Mansoura Engineering Journal, (MEJ), Vol. 22, No. 3, September 1997

STABILIZING HIGHWAYS EARTH SLOPES BY NAILING

معالجه جسور الطرق بالتسمير

BY

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ملخص :

تعتبر مشكله إنهيارجسور الطرق خاصه بعد فتحها للمرور من المشاكل الرئيسيه التي تقابل المهندس . و في أغلب الأحوال فإنه يتم علاج هذه المشكله بإستخدام أحد أنواع الحوائط السانده و التي تستغرق وقتاً طويلاً أثناء التنفيذ و تستقطع جزء كبير من تربه جسر الطريق . إلا أنه توجد طرق أخرى حديثه لمعالجه هذه الجسور بإنشاء حوائط مدعمه بنسيج دعم التربه أو بتقويه الجسر القائم بطريقه التسمير .

و الهدف من هذا البحث هو إلقاء الضوء علي طريقه تسمير الجسور كطريقه حقليه تتميز بأنها لا تحتاج لقطع جسر الطريق و لا تؤثر علي طبقات الرصف ا أثناء التنفيذ . لذلك فقد تم أولاً مراجعه الأسس التصميمية و التنفيذية لإسلوب تسمير جسور الطرق . و ثانياً إجراء إختبار معملى على نموذج مصغر لجسر طريق من الرمال و إختباره بإستخدام الأحمال التكراريه . و قد تم قياس مقدار التشكل الافقي لنموذج الجسر المعملى قبل و بعد التسمير وذلك لدراسه تأثير كلٍ من جساءه و طول و ميل هذه السامير علي تخفيض التشكل فى الجسو بعد المالجه . و قد تم التوصل إلى أنه فى حدود المعلومات المتاحه و الإختبارات المعمليه التي تمت أن تسليح جسور الطرق بطريقه التسمير هى طريقه واعده يمكنها أن تساعد في حل مشكله إنهيار جسور الطرق نتيجه الأحمال المروريه المضافه .

Acceepted September 4, 1997

ABSTRACT

A major problem that faces the highways engineer is the failure of roads side slopes, specially after being opened to traffic. In most cases this obstacle is treated either by building gravity or reinforced concrete walls. In fact, these types of retaining structures have proven successful if they are well designed and constructed. However; they are time consuming and they necessitate excavating large volumes of soils, in some cases requiring the construction of a temporary retaining system and importing a better sandy soil for refilling behind the wall.

Other methods of earth slope stabilization are by geosynthetics reinforcement or by nailing. The purpose of this study is mainly to highlight nailing as an in situe reinforcement technique that does not need any deep cutting of side slopes and in most cases does not cause any disturbance of road pavement.

The principles of side slope nailing are firstly reviewed. Secondly, a laboratory model of sand slope has been constructed and tested for cyclic loads simulating traffic loads . The slope face deformation have been recorded before and after nailing with three types of nails of different rigidities, lengths , inclinations and spacing. It was found that reinforcing highway's side slopes by nailing is a new promising technique, it can help in solving the problem of side slopes failure due to traffic loads. Our lab experience with this stabilizing method has established a significant improvement of side slope safety by nailing.

INTRODUCTION

Side slopes stabilization by rigid piles, flexible nails and other types of reinforcements is one of the earliest applications of soil reinforcement. This application has been widely used in France specially for railway slopes. Whenever a retaining wall could not be used at the toe of the slope, soil nailing was used. In general, small-diameter piles had small bending stiffness or similar inclusions were employed. In Japan, railway slope stabilization by timber piles have been reported early during this current century. In North America the nailing system was initially used during the early seventies for temporary excavation support [1,2] .

The technique of side slope stabilization by nailing consists of placing passive linear inclusions capable of withstanding tensile forces, shear forces and bending moments into an existing surface. This way a relatively uniform composite cohesive mass of reinforced ground is created. Nailing may be employed to restrain two different modes of down slope soil movement. The first is the case where little or no movement occurs but safety factor along potential sliding surface is low. The purpose of the reinforcing element is to increase the safety factor. The second is when movement is already occuring at an unacceptable rate. In this case the failure surface can be detected by field measurements, whilst, the purpose of the reinforcing element is to decrease the rate of sliding [2] .

In Egypt, it is believed that a large percentage of highways construction will be directed to new desert enplanting areas . In most cases canals and drains are firstly constructed , farmers are moved to start planting and then the need for highway pavement construction is warranted. Therefore, even if the side slopes of the newly constructed road are safe, the traffic loads may initiate a potential failure surface. The increase of load repetitions coming up from traffic by time may cause a complete side slope failure. Therefore, it is believed that if the side slope of such a road is nailed before it is opened to traffic the risk of road side slope failure is decreased

The purpose of this study is firstly,to introduce the subject of slop nailing , behavior and proposed design procedure. Secondly, it is believed that testing a lab size side slope embankment before and after nailing while subjected to a standard repeated load might provide some comparative results.

CONSTRUCTION AND BEHAVIOR OF NAILING PRACTICE

The proposed nailing system consists of a reinforced shotcrete facing and an array of reinforced members grouted or driven into the side slope soil mass. These inclusions are supposed to resist tensile stresses, shear stresses and moments. The facing can be subsequently covered, for durability considerations, by stone reprabing , concrete panels or cast-in-place concrete.

Construction Method

Nail Installation

The surface of side slope is adjusted to the required section and smoothed by cutting pumps and filling holes with a good soil. Following that reinforcing nails are installed in rows from top to bottom. Installation may be by a small vibroprecussion hydraulic hammer which is used to drive the reinforcing bars or similar, or it may consist of a drilling and grouting equipment if the reinforcing elements are to be grouted in place. The selected method of drilling depends on the type of side slope soil.

If soil is stiff cohesive or dense granular, i.e the borehole can remain open unsupported for the short time required for reinforcing element insertion, a hollow stem auger is used. Once the hole is advanced to the desired depth the reinforcing element is inserted with spacers as necessary to maintain the rod in its center position and grout is pumped under gravity to fill the space around the bar from bottom up. For nonstiff or relatively loose soils, drilling may be accomplished by use of a rotary ring with cuttings removed by water or compressed air. The holes are cased with specially casing pipes. At the completion of drilling, claming and casing, the nail with its centralizers is inserted in the cased borehole with a grout pipe extending to the bottom of the hole. Casing and the grout pipe are then withdrawn as grout filling continues from the bottom up. In general, a minimum borehole diameter of 100mm. should be used to ensure sufficient grout cover along the nail.

Drainage Installation

When required, horizontal or subhorizontal drains are installed on the slope face before covering to depths, locations and spacing necessary to intercept ground water and outlet it at the desired level by means of weepholes [3] .

Face Construction

An initial layer shotcreting is applied prior to placing the reinforcing mesh. After placing the reinforcing steel mesh the covering layer of shotcreting is then followed, ensuring a cover of (40mm) by accurate positioning. A bearing plate perpendicular to nail is then attached and positioned. The nail is tightened to plate employing a suitable nut to take up slack in system. In some cases, nails may be tensioned to some percentage of their working load to limit deflection. After finishing the nail connection to plate additional architectural cover as mentioned previously can be employed on the slope surface [3] .

Basic Behavior

The basic idea describing the behavior of a nailed slope depends on two criteria. Firstly, the transfer of tensile forces generated in the nails in an active zone to a resistant zone by friction or adhesion generated at the soil nail interforce. Secondly, passive resistance developed laterally on the surface of nail. The friction produced between the ground and the nails suppresses ground movement after construction. An apparent increase of normal stresses along potential sliding surface is induced by the resisting tensile forces mobilized in the nails. This way the overall shear resistance of the native ground is increased. On the other hand if the inertia of nails placed across a potential slip surface is big enough, they can resist shear force and bending moment through the development of passive resistance. The point of maximum tensile zone separates the nailed ground mass into two zones, Figure (1) .

1- An active zone which is the potential sliding mass, where lateral shear stresses are mobilized resulting in an increase of the tension force of the nail (zone - A).

2- A stable zone where the produced nail forces are transferred axially and laterally to the ground (zone - B).

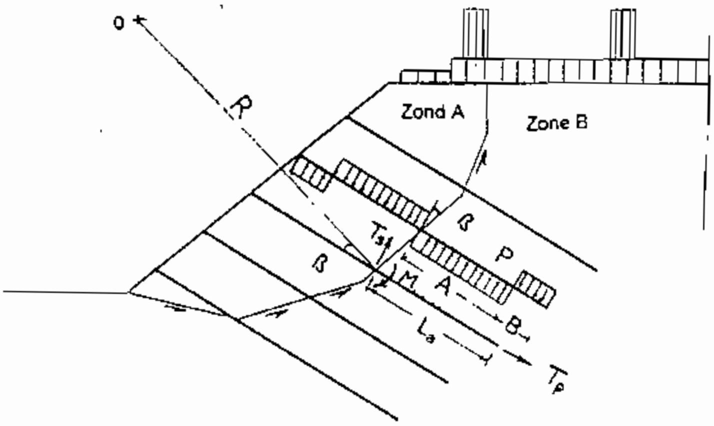


Figure (1) Sketch of Highway Slope Support By Nailing.

As the active sliding mass starts to move forces are produced in the nails and transferred to ground through the interaction between soil and nails with the result of limiting and controlling the slide of slope (active zone). The values and types of forces produced in a nailed mass will depend on the following parameters :

a) Mechanical properties of the side slope soil, particularly type, angle of friction and cohesion.

b) Mechanical properties of the reinforcement such as the tensile strength, shearing strength and bending stiffness.

c) Soil reinforcement interaction, axially in the direction of nail as measured by the friction pullout between nail and soil and laterally through the passive bearing pressure of the nail on soil as measured by modulus of lateral subgrade reaction.

d) Geometric properties of reinforcements such as crossection and length and the distribution of nails as indicated by vertical and horizontal spacing between nails.

e) External loads including pavement loads, traffic loads and water pressure .

PRINCIPLES OF DESIGN

In the design of nailed side slopes two distinct cases are to be preselected . The first is the stabilization of potentially unstable slopes where little or no movement has occurred. However, available safety factors along potential sliding surfaces are low and a sliding zone can be easily mobilized. The second is the stabilization of creeping slopes, where movement is actually occurring at unacceptable rates [2] . In this study, only the first case is considered.

EXPERIMENTAL WORK

The purpose of the testing program was to evaluate the effect of traffic loads as represented by repeated loading on a sandy slope lab size model before and after nailing with two different types of nails . To achieve that purpose a steel mold was manufactured inside which the tested slop is compacted and prepared for testing. Details of testing program are discussed below.

Testing Materials

Soil Properties :The soil employed as an earth slope was a uniformly graded sand. The general properties of soil as found are given in table 1

Table 1 Physical and engineering properties of sandy soil

Properties	Value
Angle of internal friction (ϕ)	36°
Cohesion (C)	0
Coefficient of curvature (C_c)	1.29
Uniformity Coefficient (C_u)	3.71 < 5 uniform
Maximum dry density ($_{dry}$)	1.785
Optimum moisture content	2.1 %

Reinforcing Nails : Two types of nail materials were used in nailing the lab constructed earth slope. The first were steel bars. Two nail diameters were employed i.e.; 6 mm and 3 mm, to reflect the variation of nail stiffness. The second type were prolypropelene ropes were they had low stiffness. The elastic modulus of steel (E) was 2.1×10^6 kg/cm^2. The polypropylene ropes were of the monofilament type and had total diameter of 10 mm. The elastic modulus of rope material was determined using a special machine found at the canal Rope company in Port-Said and was found $1.47 * 10^4$ kg / cm^2 . Summary of nails properties are given in table 2.

Table 2 : Nailing Material properties

Nail type	Diameter (mm)	Elastic modulus (Kg / cm^2)	Bending Stiffness[a] (Kg.cm^2)
Steel bar	3.0	$2.1 * 10^6$	835
Steel bar	6.0	$2.1 * 10^6$	13360
polypropelene ropes	10 0	$1.47 * 10^4$	721

[a] **Stiffness is defined by elastic modulus times the moment of inertia**

Facing Material :The main function of facing material in nailed slopes was to ensure local stability between nails and to protect the retained soil face. A rich cement mortar reinforced by a welded steel wire mesh of 1 0 mm wire diameter and a total weight of 0 72 kg/m^2 was employed as a facing. The percentage of mortar material were 1 : 5 : 0.5 by weight of cement; sand and water respectively.

Testing Mold and Specimen Preparation

Testing Mold

A strong steel box was manufactured to house the 4 mm thickness bottom and walls steel plates constituting the mold. A 15.0 cm height plate wes fitted at the end to construct the bed of embankment. The total clear height of the mold was 50 cm, therefore, a maximum height of allowable slope was 30 cm. One side wall of the mold was made of thin Plexiglass plate. A 10 mm square reference grid pattern was engraved on the Plexiglass side wall for the purpose of displacement measurements. A diagrammatic presentation of testing mold is shown in Figure (2)

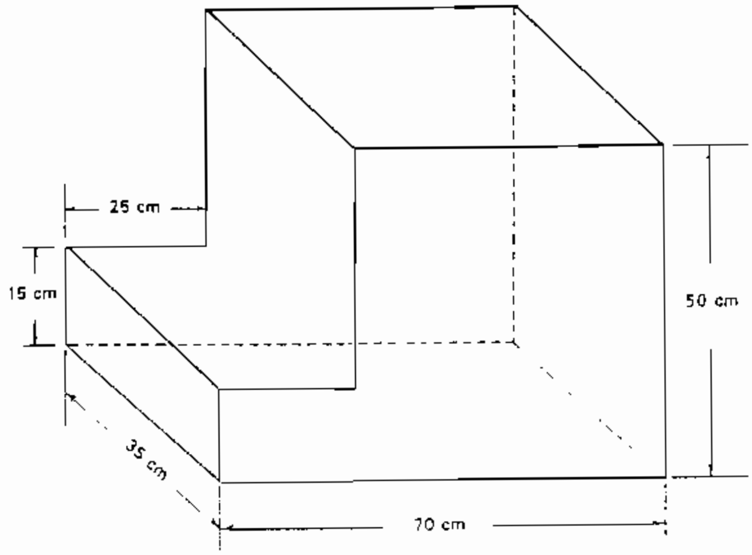


Figure (2) Dimensions of the Manufactured Model .

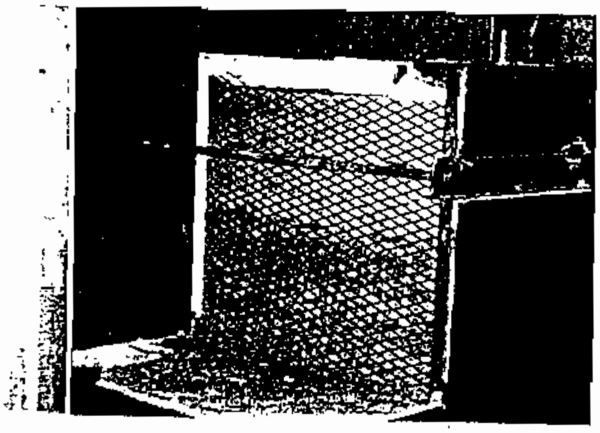


Figure (3) Finished Testing Model Before Covering Facing with Mortar

Specimen Preparation

Compaction : The soil was compacted statically in the mold to constitute a finished vertical slope of a 30 cm height . A predetermined dry soil was mixed at optimum moisture content. The wet soil was then poured into the mold whilst the steel vertical facing was fixed in place and gently damped to fill the steel mold. The soil in mold was then compressed complying a hydraulic jack until the top of soil coinscided with a computed volume mark. After finishing the compaction process, the vertical facing was gently removed and the vertical slope was generated by cutting excess materials.

Reinforcement installation :The nails employed in all tests were of the driven nails type. The horizontal spacing S_h and the vertical spacing S_v were equal. Values of S_h and S_v for each test were determined such that the quotient of nail diameter (D_s) to nail spacing (S_h or S_v) is 0.05. Therefore, when nail diameter was 3 mm the spacing between nails was taken 60 mm, whilst, the spacing between nails was taken 120 mm for a nail diameter of 6 mm For ropes , the nails spacing were 120 mm . In all cases , naills were then pushed directly at their positions until they reached the required embedded length using nail lengthes of 15 , 25 or 35 cm.

Construction of facing : After installing the nails a steel wire mesh was placed directly over the soil facing. Following that a rich cement mortar was placed over the steel wire mesh by hand and distributed over all the area of facing. To secure no friction between facing and mold sides, 5.0 mm on each sides of vertical facing were left without mortar. The mold was then sealed and left for 24 hours before starting the test. Figure (3) shows the testing mold face before covering with cement mortar.

Repeated Load Testing

Loading System :To apply a repeated load on the testing section a loading system of the dropping hammer type was employed. The system was calibrated to produce a surface pressure of 500 Kpa (70 psi) transferred to slop surface through two parallel plates. Each of the two plates was 20 mm width by 350 mm length; i.e., the full width of testing section. To achieve that, a dropping hammer weight of 6.0 kg and a height of drop of 70 mm were adjusted producing an impact pulsating load of 700 kg. The stress produced on surface was ;therefore, about 500 Kpa (70psi) . The load was repeated 84 times per minute (1.4 Hz) .

Testing Program :The purpose of the testing program was to study the effect of number of load repetitions on slope facing horizontal deformation for sections before nailing and after nailing. Since the slope section material and shape were kept constant (vertical slope height H = 30 cm) , the following parameters were varied for the nailed sections :

1- Length of nail at three levels ; i.e., L equals 15; 25 and 35 cm for L/H equals 0.5, .83 and 1.17 respectively.

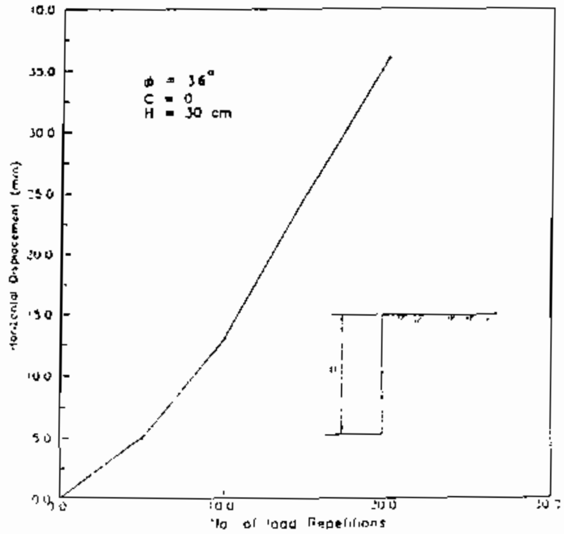
2- Nail stiffness ; i.e., flexible (polypropylene rope) , stiff (EI) for 3.0 mm steel nail has a bending stiffness of 835 kg.cm^2 and very stiff (16EI) for 6.0 mm steel nail has bending stiffness of 13360 kg.cm^2.

3- Angle of nail inclination measured clockwise with respect to the horizontal at three values; i e , θ equal to 0°, 15° and 30°

ANALYSIS AND RESULTS

Case of Without Nailing

Figure (4) shows the relation between horizontal displacement of facing top and the number of load repetitions for case of without nailing. The displacement of face top was 37 mm after only 20 load repetitions; i.e., the face of slope moved horizontally for more than 12 % of slope height . Considering this top face deformation as very high relative to slope height the test was terminated. The fast failure , due to external repeated loading , was expected for the vertical slope cohesionless sandy soil tested.



4) Effect of Number of Load repetitions on

Horizontal Movement of Model Facing Top (Without Nailing)

case of with nailing

In general , a tremendous improvement of slope face deformation after repeated loading was achieved. For the purpose of comparison and for reasons of testing time tested nailed models were evaluated after only 2500 load repetitions.

Effect of Nail Length

Figure (5) shows the effect of nail length on the shape of model facing displacement after 2500 load repetitions for 3.0 mm diameter nails spaced at 60 mm vertically and horizontally; Sh = Sv = 60mm. The angle of nail inclination with respect to horizontal line was zero; i.e., $\theta = 0$. The longer the nail length the smaller was top face horizontal displacement. A face top displacement of 7.5 mm for 15 cm length nails (L/H = 0.50) was reduced to 4.0mm for 25 cm length nails (L/H = 0.833) and to 2.5 mm for 35 cm length nails (L/H = 1.166). The percentage of maximum horizontal displacement to slope height after 2500 load repetition was 2 5 % for the shortest nail length (L/H) = 0.5) compared to 12 % for case of without nailing after only 20 load repetitions. However, when nail length was increased to L/H = .833 and L/H = 1.166 this percentage were reduced to 1.33 and 0.83 respectively after 2500 load repetitions. The effect of reducing face horizontal displacement by increasing nail length was expected since enough nail length should be embedded in the passive zone to produce enough pullout resistance.

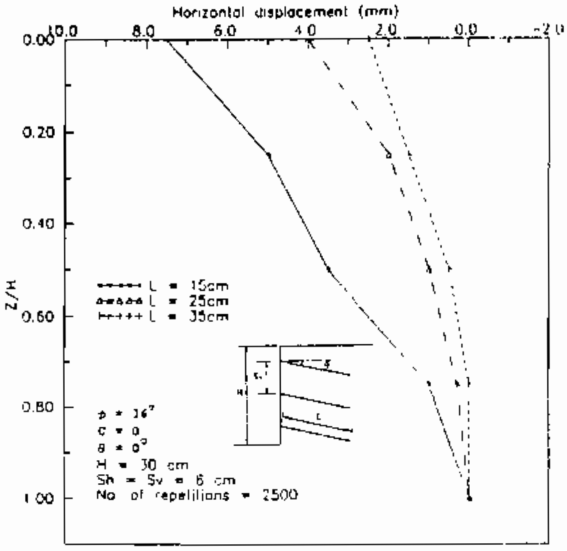


Figure (5) Effect of Nail Length on Horizontal Movements of Model Facing (Nail Diameter = 3mm) .

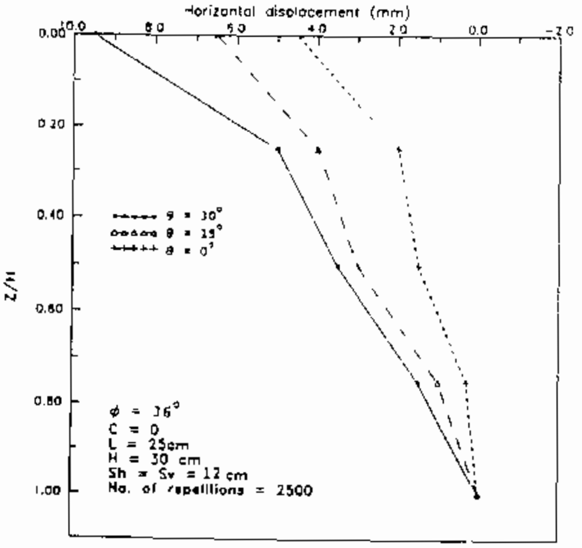


Figure (6) Effect of Angle of Nail Inclination on Horizontal Movements of Model Facing (Flexible , Polypropiene Rope)

Effect of Nail Inclination

Since a large part of the nail participation in resisting the driving moment (M_d) about slope surface failure was derived from its pullout resistance which produced an axial tensile force in its direction , the effect of angle of nail inclination was significant. As shows in Figures (6,7,8) the larger the nail inclination (θ), the larger the top face displacement after the same number of load repetition (2500).

Also the smaller the nail angle of inclination the lower the rate of displacement increase with respect to number of load repetitions . For example, in Figure (9) for case of flexible polypropelene ropes, the rates of displacement to number of repetitions increase were 0.0039, 0.0026 and 0.0016 mm/reptition for nail inclinations (θ) of 30°, 15° and 0° .

A value of nail inclination (θ) greater then zero is sometimes needed for construction reasons for facilitating the process of driving and grouting long nails specially when width of drain or canal is limited. However, horizontal or nails with small inclination are better for improving the stability of high way slope. Therefore, a comparison between the previously mentioned constraints should be decided in the design.

Effect of Nail Bending Stiffness

The effect of nail stiffness, as reflected by its EI value, interacted to nail inclination. When nail was horizontal θ = 0 , the nail stiffness had a neglected effect as shown in Figure (10) which presents the shape of vertical slope facing for the three different types of nails stiffness after 2500 load repetitions. As shown in this Figure the top facing horizontal displacements for the three types of nails were about 4.0 mm. It is believed that when nails were horizontal (θ = 0) and after this relatively limited, number of load repetitions 2500, the nail pullout resistance was more significance in improving slope stability than its bending stiffness. However, when the angle of nail inclination increased , Figure (11) for θ = 15°, relatively larger displacement occurred when employing polyproblene ropes as reinforcement which had the least stiffness. When angle of nail inclination was increased to 30° , Figure (12), the resistance by nail pullout was expected to decrease resulting in larger horizontal displacements of slope face. However, the displacement increase was more significant for the least stiffness nails ; i.e., polypropylene ropes.

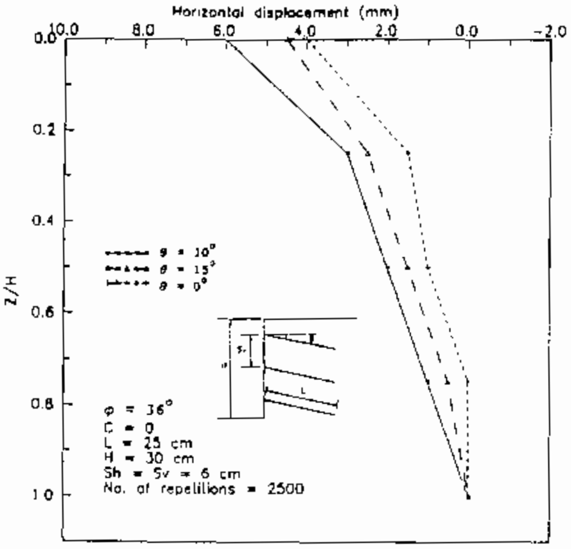


Figure (7) Effect of Angle of NailInclination on Horizontal Movement of Model Facing (EI = 835 Kg cm^2)

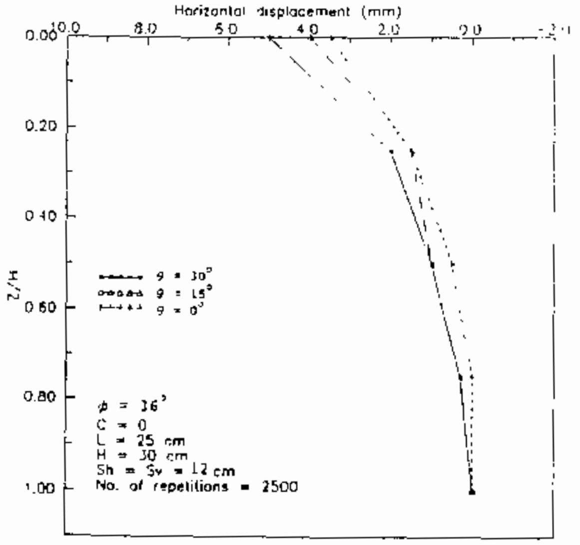
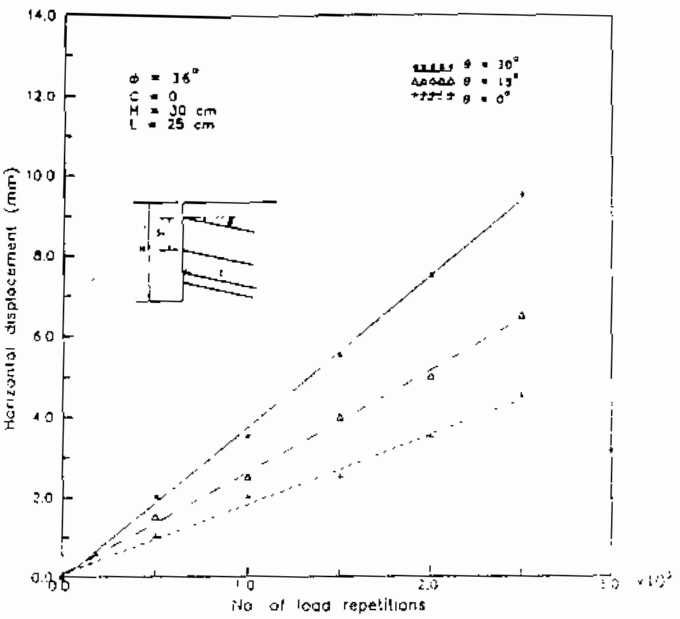
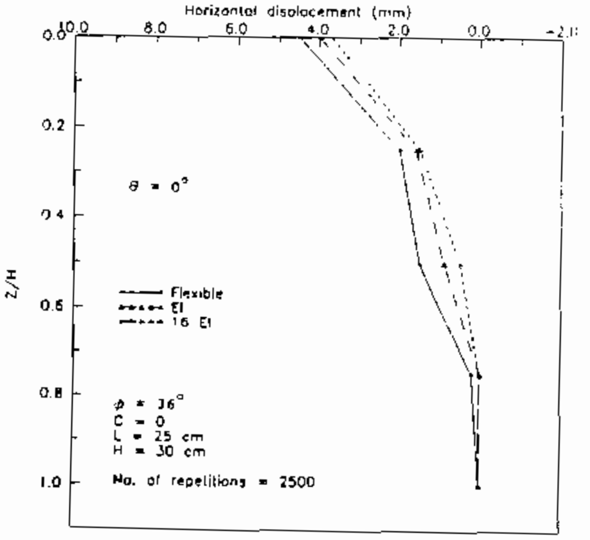


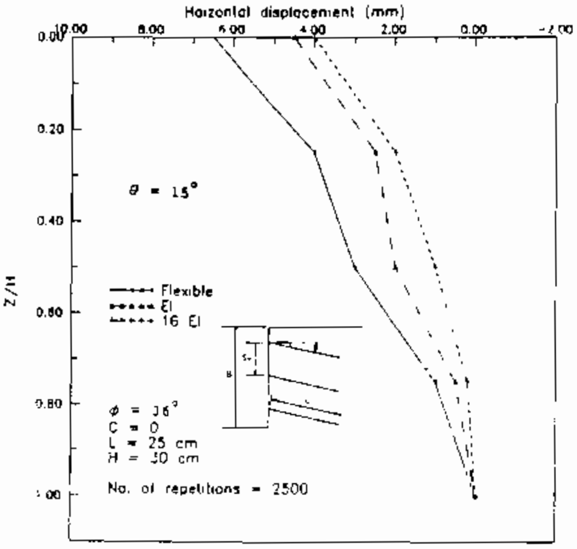
Figure (8) Effect of Angle of Inclination on Horizontal Movement of Model Facing (EI = 13360 Kg.cm^2)



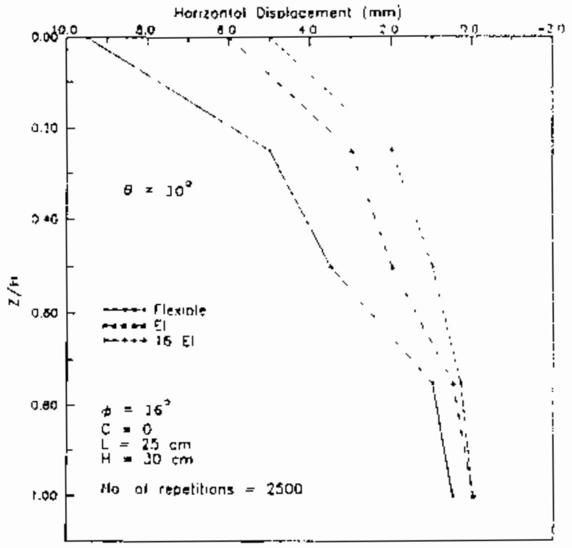
Figure(9) Effect of Number of Load Repetitions on Horizontal Movement of Model Facing (Flexible , Polyproplene Rope)



Figure(10) Effect of Nail Bending Stiffness on Horizontal Movements of Model Facing . (Nail Inclination θ = 0°)



Figure(11) Effect of Nail Bending Stiffness on Horizontal Movements of Model Facing . (Nail Inclination θ = 15°)



Figure(12) Effect of Nail Bending Stiffness on Horizontal Movements of Model Facing . (Nail Inclination θ = 30°)

CONCLUSIONS AND RECOMMENDATIONS

Based on the review made, testing materials employed and testing method mulated, the following conclusions are taken :

1- It is proposed that the design of nailed highway slope may be based on limit equilibrium analysis where the surface failure and factor of safety can be determined before nailing . Nails are then introduced to increase the factor of safety for both static and traffic loads .

2 - The influence of nail bending stiffness on stability of a slope appears to be small when compared to the axial reinforcement forces. It is believed that when only a proportion of the design axial capacity of nail can be mobilized due to low bond strength or short bond length bending stiffness can offer additional improvement .

3 - A significant improvement in the experimental model resisting stability against external repeated loads is achieved . However , horizontal displacement of nailed slope face increases linearly as the number of load repetitions increases .

4- Increasing nail length decreases the face horizontal displacement of the experimental nailed slope , therefore , a nail length equal to 0.75 to 0.85 of slope height must be at least provided .

5- Best improvement of experimental model stability is achieved when nail inclination with horizontal (θ) is zero . However , increasing θ up to 15° has no significant deteriorating effects .

6 - A full scale comprehensive testing experiment is highly recommended for any future research . In this experiment both cohesive and noncohessive soils must be evaluated .

REFERENCES

1 - Mitchel , J.K. , " Soil Improvement : State of the Art " , 10 th International conference on soil Mechanics and foundation Engineering , Stockholm , Swedn , June 1981 .

2 - NCHRP -290 , " Reinforcement of Earth slopes and Embakments" , Transportation Research Board , Appendix C , Washington , D. C , 1987

3 - Elias , V. And Juran , I . " Soil Nailing for Stablization of Highway slopes and Excavations ", FHWA - RD - 89 - 198 , June 1991 .

4 - Winter , H. , Schawrtz , W. and Gudehus G. , " Stabilization of Clay Slopes by piling " , Proceedings , 8th European Conference on soil Mechanics and Foundation Engineering , Helsinki , 1983 ..

5 - Mitchell , J K. and Villet , W C . B . " Soil Reinforcement For Stabilization Of Earth Slopes and Embankements " , FHWA 5p FCP Conference , Virginia , March 1984 .

6 - Roman D. , " Anchor Design For slope Stabilization by Surface Loading " ASCE , Vol 117 , No . 8 , August , 1991 ."

7- Yoder E. J . and Witczak M.W. " Principles of pavement Design " , John Wiley & Sons , Inc . , Second Edition , 1975