A STUDY OF THE PHENOMENON OF SOIL – REINFORCEMENT INTERACTION

Iqraz Nabi Khan[1] and Swami Saran[2]
[1]*Universiti Teknologi MARA Penang Campus, 13500 Permatang Pauh, Pulau Pinang*
[2]*Department of Civil Engineering, Indian Institute of Technology, Roorkee-247667 (Uttaranchal), INDIA*

ABSTRACT

The analysis and design of reinforced earth wall and retaining wall with reinforced backfill require the knowledge of the value of the coefficient of interfacial friction between soil and reinforcement. This coefficient is usually obtained by conducting either sliding shear test or pull-out test. It is not always possible for a field engineer to conduct pull–out tests to design a prototype-reinforced earth retaining structure. However, direct shear test facilities are generally available and sliding shear tests can be performed easily to obtain the value of friction coefficient (μ). In this paper an attempt has been made to develop a correlation between coefficient of friction (μ) obtained from sliding shear test and apparent coefficient of friction (f^*) determined from pull-out test. Effect of overburden pressure and length of reinforcement has been incorporated. Effect of width of strips and strain rate on apparent coefficient of friction (f^*) has also been studied. The effect of width of strip on apparent coefficient of friction (f^*) is very small. Increase in values of apparent coefficient of friction (f^*) was observed with increase in strain rate.

Keywords : *Experimental Study, Sliding Friction, Pull-out Friction, Reinforced Earth.*

1 INTRODUCTION

Reinforced Earth is a composite material, which is formed by the association of soil and tension resistant reinforcing elements. The reinforcement suppresses the normal tensile strains in the soil mass through friction interaction. Coefficient of friction between the reinforcement and soil is a critical property. The higher the friction, the more efficient is the reinforcement. Thus an ideally rough reinforcement is significantly better than reinforcement with smooth surface. An ideally rough surface can be produced by gluing a layer of sand to reinforcement, by deforming it using groove, ribs or embossing a pattern. Hence the analysis and design of reinforced earth wall and retaining wall with reinforced backfill (backfill supported by a conventional wall is reinforced with unattached reinforcement laid horizontally to reduce horizontal thrust on wall as shown in Figure 3a) require the knowledge of the value of the coefficient of interfacial friction between soil and reinforcement. This coefficient is usually obtained either by sliding shear test or pull out test. Both tests give different results. In sliding shear test, the local coefficient of friction (m) between the reinforcement sample and the soil is measured, while in pull out test, the reinforcement is extracted from a real structure or from an embankment.

Earlier investigators, [1-6], etc. reported that the apparent coefficient of friction (f^*) obtained through pull-out tests depends basically on two parameters, namely (i) overburden pressure and (ii) length of reinforcement.

No investigator has suggested a correlation between coefficient of friction (μ) and apparent coefficient of friction (f^*). In this paper an attempt has been made in this direction.

2 DEVELOPMENT OF TEST PROGRAMME

2.1 General

In sliding shear tests (Figure 1a), sliding of soil mass over a stationary reinforcement takes place and in pull-out tests (Figure 1b) the reinforcement is pulled out of the stationary soil mass. From the mechanics point of view the sliding test is akin to kinetic or rolling friction condition, while static friction condition prevails in pull-out tests. However, the interaction mechanisms are not so simple.

In sliding shear tests, the soil movement is minimum at the interface, since the movement of soil is restrained by reinforcement, and increases with distance away from it (Figure 2a). Whereas in the case of a pull out test, the soil movement at the interface will be maximum, since the soil resists the movement of reinforcement, and reduces away from it (Figure 2b). The above relative movements induce near constant volume condition for pull-out tests and constant normal stress condition for sliding shear tests. In pull-out test case, an increased effective normal stress on the reinforcement is induced which is not monitored in the pull-out test. However, in sliding shear test the effect of dilation is reflected in an increased shear stress, which is monitored. Keeping in view the relative movements of soil and reinforcement, it can be suggested that apparent friction coefficient (f^*) should be used in the case of reinforced earth retaining walls, since at the time of pull-out (friction) failure the reinforcement is pulled out from the stationary soil mass i.e. resisting zone (Figure 3b). Similar is the case of footing placed on loose to medium sand reinforced with flexible reinforcement where punching shear
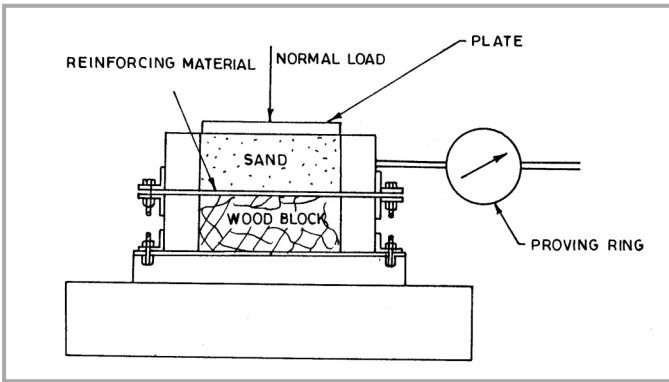
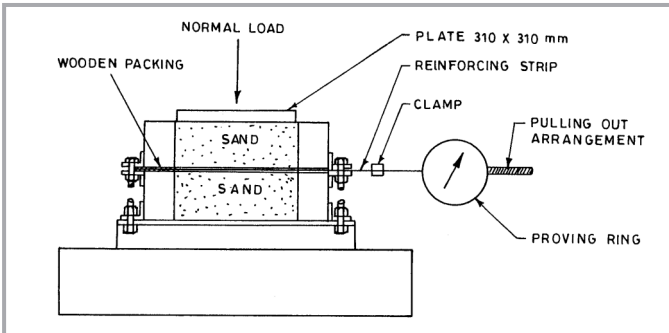*Figure 1a: Modified sliding shear test set-up*

Figure 1b: Pull-out set-up

will occur which will cause pulling-out of reinforcement (Figure 3c). Values obtained from sliding shear tests can be used for designing a footing resting on dense sand reinforced with stiff reinforcement, where soil slides over the reinforcement (Figure 3d). However, in the case of the wall with reinforced backfill, both type of relative movement can take place. In the upper region the reinforcement is pulled out of the soil mass whereas in the lower region soil moves over the reinforcement (Figure 3a).
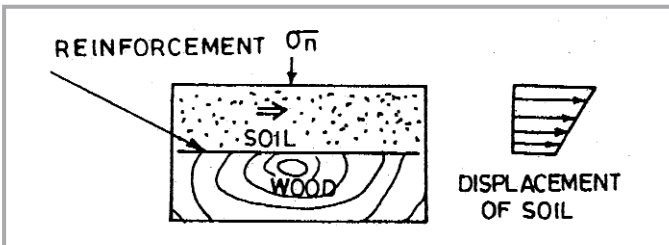
It is not always possible for a field engineer to conduct
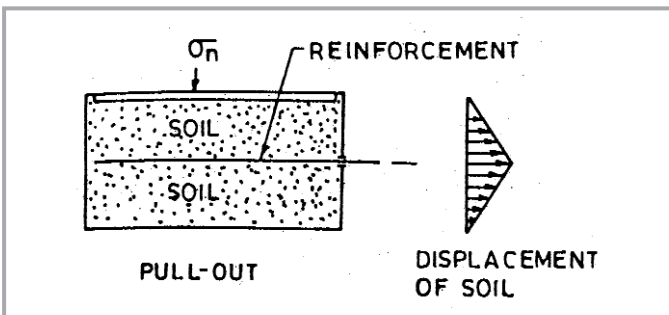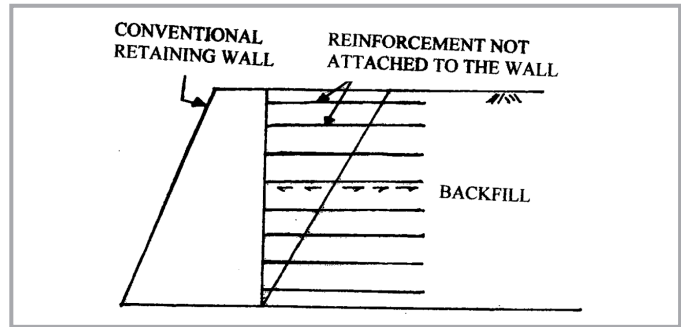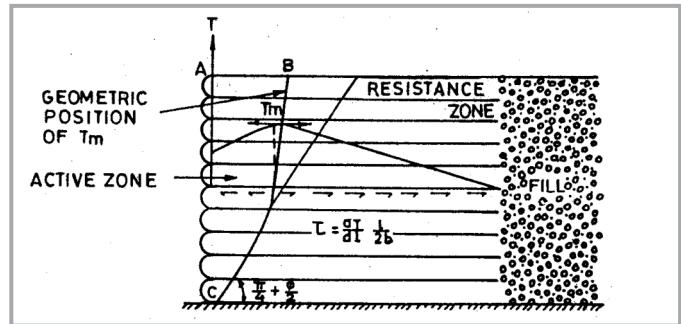

Fig 2a: Sliding shear test
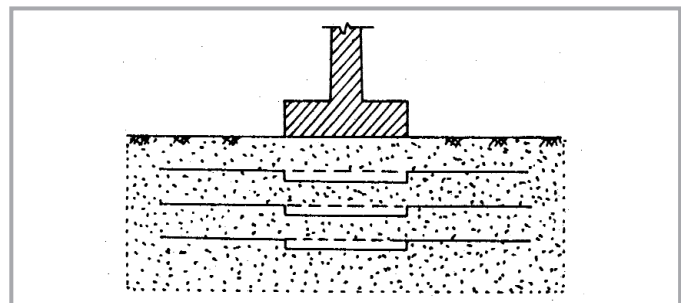

Fig 2b: Pull-out test

Figure 2: Soil Movement in mobilisation of interfacial frictional resistance
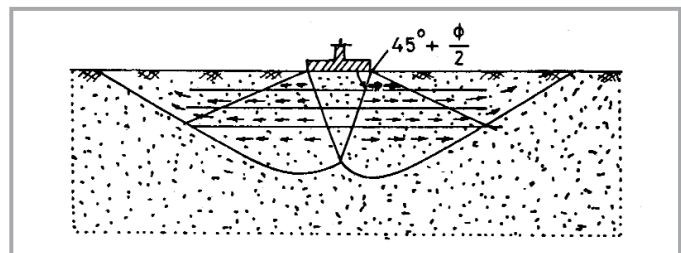

(3a) Wall with reinforced backfill

3(b) Reinforced earth wall

(3c) Pull-out resistance (loose sand)

(3d) Sliding resistance (dense sand)

Figure 3: Schematic diagram showing sliding and pull-out resistance

pull–out tests to design a prototype-reinforced earth retaining structure. However, direct shear test facilities are generally available and sliding shear tests can be performed easily to obtain the value of friction coefficient (μ). In this paper an attempt has been made to establish a correlation between apparent friction coefficient (f*) and friction coefficient (μ) taking into account the important parameters i.e. overburden pressure and length of reinforcement.

2.2 Soil Used

The soil used in the investigation was dry Amanatgarh sand [7]. The physical and mechanical properties of soil used in this experimental study are given in Tables 1 and 2.

Table 1: Physical properties of amanatgarh sand

Sr. No.	Property	Value
1.	Soil type	SP (as per IS-1498:1970)
2.	Effective size, D_{10}	0.185 mm
3.	Uniformity coefficient, C_u	1.30
4.	Coefficient of curvature, C_c	1.04
5.	Mean specific gravity	2.65
6.	Minimum voids ratio	0.533
7.	Maximum voids ratio	0.922

Table 2: Mechanical characteristics of amanatgarh sand

Sr. No.	Density γ (kN/M^3)	Relative density (%)	Angle of internal friction ϕ (obtained from direct shear test) (in degrees)
1.	15.5	55	33°
2.	16.0	60	37°
3.	16.5	81	41°

2.3 Reinforcing Materials

Bamboo strips, Aluminium strips and Nylon Niwar (strips) were used as reinforcing materials for the study. Properties of these materials are given in Table 3 (next page).
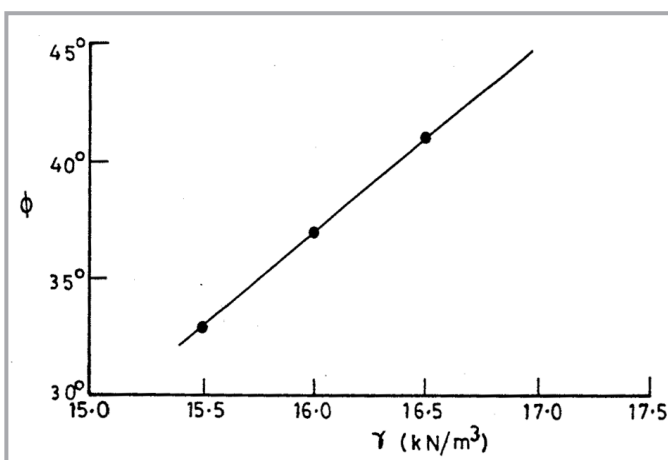
2.4 Sliding Shear Tests

Sliding shear tests were performed to determine the angle of sliding friction (μ) between sand and the reinforcing materials. Tests were carried out in shear boxes of size 60 mm x 60 mm and 315 mm x 315 mm placing sand at densities 15.5 kN/m^3, 16.0 kN/m^3 and 16.5 kN/m^3.

Table 4 gives the details of sliding shear tests performed in this study. For each normal pressure, records were taken for shear strain and the corresponding stress at regular interval. The strain rate was kept as 0.5 mm/min for each normal pressure.

2.5 Pull-Out Tests

Friction coefficient between reinforcement and sand was also determined by conducting pull-out tests in modified shear box of size 315 mm x 315 mm and tanks of size 1.5 m x 1.5 m x 1.5 m high and 3.0 m x 2.4 m x 4.0 m high. Effect of overburden pressure, length, width, and pull-out speed on the friction coefficient was studied. The details of pull-out tests performed in this study are given in Tables 5 and 6.

Figure 4: γ and ϕ relationship

3 RESULTS AND INTERPRETATION:

3.1 Sliding Shear Tests

Figures 5, 6, 7 and 8 show shear stress versus shear strain and shear stress versus normal stress curves for sliding shear tests conducted on 60 mm x 60 mm shear box and Figure 9 on 315 mm x 315 mm shear box. Friction angle was obtained from the peak shear stress corresponding to the applied normal stress. The corresponding results have been summarised in Table 7.

Table 7 shows that the angle of friction increases as the density of sand increases for reinforcement R_1, R_2, and R_3. Further, it is interesting to note that there is significant effect of the direction along which the reinforcement is placed. The value of friction angles for R_1 when placed in transverse direction was found to be more than the angles of internal friction of soil. It is due to more resistance provided by the grains of R_1 material against sliding when its strip is placed in transverse direction.

The results of sliding shear tests performed on bigger shear box i.e. 315 mm x 315 mm showed a similar trend as discussed above. However, the values of friction angles were found lesser than as obtained in smaller box. It may be attributed to the size as in longer strips full friction may not be mobilised simultaneously.

Angle of interfacial friction between the sand and reinforcement was always less than the angle of internal friction of soil, except when the bamboo strip grains were in transverse direction.

3.2 Pull-Out Tests:

Plots between pull-out resistance and displacement of strips were plotted for every normal pressure intensity. Peak of the pull out resistance for the normal stress was chosen from displacement versus pull-out resistance curve to calculate friction coefficient (f*) using the following equation:

$$f^* = \frac{T}{2\sigma.L.w} \tag{1}$$

where,
T = maximum pull–out resistance (N)
σ = Normal pressure intensity at strip level (N/m^2)
L = Length of strip (m)
w = Width of strip (m)

Figures 10a, 10b and 10c show variation of friction coefficient (f*) with overburden stress for reinforcements R_1, R_2 and R_3. Figure 11 shows effect of width on friction coefficient (f*) for reinforcement R_2. Figure 12 shows effect of rate of strain on friction coefficient (f*) for reinforcement R_2. All these tests were carried out in modified shear box of size 315 mm x 315 mm.

Result of the pull-out tests conducted in tank of size 1.5 m x 1.5 m x 1.5 m high on the reinforcement R_1 and R_3 have been shown in Figures 13a to 13d. Figure 14a shows the effects of overburden height on the friction coefficient (f*) studied on 2.8 m long reinforcement R_1 in the bigger tank (size 3.0 m x 2.4 m x 4 m high). Figures 14b and 14c show variation in f* due to change of length of reinforcement R_1 and R_2.

Table 3: Details of reinforcements

Reinforcement	Symbol used	Properties		
		Width (mm)	Thickness (mm)	Rupture strength
1. Bamboo strips	R_1	20 to 30	1.0 to 2.0	12.75×10^4 kN/m^2
2. Aluminium strips	R_2	40	0.3	13.92×10^4 kN/m^2
3. Nylon niwar(strips)	R_3	32	1.41	50N/mm (width)

Table 4: Summary of sliding shear tests

Sr.No.	Reinforcement (Ref. Table-1)	Size of box (mm)	Density (kN/m^3)	Normal pressure range (kN/m^2)
1.	R_1	60 x 60	15.5, 16.0 & 16.5	16 to 104
2.	R_2	60 x 60	15.5, 16.0 & 16.5	16 to 104
3.	R_3	60 x 60	15.5, 16.0 & 16.5	16 to 104
4.	R_1	315 x 315	15.5, 16.0 & 16.5	50 to 225

Table 5: Details of pull-out tests performed on modified shear box (315mm x 315mm)

Reinforcement	Density (kN/m^3)	Strain rate (mm/min)	Pressure intensity (kN/m^2)	Width of strip (mm)	Length of strip (mm)
R_1	16.0	1.853	20 to 200	28	150,200,250,300
R_2	16.0	1.853	20 to 80	150	300
R_2	16.0	1.853	21.8	300,250,200, 150,100,50	300
R_2	16.0	0.7378, 1.3030, 1.8530, 2.4808, 8.4715	21.8	150	300
R_3	16.0	1.853	20 to 200	32	300

Table 6: Details of pull-out tests performed in tanks (1.5m x 1.5m and 3.0m x 2.4m)

Reinforcement	Strain Rate (mm/min)	Tank Size (m)	Density (kN/m^3)	Width of Strip (mm)	Length of Strip (m)	Overburden Height (m)
R_1	1.853	1.5x1.5	16.0	28.0	1.4,1.1,0.8	0.15 to 1.4
R_1	1.853	3.0x2.4	16.0	28.0	0.7 to 2.8	1.65
R_1	1.853	3.0x2.4	16.0	28.0	2.8	1.65 to 4.1
R_2	1.853	3.0x2.4	16.0	40.0	0.25 to 3.0	1.75
R_3	1.853	1.5x1.5	16.0	32.0	1.0	0.2 to 0.9

Table 7: Sliding shear test results

Reinforcement Type	Size of Shear Box (mm)	Density (kN/m^3)			Remarks
		15.5	16.0	16.5	
		Friction angle (degrees)			
R_1	60 x 60	31.0°	34.0°	36.0°	Sheared along longitudinal direction
R_1	60 x 60	38.0°	38.5°	42.0°	Sheared along transverse direction
R_2	60 x 60	23.0°	25.0°	25.5°	
R_3	60 x 60	32.0°	34.0°	36.0°	
R_1	315 x 315	29.5°	31.0°	32.5°	

Figures 10a to 10c and 14d clearly indicate a decrease in friction coefficient f* with increased overburden pressure. However in some cases, for small range of normal pressure, friction coefficient increases and attains the peak values and then decreases with the increase in normal pressure. More scatter was observed in the test data obtained through 1.5m x 1.5m tank. Figures 13a to 13d confirm the above finding.

Figure 11 shows the increase in friction coefficient with decrease in width of reinforcing strips R_2. The decrease is very small and may be ignored for practical applications.

Figure 12 shows an increasing trend in friction coefficient with increasing strain rate. The cause may be attributed to simultaneous mobilisation of friction along the length of the strip at higher strain rate.

Figure 14b shows decrease in friction coefficient (f*) with increasing length of reinforcement R_1 in the bigger tank. Figure 14c shows the results of the same study on reinforcement R_2. It may be concluded that in case of smooth strips the length does not play a significant role and friction coefficient (f*) remains constant. However, friction coefficient for strips smaller than 1.0 m showed an increasing trend with length and become constant (Figure 14c).
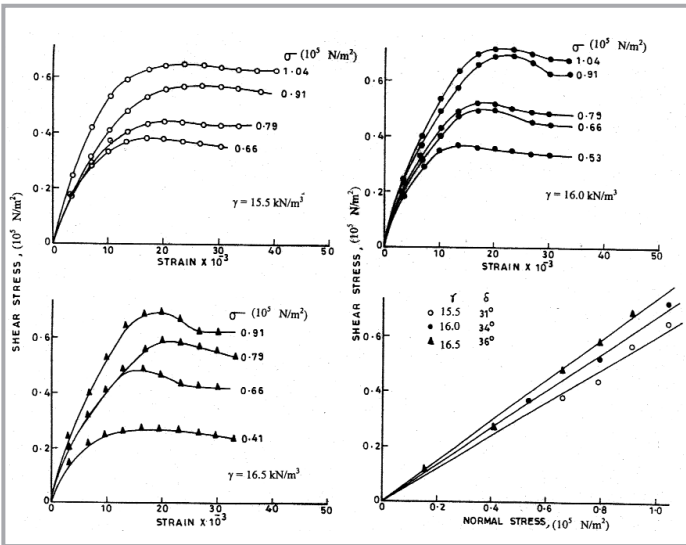
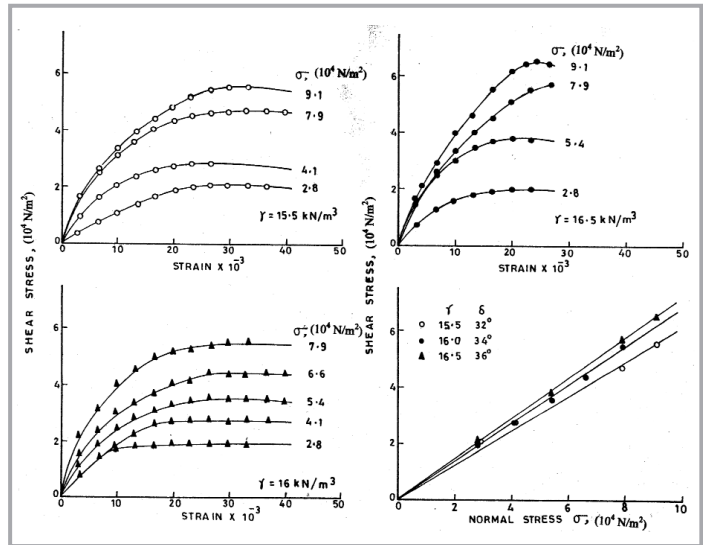*Figure 5: Sliding shear (60 mm × 60 mm box) tests on bamboo strip (along grains)*

Figure 8: Sliding shear (60 mm × 60 mm Box) tests on nylon niwar (strip)
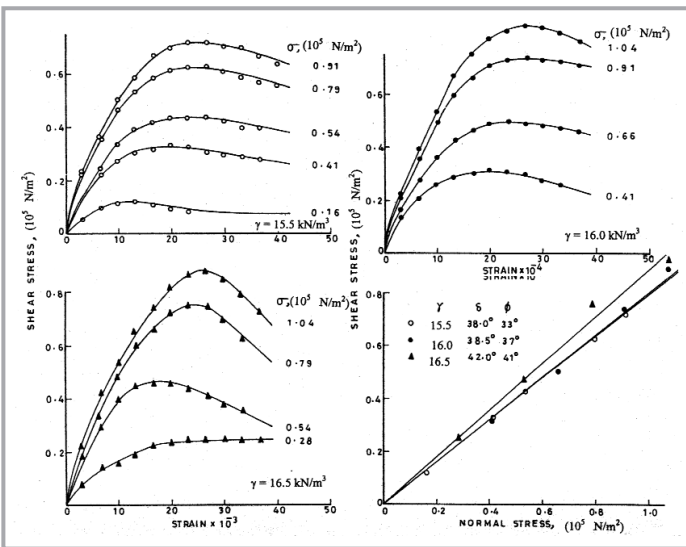

Figure 6: Sliding shear (60 mm × 60 mm box) tests on bamboo strip (transverse direction)
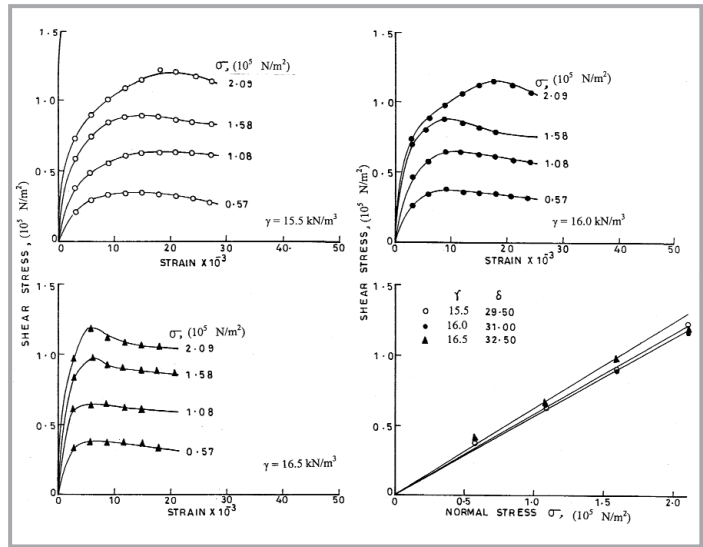

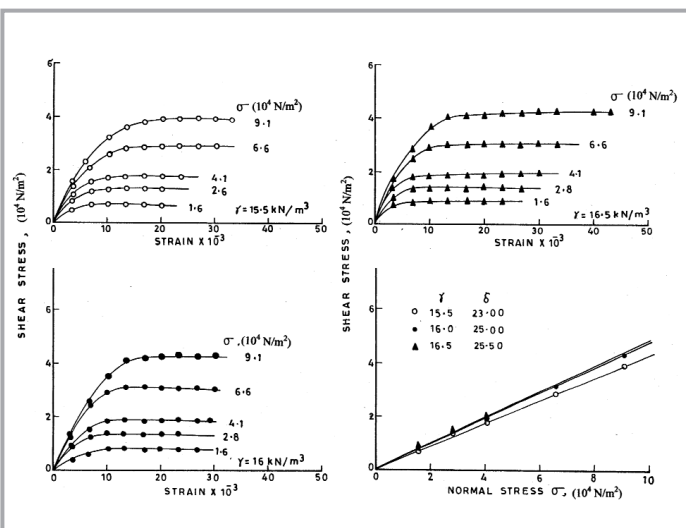*Figure 9: Sliding shear (315 mm × 315 mm box) tests on bamboo strips*

Figure 7: Sliding shear (60 mm × 60 mm box) tests on aluminium strip

4 CORRELATION

It is not always possible for a field engineer to conduct the pull-out test prior to taking up the construction of every prototype structure. However, direct shear test facilities are available everywhere, so sliding shear tests may be conducted to find out friction coefficient (μ) between soil and reinforcement. Keeping this in view an attempt has been made to suggest such an equation, which takes into account the length of reinforcement and overburden pressure. For this purpose, Figures 10a, 10b and 14b were used. This data was plotted in non-dimensional form as shown in Figure 15. Regression analysis was done for the data presented in Figure 15 and the following correlation was obtained:

$$f^* = [1 - 0.00625\,(\sigma - 20)]\,[1 - 0.35\,(L - 1)]\,\mu \qquad (2)$$

where:
f^* = friction coefficient (pull-out)
σ = Normal pressure intensity at strip level (kN/m_)
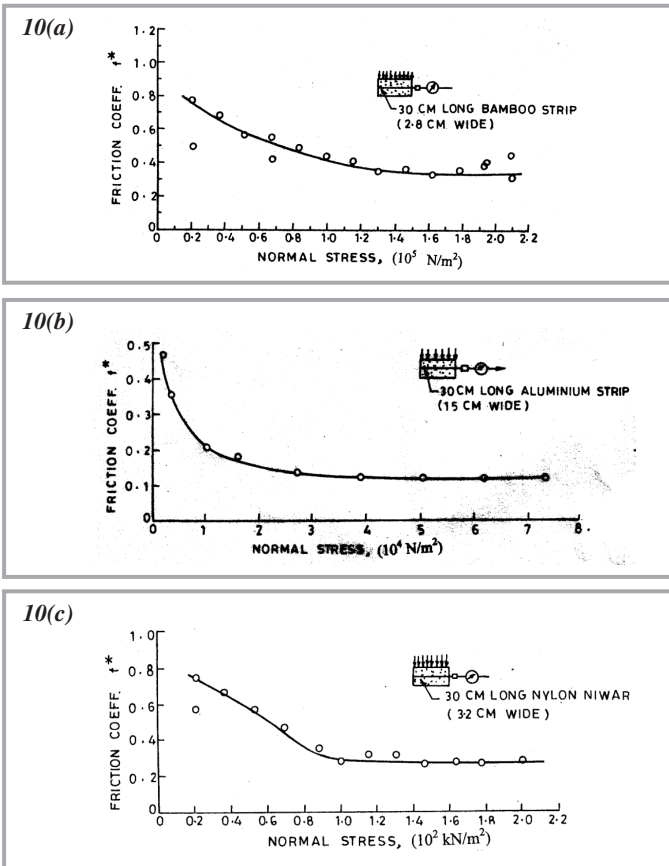
10(a)

10(b)

10(c)

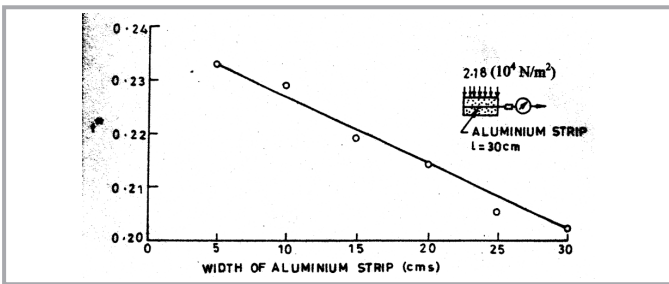**Figure 10: Friction coefficient f* v/s overburden stress**

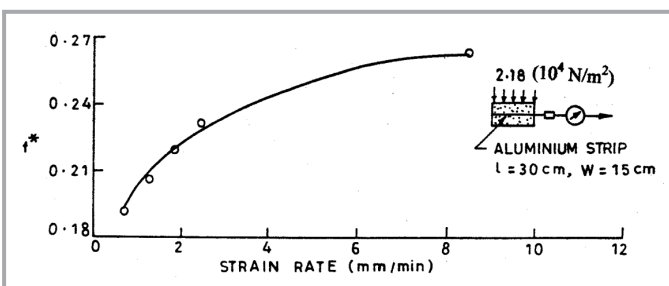**Figure 11: Friction coefficient f* versus width of strip**

Figure 12: Friction coefficient versus strain rate

L = Length of strip (m)
μ = friction coefficient (sliding shear)
The above equation is valid when
   20 (kN/m²) ≤ σ ≤ 100 (kN/m²) and
   1.0 (m) ≤ L ≤ 3.0 (m)

A comparison in values of friction coefficient (f*) obtained from Equation 2 and experimental values of friction coefficient (f*) has been shown in Figures 16a and 16b.

5 CONCLUSION

In this investigation the study has been made to get the interfacial resistance between different reinforcing materials and soil by pull–out tests and sliding shear tests. Bamboo strips, Aluminium strips and Nylon Niwar (strip), were chosen as the reinforcing material and dry sand as soil.

Salient conclusions obtained from this study are as given below:

5.1 Sliding Shear Tests

(i) Angles of interfacial friction (δ) between the sand and reinforcement were less than the corresponding angles of internal friction of soil, except when the bamboo strip grains were in transverse direction.

(ii) Values of angles of interfacial friction (δ) obtained by using large shear box (315 mm x 315 mm) were lesser than as obtained using smaller shear box (60 mm x 60 mm).
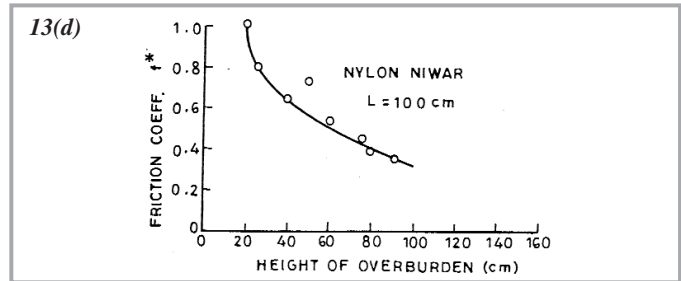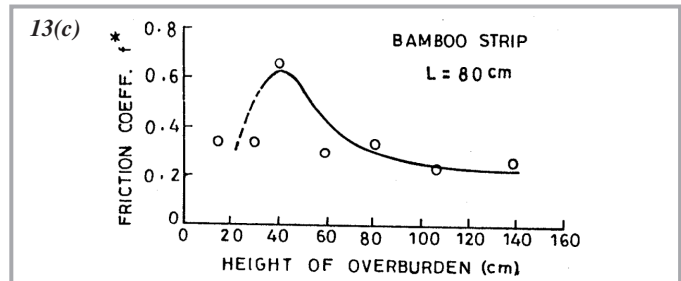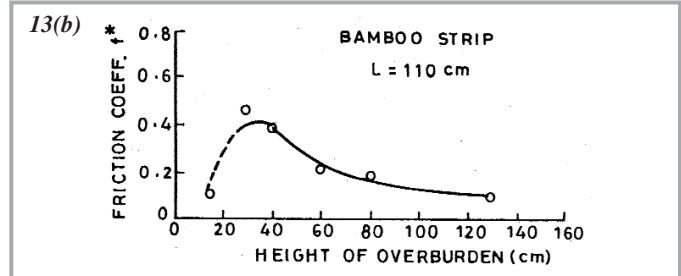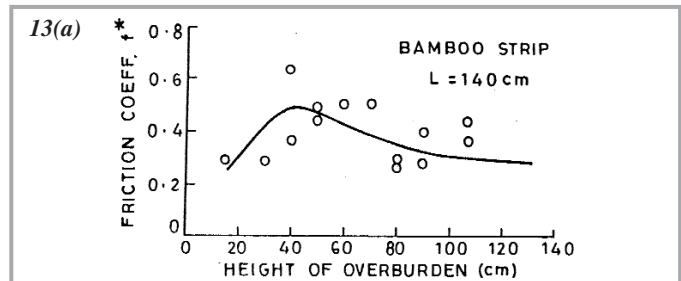

13(a)

13(b)

13(c)

13(d)

Figure 13: Friction coefficient f* versus overburden height (1.5m x 1.5 m tank)
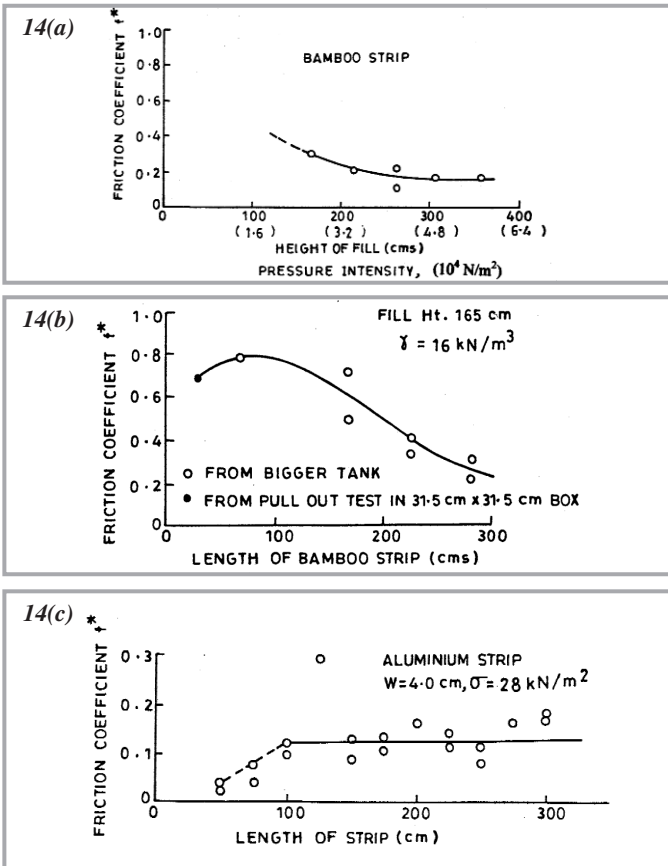
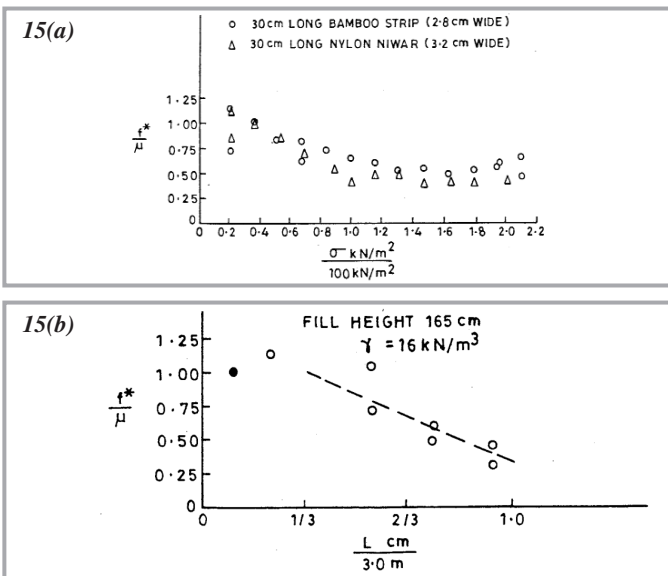Figure 14: Friction coefficient f* obtained in tank (3.0 m × 2.4 m)

Figure 15: Non-dimensional charts for friction, overburden and length relationship

(iii) Angles of interfacial friction (δ) increased with increase in density of soil and surface roughness of the reinforcement.

(iv) Distinct peaks were observed (shear stress- shear strain curves) in case of friction between dense sand and relatively rougher reinforcing material.

5.2 Pull-Out Tests

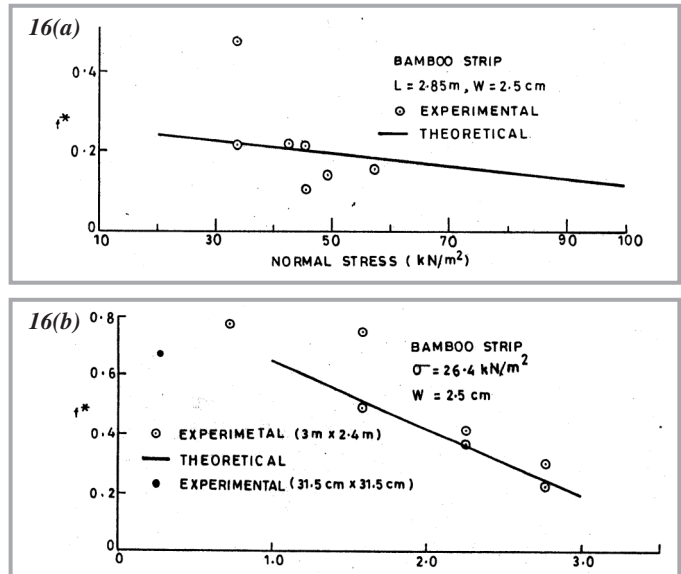(i) Value of apparent coefficient of friction (f*) decreases

Figure 16: Predicted and experimental values of f*

with increase in overburden pressure. It becomes constant at around 100 kN/m^2 overburden pressure.

(ii) Value of apparent coefficient of friction (f*) decrease with increase in width of strips. The decrease is very small and may be ignored for practical applications.

(iii) Value of apparent coefficient of friction (f*) increase initially with length of reinforcement (up to 1.0 m) and then decreases with increase in length of reinforcement and becomes constant when the length is more than 3.0 m.

(iv) Increase in values of apparent coefficient of friction (f*) was observed with increase in strain rate.

The analysis of result of sliding shear and pull-out tests indicated that the values of coefficient of friction μ (μ = tan δ) and apparent coefficient of friction f* are different and should be used carefully. A correlation between apparent coefficient of friction (f*) and coefficient of friction (μ) has been obtained and given below:

f* = [1 - 0.00625 (σ - 20)] [1 - 0.35 (L - 1)] μ

where:
σ = Normal pressure at strip (kN/m^2)
L = Length of strip (m)

The above correlation has been developed based on limited tests, more tests should be conducted on different reinforcements, soils and densities to refine the relationship. ∎

REFERENCES

[1]   Bacot, J.; Itlis, M.; Lareal, P.; Paumier, T. and Sanglert, G.; "Study of the Soil Reinforcement Friction Coefficient", *Proc. Symposium on Earth Reinforcement, ASCE, Pittsburgh*, pp. 157-185, 1978.

[2]   Garg, K.G.; "*Earth Pressure Behind Retaining wall with Reinforced Backfill*", Ph.D. Thesis Department of Civil Engineering., University of Roorkee, Roorkee-247667, India, 1988.

[3]   Mckittrick, D.; "Reinforced Earth Application of Theory and Research to Practice", *Soil Reinforcing and Stabilising Techniques in Engineering Practice, Sydney, Australia*, Oct. 1978, pp. 1-44, 1978.

[4]   Schlosser, F.; "Reinforced Earth", *Note D' Information Technique*, LCPC, France, pp. 1-23, 1976.

[5]   Schlosser, F. and Elias, V.; "Friction in Reinforced Earth", *Proc. Symposium on Earth Reinforcement, ASCE Pittsburg*, pp. 735-761, 1978.

[6]   Talwar, D.V.; "*Behavior of Reinforced Earth in Retaining Structures and Shallow Foundation*", Ph.D. Thesis Deptt. of Civil Engg., University of Roorkee, Roorkee-247667, India, 1981.

[7]   Khan, Iqraz Nabi; "*A Study of Reinforced Earth Wall and Retaining Wall with Reinforced Backfill*", Ph.D. Thesis Department of Civil Engineering., University of Roorkee, Roorkee-247667, India, 1991.

[8]   IS:2720 (Part XIV-1968), *Indian Standard Method of Test for Soils*, Bureau of Indian Standards, Delhi.

[9]   IS1498-1970, *Indian Standard on Soil Classification for General Engineering Purposes*, Bureau of Indian Standards, Delhi.

ANNOUNCEMENT

ASEAN ENGINEERS' ATTACHMENT PROGRAMME IN MALAYSIA

The 20th Conference of the ASEAN Federation of Engineering Organisations (CAFEO) in 2002 concluded with a resolution, which includes:

1) AFEO member institutions to request their respective governments to offer training for engineers of the less developed member countries. The training should target areas that would alleviate poverty.

2) AFEO member institutions to arrange on-the-job industrial training and placements for engineers from less developed member countries.

3) AFEO to establish a common standard for benchmarks on engineering education and the development of professional engineers. The blueprint on benchmarks would improve engineering standards in ASEAN and also facilitate mobility of engineers and engineering services.

In line with this resolution, the following Malaysian companies are offering an attachment programme for qualified engineers particularly those from Cambodia, Laos, Myanmar and Vietnam to spur further cooperation between the countries and the possibility of joint-venture opportunities after completion of the attachment.

Engineers who go through the attachment programme will among other things study the system and gain an opportunity to understand the country and companies' practices. They will also gain knowledge and experience of the structure and system of practice in the engineering field.

PURPOSE OF ATTACHMENT PROGRAMME
Leading towards further cooperation between engineers and/or companies including possible Joint Venture opportunity upon completion of programme.

The companies offering the attachment programme are:

(A) G & P PROFESSIONALS SDN BHD

G & P Professionals Sdn Bhd consists of specialist consulting firms that provide a wide range of quality engineering services, which includes geotechnical, civil & structural, mechanical & electrical, infrastructure, maritime and project management.

The company is offering attachment in the field of geotechnical and structural consultancy experience to qualified candidates.

Qualifications
Candidates must have successfully gone through an engineering programme that is recognised by the ASEAN Engineers Register along with sufficient experience within the field. They must have at least five years' experience (must be recent) in geotechnical or structural engineering consultancy.

The Package
Duration: 3 months (extendable)
Allowance to cover living and transportation expenses of about RM2, 000/month.

Places Offered: Two

More information on G & P Professionals Sdn Bhd can be viewed via: http://www.gnpgroup.com.my

(B) AE CONSULTANT

AE Consultant is a consultancy firm providing Civil & Structural Engineering Services

The Company is offering attachment programme in the field of Structural Consultancy experience to qualified candidates.

Qualifications
Candidates must have a successful engineering programme that is recognised by The ASEAN Engineers Register along with sufficient experience within the Structural Engineering field.

They should have at least 4 years of recent experience in Structural Engineering design works and on site experience, and be able to communicate in English orally and in writing.

The Package
Duration: 3 to 6 month (extendable)
Allowance to cover living expenses and transportation of about RM 2,000/month. Accommodation can be arranged for the successful candidates upon request.

Places Offered: Two

More inquiries please email to *aecsb@po.jaring.my* attention to: Ir. Cheong Chee Kwong.

(C) MULTIMEDIA UNIVERSITY

Qualifications
The Multimedia University, Cyberjaya, Malaysia is offering one full time PhD scholarship to each CLMV country, covering a single return economy air ticket to home country, the tuition fees and a monthly allowance of RM 1,000.00 for accomodation and food. The Scholarship is offered for an initial period of one year, and is renewal upon excellent progress of the candidates until completion of the PhD programme (which normally takes a period of 3 years). The areas of research interest are in electrical and electronic engineering, telecommunications, information technology, robotics and automation, multimedia technologies and biometrics and bio-informatics. The candidates are expected to have a bachelor degree with a first class honours or equivalent; and a good Master's degree.

The Package
Duration: 12 months (but extended to 36 months with excellent progress)

Scholarship coverage: Tuition fees, stipend of RM 1,000.00 per month and single return economy air fare to home country.

Places Offered: One to each CLMV country

HOW TO APPLY?
Interested applicants are welcome to submit their completed official application form from MMU and the application form as attached to the registrar of their respective country for vetting. After vetting, forms of shortlisted candidates will be sent to the respective companies for selection.

The official form for postgraduate studies at MMU can be downloaded from: http://www.mmu.edu.my/~crpp/

More inquiries please email to *sltan@mmu.edu.my* attention to: Dr Tan Sin Leng

HOW TO APPLY?
Interested applicants are welcome to submit their completed official application form to the registrar of their respective country for vetting. After vetting, forms of shortlisted candidates will be sent to the respective companies for selection.