Optimum Design of Nailed Soil Wall

M. Muthukumar† and K. Premalatha†

ABSTRACT: Nailed wall is used to support both temporary and permanent structures. The objective of this study is to propose a simplified method of design of nailed soil wall based on experimental investigation and analysis through program SNAILZ. The nail rigidity number was arrived based on properties of nail and soil. Experimental investigations are carried and to find the influence of nail rigidity number in the failure surface and nail displacement. The snailz program is used to understand the influence nail rigidity number in the global and local stability of nailed soil wall. A simplified method for optimum design of nailed wall is proposed for sandy deposit. Evolution of design chart for different Soil Nail parameter is the future scope of this study.

KEYWORDS: Nailed soil wall, SNAILZ, Nail rigidity number, Excavation slopes, Soil nail

Background

Soil nailing is an insitu soil reinforcement technique that has been used during the last two decades mainly in France and Germany to retain excavation or slopes. The origin of soil nailing can be traced to a support system for underground excavations in rock referred to as the “New Austrian Tunneling Method”. One of the first applications of soil nailing was in 1972 for a railroad widening project near Versailles, France; Where an 18 m high cut slope in sand was stabilized using soil nails (FHWA, 2009). In India, Srinivasa Murthy et.al (2002) reported the use of a nailed soil wall as permanent retaining wall for subway underneath a busy national highway. Patra (2005) used the optimization technique for the optimum design of nailed slope and also established a generalized procedure (2008) for the design. Sivakumar Babu (2007) used this nailing technique to stabilize a vertical cut in a hilly terrain.

From the failure mode and stability analysis, it is understood for a given type of deposits, the stability of nailed soil wall depends on the physical and material properties of nail and nail spacing. The interrelation between nail spacing, nail and soil material properties are to be understood for the optimum design of nailed soil wall based on local and global stability. The main objective of this investigation was to find the influence of nail diameter, nail material and point of application of load within the active zone in the failure surface and in the nail displacement and to improve a simplified method of design of nailed soil wall based on interpretation of experimental results in terms of Nail rigidity number (Juran 1990) and analysis through the program snailz from snailz program.

Experimental Investigation

Although the construction procedure of a soil nailed structure is difficult to simulate experimentally and the similitude requirements between the laboratory models and prototype is difficult to satisfy, Juran and his colleagues (Juran et.al. 1990; Juran and Elias 1987) have successfully used soil nailed models to investigate the effects of main design parameters on the failure mechanism and have demonstrated that the observed model behavior is quite consistent with field observations on instrumental full scale structures.

Experimental Setup

In the experimental investigation, there is a difficulty to exactly replicate the procedure that followed in the field. The main objective of the experimental investigation was to observe the failure pattern for different nail rigidity number. Hence nailed soil wall were constructed as briefed below and loaded to observe the stability of nailed earth wall. It is assumed that the difference in the procedure in the field and laboratory will not have or have little effect in the failure pattern and failure mechanism. Experimental facility that was available to carry out test on model nailed soil wall consists of Model tank, Instrumentation, Loading System, Facing and Nail and Nail connection.

The tank was made up of 4 mm Mild steel sheets welded together and stiffened with suitable angle sections. The size of the tank was 1.5m x 0.5m x 0.6m. Both the longer sides of the tank were made of acrylic sheet of thickness 8mm to reduce the friction. One of its shorter faces was provided with sufficient holes of 12 mm diameter to fix the measuring equipments. When the load was applied, the structure may move both vertically and horizontally. The arrangements were made to measure the vertical movements of soil and to measure the horizontal movements of nails by using dial gauges.

The loading method was selected based on the actual field conditions. A wooden block of size 480mm x 140 mm x 65 mm was kept over the model wall at a suitable distance from the face of the cut. The block was rigid and distributed the applied load equally over its entire area. The load was applied on the block by loading frame arrangement.

†Post Graduate Student, Department of Civil Engineering, Anna University Chennai, Chennai-25, India, smmuthukumar19@gmail.com

‡Assistant Professor, Department of Civil Engineering, Anna University Chennai, Chennai-25, India, kvprema@annauniv.edu
In actual soil nailed cuts, where the soil can stand unsupported for excavation depth of about 0.5 m to 1.0 m, a shot Crete or precast panel facing is commonly used. Since dry sand was used in these tests, a vertical excavation face could only be maintained using as a rigid facing. A 10 mm thick ply board was used as a preplaced continuous facing. Circular holes of diameter 8 mm were made on replaced continuous facing at selected horizontal and vertical distance. The inner periphery of these holes was made smooth by grinding to avoid any friction of the wall material with nail. Plastic bush of size 15mm diameter was fixed at the nail head using glue. This bush held the nails with cardboard in position and eventually, the soil mass also.

Materials

Medium dry sand, classified as SP in the Unified Soil Classification System, was used as test media. The minimum dry density of sand was 1.43 g/cm³ the nails used for this experimental investigation are 3mm, 6mm and 8mm diameter Mild steel and 6mm diameter nylon nails. The vertical spacing of nails is 100mm and horizontal spacing of nails is 167mm. the loading was applied at a distance of 125mm from the face of the cut. The length of nail was 400mm.

Construction of Nailed Soil Wall

The following procedure was adopted for the construction of nailed soil wall. Ply board facing was placed vertically across the tank at a distance of 1m from rear end of tank as shown in Figure 1. The facing was brought to absolute vertical position with help of tri-square and was clamped at the top to avoid the lateral movement of facing during filling of tank. Support was also given at the bottom of board during construction. The narrow gaps between the facing and the tank sides were closed properly along the length. The sand was filled at a density of 1.7 g/cm³. When the tank was filled, the holes were closed. The top surface of sand was leveled. After filling the sand at the above density, the nails were driven in to the wall. To avoid the lateral deformation during installation of nails, necessary support was provided. Figure 1 shows the full view of nailed soil wall with facing and Figure 2 shows the overall view of the instrumentation and loading arrangement.

After the construction of nailed wall, the clamps holding the wall and also support placed at the bottom were removed. The lateral movements of nails were measured with the help of dial gauges. The wooden block was kept over the model wall at a selected distance from the face of the wall. Immediately after the removal of the clamps, the load was applied in stages. The applied load intensity versus horizontal displacement and applied load intensity versus vertical displacement was observed for further interpretation. The inclination of failure surface, which was developed due to the loading was observed and recorded.

Results and Discussions

Effect of Nail Diameter in Nailed Soil Wall

The applied pressure versus settlement for 3mm, 6mm and 8 mm MS Nail for the selected loading conditions from face were obtained. The nail displacement verses the height of the wall are drawn and shown in Figure 3. The maximum nail displacement is for middle row of nails. It is observed that the increase in nail diameter decreased the settlement. The displacements of top and bottom row of nails are comparatively lesser than middle row of nails. Increase in the stiffness of nail increased the stability of nailed wall.
Failure Surface Observed in the Model Nailed Wall

Failure surface mobilized during loading of the model nailed wall was observed for all the tests. During the filling the tank with sand in layers, each layer of sand was lined by colorized sand to observe the failure surface. Figure 4 shows the marking in the sand before the test. Figure 5 shows the changes in the markings after the test. This failure surface also indicates the possibilities for bending failure of nails.

The failure surface observed from this experimental investigation for different nails are shown in Figure 6. To understand the influence of nail material and loading distance in the failure surface data from previous investigators were collected and the failure surface are shown in Figure 7 and 8. To understand the stiffness of the nail in the failure surface of 6mm MS nail and 6mm Nylon nail were also drawn and are shown in Figure 9.

To identify the pattern of failure surface, the failure surface assumed for simplified wedge analysis and the logspiral failure surface were also drawn. The logspiral failure surface was constructed based on procedure described by Swami Saran (2005), by assuming the included angle as 45°. This included angle failure surface is the critical failure surface (swami saran, 2005). This failure surface are also included in the figures 6, 7, 8 and 9.

Fig. 4 Before Test

Fig. 5 After Test

Fig. 6 Failure Surface for Loading at 125 mm from the Face of the Wall

Fig. 7 Failure Surface for Loading at 125 mm from the Face of the Wall

Fig. 8 Failure Surface for Loading at 50 mm from the Face of the Wall

Fig. 9 Failure Surface for Loading at 125 mm from the Face of the Wall
The observations made from the above figures are briefed below

The failure surface is the independent of loading position. The failure surface of 8 mm MS nail lies within the simplified wedge failure surface. The failure surface of 6 mm MS nail coincides almost within the simplified wedge failure surface. The failure surface for 8 mm HYSD bar is away from simplified wedge failure surface and close to vertical face. All other failure surfaces lie away from the simplified wedge analysis and very close to log spiral failure surface. Hence it is concluded that increase in stiffness of nail beyond certain value, changes the failure surfaces. This qualitative description was quantified using Nail Rigidity Number (Juran et.al 1990)

Failure Surface and Nail Rigidity Number

The Non dimensional rigidity number (Juran et.al 1990), N is defined as

\[ N = \left( \frac{K_s D l_0^2}{H^2 S_v S_h} \right) \]  \hspace{1cm} (1)

In the above equation, \( K_s \) is the lateral soil reaction modulus, which is the function of soil strength, D is the diameter of reinforcement, \( y \) is the unit weight of the soil, H is the wall height, and \( S_v \) and \( S_h \) are the horizontal and vertical spacing between two nails and \( l_0 \) is the transfer length that characterizes the relative rigidity of the nail and soil and \( l_0 \) is defined as

\[ l_0 = 4\sqrt{\frac{4E_l}{K_sD}} \]  \hspace{1cm} (2)

where E and I are the elastic modulus and the moment of inertia of the nail

The Nail Rigidity number (N) for 6 mm, 7 mm and 8 mm MS Nail was calculated and is listed in Table 1.

### Table 1 Rigidity Number of Nails

<table>
<thead>
<tr>
<th>Nail Diameter mm</th>
<th>Nail Rigidity Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>26.1</td>
</tr>
<tr>
<td>8</td>
<td>53.2</td>
</tr>
<tr>
<td>7 (assumed)</td>
<td>38.1</td>
</tr>
</tbody>
</table>

The N value for 6mm nail is 26.13 and 8 mm is 53.32. It is observed that for N values lesser than 26, the failure surface is very close to log spiral. Considering the N value of 7 mm dia nails, it is concluded that if N value of a nailed wall system is less than 40 the failure surface is log spiral and greater than 40, the failure surface is simplified wedge. Further increases in N value reduce the failure surface distance, from the crest or increase the angle of simplified active wedge surface at the toe.

This Nail rigidity number N, includes the height of nailed wall. Increase in the height of the nailed wall, with all other parameters remains the same, the N value get decreased. This is due to the scale effect and to be considered based on prototype dimension.

Nail Displacement and Nail Rigidity Number

From the literature it is observed that the maximum nail displacement occurs only at the surface, which is in active state. The surcharge on the wall with in the active failure wedge changed the pattern of nail displacement. For 8 mm nail diameter the observed failure plane angle is greater than 45°/2 and this reduction in failure surface, increased the displacement of first row of nails. The value of \( \delta_{max}/H \) for different nails at different levels were obtained and presented in Table 2.

### Table 2 \( \delta_{max}/H \) for Different Nails

<table>
<thead>
<tr>
<th>Location of Nails</th>
<th>3mm MS Nail</th>
<th>6mm MS Nail</th>
<th>8mm MS Nail</th>
<th>6 mm Nylon Nail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top nail</td>
<td>0.018</td>
<td>0.05</td>
<td>0.04</td>
<td>0.045</td>
</tr>
<tr>
<td>Middle nail</td>
<td>0.098</td>
<td>0.096</td>
<td>0.046</td>
<td>0.099</td>
</tr>
<tr>
<td>Bottom nail</td>
<td>0.022</td>
<td>0.02</td>
<td>0.01</td>
<td>0.0268</td>
</tr>
</tbody>
</table>

The displacement of all nails decreases with increase in Nail rigidity number. The displacements of bottom nails are lower than all nails. For 3 mm MS nail, the displacement of middle nail is 5 times greater than that of bottom and top nail. For 6 mm dia MS nail the top nail displacement is 2.5 times that of bottom nail and middle nail displacement is two times of the top nail displacement. The displacement of middle nails is almost same for 3 mm and 6 mm MS nail. Increase in nail diameter of MS nail by 3 mm from 6 mm decreased displacement of the bottom nail and middle nail by 50% and top nail by 20%. Also it is observed that increase of nail rigidity number from 26 to 53 changed the pattern of nail displacement i.e., reduces the difference between the top and bottom nail displacement. This variation in the nail displacement indicates the change of structural behavior of nailed wall from flexible to rigid. Thus the behavior of optimum designed nailed wall should be rigid.

Scale Factor for Prototype Nailed Soil Wall

To use of the observation made in the model study, the nail rigidity number of a prototype wall of height 2m to 9m was considered and scale factor between the model and prototype was calculated. Figure 8 shows the relation between wall height and scale factor for two different types of nail. The scale factor is constant for different dry density of sand and were verified by considering the recommend \( K_s \) values of loose and dense dry sand. For other dimensions of nails, scale factor can be computed.

Design of nailed soil wall based on nail rigidity number

To design a nailed soil wall using nail rigidity the following procedure is used.

The Nail rigidity number for rigid behavior of wall
is 40 from experimental investigation.

Scale factor for 9 m wall : 0.16

Nail rigidity number of 9 m wall : 6.4

For N = 6.4, for 100 mm grouted nail found out the spacing obtained is 1.2 m *1.2 m, based on the Nail Rigidity Number.

Analysis was also done using these input parameters in the SNAILZ program. The global factor of safety of this wall is 1.88 and the factors of safety for individual nails are greater than 1. Hence the design is safe and the proposed simplified method of design of nailed wall is valid.

Conclusions

The important conclusions arrived from this study are listed below

It is concluded that the N value of a nailed wall system is less than 40, the failure surface will be log spiral and greater than 40, the failure surface will be simplified active wedge. Increase in Nail rigidity number changes the pattern of nail displacement and increase of nail rigidity number up to 40 reduces the displacement of nails. Further increase in the nail rigidity number reduces the difference between top and bottom nail displacement and increase the failure surface angle at toe. Based on Experimental and analysis through SNAILZ, a simplified method for optimum design of nailed wall is proposed for sandy deposit. Evolution of design chart for different Soil Nail parameter is the future scope of the study.

References


FHWA (2003), Soil NAIL walls, Geotechnical Engineering circular No 7, Report No FHWA-IF-03-017, Federal Highway Administration.


