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FEM Analysis of Soil Nails Performance in Excavation of Different Soil Types

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Abstract: Performance analysis of soil nail walls are generally carried out to ensure the stability of the soil. It has an important role in lowering the cost and time of the construction compared to other conventional systems which are in practice. In this study, an attempt has been taken to imply the Soil nails into two different advanced Finite Element soil models and variation in different inclination with the horizontal. Simulation analysis was carried out by using Plaxis-2D. From this study, the soil nail wall proved to be desirable reinforcement system to provide stability against the displacement for different soil types.

Keywords*:* Finite element models, Soil nailing, Material parameters, Global factor of safety.

1. INTRODUCTION

The soil nailing retaining system has major three components: the soil, the nail reinforcement and the facing unit of the soil nail walls. So, in this complete reinforced system, there is one complicated interaction exist between these major components of the system. The behavior of the soil nail walls in the post implemented stage is directly affected by the interaction between these aforesaid components. This interaction has two different parts which actually provide and increase the stability of the native soil mass. These two interactions are Reinforcement friction which is leading to axial tension and compression and transfer of tensile strength into the soil. Another one is Reinforcement bearing which leads to shear and stiffness. The strong interaction between the soil and the facing provides external stability of the Soil nail wall system to ensuring from direct sliding and overturning.

The conventional limit equilibrium system fails to address all these important factors. So, here the simulation analysis by using its rigorous calculation based on the Finite Element model able to provide the answers of all such unknown questions related to the performance of soil nail wall in long term.

2. GEOMETRIC NUMERICAL MODELLING

Commercially available software “Plaxis-8.2" for two-dimensional finite element analysis to measure the deformation and stability related to various Geotechnical problems. By using this software here, two advanced version soil simulation model: HS model, hardening soil small model has been analyzed here with the implication of the soil nails. In this software Plain-strain model and Axis symmetric model both are available here for the analysis and specially Phi-C reduction technique has been used here for the calculation of Factor of safety.

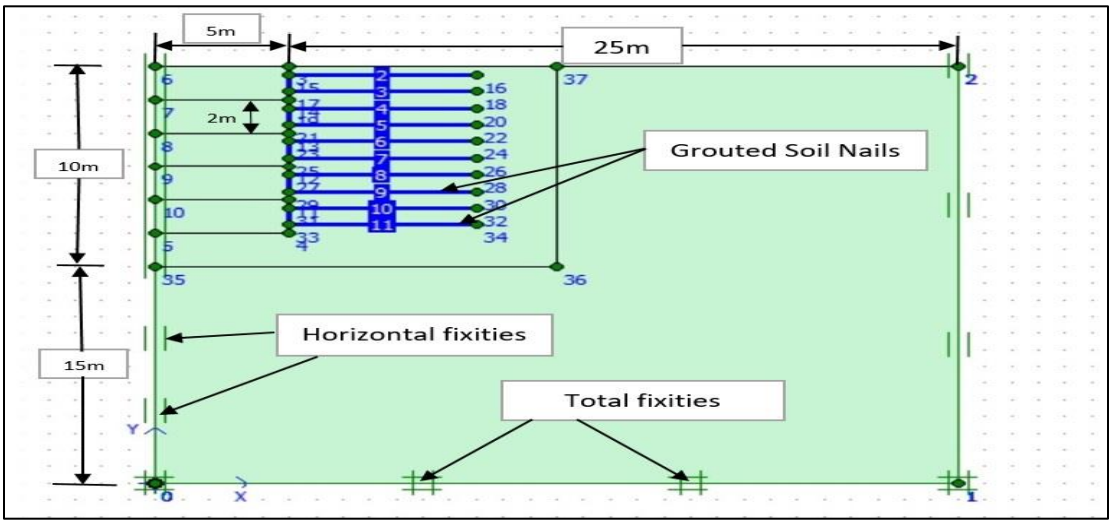


Figure 1: FEM soil nail wall with no inclination, 10m high

Along with that calculation of Axial stiffness, a parameter has been made through this simulation analysis. The following section will discuss the Material analysis, Material parameters choose for this study.

3. MATERIAL PARAMETERS

For the purpose of this study, here the taken height of deep excavation is 10m and along with it backfill material and vertical facing are also included here for the analysis. Conventional design and the calculation of the soil nail wall has been done here according to the FHWA (2003) design procedure.

The various parameters for the material which are selected for the simulation analysis of the soil model are summarised in Table 1 with their geometric configuration.

Table 1: Soil nails wall geometry and parameters:

Parameter	value
The Vertical height of the wall	10.0
Nail type	Grouted
Simulation model	Plain strain
Element type	15 node
Material model	Elastic
The Yield strength of reinforcement f_y (MPa)	415
Elasticity modulus of reinforcement E_n (Gpa)	200
Elasticity modulus of grout (concrete) E_g (Gpa)	22
A diameter of reinforcement **d** (mm)	20
Drill hole diameter D_{DH} (mm)	100
Length of nail L (m)	7
Inclination with horizontal I (deg)	15 and 0
Spacing S_h x S_v (m x m)	1.0 x 1.0
Facing thickness t (mm)	200

For Finite element model analysis of Soil nail wall system, Plain –strain model and drained conditions are considered here. Simulation analysis has been performed here with HS model and HS-small model with a variable angle of inclination of soil nails for both the afore-mentioned models and the output results are located including Global factor of safety, Axial stiffness and strength and bearing stiffness after different construction stages.

Table 2: Soil model parameters (Bringreve et al.2006)

Parameter	HS	HS small
Cohesion c (kN/m^2)	**10.0**	**10.0**
Friction angle φ (deg)	**27.5**	**27.5**
Unit weight γ (kN/m^3)	**19.0**	**19.0**
Secant stiffness in standard drained Triaxial test E_{50}^{ref} (kN/m^2)	**20,000**	**20,000**
Tangent stiffness for primary oedometer loading E_{oed}^{ref} (kN/m^2)	**20,000**	**20,000**
Unloading/reloading stiffness E_{ur}^{ref} (kN/m^2)	**60,000**	**60,000**
Reference shear modulus G_0^{ref} (kN/m^2)	**-**	**75,000**
Reference stress for stiffness P_{ref} (kN/m^2)	**100.0**	**100.0**
Poisson's ratio ν	**0.2**	**0.2**
Power for stress level dependency of stiffness m	**0.5**	**0.5**
Shear strain at which $G_{secant} = 0.7\ G_0$ $\gamma_{0.7}$	**-**	**0.0001**

The basic objective of this study to bring out the comparative performance analysis of different soil model with the different angle of inclination of soil nails induced in it.

Here the selected advanced soil model has the capability of simulation analysis for both the soft soils and the stiff soil. These soil models required large numbers of input parameters compare to conventional Mohr's-Coulomb soil model. Here three numbers of stiffness parameters are present: $E_{o\text{-}ed}$ – The Oedometer stiffness of loading, E_{ur} –The Triaxial stiffness unloading, E_{50}- The Triaxial stiffness loading are specially included in this advanced soil model.

4. CALCULATION OF EQUIVALENT SOIL NAIL PARAMETERS

For the simulation of the soil nail wall the most important parameters to include are Axial stiffness **EA** and Bending stiffness **EI.** In Plaxis for both Plate and Geo-grid is the rectangular element of 1m width, but the soil nail has the circular cross-section and has to be placed horizontally according to the design itself, so it is very important to find out the Equivalent axial and bending stiffness for accurate simulation analysis.

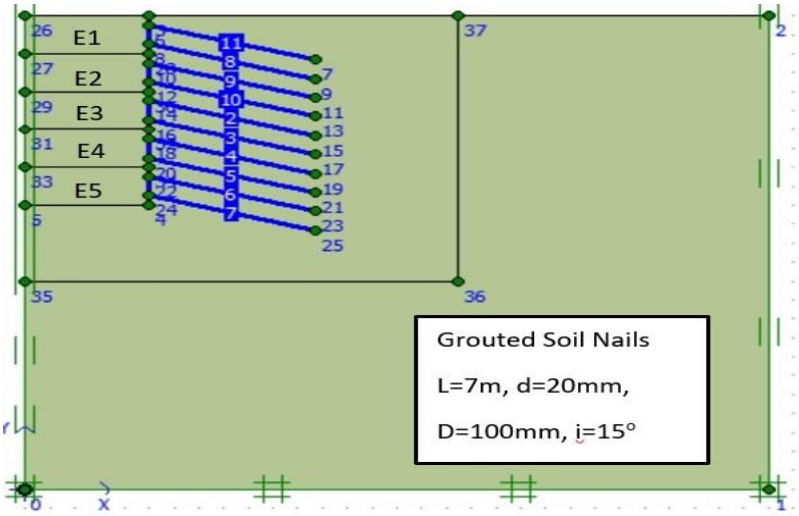


Figure 2: The Simulation model of soil nail wall with a 15-degree inclination and nail length-7m

Calculation of Equivalent modulus of elasticity: It can be determined as:

$E_{eq} = E_n (A_n/A) + E_g (A_g/A)$

Where, E_g= Modulus of elasticity of grout material

E_n= Modulus of elasticity of Nail

E_{eq}= Equivalent modulus of elasticity of grouted soil nail

$A= 0.25\ \pi\ (D_{DH})^2$ =Total cross-section area of grouted nails

$A_g = A-A_n$ = Cross-section area of grout cover

$A_n= 0.25\ \pi\ d^2$ = Cross-section area of reinforcement bar

D_{DH}= Diameter of the drill hole

So, from the above equation and by putting the calculated value of Equivalent modulus of elasticity of the grouted soil nail it's then easy to determine the accurate value of Axial stiffness and Bending stiffness from these below equations:

Axial stiffness EA (kN/m)= $E_{eq}/s_h\ (\pi\ D^2_{DH}/4)$

Bending stiffness EI (kNm^2/m) = $E_{eq}/s_h\ (\pi\ D^4_{DH}/64)$

5. SIMULATION ANALYSIS

Here two types of advanced soil models are considered for the numerical simulation analysis with the inclusion of soil nail walls with the different inclination of
$\Theta= 0^o$ and $\Theta= 15^o$ and the stage-wise construction and performance analysis have been done here by numerical modeling.

Case1: HS model with $\Theta= 0^o$ and $\Theta= 15^o$

Case 2: HS small model with $\Theta= 0^o$ and $\Theta= 15^o$

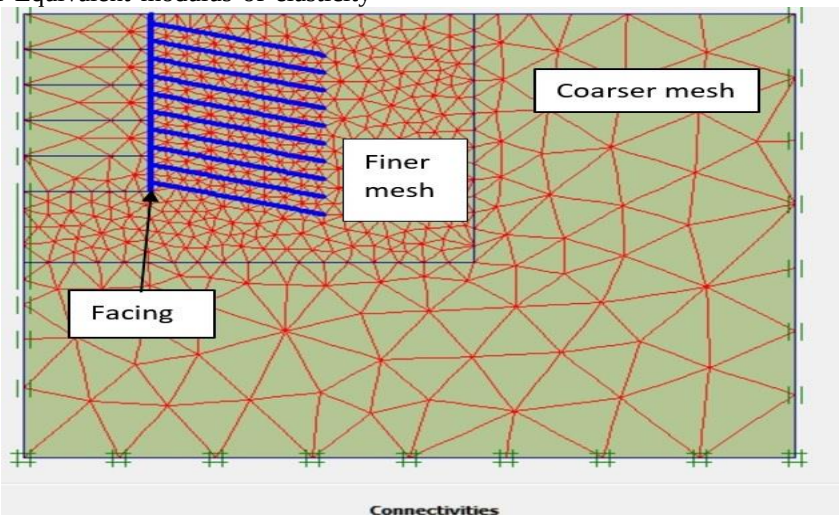


Figure 3: Simulated soil nail wall with different clustered mesh generation

Here finer mesh generation has been created for more accurate calculation and analysis of soil nail wall, and 5 stages of excavation of total depth of 10m performed stage wise with a 2m depth of each stage. After each stages Global factor f safety was calculated by Phi/c reduction technique and by this here the critical failure mechanism was identified automatically. According to the FHWA recommendation, the value of Global factor of safety should be equal or greater than 1.5, to follow this length of the soil nails should be prolonged up to a passive zone of failure if required.

Results and Discussions: Here static analysis was carried out to find the effect of with angle of inclination and without the angle of inclination of soil nail in two different advanced soil models.

- **Analysis of Factor of safety:** The value of Global factor of safety with the different construction stages for different soils are tabulated and plotted here accordingly.

Table 3: Global FOS with construction stages: (Θ=15^o)

The depth of excavation in meters	Construction stages %	No. of Nails	The Global factor of safety	
			HS model	HS small model
2	20	2	5.939	5.962
4	40	2	3.785	3.831
6	60	2	2.565	2.682
8	80	2	1.850	1.9
10	100	2	1.420	1.357

From the above data, it has been shown that the value of the factor of safety is decreasing with increasing amount of depth as well as construction stages.

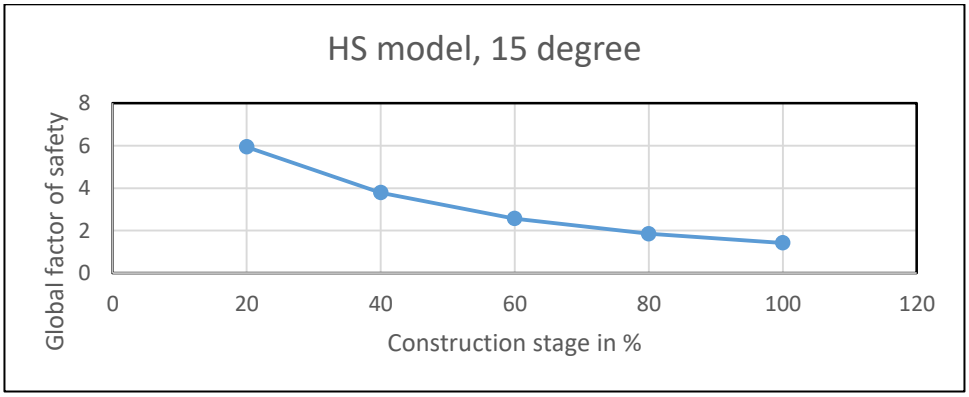


Figure 4: FOS with construction stages

- **Comparative analysis of FOS for different soils:** After the proper analysis from this plotted graph the output is showing that with same inclination but different soil model does not have many differences in their FOS values but same soil model with different inclination possess different values of FOS especially at their early stages of construction.

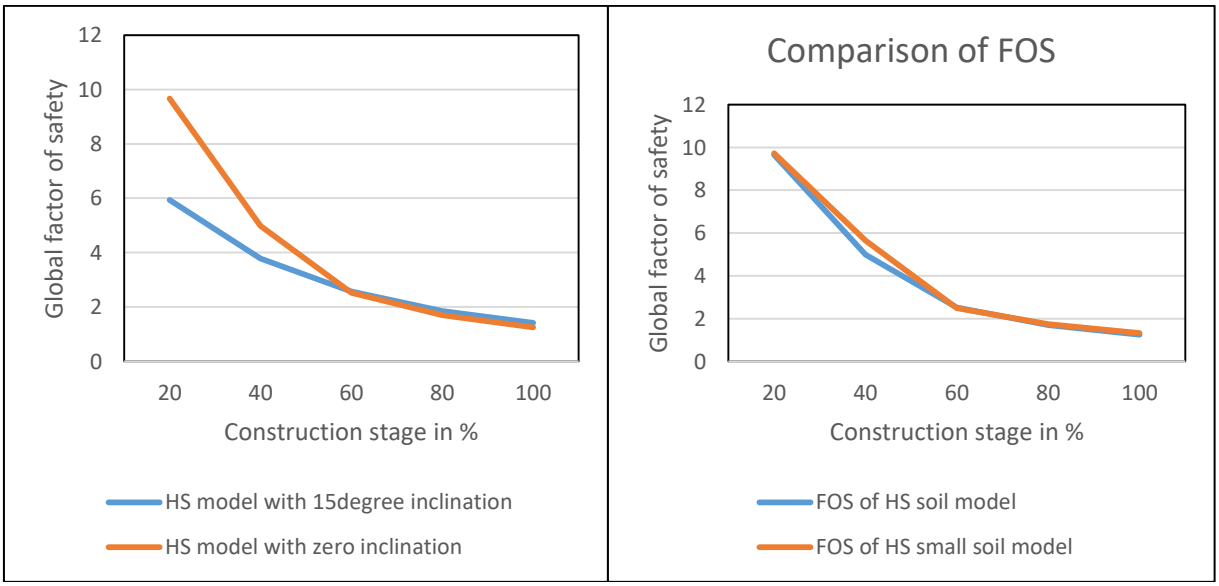


Figure 5: HS model with different inclination

Figure 6: Different soil model same inclination

- **Influence of Axial Force development in soil Nails:** The below-plotted graph is showing the development of maximum axial force with the construction stages of the soil nail walls, it has been observed that the maximum axial force developed along the length of the soil nail. The value of maximum axial force can be determined also theoretically by this formula, i.e. [$T_{max}=K_{a\gamma z}S_hS_v$] where K_a is the active earth pressure coefficient (FHWA 2003) and z= depth below the ground surface and S_h & S_v are the horizontal and vertical spacing of the soil nails respectively.

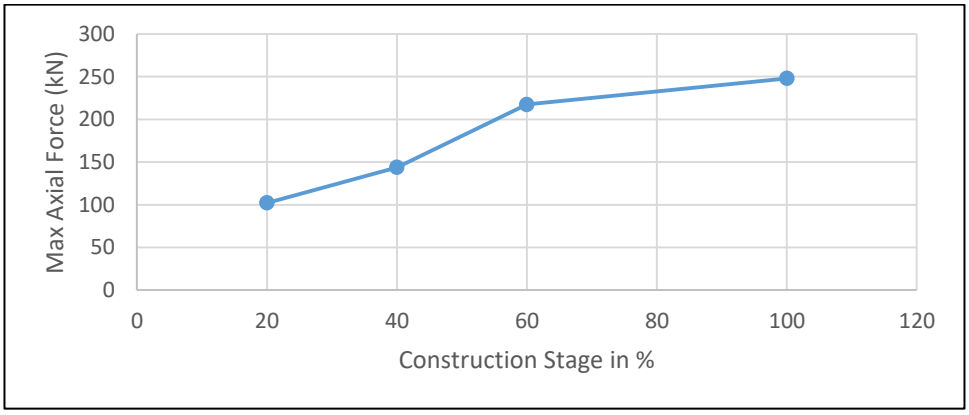
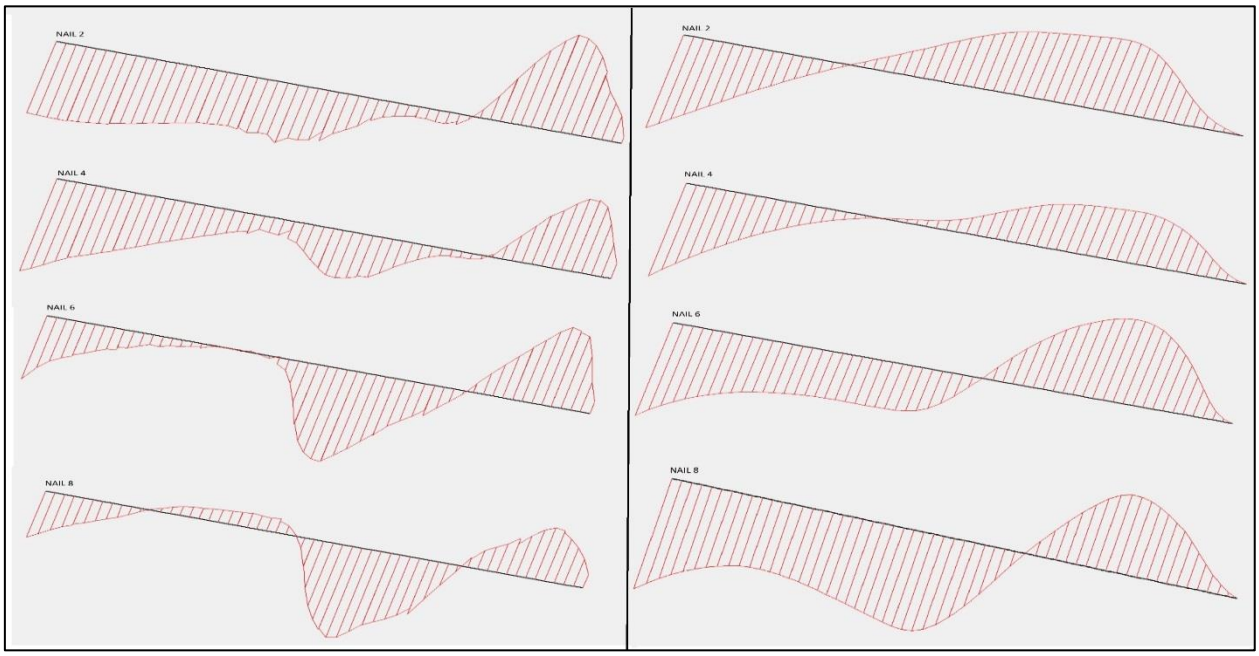


Figure 7: Development of Axial Force in soil nails

It has been observed from the graph that the change in value of maximum axial force with the related construction stages is linear in nature and also it has been found from the simulation analysis that the development of axial force with the development of bending moment and shear force in the nails does not possess any considerable influences for different soil models in this regards.

- **The Behaviour of Bending moment and Shear force of Soil Nails:** The effect of bending moment and shear force should not be ignored for soil nail analysis. In conventional analysis system sometimes Shear and Bending resistance of the soil nails ignored to some extent.



[Shear force] **[Bending moment]**

Figure 8: Variable SF and BM along nail length

In Finite element model analysis, it's an enlightening fact of consideration of BM and SF. From the given output results, it's perceived that maximum value of Bending moment and Shear force as well occurred for the Soil nail inclination of 15 degree, but some differences are also observed from the analysis that in the earlier stage of construction the Shear force value with no inclination is higher than the than the 15 degree inclined soil nails.

6. REMARKS AND CONCLUSIONS

This paper provides the comparative performance analysis of 10 m high Soil nail walls of two advanced finite element soil model. This analysis was time-consuming because of the choice of soil model which takes more time for analysis compares to the other finite element models and it is capable to provide a very small value of displacements also.

From this study it can be concluded that with the increase in depth the value of Global factor of safety decreased and with the increase in length of the soil nail it will automatically increase the stability of the soil especially at 10 m depth the length of the soil nails has to be prolonged after 7m also to maintain the desired level of Factor of safety.

It can also conclude that the finer mesh density helps to provide appropriate simulation analysis. This study provides the information that the Global factor of safety value HS soil model with zero-degree inclination possesses a greater value rather than the HS model with 15-degree inclination. But, with the same inclination value for both type of soil does not show any higher margin influence of having many different FOS values.

REFERENCES

[1]Sivakumar Babu GL, Vikas Pratap Singh(2010) 2D Numerical simulations of soil nail walls

[2]Chen CS et. Al. (2004) Failure of soil nail slopes.15th Southeast Asian Geotechnical society, Thailand

[3]Gurpersaud N.Vaanapalli, S.Sivathyalan(2013)Semi-empirical method for estimation of pullout capacity of grouted soil nails in saturated and unsaturated soil environments. Geo-tech geo-environ engineering.

[4]Shaw-Shong L(2005) Soil nailing for slope strengthening Gue & Partners Sdn Bhd.kuala Lumpur.

[5] R.J. Byrne, D. Cotton, J. Porterfield, C. Wolschlag, G.Ueblacker, Manual for Design and Construction Monitoring of Soil Nail Walls, Report FHWA-SA-96-69R, Federal Highway Administration, Washington, 1998.

[6] C. Lazarte, V. Elias, D. Espinoza, Sabatini. Geotechnical Engineering Circular No.7: Soil Nail Walls, Report No. FHWA0-IF-017, Washington, 2003, p. 182.

[7] PLAXIS b.v. 2002. PLAXIS 2D – [software]. (Version 8, Finite Element Code for Soil and Rock

Analyses). P.O. Box 572, 2600 AN DELFT, Netherlands.

[8] K.B. Ebert, Validation and Verification of the Commercial Finite Element Code PLAXIS for Non-Linear Geomechanics, University of Colorado, Colorado, 1994, p. 229.

[9] S.A. Tan, W. Cheang, P. Ooi, D. Tan, Finite Element Analysis of a Soil Nailed Slope-Some Recent Experience. 3rd Asian Regional Conference on Geosynthetics: Now and Future of Geosynthetics in Civil Engineering, 2004.

[10] K. Morrison, F. Harrison, J. Collin, A. Dodds, B. Arndt, Shored Mechanically Stabilized Earth (SMSE) Wall Systems Design Guidelines. Report No. FHWA-CFL/TD-06-001, FHWA, Lakewood, CO, 2006.

[11] B.S. Yiqing wei, Development of equivalent surcharge loads for the design of soil nailed segment of MSE/SOIL NAIL HYBRID Retaining walls based on results from full-scale wall instrumentation and finite element analysis, 2013.