Stabilization of vertical cut using soil nailing

G. L. Sivakumar Babu, Associate Professor
Department of Civil Engineering, Indian Institute of Science, Bangalore, Karnataka, India
Vikas Pratap Singh, Research Scholar
Department of Civil Engineering, Indian Institute of Science, Bangalore, Karnataka, India

Introduction

Soil nailing has been used extensively as an in-situ reinforcement technique in many parts of the world. The design and analysis are essentially based on limit equilibrium methods (Gassler and Gudehus, 1981; Juran, 1985). One of the important aspects of the analysis of in-situ earth reinforcement is in understanding the behaviour of soil-nailed retaining walls. In a soil-nailed retaining wall, the properties and material behaviour of three components—the native soil, the reinforcement (nails) and the facing element—and their mutual interactions significantly affect the performance of the structure. The behaviour of reinforced soil walls can be understood to some extent by studying the state of stress within the reinforced zone (Rowe and Ho, 1996). In addition, various factors such as the construction sequence, the installation of nails, the connection between the nails and the facing are likely to influence the behaviour. These influences are not adequately addressed in the conventional design procedures based on limit equilibrium methods, with which the wall in the present study was designed. Hence, for a better understanding of the behaviour, it is necessary to assess the stability and performance of soil-nailed walls using numerical simulations.

Applications of soil nail walls

Soil nail walls are particularly well suited to excavation applications for ground conditions that require vertical or near-vertical cuts. They have been used successfully in highway cuts; end slope removal under existing bridge abutments during underpass widening; for the repair, stabilization, and reconstruction of existing retaining structures; and tunnel portals. Figure 1a and 1b shows examples of the use of soil nail walls in temporary and permanent cut applications.

Soil nail walls can be considered as retaining structures for any permanent or temporary vertical or near-vertical cut construction, as they add stabilizing resistance in situations where other retaining structures (e.g., anchor walls) are commonly used and where ground conditions are suitable. The relatively wide range of available facing systems allows for various aesthetic requirements to be addressed. In this application, soil nailing is attractive because it tends to minimize excavation, provides reasonable right-of-way and clearing limits, and hence, minimizes environmental impacts within the transportation corridor.

Objective

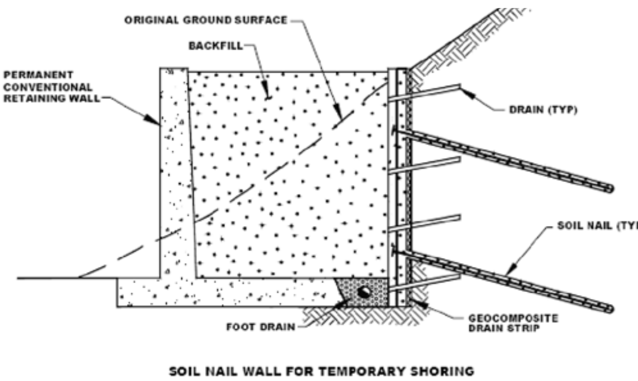
The objective of current study is to emphasize on the feasibility of soil nail wall as an effective technique of stabilization of vertical cuts. To accomplish this purpose a case study is referred, wherein, a 6.8m high vertical cut in soil was supported using Soil-Nail wall system. The cut was made for the approach road to the subway underneath a busy highway connecting two sections in an area of considerable importance in Bangalore.

A Soil-Nail wall system was designed conventionally based on the Federal Highway Administration (FHWA, 2003) guidelines. An extensive geotechnical investigation was carried out to assess in-situ soil conditions. The entire soil-nail wall system was numerically simulated using a finite element code PLAXIS. Various design variables were studied and compared. In particular, emphasis is laid on the effect of nailing on deformations and global factor of safety.

In-situ soil investigation and reinforcement properties

The in-situ ground is a residual soil deposit weathered to a moderate degree. No groundwater is found within the influence zone. The unit weight of the soil is approximately 18 kN/m3. Undrained shear tests on undisturbed saturated samples indicate that the large-strain total friction angle is 25º, and cohesion is in the range 10 – 20 kPa. The spacing and length of reinforcements were worked out based on the methods of Gassler and Gudehus (1981)and FHWA (1990). The overall factor of safety was computed as 1.5, and the factor of safety against pullout was 2.0. Ribbed mild steel bars 20 mm in diameter and 3500 mm long were used as nails and driven into the excavated soil.

The interfacial friction angle between soil and nail, φ_u, was determined from direct shear tests on representative soil samples, compacted to the field density and moisture content. The area of ribs/striations over the nail surface was measured as 6 %. This was represented in the direct shear box test by a mild steel plate (60 mm x 60 mm x 2 mm) with equivalent striations at the interface. The steel plate was fixed to a wooden plate (60 mm x 60 mm x 8 mm) and was used as the bottom half of the sample; the soil



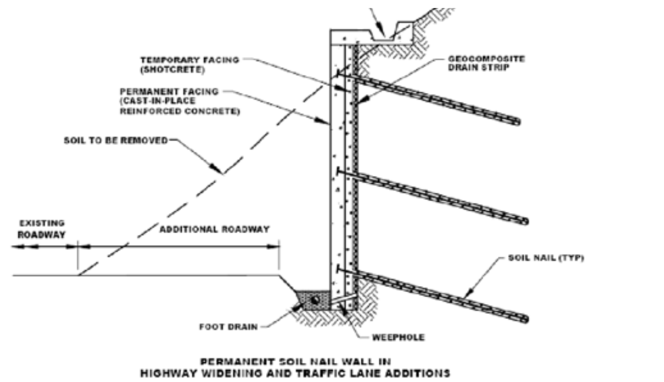


Figure 1. Examples of use of soil nail walls in temporary and permanent cut applications.

Parameter	Value
Wall layout	
Height , H (m)	6.80
Face batter, α (Degrees)	0.0
Slope of backfill, β (Degrees)	0.0
Soil properties	
Cohesion, c (kPa)	10 - 20
Friction angle, φ (Degrees)	25
Unit weight, γ (kN/m^3)	18
Modulus of elasticity, E_S (kN/m^2)	20000
Poisson's ratio, ν	0.3
Nail properties	
Length, LN (m)	3.50
Diameter, D (m)	0.02
Spacing, S_V x S_H (m x m)	0.5 x 0.5
Modulus of elasticity, E_N (kN/m^2)	2 x 10^8
Soil-nail interface friction, φ_u (Degrees)	25
RCC facing properties	
Thickness, t (m)	0.1
Modulus of elasticity, E_C (kN/m^2)	2 x 10^7
Cross-sectional area, A (m^2/m length)	0.1
Moment of inertia, I (m^4/m length)	8.3 x 10^{-5}

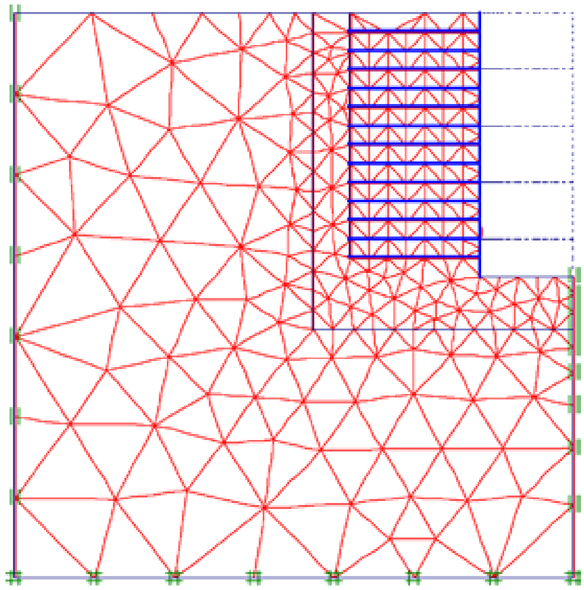


Figure 2 Finite element model for the soil nailed wall

sample was compacted to the field conditions, and sliding tests were carried out under different normal pressures of 25 kPa, 50 kPa and 100 kPa. The samples were sheared at a rate of 0.4mm/min, which could be considered to represent undrained conditions in the field. Pore water pressure was not measured, and the interface parameters are expressed in terms of friction angle and cohesion. The interfacial friction angle between nail and soil, φ_u, was obtained as 25º, and cohesion was in the range 10–20 kPa. The interface properties and the soil properties were nearly the same, as the striations present on the plane surface cause the failure plane to pass through the soil. The properties of the native soil and the reinforcement are given in Table 1.

Construction sequence

The construction procedure consisted of excavation, nailing of the reinforcement, and construction of RCC facing. First, the soil was excavated to a depth of 1500 mm, and nails were driven at the desired spacing in both the horizontal and vertical directions. Nominal reinforcement for the RCC facing was provided and rigidly connected to the nails by welding. Subsequently, a 100 mm thick RCC facing was constructed. The process was repeated until the desired depth of excavation was reached.

Numerical simulation – using Plaxis

For the numerical simulation, two-dimensional finite element code PLAXIS was used. The Mohr-Coulomb model is used to model soil, and for nails along with facing elements an elastic model is used. Beam elements were used to model nails and facing elements. Input parameter definitions in PLAXIS require averaging the effect of a three-dimensional problem to a two-dimensional problem. Figure 2 shows the modelled state of the soil nailed wall.

Simulation of excavation stages

Accomplishment of physical modelling, including simulation for gravity stresses using K_o -procedure, was followed with the calculation program. Simulation of the entire soil-nail wall construction process was carried out in a sequence of construction stages. In each construction stage a sufficient number of calculation steps were used to obtain an equilibrium-state. Since the properties of the soil at the location are highly variable, the representative values of soil cohesion 10, 15 and 20 kPa were used for numerical analysis. Also, factor of safety is determined after each construction stage using strength reduction technique.

Results and discussions

Global factor of safety is obtained using strength reduction technique after each construction stage. Three sets of observations corresponding to cohesion value of 10 kPa, 15 kPa and 20 kPa were obtained and the improvement in factor of safety is observed. Table 2 indicates the obtained factors of safety. An improvement of about 1.5 – 2.5 times in values of factor of safety is observed. Also, it could be noticed that a global factor of safety in the range of 1.20 – 1.53 is obtained for the entire depth (6.8 m) of excavation supported using nails. This value reasonably agrees with the minimum range

Stabilization of vertical cut using soil nailing

Continuation

Depth of Excavation, m	Factor of Safety					
	Without Nailing			With Nails		
Cohesion, C , kPa	10	15	20	10	15	20
1.50	1.32 (1.48)	1.87 (2.22)	3.29 (2.96)	3.40	4.48	5.17
3.00	-- (0.74)	1.06 (1.11)	1.18 (1.48)	2.03	2.43	2.86
4.50	--	-- (0.74)	0.96 (0.98)	1.62	1.87	2.18
6.00	--	--	-- (0.74)	1.28	1.51	1.72
6.80	--	--	--	**1.20**	**1.37**	**1.53**

Note: Figures in bracket indicates theoretical factor of safety based on critical excavation depth concept.

Table 2 Factors of Safety obtained using strength reduction technique

Depth of Excavation, m	Extreme Horizontal Displacement , mm					
	Without Nails			With Nails		
	Cohesion, C , kPa			Cohesion, C , kPa		
	10	15	20	10	15	20
1.5	1.20	1.20	1.21	1.24	1.25	1.25
3.0	3.45	2.04	1.86	2.23	1.67	1.66
4.5	--	7.33	6.03	5.20	3.83	3.48
6.0	--	--	27.25	11.23	9.05	7.60
6.8	--	--	--	16.17	12.55	11.00

Table 3 Horizontal displacements with excavation stages

1.20 – 1.30 of recommended factor of safety for global stability, as per FHWA guidelines. Figure 3 shows the graphical representation of variation of factor of safety with the depth of excavation.

Table 2 Factors of Safety obtained using strength reduction technique

Another important aspect studied is the deformations in the soil nailed wall system. It could be noticed that a maximum horizontal deformation of 7.60 mm is observed for the nailed wall, contrary to that of 27.25 mm for excavation of 6 m without nailing. This shows a significant reduction (about 70%) in the displacement of the vertical cut. Table 3 shows the comparison of extreme horizontal displacements for different excavation stages.

Figure 4 represent graphically the variation of extreme horizontal displacements with the depth of excavation.

In addition to the stability and deformations aspect of soil-nail wall system, various design parameters with regard to development of axial forces, shear forces, moments and deformations in individual nail and facing elements were also taken into account. Some of these results are as shown in Figure 5 to 8 and are summarized in Table 4. Earth pressure distribution behind the nailed wall is as shown in Figure 9. A maximum value of 96 kN/m^2 passive earth pressure is obtained. The trend of variation of forces and moments are found to conform to theoretical expectations. It also justifies the effectivene of numerical simulations.

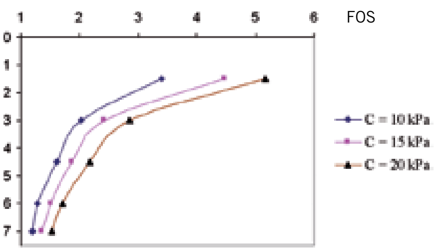


Figure 3 Variation of factor of safety with the depth of excavation

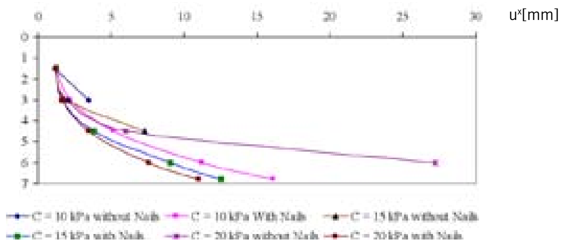


Figure 4 Variation of horizontal displacement of vertical cut with depth of excavation

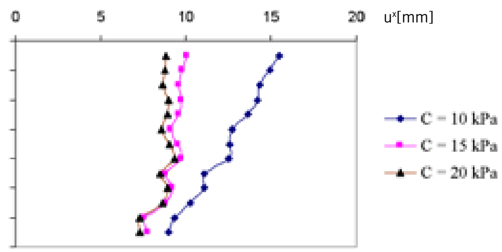


Figure 5 Variation of maximum horizontal displacement of nails with depth

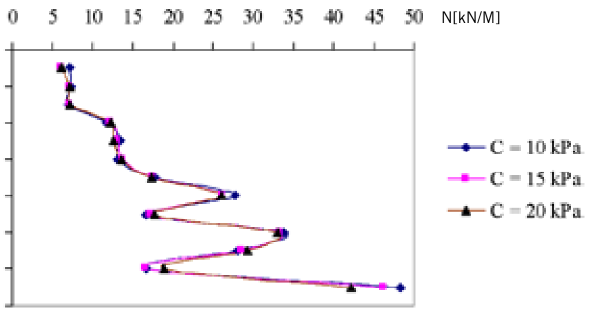


Figure 6 Variation of maximum axial force in nails with depth

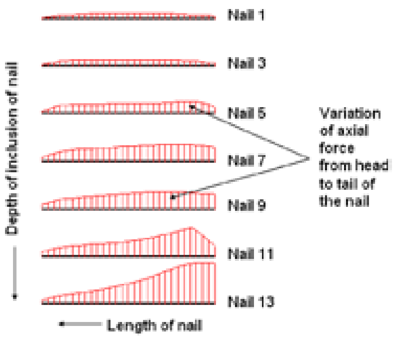


Figure 7 Pattern of variation of axial force along nail length (alternate nail from top shown)

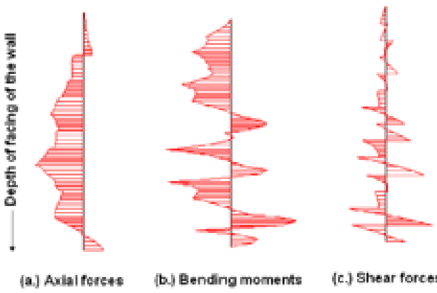


Figure 8 Variations of axial forces, bending moments and shear forces in facing elements

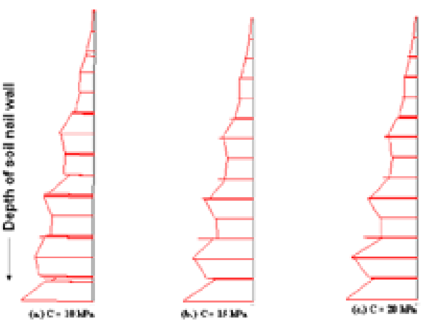


Figure 9 Variation of earth pressures behind the soil nail wall

Parameter	Cohesion, C , kPa		
	10	15	20
Nails			
Extreme Horizontal Displacement, mm	15.46	10.00	9.31
Extreme Vertical Displacement, mm	9.42	9.87	9.74
Extreme Axial Force, kN/m	48.28	46.27	42.10
Extreme Shear force, kN/m	5.77	6.94	7.00
Extreme Bending Moment, Nm/m	276.46	333.06	339.26
Facing Elements			
Extreme Axial Force, kN/m	28.45	36.97	38.28
Extreme Shear force, kN/m	25.59	23.04	23.73
Extreme Bending Moment, kNm/m	5.02	3.49	2.52
Extreme Horizontal Displacement, mm	16.17	12.55	11.00
Extreme Vertical Displacement, mm	28.34	27.98	27.67

Table 4 Summary of design parameters for nails and facing element

Concluding remarks

The results provide an understanding of the effect of soil-nailing on the global stability of vertical cuts using numerical simulations. The results and analysis indicate that the soil-nailed wall is stable with respect to both stability and deformation considerations. Further, it could be concluded that soil nailing is a viable and economical option for supporting vertical cuts particularly in locations where site-constraints are more predominant and project duration is very limited.

Acknowledgements

The work presented in this article is a part of the research project Guidelines for Soil Nailing Technique in Highway Engineering (R-86) financed by the Ministry of Shipping, Road Transport and Highways, Government of India, New Delhi. The authors express thanks to the Ministry for funding and providing necessary support for the project.

References

- Dawson E. M., Roth W. H. A. and Drescher A. (1999) Slope stability analysis by strength reduction. Geotechnique, 49, No. 6, 835–840.
- FHWA (2003) Carlos A. Lazarte, Victor Elias,
- R. David Espinoza, Paul J. Sabatini, Geotechnical engineering circular No. 7, Soil Nail - Walls, 0-IF-03-017.
- Matsui, T. and San, K-C. (1992) Finite element slope stability analysis by shear strength reduction technique, Soils and Foundations, Vol. 32, No. 1, pp. 59-70.
- PLAXIS (2006) Reference Manual, PLAXIS B.V., The Netherlands.
- Babu, G. L. S., Murthy, B. R. S. and Srinivas, A. (2002): "Analysis of construction factors influencing the behavior of soil nailed earth retaining walls", Ground Improvement, 6, No. 3, pp. 137 – 143.