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Cohesive-frictional backfill used in reinforced earth-wall for Seismic analysis

M.C. Venkatasubbaiah[1,2], G.V Narasimha Reddy[1]

[1]Department of Civil Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana, India. [2]Department of Civil Engineering, KSRM College of Engineering, Kadapa, AP, India-506005

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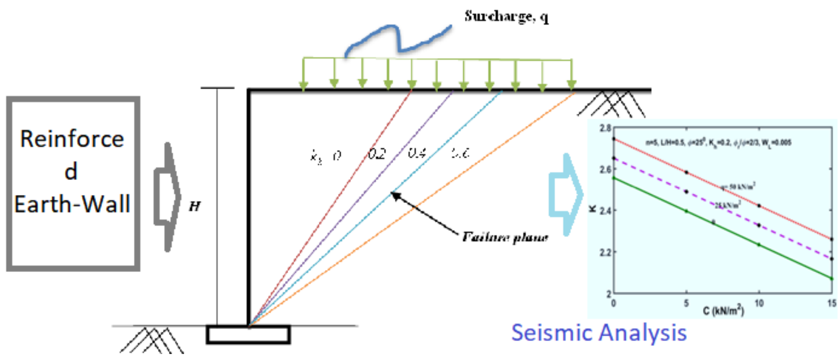
ABSTRACT



A reliable technique based on limit equilibrium for a failure wedge of a reinforced vertical wall with cohesive-frictional backfill which undergoes a seismic acceleration pertains to the pseudo-static assessment has been reported in this work. The procedure is aimed to assess the inextensible reinforcement which is undergoing oblique pullout by considering the effect of modest cohesion and surcharge. The oblique pull under seismic stress usually has ramifications for various parameters such as reinforcing strength (k), sliding wedge size (L/H), and safety factor (F_{ST}). It is observed that the stability of the Reinforced earth (RE) wall has improved by increasing the angle of internal friction of the soil. The factor of safety is greater in the static situation than in the dynamic case and there is less difference in cohesiveness as kh increases. Inextensible sheet reinforcement of the normalized displacement is proportional to the transverse force, because the angle of shear and the cohesion (c) increases with in Factor of safety (F_{ST}) due to the shear/bond resistance.

Keywords: RE wall, Horizontal Slice procedure, c- ϕ soil backfill, Surcharge, Factor of safety (FST).

INTRODUCTION

In an earthquake zone the unstable soil may lead to catastrophic destruction as a consequence of seismic acceleration. Moreover, lateral displacement of soil wedge due to loss of shear strength throughout an earth movement can be reason for the massive-scale damage. Over the decades, the seismic stability of unreinforced system has become popular due to its advantage over the performance of ordinary retaining walls.[1,2] A pseudo-static approach is considered for solving the unreinforced wall with the effect of uniform surcharge. At underneath low seismic coefficient, the failure occurs with higher failure perspective in horizontal surface without surcharge. The vertical and horizontal seismic coefficients inside the geo-synthetic Reinforced earth (RE) wall for given strength and length of reinforcement layer have been evaluated[3,4] by assuming a bilinear failure plane and with the help of Horizontal slice method (HSM), earlier reports have evaluated the most tensile load required inside the soil wall with vertical and horizontal seismic outcomes. A new method have been reported to decide active earth thrust of cohesive-frictional soil and the report concluded that the failure perspective with horizontal surface is linearly proportional to cohesion of soil.[1] It has been confirmed that an impact of transverse displacement in a pseudo-static method by using the horizontal slice technique and the Parametric solutions given by considering the effect of wall geometry, reinforcement parameters and backfill on the factor of safety (FST) increased with tensile reinforcement due to bond resistance.[5]

The shear characteristics of cohesive-frictional soil with geosynthetics have been investigated by different researchers.[3,6] In particular, geo-grid and nonwoven geotextiles have been proved to be sufficient tensile strength to increase the strength of cohesive soils.[7–9] The variation of earth pressure for c- ϕ backfill by the depth of wall has to be nonlinear, but the angle failure surface with horizontal increases linearly with the increase of cohesive backfill strength.[10] Based on this study, the effect of RE wall without surcharge when compared with surcharge and cohesion of backfill

* M.C. Venkatasubbaiah, Department of Civil Engineering, KSRM College of Engineering, Kadapa, AP, India-506005
Tel: +91 9985855672
Email: mcvs@ksrmce.ac.in

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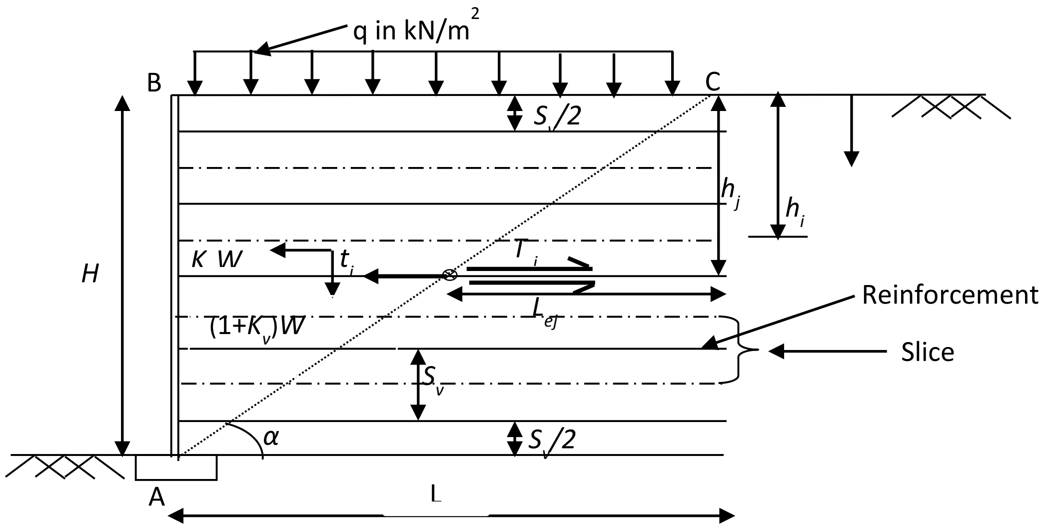

Figure 1. Geometrical characteristics of the RE Wall

is proportional to the stability of RE soil wall. The internal stability of geosynthetic RE wall is meant for the determination of strength of inextensible sheet reinforcement, L/H ratio and FST due to oblique pull/displacement of reinforcement.[5,11]

The present study assumes that the vertical RE wall with homogeneous cohesive-frictional backfill and the failure surface is linear passes through the claw and stand responsible for the inextensible sheet reinforcement at centre of each slice. The reinforcement strength is considered always same as the earth pressure. The availability of facing elements are neglected in this study. There are limited studies are available for RE soil walls with the effect of cohesion and surcharge of backfill under seismic effect. This study also considered the parameters such as the impact of vertical (k_v) and horizontal (k_h) accelerations, friction angle (ϕ), angle of shearing resistance between soil-reinforcement interface (ϕ_r) dimension of failure edge (L/H) number of inextensible sheet reinforcement (n), particularly the effect of surcharge and cohesion to evaluate the internal stability of reinforced soil wall.

Methodology

The geometrical structure of the RE wall is shown in figure 1 having reinforced retaining wall of height (H), supported by horizontal cohesive backfill (c) with uniform surcharge (q), embedded with inextensible sheet reinforcement of length (L), the backfill soil of unit weight (γ), angle of internal friction (ϕ) and angle of internal friction of backfill soil with reinforcement (ϕ_r). Sheet reinforcements in the form of 'n' numbers are used to strengthen the backfill soil. The effective length of reinforcement of j^{th} layer of the reinforcement. The length of reinforcement after the failure surface in the backfill is given as

$L_{ej} = L - (H - h_j)cot\alpha$ and

The active length of reinforcement is

$L_a = L - L_{ej}$

The length of reinforcement (L_a) is present in the active failure wedge. Because of this the spacing between the top and bottom layers is $S_v/2$, and the rest of the layers have the same spacing as the top and bottom layers. Inter-slice shear (H_i) was assumed to be a constant fraction of overall shear strength by Ahmadabadi and Ghanbari (2009),[10] and the coefficient of shear strength at yield condition for each slice is given by

$$H_i = V_i\ tan\phi + c$$

The underlying assumptions of this study are outlined below:

1. The vertical stress acting on each horizontal slice is assumed to be overburden pressure given by

   $V_i = q.L_a + \gamma h_i$ (For the vertical wall)
2. The method is applicable to homogeneous cohesive frictional soils.
3. The factor of safety is the same for all slices.
4. The length of failure i^{th} slice is $b_i = \frac{h.i}{n.sin\propto}$

Figure 2 depicts the forces acting on a single horizontal slice stabilizing with inextensible sheet reinforcement. For stabilizing the reinforced vertical soil wall, the instability of backfill soil is opposed by the reinforcement tension. Since each horizontal slice in the backfill has the same height. Maintaining wall stability by meeting both vertical and horizontal equilibrium equations for each slice and for the whole sliding wedge soil mass, the tensile forces created by the reinforcing. The analysis is carried out by considered that the shear resistance is mobilized fully along soil-sheet interfaces and linear backfill response to transverse displacement of reinforcement. As a result of a large number laboratory centrifuge tests and shake table on models of reinforced slopes, observed that the most frequently identified failure plan is during seismic condition is a log-spiral failure surface, which degenerates into a planar failure for steep reinforced slopes.[12] A planar failure plane is assumed in this analysis. Hence, the critical failure surface (Figure 3) assumed independent of the provision of reinforcement and inclined at an angle of α with respect to horizontal is considered.[5]

A precise solution requires satisfying both vertical, horizontal and the moment equilibrium equations for the individual slices and for the whole of the sliding mass. The simplified formulation is only if the vertical equilibrium of individual slices is considered together with overall horizontal equilibrium for the overall failure wedge.[4]

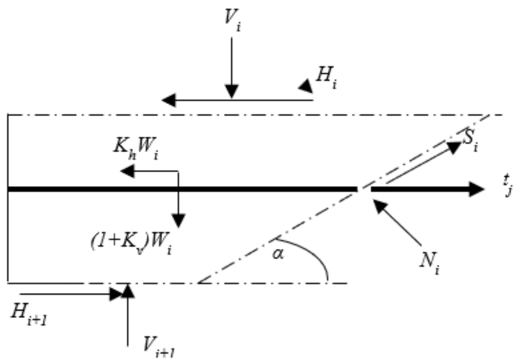

Figure 2. Forces acting on a Horizontal Slice Subjected to Seismic Forces and mobilized Transverse Force.

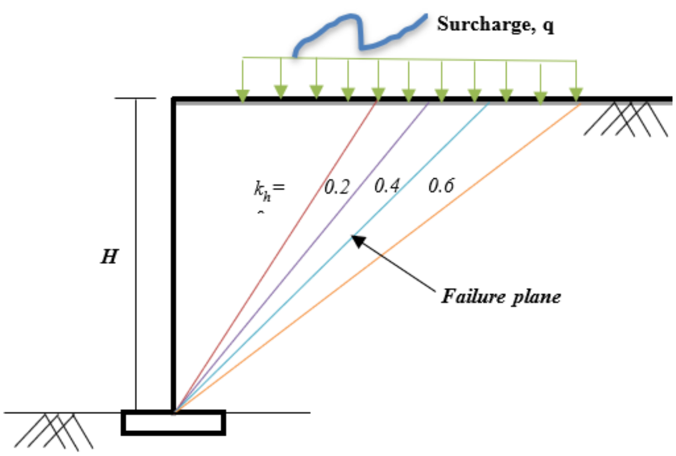

Figure 3. Effect of seismic coefficient on inclination of failure plane.

The equation for the vertical force equilibrium for the ith slice is

$$\sum F_y = 0;$$

$$V_{i+1} - V_i - [1+k_v]W_i + S_i sin \propto + N_i cos \propto = 0 \qquad (1)$$

Where V_i is Vertical inter slice forces, k_v is vertical seismic coefficient, N_i is normal force acting on base, and W_i is angle between failure plane (failure plane) and horizontal.

When the transverse force is deployed the shear force at the base of each slice (*Si*) is given by

$$S_i = \frac{Cb_i + N_i tan\phi}{FS_{sr}} \qquad (2)$$

Where $b_i = \frac{h.i}{nsin\alpha}$

Substituting for S_i from Equation (2) in Equation (1) and solving for the normal force (N_i), once get

$$N_i = \frac{V_i - V_{i+1} + (1+k_v)W_i - \frac{C.b_i sin\alpha}{FS_{sr}}}{\frac{tan\emptyset}{FS_{sr}}.sin\propto + cos\propto} \qquad (3)$$

The tensile force generated in any reinforcing element is determined by considering horizontal force equilibrium of the whole sliding mass.

$$\sum F_x = 0$$

$$\sum_{j=1}^{m} \bar{t}_j = \sum_{i=1}^{n} \bar{N}_i \, sin \propto - \sum_{i=1}^{n} \bar{S}_i cos \propto + \sum_{i=1}^{n} \bar{W}_i K_h + \bar{H}_i - \bar{H}_{i+1} \qquad (4)$$

Calculated using Equation (4) which takes into account the mobilised transverse force, sums the tensile forces generated in the reinforced soil wall, we get

$$N_i sin \propto = \left[\frac{sin \propto . FS_{sr}}{tan\,\phi\,.\,sin \propto + FS_{sr}.\,cos \propto}\right][1+k_v]\gamma h_i l_i - [1+k_v]\gamma h_{i+1} l_{i+1} + [1+k_v]\frac{\gamma H}{2n}[l_i + l_{i+1}] - \frac{cH}{n}$$

$$S_i \, cos \propto = \left[\frac{tan\,\emptyset.\,cos \propto}{tan\,\phi\,.\,sin \propto + FS_{sr}.\,cos \propto}\right][1+k_v]\gamma h_i l_i - [1+k_v]\gamma h_{i+1} l_{i+1} + [1+k_v]\frac{\gamma H}{2n}[l_i + l_{i+1}] - \frac{cH}{n\,sin \propto}.\,cot\,\phi\,.\,cos \propto$$

$$W_i K_h = \frac{\gamma H}{n}\left[\frac{l_i + l_{i+1}}{2}\right] K_h$$

$$\sum_{j=1}^{m} \bar{T}_{Tj} = \left[\frac{tan\emptyset_r}{n}\left[\frac{L}{H}\right] - \frac{tan\emptyset_r}{n} tan[90-\propto]\right] \sum_{j=1}^{m}[2+P_j^*]\left[j-\frac{1}{2}\right] + \left[\frac{2\,tan\emptyset_r}{n^2} tan[90-\propto]\right] \sum_{j=1}^{m}[2+P_j^*]\left[j-\frac{1}{2}\right]^2 \qquad (5)$$

Table: 1 Soil properties has been considered

Terms	Description	Values	Unit
γ	backfill Unit weight	18	*kN/m^3*
H	Vertical reinforced wall	5	*m*
L/H	Normalized length of reinforcement	0.5	Dimensionless
m	Number of reinforcement layers	5	
n	Number of horizontal slices	5	
μ	Stiffness of backfill	50, 200, 2000, 5000, 10000	
W_L	Normalized displacement	0.001, 0.0025, 0.0005, 0.0075, 0.01	Dimensionless
ϕ	Angle of shearing resistance	20, 25, 30	Degree
ϕ_r/ϕ	Normalized angle of interface friction	2/3	Dimensionless
k_h	seismic coefficient at horizontal	0.0, 0.2, 0.4, 0.6, 0.8 and 1.0	Dimensionless
k_v/k_h	Normalized seismic coefficient	0.5	Dimensionless
c	Cohesion	0, 5, 10, 15	*(kN/m^2)*
q	Surcharge load	0, 25, 50	*(kN/m^2)*

$$\sum_{j=1}^{m}\bar{P}_j = \left[\frac{1}{n}\left[\frac{L}{H}\right] - \frac{1}{n}\tan[90-\propto]\right]\sum_{j=1}^{m}P_j^*\left[j-\frac{1}{2}\right] + \left[\frac{1}{n^2}\tan[90-\propto]\right]\sum_{j=1}^{m}P^*_j\left[j-\frac{1}{2}\right]^2 \quad (6)$$

$$\sum_{i=1}^{n}\bar{N}_i\sin\propto = \sum_{i=1}^{n}\left[\frac{\sin\propto.FS_{sr}[1+k_v]}{\tan\emptyset.\sin\propto + FS_{sr}.\cos\propto}\right]\left[\bar{H}_i\bar{L}_i - \bar{H}_{i+1}\bar{L}_{i+1} + \frac{1}{2n}[\bar{L}_i+\bar{L}_{i+1}] - \frac{\bar{C}}{n}\right] - \sum_{j=1}^{m}\bar{P}_j\left[\frac{\sin\propto.FS_{sr}}{\tan\emptyset.\sin\propto + FS_{sr}.\cos\propto}\right]$$

$$\sum_{i=1}^{n}\bar{S}_i\cos\propto = \sum_{i=1}^{n}\left[\frac{\tan\emptyset.\cos\propto[1+k_v]}{\tan\emptyset.\sin\propto + FS_{sr}.\cos\propto}\right]\left[\bar{H}_i\bar{L}_i - \bar{H}_{i+1}\bar{L}_{i+1} + \frac{1}{2n}[\bar{L}_i+\bar{L}_{i+1}] - \frac{\bar{c}}{n}\cot\emptyset.\cot\propto\right] - \sum_{j=1}^{m}\bar{P}_j\left[\frac{\tan\emptyset.\cos\propto}{\tan\emptyset.\sin\propto + FS_{sr}.\cos\propto}\right]$$

$$\sum_{i=1}^{n}\bar{W}_iK_h = \sum_{i=1}^{n}\frac{k_h}{2n}[\bar{L}_i+\bar{L}_{i+1}]$$

The inextensible reinforcement normalized to a parameter k [dimensionless] which is equivalent to the earth pressure coefficient.

$$k = \frac{\sum_{i=1}^{n}\bar{\bar{t}}_j}{0.5\gamma H^2}$$

$$P^* = \mu_j\frac{W_L}{L_{ej}}\frac{1}{n_e}\left[\frac{W_{i+1}}{2} + \sum_{k=2}^{n}W_k\right] \quad (7)$$

$$W_k = \frac{T_i^* n_e^2[W_{k-1}+W_{k+1}]}{\left[2n_e^2T_k^* + \frac{\mu_j}{2\tan\emptyset_r}\right]} \quad (8)$$

$$T_{k+1}^{\;*} = \frac{1}{2n_e}\left[\mu_j W_k\frac{W_L}{L_{ej}} + 2\right] + T_k^{\;*} \quad (9)$$

Where n_e is the number of sub-elements into which inextensible reinforcement is divided, W_k and T_k^* are the normalized displacement and normalised tension at node k. Based on Equation (7) the normalized transverse force P^* for a single sheet reinforcement assuming linear backfill response utilizing local factors μ_j and w_L/L_{ej} are expressed as follows.

$$\mu_j = \mu\frac{\left[{L_{ej}}/{L}\right]}{\left[{h_j}/{H}\right]} \quad (10)$$

$$\frac{w_L}{L_{ej}} = \frac{w_L}{L}\frac{1}{\left[{L_{ej}}/{L}\right]} \quad (11)$$

The normalised transverse force for each layer of reinforcement is taking into account to the linear backfill response is calculated using Equation (7) and the local relative stiffness factor and normalised displacement from Equations (10) and (11). From Equations (4) and (5) the factor of safety (FS_T) considering increases in tension due transverse displacement is obtained as

$$FS_T = \frac{\sum_{j=1}^{m}\bar{T}_{Tj}}{\sum_{j=1}^{m}\bar{t}_{pj}} \quad (12)$$

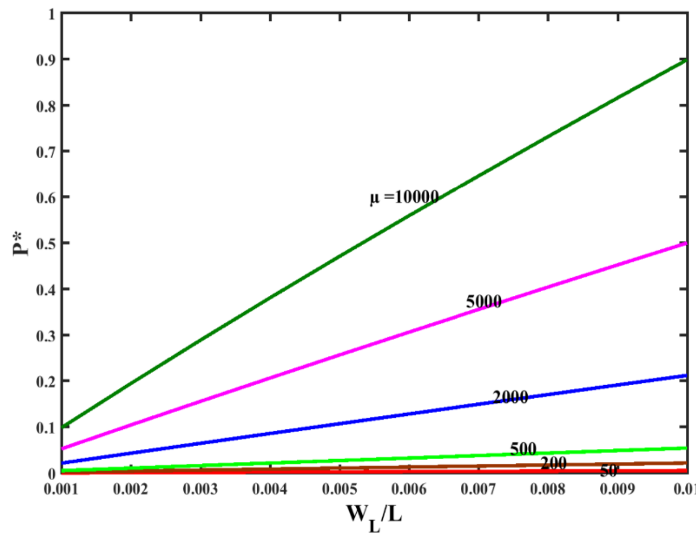

Figure 4. Variation of P^* with w_L/L-Effect of μ

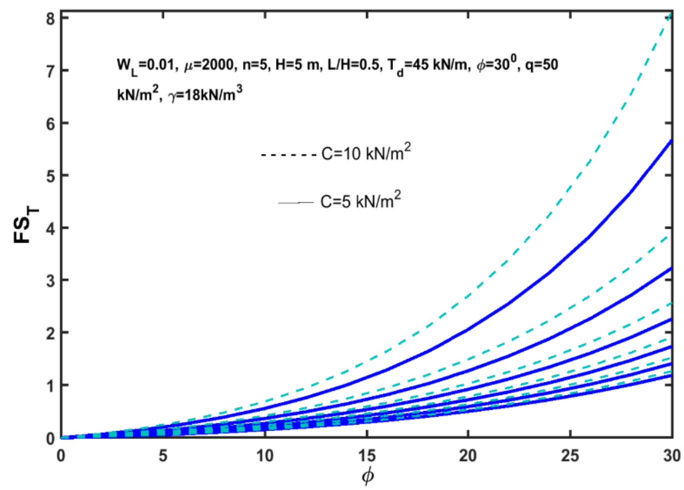

Figure 5. Response of FS_T with ϕ for various values of k_h.

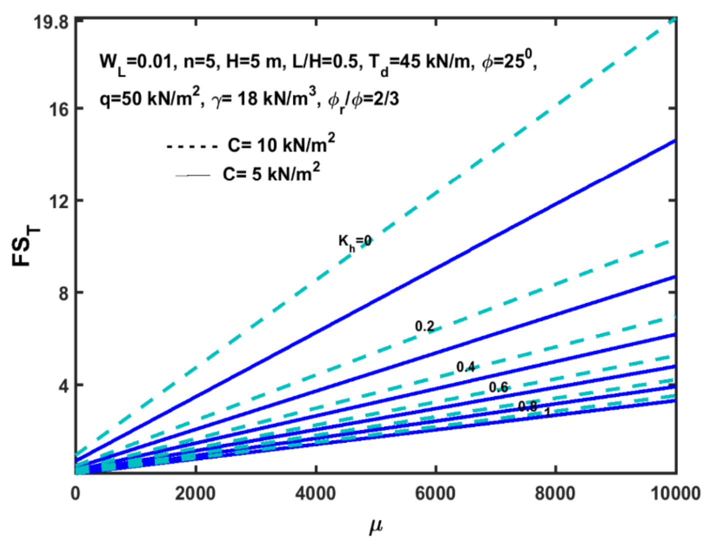

Figure 6. Variation of FS_T with μ- Effect of k_h.

Results and Discussions

Variation of P^* versus w_L/L – Effect of μ

The Normalized transverse force *(P*)* is shown in Figure 4 as a function of displacement w_L/L. To find the displacement at the reinforcement free end for a given value, the response of the normalized displacement of inextensible sheet reinforcement is obtained by considering the coupled Equations (7), (8) and (9). The transverse force (P^*) is increases linearly with the increase of the normalized displacement (w_L/L) by taking account all the parameters of backfill soil properties such as $\gamma=18\ kN/m^2$, $H=5\ m$, $\phi=30^0$, $n=5$, $L=5\ m$, $\phi=30^0$, and $\phi_r/\phi=2/3$. The critical failure surface is considered as independent of the provision of reinforcement with respect to horizontal. During seismic events, in case of vertical reinforced walls the angle α depends on the ϕ and seismic inertia forces (k_h &k_v). For $\mu>2000$, need high forces to move greater displacement, and the curve tends to concave upward. For Larger displacements need more stresses, hence longer reinforcements positioned at shallow depths tend to deform. At various depths, the failure plane cuts the reinforcing layers at varied distances from the facing. Consequently, the relative stiffness factor and normalised displacement changes with the depth of deployed reinforcing layer. The subgrade stiffness factor ($\mu<2000$) and considerable depth of embedment are considered in this analysis. For backfill stiffness ($\mu<2000$), small forces are sufficient to mobilize the small displacements. The obtained results are in good agreement with the TSN Moghaddas and Nouri 2014 report.[13]

Variation of FS_T Versus ϕ – Effect of k_h

The variation in Factor of safety (FS_T) with the angle of internal friction (ϕ) along with the parameters $n=5$, $L/H=0.5$, $\mu=2000$, $W_L=0.01$, $k_v/k_h=0.5$ and $q=50\ kN/m^2$ for various horizontal seismic coefficients is shown in Figure 5. The frictional resistance is mobilised by the transverse pull, so that the Factor of safety (FS_T) is nonlinearly varying as the angle of internal friction of soil increases and also as the k_h is increasing the FST is decreasing. The shear resistance and transverse force are increasing as the c increases form $5\ kN/m^2$ to $c=10\ kN/m^2$ due to minimization of extra bond resistance when the mobilisation of transverse force decreases with rising of the seismic forces.

Variation of FS_T versus μ - Effect of k_h

Figure 6 illustrates the factor of safety for different horizontal seismic coefficients while the relating transverse displacement to the stiffness of the backfill soil for the values of $n=5$, $L/H=0.5$, $\phi_r/\phi=2/3$, $W_L=0.01$ and $q=50\ kN/m^2$. For low values of seismic coefficients, the factor of safety increases with an increase in soil stiffness because of the backfill surcharge and cohesion due to transverse displacement. For $k_h>0.2$, provide higher length of reinforcement and shear resistance to increase the factor of safety due to normalized displacement. FS_T increased by 91% for $k_h=0$, $q=50\ kN/m^2$, $c=10\ kN/m^2$ with increase of subgrade stiffness from 50 to 10,000. The increase in FS_T up to 60% for the values of $k_h=0$, $q=50\ kN/m^2$, $c=5kN/m^2$ for corresponding values of μ. Hence, when compare with cohesion-less soil the factory safety is increased in c-ϕ soil due to transverse pull-out.

Variation of FS_T versus k_h – Effect of ϕ_r/ϕ

The response of factor of safety (FS_T) and horizontal seismic coefficients (k_h) is shown in Figure 7 for various values of the interface friction for $q=50\ kN/m^2$, $\mu=2000$, $n=5$ with $L/H=0.5$, $\phi=30^0$, $W_L=0.01$ and $q=50\ kN/m^2$. The factor of safety is increased with an increase of angle of interface friction owing to an increase in the mobilised transverse force. The rate of increase of FS_T rises with an increase of angle of interface friction and also FS_T decreases with an increase of k_h. For a given interface friction angle, the bond resistance increases as the transverse force mobilisation occur. It clearly illustrates that a non-linear relationship between k_h and FS_T. For $\phi_r/\phi=0.67$ the value of FS_T increases from *0.1 to 8.0* and for $\phi_r/\phi=1$ FS_T increased from 2.0 to 12.9.

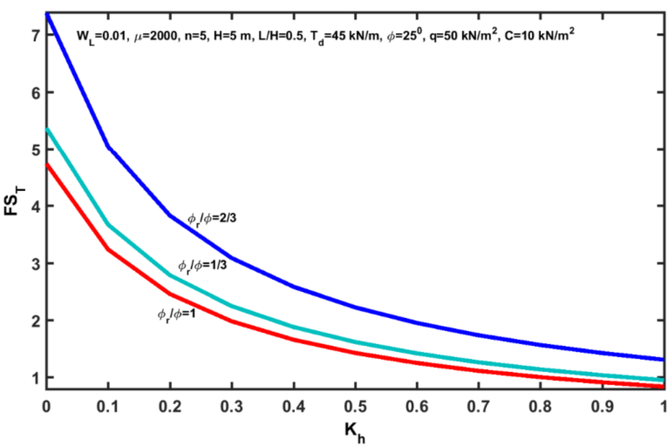

Figure 7. Variation of FS_T with k_h - Effect of ϕ_r/ϕ

Variation of k versus c – Effect of q

Figure 8 depicts the relationship between earth pressure coefficient (k) and cohesion (c) for various surcharge loads on a vertical wall. The effect of cohesion (c=0, 5, 10, 15 kN/m²) on the equivalent earth pressure coefficient k for the values of $q=0$, *25 and* $50\ kN/m^2$. From the reinforced soil wall, the reinforcement strength is assumed to maintain stability which is same as the earth pressure coefficient. The figure shows the variation of k with cohesion at different backfill surcharge loads with $\phi=25^0$, $k_h=0.2$, $W_L=0.01$.

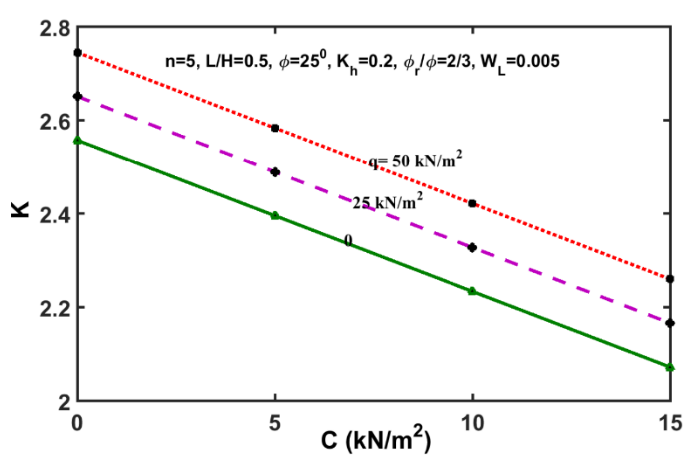

Figure 8 the relationship between earth pressure coefficient (k) and cohesion (c) for various surcharge loads

It is found that for a vertical wall, there is a 15 % decrease in *k* value when *c* changes from 0 to 15kN/m^2. So, it can conclude that the variation of soil cohesion is critical on reinforcement strength decrement of an equal amount to maintain the stability for higher values of cohesion. For a vertical wall with backfill surcharge load increasing from 0 to 50 kN/m^2, the reinforcement strength to maintain wall stability is also increases.

Variation of FS_T versus k_h – Effect of *L/H*

Figure 9 represent that the different horizontal seismic coefficients have different effects on the factor of safety. The cohesion of soil c=10 kN/m^2 (static case $k_h=0$) increases the factor of safety (FS_T) of the vertical wall. When there is a surcharge, the value of *L/H* rises (i.e. the failure wedge angle in relation to horizontal decreases) which increases the value of k_h but it can prevent the failure zone from expanding. The size of the failure wedge remains constant for a given value k_h with the surcharge, but the value of k_h rises as the surcharge value increases. It is also observed that the difference between cohesion and factor of safety decreases as *L/H* ratio increases. For the various *L/H* ratios, the safety factor of 1.5 is ideal for maintaining stability in the marginal soils. If k_h is greater than *0.2*, the conventional factor of safety is less than the 1.5 in the dynamic case. As seismic force is increasing the mobilised transverse force is reducing, which in turn reduces additional bond resistances, which results in a reduction in the factory of safety.[14,15]

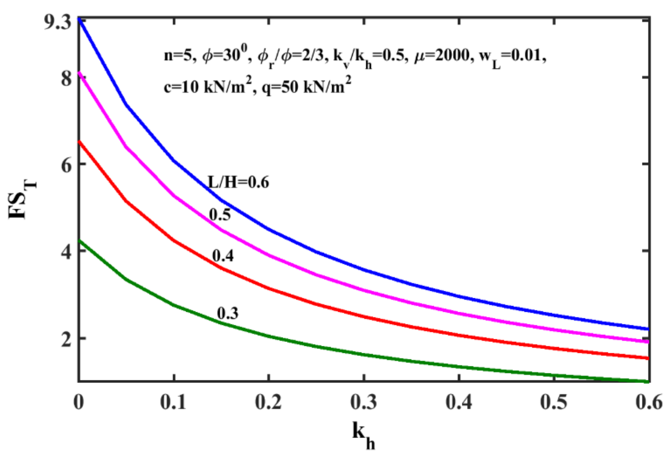

Figure 9. Variation of FS_T with k_h – Effect of *L/H*

This paper illustrates the effect of Cohesive-Frictional Backfill in the Reinforced Earth-Wall for Seismic Analysis. The results evident that tiny forces are enough to move a small displacement for backfill stiffness. The shear resistance and transverse force are increasing as the *c* increases owing to minimization of extra bond resistance when the mobilisation of transverse force decreases with rising of the seismic forces. The factory of safety is increased in c-ϕ soil due to transverse pull-out than the- cohesion-less soil. It is also clearly observed that a non-linear relationship between the k_h and FS_T. For a vertical wall with backfill surcharge for increasing load, the reinforcement strength is also increases to maintain wall stability. It is observed that as seismic force is increasing the mobilised transverse force is reducing, which in turn reduces additional bond resistances may results in a reduction in the factory of safety.[16–20]

Conclusion

These ideas informed the development of computational code for a pseudo-static seismic analysis of a reinforced soil wall with uniform surcharge and c-ϕ soil backfill. The stability of the RE wall can be improved by increasing the angle of internal friction of the soil. The factor of safety is greater in the static situation ($k_h=0$) than in the dynamic case, there is less difference in cohesion as k_h is increased. A linear increase in normalized displacement of inextensible sheet reinforcement results in a linear increase in the transverse force on the reinforced soil wall. As the backfill surcharge load on a vertical wall increases from 0 to 50 kN/m^2, the reinforcing strength is increased and it keep the wall stable. The factor of safety (FS_T) is decreased with increase of cohesion for $k_h=0$ (static case). The angle of failure plane with horizontal increases non-linearly because the weight of the wedge reduces and the (FS_T) is raised. As the more number of reinforcement layers, the greater is the shear resistance between the soil and reinforcement. When k_h exceeds 0.2, it is evident that the deployed transverse force is increasing critically. The angle of shear value grows as FS_T increases, and cohesion (*c*) is increases as transverse force increases the shear/bond resistance. For a larger horizontal seismic acceleration for $k_h > 0.2$ and $\phi < 30^0$, the FS_T is improved owing to the mobilized transverse force is more effective.

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Conflict of Interest

Authors declare no confict of interest is there for publication of this piece of work.

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Symbols	**Basic SI units are given in parentheses**
FS_T	Factor of safety considering increase in tension due to transverse force (dimensionless)
H	Height of the reinforced earth wall (m)
h_j	Embedment depth of reinforcement (m)
k_h	Horizontal seismic coefficient(dimensionless)
k_v	Vertical Seismic coefficient (dimensionless)
L	Length of reinforcement in the backfill (m)
L_a	Effective length of reinforcement beyond critical failure plane (m)
m	Number of reinforcement layers
n	Number of horizontal slices
S_i	Shear force upon the base of *i*th slice
N_i	Normal force upon the base of the slice *i*th slice (kN)
ϕ	Angle of shearing resistance (degree)
ϕ_r	Angle of interface friction between soil and reinforcement (degree)
γ	Unit weight of backfill (kN/m^3)
α	Inclination of failure plane with the horizontal (degree)
t_j	Tensile force generated in the *j*th reinforcement (kN)
q	Surcharge load on backfill (kN/m^3)
W	Weight of the slice (kN)
P^*	Normalized transverse force in the layer of the reinforcement (kN)
T^*	Normalized tension developed in the kth element of reinforcement ($= T_d/2gh_jL\tan\phi_r$) (kN)
μ_j	Local stiffness factor ($=k_sL_e/\gamma h_j$)
μ	Global stiffness factor ($= k_sL/\gamma H$)
k	Earth pressure coefficient
b_i	Inclined length of slice
V_i	Vertical interslice force of *i*th slice (kN)
W_L	Normalized oblique displacement at failure plane