An Investigation on the Dynamic Behaviour of Soil Nail Walls

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***Abstract*-Soil nailing is one of the extensively used techniques for stabilizing cut slopes in railway and highway construction. In this method, the native soil is strengthened by placing steel rods into drilled holes in the walls and grouted. The dynamic behaviour of soil nail walls is affected by the relative density of backfill, the length and diameter of nails, axial force, shear force and bending moment developed along the nails. Laboratory plate load tests were performed on a soil nail wall model of 1 m height having vertical facing with relative densities of 25% and 50% and two nail lengths of 0.5 m and 0.6 m to study the effect of relative density of soil and length of nails on stability of soil nail wall. A detailed finite element analysis was carried out on soil nail wall model having 1 m height and vertical facing in order to determine the axial force, shear force and bending moment developed along nails. The settlement of the soil nail wall was decreased with the increase in relative density of sand. The increase in length of nail from 0.5 m to 0.6 m resulted in decrease of settlement for the soil nail wall having 1 m heght. The axial force along nails increased with the embedment depth. Both the bending moment and shear force were found to be concentrated near the face of the wall. A parametric study was also carried out and design tables were prepared for various earthquake coefficients.**

Keywords- Soil Nail Walls; Factor of Safety; Relative Density; Settlement

I. INTRODUCTION

Over the past few years there has been a rising demand for the construction of high-rising structures and shopping malls having various basements. But due to the scarcity of land, the structures are constructed in areas with mountainous topography. The ground slopes in these regions may not permit housing construction as the slopes become unstable to withstand the stresses caused by dwelling units. As a result, such massive constructions demand the need for deep excavations and retaining structures. Moreover, there is an increasing demand for stabilizing vertical cuts supporting roadways against dynamic loads. The stabilizing of vertical cuts using modern technologies will provide a new pathway for the construction industry to build roads and structures on slopes.

Soil nailing is an innovative and cost-effective retaining system for deep excavations in steep slopes. The native soil is strengthened by placing steel rods into holes drilled into the walls and grouted. When compared to the conventional retaining wall system, soil nail wall construction requires less space and hence suitable for an urban area where excavations are surrounded by structures. It does not have any potential impact on environment during and after construction. The soil nailing technique can also be used for underground construction.

The case histories are available in literature which shows the successful application of the soil nailing for in-situ ground modification. Most of the available literature on soil nail wall gives emphasis on the mechanism of reinforcement and design of structures under static loads only. However, very few studies on the dynamic resistance soil nail walls are available. In this study, the dynamic behaviour of steep soil slopes retained by steel nails is investigated based on the pseudo-static approach. Laboratory model studies are conducted on soil nail wall having height 1 m and vertical facing. A detailed finite element analysis of soil nail wall model is carried out to determine the wall deformations. The factor of safety of the wall is calculated from both laboratory model study and finite element analysis of the soil nail wall. A parametric study is conducted using the pseudo-static approach. Based on the parametric study, design tables are prepared to serve as design aid for the construction of safe soil nail walls for different seismic coefficients.

II. OBJECTIVES OF THE STUDY

a) To design a soil nail wall system using pseudo-static approach.
b) To conduct laboratory model study on soil nail wall.
c) To carry out a numerical study using finite element model of soil nail wall.
d) To carry out a parametric study using pseudo-static approach.

III. PREVIOUS STUDIES

Many investigators (Jeffrey and George 1992; Chin 2005; Babu et al. 2006 and Dodagoudar 2010) have proposed soil nailing technique as a suitable method for stabilising vertical/nearly vertical excavations. Carla and Donatella (2008), Muthukumar and Premalatha (2009) and Gosavi et al. (2009) presented an overview of experimental studies conducted on soil nail wall models. All the studies were carried out in test tanks and the difference was noted in the size of tank. The size of tank varied from 48 cm to 2.5 m.

In order to study the deformation behaviour of soil nail walls, many researchers (Alhabshi 2006; Liew et al. 2007; Cheng and Lou 2007; Babu 2009 and Liu 2010) carried out finite element analysis of soil nail wall. The importance of facing design in the stability of soil nail walls was pointed out in their findings. The behaviour of soil nailed walls under dynamic loads has been studied by very few investigators. Mark and Mladen (2000) performed dynamic centrifuge tests. Debabrata and Aniruddha (2010) conducted a series of laboratory shaking table tests. In this paper, a soil nail wall having 1 m height has been designed based on pseudo-static approach. Laboratory plate load tests are conducted by varying the density of soil and the length of nails and corresponding factor of safety values is determined. Finite element analysis is performed to study the wall deformations. Using Phi–C reduction method, factors of safety values are computed from the finite element analysis of soil nail wall. A parametric study is conducted using pseudo-static approach, to prepare a series of design tables for different seismic coefficients.

IV. PSEUDO-STATIC APPROACH FOR DESIGN OF SOIL NAIL WALLS

Pseudo-static approach is a simple method which is applicable for both total and effective stress slope stability analyses. In this method, the cyclic nature of earthquake is ignored. It assumes that an additional static force is applied on the slope due to earthquake. The basic principle of pseudo-static method is that, the earthquake-induced, time-varying forces of inertia acting within a potentially sliding rigid block involving the soil nail wall system are replaced by an equivalent, pseudo-static force (F_{in}) acting at the center of gravity of the analyzed block. The horizontal (F_{inh}) and vertical seismic components (F_{inv}) are expressed as shown in Eq. (1) and Eq. (2).

$$F_{inh} = K_h W \tag{1}$$

$$F_{inv} = K_v W \tag{2}$$

in which W is the weight of the block, K_h and K_v are non-dimensional horizontal and vertical seismic coefficients respectively. The equivalent pseudo-static inertia force is calculated using the Eq. (3).

$$F_{in} = \frac{H^2\gamma}{2} A_m \left[0.5\tan\alpha + \left(\frac{L}{H}\right) + 0.5\left(\frac{L}{H}\right)^2 \tan\beta \right] \tag{3}$$

Where L is the length of nail, H is the height of wall, β is the backslope angle, α is the wall face batter and A_m is the design acceleration coefficient at center of gravity of soil nail wall.

The procedure for design of soil nail walls using pseudo-static approach comprises of following four steps: (A). determination of seismic coefficients; (B). computation of total load acting on soil nail wall; (C). stability analysis of soil nail wall and (D). determination of nail diameter.

A. Determination of Seismic Coefficients

In this study, the guidelines put forward by the Federal Highway Administration (2003) have been followed for the pseudo-static design of soil nail walls. The first step in the design of soil nail walls using pseudo-static approach is the determination of seismic coefficients. The various steps involved in determining the seismic coefficients are as below.

(i) In the present study, it is assumed that the site for soil nail wall is located in Kerala state, which belongs to seismic zone III.

(ii) The maximum ground acceleration coefficient (A_1) is obtained as 0.16 g for sites in zone III.

(iii) The site coefficient (S) is identified as 1.

(iv) The potential soil amplification factor (A) is computed from S and A_1 as shown in Eq. (4).

$$A = S \times A_1 \tag{4}$$

(v) The design acceleration coefficient (A_m) at center of gravity (C.G) is computed from A as Eq. (5).

$$A_m = (1.45 - A)A \tag{5}$$

(vi) The value of the horizontal earthquake coefficient (K_h) is taken as 0.6 A_m.

(vii) The value of the vertical earthquake coefficient (K_v) is taken as half of A_m.

Based on the above calculations, the horizontal earthquake coefficient (K_h) was obtained as 0.12 g and the design acceleration coefficient at the centre of gravity of the soil nail wall system (A_m) was obtained as 0.21 g.

B. *Computation of Total Load Acting on Soil Nail Wall*

Soil nail walls used on highway projects are subjected to different loads during their service life. Typical applied loads are dead loads which include weight of the soil nail wall system, lateral earth pressure and the weight of nearby structures, traffic loads and impact loads due to vehicle collision on barriers above the soil nail wall and earthquake load. For most soil nail wall applications, load groups with static loading and seismic loading are considered by American Association of State Highway and Transportation officials (AASHTO, 1996). In this study, the dynamic effect of the vehicles on highways is computed using pseudo-static approach. The total surcharge load acting on the soil nail wall model is taken as the sum of static and dynamic load as shown in Eq. (6).

$$P_{AE} = P_A + \Delta P_{AE} \tag{6}$$

In which P_A is the active earth pressure due to static load and ΔP_{AE} is the dynamic earth pressure increment.

C. *Stability Analysis of Soil Nail Wall*

When the load computations are over, the next step is to analyse the stability of soil nail wall against external and internal failure modes. In this study, the stability analysis was performed based on limit equilibrium method using SNAILZ computer program. SNAILZ is a DOS-based computer program developed by the California Department of Transportation (CALTRANS) in 1991. The SNAILZ program gives the factor of safety values as the output at the end of analysis. These factors of safety values are compared with the minimum recommended values of factor of safety by the Federal Highway Administration guidelines (FHWA, 2003).

D. *Determination of Nail Diameter*

The final step in the design of soil nail walls using pseudo-static approach is the determination of nail diameter. In this study, a soil nail wall having height of 1 m and vertical facing was considered for the analysis. From the pseudo-static design of soil nail wall, nails of 3 mm diameter were found to be safe for the stability of this 1 m high wall. The various parameters considered during the design stage of soil nail wall are given in Table 1.

TABLE 1 DESIGN PARAMETERS OF SOIL NAIL WALL MODEL USED FOR THE STUDY

Design parameters of soil nail wall	**Design value**
Height of soil nail wall (H)	1.0 m
Wall face batter (α)	0^o
Vertical nail spacing (S_v)	0.2 m
Horizontal nail spacing (S_h)	0.2 m
Soil nail pattern on facing	Square
Soil nail inclination	0^o to horizontal
Soil nail length (L)	0.5m and 0.6m
Distribution of soil nail lengths	Uniform throughout the wall height
Soil nail material	Mild steel
Classification of soil	Uniformly well graded
Angle of internal friction of soil (φ)	40^o
Cohesion (C)	0

V. EXPERIMENTAL STUDY ON SOIL NAIL WALL MODEL

Laboratory plate load tests were performed on soil nail wall model having 1 m height. In actual soil nailed cuts, where the soil can stand unsupported for excavation depth of about 0.5–1.0 m, a shotcrete or precast panel facing is commonly used. Since dry sand was used in the present study, a vertical excavation face was maintained [13]. In this model test, firstly stable and safe vertical nailed cut with factor of safety greater than 1.0 was designed based on FHWA guidelines (2003). Then the surcharge load was applied on the soil nail wall gradually using a hydraulic jack and the surcharge intensity at which the stable soil nail wall failed was recorded. For the failure surcharge intensities, the factor of safety of the designed soil nail wall was determined based on limit equilibrium method using SNAILZ software. The obtained factors of safety values were compared with that of the minimum recommended factors of safety values proposed in FHWA guidelines for the seismic stability of soil nail wall.

A. *Soil and Nails Used for the Study*

The soil used in the study is uniformly well graded river sand. The particle size distribution curve for river sand used in the experimental study is shown in Fig. 1.

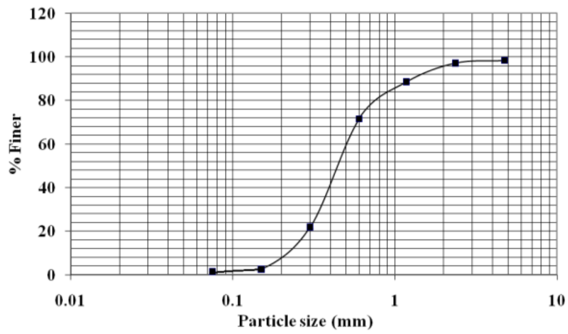

Fig. 1 Particle size distribution curve for river sand used in experimental study

Two relative densities of 25% and 50% corresponding to loose and medium dense conditions respectively of the soil were fixed for analysis. The angles of internal friction corresponding to these two relative densities of 25% and 50% were obtained as 16.41KN/m^3 and 16.92KN/m^3 respectively using the empirical relation shown in Eq. (7), where D_r is the relative density of sand. Table 2 shows the properties of soil used for this study.

$$\Phi=26+0.2D_r \tag{7}$$

TABLE 2 SOIL PROPERTIES USED FOR THE STUDY

Soil property	**Value**
Soil type	River sand
Effective size (D_{10})	0.2 mm
Uniformity coefficient (C_u)	2.5
Coefficient of curvature (C_c)	1.16
Classification	Uniformly well graded
Cohesion (C)	0
Angle of internal friction (φ)	40^o
Specific gravity (G)	2.64

In order to investigate the effect of reinforcement (nail) on the stability of soil nail wall, mild steel bars of 6 mm diameter and having two nail lengths of 0.5 m and 0.6 m has been adopted in this study. The nail properties used in the study are given in Table 3.

TABLE 3 NAIL PROPERTIES USED FOR THE STUDY

Nail characteristic	**Value**
Material	Fe 415 Mild steel bar
Length	0.5 m, 0.6 m
Diameter	6 mm
Horizontal nail spacing	0.2 m
Vertical nail spacing	0.2 m
Nail inclination	0^o (Horizontal)

B. Effect of Relative Density on Load Displacment Characteristics of Soil Nail Wall

The effect of relative density of soil on the load carrying capacity of the soil nail wall was investigated by conducting plate load tests on soil nail wall model by varying the relative densities as 25% and 50%. For each relative density of the soil, experiments were conducted for nail lengths of 0.5 m and 0.6 m. Based on the plate load tests carried out, load displacement curves were plotted for each of the three cases: one set of experiment without inserting nails and other two sets of experiments with nails of 6 mm diameter. Fig. 2 shows the load displacement curves obtained from plate load tests conducted by varying the density of sand from 25% to 50%.

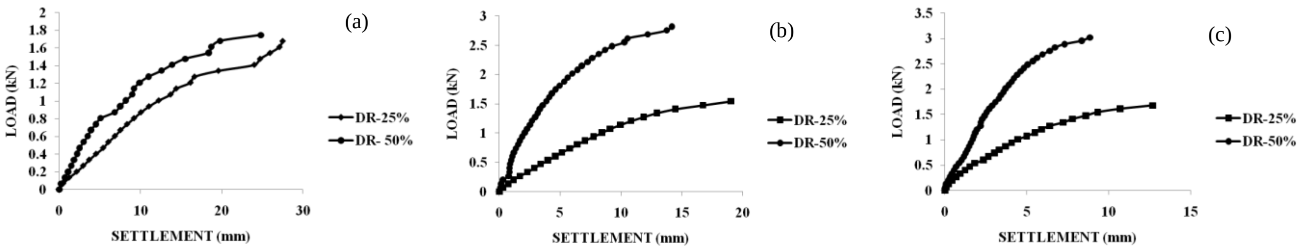

Fig. 2 Load settlement curves for relative densities of 25% and 50% (a) without inserting nails;
(b) after inserting nails of 0.5m length; (c) after inserting nails of 0.6m length

Fig. 2a shows load settlement curve obtained from plate load tests conducted on soil nail wall model without inserting nails. In the experimental study, the failure of soil nail wall occurred at a load of 1.344 KN. The settlement for this failure load was obtained as 19.59 mm for 25% relative density and 12.66 mm for 50% relative density from Fig. 2a. It is evident that for the same load of 1.344KN, the settlement was decreased by 35.68% when the relative density of sand was increased from 25% to 50%.

Fig. 2b shows load settlement curve obtained from plate load tests conducted on soil nail wall model after inserting nails of 0.5 m length. In the experimental study, when nails of 0.5 m were inserted, the failure of soil nail wall occurred at a load of 1.546 KN. The settlement for this failure load was obtained as 19.04 mm for relative density of 25% and 3.87 mm for relative density of 50% from Fig. 2b. It is revealed that, for the soil nail wall model having nails of 0.5m length, for the same load of 1.546 KN, the settlement was decreased by 79.67% when the relative density of sand was increased from 25% to 50%.

Fig. 2c shows load settlement curve obtained from plate load tests conducted on soil nail wall model after inserting nails of 0.6 m length. In the experimental study, when nails of 0.6 m were inserted, the failure of soil nail wall occurred at a load of 1.68 KN. The settlement for this failure load was obtained as 12.68 mm for relative density of 25% and 2.88 mm for relative density of 50% from Fig. 2c. It is seen that for the soil nail wall having nails of 0.6 m length, for the same load of 1.68 KN, the settlement was decreased by 77.28% when the relative density of sand was increased from 25% to 50%. As the relative density of the soil increases, the angle of internal friction also increases thereby enhancing the shear strength of backfill. This enhanced shear strength has resulted in a considerable decrease in the settlement of soil nail wall.

C. Effect of Nail Length on Stability of Soil Nail Wall

The length of nail (reinforcement) has a major influence on the behaviour of soil nail wall system. The resistance against failure of the soil nails is provided by the part of soil nail that is embedded into the ground behind the potential failure surface. In order to investigate the effect of nail length on the load carrying capacity of the soil nail wall, plate load tests were carried out on soil nail wall model using nails of 6 mm diameter and by varying the length of nail from 0.5 m to 0.6 m. Two sets of experiments were conducted corresponding to two relative densities of 25% and 50%. The load displacement curves obtained from plate load tests conducted by varying the nail length from 0.5 m to 0.6 m for two relative densities of 25% and 50% are shown in Fig. 3.

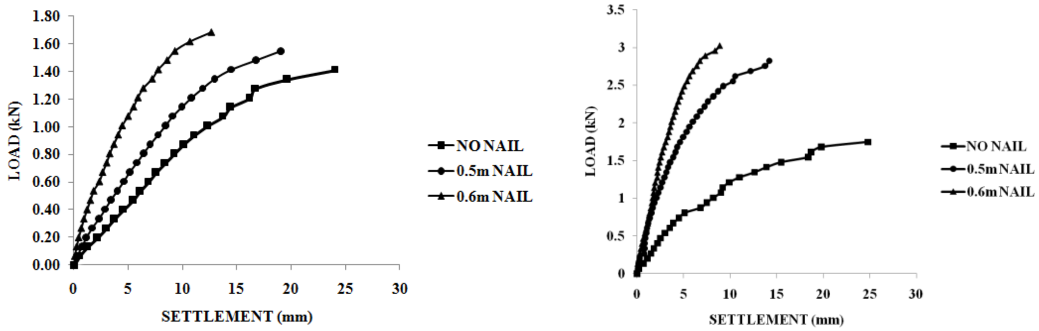

Fig. 3 Load settlement curve (a) for relative density of 25%; (b) for relative density of 50%

During the plate load test conducted on soil nail wall having density of 25% and without inserting nails, the failure occured at load of 1.344 KN. The settlement corresponding to this failure load was obtained as 19.59 mm from Fig. 3a. The settlement corresponding to the same failure load of 1.344 KN was obtained as 12.95 mm in the case of 0.5 m nails and 7.22 mm in the case of 0.6 m nails respectively from Fig. 3a. It is evident from the above observation that, there has been a decrease of 44.2% in the settlement of soil nail wall when the length of nail was increased from 0.5 m to 0.6 m.

Fig. 3b represents the load displacement curves obtained when the density of soil was 50%. During the plate load test conducted on soil nail wall having density of 50% and without inserting nails, the failure occured at load of 1.478 KN. The settlement corresponding to the failure load was obtained as 15.5 mm from Fig. 3b. For the same relative density of 50%, the settlement corresponding to the same failure load of 1.478 KN was obtained as 3.55 mm in the case of 0.5 m nails and 2.42 mm in the case of 0.6 m nails from Fig. 3b. It is evident that, there has been a decrease of 31.83% in the settlement of soil nail wall when the length of nail was increased from 0.5 m to 0.6 m. This decrease in settlement of soil nail wall can be attributed to the effect of embedment of nails into the potential failure surface which enhanced the resistance of soil nail wall system.

D. Validation of Laboratory Study

Section H The results from plate load tests carried out on soil nail wall model were used to calculate the factor of safety of the wall, based on the limit equilibrium method using SNAILZ computer program. In order to validate these results, finite element simulation of the soil nail wall model was done using PLAXIS package. The factor of safety (FS) values obtained from the experimental study and finite element analysis are given in Table 4.

TABLE 4 FS VALUES OBTAINED FROM LAB STUDY AND FINITE ELEMENT ANALYSIS

D_r%	Length of nail (m)	Factor of safety	
		Experimental study	Finite element analysis
25	0.5	1.59	1.77
25	0.6	1.83	1.9
50	0.5	1.93	2.25
50	0.6	2.21	2.41

From the Table 4 it is evident that the FS values obtained are all higher than the minimum recommended values proposed by FHWA guidelines for design of soil nail wall. The FS values obtained from finite element simulation using PLAXIS are consistent with the FS values obtained from plate load tests conducted on soil nail wall model. Thus, the soil nail wall model having height of 1.0 m and nails of 6 mm diameter is safe under seismic and static failure conditions.

VI. FINITE ELEMENT ANAYSIS OF SOIL NAIL WALL

The finite element method has been increasingly used in slope stability analysis in the area of geotechnical engineering. In this study, the two-dimensional finite element program PLAXIS V.8 has been used to perform the numerical analyses of the soil nail wall. For the purpose of illustration and better understanding, a typical 1 m high soil nail wall with vertical face and horizontal backfill and 6 mm diameter nails is considered for the study. The geometry model of the soil nail wall is shown in Fig. 4.

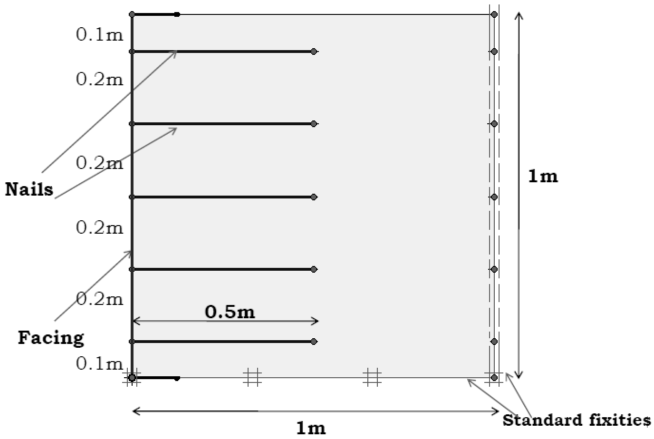

Fig. 4 Geometry of the soil nail wall model

A. Simulation of Soil Nail Wall Using PLAXIS

The finite element based simulation of the soil nail wall was carried out in the present study, considering it as a plane strain problem and accounting for the long term behaviour using drained conditions [1]. 15-noded triangular elements were used for generating finite element mesh of coarse density. Numerical simulations of the soil nail wall were performed considering Mohr-Coulomb (MC) model. The various soil model parameters adopted for the study are summarised in Table 5.

TABLE 5 SOIL MODEL PARAMETERS USED FOR FINITE ELEMENT ANALYSIS

Parameter	Symbol	Properties of Sand	Unit
Material model	Model	Mohr-Coulumb	-
Type of behaviour	Type	Drained	-
Dry unit weight of soil	γ_{dry}	16.92	kN/m^3
Young's Modulus	E_{ref}	20000	kN/m^2
Cohesion	C	1	kN/m^2
Poisson's ratio	υ	0.3	-
Friction angle	φ	40	degree
Dilatancy angle	ψ	1	degree

The boundary conditions were simulated using total fixities along base of the wall and horizontal fixities along vertical face of the wall. The soil nail interaction factor of 0.67 was provided in order to account for interation between soil and nail. In practice, a nail is rigidly connected to the wall facing. In PLAXIS 2D, connection between two plate structural elements by default represents a rigid connection. Therefore, use of plate structural elements to simulate soil nails and wall facing has been adopted in this analysis to account for the rigid nail-facing connection. The most important input material parameters for plate elements are the flexural rigidity or the bending stiffness (EI) and the axial stiffness (EA). The nail parameters selected for the numerical simulation are given in Table 6.

TABLE 6 NAIL PARAMETERS USED FOR FINITE ELEMENT ANALYSIS

Parameter	Symbol	Properties of nail	Unit
Nail diameter	D	6	mm
Young's modulus	E	210×10^{6}	kN/m^2
Axial stiffness	EA	3×10^{7}	kN/m
Bending stiffness	EI	90	kNm^2/m

B. Effect of Embedment Depth on Axial Force in Nails

The variation of maximum axial forces along the nails with embedment depth for nails of 0.5 m length in soil with density of 25% and 50% is shown in Fig. 5.

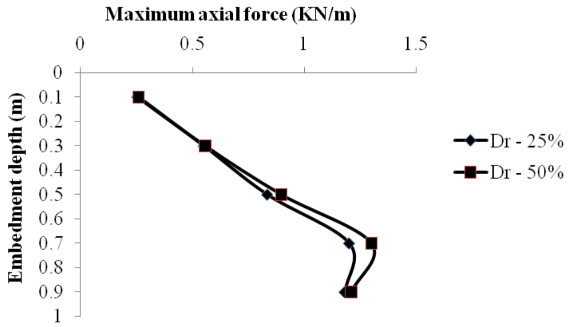

Fig. 5 Variation of axial force in nails with embedment depth for 0.5 m nails

The maximum axial force (T_{max}) developed along nails increases with the embedment depth as the axial force depends on depth and unit weight of soil. From the Fig. 5, it is seen that for the same nail length of 0.5 m, the axial force developed in nails increased with depth of embedment up to 0.9 m and then decreased for a soil nail wall of height 1 m. This decrease in axial force is attributed to the fixity provided at the base of facing.

C. Importance of Facing Design in Stability of Soil Nail Wall

Generally, nails are rigidly connected with the facing and in such cases it is desirable to evaluate the facing design. Improper design may lead to the bending and/or shear failures of soil nails at or near the facing [3]. For this purpose, the variation of shear force and bending moment along the length of nails were observed from the facing towards the end of nail. Development of maximum shear force along nails of 0.5 m length and density of 25% is shown in Fig. 6.

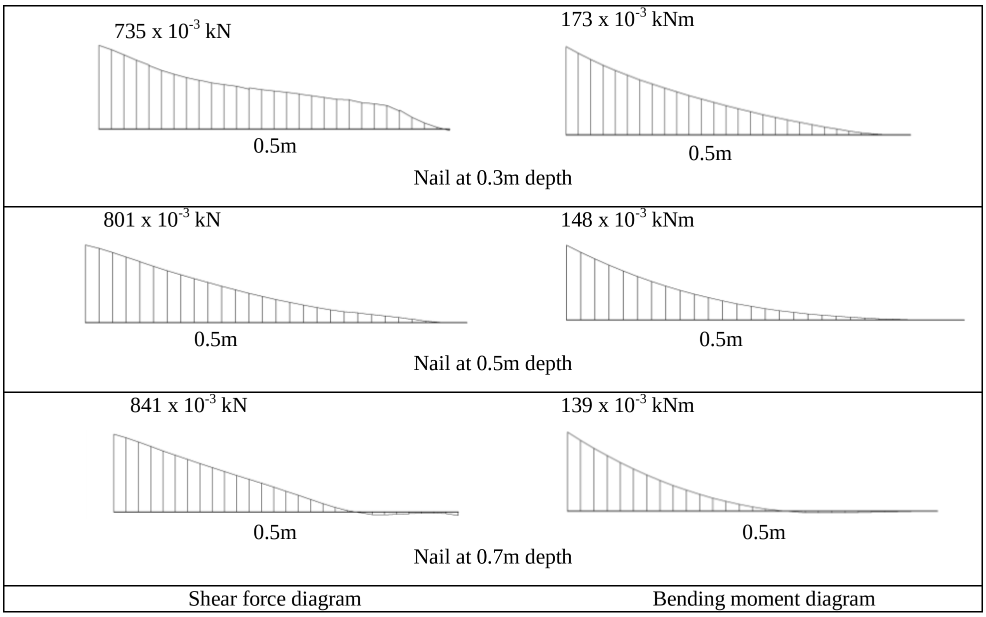

Fig. 6 Variation of shear force and bending moment along nail length

It is evident from the above figure that bending moments and shear forces are concentrated near the face of the wall. Thus, improper design of facing by ignoring bending stiffness of soil nails may lead to the bending or shear failures of soil nails at or near the facing. Hence, it is recommended that bending stiffness of nails shall be considered in the finite element simulations in order to avoid facing failure of soil nail walls.

VII. PRELIMINARY DESIGN TABLES FOR SOIL NAIL WALL

A series of design tables were developed as a design aid to provide preliminary nail length and maximum number of nails. The tables were developed using the computer program SNAILZ. The pseudo-static analysis has been carried out to check the seismic stability of soil nail wall. The FS values were determined from the analysis for different earthquake coefficients. The FS values described in these tables satisfy the minimum recommended values of FS proposed by FHWA guidelines for design of soil nail wall. Length of nail/Height of wall ratio varies between 0.5 to 0.7 according to FHWA guidelines. For the present study, L/H was kept constant as 0.7 and the vertical and horizontal spacing of nails were fixed as 1.0 m. Nail diameter adopted for the study is 20 mm. The total number of nails along the wall height was obtained by dividing the wall height by vertical nail spacing for each of the cases. The vertical earthquake coefficient was taken as 50% of the horizontal earthquake coefficient. The variable parameters used for preparation of the design table is shown in Table 7.

TABLE 7 VARIABLE PARAMETERS USED IN DESIGN TABLE

Parameter	**Unit**	**Value**
Wall height (H)	m	5, 8, 10
Face batter (α)	Degrees	0, 5, 10, 15
Earthquake coeffitients (k_h, k_v)	g	0, 0.05, 0.1, 0.15
Unit weight of soil (γ)	KN/m^3	16.41, 16.92, 17.47
Angle of internal friction (φ)	Degrees	31, 36, 41
Cohesion (C)	KPa	0, 10, 20

A total of 9 tables were created for different parameters of soil nail wall like height of wall, unit weight of soil and earthquake coefficients. A typical Table 8 for H = 5 m, $\varepsilon = 0^o$, $\varphi = 31^o$ is presented here for illustration.

TABLE 8 DESIGN TABLE FOR H = 5M, $E = 0^O$, $\Phi = 31^O$ $\Gamma = 16.41$ KN/M^3, N = 5, L/H = 0.7, D = 20MM, $K_V = K_H/2$, $F_Y = 4.15X10^5$ KPA

k_h	**α**	**FACTOR OF SAFETY**		
		C=0	**C=10kPa**	**C=20kPa**
0	0	2.1	2.7	3.21
0	5	3.47	3.9	4.34
0	10	3.76	4.47	4.89
0	15	3.89	4.66	5.28
0.05	0	1.76	2.5	2.98
0.05	5	2.93	3.8	4.23
0.05	10	3.68	4.39	4.82
0.05	15	3.82	4.58	5.21
0.1	0	1.49	2.32	2.78
0.1	5	2.48	3.49	4.12
0.1	10	3.62	4.32	4.75
0.1	15	3.74	4.5	5.14
0.15	0	1.28	2.02	2.6
0.15	5	2.13	3.02	3.91
0.15	10	3.44	4.24	4.68
0.15	15	3.67	4.42	5.07

VIII. CONCLUSIONS

A soil nail wall of 1 m height has been designed following the guidelines of FHWA (2003). Laboratory plate load tests and detailed finite element analysis were performed to investigate the behaviour and wall deformations of soil nail wall. The laboratory study conducted on soil nail wall showed that the settlement of the soil nail wall was decreased with the increase in relative density of sand [11]. The settlement of the soil nail wall was decreased by 79.67%, when the relative density of sand was increased from 25% to 50% (L = 0.5 m and D = 6mm). The settlement of soil nail wall model was seen to decrease with the increase in nail length. When the length of nail was increased from 0.5 m to 0.6 m, in the laboratory study, the settlement of soil nail wall model was decreased by 44.2% (D_r = 25% and D = 6 mm).

The FS values obtained from Phi-C reduction method were validated with the FS values obtained from plate load tests conducted on soil nail wall model. The results from finite element analysis of the soil nail wall showed that the axial force along nails increased with the embedment depth. It was observed that in the case of 1 m high soil nail wall, the axial force along nails increased up to a depth of 0.9 m and then decreased. This decrease in the axial force along the lowermost nails is attributed to the fixity provided at the base of facing.

The variation of bending moments and shear forces along nails was obtained from finite element analysis of the soil nail wall. The results showed that both the BM and SF are concentrated near the face of the wall. This observation emphasises the need for proper facing design in order to avoid failure. Tables were prepared as design aid for evaluating the FS of soil nail walls for different seismic coefficients.

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