USE OF SOIL NAILED STABILIZED WALLS AND SLOPES IN TRANSPORTATION PROJECTS

Jerko Kocijan[1], Predrag Kvasnička[2], Mladen Vučetić[3]
1 Fugro West, USA
2 University of Zagreb, Croatia
3 University of California, Los Angeles, USA

Abstract

The use of soil nailing for stabilization of cuts and slopes in transportation projects can result in effective design solutions and cost savings. Its application varies from shallow erosion type failures to excavations of significant heights. Construction process is relatively straightforward and cost-effective while the historical performance under both static and seismic conditions has been very good. After 40 years of successful application in a variety of projects, soil nailing today is both a viable and visually attractive solution. This paper presents a brief summary of the soil nailing methodology and its applicability to various types of transportation projects, soil and groundwater conditions. A discussion on the performance during high intensity earthquakes is included.

Keywords: soil nail, retaining structure, slope stabilization, in-situ stabilization

1 Introduction

Soil nailing is an in-situ technique for mechanically stabilizing soil masses that has been employed successfully for stabilization of vertical cuts and slopes. Since one of the first applications in France during a railroad widening project in the early 1970s [1], it has spread worldwide. The main feature of soil nailing as an in-situ technique is that it reinforces the existing native soils, as opposed to the backfill reinforcement.

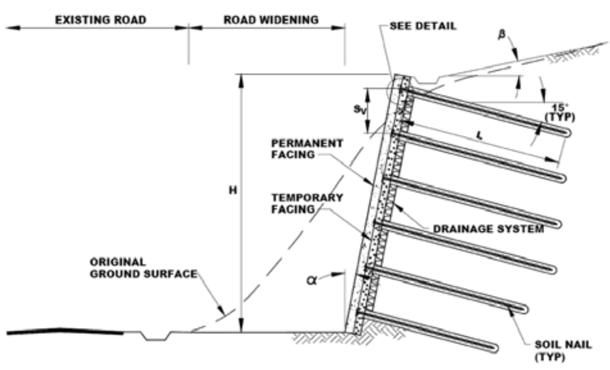

Figure 1 Typical cross-section of soil nailed wall used for widening of existing roads [2].

By reinforcing the native soils, soil nailing minimizes the required excavation and can have smaller environmental impact making it a very attractive solution. Compared to other reinforcement options, soil nailing is also a cost effective solution.
Soil nailing for stabilization of vertical or near vertical cuts is frequently used in road and highway construction and widening. Such structures are called soil nailed walls, because the reinforced soil mass together with its relatively thin reinforced concrete facing performs the function of a massive retaining wall. A typical cross-section is shown in Fig. 1.

1.1 Construction procedure

Soil nailed walls are installed top down as shown in Fig. 2. As the excavation proceeds, the nails and facing are installed at consecutive excavation levels until the target depth is reached. While the soil nails provide global stabilization of the soil mass, the temporary and final facing serve to protect the excavation surface from local failures and erosion. A good connection between nails and facing also ensures better transfer of active soil forces between the rows of nails, which enhances the integrity of the entire structure. As the soil nailed wall is installed from top down in stages, at each excavation level the soil surface is temporarily exposed without facing. Consequently, the soil in which the soil nailed wall is to be installed needs to have sufficient cohesion to maintain temporary stability over the individual level excavation height (typically about 1 to 1.5 meters). For slope stabilization with no cuts, soil cohesion is not a controlling factor in determining soil nailing applicability.
Applicable Soil Conditions. The most suitable soils for soil nailing are moist and relatively dense sandy soils with a content of fines that provides sufficient cohesion which allows for stable cuts during the construction. First soil nailed walls were constructed in such soils. Nails installed in medium dense to dense sands have high pullout capacity resulting in excellent performance. For all soil nail types, the pull-out tests are performed at the beginning of the construction to verify soil nail design values.

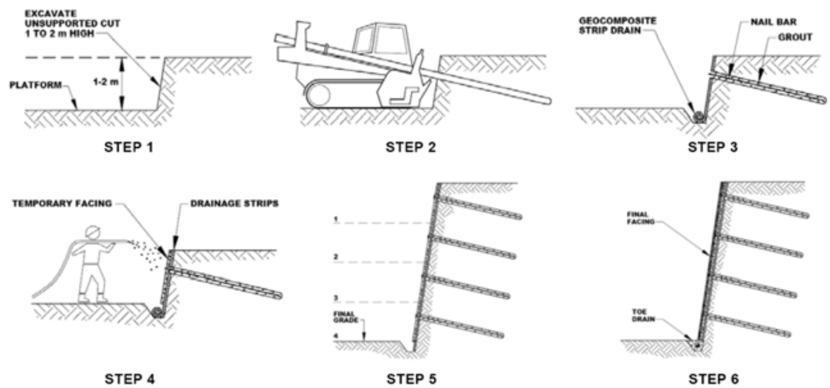

Figure 2 Typical soil nailed wall installation steps: (1) first level cut, (2) drill nail hole, (3) install nail, (4) place temporary facing, (5) construction of subsequent levels, and (6) installation of final facing and toe drain (modified from [2]).

With the increased experience and understanding of the nail-soil interaction in various types of soil, soil nailing is today used in variety of soil conditions including clays, sands and heterogeneous and stratified soils. However, either due to the concerns about the quality of installation or long term performance, soil nailing is not generally recommended or is not economically feasible in soils with high groundwater level, dry poorly graded cohesionless soils, soft fine grained soils, organic soils and peats, highly corrosive soils, weathered rock and karst. Also, in seismically active areas, soils that are prone to liquefaction are not good for soil nailing application.

1.2 Soil nails

Several soil nail installation methods have over the years introduced different types of nails, including grouted drilled nails, post-grouted driven nails, percussion driven nails, and jetted nails. Installation of the grouted drilled nail involves drilling a hole, inserting a steel bar with sacrificial centralizers and grouting the hole. In this manner, the soil nail interaction occurs along the grout soil interface while the steel bar provides tensile nail capacity. In many critical applications, grouted drilled nails are still preferred selection due to long history of their satisfactory performance. However, other installation methods have gained popularity. The advantages of some of the other installation methods, such as jetting, is that their production rate can be significantly higher because they require less personal and smaller construction area. The installation methods that can be applied in limited construction space are suitable for soil stabilization around existing roads and railways that cannot be closed during construction. Additionally, fast installation methods are suitable for emergency stabilizations. Two examples of soil nail installation are shown in Fig. 3.

Figure 3 Installation of soil nails from the top of existing railway embankment using Soil Nail Launcher technology [12] (left) and installation using mobile rig under a bridge end-span (right).

Facing. The main role of the soil nailed wall facing is to protect soil behind vertical cut and to augment the integrity and stability of the entire system. When soil nailing is used for the slope stabilization, the facing, if used at all, typically serves as erosion protection and is of significantly lighter design. For soil nailed walls the facing is usually installed in two stages. The temporary facing is installed first as the installation proceeds to prevent sloughing and local soil failures. Once the final depth of the excavation is reached the permanent facing is installed to strengthen the soil nail-facing connection and provide the final aesthetic cover. To avoid pore pressure build-up behind the facing, drainage material (usually geosynthetics) is placed on the excavated surface before the placement of the facing. In recent years, the visual design of the final facing has become a significant part of the overall project design. Facings are typically designed to mimic the natural texture and color of the surrounding area. Also, in some urban areas, planters for vegetation growth are built into facing or fully vegetative facings are installed to promote green areas. Several examples of the final facing designs are shown in Fig. 4.

2 Design of soil nailed walls

The design of soil nailed wall has to account for all loading scenarios that occur during the wall lifetime: (1) stability during construction; (2) long term stability under various loadings, such as due to traffic and structures on top of the wall; and (3) stability during earthquakes in seismically active areas. The selection of the nail spacing, length of nails and the facing thickness must satisfy the stability under all of these conditions. In current USA practice the design of soil nail walls involves simplistic and straightforward limit equilibrium analyses using specialty calculation software (developed by different designers) or commercially available limit equilibrium slope stability software (i.e., Slope/W by Geo-Slope or Slide by Rockscience). The limit equilibrium analysis approach is also used for the evaluation of the stability of soil nailed slopes.

Figure 4 Various types of soil nailing facing finishes: precast face panels (left), shotcrete facing styled as rock outcrop (top right), panels with vegetation growth (bottom right)

For the soil nailed walls of significant height, adjacent to critical structures or placed in challenging soil conditions, the design frequently includes modeling using more advanced numerical tools such as finite element and finite difference computer programs. For example, by combining advanced numerical modeling with site specific nail pull-out test data and soil behavior information, displacements during the soil nailed wall installation can be calculated to evaluate their effects on adjacent structures [4]. Some of the standards for soil nailing are included in the USA Federal Highway Administration report on design and construction of soil nailed walls [2], British standard BS 8006 Part 2 on design of soil nailed walls (which is currently under development and should be Eurocode compatible), and existing publication BS EN 14490 [3] covering construction and supervision requirements for soil nailing works.

3 Seismic stability

Some of the first experiences of earthquake effects on soil nailed walls were gained after the 1989 Loma Prieta Earthquake in California [5]. Seven soil nailed structures shaken by the earthquake were inspected and no considerable damage or displacements were observed, even though at the location of one structure peak horizontal acceleration was around 0.47 g. These findings showed a high resistance of soil nailed walls to dynamic loading. However, due to such high resistance no seismic failures have been recorded and no insight on the seismic failure behavior has been gained. Consequently, the centrifuge testing was employed to model the behavior of soil nailed walls under cyclic loads. For example, two dynamic centrifuge investigations of soil nailed excavation models were performed at the University of California, Los Angeles [6], [7], [8]. The centrifuge test results showed excellent performance of soil nailed wall models under dynamic loading. They also revealed a two-block failure mode along a bi-linear failure surface shown in Fig. 5. Using the displacement results of these investigations and sliding block analysis approach a seismic displacement prediction model that takes into account specifics of soil nail pullout behavior observed in pull-out tests was developed [9].

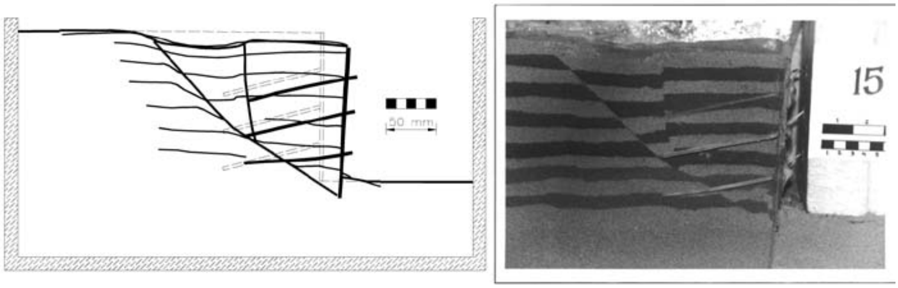

Figure 5 Failure of soil nailed wall centrifuge model (prototype height of 7.6 meters) with three rows of nails inclined at 15º [9]

4 Soil nailing in transportation

Construction of soil nailed walls along highways in USA has been promoted by the USA Federal Highway Administration. In many cases wall heights in USA are between 5 and 10 meters with the lengths from 50 meters to a couple of kilometers (Route 85, San Jose, California). Some examples include soil nailed wall in Kentucky with 800 square meters of facing sculpted and stained to mimic the adjacent highway cuts in natural soil and a soil nailed wall along the interstate highway I-235 in Des Moines, Iowa, which has almost 6,000 square meters of facing area [10]. One of the recent projects in UK includes installation of over 4900 soil nails for a road widening along about 18km of M1 freeway where work was confined to shoulders to avoid disrupting the traffic flow along existing lanes [11]. The repairs of existing railways corridors have also been taking advantage of soil nailing technology, such as for example the nail installation from top of the existing railway embankment shown in Fig. 3 [12]. In this case soil nailing was used to stabilize a pair of failing piling walls on either side of the high embankment of the Canadian Pacific Railroad tracks. Construction was performed with limited interruption of train traffic. Soil nailing was also used as part of the temporary soil retention system during the construction of Reno Transportation Rail Access Corridor (ReTRAC), during which 3,050 meters of soil nailed wall were constructed with the total shotcrete facing area of more than 17,500 square meters and about 43,000 meters of soil nails [13]. Most available information indicates that typical cost savings achieved using soil nailing are in the range of about 20 to 40 percent compared to other methods. Cost of soil nailed walls construction in the USA typically ranges in the order of $300 to $600 per square meter of wall facing.

5 Soil nailing in Croatia

Although soil nailing is most frequently used in sandy soils, two soil nailed walls in Croatia were constructed in clayey soil (both in the City of Zagreb). One was in very soft clay in Mandrovićeva street [14], where the whole project ended successfully in spite of some excessive wall deformations. The other wall was built in Dežmanova Street where the soil was overconsolidated clay [15]. The wall enclosed the working site for a residential and office building with an underground garage. The excavation pit was located on a very steep slope, between two old buildings. Because the backside of the excavation pit (20m high!) was hardly accessible to heavy machines, a soil nail wall was selected as the preferred excavation shoring technique. The nailed wall had two functions: a temporary support of the working pit and the permanent retention of the earth after the completion of the building. During excavations only minimum displacements were recorded. The wall was completed in only three months. To authors knowledge this is one of the highest soil nailed walls in clays ever built.

6 Conclusion

Based on the current experience in engineering practice, the soil nailing is recognized as a cost-effective solution for stabilization of excavations and slopes. Economic and engineering benefits of using soil nailing as compared to other stabilization methods will depend on the soil conditions and availability of experienced contractors. However, if the project site is suitable for soil nailing applications, use of soil nailing will likely result in faster and cheaper construction process and the retaining structure with excellent performance under long term and seismic loading.

References

[1] Rabejac, S. and Toudic, P.: Construction d'un mur de soutènement entre Versailles-Chantiers et Versailles-Matelots, (Construction of a retaining wall between Versailles-Chantiers and Versailles-Matelots). Revue générale des chemins de fer, Vol. 93, pp. 232-237, 1974.

[2] Federal Highway Administration. Geotechnical Engineering Circular No. 7 - Soil Nail Walls. US Department of Transportation, Washington, D.C., USA, Report No. FHWA0-IF-03-017, 210 p., 2003.

[3] BS EN 14490. Execution of special geotechnical works. Soil nailing. British Standards Institution, 58 p., 2007.

[4] Marić, B., Kvasnička, P., Radaljac, D. & Mavar, R. An example of a high soil nailed wall in plastic clayey soil, Landmarks in Earth Reinforcement, Hidetoshi Ochiai et al. (ur.). Balkema, pp 669-674, 2001.

[5] Vucetic, M., Tufenjkian, M.R., Felio, G.Y., Barrar, P. & Chapman, K.R. Analysis of Soil-Nailed Excavations Stability during the 1989 Loma Prieta Earthquake in California. USGS Professional Paper 1552 "Performance of the Built Environment", part of NEHRP Report to Congress: "The Loma Prieta, California, Earthquake of October 17, 1989."

[6] Tufenkjian, M. R., & Vucetic, M.: Dynamic Failure Mechanism of Soil-Nailed Excavation Models in Centrifuge. Journal of Geotech. and Geoenvir. Engineering, ASCE Vol. 126, No. 3, pp. 227-235, 2000.

[7] Kocijan, J. & Vucetic, M.: Organization and Interpretation of the Results of Dynamic Centrifuge Tests Conducted on 14 Models of Soil Nailed Walls, Research Report UCLA ENG-02-229, C&EE Department, University of California, Los Angeles, 318 p., 2002.

[8] Vucetic, M., Iskandar, V.E., Doroudian, M., and Luccioni, L.: Dynamic Failure of Soil-nailed Excavations in Centrifuge, Proceedings, Intl. International Symposium on Earth Reinforcement, Fukuoka, Kyushu, Japan, Editors: Ochiai, H., Yasufuku, N. and Omine, K., Publisher: A.A. Balkema, Rotterdam/ Brookfield, Vol. 1, pp. 829-834., November 1996.

[9] Kocijan, J. & Vucetic, M.: Analysis of Forces and Displacements Leading to Failure of Different Configurations of Soil-Nailed Excavation Centrifuge Models under Cyclic Loads, Research Report UCLA ENG-05-261, C&EE Department, University of California, Los Angeles, 516 p., 2005.

[10] www.judycompany.com/engineer/articles/betterroads-0309.pdf

[11] www.sysgeo.co.uk/images/uploaded/page_30/NLSoilNailCS_M1.pdf

[12] www.soilnaillauncher.com

[13] Chapman, K.R., Ludwig, C. & Jenevein, D, Underpining and Temporary Earth Retention for the ReTRAC Trench in Reno, Deep Foundations Magazine, Fall 2006.

[14] Kvasnička, P., Matešić, L. & Vukadinović, B. (1998). "Analysis of an example of a nailed wall in soft clayey soil". Proceedings of the XIth Danube-European conference on soil mechanics and geotech. engineering, Poreč, Croatia, Balkema, Rotterdam, pp. 547-552.

[15] Marić. B., Kvasnička, P., Matešić, L. & Radaljac, D. (2002). "Effects of prestressed anchors on a high nailed wall in clay". 12. Danube-European Conference, Passau, pp. 93-96.