Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

Numerical analysis of soil nailed retaining wall

B.R. Srinivasa Murthy
Indian Institute of Science, Bangalore, India

G.L. Sivakumar Babu
Indian Institute of Science, Bangalore, India

A. Srinivas
Indian Institute of Science, Bangalore, India

ABSTRACT: Two 5.0m high soil nailed permanent retaining walls as a part of a subway underneath a busy National Highway are designed, constructed and in operation at Indian Institute of Science, Bangalore, India. The walls are designed by conventional design methods and constructed with different types of facing using locally available technology and personnel. The paper examines the behavior of these soil nailed retaining walls using numerical simulations. The behavior of the soil nailed wall is numerically simulated using FLAC (Fast Lagrangian Analysis of Continua). The paper describes the modeling features such as simulation of excavation, installation of nails and construction of facing element and examines aspects such as variation of lateral earth pressure coefficients, tensions mobilized and deformations developed.

I INTRODUCTION

One of the challenging aspects of in-situ earth reinforcement is in understanding the behavior of soil nailed retaining walls. In soil nailed retaining walls, the properties and material behavior of three components namely the native soil, reinforcement (nails) and facing element significantly affect the performance of the structures. The behavior and performance of the wall are influenced by interaction of the components. The behaviour of the reinforced soil walls can be understood to some extent by studying the state of stress within the reinforced zone (Rowe and Ho, 1996). These influences are not adequately addressed in the conventional design procedures, based on limit equilibrium methods.

In this paper, the performance of the retaining wall and the role of soil nailing in increasing the stability and in controlling the lateral deformations of the wall has been examined. Two types of facing and placement conditions are simulated. Variation of lateral earth pressure coefficients with depth, maximum tensions mobilized in soil nails have been obtained as a function of percent lateral deformation of the wall and the results are examined.

2 FEATURES OF THE SOIL NAILED WALLS

2.1 *Geometrical features*

Soil nailed walls have been constructed as a part of the subway in Indian Institute of Science campus, Bangalore. The height of the walls varies from zero at one end of the ramp to 5.0m at the other end. The length of the ramp is 60m. The walls are designed using conventional methods of analysis and constructed. Typical sections are shown in Fig. 1.

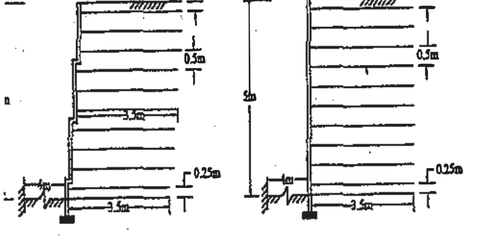

Figure 1. Cross sections of soil nailed walls.

2.2 *Features of the subway*

One of the walls is vertical and the other wall has a batter of 5^0 and is adopted by providing 0.15m offset for each 1.5m depth of excavation. The total offset of 0.45m in stages, for 5.0m height is considered to be a better alternative as it enables better concreting of the facing during construction. The length of the nail is 3.5m. The behavior of soil nailed walls is studied from numerical simulations and some results are presented in the following sections.

3 NUMERICAL SIMULATIONS

3.1 *Problem descritisation in FLAC*

The complete soil mass is descritized into 6480 zones in plane strain condition. An excavation of 5.0m depth is simulated using null model by deleting the corresponding elements from the mesh. Nails are simulated with pile elements and are introduced at designed spacing. The RCC facing is simulated using beam elements and is connected rigidly to the nails. The size of the mesh is 14m x 12m and sufficiently large enough to avoid boundary effects. Displacement boundary conditions are such that along the vertical boundary, in the sides x-displacements are fixed while y-displacements are free. At the bottom horizontal boundary, both x and y displacements are fixed (restrained) while at the top boundary it is unrestrained.

3.2 *Simulation of excavation stages*

The complete soil mass is initially simulated for gravity stresses before excavation using elastic model and later converted to Mohr-Coulomb material. At the end of the simulation, the unbalanced force is brought to negligible level (up to 1 Newton) and displacements due to gravity are initialized to zero. Simulation of excavation, introduction of nails and providing the RCC facing are carried out as described in the following sections for two types of facings (vertical and offset) following the sequences of construction explained below.

Sequence I

Excavation up to 0.5 m depth and obtaining stability in terms of reduction of unbalanced force to the minimum value (1 Newton) is simulated. Reinforcement modeled as pile element is introduced into the soil at 0.25 m depth from top (corresponding to 0.5 m vertical spacing). Subsequently a beam element representing RCC facing is introduced at 0.25 m and is rigidly connected to the pile element. Further excavation of 0.5 m depth is simulated and numerical stability is ensured. Reinforcement is introduced at 0.75 m depth from top. Facing element is introduced between 0.5 m to 1.0 m. The above sequence is repeated till the desired depth of excavation is reached.

Sequence II

Excavation up to 1.5 m depth in three steps, each 0.5 m depth and obtaining stability in terms of reduction of unbalanced force to the minimum value (1 Newton) is carried out. Reinforcement modeled as pile element is introduced into the soil at 0.25 m, 0.75 m and 1.25 m depths (corresponding to 0.5 m vertical spacing). RCC facing modeled as beam element is introduced between 0.0 and 1.5 m and is rigidly connected to the facing. Further excavation to next 1.5m depth in three 0.5m steps is conducted and numerical stability is obtained. RCC facing is introduced from 1.5m to 3.0 m is rigidly connected to nails. The above sequence is repeated till the desired depth of excavation is reached. Table 1 shows the soil and nail properties used for both the sequences.

Since the properties of soil at the location are highly variable in nature, three representative values of cohesion of soil (10, 15 and 20 kPa) are used for numerical analysis. Simulations are conducted for both sequences of construction. Reducing 3D problems with regularly spaced beams, cables or piles to 2D problems involves averaging the effect in 3D over the distance between the elements. Donovan et al. (1984) suggest that linear scaling of material properties is a simple and convenient way of distributing the discrete effect of elements over the distance between elements in a regularly spaced pattern. The above procedure is used in the present study.

Table 1. Properties of in-situ soil and nails

Parameter adopted	Value
Soil cohesion, c	10, 15 and 20 kPa
Soil friction angle, ϕ	25°
Soil unit weight, γ	18 kN/m^3
Soil elastic modulus, Es	20 MPa
Soil Poisson's ratio, ν	0.3
Nail diameter, d	0.02m
Nail length, L	3.5m
Nail spacing, S_v x S_h	0.5m x 0.5m

4 RESULTS AND DISCUSSION

4.1 *Lateral deformation of wall*

Effective performance of reinforced soil structures is dictated by the mobilized strains in soil and reinforcement as a result of force field equilibrium (Jewell, 1987). Strains or deformations mobilized need to be evaluated to establish appropriate serviceability limits for the retaining walls. Normally, horizontal deformations at the top of stable retaining wall are of considerable importance. Figure 2 shows the variation of horizontal deformation of the soil without nailing and nailing using sequences I and II. It can be observed that the wall is stable without nailing and the deformation is of the order of 25mm (0.5% of H). Soil nailing leads to considerable reduction in percent horizontal deformation as shown in Fig.2.

Sequence I gives comparatively lesser horizontal deformations. The maximum horizontal deformation is 0.07% and the corresponding deformation in sequence II is 0.12%. The maximum tension mobilized for sequence I is 7 kN and for sequence II is 5.75 kN. The results suggest that the mobilization of strains

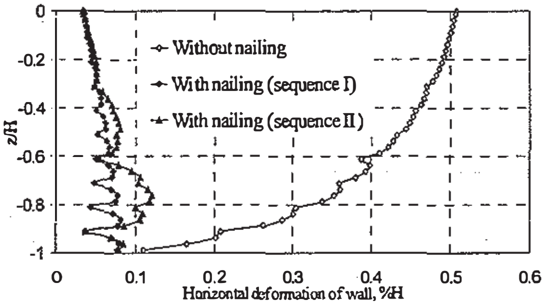

Figure 2. Variation of horizontal defonnation (%H) with z/H (c = 20 kPa, $\phi = 25^0$, Es = 20 MPa).

is affected by sequence of construction and the insertion of nails in soil mass before larger deformations are developed in soil mass is advantageous (as in the case of sequence I). The results are in agreement with the observations of Ho and Smith (1993) which suggest that early placement of the nail in the soil is useful.

4.2 *Variation of lateral earth pressure coefficients*

Figure 3 shows the variation of lateral earth pressure coefficients with depth for c = 20 kPa, $\phi = 25°$ and Es = 20 MPa. As mentioned in section 4.1, the wall is stable and the deformations are 0.5% of H. The corresponding lateral earth pressure coefficients immediately next to the facing are very small. The effect of nailing and sequence of construction on lateral earth pressures is also shown in Fig. 3. As the deformations are restrained, lateral earth pressures are mobilized in the opposite direction. The corresponding lateral earth pressure coefficients are shown and the values are high and in the range of 0.7 to 0.8 immediately at the nail of leveling.

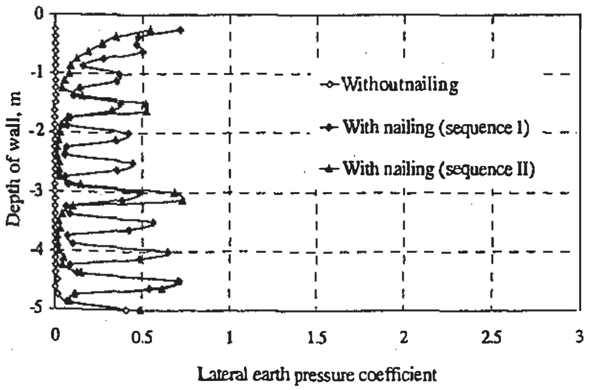

Figure 3. Variation of lateral earth pressure coefficients (c = 20 kPa, $\phi = 25^0$, Es = 20 MPa).

4.3 *Mobilization of maximum tensile force in nails with cohesion and corresponding percent horizontal deformation*

Figure 4 shows the variation of maximum tensile force in nails versus deformation at the top of wall (%H) for three cohesion values (10, 15 and 20 kPa) which are considered for the present analysis. It can be observed that at the same percent horizontal deformation of the soil, for higher values of cohesion, higher is the maximum tensile force mobilization.

This can be attributed to the stiffness of the soil surrounding the nails. Figure 5 shows the variation of percent horizontal deformation of wall as a function of maximum tensile force corresponding to different critical heights of excavation with sequence I type of construction.

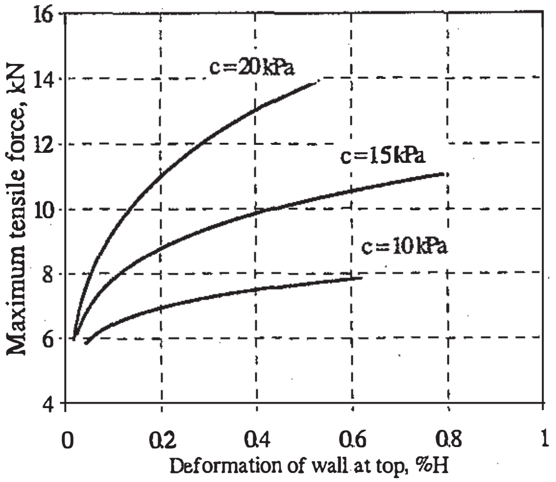

Figure 4. Variation of maximum tensile force in nails with deformation of wall (%H) (sequence I, vertical facing, $\phi = 25^0$, Es = 20 MPa).

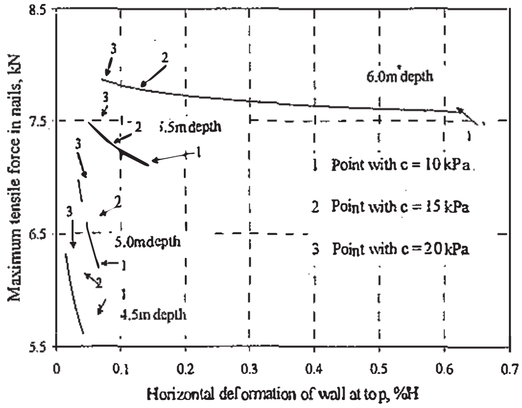

Figure 5. Maximum tensile forces in nails and horizontal deformation of wall at top (%H) at different depths of excavation for different values of cohesions (10,15 and 20 kPa).

Critical height of excavation in the present study is the height beyond which the soil nailed wall collapses resulting in unacceptably high deformations. It can be observed that as critical height of excavation increases, maximum horizontal deformation increases. From the above results one can estimate maximum horizontal deformation as well as maximum tensile force in nails and critical height of excavation for known value of cohesion.

Development of relationships indicated in Fig.5 for a given sequence of construction and range of soil parameters likely to be encountered in the in situ ground state are useful as design guidelines for construction of soil nailed walls.

5 CONCLUDING REMARKS

The study examined the behavior of soil nailed walls using numerical simulations. The results suggest that the performance of the walls in terms of maximum tensile force in nails and horizontal deformation at the top of walls is dependent on sequence of construction and placement of nails.

REFERENCES

Donovan et al. (1984) "Finite element approach to cable bolting in steeply digging VCR slopes", Geomechanics application in underground hardrock mining, 65-90.

Fast Lagrangian Analysis of Continua (1996), Version 3.3, Reference manuals I, II, III and IV. Itasca consulting group, Inc. Minnesota.

Ho, D.K.H. and Smith, I.M. (1993) "Modeling of soil nailing construction by three dimensional finite element analysis", Mathematical modeling of soil improvement (continuing education course:), Milano.

Jewell, R.A. (1988) "Compatibility, serviceability and design factors for reinforced soil walls", Proceedings of the international symposium on earth reinforcement, Fukuoka, 611-616.

Rowe, R.K. and Ho, S.K.P. (1996) "Some insights into reinforced wall behavior based on finite element analysis", Proceedings of the international symposium on earth reinforcement, Fukuoka, 485-490.