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Influence of Nail Fixity to Facing on the Performance of Soil Nail System

Krupa H R
Post Graduate Student, Department of Civil Engineering
SJCE, JSS Science and Technology University
Mysuru, India

Prasad S. K
Professor & Head of Civil Engineering
Vidyavardhaka College of Engineering
Mysuru, India

***Abstract*—Soil Nailing application for the stabilization of vertical cuts or nearly vertical slopes has become one of the popular methods of deep excavation and ground improvement techniques. Soil nail walls are constructed in 'top down' construction sequence, suitable and cost economical for various ground conditions. Soil nails and initial facing are provided at each excavation stage at site using connecting components and reinforcement for shotcrete of initial facing. The connecting components like bearing plates, washers and nuts are used, but their mechanism as fixity is not given importance while studying the load transfer mechanism of the soil nail system. In this paper, efforts have been made to study the behavior of bearing plate as horizontal fixity, vertical fixity and total fixity at the nail and facing junction using finite element models created using PLAXIS. The results show that the development of axial forces along the length of the nail is greatly influenced by horizontal and total fixities and less influential for vertical fixity when compared to the no fixity condition of the soil nail system. It is also observed that there will be reduction in axial forces in the nails due to the provision of horizontal and total fixities. This is due to the decreased displacement of the soil and nail which in turn reduces the bond shear resistance at the soil and nail interface along its length. Further, it is observed that there will be reduced mobilization of flexural forces (shear forces and bending moments) near the nail head, but this reduction is negligible. The nails at the junction should be able to withstand these negligible flexural forces and thus be flexible. The bearing plates and other connecting components provided at the junction should be designed and installed in such a way that they provide either horizontal fixity or total fixity so as to enhance the performance of the system.**

Keywords—Soil nailing, Bearig plate, Connection components, Fixity.

I. INTRODUCTION

Soil Nails are reinforcing, passive elements that are drilled and grouted sub horizontally in the ground to support excavations in soil, or in soft or weathered rock. The stability of the earth-resisting systems is the main criteria achieved through soil nails which act as tension members due to the deformation of the retained soil or weathered rock mass. They transfer the tensile forces to the surrounding soil through bond stresses (shear stresses) along the grout-ground interface and ensure long term performance of the system. Other applications of soil nail walls are in roadway cuts, road widening under existing bridge abutments, tunnel portals, repair and reconstruction of existing retaining structures (Briaud and Lim (1997)). The behavior and performance of the Soil nail system are influenced by many factors (ShivakumarBabuet.al. (2002)). some researchers have done a detailed study of the reinforced earth structures for only load transfer mechanism between nail and soil. However, the facing characteristic such as connection between facing and nail is given less importance. According to FHWA (2003) , the soil wall is furnished with initial facing of shotcrete on welded-wire mesh reinforcement, where the horizontal waler bars and vertical bearing bars are provided to resist bending in horizontal and vertical direction respectively. The nail is connected to the facing using bearing plates, nuts washers and headed studs. The purpose of the bearing pate is to distribute the force applied at the nail end onto the shotcrete facing and to the soil behind the facing. However, the behavior of the bearing plate in providing resistance to flexural forces at nail head and its effect on the axial force development along the length of the nail are still uncertain. Hence, efforts have been made in this paper to study the effect of bearing plate and other connecting components considering them as different types of fixity (horizontal fixity, vertical fixity and total fixity) conditions on the performance of the soil nail system. From the study, Elias and Juran (1991) have observed that shear and bending nail strengths contribute less than 10 percent to the overall stability of the wall. Due to this relatively moderate contribution, the shear and bending strengths of the soil nails are conservatively neglected in the conventional design procedure. In this paper, the variation of flexural forces and its

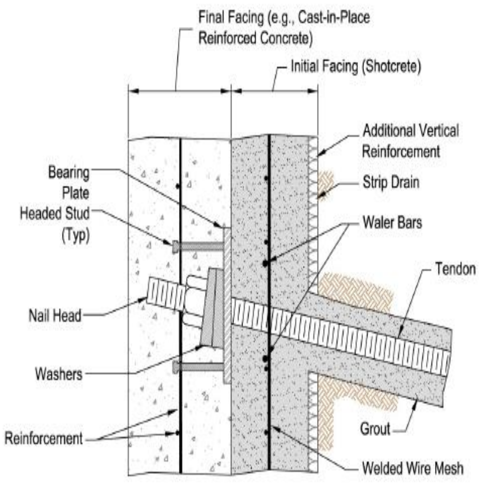

Fig.1. Typical cross section of soil nail wall, FHWA(2003)

effect on the soil nail system are also studied. Fig 1 shows typical cross section of the soil nail system.

II. NUMERICAL SIMULATIONS

A. Conventional Design

The manual design procedure (FHWA (2003)) consists of two parts in the design, a preliminary design and the final design. The final design includes analysis of external failure modes (global stability and sliding stability), analysis of internal failure modes (nail pullout failure and nail tensile strength failure), design of permanent facing and verification of important facing failure modes (facing flexure failure and facing punching shear failure), and influence of other site-specific considerations, such as seismic loading. The model and material parameters are as mentioned in Table I. In the present study, only the important internal failure modes and facing failure modes are considered to assess and compare the performance of (conventionally designed) soil nail wall. Table II comprises of conventional design details. It is observed that the factors of safety are greater than the target assumed thus making the design procedure dependable.

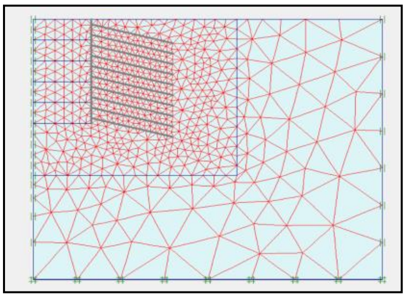

Fig. 3. Finite Element Model of Soil Nail Wall

Please Note: The values taken in Table 1 are from an already published information (Shivakumar Babu et al, 2002), for comparison of the paper for validation.

TABLE I. MATERIAL PROPERTIES

Parameter	Value
Vertical height of wall, H, m	10m
Face batter, α, degrees (with vertical)	0
Slope of backfill, β, degrees (with horizontal)	0
Soil type	Dense silty sand
Cohesion, c, kPa	5
Friction angle, φ, degrees	31.5
Unit weight, γ, kN/m^3	17
Modulus of elasticity of soil, Es, MPa	20
Poisson's ratio, ν	0.3
Nail installation method	Rotary Drilled and grouted
Grade of steel	Fe415
Modulus of elasticity of nail, En, GPa	200
Nail spacing, S_V x S_H , m x m	1x1
Nail inclination (wrt horizontal), i, degrees	15
Drill hole diameter, D_{DH}, mm	100
Nail diameter, D_{DH}, mm	20
Compressive strength of grout, f_{ck}, MPa	20
Ultimate bond strength, qu, kPa	100
Modulus of elasticity of grout, E_g,GPa	22

B. Numerical Simulation Result

Before doing any numerical simulation, it is necessary to check the boundary and convergence effects of the software on the model. In the present study efforts were made to find out finite length of soil beyond the soil nail representing semi-infinite soil medium to be adopted on either side of the soil nail model. For this purpose, suitable lengths beyond the soil nail system are considered and soil parameters are idealized and modeled in PLAXIS. The soil length on both side of soil nail wall is considered to be a function of H in the model, where H is the height of the wall. The stress and displacement parameters were computed at different locations on either side of the soil nail wall. Fig 3 shows the typical soil nail wall showing points at which the displacements and stresses are calculated.

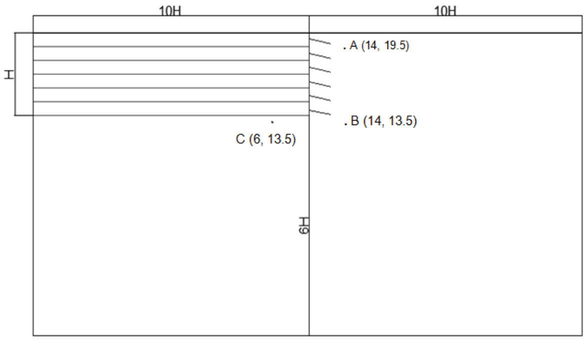

Fig. 2. A typical Soil-Nail Model showing the points for tabulating Displacements and stresses

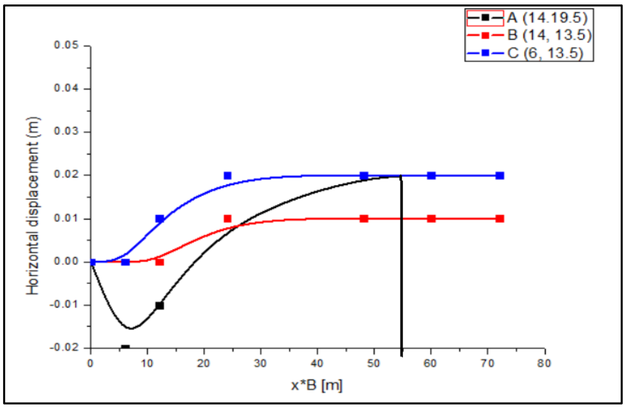

Fig. 4. Variation of Horizontal Displacement with boundary width

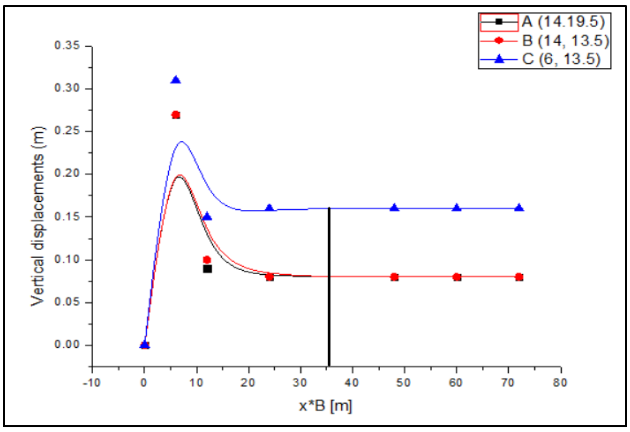

Fig. 5. Variation of Vertical Displacement with boundary width

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The stress and displacement parameters in horizontal and vertical directions are computed and thus the graphs are generated. It is observed that lengths of 10H on both side and 6Hbelow the base of wall yield satisfactory results. The effect of boundary is not felt close to the soil nail system either in terms of stresses or in terms of deformation. Fig 4 and Fig 5 show the boundary effect range on the system.

Fig 6 and Fig 7 show the effect of convergence on horizontal displacements and vertical stresses respectively on the soil nail wall. The global coarseness setting in governs the average element size and the number of triangular elements generated. At the most vulnerable locations, stresses and displacements are tabulated and it is observed that idealization with medium to fine mesh size yielded satisfactory results.

In order to study the behavior of soil nail system and for its stability analysis, numerical simulations were made using PLAXIS 2D. For preliminary design, input data was obtained from reference manual (FHWA (2003)). A two dimensional plane strain 15-noded finite element model was idealized. The model was idealized for a 10m vertical cut for soil nailing with grouted nails installed at an inclination of 15degrees and spaced at 1m both vertically and horizontally. The initial facing is provided at the face of the wall simultaneously at each excavation stage and the nails are installed using centralizers. The angle of 15 degrees inclination helps in easy installation of the nail and easy flow

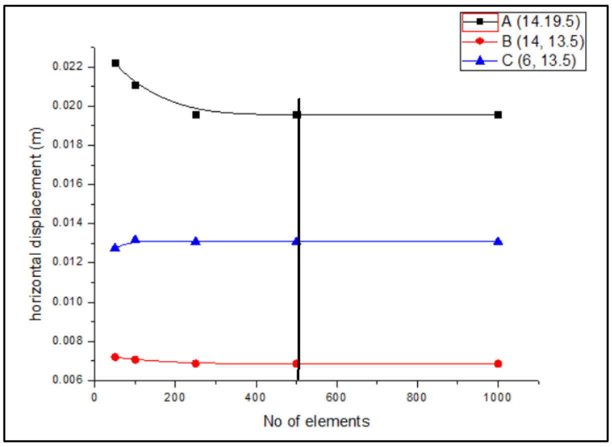

Fig.6.Variation of Horizontal Displacement with Mesh Size

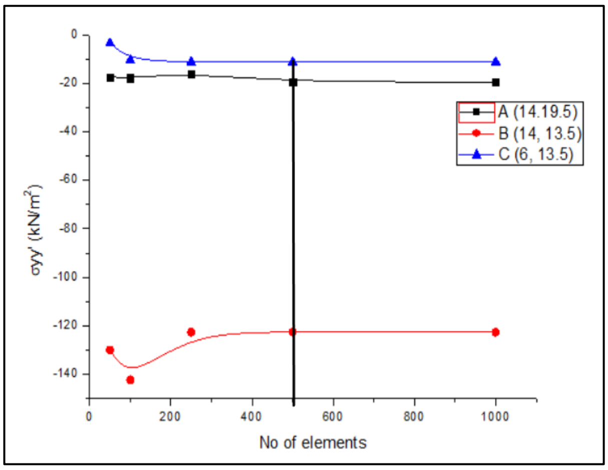

Fig. 7. Variation of Vertical Stresses with Mesh Size

of the grout into the drilled hole. The finite element model is as shown in Fig 2.

The theoretical value obtained for maximum tensile force developed in the system of soil nails is 47.60kN and maximum tensile force at the nail head is 28.56kN. The value from the numerical simulations in PLAXIS for maximum tensile force is 79.10kN and at the nail head it is 7.013kN. It is observed that the maximum tensile force obtained from the numerical simulated model is much higher than the theoretical value (about 40%). It is mentioned in the FHWA manual (2003), that the maximum axial force of the system varies between $0.5K_a\gamma_sHS_HS_V$ to $1.1K_a\gamma_sHS_HS_V$, i.e., between 40.63kN to 89.37kN for this problem, where the maximum tensile force obtained is well within the limits.

Also, maximum tensile force at the nail head (face of wall) is about 90% of the maximum tensile force of the nail, where in theoretically it is about 60% of the maximum tensile force. As per the reference manual, the values of T_o vary approximately 60% to 100% the maximum tensile force. Form these results, it can be inferred that the soil present in between the nails is responsible for the redistribution of forces in nails.

TABLE II. CONVENTIONAL DESIGN DETAILS

Description	**Formulae**	**Value**
Normalized Bond Resistance, μ	$(quD_{DH})/(FS_{PO}\gamma_sS_HS_V)$	0.29
Normalized SN length , L/H	from the charts of FHWA(2003)	0.65
Normalized,t_{max}		0.29
Correction for drill hole dia, C1	$C1=1.50-0.15D_{DH}+0.0065D_{DH}^2$	1.00
Correction for cohesion, C2	C2=-4.0c*+1.09	0.97
Correction for $F_{OS,}$ C3	$C3=0.52FS_{OS}+0.30$	1.00
Correction for drill hole dia, T1	$T1=-0.3+0.4D_{DH}-0.017D_{DH}^2$	1.00
Correction for cohesion, T2	T2=-4.0c*+1.09	0.97
Corrected Length factor, L/H*	C1*C2*C3*L/H	0.63
Corrected Tmax factor, t_{max}*	$T1*T2*T_{max}$	0.28
Length of the Nail, L, m	rounded up	7.00
Maximum tension in the Nail, T_{max}, kN	$\gamma_sS_HS_Vt_{max*}$	47.60
Tension at face $T_{o,}$ kN	$T_{max*}(0.6+0.2(S_{max}-1)$	28.56

As per FHWA (2003), the maximum axial force in the nail occurs at 0.3 to 0.4 of the Nail length at upper $2/3^{rd}$ of the system and at 0.1 to 0.2 of the nail length towards the lower bottom. This approximately holds good for the numerically simulated model.

The results are also verified with already published information. The maximum axial force developed in the nails according to the published information (Shivakumar Babu et al, 2002) was 78.20kN. This value has less error with the result obtained from the numerical analysis using PLAXIS. This error might be due to the changes in the calibration capacity of the system (laptops and desktops) and also depends on the type of meshing adopted. For any soil nail project, the maximum axial force developed in the nail is an important aspect for calculating factors of safety for internal stability. Thus comparing the axial force values, it can be concluded that the method adopted here is acceptable.

The PLAXIS model was initially prepared for no fixity condition between the nail and facing element as carried out in general. Only after this verification, the study on the effect of fixity condition between nail and facing element is carried out. The results from the numerical simulations for all four fixity conditions i.e., no fixity, horizontal fixity, vertical fixity and total fixity are as shown in Table III**.**

III. RESULTS AND DISCUSSIONS

A. Axial Force Development

Fig 8, Fig 9and Fig 10show the axial force developed along the length of the nail for 5th nail and 10th nail

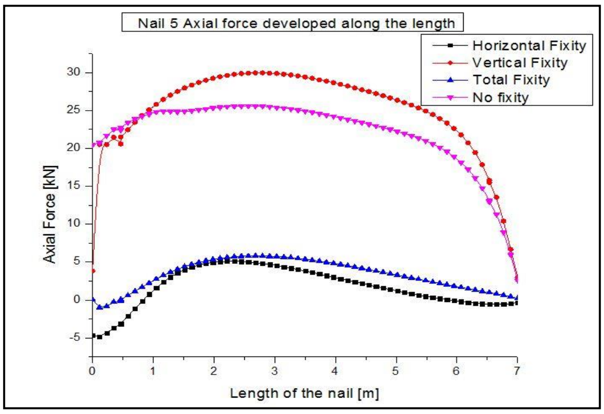

Fig. 8.Axial force developed in Nail 5 along its length for all 4 fixity cases

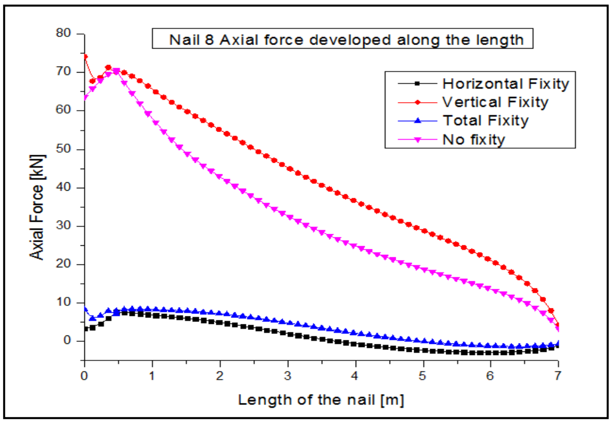

Fig.9. Axial force developed in Nail 8 along its length for all 4 fixity cases

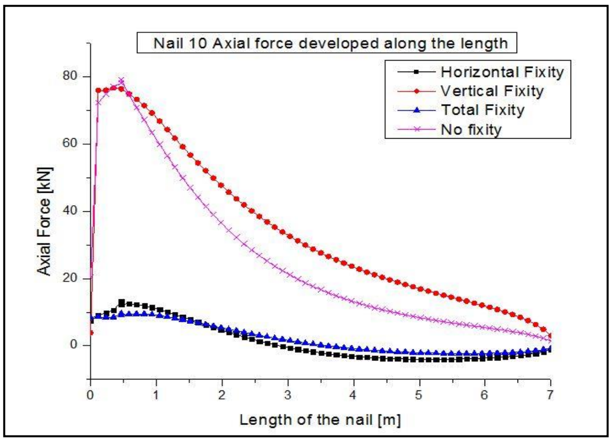

Fig.10. Axial force developed in Nail 10 along its length for all 4 fixity cases

(bottommost nail). It can be observed that the axial forces developed along the length are greatly decreased when horizontal and total fixities are provided. It is also seen that vertical fixity has less or no effect on the nail's axial force development when compared to no fixity condition. The reduction in axial forces in the nails is due to the reduced displacement of the soil, which in turn reduces the frictional and bond resistance developed between soil and grouted nail interface along its length. Where as in vertical fixity condition, the soil is free to move in horizontal direction to some extent and vertical heaving of the soil at face is only reduced.

B. Maximum Axial Force

The maximum axial force developed in the nails is taken into account for studying the performance of the soil nail system. From Table III, it can be observed that the maximum axial force developed in the nails is reduced considerably when horizontal and total fixity conditions are used. It is also observed that the force at the nail head has considerably decreased due to the provision of horizontal and total fixities.

C. Shear Force and Bending Moment

The shear and bending resistances of the soil nail are mobilized only after relatively large displacements have taken place along the slip surface. Elias and Juran (1991) have observed that shear and bending nail strengths contribute less to the overall stability of the wall. Due to this relatively moderate contribution, the shear and bending strengths of the soil nails are conservatively neglected in the conventional design procedure.Fig 11 and Fig 12 show that the variation in the shear forces near the nail surface is less affected by fixity conditions. Also, Fig 13 and Fig 14 show that the bending moment near the nail surface has less effect on fixity conditions. However, it should be seen that shear force and bending moment are considerable near the junction between facing and soil nail indicating the importance of good connection and stiffer nail at the edge.

D. Horizontal Displacement

Fig 15 shows the displacement pattern of the soil nail wall for different fixity conditions. It was observed that the displacement at the wall face was less in case of horizontal and total fixities. Also, for vertical fixity, the displacement pattern was similar to that of no fixity condition. Therefore,based on the observation, it can be assumed that the bearing plates that are provided only act as vertical fixities.

TABLE III. NUMERICAL SIMULATION RESULTS

Description	Value			
	No fixity	Horizontal fixity	Vertical fixity	Total fixity
Maximum Axial Force, kN	79.10	10.86	78.16	9.62
Maximum Nail Head Axial Force, kN	20.13	7.204	78.16	8.45
Horizontal Displacement of wall surface, mm	20.64	3.46	22.67	2.25
Maximum Shear Force, kN	16.08	8.75	9.03	5.58
Maximum Bending Moment, kN-m	2.54	1.27	1.06	0.78

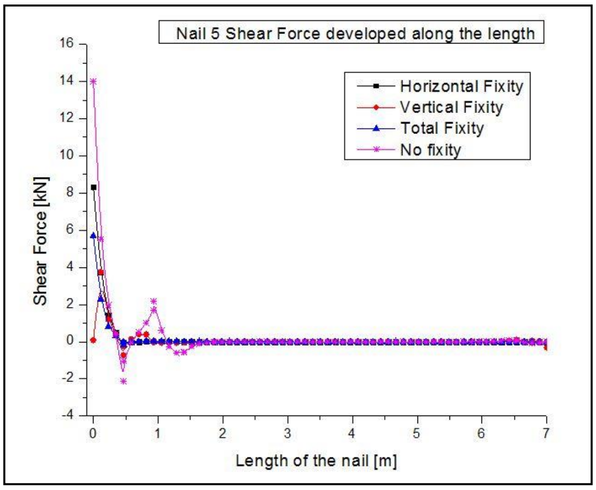

Fig.11. Shear force developed in Nail 5 along its length for all 4 fixity cases

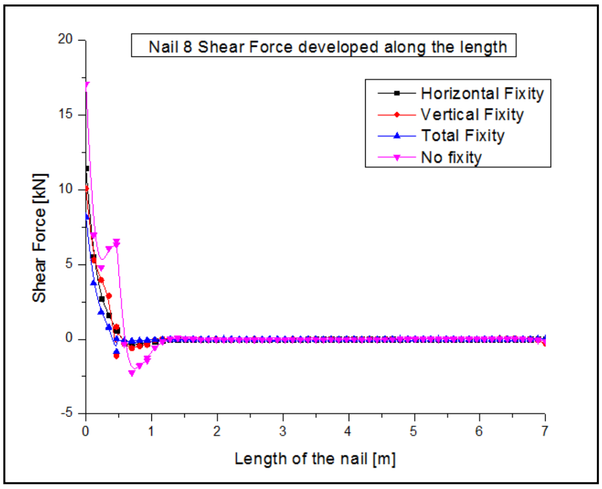

Fig.12. Shear force developed in Nail 8 along its length for all 4 fixity cases

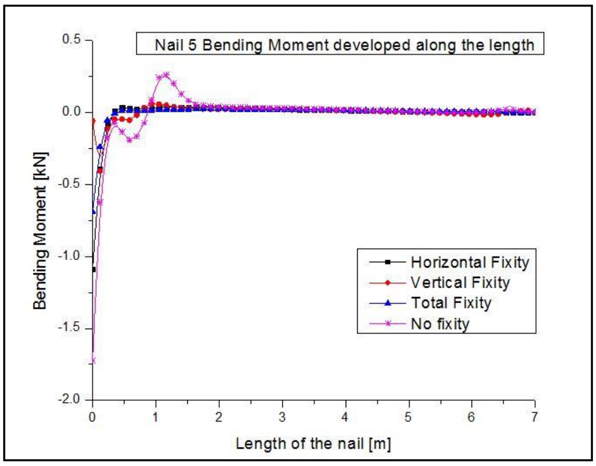

Fig. 13. Bending moment developed in Nail 5 along its length for all 4 fixity cases

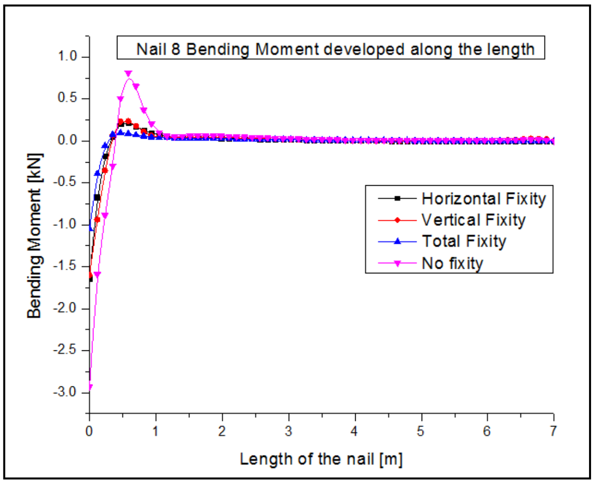

Fig. 14. Bending moment developed in Nail 8 along its length for all 4 fixity cases

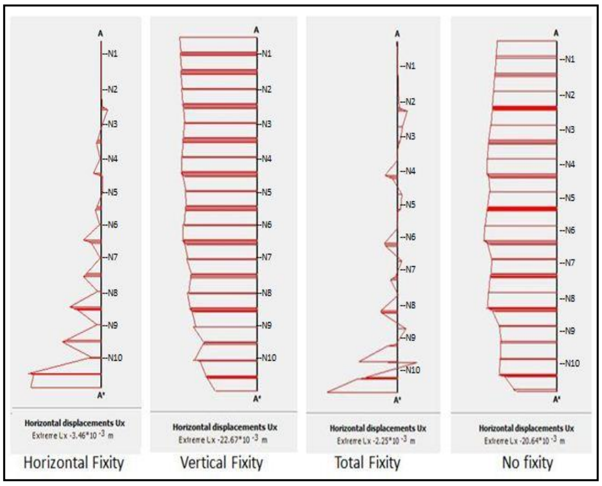

Fig. 15. Displacement pattern of the Soil Nail system for types of fixities considered

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IV. CONCLUSION

The bearing plate and other connecting components at the facing and nail junction help in ensuring fixity. By providing suitable total or at least horizontal fixity, the performance of the system can be improved to a very large extent. It is observed that the axial forces in the nails reduce considerably due to the provision of fixity. Since the factors of safety for internal stability and external stability depend on axial forces for the soil nail system, the factors of safety obtained will also be considerably higher. Vertical fixity has no or very less effect on the performance of the system. Also fixity conditions have less effect on the flexural stress mobilization on the system. Thus while providing connection components and initial facing, necessary precautions should be taken so that they act as total or horizontal fixities and thus providing more efficient soil nail wall.

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