Stability Analysis of Road-cut slope: A Case Study of Kanti Lokpath

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***Abstract*— This paper presents the stability analysis of natural slope subjected to cutting for the construction of road at three different chainage along Kanti Lokpath using limiting equilibrium method by means of computer based geotechnical software slope/W(Geo-studio) 2019 and compare the results obtained with finite element method by means of software Phase2 Data required for the slope stability analysis is obtained from the laboratory test, carried out in many samples, in order to determine physical and mechanical properties of soils and field survey. Factor of safety for the cut slope was determined for different anticipated conditions. From the analysis it is found that factor of safety by LEM is slightly conservative than that of by FEM. The result shows that stability of the slope decreases with increase in ground water level, increase in unit weight, decrease in cohesion strength and decrease in friction angle.**

Keywords*— *slope stability, Slope/W, Phase2, Factor of Safety (FOS), Cohesion, internal friction angle

I. Introduction

Slope failure is the most frequent disaster faced by many road projects, especially when relatively steep natural slopes are subjected to cutting for the development of space for carriageway. Most failures of road cut slope are caused by design errors which include geometric design i.e. slope inclination, slope height and inability to estimate the load and the soil resistance. During excavation work of natural slopes, the slope face may deform and results in the reduction of shear strength, and this can lead to slope failure [1]. So the slope stability analysis is performed to assess safe and economic design of human made and natural slopes. The main objectives of slope stability analysis are finding the endangered areas, investigation of potential failure mechanism, determination of slope sensitivity towards different triggering factors, designing of optimal slope with regards to safety reliability.

II. Study Area

Study area lies in the Kanti Lokpath at the chainage of 62+300 ,68+300 and 68+700 in the Lalitpur district near Bhatte Danda of Province -3 of Nepal as shown in figure 1.

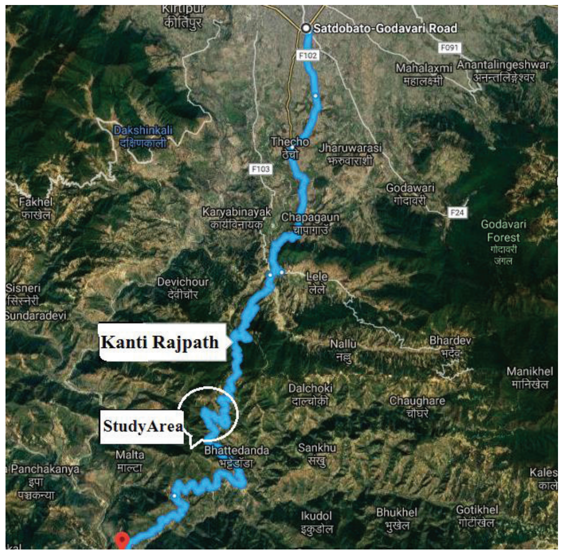

Fig. 1. Study area along aligment of kanti Lokpath.

III. Literature Review

For a slope to be stable the resisting forces in the slope must be sufficiently greater than the forces causing the failure [2].To perform a slope stability analysis the geometry of the slope, external and internal loading, soil startigraphy and strength parameters and variation of the ground water table all along the slope must be defined. In the current state of practice, there are many number of slope stability analysis methods available. However, the scope of this report is limited to a discussion on the limit equilibrium methods and finite element methods.

A. Limit Equilibrium method

Limit equilibrium analyses consider force and/or moment equilibrium of a mass of soil above the potential failure surface. The available shear strength is assumed to be mobilized at same rate at all points on the potential failure surface. Therefore, as a result the factor of safety is constant over the entire failure surface. Limit equilibrium analysis provide no information on slope deformations. A variety of limit equilibrium procedures have been developed to analyze the static stability of slopes. Slope that fail by translation on a planar failure surface such as a bedding plane, rock joint, or seam of weak materials can be analyzed quite easily by the Cullman method[3].Slopes in which failure is likely to occur on two or three planes can be analyzed by wedge methods([4];[5])surfaces are very close, homogeneous slopes are usually analyzed by methods such as the ordinary method of slices [6] or Bishop‘s modified method assume circular failure surfaces. When sub-surface conditions are not homogeneous (e.g., when the layers with significantly different strength, high anisotropic strength, or discontinuous exists), failure surfaces are likely to be non-circular. In such cases, methods like those of [7], [8] and[9] may be used. Nearly all limit equilibrium methods are susceptible to numerical problems under certain conditions.

B. Finite Element method

In a finite element approach the slope failure occurs through zones which cannot resist the shear stresses applied. Hence, the results obtained from this analysis are considered to be more realistic compared to limit equilibrium method [10].The finite element method considers linear and non-linear stress – strain behavior of the soil in calculating the shear stress for the analysis. The types of soil stress-strain relationships that can be used are linear elastic, elastoplastic, hyperbolic, Modified Cam Clay, elastoviscoplastic and multilinear elastic models. The selection of a particular stress-strain relationship depends on the state of the soil structure to be analyzed, its purpose of analysis and its laboratory and field properties available. The determination of soil properties in the field involves a large amount of uncertainty and so the application of finite element analyses imposes complexity on the stability problem [10]. Traditionally, the slope stability analysis with a finite element approach is performed by Strength reduction method (SRM). In this method, the factor safety is defined as the factor by which the original shear strength parameters must be divided to bring the slope to be in failure mode [10]. A systematic estimation is required for the SRF value to find out the value which will just cause the slope to fail. The SRF value, at which the slope fails, is known as the factor of safety. The failure condition in this method could be when 1) the non-linear equation solver cannot achieve convergence after a few iterations, 2) sudden rate of change in displacement and 3) a failure mechanism is developed. However, this method has some limitations such as appropriate selection of constitutive model and geologic parameters, boundary conditions and defining a failure condition [11].

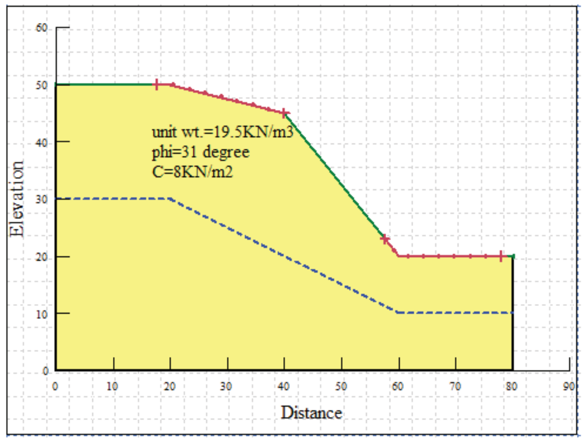

Fig. 2. Cut slope model in slope/W at SS1

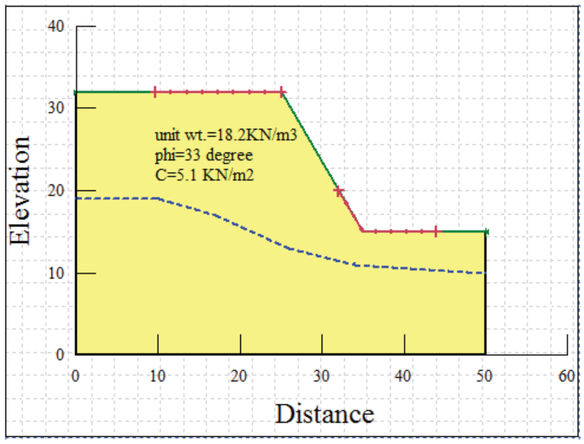

Fig. 3. Cut slope model in slope/W at SS2

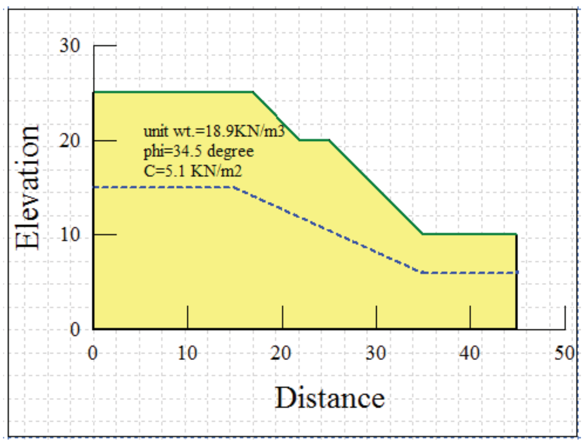

Fig. 4. Cut slope model in slope/W at SS3

IV. RESEARCH METHODOLOGY

The study reanalyzes the case of effect of cut slope stability as presented in literature. Before field different work have been done to acquire the detailed information about the area and to be well prepared for field work. The methodology include the preparation of the contour map of the slope to determine the geometry and assessing the soil characteristics over the entire slope by collecting fairly representative sample and determining the input soil parameter from laboratory. The stability of the existing slope was obtained by calculating the factor of safety of the slope by using Slope/W software and Critical SRF by Phase2. Three different critical Slope sections (SS1, SS2 and SS3 at the chainage of 62+300, 68+300 and 68+700 respectively) were selected and geometric input model is prepared as shown in fig 2, fig 3 and fig 4 respectively for this research purpose and study was performed by considering different geotechnical parameters of slope.

V. Result and Discussion

Slope stability analysis was performed under different anticipated conditions. The factor of safety of the slope sections SS1 and SS2 are found 0.777 and 0.709 respectively at the dry condition as per Morgenstern – Price method and 0.78 and 0.71 by FEM which are found to decreases to very low i.e. 0.217 and 0.121 respectively at fully saturated conditions. The factor of safety in slope sections SS3 is found 1.127 as per Morgenstern –Price method and 1.16 by FEM at the dry condition which decreases to 0.443 at fully saturated condition as per Morgenstern–Price method and finite element method. The factor of safety of slope sections with variation of depth of ground water table, cohesion of soil, friction angle of slope material and unit weight of slope material are shown in fig. 11, fig. 12, fig 13 and fig. 14 respectively.

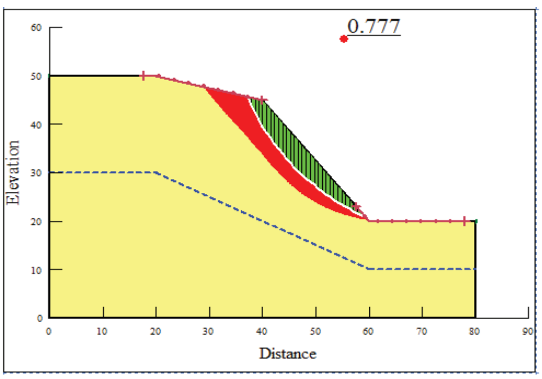

Fig. 5. The Critical Slip surface and possible slips surfaces during static condition in slope/W at SS1

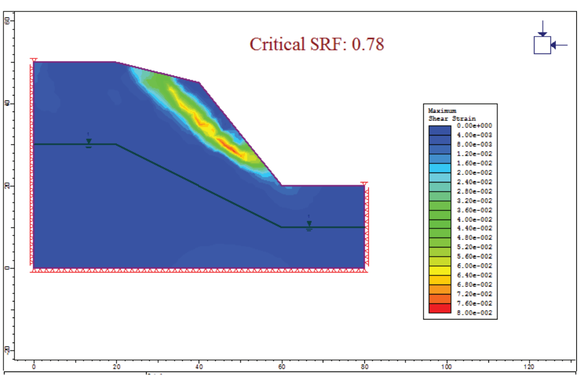

Fig. 6. Total displacement diagram during static condition by Phase2 with critical SRF 0.78 at SS1

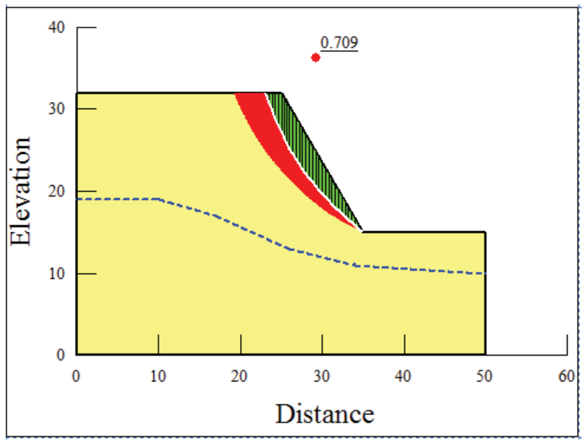

Fig. 7. The Critical Slip surface and possible slips surfaces during static condition in slope/W at SS2

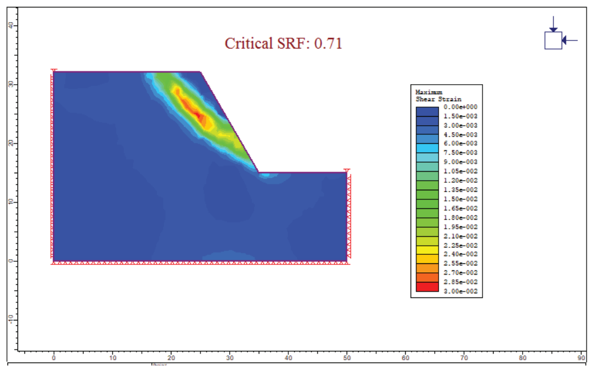

Fig. 8. Total displacement diagram during static condition by Phase2 with critical SRF 0.71 at SS2

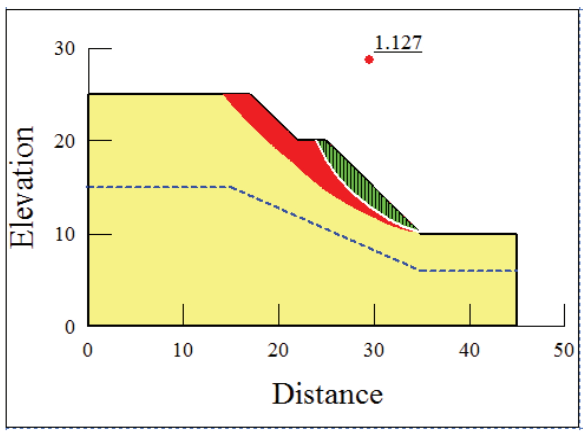

Fig. 9. The Critical Slip surface and possible slips surfaces during static condition in slope/W at SS3

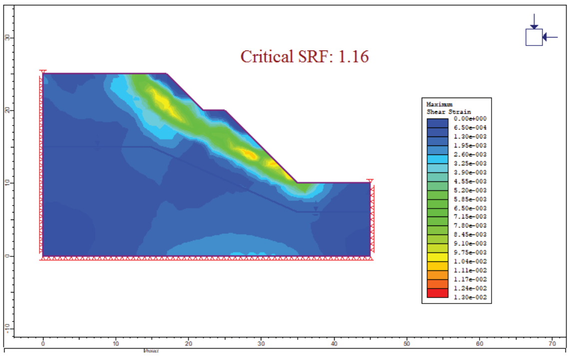

Fig. 10. Total displacement diagram during static condition by Phase2 with critical SRF 1.16 at SS2

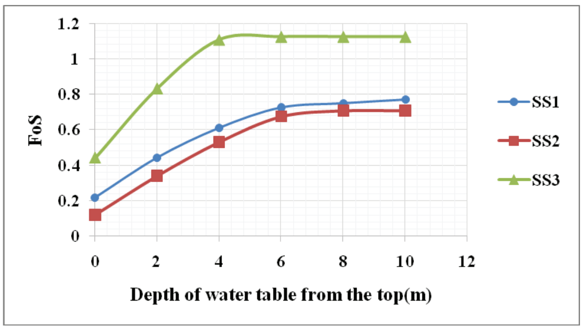

Fig. 11. Variation of FoS of slope with variation of GWT

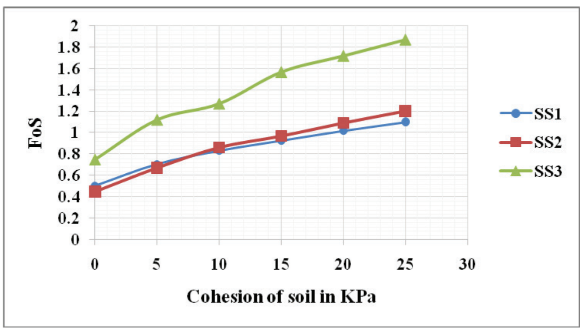

Fig. 12. Variation of FoS of slope with variation of Cohesion

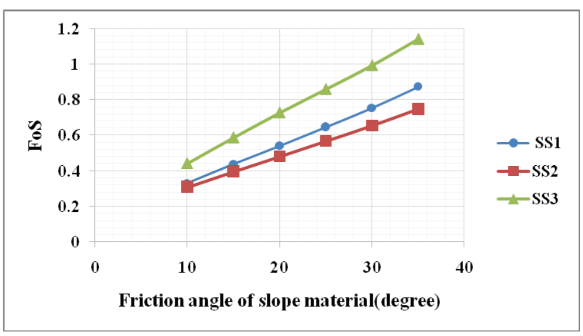

Fig. 13. Variation of FoS of slope with variation of friction angle of slope material

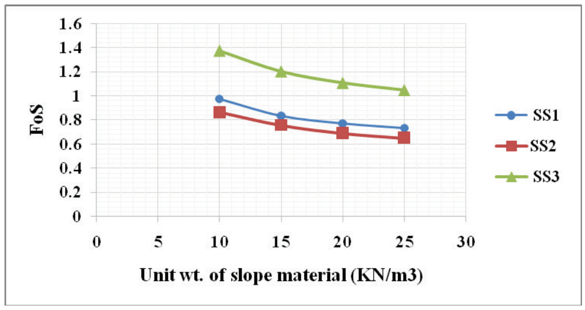

Fig. 14. Variation of FoS of slope with variation of unit wt. of slope material

VI. Conclusion

Slope sections SS1 and SS2 has very high landslide susceptibility in static dry condition and are more susceptible when get saturated so requires preventive measures. In case of slope section SS3, this slope section is stable in static dry condition but will have high landslide susceptibility when get saturated and also requires preventive measures. From the results of numerical calculations, it is found that the four parameters studied have significant influence on the stability of cut slope, especially increase in ground water table highly reduce the the factor of safety of slope. From the analysis it is also found that factor of safety value obtained from LEM is found to be slightly conservative than that by FEM.

References

[1] John Dunnicliff and Gordon E Green. Geotechnical instrumentation for monitoring field performance. John Wiley & Sons, 1993.

[2] JM Duncan and SG Wright. Soil strength and slope stability, john willey & sons. Inc., Hoboken, New Jersey, 2005.

[3] Donaldw Taylor. Fundamentals of soil mechanics. Chapman And Hall, Limited.; New York, 1948.

[4] WilliamHPerloffandWilliamBaron.Soilmechanics. principles and applications. 1976.

[5] TW Lambe and RV Whitman. Soil mechanics, 553 pp. Jhon Wiley & Sons, N. York, 1969.

[6] GG Meyerhof. The ultimate bearing capacity of foundations on slopes. In Proc., 4th Int. Conf. on Soil Mechanics and Foundation Engineering, volume 1, pages 384–386, 1957.

[7] NR Morgenstern and V Eo Price. The analysis of the stability of general slip surfaces. 1965.

[8] E Spencer. A method of analysis of the stability of embankments assuming parallel inter-slice forces. Geotechnique, 17(1):11–26, 1967.

[9] N Janbu. Slope stability computations, soil mechanics and foundation engineering report. Technical University of Norway, Trondheim, 1968.

[10] DV Griffiths and PA Lane. Slope stability analysis by finite elements. Geotechnique, 49(3):387–403, 1999.

[11] J Krahn. Limit equilibrium, strength summation and strength reduction methods for assessing slope stability. In Rock Mechanics: Meeting Society's Challenges and Demands, pages 311–318. sn, 2007.