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STABILIZATION OF EARTH SLOPES BY USING SOIL NAILING

Asst. Lect. Nadher Hassan Al-Baghdadi
Department of Civil Engineering,College of Engineering, University of Kufa
Nadherhj@eng.kuiraq.com

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Abstract

The basic concept of soil nailing is to reinforce and strengthen the existing round by installing closely spaced steel bars, called "Nails", into a slope as construction proceeds from "top-down". This process creates a reinforced section that is in itself stable and able to retain the ground behind it. Soil nailing technique is used to support new very steep cuts with advantage of strengthening the slope with excessive earth works to provide construction access and working associated with commonly used retaining systems. In the present research work a parametric study has been made using commercial computer program "Slide *6*", which utilize different methods for solving slope stability problem, Bishop method has been used herein to analyze un nailed and nailed slopes with granular soil, different slope heights and angles have been considered. Some of nails parameters have been studied here in, positions of nail, length of nail, angle of nail inclination, and nail spacing. The optimum length of nail depends on height and angle of slope. The optimum angle of nail is found to be ranged between (10-25) degree down from the horizon, but it's also relates with the angle of slope. The spacing of nail was found to be (1 m) to give the best improvement of F.S.

Keywords: Soil, Nailing, Reinforce ,Strengthen Slide 6 , Stability.

تثبيت الميول الترابية بواسطة مسامير التربة

مدرس مساعد ناظر حسن البغدادي
قسم الهندسة المدنية/ كلية الهندسة/ جامعة الكوفة

الخلاصة

المبدأ الاساسي لتقنية مسامير التربة هو تسليح وتقوية التربة بأدخال قضبان حديدية تسمى "مسامير" في بنية الميول الترابية، وبتسلسل عمل من الاعلى الى الاسفل. تخلق هذه العملية مقطعا مسلحا من التربة يستطيع اسناد نفسه بل ويستطيع اسناد التربة التي خلفه. تستخدم تقنية "مسامير التربة لاسناد حافات الحفر الحادة بدون أستخدام اعمال ترابية اضافية للاسناد والتي غالبا ما تستخدم في هذه الحالات. في البحث الحالي تم القيام بدراسة للعوامل المؤثرة في استخدام تقنية "مسامير التربة" باستخدام برنامج Slide 6 ، تم اعتماد طريقة الشرائح لـ(بيشوب) لايجاد معامل الامان، تمت دراسة العديد من العوامل المؤثرة على سلوك الميول الترابية المثبتة بواسطة مسامير التربة، حيث تمت دراسة طول المسمار وزاية الميل وكذلك تمت دراسة عدد المسامير المناسب لكل طول منحدركما تمت دراسة المسافة البينية بين المسامير. تم ايجاد الطول الامثل للمسمار حيث انه على ارتفاع المنحدر وعلى زاوية المنحدر، اما الزاوية المثلى فهي تتراوح من (10) الى (25) درجة اسفل الافق كما انها ترتبط بعلاقة مع زاوية ميل المنحدر.أفضل معامل امان يكون عندما تكون المسافة البينية بين المسامير تساوي 1 متر.

1. Introduction

The fundamental concept of soil nailing consists of placing in the ground passive inclusions, closely spaced, to restrain displacements and limit decompression during and after excavation. Slope stability analysis procedures have been developed to evaluate the global stability of the soil nailed mass and/or the surrounding ground, taking into account the shearing, tension or pull-out resistance of the nails crossing the potential failure surface. In the present research work a parametric study was conducted to study the following variables of nailed slope system:

1. The best location of nail and nails group within the slope.
2. The optimum length of nails.
3. The optimum angle of nails inclination.
4. The optimum spacing of nails.

Commercial software, well known (Slide 6) was used herein to conduct the parametric study. Verification of program (Slide6) results was made with Finite Element Solution.

1.2 Design of Soil Nailing

The following documents have been widely referred by designers in designing the soil nailing strengthen in works:

a) BS 8006:1995 code of practice for strengthened reinforcement soils and other fills.
b) Federal Highway Administration (FHWA): Manual for Design and Construction Monitoring of Soil Nail walls.
c) BS 8081:1989 code of parametric for ground Anchorage.

1.3 Review of Literature

The available design procedures involve different definitions of safety factors and different assumptions with regard shape and failure surface the type of soil-nail interaction, and the resisting forces in the nail.Limit-Force equilibrium methods were developed by Stocker et. al. (1979) assuming a bilinear sliding surface and by Shen et. al. (1981) considering a parabolic surface. Both methods take into account only the tension resistance and pull-out capacity of the inclusions. A more general solution, integrating the two fundamental mechanisms of soil-inclusion interaction (i.e., lateral friction and passive normal soil reaction) was developed by Schlosser (1983). This solution considers both the tension and the shearing resistance of the inclusions as well as the effect of their bending stiffness. A kinematical limit analysis design approach was presented by Juran et. al. (1990) and Byrne (1992). This approach allows for the valuation of the effect of the main design parameters (i.e., structure geometry, inclination, spacing, and bending stiffness of the nails) on the tension and shear forces generated in the nails during construction.The kinematic limit analysis approach was applied by Askari et. al. (2009) to study the three dimensional stability of reinforced slops.

2. Method of Analysis and Method used

Program well known (SLIDE 6) has been used in the present research work to analyze un-nailed slopes. The program utilize Bishop Limit equilibrium analysis method has been used.

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2.1 Nail Implementation in Program

2.1.1 Intersection with Slip Surface

In order for the nail to have an effect on a given slip surface, the nail must intersect the slip surface. If the nail does not intersect a slip surface, then no nail force will be applied to the slip surface, and the nail will have no effect on the safety factor of that slip surface.

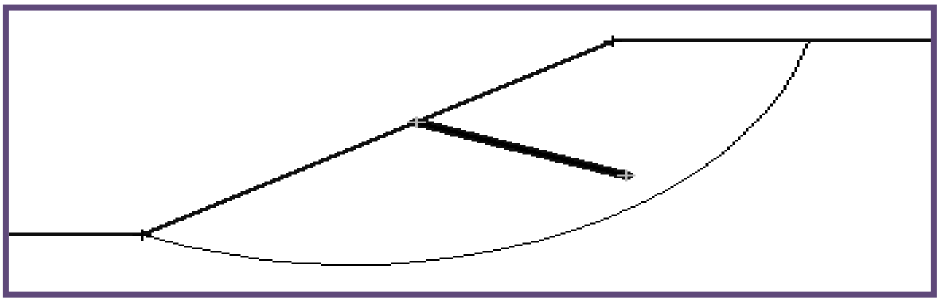

Fig.1 Nail does not Intersect Slip Surface - No Effect on Safety Factor.

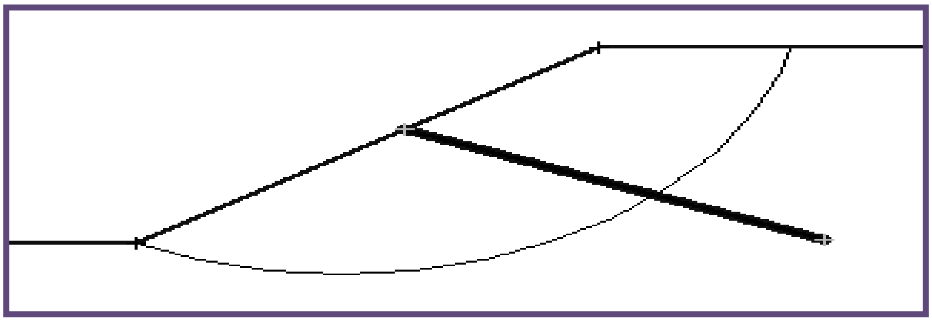

Fig.2 Nail Intersects Slip Surface - Nail Force Will Be Applied.

2.1.2 Location of the Applied Force

When nail intersects a slip surface, a force is applied at the point of intersection of the slip surface with the nail (i.e. to the base of a single slice). The applied force is simply a line load, with units of force per unit width of slope.

2.1.3 Orientation of Applied Nail Force

The orientation of the applied force is assumed to be parallel to the direction of the nail, as shown in Figure 3.

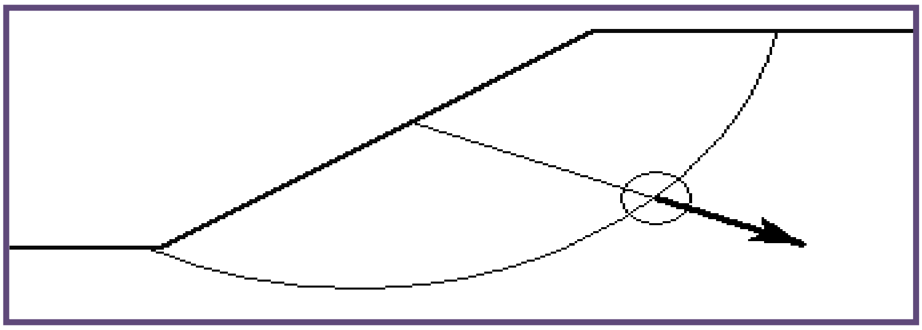

Fig.3 Nail Force is applied at the Point of Intersection with Slip Surface.

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2.1.4 Factor of Safety Calculations

The factor of afety is defined as the ratio of the forces resisting motion, to the driving forces. Driving forces include the mass of each slice accelerated through gravity, seismic forces, and water in a tension crack. Resisting forces arise from the cohesion and frictional strength of the slip surface.

Active Support is included in the Slide analysis as in Eq.1.

$$F.S = \frac{\text{Resisting force} + T_n . \tan\phi}{\text{Driving force} - T_s} \quad ....eq.(1)$$

Where: T_n is the normal component of the force applied to the base of a slice, by the support.
T_s is the shear component of the force applied to the base of a slice, by the support.

Passive support is included in the slide analysis as in Eq.2

$$F.S = \frac{\text{Resisting force} + T_n . \tan\phi + T_S}{\text{Driving force}} \quad ....eq.(2)$$

By this definition, Passive Support is assumed to increase the resisting force provided by shear restraint, in the factor of safety equation. Soil nails or geo-textiles, which only develop a resisting force after some movement within the slope has taken place, could be considered as passive support.

2.2 Verification of the Method and Program used

Verification of the method used was done by comparing the results of un-nailed and nailed slopes by both limit equilibrium method (slide method) and Finite Element Method. The finite element solution was conducted using 2D Plaxis software. The properties of the model solved are in Table 1, and the results are presented in Table 2. The results show very good agreement among the limit equilibrium method, finite element method, and the used method results (i.e. slide 6). Figure 4 shows slide 6 model of the verification problem.

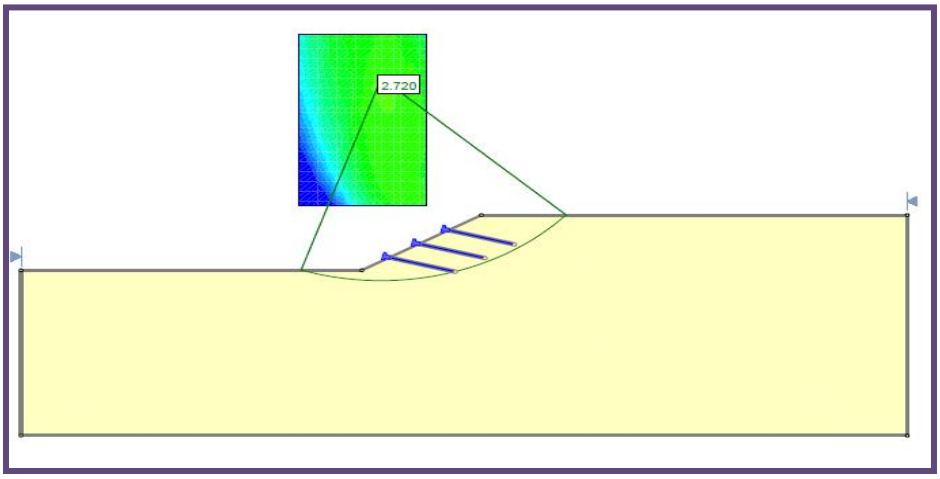

Fig.4 Model of Nailed Slope of Verification.

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Table 1 Properties of Verification Model

Slope Properties	*Value*
Height of Slope H	10m
Angle of Slope β	30^o
Cohesion of Soil C	20kPa
Angle of Internal Friction Ø	30^o
Soil unit weight γ	19 kN/m^3
Failure Criterion	Mohr-Coulomb
Nails Properties	
Length of Nail L_n	10m
Angle of Nail inclination θ	15^o
Spacing of Nails	3*3m
Tensile Capacity	100 kN
Plate Capacity	100kN
Bond Strength	50kN/m
Shear Capacity	50kN

Table 2 Results of Verification.

	L.E. F.S.	*F.E. F.S.*	*SlideF.S.*
Un-Nailed Slope	2.216	2.198	2.230
Nailed Slope	2.575	2.568	2.571

3. Parametric Study

A parametric study is conducted to investigate the influence of the various parameters of the nailed slope system. The parameters are nail position, nails length, nail inclination angle, and nails spacing. Un-nailed and nailed slope were modeled by program (SLIDE 6). Soil extent for both sides of each model were enough to be not intersect by any possible failure surfaces (SLIDE 6 Manual). Three different Height of slopes were considered (H = 10, 15, 20 m), and three different angle of slopes were considered (β =30^o,45^o,60^o). Granular soil was used with Ø =30, small cohesion value was introduced (C = 5kPa). The small cohesion value prevent the development of small failure surfaces which gives a small unreal value of F.S. Nails properties used are presented in Table 3 (FHWA, 1998). Figure 5 shows un-nailed slope model with (H = 20m, β =30).

Table 3 Nail Properties of Parametric Study.

Nails Properties	*Value*
Length of Nail L_n	Variable
Angle of Nail inclination θ	Variable
Spacing of Nails	Variable
Tensile Capacity	100 kN
Plate Capacity	100kN
Bond Strength	50kN/m
Shear Capacity	50kN

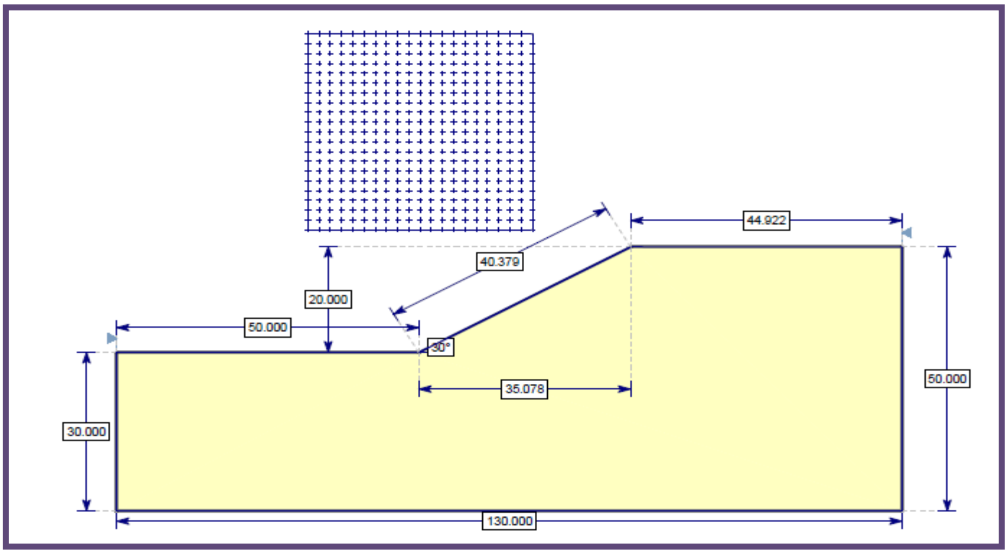

Fig.5 Un-Nailed Slope Model.

3.1 Best Position of Nail

The best position of nail has been investigated by using single nail moving along slope from toe to top. Figure 6 shows the relation between the nail position and the improvement in Factor of Safety, which expressed by F.S% (F.S% = (Factor of safety of nailed slope divided by the factor of safety of same slope without nail)). The position of nail are expressed by the ratio (x/L_s), where x value represent the distance of nail position from slope toe, and the L_s value represent the length of slope (L_s=H/sinβ). The curve in Figure 6 indicates that when single nail used to support slope, regardless of its length (length of nail should be enough to be intersected by possible failure surfaces), the optimum position of nail is ranged between 10% of slope length from the toe and 75% of slope length less than the top. The toe of slope should be excluded (x/L_s=0), because the failure surface could develop without passing through the nail which make him benefit less. Figure 7 shows the nail in the toe of the slope and failure surface does not passing through the nail. When the nail putted in the last quarter of slope the percentage of F.S. improvement reduced to one third the total improvement percentage.

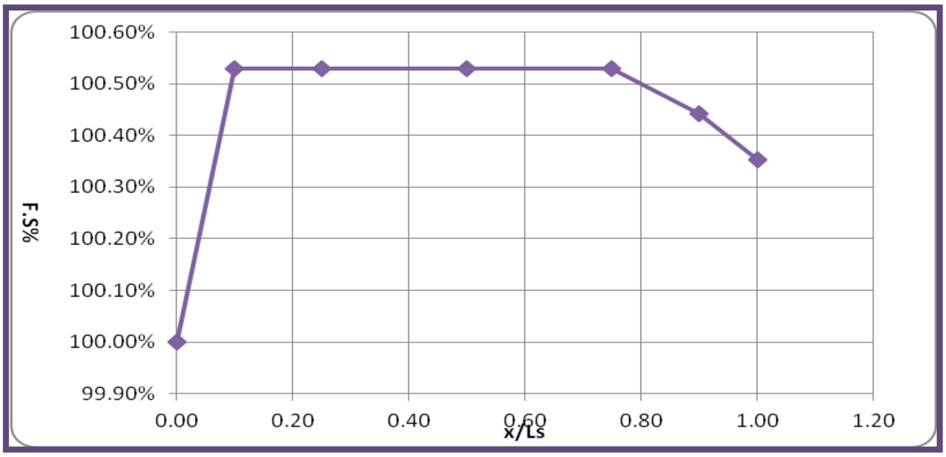

Fig.6 The Relation Between the F.S% and Nail Position.

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3.2 Optimum Length of Nails

To investigate the optimum length of nails group, many models were conducted. The properties of these models are presented in Table 4. Figures (8, 9, and 10) show the relationship between length of nails and improvement percent in factor of safety F.S%. Referring to the previous figure, the value of the optimum length could be obtained at the point of zero slope in each curve, these points were developed when the failure surface cross all the nails in the models (i.e. the slide soil mass become larger and it cannot be supported by the resisting force of the soil itself in addition of the force of nails group). Also the Figures 8, 9, and 10 show in obvious manner that the optimum length of nails is a function of height of slope (H) and angle of slope inclination (β), where the all other variables is assumed to be constant. The relationship among K variable, (K= {optimum nail length divided by length of earth slope}), the height of earth slope (H), and angle of slope (β) could be obtained as shown in Figure 11, which could be used in nailed slope design procedure.

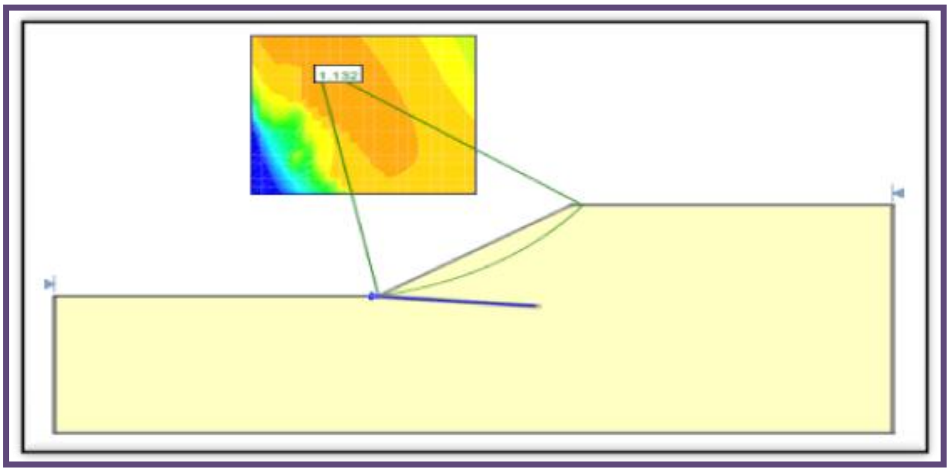

Fig.7 Failure Surface Developed above Nail Position (at Toe of Slope).

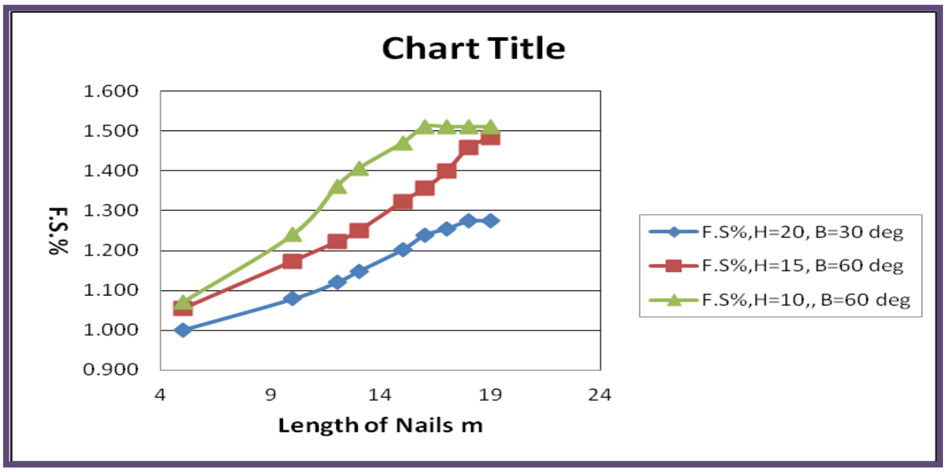

Fig.8 Relation between Length of Nails and F.S Improvement Percentage, $\beta=30^o$.

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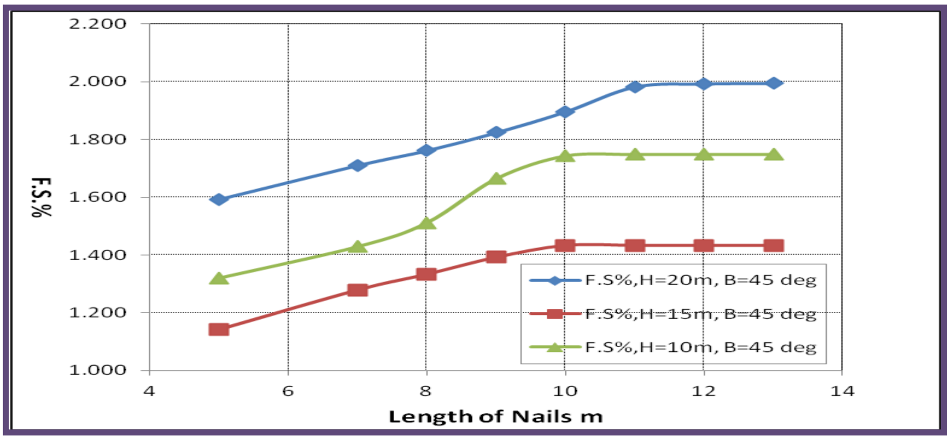

Fig.9 Relation Between Length of Nails and F.S Improvement Percentage, β=45^o.

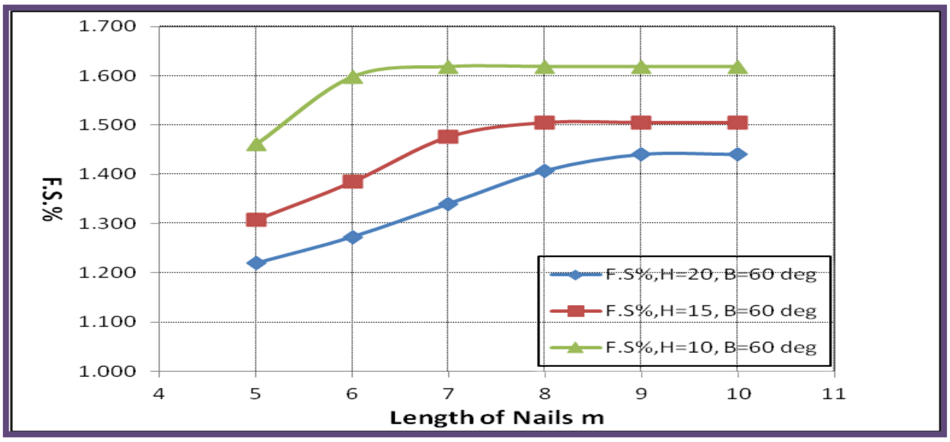

Fig.10 Relation between Length of Nails and F.S Improvement Percentage, β=60^o.

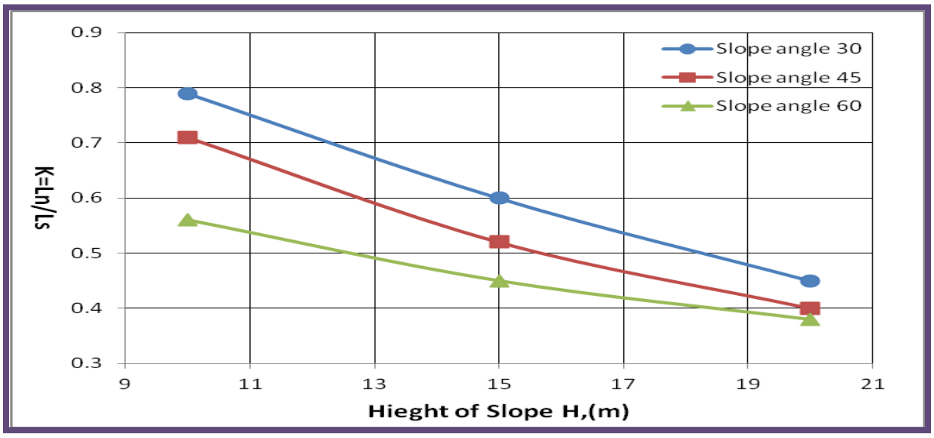

Fig.11 Relation between K and Height of Slope of Certain β.

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3.3 Optimum Angle of Nail Inclination

Many models have been used to investigate the optimum angle of nail. The properties of the used models are presented in Table 4. The length of nail has been selected depending upon the variable (K) as stated in previous article (2.3) in the present study. Figures 12, 13, and 14 show the relationship between the angle of nail inclination (θ), (measured from the horizon), and the factor of safety improvement percent F.S%. These curves show obviously that the larger improvement in Factor of Safety can be produced with different nail inclination angles (θ), and it ranged between 10^{o} to 25^{o}. Figure 15 shows the relationship between the angle of earth slop (β) and the percent of the tangent of nail angle to the tangent of slope angle (δ= tan θ/ tan β). The Figure 15 could be used in the design procedure to obtain the optimum angle of nail inclination.

3.4 Optimum Spacing of Nails

Three angles of earth slopes have been investigated ($\beta=30^{o}$, 45^{o}, 60^{o}) with height of slope (H=20m), the length of nails were used depending on K variable (article 2.3. in the present study). Inclination angle of nails ($\theta=15^{o}$). Figure 16 shows the relationship between F.S% and nails spacing for the three different angles of slope. This relationship indicates that the influence of nails spacing was the same regardless of slope angle until the spacing become less than 2 m, different influence obviously noticed. The behaviour of nails and in between soil become like a block, when spacing less than 2 m, and the failure surface cannot pass through the nails group. In this case the length of nails govern the value of F.S.

Fig.12 Angle of Mail Inclination vs. F.S%, β=30°.

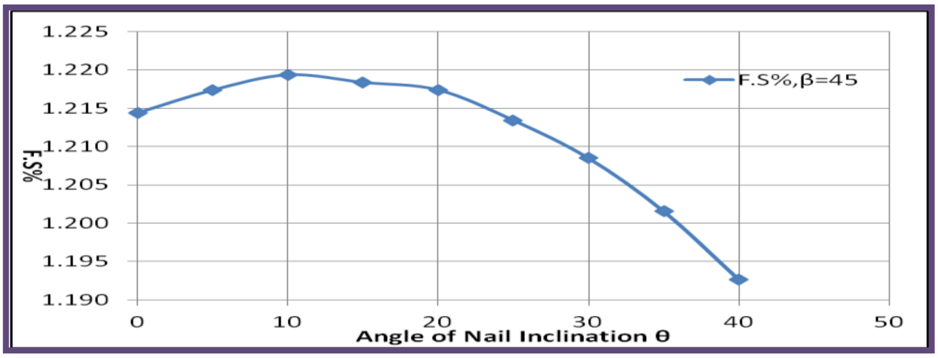

Fig.13 Angle of Nail Inclination vs. F.S%, β=45°.

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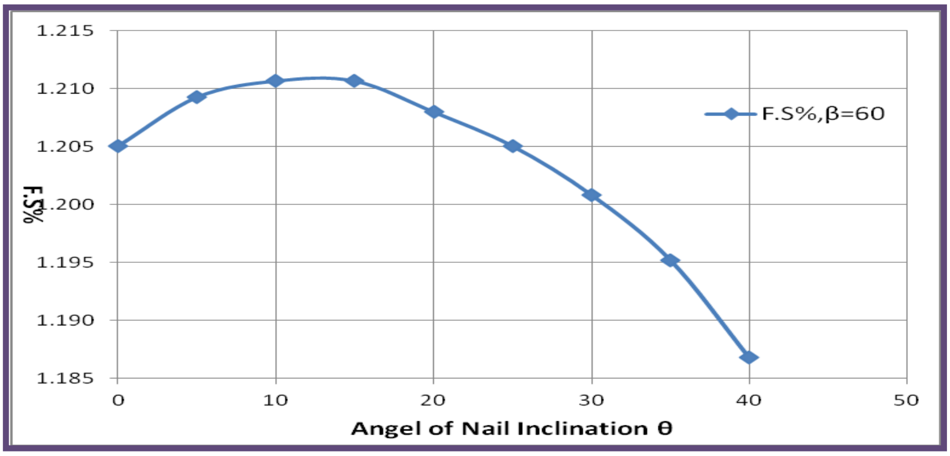

Fig.14 Angle of Nail Inclination vs. F.S%, β=60°.

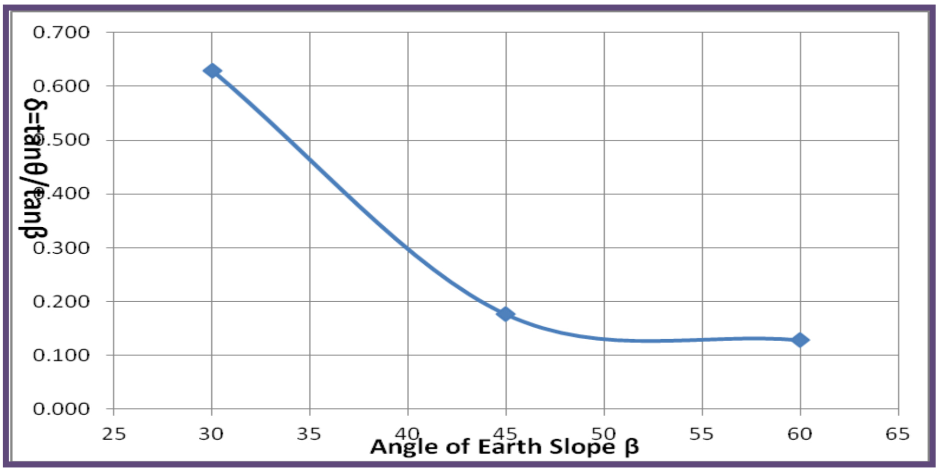

Fig.15 Angle of Earth Slope (β) vs. δ .

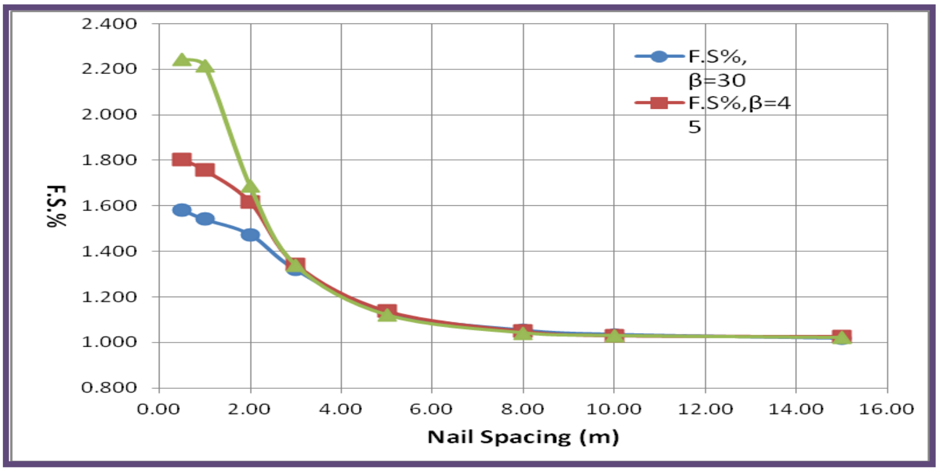

Fig.16 Nail Spacing vs. F.S. Improvement Percentage (F.S%).

5. Conclusions

1. When single line of nails used, it should be placed in middle two third of the slope length.

2. The optimum length of nails, with spacing larger than to cause block effect, related in obvious manner with height and angle of slope. In the case of spacing which can cause block effect, the increment in length of nails causes increment in F.S. because the failure surface cannot pass through the nails group so it pushed behind the block (nails group), which cause increasing in failure surface length.

3. The best angle of nail inclination is ranged between (5 to 25 degrees) below the horizon. A relationship could be obtained between the nail angle and slope angle and it could be useful in design procedure.

4. In the case of nails spacing more than 2m, the influence of spacing is quite similar against different slope angles. The other case where spacing equal to 2m or less the behaviour become relatively different in determining the F.S%, because it related with the length of slope (L_s). In spacing 1.5 m the group of nails can form a block with the in between soil and its very hard to pass through by failure surface.

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