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Analysis of Landslides and Slopes (Nepalthok–Khurkot section) using SVSLOPE model and Remediation using Soil Nail

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Abstract

Landslide and slope failure, a specific category of geomorphological calamitous events endangering human life and property, are recurrent phenomenon and repeated withering risks in the Nepalese Himalaya. The study area incorporated in this paper for slope analysis comprises of two slopes as: Landslide slope (ch.82+835 to ch.82+885 (from Dhulikhel)) stretches up to 50m and critical slope (ch.79+060 to ch.79+220 (from Dhulikhel)) stretches up to 160m. The objective of the study has been focused primarily in analyzing the mechanism and contributing to the reduction of risk posed to human life and economic values through mitigation measures because of landslides and slope instability.

Fundamentally, the commencement of this research has been with field mapping, data collection and soil sample collection with the material properties being determined from laboratory and consequently verified by various literature.

SVSLOPE 3D model has been the major tool for analysis of both slopes and soil nailing has been proposed as a remedial measure for risk reduction. Numerical verification of both slopes have been done using PLAXIS-3D and parametric verification of nail has been done using PHASE and literature along with sensitivity analysis of parameters being carried out.

Keywords

Landslide – slope failure – soil nailling – SVSLOPE–PLAXIS–PHASE

1. Introduction

1.1 Background

Slope stability analysis are performed to access the safe and economic design of human made or natural slopes. Slope stability are generally assessed in terms of factor of safety, if FOS is greater than one it is considered to be stable otherwise remedial measures are used to stabilize the slope. Method of analysis of slope include: Limit Equilibrium Method and Finite Element Method. LEM is mostly used method for analysis of slope despite a lot of prior assumption. On the other hand FEM has less prior assumption and also uses complex phenomenon for safety calculation.

If slope has factor of safety less than one than careful analysis of mitigation measure and appropriate choice of mitigation measure is vital. Traditionally different measures have been practiced in slope stability like anchor, grouted tieback etc and soil nailing is one of the recent development in stabilization of slope. Soil nailing shows significant promises however, very scatter research has been made on the field of soil nailing. This paper attempts to explore various aspects of nail stabilized slopes (where should nail be positioned in the slope, at what inclination nail should be used) as to make them as engineering solution.

1.2 Study area

Study area considered in this paper is BP highway (Banepa- Bardibas), within it Nepalthok-Khurkot section is taken which is aligned along Sunkoshi river valley. Two slopes are considered one as landslide slope (actual landslide area) and other as critical slope (probability of failure is high, as there is unequal distribution of soil mass along the slope). Characterstics of slope: latitude, longitude, altitude at top and base(ft), slope length(m), chainage(from Dhulikhel(Km+m))- 27.33861, 85.99358, 1627,1662,50,82+835 and

27.35211,85.97931, 1760, 1830, 160,79+060 for landslide slope and critical slope respectively. Figure 1 and 2 represents Google earth images and close up view of landslide slope and critical slope.

Figure 1: Google earth image of landslide slope (left) and critical slope (right) in 2014

Figure 2: Close up view of landslide slope(left) and critical slope (right) clicked in 20th May, 2017

1.3 Objectives of the Study

The overall objective of the present study is to contribute to the reduction of the risk posed to human life and economic values by landslides and slope instability. For being operationalized, this objective has to be split up into smaller and more specific objective in order to achieve the overall objective. The specific objectives of the present thesis are -

1. To access the applicability of SV slope 3D model in Nepalese environment.

2. To find optimum value of various parameters that effect the stability of soil nailed slope

3. To evaluate the sensitivity of stability towards friction angle, cohesion, unit weight, water table and seismic activity

1.4 Scope of study

While stabilizing the highway slopes, remediation measure used traditionally (anchor, grouted tieback etc) disrupt traffic and measures used are also not cost effective in construction and performance. Stabilizing of slope can be done by increasing shear strength, adding mass on the slope, changing the inclination of slope but these measures requires high cost as well as traffic disruption. Remedial measures need to be cost effective, requiring less right of way, less disruptive to traffic, small work space and quick installation which can be achieved by using soil nailing.

This research work covers the analysis of slope stability of the landslide area and critical area. Soil nails are chosen as the technique to reinforce the slopes over other conventional methods. Improvement in stability of slopes after use of nails as stabilizing measure is analyzed by varying different parameter which influence the stability of soil nail system.

2. Research Approach and Methodology

The research work started with the study of article related to the landslides and slope stability. Application of remedial measures their suitability and efficiency is studied. For collection of technical information site is visited, in field samples which are disturbed and representative are collected as undisturbed sample collection is difficult.

Parameters for landslide slope and critical slope includes: Texture, cohesion, friction angle and unit weight.

Silty clayey gravel with little fines, 1kpa, 38 degrees, 18kn/m3 for landslide slope

Silty clayey gravel with little fines, 1kpa, 37 degrees, 18 kn/m3 for critical slope.

Fine content in soil are about 17 percentage for both the slope.

SV slope 3D model (Limit Equilibrium Method) is used for stability analysis of the slope and remediation of slope is done using soil nailing.

Geometry of Slope: 3D slope geometry is used in this study. 3D geometry used is extruded from 2D geometry. Topographic map is obtained from Department of Survey (2007) and with that contour of study area is identified.

Contour obtained from Google earth image is overlapped in topographic map of that section and location of entry and exit points are determined. Entry point refers to the point from which the slope failure starts and exit point refers to the end of slope failure. As exact point is difficult to get so location of entry points and exit points are given.

Calculation method: Calculation method used in this study is GLE (General Limit Equilibrium). GLE method with half sine function provide best result [1].

3D slip surface

Search method: Entry and Exit method.

Slip direction: Right to Left in XZ plane.

Slip surface: Ellipsoid.

LEM solves directly for factor of safety for trail slip surfaces and then it checks for other slip surfaces with the lower factor of safety. The critical slip surface is the one that has lower factor of safety. Shear strength at base is set to zero when base is in tension.

LE convergence: Tolerance- 0.0010

Soil parameters: cohesion, friction angle and unit weight.

Soil strength model: Mohr-Coulomb.

2.1 Input models

In this study, two slopes are considered i) landslide slope (actual area of landslide) and ii) critical slope (failure probablity is high)

Parameters used in model are calculated in the lab and verified using literature. In landslide slope (as shown in Figure 3), factor of safety is calculated and parametric variability of soil nail is observed. Then the landslide slope is stabilized using optimum nail parameters. In critical slope (as shown in Figure 4), geotechnical parameters, seismic load and water table is varied to observe the sensitivity of those parameters towards slope stability and is also stabilized using nails.

Nail parameter Pull-out Strength: Bond Strength= 100 KN/M Capacity: Tensile strength =100KN, Plate Strength= 100KN Diameter of Nail= 20mm , Grout Diameter of Nail= 30mm Length of Nail= 14m (Landslide slope) and 20m (Critical Slope)

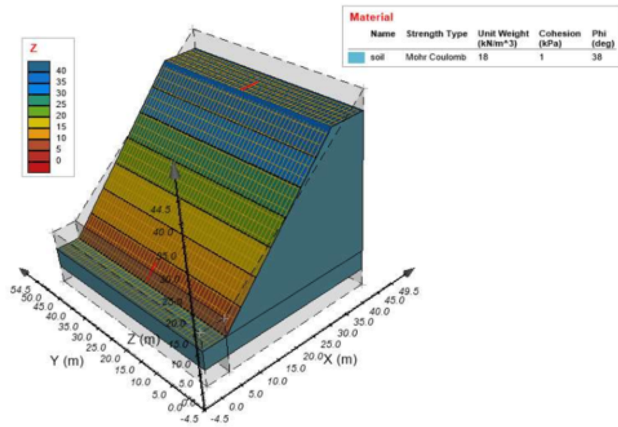

Figure 3: Input model for Landslide slope

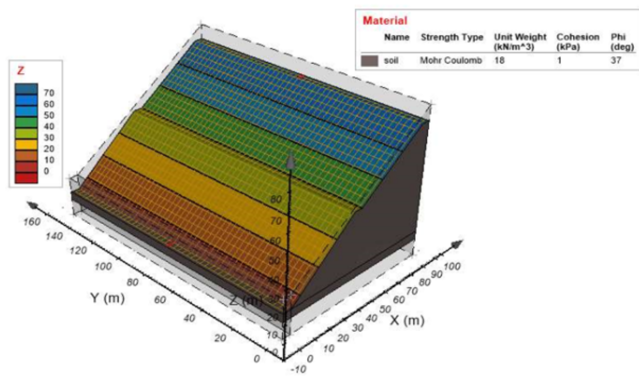

Figure 4: Input model for Critical slope

3. Result and Discussion

3.1 Stability Analysis of landslide slope

Factor of safety of landslide slope obtained is 0.963. Friction angle of the slope is varied as 35, 38 and 41 degrees respectively. Variation of Friction Angle and FOS of landslide slope is shown in figure 5.

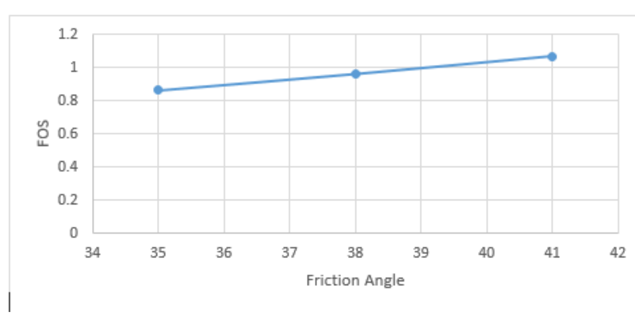

Figure 5: Plot of FOS and Friction Angle for landslide slope

3.2 Parameter Variation of Soil nail

Soil nail position and angle of inclination of nail is observed for different friction angles 35, 38 and 40 degrees respectively. Length of nail used is 14m.

Variation in position

This study is done to identify the location(section) in slope where nail positioned will provide maximum factor of saftey.

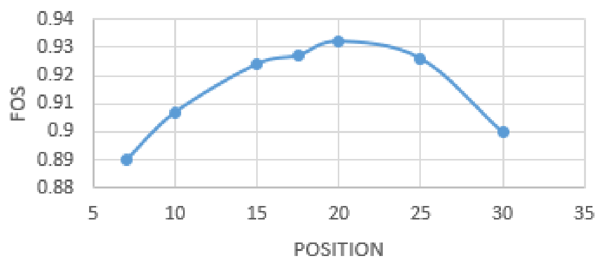

Figure 6: Plot of FOS and Position (from Top of slope) for phi 35 degrees

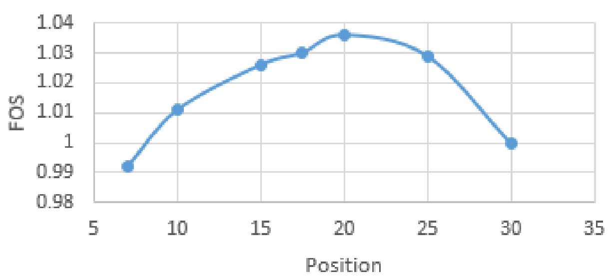

Figure 7: Plot of FOS and Position (from Top of slope) for phi 38 degrees

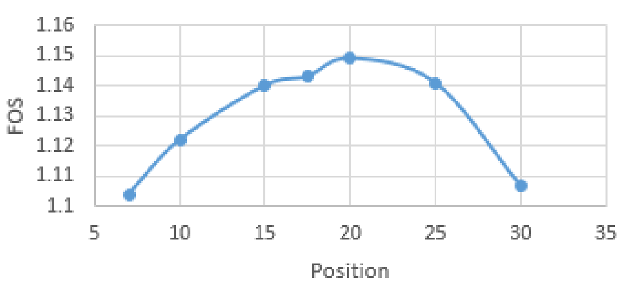

Figure 8: Plot of FOS and Position (from Top of slope) for phi 41 degrees

In figure 6, 7, 8, As we move from top to bottom, FOS goes on increasing up to middle portion and on further move down it goes on decreasing. If we divide the slope height into three sections upper one third, middle one third and lower one third, then maximum factor of safety is obtained at middle one third portion of slope.

Angle of Inclination of soil nail

Nail are inclined at 0, 30, 45, 60 and 90 degrees respectively for different values of friction angle.

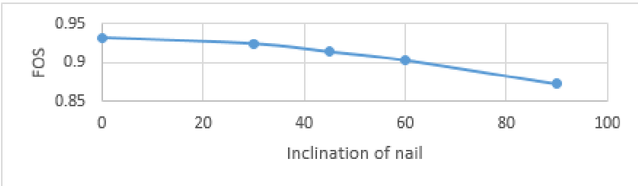

Figure 9: Plot of FOS and Inclination of nail for phi 35 degrees

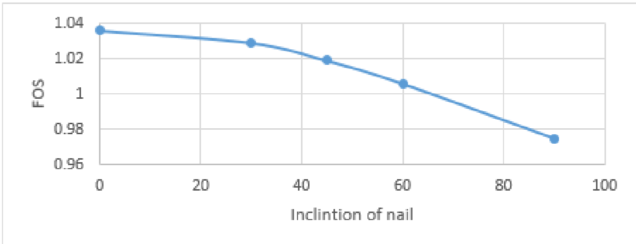

Figure 10: Plot of FOS and Inclination of nail for phi 38 degrees

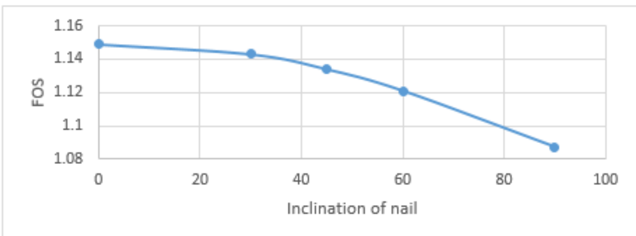

Figure 11: Plot of FOS and Inclination of nail for phi 41 degrees

From figure 9,10,11. It is clear that, nail at horizontal is observed to give higher FOS. The increase in FOS when nail placed horizontally and at 90 degrees is 5.88%.

Considering both the parametric variation, nail placed horizontally and positioned at middle one 3rd gives maximum FOS.

So, landslide slope is stabilized by nails positioned at middle one 3rd and horizontally. Nail is provided at height of 17.5m, 20m, 22.5m and 25m from bottom of slope and horizontal spacing of 0.5m in square pattern. Landslide slope is stabilized and the FOS obtained is 1.373.

3.3 Analysis of Critical slope

FOS obtained for critical slope is 1.125.

3.4 Seismic Load Variation in critical slope

For seismic variation only horizontal seismic coefficient (kh) is varied vertical seismic coefficient (kv) is considered zero.

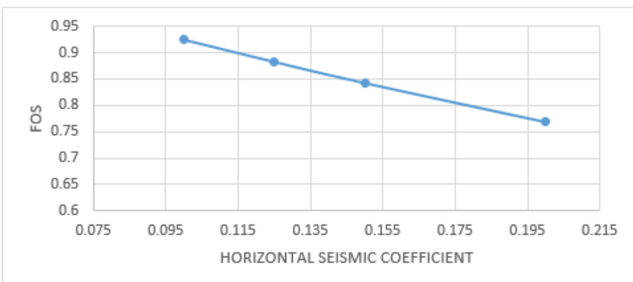

Figure 12: Plot of FOS and Horizontal Seismic Coefficient for critical slope

From figure 12. Actual field FOS (fos for critical slope i.e. 1.125) and FOS obtained after horizontal seismic coefficient of 0.2 (i.e. kh= 0.2, fos 0.769) shows difference of 31.64%. Difference of 16.86% is observed when horizontal seismic coefficient increases from 0.1 to 0.2.

3.5 Water table variation in critical slope

Water table is kept at various height for study purpose and its effect is studied.

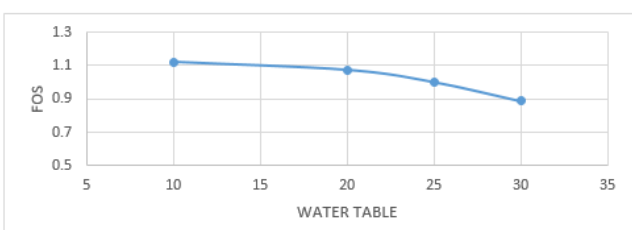

Figure 13: Plot of FOS and Water Table for critical slope

From figure 13, that the effect of WT on slope is more dominant when water level reaches the zone of critical slip surface. Up to 20m not significant change in FOS is observed. When WT increases to 30m from actual field condition used in analysis difference of 20.08% is observed. Only 4.19% decrease in FOS is observed when WT changes from 10m to 20m as sufficient sliding mass is not intersected by water level.

3.6 Sensitivity analysis of cohesion, friction angle and unit weight in critical slope

Variation of parameters cohesion, friction angle and unit weight is done using SVSLOPE 2D model as sensitivity analysis can only be performed in 2D model.

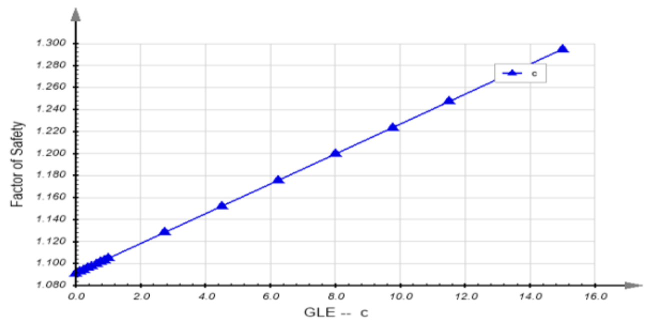

Figure 14: Plot of FOS and cohesion for critical slope

From figure 14. Increase in cohesion increases FOS

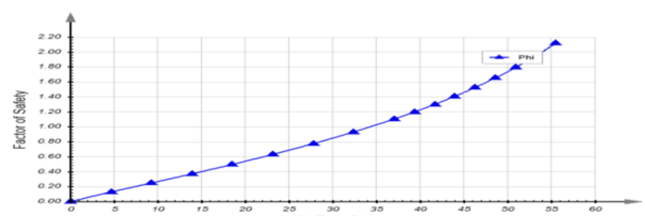

Figure 15: Plot of FOS and friction angle for critical slope

From figure 15. Increase in friction angle increases FOS.

From figure 16. Increase in unit weight decreases FOS. But significant effect is not seen.

From figure 17,18,19. When friction angle is involved than significant effect in FOS is observed.

Now, soil nails are applied on critical slope to increase its FOS. Length of nail = 20m Nail is placed at 32.5m, 35m, 37.5m and 40m from bottom of slope inclined

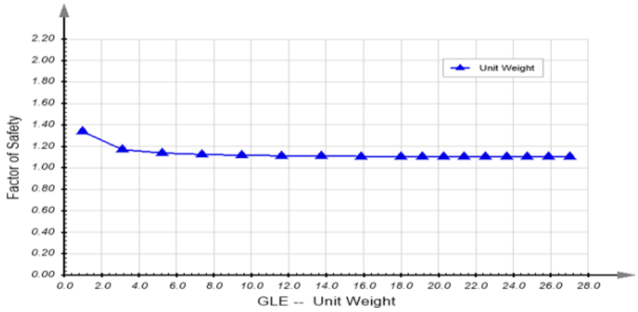

Figure 16: Plot of FOS and unit weight for critical slope

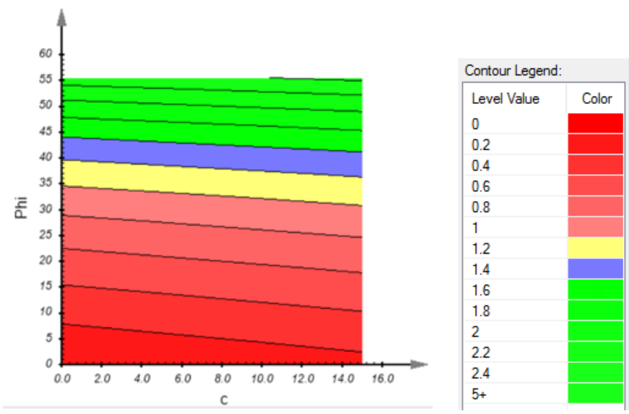

Figure 17: Plot of cohesion, friction angle and FOS for critical slope

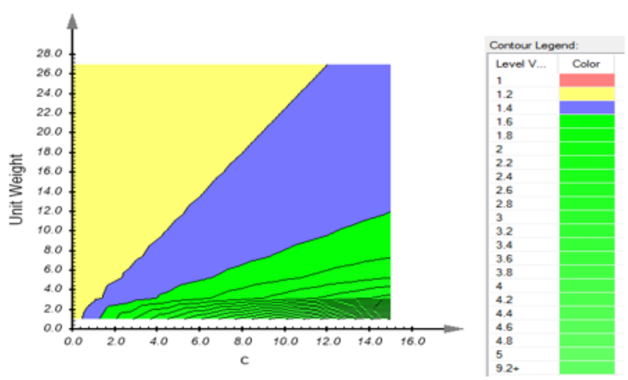

Figure 18: Plot of cohesion, unit weight and FOS for critical slope

horizontally at horizontal spacing of 0.5m in square pattern. Factor of safety obtained is 1.283.

4. Verification

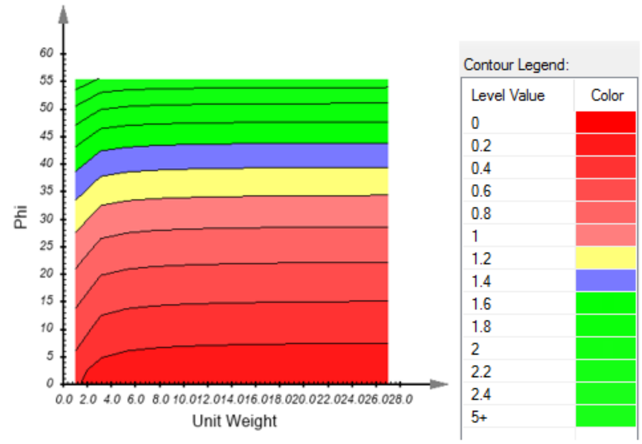

Figure 19: Plot of unit weight, friction angle and FOS for critical slope

4.1 Verification of lab results

Lab results is verified by [2].

4.2 Verification of landslide slope and critical slope

landslide slope and critical slope is verified using PLAXIS.

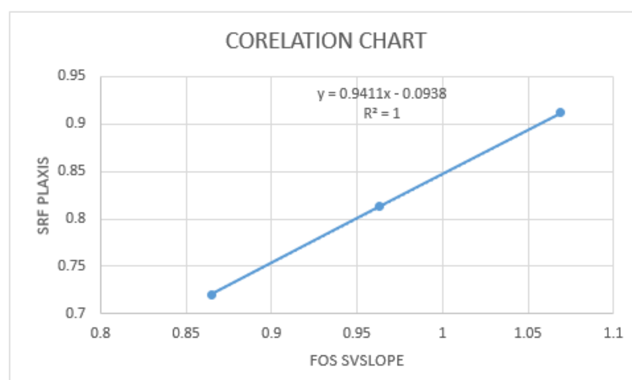

Figure 20: Correlation chart obtained for SVSLOPE and PLAXIS

Landslide slope is modeled in PLAXIS-3D and factor of safety is obtained for different values of phi 35, 38 and 41 degrees respectively. Thus, obtained FOS is compared with FOS obtained in SVSLOPE and correlation chart is prepared. FOS obtained is found to have good correlation. Certain difference in the value is due to additional parameter used in PLAXIS-3D and also due to different approach used LEM (SVSLOPE) and FEM (PLAXIS-3D). Also for critical slope FOS (SVSLOPE-1.125 and PLAXIS-1.039) is obtained and tolerance of 7.64%.

4.3 Verification Parametric assesment of soil nail

For verification of parametric assessment of soil nail, PHASE software and literature is used. For verifying position of nail to produce maximum factor of safety PHASE software is used and for verifying inclination angle PHASE software and literature is used.

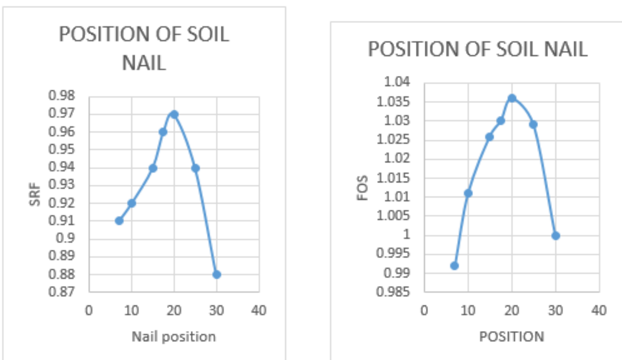

Figure 21: Comparison of location using PHASE left and SVSLOPE right

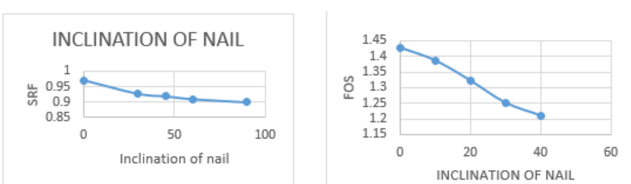

Figure 22: Comparison of inclination of nail using PHASE (left) and [3] (right)

In the curve generated by author the middle one 3rd section of the slope has produced maximum factor of safety and on observing lower and upper section of slope FOS goes on decreasing. Similar result is obtained using PHASE (Figure 21), the nature of curve produced is similar as maximum factor of safety is produced at middle one 3rd section of slope and on observing lower and upper section of slope FOS goes on decreasing. From Figure 22, it is clear that nail inclined horizontally produces maximum FOS which is similar to result obtained by author.

5. Conclusions

Landslide slope was unstable in actual field and critical slope was stable in actual field which is similar to the result obtained by SVSLOPE and also using PLAXIS showed good correlation. So SVSLOPE model can be used in Nepalese environment with reasonable accuracy. From the result obtained in analysis, nail positioned at middle one third and inclined horizontally produces maximum efficiency. Increase in horizontal seismic coefficient decreases FOS and effect of water table is significant only when sufficient sliding mass is intersected and also effect of friction angle shows significant change in FOS.

References

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[3] CR Patra and PK Basudhar. Stability computations in nailed slopes. In *Ground Improvement Geosystems: Densification and Reinforcement: Proceedings of the Third International Conference on Ground Improvement Geosystems, London, 3-5 June 1997*, page 375. Thomas Telford, 1997.