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Comparative Analysis of the Driven and Grouted Soil Nail using Numerical Simulation

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Abstract

Soil Nailing is an in-situ method of soil retention where a long slender reinforcing member are installed in closed space on an in-situ soil either by driving or drilling and grouting method. Soil nailing technique are classified into different types according to their mode of installation. In Driven type of soil nailing, nail is directly driven into the structure along with the excavation whereas in drilled and grouting type of soil nailing, nail is installed in the predrilled hole and hole is filled with grout at low pressure. Different methods are available to design the soil nail wall among these numerical methods using finite element modelling is also a one of popular method. Here, in this study a comparative analysis between the driven and grouted nail is performed using finite element analysis in Plaxis 2D. As soil nail element are primarily subjected to the axial tensile force, Plaxis 2D allows to simulate soil nail element by taking element types as geogrid, plate or embedded beam element. In this study both driven and grouted soil nail is simulated as all three element type and Factor of Safety, deformation at the top of the wall, and induced maximum axial tension force and different depth of construction is observed. Results shows that Factor of Safety of the grouted soil nail is more as compared to the driven nail while taking nail element as an embedded beam. Top deformation of the wall is found to be more in case of driven soil nail as compare to the grouted nail in all three element types and there is no significant difference in the induced axial tension along both grouted and driven soil nail.

Keywords

Soil Nail, Driven, Grouted, Plate, Embedded beam, Geogrid

1. Introduction

Soil Nailing is an in-situ method of soil retention[1], where a long slender member are installed closed spacing on a in-situ soil either by driving or drilling and grouting methods. Although soil nailing is developed out of the "New Austrian Tunnelling Method", soil nailing can be used in various other underground and surface works in the field of the civil engineering[2]. Soil nailing activities has becoming popular in recent days due to its flexibility, easy adaptability, environment friendly, easy and fast construction rate[3]. Different components of the soil nailing consists of Reinforcement bar (Nail or Tendon), Nail head, Grout, Centralizers, Temporary and Permanent facing[4].

Based on the method of the installation, soil nailing technique are classified into several types. Common types of soil nailing technique include drill and grouted soil nailing technique, driven soil nailing technique, self-drilling soil nail method, jet grouted and launched soil nail methods. Drill and grouted is the most common soil nailing technique where a nail is inserted on the predrilled hole then hole is filled by grout at low pressure. It can be used for both permanent and temporary structure. Driven soil nailing technique is the method where nail is driven to the structure along with the excavation. This type of nailing technique is suitable for the temporary purpose.

Various numerical study had been carried out in order to perform the numerical analysis of the soil nail wall using finite element methods. Study had been carried out to determine the influence of the orientation of the nail layout on the safety and deformation of the structure. A study carried out by Alsubal and Harap on the stability of the slope by varying the spacing of soil nail shows that stability of the slope decreases with increase in spacing between the nails[5]. Johari, Hajivand, and Binesh performed the reliability analysis of the factor of safety, deformation and axial tensile force using the random finite element analysis[6]. Babu and Singh performed the two-dimensional analysis a soil nail wall in a Plaxis 2D by simulating the nail as both geogrid and plate material. Similarly, Another study performed by Babu and Singh using FEM method suggest to use of advance models like hardening model to simulate the soft soil[7].

2. Materials and Methods

2.1 Wall Geometry

A numerical simulation of 12m depth vertical excavation is performed in a clayey sand. Soil nailing is supposed to performed by using both driving and grouted methods for the analysis. On both method identical soil nail is used with same inclination and spacing. Drilling operation is performed in before the insertion of the soil nail in case of drilled grouted nail whereas nail is directly driven in case of driven soil nail. Shotcrete is used as permanent facing in both cases. A surcharge load of 8kN/m2 is simulated to represent the effect of operation of construction material [8].Summary of the soil nail wall and grouted nail and facing detail was shown in Table 1.The property and nail, grout and facing is taken from the article of GS Babu and Vikas Partap Singh[7].

Table 1: Soil Nail excavation geometry, Nail, Grout and facing

Parameter	Value
Wall Geometry	
Vertical Height of Wall H (m)	12
Face batter angle α(deg)	0
Backslope angle β(deg)	0
Nail, Grout and Facing [7]	
Material Property	Elastic
Yield Strength of Bar f_y (Mpa)	415
Elastic modulus of Bar E_n (Gpa)	200
Elastic modulus of Grout E_g (Gpa)	22
Elastic modulus of Shotcrete E_c (Gpa)	22
Drill hole Diameter D_{DH} (mm)	100
Facing thickness t (mm)	200
Live load during Construction (kN/m^2)	8

2.2 Soil Properties

Soil nailing operation is assumed to be performed in a clayey sand. Due to the limitation of the availability of the parameters from secondary data source soil model is simulated as a Mohr Columb model. Soil Parameter for the Clayey Sand is taken as secondary data from the article published by the J. Krahenbuhl and A. Wanger for the design and construction of the Trail suspension bridge in remote areas [9] and Soil Nailing manual published by Federal Highway Administration[8]. Values of the different soil parameters required for the numerical analysis of these four soils is summarized in the Table 2

Table 2: Soil Parameter used in Numerical Analysis

Parameter	Value
Cohesion, c (kN/m^2)	10 [9]
Friction angle, ϕ(deg)	27[9]
Dilatancy angle, ψ (deg)	0
Unit Weight, $\gamma(kN/m^3)$	19[9]
Modulus of Elasticity,$E(KN/m^2)$	20000[8]
Poissions ratio, ν	0.3[8]

2.3 Nail Parameters

Both driven and grouted soil nail is simulated as all three geogrid, plate type and embedded beam type element. Effect of these element type on the safety, deformation and axial force of the nail is observed. The detail nail parameters used for the simulation is shown in Table 3.

Table 3: Nail Parameter used in Numerical Analysis

Parameter	Value
Diameter of nail, d (mm)	25
Spacing of Nail, $S_h \times S_v (m \times m)$	1.5×1.5
Unit Weight, $\gamma_{nail}(kN/m^3)$	78.5
Skin Friction for Driven Nail below 8m(kN/m)	28.15 [8]
Skin Friction for Driven Nail above 8m(kN/m)	17.32 [8]
Skin Friction for Drilled Nail (kN/m)	43.32 [8]

2.4 Numerical Analysis

Fifteen nodded triangular elements under plane strain condition is chosen for the numerical analysis in “PLAXIS 2D”. Soil model is simulated as a Mohr Columb Model to analyse the results in the the $C-\phi$ soil and Nail element is simulated in all three elements type i.e. Geogrid, Plate element and Embedded Beam. Plaxis 2D under plane strain condition cannot simulate the soil nail as axisymmetric cylindrical soil nail model so it is simulated as a rectangular element. In order to simulate soil nail as geogrid element axial stiffness (EA) per unit length and in order to simulate nail element as a plate element both bending stiffness (EI) and axial stiffness (EA) per unit length is required.

For the grouted nail as a geogrid, plate and embbeded beam row element, equivalent modulus of elasticity is need to be obtained to calculate the value of the axial stiffness and flexural stiffness. Equivalent modulus of elasticity (E_{eq}) is obtained by considering the elastic stiffness of both grout and nail. The equation for ($E_{eq.}$)is given in Equation 1

$$E_{eq} = E_n \left(\frac{A_n}{A}\right) + E_g \left(\frac{A_g}{A}\right) \quad (1)$$

Axial Stiffness and Bending stiffens is calculated as:

$$EA[kN/m] = \frac{E_{eq}}{S_h} \left(\frac{\pi D_{DH}^2}{4}\right) \quad (2)$$

$$EI[kNm^2/m] = \frac{E_{eq}}{S_h} \left(\frac{\pi D_{DH}^4}{64}\right) \quad (3)$$

Where:
E_{eq} = Modulus of elasticity of nail
A_n= Area of the Nail ($A_n = 0.25\pi d^2$)
d = Diameter of Nail
A = Cross-Section area of the hole (A = $0.25\pi D_{DH}^2$)
E_g = Modulus of elasticity of grout
A_g = Cross sectional area of the grout($A_g = A – A_n$)
D_{DH}= Diameter of hole
S_h = Spacing of Nail

After the definition of the material model a soil nail structure is created as shown in Figure 1. Separate model is used to simulate the nail model for all three-material type in both type of soil nail. A surcharge load as defined in Table 1 is applied to the top of the wall. A global medium mesh is selected whereas mesh is refined to half of its size in the vicinity of the soil nail element. The top boundary of the soil element is set free in both horizontal and vertical direction. Side boundary is set free in the vertical direction only and bottom boundary is confined in both horizontal and vertical direction. Different stages are constructed in order to simulate the construction procedure of the site. Excavation is performed with vertical height of 1.5m and nail is installed in middle of each excavation lift. Safety, Deformation and Induced Axial tension is observed in all stage of excavation.

3. Results and Discussion

3.1 Soil Nail as a Geogrid Element

Both driven and grouted Nail is simulated as a geogrid element in the Plaxis 2D. The effect of taking soil nail as a geogrid element on safety, deformation and axial tensile force of an element is shown in Figure 2, 3, 4 respectively.

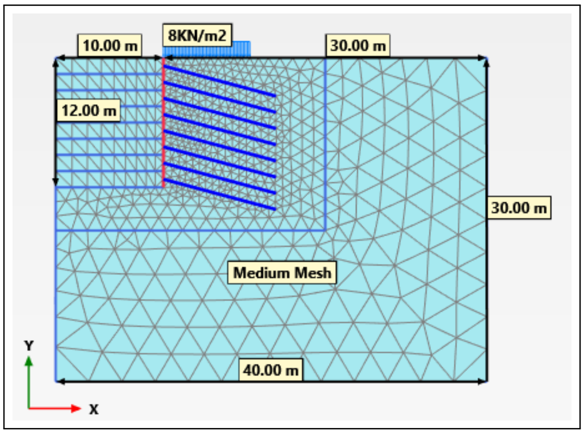

Figure 1: Soil Nail Model with mesh used for Analysis

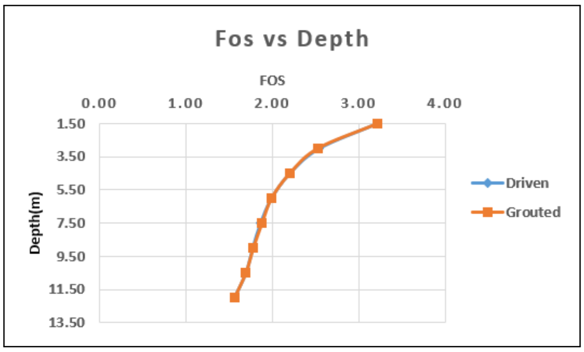

Figure 2: Fos of Driven and Grouted nail as Geogrid Element

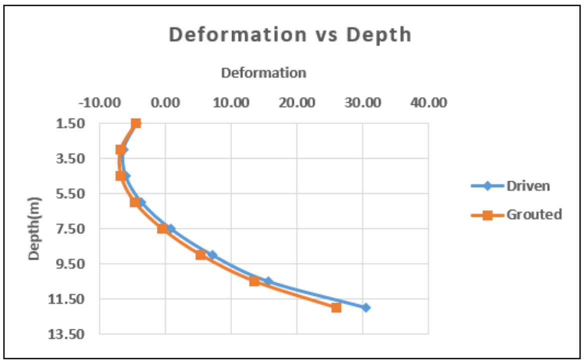

Figure 3: Deformation of Driven and Grouted nail as Geogrid Element

Numerical analysis of a soil nail wall taking soil nail element as a geogrid element shows that there is no significant difference in the safety of the structure in both the driven and grouted type nail in all depth of excavation. Top deformation of the nail wall at final depth of excavation seems to be high by 18% in case of driven nail. Maximum axial tensile force developed in the soil nail seems to be slightly larger in case of grouted nail at all excavation depth.

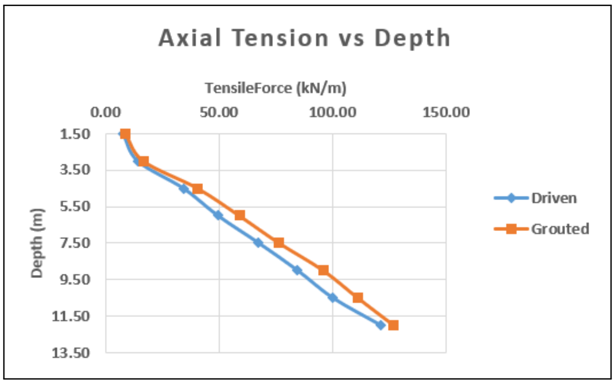

Figure 4: Axial Tension of Driven and Grouted nail as Geogrid Element

3.2 Soil Nail as a Plate Element

Both driven and grouted Nail is simulated as a plate element in the Plaxis 2D. The effect of taking soil nail as a plate element on safety, deformation and axial tensile force of a element is shown in figure 5,6, 7 respectively.

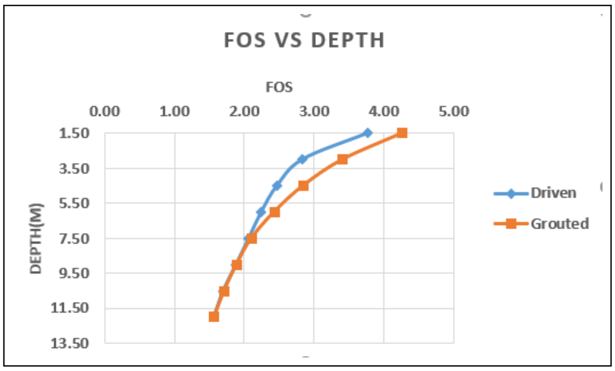

Figure 5: Fos of Driven and Grouted nail as Plate Element

Factor of the safety in both driven and grouted case is found to be same where as Factor of Safety of grouted nail is found to be higher at initial depth of the excavation. Deformation at the top of the wall is found to be 18% at final stage of excavation in case of driven nail. Axial tension force developed on the soil nail in both driven and grouted case is found to be similar in this case.

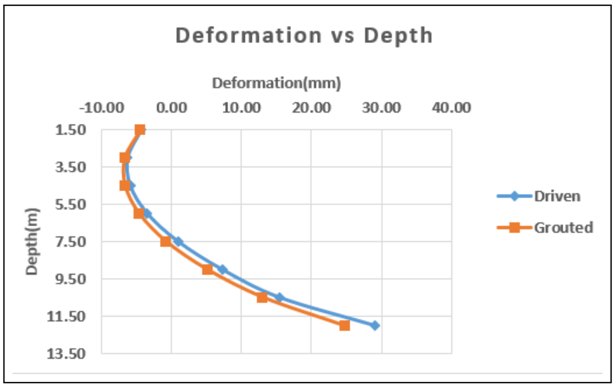

Figure 6: Deformation of Driven and Grouted nail as Plate Element

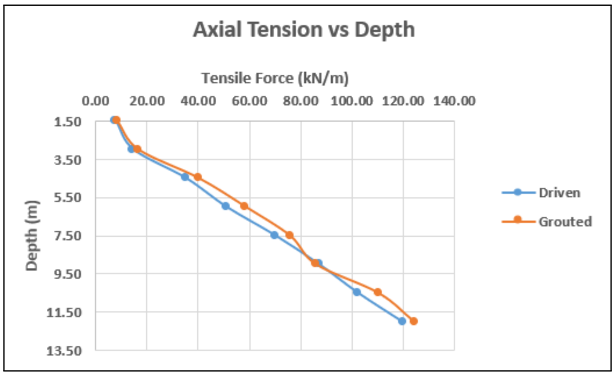

Figure 7: Axial Tension of Driven and Grouted nail as Plate Element

3.3 Soil Nail as a Embedded Beam Row Element

Both driven and grouted Nail is simulated as a embedded beam row element in the Plaxis 2D. value of the frictional resistance for both case of grouted and driven nail given in Table 3 as suggested by the [8] The effect of taking soil nail as an embedded row element on safety, deformation and axial tensile force of an element is shown in figures 8, 9, and 10 respectively.

Numerical analysis of the soil nail wall by taking nail as a embedded beam row element shows that factor of safety of the soil nail wall is more by 19% in case of grouted nail as compare to driven element at all depth of excavation. In this case deformation of the soil nail wall with grouted nail is found to be more as compare to grouted nail. The difference between the deformation of the driven and grouted soil nail wall also increases with increase in excavation depth.

Axial tensile force developed in the grouted soil nail is slightly higher in all depth of excavation as shown in figure 10.

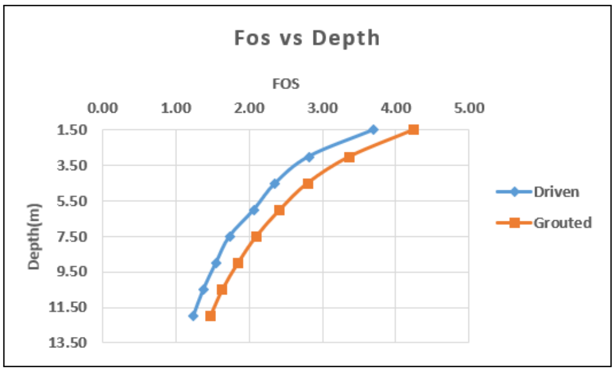

Figure 8: FOS of Driven and Grouted nail as Embedded Beam Row Element

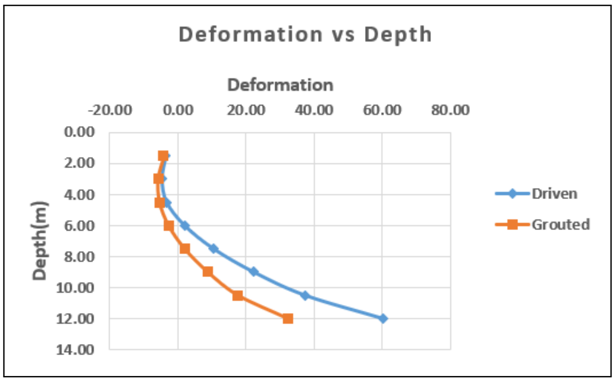

Figure 9: Deformation of Driven and Grouted nail as Embedded Beam Row Element

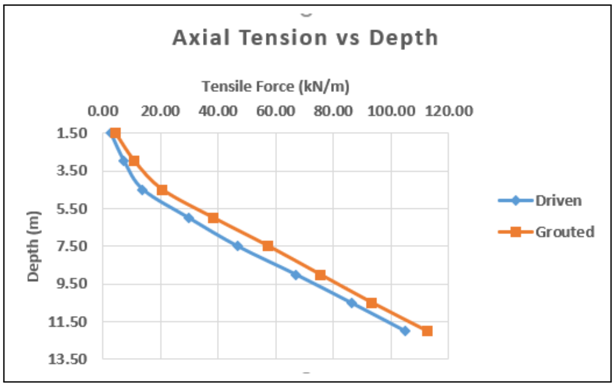

Figure 10: Axial Tension of Driven and Grouted nail as Embedded Beam Row Element

3.4 Verification

Similar results can also been seen in the different literature. A study by VP Singh and GL Babu on the numerical simulation of the grouted soil nail wall in PLaxis 2D shows the similar pattern in the safety, deformation and induced tensile stress in the soil nail element taking plate element as a geogrid and plate element [7]. Numerical study on a driven nail using finite deference software FLAC 2D on a prototype driven soil nail wall also conclude that there is increase in lateral deformation and tensile force with the increase in depth of excavation in a similar pattern[10].

4. Conclusion and Recommendation

This study shows the comparative analysis of the driven and grouted soil nail under similar condition. Safety, deformation, axial force developed in the soil nail is observed by simulating the nail element as geogrid material, plate material and embedded beam material. This study leads to following conclusion.

- There is no significant difference in the Fos between the driven and grouted nail in all stage of construction while taking nail as a geogrid element.
- Lateral deformation at the top of the excavation face is found to be around 18% more in case of driven nail while taking nail as a either geogrid element or plate element.
- There is no significant difference in the Maximum Axial Tension developed between the driven nail and drill grouted nail at final excavation stage while taking nail as a either geogrid element or plate element or embedded row element.
- Fos at the second stage of excavation in grouted nail is found to be 20% more than driven nail but there is no significant difference in Fos between both nail type in the final stage of excavation while taking nail as a plate element.
- Fos at the all stage of excavation in grouted nail is found to be around 20% more than driven nail while taking nail as a embedded beam row element.
- Lateral deformation at the top of the excavation face is found to be around 45% more at the final stage of excavation in case of driven nail while taking nail as a embedded beam element.

Results of the study conclude that there is a significant effect of the skin resistance on the safety, deformation and the axial force development. Embbeded beam row element shows the lower value of the safety, higher value of the deformation and lower value of developed axial tensile force as compare to the other geogrid and plate element type. The value of the skin resistance used in the analysis is theoretical value which depends upon various field parameters. So it is recommended to either to evaluate or verify the skin resisting while dealing with real life scenario.

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