strength and S_f is shear stress. If the FOS value is greater than 1 it implies a stable slope, if less than 1 unstable and if FOS is equal to 1 the slope is in a critical equilibrium state.

$$FOS = \frac{S_s}{S_f} \tag{1}$$

Many studies have investigated the effect of surcharge load on a homogenous slope. Lin & Cao (2012) examined how the relationship between soil dilation angle and load intensity affects the factor of safety. Chowdhury & Dasgupta (2013) proposed a new analytical solution for predicting the failure plane of a slope under static loading. Sazzad & Haque (2014) conducted a parametric study of a slope subjected to a gradually increasing surcharge load by using the finite element approach. Manna et al. (2014) conducted a series of laboratory model tests to investigate the response of a slope under a surcharge load and compared the outcomes with those obtained from 3D finite element software. Cheng et al. (2015) developed a semi-analytical solution for a homogenous slope and verified the results using both finite difference and laboratory tests.

The spatial variability of soil properties has a considerable influence on soil stability. Research on layered or non-homogenous slopes is still in its initial stage and not comprehensive. Therefore, there is a need to investigate the stability of non-homogenous slopes subjected to surcharge load. Kumar & Samui (2006) examined the stability of layered slope using a conventional kinematic approach with a different log spiral. Halder et al. (2016) adopted the reduced strength method to analyse the response of a non-homogenous slope to varying surcharge loads. Ni et al. (2016) presented the response of a layered slope imposed with an increasing surcharge load using a laboratory model and compared to the results obtained using the finite difference method. Li & Jiang (2019, 2020) developed a statistical admissible failure mechanism for non-homogenous slope subjected to surcharge load. The newly proposed failure mechanism showed conservative results compared to the conventional method.

The present work is a continuation of previous research on the stability of man-made slope constructed on the UPNM campus. The main objective of this paper is to determine the slope's FOS and critical slip surface geometry due to the imposition of a gradually increasing surcharge load from different distances by using the limit equilibrium method employed in the SlopeW software.

STUDY AREA

The UPNM campus is located in the Sg Besi military camp approximately 12 km from the Kuala Lumpur city centre. The study area has limited flat land as it is surrounded by hilly topography, where the highest spot is Bukit Gemilang. Due to the growing demand for facilities development, such as buildings for lecture halls and laboratories as well as road infrastructure, the current facility development is carried out on hillsides.

One of the completed projects is the road infrastructure that has five slopes, as shown in Figure 1. This research investigated one of the slopes, which is the steepest slope and located at the highest point. The slope has a height of about 28 m and an inclination of about 70°. It has nine berms and is planted with grass to prevent excessive exposure to weathering. Site investigation showed that this area has two distinct layers of soil underlain by fractured igneous rock. The geology of Sg Besi is composed of granite that comprises predominantly medium-grained muscovite that occasionally contains tourmaline. The residual soil is derived primarily from the weathering of granitic rock and generally consist of silty sand and sandy silt with traces of gravel that was deposited during the Quaternary period (Ayob 1970).

There is no record of slope failure after completion of the road project. However, a site survey conducted in 2019 revealed the occurrence of several slope failures, as shown in Figure 2.

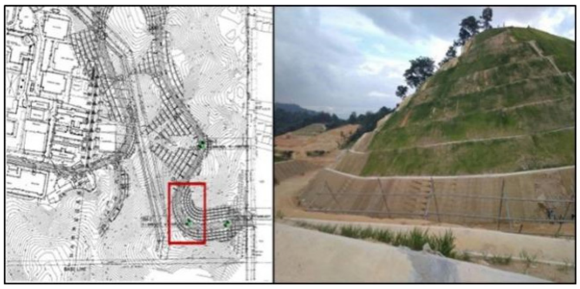


FIGURE 1. Location of the investigated slope
Source: Jelani, et.al. (2020)

FIGURE 2. Examples of slope failures close to the study area

METHODOLOGY

The methodology of this research comprises two parts, as shown in Figure 3. The first part is the laboratory test and the second part is simulation works that determines the effect of surcharge load and distance on the slope stability by using SlopeW software.

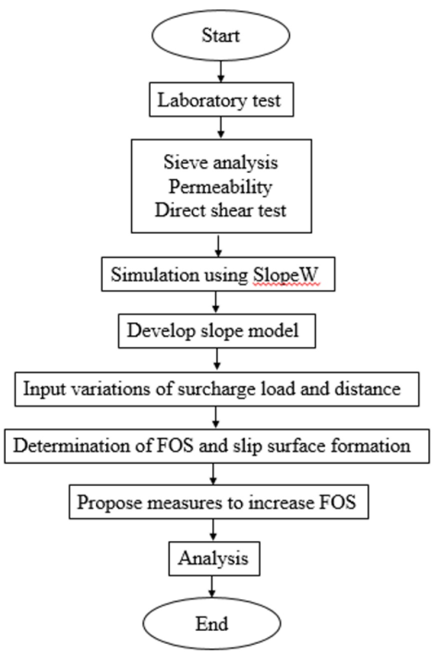


FIGURE 3. Flow chart of the study

LABORATORY TEST

The disturbed and undisturbed soil samples were taken from two locations, the crest and toe of the slope. The disturbed soil sample was used in the sieve analysis and permeability testing, whereas the undisturbed soil sample was used in the shear strength test.

Sieve analysis was conducted following BS 1377 Part 2 to classify the soil. The sample for the permeability test was prepared and tested following BS 1377 Part 6. Soil permeability is the rate of the flow of water through a unit of a cross-section of the soil sample. The shear strength test used an automated direct shear test machine and complied with BS 1377 Part 7. The shear strength of the soil was measured by the cohesion and angle of friction components defined in Equation (2), where τ_s is shear strength, c is cohesion, σ is normal stress, and φ is the angle of friction.

$$\tau_s = c + \sigma \tan\varphi \qquad (2)$$

SLOPEW

SlopeW is a software that uses the limit equilibrium principle to determine the stability of a geotechnical structure. This study used the Morgenstern-Price method because it includes all inter-slice forces in the calculation.

Figure 4 shows the geometric model setup of the slope, which has a height of 28 m and an angle of inclination of 70°. The slope has two distinct layers, and the properties of each layer were specified using the results of the laboratory test.

A uniformly distributed surcharge load (from 2 to 30kN/m^2) was applied to the crest of the slope from different distances of 0 to 2 m.

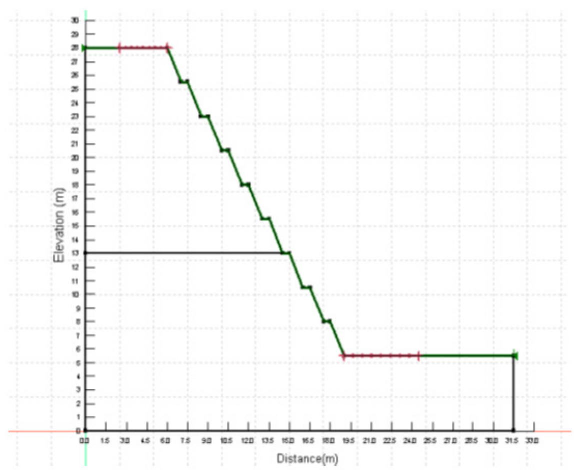


FIGURE 4. Geometrical model setup

RESULTS AND DISCUSSION

LABORATORY TEST RESULTS

Figure 5 shows the results of the sieve analysis for both soil layers. The upper and lower layers of the soil are classified as sandy silt and silty sand, respectively. Both types of soil have an average permeability of approximately 3.14 x10-3 m/s. Table 1 and Figure 6 show the average cohesion and angle of friction, respectively.

TABLE 1. Shear strength parameters

Soil type	Cohesion, c (kN/m^2)	Angle of friction, φ (°)
Sandy SILT	16	21
Silty SAND	13	23

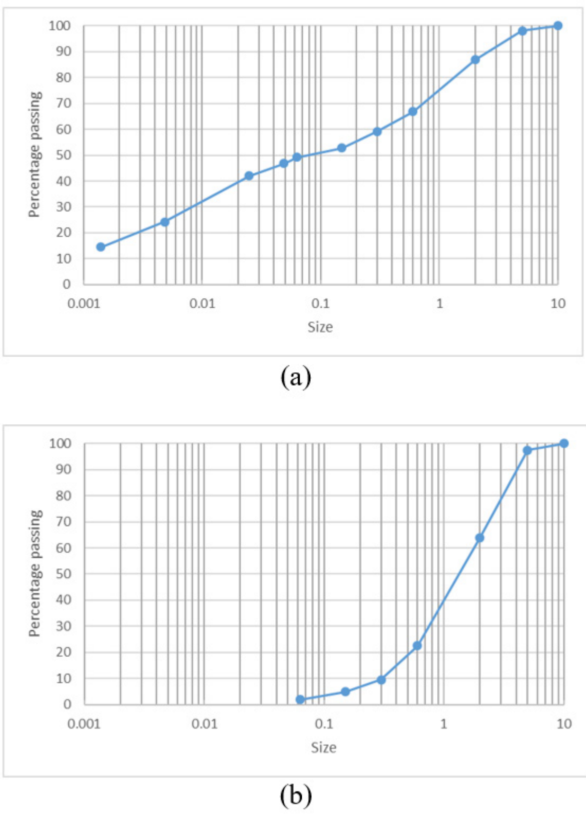


FIGURE 5. Results of the sieve analysis. (a) sandy silt, and (b) silty sand

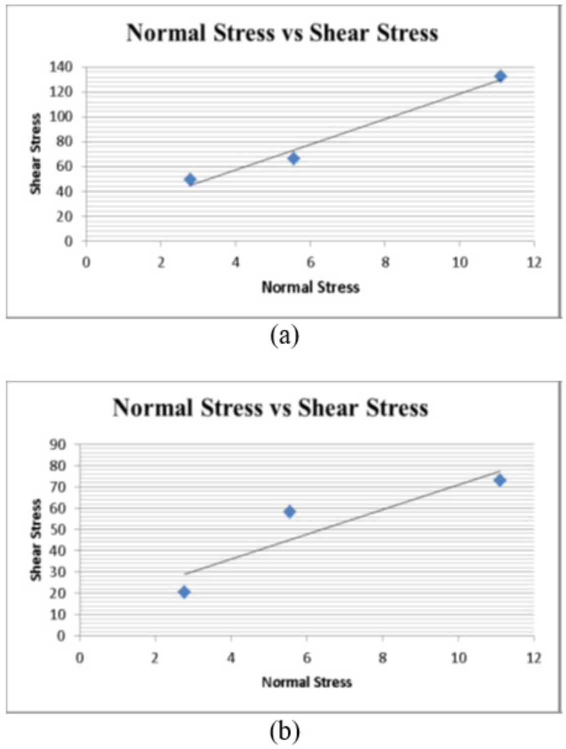


FIGURE 6. Result of the direct shear strength test. (a) sandy silt, and (b) silty sand

EFFECT OF SURCHARGE LOAD AND DISTANCE ON FOS

Table 2 shows that the FOS value varies with a gradually increasing surcharge load imposed from different distances. The maximum FOS of 0.735 was obtained when the surcharge load and distance are 2 kN/m^2 and 2 m, respectively. The lowest FOS of 0.665 was achieved at a load of 30 kN/m^2 imposed closest to the slope edge.

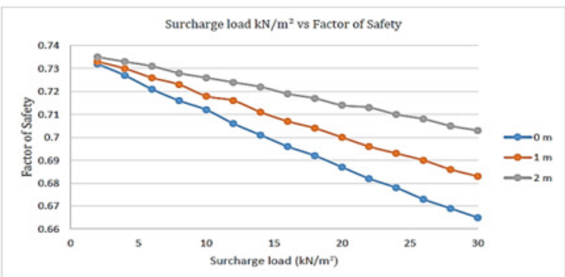
Figure 7 shows the effect of the surcharge load and distance on the FOS values. There is a clear trend of decreasing FOS values as the surcharge load increase. This is due to such surcharge load directly add to the weight of sliding mass, thus shearing stress is increased and instability in the slope is induced. These results are similar to those reported by other researchers (Halder et al. 2016; Moni & Sazzad 2015; Sazzad & Haque 2014).

On the contrary, the FOS increased as the load distance increase. Appropriate distance between the surcharge load and edge of slope is required to achieve desirable FOS.

In this case study, the FOS is less than 1 for all values of the imposed surcharge load. These low values indicate that the ability of slope to support surcharge load reduces and development must not be carried out on the slope crest.

TABLE 2. Effect of surcharge load and distance on FOS

Surcharge load(kN/m²)	Distance from the edge of the slope (m)		
	0	1	2
2	0.732	0.733	0.735
4	0.727	0.73	0.73
6	0.721	0.721	0.721
8	0.716	0.723	0.728
10	0.712	0.718	0.726
12	0.706	0.716	0.724
14	0.701	0.711	0.722
16	0.696	0.707	0.719
18	0.692	0.704	0.717
20	0.687	0.700	0.714
22	0.682	0.696	0.713
24	0.678	0.693	0.710
26	0.673	0.69	0.708
28	0.669	0.686	0.705
30	0.665	0.683	0.703



FORMATION OF CRITICAL SLIP SURFACE

Figures 8 to 10 shows the formation of a critical slip surface as a result of the imposition of a surcharge load of 2, 14, and 30 kN/m2. The figures show the slip surface passing through the slope crest and intersecting the toe of the slope, and is classified as a toe failure. The sliding soil mass lies close to the slope surface, and the line is non-circular. The non-circular failure surface is expected as it is the most common type of failure in heterogeneous slope, as mentioned by (Zolfaghari et al. 2005). The results also showed that there is no significant change in the formation of slip surface as the surcharge load increase.

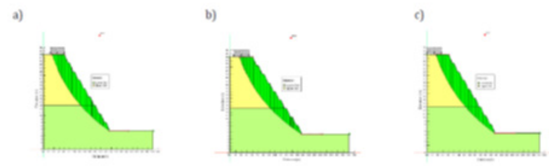


FIGURE 8. Critical slip surface formation for a surcharge load intensity of 2kN/m² imposed from a distance of (a) 0m, (b) 1m, and (c) 2m

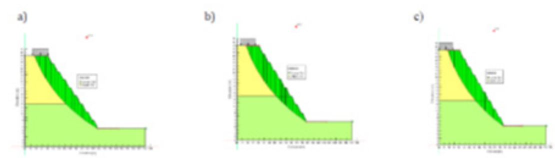


FIGURE 9. Critical slip surface formation for a surcharge load intensity of 14kN/m² imposed from a distance of (a) 0 m, (b) 1 m, and (c) 2 m

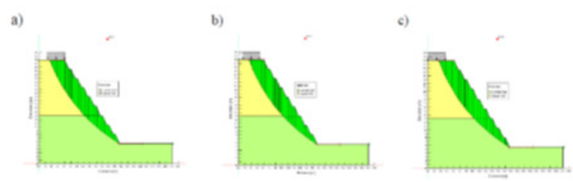


FIGURE 10. Critical slip surface formation for a surcharge load intensity of 30kN/m² imposed from a distance of (a) 0 m, (b) 1 m, and (c) 2 m

RECOMMENDATIONS

Further analysis was conducted to enhance the stability of the slope. The proposed slope model setup is shown in Figure 11, where the existing slope height is reduced to 20 m from its initial height, 28 m. By reducing 40% of slope height, the stability of slope is increased to 44%. Similarly, the value of FOS increased from 0.736 to 1.03 due to decrement of slope height (without surcharge load). The FOS is inversely proportional to the height of slope. This is due to the increase in height of slope will increase the shear stress, thus FOS will decrease (Raghuvanshi 2019).

It is also suggested that no activity or development should be carried out on the slope crest to avoid the occurrence of slope failure in the future based on the findings from this study.

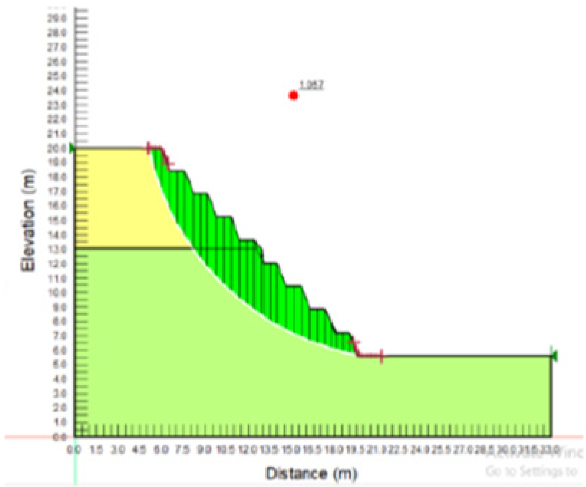


FIGURE 11. The proposed model setup

CONCLUSION

This study performed a slope stability analysis to evaluate the performance of a non-homogeneous man-made slope constructed on the UPNM campus. A gradually increasing surcharge load was imposed on the man-made slope from different distances, and the outcomes were evaluated using the limit equilibrium method by employing SlopeW sofware. The findings of the study are as follows.

1. The surcharge load and distance determine the FOS value. The FOS decreased with an increasing surcharge load. However, the FOS increased as the distance of the load increase.

2. There is no significant change in the formation of a critical slip surface with a higher surcharge load.

3. The slope failure in this case study is classified as toe failure.

4. By reducing almost 40% of slope height, the stability of slope increased to 44%. Similarly, the value of FOS increased from 0.736 to 1.03 due to decrement of slope height.

ACKNOWLEDGEMENT

The authors wish to thank the National Defence University of Malaysia for providing financial support under grant no. UPNM/2019/GPJP/TK/5.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Ayob, M. 1970. Quarternary sediments at Sungei Besi, West Malaysia. *Geological Society of Malaysia* (3): 53–61.

Azzmi, N.M., Noor, N.M. & Jamaludin, N. 2011. Geotechnical approaches for slope stabilization in residential area. Procedia Engineering, 20: 474–482.

Cheng, Y.M., Li, N. & Yang, X.Q. 2015. Three-dimensional slope stability problem with a surcharge load. Natural Hazards and Earth System *Sciences* 15(10): 2227–2240.

Chowdhury, I. & Dasgupta, S.P. 2013. Stability of slopes and embankments under static load. Electronic *Journal of Geotechnical Engineering* 18: 5351–5382.

Halder, S., Imam, M.O. & Basir, M.S. 2016. A detailed analysis of slope stability using Finite Element Method (FEM). Proceedings of 3rd *International Conference on Advances in Civil Engineering* 21–23.

Jelani, J., Adnan, N.A., Husen, H., Mohd Daud, M.N. & Sojipto, S. 2020. The effects of ground water level fluctuation on slope stability by using SlopeW. *Defence Science , Engineering & Technology* 3(1): 1–7.

Kumar, J. & Samui, P. 2006. Stability determination for layered soil slopes using the upper bound limit analysis. *Geotechnical and Geological Engineering* 24(6): 1803–1819.

Li, C. & Jiang, P. 2019. Ultimate load of nonhomogeneous slopes determined by using the method of characteristics. *Engineering Geology* 261(105281): 1–11.

Li, C. & Jiang, P. 2020. Failure mechanism of two-layered slopes subjected to the surcharge load. International *Journal of Geomechanics* 20(2).

Lin, H. & Cao, P. 2012. Influence of material dilation angle on stability of homogeneous slope with surcharge load. *Electronic Journal of Geotechnical Engineering* 17: 329–340.

Manna, B., Rawat, S., Zodinpuii, R. & Sharma, K.G. 2014. Effect of surcharge load on stability of slopes - testing and analysis. *Electronic Journal of Geotechnical Engineering* 19: 3397–3410.

Moni, M.M. & Sazzad, M.M. 2015. Stability analysis of slopes with surcharge by LEM and FEM. International *Journal of Advanced Structures and Geotechnical Engineering*: 4(4).

Ni, P., Wang, S., Zhang, S. & Mei, L. 2016. Response of heterogeneous slopes to increased surcharge load. *Computers and Geotechnics* 78: 99–109.

Paul, D.K. & Kumar, S. 1997. Stability analysis of slope with building loads. *Soil Dynamics and Earthquake Engineering* 16(6): 395–405.

Raghuvanshi, T.K. 2019. Plane failure in rock slopes – A review on stability analysis techniques. Journal of King Saud University - *Science* 31(1): 101–109.

Sazzad, M.M. & Haque, M.F. 2014. Effect of surcharge on the stability of slope in a homogeneous soil by FEM. *2nd International Conference on Advances in Civil Engineering* (1): 314–318.

Zolfaghari, A.R., Heath, A.C. & McCombie, P.F. 2005. Simple genetic algorithm search for critical non-circular failure surface in slope stability analysis. *Computers and Geotechnics* 32(3): 139–152.