A Deep Retaining System Construction with Soil Nailing in Soft Rocks in Istanbul, Turkey

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Abstract

In-situ reinforcement of ground by a series of inclusions is an effective technique for the purpose of improving the stability of slopes and excavations. During the past fifteen years, significant development has taken place in the techniques of in-situ reinforcement using nails and anchors. Especially, soil nailing has gained world-wide acceptance in both theory and practice due to its economy, technical advantages and construction speed. Applications of soil nailing system is documented in a detailed case study in the new commercial center of the city of Istanbul, Turkey in greywacke formation. The total excavation height reaches approximately 27 m with an angle close to vertical. During the construction of the retaining system the deformations and therefore the behavior of the system are monitored systematically with fourteen inclinometers installed throughout the site. System is numerically modeled and displacement patterns together with nail loads are determined using the software FLAC for every step of the excavation. It is shown that the measured and calculated displacement patterns and their values are very closely comparable. It is also shown for the first time that the estimation of lateral displacements as a certain percentage of excavation height according to present state-of-the art may lead to considerable underestimation of lateral displacements especially after certain depth of excavation.

1 INTRODUCTION

In-situ reinforcement of ground by a series of inclusions is an effective technique for the purpose of improving the stability of slopes and excavations. During the past fifteen years, significant development has taken place in the techniques of in-situ reinforcement using nails and anchors. Especially, soil nailing has gained world-wide acceptance in both theory and practice due to its economy, technical advantages and construction speed. In today’s world, for the highly populated cities as Istanbul, the value of land is very important. Therefore high-rise buildings with many basement levels are being constructed within the city, creating the need for the construction of retaining systems which are both financially feasible, time-wise efficient and safe. In a detailed case study, application of a deep soil nailed retaining system in the new commercial center of the city of Istanbul, Turkey in greywacke formation is presented in this paper. The total excavation height reaches approximately 27 m with an angle (5 degrees with vertical) close to vertical. The site is surrounded by main boulevards, road, major buildings and also by the subway tunnels. Therefore, estimation and monitoring of lateral and vertical displacements is of primary concern considering that the area to be excavated is 290mx90m and the total volume of excavation is more than 550,000m3. During the construction of the retaining system the deformations and therefore the behavior of the system are monitored systematically with fourteen inclinometers installed throughout the site. System is numerically modeled and displacement patterns together with nail loads are determined using the software FLAC for every step of the excavation. It is shown that the measured and calculated displacement patterns and their values are very closely comparable. It is also shown for the first time that the estimation of lateral displacements as a certain percentage of excavation height according to present state-of-the art may lead to considerable underestimation of lateral displacements especially after certain depth of excavation. In summary, emphasis is given in this paper that soil nailing is a very versatile method not only for shallow excavations away from any structures but also for very deep excavations in the middle of various major structures provided that a sound design and monitoring scheme is implemented.

2 SITE INFORMATION

The system is designed for the construction of a large business and shopping center covering an area of approximately 23,000 m^2 with twenty-seven storey above the ground level. Figure 1 below presents the site lay-out.

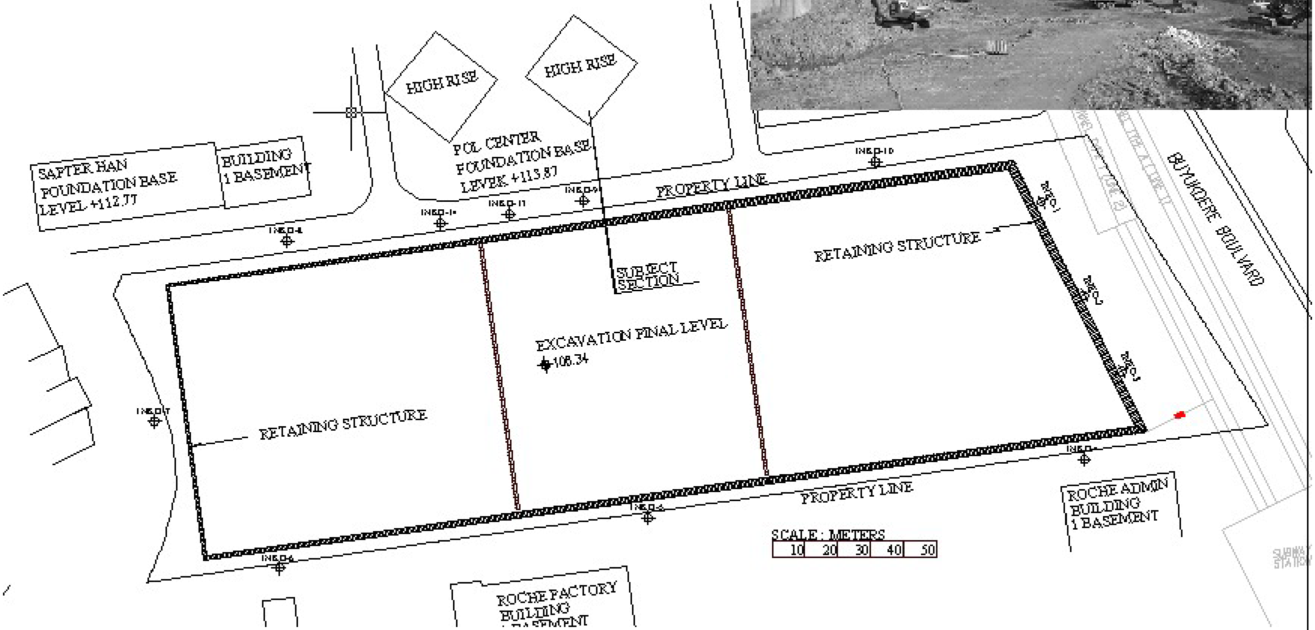

Figure 1 Site Layout

The site is surrounded by main roads and boulevards. There are several buildings and the subway tunnels / station at close distance (12.0m-21.0m) to the excavation relative to the depth of excavation (max. 27.0m). It is therefore very critical to estimate / monitor the lateral displacements and settlements parallel to the excavation of the foundation pit (290mx90m). This paper presents the calculations, inclinometer (inco 9) readings and relevant evaluations for one of the most critical sections (indicated as subject section in the above figure) where there is a high rise commercial building at 21.0m distance to the top of the soil nailed wall. The site is situated within 20 km distance to the North Anatolian Fault (NAF). According to the risk analysis performed for Marmara Region in which the subject site is located, for a risk of 10%, maximum earthquake magnitude according to the Richter scale is given as M=7.7 for a structure lifetime of 50 years. Further, according to the recent study performed, there is a probability of 65% within 30 years for a major rupture in NAF located within the Marmara Sea. Therefore although the retaining system was temporary, it was preferred as well to have a flexible system like soil-nailed wall, that could stand for a bedrock acceleration of a_{max}=0.40g.

3 SOIL CONDITIONS

The geological units encountered at the subject site are graywackes which are classified as Thrace formation. This unit is composed of shales, siltstones and weak sandstones including many joints and fractures. Soil investigations by means of full coring and pressuremeter testing are carried out at the site to determine the proper geotechnical parameters to be used in the soil nailed wall design. Table 1 summarizes the parameters utilized in FLAC analysis for the subject section.

4 MONITORING

Monitoring is carried out by means of fourteen inclinometers installed around the excavation pit at critical (an accessible) locations (see plan). Optical measurements at surface points are also carried out but it was concluded after certain

Table 1 Geotechnical Modeling

Description	Depth-m		γ	φ	c	E	ν	K	G
	from	to	kN/m3	deg	kPa	Mpa		Mpa	Mpa
CLAY, totally weathered greywacke	0	9	19	28	0	75	0.3	63	29
GREYWACK weak - very weak	E, 9	30	20	28	5	180	0.4	200	67
GREYWACK weak - medium strong	E,30	40	20	30	5	250	0.4	278	93

period of readings that the precision of optical measurements were not sufficient for the purpose. The inclinometer readings taken from INCO 9 which is the closest one to the section analyzed in this paper is presented below in Figure 2.

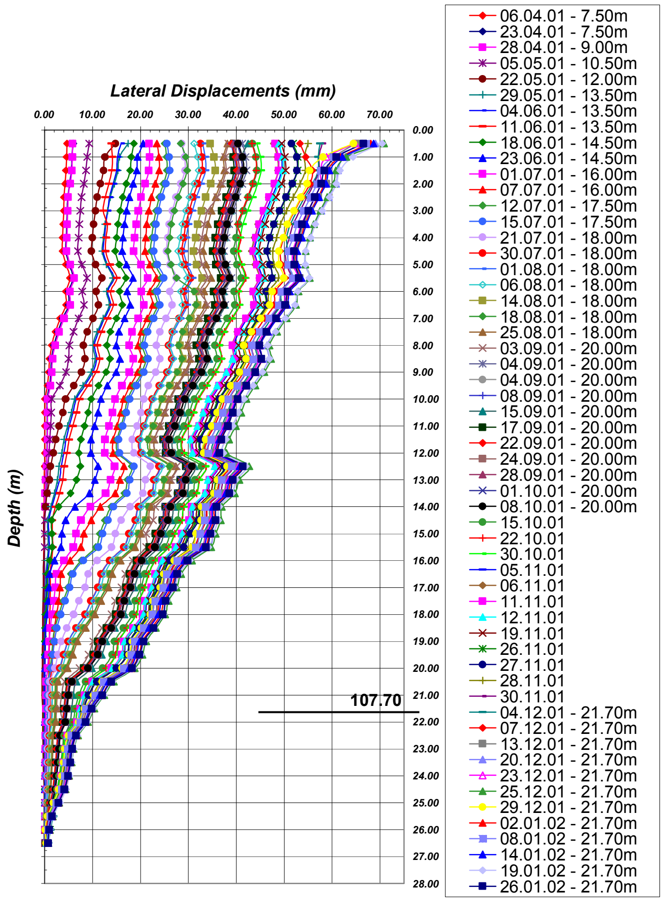

Figure 2 Inco 9 Readings

The inclinometer reading and the relevant excavation depth are illustrated to follow the ratio of lateral displacement / excavation depth and continuation of lateral displacements at one excavation level in time. The Figure 3 presentsthe progress of excavation and lateral displacements (at the top of the soil nailed wall) in time. It is determined from this figure that the lateral displacements increase in parallel with the increased excavation depth and continued to increase 30-40 days more even after the excavation stopped at 21.70m.

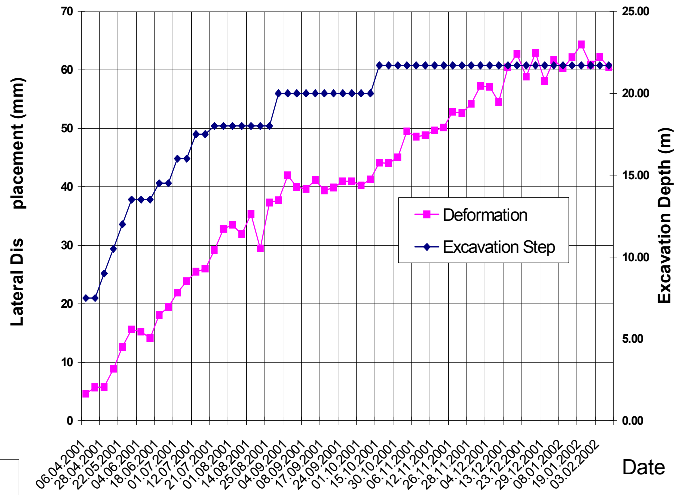

Figure 3 Lateral Displacements

5 ANALYSIS BY FLAC

FLAC is a two dimensional explicit finite difference program for engineering mechanics computation. This program simulates the behavior of structures built of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Materials are represented by elements or zones which form a grid that is adjusted by the user to fit the shape of the objects to be modeled. Each element behaves according to the prescribed linear or non linear stress / strain law in response to the applied forces or boundary restraints. The material can yield, flow and the grid can deform and move with the material that is represented. The explicit Lagrangian calculation scheme and the mixed discretization zoning technique used in FLAC ensure that plastic collapse and flow are modeled very accurately. FLAC contains many special features including interface elements, plane strain/stress, axisymmetric modes, ground water and consolidation calculations, structure elements (beams, cables, piles) and dynamic analysis capability. FLAC is used in this case to model the behavior of the soil nailed wall mainly for the purpose of determining / comparing the displacements within the wall and the surrounding roads, buildings etc and also to determine the tensile nail loads with its distribution along the nail The analysis is carried out in step wise manner in parallel to the real excavation and nail installation steps of vertically 1.5m. The required parameters (displacement, stresses etc) are calculated for each step and a very limited and compacted amount of the calculations / plots / tables that can be obtained from FLAC is presented herein. The Figure 4 illustrates the section of analysis and the nail configuration used in this section (sh : horizontal /sv : vertical nail spacing ; L : nail length).

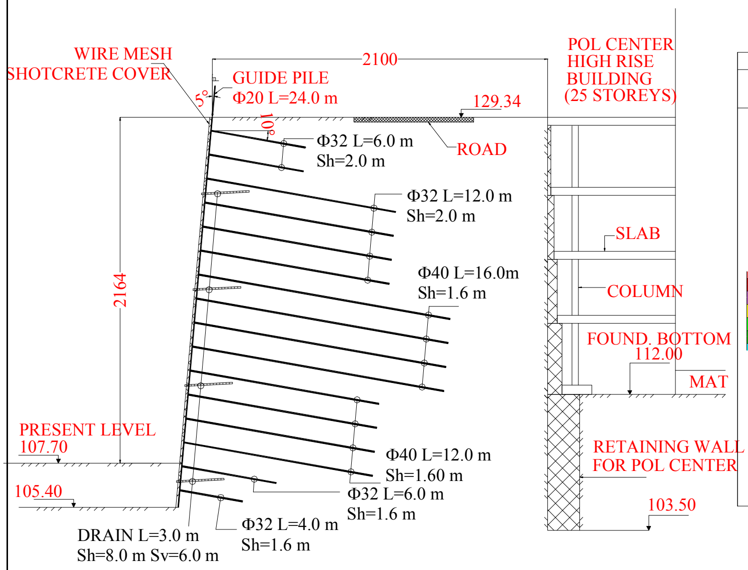

Figure 4 The Analyzed Section

The above shown section is simulated by the following FLAC model as given in Figure 5 (where also distribution of nail load in one nail is shown).

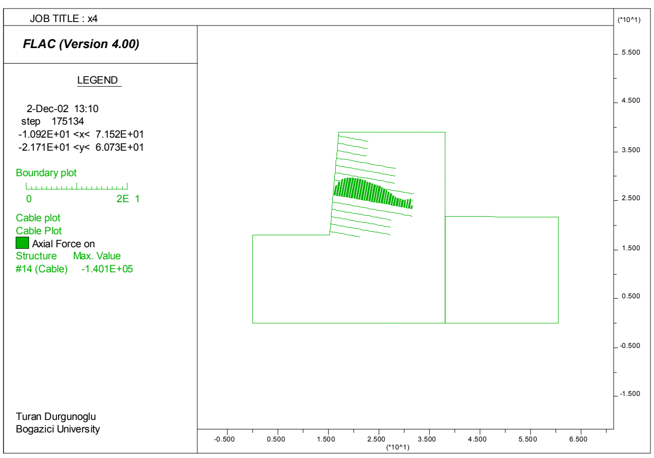

Figure 5 FLAC Model

In FLAC, soil is modeled as a viscoelastic material (that behaves according to Mohr-Coulomb law), the shotcrete cover is modeled as elastic beam elements and nails are modeled as cable elements (that can only carry tensile loads). The existing retaining wall of neighboring POL Center Building and its contact with the surrounding soil are modeled by beam elements and special interface elements.

One sample output plot of FLAC is given below in Figure 6 to illustrate the distribution of displacements (horizontal) when the excavation is at 107.70m (i.e. excavation step 14).

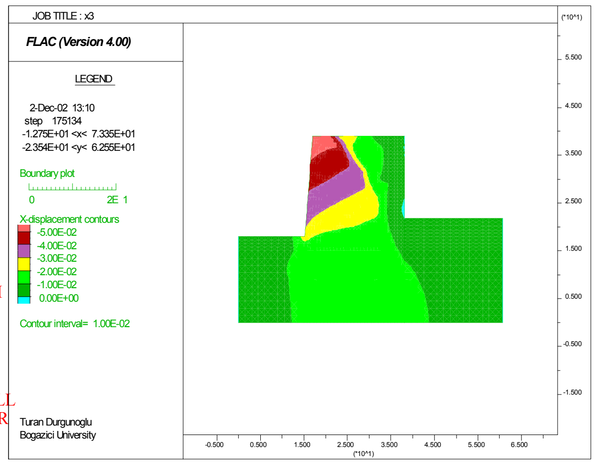

Figure 6 Sample Output

It should be noted that the lateral displacement distribution obtained in this model is affected by the presence of Pol Center building. The interface element used to model the reduced friction resistance between the existing retaining wall of Pol Center building and the surrounding soil leads to increase in settlements along this interface affecting the deformation pattern of the complete model. Therefore, the deformations presented in this paper are to be evaluated knowing this fact and should not be fully extrapolated for any soil nailed wall in similar soil conditions. Nevertheless, the, deformation (especially the lateral displacement versus depth) evaluations given in this paper is believed to add a significant information to the soil nailing behavior mainly due to the reason that this case study is based on a very deep (27m in the max. section and 21.7m in the subject section analyzed in this paper) application of soil nailing system where very reliable and long term inclinometric data is available.

In addition, FLAC provided very reliable information of axial / tensile forces and its distribution along the nails. The model figure presented in this page illustrates the distribution of the tensile load in one of the nails. The analysis show that the nail force at the connection with the facing is 60-70% of the maximum force in the nail especially for long nails that extend sufficient distance behind the potential most critical sliding wedge (surface with the minimum factor of safety for overall stability). The Table 2 presents the variation of nail loads at each excavation step (from 10 to 14, i.e. from depth 15m to 21.7m) and final max. design loads that are estimated to develop within nails.

Table 2 Nail Loads

Anchor Loads at every Construction Stage								
Anchor Level	Sh m	Excavation Stages / Anchor Loads (kN/m) 10	11	12	13	14	Max kN/m	Nail Load (kN)
1	2.0	19	18	18	18	18	21	41
2	2.0	29	29	29	29	29	30	60
3	2.0	63	82	101	104	104	104	207
4	2.0	64	65	65	65	66	66	131
5	2.0	72	72	72	72	72	73	145
6	2.0	66	69	70	71	71	71	143
7	1.6	114	118	124	136	151	151	242
8	1.6	125	125	126	132	137	137	219
9	1.6	134	144	143	147	151	151	242
10	1.6	108	151	162	165	167	167	267
11	1.6		125	163	182	183	183	292
12	1.6			141	183	197	197	314
13	1.6				151	198	198	316
14	1.6					161	161	258

This analysis is necessary to check single nail capacity and safety (both bond and steel strengths). It is recommended to install strain gauges to some of the nails to determine the tensile forces and its distribution along the nail in very deep soil nailing applications as a further supplement to the monitoring scheme that is implemented in this case study.

6 MEASURED-CALCULATED LATERAL DISPLACEMENTS

Figure 7 is prepared from measured inclinometers) and calculated (FLAC) data. The figure shows that both results (i.e. inclinometer measurements and FLAC calculations) agree favorably for all excavation and construction steps. The lateral displacement at the top of the soil nailed wall is 0.1% of the excavation depth but only up to the level of 13.5m excavation depth. From this point downwards, this ratio increases radically to 0.2% at 19.0m and 0.3% at 21.7m excavation depths. In other words, assuming one ratio (as frequently done) for the estimation of the lateral displacement of the soil nailed walls as a proportion of the excavation depth might be very misleading especially for deep applications. It is therefore essential that deep (>10m) soil nailing applications are to be monitored by means of proper devices (inclinometers, extensometers, strain gauges etc) and numerical calculation schemes (eg FLAC) are to be used for design calculations. Conventional design methods (such a limit state analysis) and lateral displacement predictions based on the previous recommendations will not be sufficient and especially misleading for displacements for such major soil nailing applications.

7 CONCLUSIONS

Following conclusions are obtained from this case study;

(a) Soil nailing is a very versatile excavation retaining system even for deep excavations close to major structures.

(b) There was a substantial saving (about 20%)

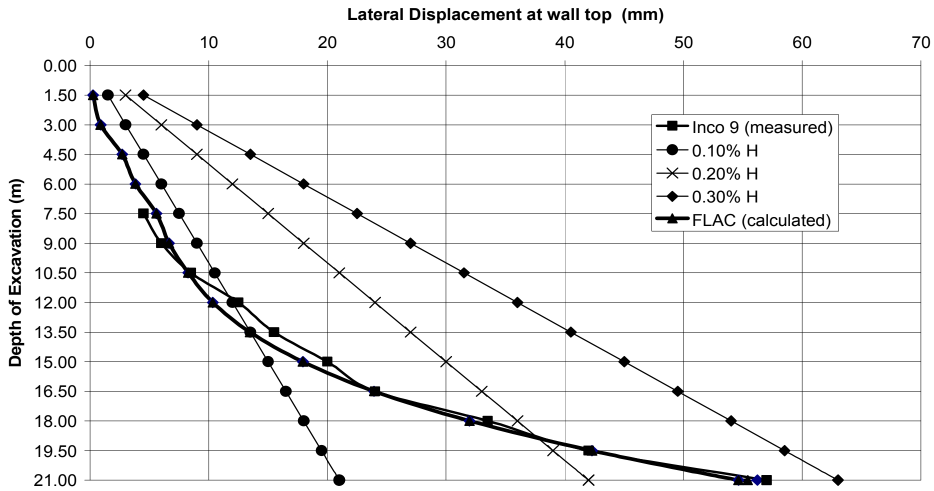

Figure 7 Lateral Displacements

due to implications of soil nailing compared to originally designed bored piled tie-back system using prestressed anchors.

(c) However, monitoring and implications of numerical analysis design methods are of primary significance for such deep applications of soil nailing.

(d) Conventional design methods shall not be sufficient and assumptions such as taking lateral displacement as a certain percentage of wall height might be very misleading for deep soil nailing applications.

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