STABILITY OF BASAL REINFORCED (INEXTENSIBLE) EMBANKMENTS ON SOFT GROUND: EFFECT OF OBLIQUE PULL IN REINFORCEMENT.

V.K.Chakravarthi[1], K.Ramu[2], and M.R.Madhav[2]
[1]Associate Professor in Civil Engineering, GMR Institute of Technology, Rajam, AP, India, chakravarthi.vk@gmrit.org
[2]Professor in Civil Engineering, JNT University Kakinada, Kakinada, AP, India, kramujntuk@hotmail.com
[2]Professor (Emeritus) in Civil Engineering, JNT University Hyderabad, Hyderabad, AP, India, madhavmr@gmail.com

ABSTRACT

The design of basal reinforced embankment is usually carried out by considering “short-term” strength for the soft soil, i.e., without considering increase in strength due to consolidation, associated with “long-term” strength for the reinforcement, which includes creep and other reduction factors. The force mobilized in reinforcement is based on the effective length of reinforcement (length in the stable zone) and the bond between the fill and the reinforcement. The tensile force in the geosynthetic layer at the base of the embankment is considered as horizontal and it contributes to the resisting moment. But, for rotational failure, the sliding mass of soil intersects the reinforcement obliquely causing the reinforcement to deform obliquely. The transverse force due to downward pull of reinforcement increases the normal stresses and contributes to additional tensile force in the reinforcement. In this paper, the stability of basal reinforced embankment is analyzed considering the resisting moment developed by the reinforcement due to oblique pull. Parametric study carried presents results for by homogeneous and non-homogeneous ground (c_u increasing with depth), thickness of soft ground, H, modulus of subgrade reaction, $K_{s,}$ and tensile capacity of reinforcement, T.

Keywords: Embankment on soft ground, non-homogeneity, geosynthetic reinforcement, oblique force, stability.

INTRODUCTION

Basal reinforced Embankments on Soft Soils

Provision of basal reinforcement has gained increased acceptance to enhance stability of embankments constructed on soft ground, owing to the mechanism of load spread and the ease of construction. The reinforcement is provided at the interface of fill-ground spreading over the entire width of the base. The functions of this layer of reinforcement are: (*i*) to provide stability through the tensile force mobilized in the reinforcement and (*ii*) to provide confinement to the embankment fill and foundation soil adjacent to reinforcement. The confining effect reduces the lateral movement of the subsoil due to the embankment load, and therefore, the magnitude of the shear stresses in the soft subsoil thus increasing bearing capacity and stability (Jewell 1988). The basal reinforcement resists some or all the lateral pressure within the embankment. Fig.1 explains the mechanism.

Stability of Geosynthetic - Reinforced Embankment on Homogeneous and Non-Homogeneous Soils.

The stability of embankments on soft ground is often studied assuming the ground to be homogeneous. In general soils are non-homogeneous as their strength increases with depth. This non-homogeneous nature of soil effects stability. Often the stability is expressed in terms of collapse height which is numerically equaled to critical factor of safety times the embankment height. The collapse height is dependent on the geometry of embankment, type and thickness of soft soil, drainage conditions, rate of construction of the embankment, strain in and tensile strength of the reinforcement (Rowe et al. 2005).

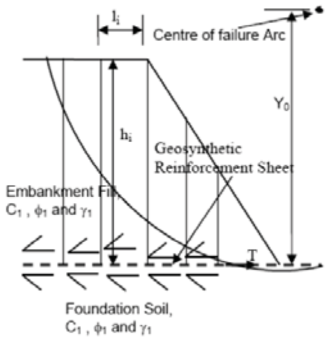


Fig. 1 Mechanics of development of reinforcement force in basal reinforced embankments

FACTORS AFFECTING SOIL REINFORCEMENT INTERACTION RESPONSE

The interaction between fill and reinforcement dictates the strain in the reinforcement, mobilized tensile force and the orientation of tensile force. In most of the methods the interaction at the onset of failure is only considered. The shear stresses developed due to the weight of the failure mass are considered uniform along the reinforcement length and with the tensile force in the reinforcement in the horizontal direction. Several factors such as bilinear shear stress - displacement relation for frictional component mobilization, influence of angle of dilatancy of fill are considered by Wang et al. (2002) and the influence of extensibility of geosynthetics on the soil/backfill-reinforcement interface response is studied the Madhav et al. (1998).

KINEMATICS OF REINFORCEMENT-BACKFILL RESPONSE-OBLIQUE PULL

The sliding mass at failure deflects the reinforcement at the intersection point (Fig. 2) resulting an oblique pull in the reinforcement. Almost all the available design methods incorporate only the axial pull in the reinforcement (Fig. 3). However, in actual case, at failure the reinforcement is subjected oblique pull (Figs. 4 and 5). Under the action of the oblique force or displacement, the soil beneath the reinforcement mobilizes additional normal stresses as the reinforcement deforms transversely. Madhav and Umashanker (2003) developed the governing equations for the analysis considering linear subgrade response. The contribution of oblique pull in the reinforcement is quantified for geosynthetic reinforced embankments and retaining walls (Ramu et al. 2009 and Shahu 2007).

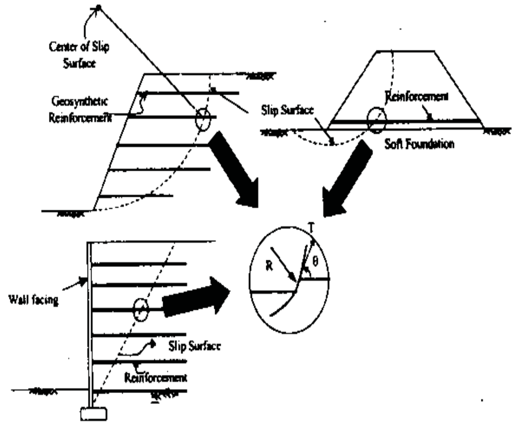


Fig. 2 Kinematics of Reinforcement and Soil Interaction

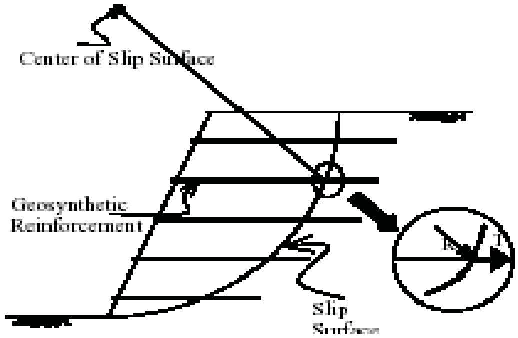


Fig. 3 Horizontal Pullout Force

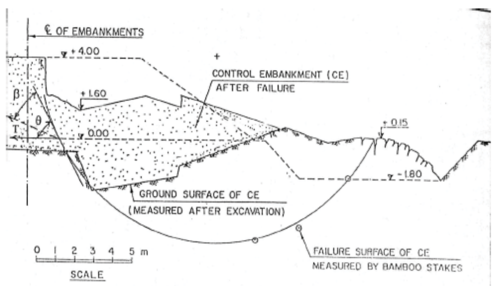


Fig. 4 Cross section of Failed Embankment showing Obliquity of Reinforcement Force (after Bergado et al. 2000)

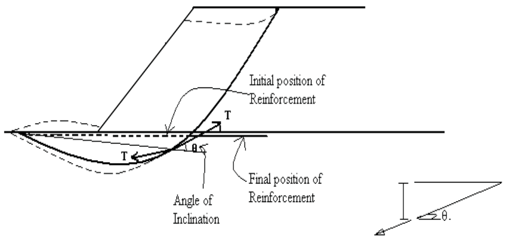


Fig. 5 Basal reinforced embankment with oblique failure (Bergado et al. 2000)

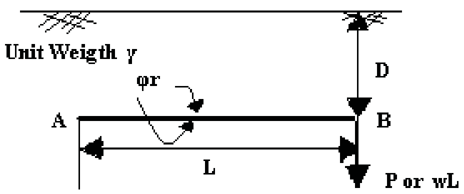
ANALYSIS FOR BASAL REINFORCEMENT - TRANSVERSE PULL

As shown in Fig. 5, the geosynthetic layer, at the intersection with slip surface, deforms at an oblique angle, 'θ'. The vertical component of the force, T, causes transverse displacement, while the horizontal component is the axial pullout. This vertical component of T, acting downward generates the normal reaction from the ground.

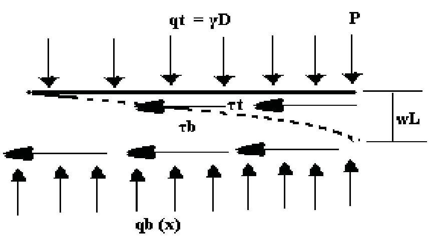
The definition sketch of model developed by Madhav and Umashanker (2003) is given in Figs. 6a and b. The transverse downward force at point, B in the normalized form is

$$P^{\bullet} = \frac{P}{\gamma DL} = \mu \frac{w_o}{L} \frac{1}{n} \left[\frac{W_1 + 1}{2} + \sum_{i=2}^{n} W_i \right] \tag{1}$$

The horizontal component of maximum tension (i.e. the pullout force) in non-dimensional form is



(a)



(b)

Fig. 6 a) Definition Sketch for Transverse Pull and b) Equilibrium of element (Madhav and Umashanker 2003)

$$T^{\bullet}_{\max} \cos\theta_{n+1} = \frac{T_{n+1} \cos\theta_{n+1}}{2\gamma DL \tan\phi_r} = T^{\bullet}_{n+1} \cos\theta_{n+1}$$

(2)

The normalized normal component of maximum tension is

$$T^{\bullet}_{\max} \sin\theta_{n+1} = \frac{T_{n+1} \sin\theta_{n+1}}{\gamma DL} = 2T^{\bullet}_{n+1} \sin\theta_{n+1} \tan\phi_r \tag{3}$$

For various free-end displacement ratios ranging from 0 to 0.01 the tensile force in reinforcement is computed using expressions (2) and (3) above.

COMPUTATION OF FACTORS OF SAFETY WITH TRANSVERSE PULL

For the critical failure circle as in the axial pullout case, transverse force, P, and the additional axial force are computed knowing the geometry of the slip circle, intersection point of the reinforcement with the slip surface, and the effective length of reinforcement, L_e,. Normalized transverse displacements, w_{ol} and transverse force, P, are computed from the Eq.s 1, 2 and 3 for various rotations ranging from 0.001 to 0.01 radians. Additional tensile resistance due to P is obtained as 2Ptan Φ_r. Additional resisting moments due to these forces are computed from the lever arm with respect to the center of the failure surface. The following the notations are used for different factor of safeties along with their ratios in the computations:

F_s*(unreinforced)*, F_{su}= $\dfrac{M_{resisting}}{M_{driving}}$

F_s *(axial)*, F_{sc} = $\dfrac{M_{resisting} + Ty_0}{M_{driving}}$

$$F_{s\text{-addi..}} = \frac{M_{resisting} + Ty_0 + 2\left(\left(P/l_e\right) Tan\varphi_r\right) l_e y_0}{M_{driving}}$$

F_s*(oblique)*=

$$\frac{M_{resisting} + Ty_0 + 2\left(\left(P/l_e\right) Tan\varphi_r\right) l_e y_0 + Px_c}{M_{driving}}$$

where $M_{resisting}$, $M_{driving}$, P, T, l_e y_0, x_c are resisting moment, driving moment, transverse force, tensile capacity of reinforcement, effective length of reinforcement, lever arm of reinforcement w.r.t. centre of slip circle and distance of slip surface cut point with reinforcement from centre. The following ratios of factor of safeties are computed to quantify the effect of oblique pull

$R_{f-axial\,pull}$ $= F_{sc} / F_{su}$
R_{fT} $= F_{s\text{-addi.}} / F_{sc}$
R_{fP} $= F_{s\,oblique.} / F_{sc}$
$R_{f\,oblique}$ $= F_{s\,oblique.} / F_{su}$
R_{fa} $= Fs_{\text{-addi.}} / F_{su}$

PROBLEM STATEMENT

A trapezoidal embankment (Fig. 7) of height, H_e, side slopes n (H): 1(V), top and bottom width are B_t & B_B respectively is considered on non-homogeneous soft clayey soil subgrade whose strength is increasing with depth. The embankment soil properties are cohesion, c_e, angle of internal friction, Φ_e and unit weight γ_e.

The subgrade soil properties are cohesion, c_g, angle of internal friction, φ_g, and unit weight, γ_g. The non homogeneous soil strength at any depth z, is expressed as $c_g(z) = c_g(0)[1+ \alpha z/H_g]$, where, $c_g(0)$, H_g and α are strength at ground level, total thickness of soft ground and non-homogeneity parameter respectively.

Geosynthetic reinforcement of tensile capacity, T is provided at the foundation-fill interface with an embedment of 0.3m in to fill over the entire base of embankment. The soil-reinforcement interface friction or bond resistance is characterized by φ_r. Stability of embankment, unreinforced, reinforced but considering only axial pull and reinforced with oblique pull are carried out and factors of safety, F_s, are computed for different properties of fill, the foundation soil and the ultimate tensile capacity of reinforcement. Bishops simplified method and SlopeW program are used to generate the critical failure circle.

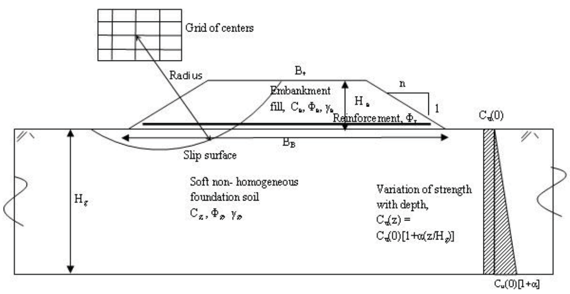


Fig. 7 Definition sketch

The geometry, properties of embankment fill, soft ground and the reinforcement considered in the analysis are given in Tables 1 to 4.

Table 1 Embankment properties for study

Parameter	*Range*
Top width	27 m
Bottom width	39 m
Side slope (1: l)	2:1
Height of embankment, H_e	3.0 m

Table 2 Embankments fill properties for study

Parameter	*Range*
c_e	0 kPa
Φ_e	37^0
Unit weight	18 kN/m^3

Variation of F_s with non-homogeneity parameter, α, for different tensile capacities, T, of reinforcement are shown in Fig. 8. As expected the base shear resistance increases over the length of slip surface with increase in the reinforcement strength, contributing to increased resisting moments. The trend is similar for both unreinforced and reinforced embankments. F_s, increases with the tensile capacity of reinforcement,. For unreinforced embankment (T=0) the factor of safety, F_s increase from 1.06 to 1.42 for non-homogeneity coefficient, α increasing from 0 to 2 kPa/m. For reinforced embankments the factor of safety increases from 1.14 to 1.65, from

Table 3 Foundation soil properties for study

Parameter	*Range*
Thickness H	15m
c_g (0)	10 kPa
Φ	0
Unit weight	17 kN/m^3
Non-homogeneity	c_g (z)= c_g (0)(1+ αz/H), where α, is the non homogeneity parameter, varied as 0, 0.5, 1, 1.5, 2
Modulus of subgrade reaction K_s	5000 ,10000 and 15,000 kN/m^3

Table 4 Reinforcement details

Location of reinforcement	At interface of fill to ground, with an embedment of 0.3m
Length	over entire base width
Tensile capacity, T	50,100,150 kN/m
Transfer efficiency of interface friction Φ_r/ Φ	0.8

RESULTS AND DISCUSSIONS

Variation of Factor of Safety, F_s, with Non-Homogeneity Parameter, α, and Tensile Capacity of Reinforcement, T:

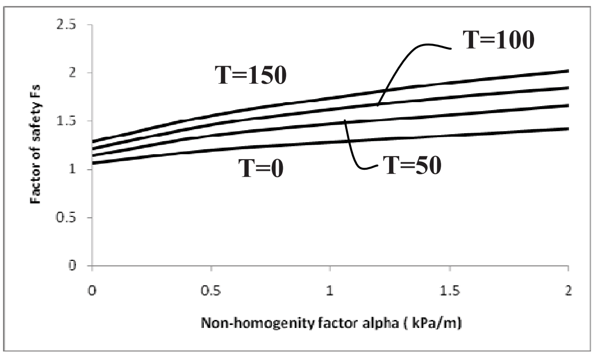


Fig. 8 Variation of F_s with α, effect of tensile capacity of reinforcement T

Variation of F_s with non-homogeneity parameter, α, for different tensile capacities, T, of reinforcement are shown in Fig. 8. As expected the base shear resistance increases over the length of slip surface with increase in the reinforcement strength, contributing to increased resisting moments. The trend is similar for both unreinforced and reinforced embankments. F_s, increases with the tensile capacity of reinforcement,. For unreinforced embankment (T=0) the factor of safety, F_s increase from 1.06 to 1.42 for non-homogeneity coefficient, α increasing from 0 to 2 kPa/m. For reinforced embankments the factor of safety increases from 1.14 to 1.65, from 1.21 to1.84 and from 1.28 to 2.01 respectively for tensile strengths of the reinforcement, T = 50, 100 and 150 kN/m for increase in non-homogeneity coefficient, α from 0 to 2 kPa/m.

Variation of R_f–Axial Pull with Non-Homogeneity - effect of T:

Variation of R_f with non-homogeneity coefficient, α, is shown in Fig. 9. R_f increases non-linearly with, α, varying from 0 to 2 kPa/m. Similar trend is visible for all T values. In homogeneous ground, $R_{f\text{-axial pull}}$ increases from 1.07 to 1.20 with T varied from 50 to 150 kN/m. R_f increases from 1.12 to 1.16, 1.21 to 1.29 and 1.3 to 1.42 respectively for 'T' equal to 50, 100 and 150 kN as non-homogeneity coefficient, α, increases from 0.5 to 2.0 kPa/m.

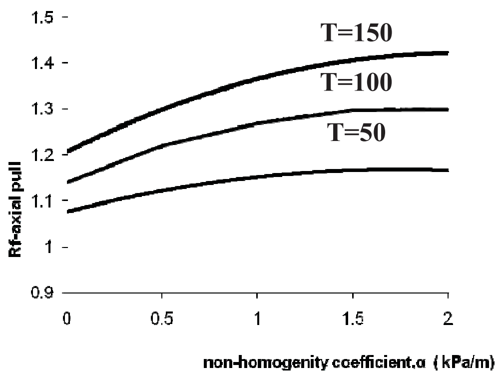


Fig. 9 Variation of F_s ratio $R_{f\text{-axial pull}}$ – effect of T

Variations of R_{fp}' R_{fa}', R_{fT} and $R_{foblique}$ with Rotation in Oblique Pull:

Variations of R_{fp}, R_{fa}', R_{fT}, and $R_{foblique}$ with rotational displacement for non-homogeneous coefficient α, of 0.5, are presented in Fig. 10. R_{fp}, R_{fa}', R_{fT}, and $R_{foblique}$ increase with rotation. The moments due to transverse pull and the additional tensile force about the center contribute to increased stability for rotation increasing from 0.001 to 0.01 rad. $R_{foblique}$ increases from 1.12 to 2.61, R_{fp} from 1.00 to 2.32, R_{fa} from 1.12 to 1.79 and R_{fT} from 1.00 to 1.5975 with rotation increasing from 0 to 0.001 radian. Similar trend is observed for all α.

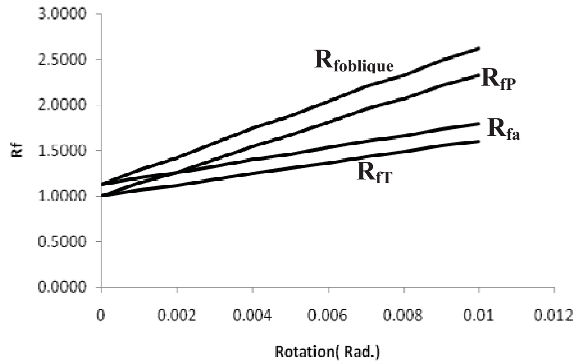


Fig. 10 Variation of R_{fp}' R_{fa}', R_{fT}, $R_{foblique}$ with rotation for T =50, α=0.5, K_s =5000

Variation of transverse force P with Coefficient of Subgrade Modulus K_s:

Variation of transverse force P with coefficient of subgrade modulus K_s for a non-homogeneous coefficient α, 1.0 is discussed in Fig. 11. From the figure it is seen that the subgrade modulus, K_s, has influence on P. Stiffer ground offers more resistance to downward pull/displacement of reinforcement, i.e., P increases with K_s.. The transverse pull, P, increases with rotation. P increases from 28 to 273 kN, 56 to 546 kN and 92.1 to 891 as K_s increase from 5,000 to 15,000.

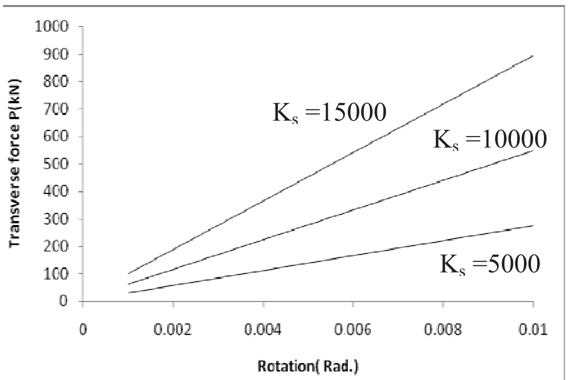


Fig. 11 Variation of transverse force, P, with rotation, θ, for α = 1.0 - effect of K_s

Variation of $R_{f\,oblique}$ with Coefficient of Subgrade Modulus K_s:

Variation of $R_{f,oblique}$ with coefficient of subgrade modulus K_s for a non-homogeneous coefficient α, 2.0 is shown in Fig. 12. The variation is similar to the effect on the transverse pull P as explained in section *6.4*. $R_{foblique}$ increase from 1.29 to 2.64, 1.41 to 4.11 and 1.53 to 5.58 respectively with K_s, varying from 5,000 to 15,000 kN/cu.m. due to increase of P, resulting in increase of resisting moments.

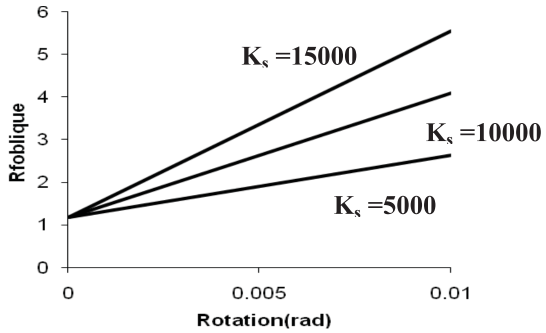


Fig. 12 Variation of F_s ratio $R_{foblique}$ with rotation for alpha=2.0, effect of K_s

CONCLUSIONS

From the studies carried out on basal reinforced embankment the following conclusions are made.

i) The stability of unreinforced and reinforced embankment is greatly influenced by the non-homogeneity of the ground whose strength increases with depth.

ii) The significance of non-homogeneity is pronounced in stability of reinforced embankments. An increase of up to 120% resulted due to non- homogeneity.

iii) The oblique pull induced in the reinforcement if considered for studies greatly benefits in constructing higher embankments due to added stability. The oblique pull approach is observed as superior over conventional ones since it involves the actual mechanics. An increase of 1.12 times to that with conventional method at low rotations is observed. At larger rotations stability is enhanced up to 4 times.

iv) Stability is more pronounced for embankments on stiffer grounds, due higher resistance offered from subgrade, for a given transverse deformation in the reinforcement. While the contribution of additional tensile force on stability is significant, the effect is more pronounced with consideration of transverse pull.

REFERENCES

Bergado, D.T., Teerawattanasuk, C. and Long, P.V. (2000). Localized mobilization of reinforcement force and Its direction in the vicinity of failure surface. Geotextiles and Geomembranes, 18: 311-331.

Jewell, R. A. (1988). The mechanics of reinforced embankments on soft soils. Geotextiles and Geomembranes, 7: 237–273.

Madhav, M.R., Gurung, N. and Iwao, Y. (1998). A Theoretical model for pullout response of extensible reinforcements. Geosynthetics International, 5(4): 399-424.

Madhav, M.R. and Umashankar, B. (2003). Analysis of inextensible sheet reinforcement subjected to transverse displacement/force: linear sub grade response. Geotextiles and Geomembranes, 21: 69-84.

Ramu, K., Madhav, M.R., Chakravarthi, V.K. (2009). Stability of basal reinforced embankment on soft foundation soil considering oblique pull. Proc. of 2nd Intl. Conf. on Long Term Behavior of Dams, Graz, Austria: 258-263.

Rowe, R. K. and Li, L. L. (2005). Geosynthetic-reinforced embankments over soft foundations. Geosynthetics International, Special Issue on the Giroud Lecture, 12(1): 50–85.

Shahu, J.T. (2007). Pullout response of inextensible sheet reinforcement subject to oblique end force. Journal of Geotechnical and Geoenvironmental Engineering, 133(11): 1440-1448.

Wang, Z. and Richwien, W. (2002). A Study of soil-reinforcement interface friction. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 128(1): 92-94.