Performance of soil nailed walls based on case studies

Comportement des parois cloutées sur la base d'etudes de cas

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ABSTRACT

Deep excavations and retaining structures are constructed in the city of Istanbul at different locations of the city due to the recent demand for the construction of high-rise structures and shopping malls having various basements. The main lithological unit of Trace Formation, i.e. alternating layers of sandstone, siltstone and claystone are encountered during these excavations. The lithological unit is extensively fractured. Consequently, stress relief in horizontal direction as a result of excavations is the main potential hazard that has to be handled with care. Istanbul is located at a very seismically active region and a major earthquake magnitude of M_w>7.0 are expected to occur with a 65% probability within the next 30 years. It is well known that flexible earth retaining structures in cuts as soil nailed walls offer a great advantage under the described subsoil and seismic conditions. As a result many soil nailed walls having various heights have been constructed recently in the city. The performances of these walls are monitored by means of inclinometers. The displacement data for various projects are evaluated in terms of various design parameters of the soil nailed walls and the excavation depth. In the paper the basic guidelines for soil nailed walls in typical greywacke formation of the city are developed for future applications.

RÉSUMÉ

La demande récente dans la ville d'Istanbul en immeubles de grande hauteur et en centres commerciaux comportant plusieurs niveaux de parking en sous-sol entraine le développement de la mise en oeuvre d'excavations profondes et de structures de soutènement. Le principal horizon lithologique rencontré lors de ces excavations est la formation dite Trace Formation, c'est-à-dire une alternance de grès, silt and argilolite. Cette formation est fortement fracturée. En conséquence, le relâchement des contraintes horizontales lors des travaux constitue le principal risque qu'il convient de traiter avec soin. La ville d'Istanbul est située dans une zone à très forte activité sismique, où la probabilité de survenance dans 30 ans à venir d'un séisme majeur d'intensité supérieure à 7 est estimée à 65%. Il est bien connu que les structures de soutènement souples, telles que les parois cloutées, présentent un grand avantage dans les terrains décrits plus haut, en zone sismique. C'est pourquoi, de très nombreux murs de soutènement cloutés, de différentes hauteurs, ont été construits récemment dans la ville. Leur comportement est contrôlé par des inclinomètres. Les déplacements constatés sur différents projets sont évalués en fonction des divers paramètres de calcul des parois et de leur hauteur. Cela permet de développer des règles générales de dimensionnement des parois cloutées dans la formation géologique caractéristique de la ville utilisables pour de futurs projets.

Keywords: soil nailing, deep excavations, lateral displacement, design parameters, case studies

1 INTRODUCTION

The city of Istanbul due to its recent growth in economy caused a great attraction for the construction of high-rise residential and office buildings. In order to obtain parking space, deep excavations are employed to allow great number of basements below these tower structures. The depths of the excavations commonly reach to 25-40 meters below the ground surface.

The city of Istanbul is potentially under the influence area of the Marmara Fault System, located at the south, in the Marmara Sea, which is the western end of the North Anatolian Fault-NAF of Turkey. After the 1999 Kocaeli and Düzce earthquakes occurred on NAF within the Marmara Region in approximately 100-150 kilometers from the city of Istanbul, the structure of NAF system in Marmara Sea attracted worldwide scientific attention.

Recent studies conducted after the 1999 Kocaeli (M_w=7.4) and Düzce (M_w=7.2) earthquakes indicated that about 65% probability for the occurrence of a M_w>7.0 effecting Istanbul within the next 30 years due to the existence of potential seismic gaps. (Parsons *et al* 2000).

The encountered subsoil formation is soft rock greywacke locally known as Trace Formation, which is lithologically alternating sandstone, siltstone and claystones with various degree of weathering and fracturing. Obviously, the extend of weathering and fracturing controls the mechanical properties and in fact geological observations do well agree with the results of measurements reflecting mechanical properties of the formation. The geotechnical modeling of formation, weathered zones, extend of fracturing and compressibility modulus of formation are usually obtained by means of integrated seismic survey and Menard pressuremeter testings performed within the boreholes at various locations and depths. (Durgunoglu & Yılmaz 2007)

Based on the previous positive records of flexible earth retaining structures during earthquakes in Turkey by Mitchell *et al* (2000) and Durgunoglu *et al* (2003), soil nailed walls in such excavations performed within the city offer great advantage especially for the encountered subsoil and seismic conditions.

The results of the performance of walls with different heights in various sites having the similar greywacke subsoil formation are compiled in this study. The performances of walls are monitored by inclinometer recordings taken at certain time intervals in parallel to the excavation at various locations. The displacement and normalized displacement (i.e. performance ratio, P_r) data are presented together with some basic parameters of soil nailed walls such as, height of wall (H), area per nail (S), average nail length (L), nail density (η=L/S), length ratio (L_r), bond ratio (B_r) and strength ratio (S_r). As a result the values of performance ratio for soil nailed walls together with nail density in typical greywacke formation of the city of Istanbul are developed based on these extensive case studies as a guideline for future applications.

2 CASE STUDIES

During the past ten years soil nailed walls are extensively constructed within the city of Istanbul as temporary retaining walls for to support the basement excavations of various structures. According to recent compilation by Zetas (2006) about 160,000 m^2 of wall had been constructed in 60 different project, the performances of some of these soil nailed wall structures have been reported previously by Durgunoglu and *et al* (1997), Ozsoy (1996) and Yılmaz (2000). In this study six major case of deep soil nailing walls constructed in locally well known Trace Formation – greywacke are presented. In general, the greywacke is alternating fractured sandstone, siltstone and claystone formation having some degree of weathering close to surface. They are classified as soft rocks having shear wave velocities in the range of v_s=400-800 m/sec depending on the extend of fracturing. The shear modulus estimated form the Menard pressuremeter tests vary in the range of G_m=20-100 MPa and the modulus of elasticity, E_m=50-250 MPa depending weather sandstone or siltstone and claystone dominates the greywacke formation.

The variation of shear modulus, G_0 with depth obtained from Rayleigh wave measurements representing greywacke formation is given in Figure 1, after Durgunoglu and Yılmaz (2007). On the same figure the variation of shear modulus, G_m with depth obtained from pressuremeter measurements are also presented.

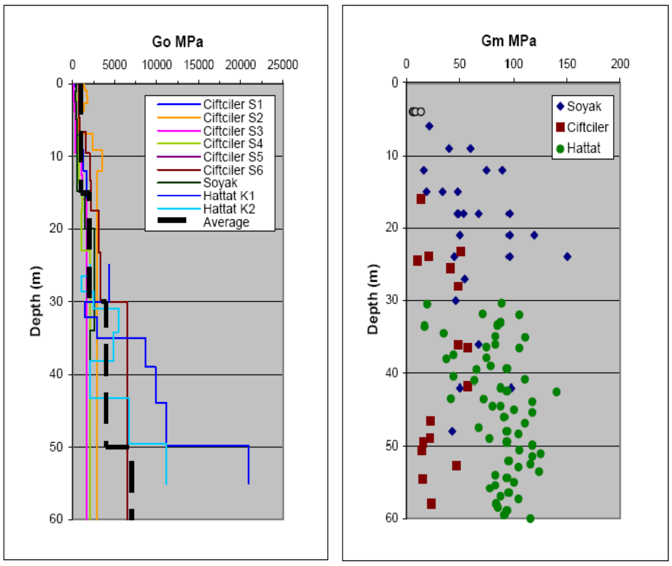

Figure 1. The variation of shear modulus with depth

In the case studies evaluated the maximum height of soil nailed walls varied between 10.0 m to 32.5 m. Since it is known from the previous studies that a small inclination from the vertical has a great advantage in the performance of the walls (Clouterre 1993), (Elias & Juran 1989), the slope angle β for the studied cases were 85° except for case 2, Istinye Park having β=80°.

Nail orientation with horizontal were adopted as ω=10° in all the cases together with a common nail diameter of D=105 mm. The main lithological features of the greywacke formation are given together with other geometrical data; the maximum excavation height, H, slope angle, β, nail orientation, ω and the nail hole diameter, D in millimeters in Table1.

Table 1. Geometrical data and soil conditions of case studies

Case(*) No. #	Max. Exc. Height H_{max} (m)	Slope Angle β (degrees)	Nail Orientation ω (degrees)	Nail Hole Diameter D (mm)	Subsoil Conditions
1	32,5	85 °	10 °	105	fractured silicified **sandstone**
2	22,0	80 °	10 °	105	extensively fractured **siltstone, claystone**
3	28,3	85 °	10 °	105	extensively fractured **sandstone, siltstone, claystone**
4	24,9	85 °	10 °	105	extensively fractured **siltstone, claystone**
5	10,0	85 °	15 °	105	extensively fractured **sandstone, siltstone, claystone**
6	28,7	85 °	10 °	105	extensively fractured **sandstone**

(*) Projects related to various cases are given in Table 2.

3 TYPICAL LATERAL DISPLACEMENT DATA

A typical lateral displacement data for the case no. 3 (Kanyon Complex, Istanbul), inclinometer 7 is presented in Figure 2. At the top the excavation depth vs. date, in the middle lateral displacement vs. date and at the bottom lateral displacement vs. depth are provided. A photograph from this site is also given in Figure 3.

Although the major height of the soil nailed wall was completed within six months, the excavation was kept open for almost another two years due to delay in final design of the upper structures to be constructed and obtaining related building permit from the municipality. It is interesting to note the followings:

- The lateral displacement has increased linearly with depth up to an excavation depth of approximately 18.0 m. For greater depths the rate of increase in the lateral displacement was increased considerably.
- Although the temporary excavation with soil nailed retaining structure left open more than two years, almost no additional lateral displacement was observed in spite of heavy rain and snow within that period indicating that the drainage system designed and implemented which in Figure 3 were performed satisfactorily. Subhorizontal drains, in length of l_d=3m, were implemented at S_h = 8 to 9m horizontal spacings with an inclination of 3° to the horizontal. The typical vertical spacings were S_v = 4 to 6m.

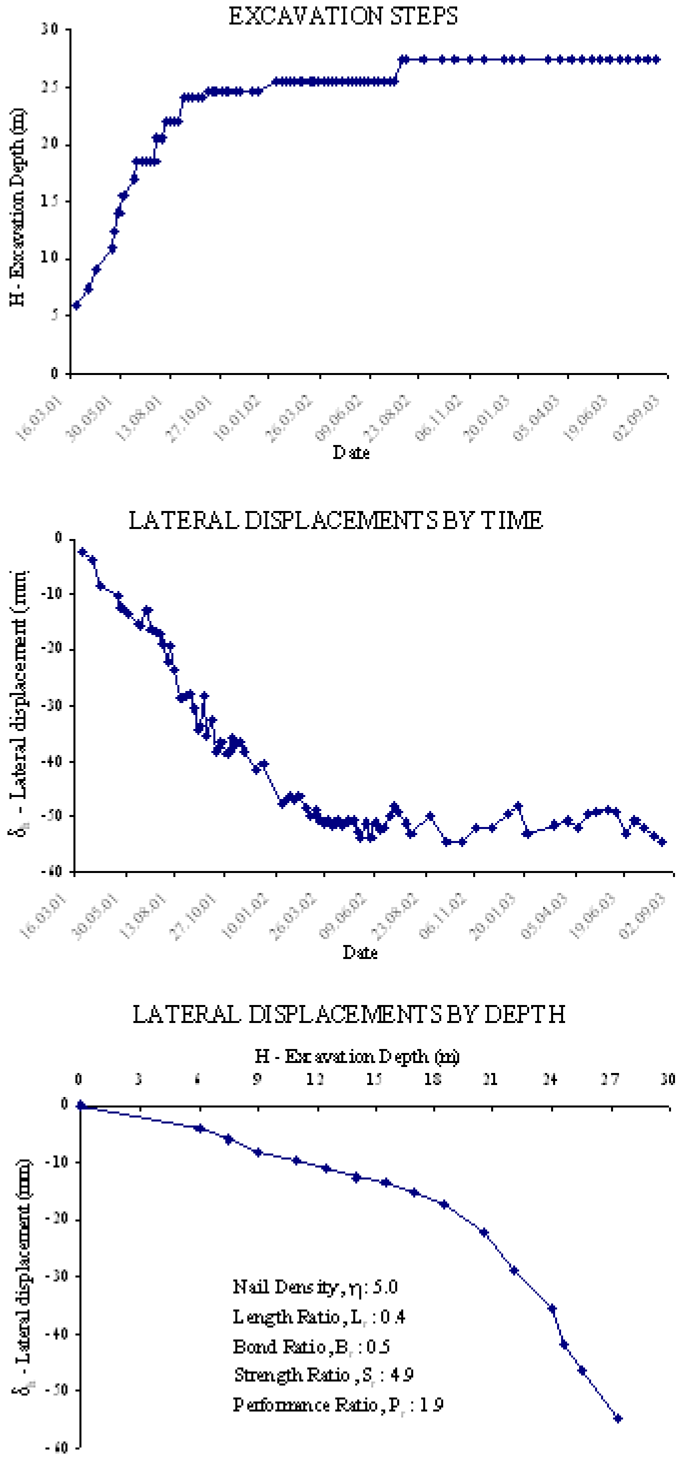

Figure 2. Lateral displacements for Case No.3, Kanyon Complex

Figure 3. A photograph from Kanyon Complex

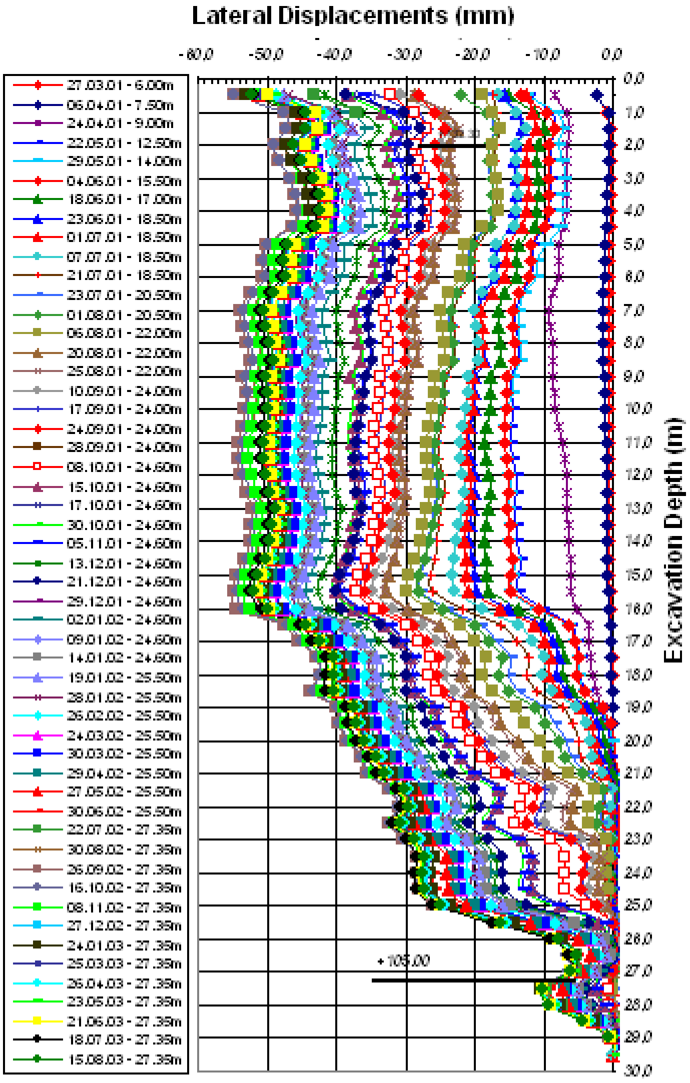

Figure 4. Case No.3, inclinometer 7 readings

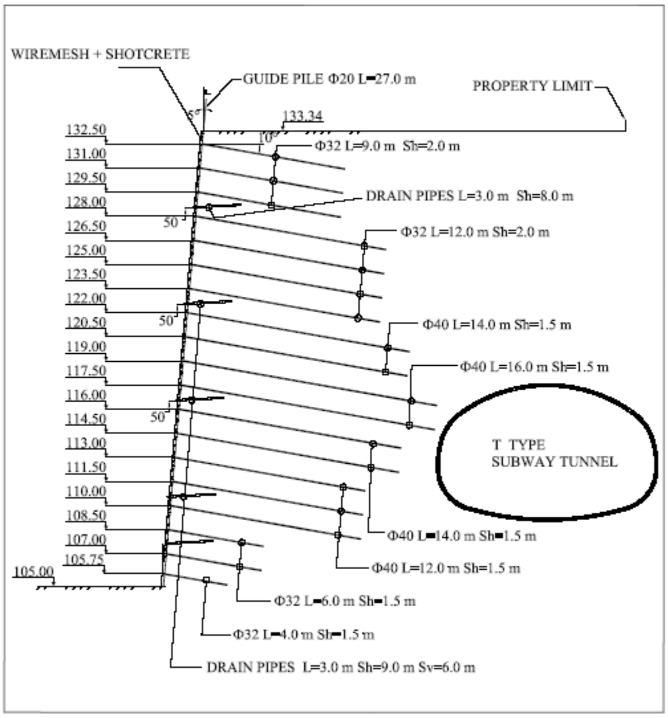

Figure 5. Detailed cross-section at inclinometer 7 location

4 PERFORMANCE OF SOIL NAILED WALLS

For the each case study, some of the basic design parameters for the soil nailed walls, (Phear *et al* 2005) are determined from the final design drawings and are given in Table 2.

Table 2. Design and performance parameters for soil nailed case studies

Case 1: BJK Fulya Complex, Fulya,Istanbul

Inc. No.	H (m)	S (m^2)	L (m)	δ_h (mm)	η (m/m^2)	L_r	B_r	S_r (10^{-3})	P_r (10^{-3})
1	18.5	2.7	9.2	14.0	3.4	0.5	0.4	4.1	0.8
2	25.0	2.1	11.2	22.7	5.3	0,4	0.6	5.3	0.9
3	32.5	2.1	10.2	50.6	4.9	0,3	0.5	5.3	1.6

Case 2: Istinye Park Complex, Istinye, Istanbul

Inc. No.	H (m)	S (m^2)	L (m)	δ_h (mm)	η (m/m^2)	L_r	B_r	S_r (10^{-3})	P_r (10^{-3})
1	10.0	3.0	5.1	26.6	1.7	0.5	0.2	3.7	2.7
2	10.0	3.0	8.3	22.0	2.8	0.8	0.3	3.7	2.2
3	12.0	3.0	6.0	36.7	2.0	0.5	0.2	3.7	3.1
4	12.0	3.0	8.8	24.7	2.9	0.7	0.3	3.7	2.1
5	14.0	3.0	9.1	19.9	3.0	0.7	0.3	3.7	1.4
6	16.0	3.0	8.2	45.3	2.7	0.5	0.3	3.7	2.8
7	18.0	3.0	9.3	56.7	3.1	0.5	0.3	3.7	3.1
8	20.0	3.0	9.7	80.8	3.2	0.5	0.3	3.7	4.0
9	22.0	3.0	10.1	96.5	3.4	0.5	0.4	3.7	4.4

Case 3: Kanyon Complex, Levent, Istanbul

Inc. No.	H (m)	S (m^2)	L (m)	δ_h (mm)	η (m/m^2)	L_r	B_r	S_r (10^{-3})	P_r (10^{-3})
1	14.0	2.7	8.4	27.8	3.1	0.6	0.3	4.1	2.0
2	15.7	3.0	9.4	45.1	3.1	0.6	0.3	3.7	2.9
3	18.8	2.4	9.5	32.5	4.0	0.5	0.4	4.6	1.7
4	21.3	2.7	11.6	69.2	4.3	0.5	0.5	4.1	3.2
5	25.3	2.4	11.2	57.5	4.7	0.4	0.5	4.6	2.3
6	26.3	2.4	11.8	85.7	4.9	0.4	0.5	4.6	3.3
7	28.3	2.3	11.3	54.8	5.0	0.4	0.5	4.9	1.9
8	28.3	2.3	11.3	69.2	5.0	0.4	0.5	4.9	2.4
9	28.3	2.3	11.6	97.0	5.1	0.4	0.5	4.9	3.4

Case 4: Mashattan Residence, Maslak, Istanbul

Inc. No.	H (m)	S (m^2)	L (m)	δ_h (mm)	η (m/m^2)	L_r	B_r	S_r (10^{-3})	P_r (10^{-3})
1	18.3	2.4	6.7	59.3	2.8	0.4	0.3	4.6	3.2

Case 5: Tepe Shopping Mall, Maltepe, Istanbul

Inc. No.	H (m)	S (m^2)	L (m)	δ_h (mm)	η (m/m^2)	L_r	B_r	S_r (10^{-3})	P_r (10^{-3})
1	7.0	2.7	6.4	5.6	2.4	0.9	0.2	4.1	0.8
2	9.0	2.3	12.0	15.8	5.3	1.3	0.6	4.9	1.8
3	9.0	2.4	7.3	15.4	3.1	0.8	0.3	4.6	1.7
4	10.0	2.3	12.0	24.3	5.3	1.2	0.6	4.9	2.4

Case 6: Besler Warehouse, Pendik, Istanbul

Inc. No.	H (m)	S (m^2)	L (m)	δ_h (mm)	η (m/m^2)	L_r	B_r	S_r (10^{-3})	P_r (10^{-3})
1	14.7	4.0	9.3	10.2	2.3	0.6	0.2	2.8	0.7
2	16.2	4.0	9.6	18.3	2.4	0.6	0.3	2.8	1.1
3	18.4	3.6	9.6	13.4	2.7	0.5	0.3	3.1	0.7

In Table 2;

H = excavation height, m
S = S_h x S_h, area per nail, m^2
L = average nail length, m
δ_h = lateral displacement at top, mm
η = L/S, nail density, ave. nail length per area, m/m^2
L_r = L/H, length ratio
B_r = DxL/S, bond ratio
S_r = D^2/S, strength ratio
P_r = δ_h /H, performanced ratio

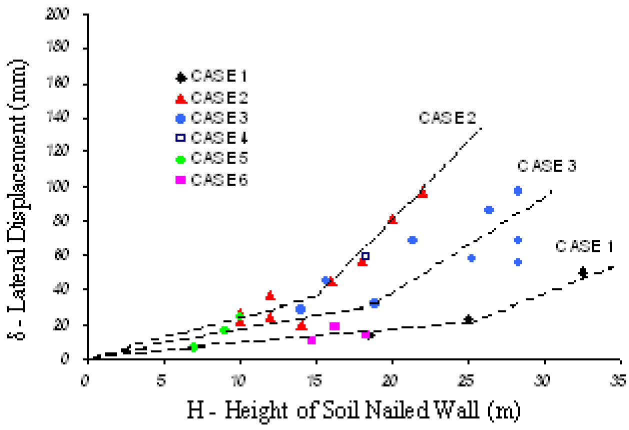

Figure 6. Lateral displacements vs. height

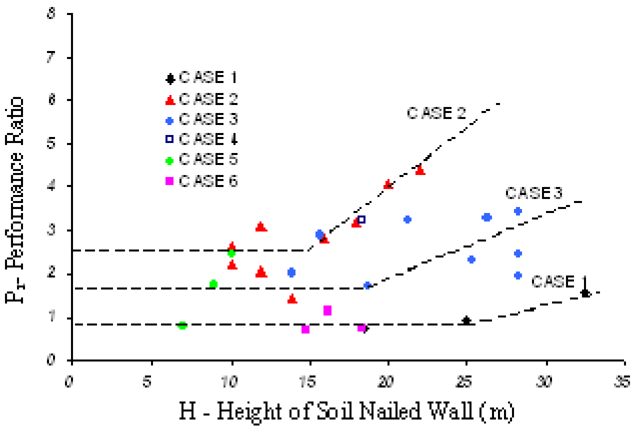

Figure 7. Performance ratio vs. height

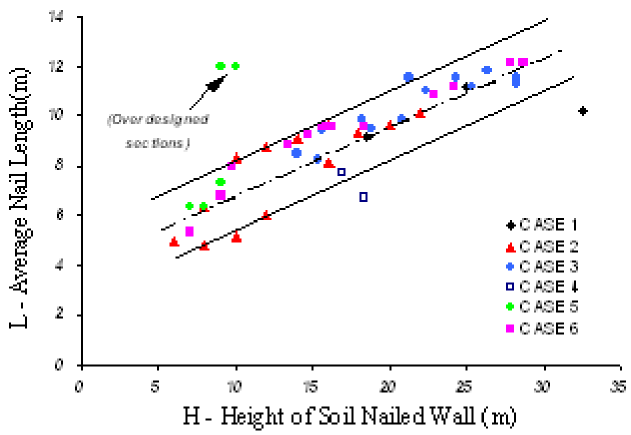

Figure 8. Average nail length vs. height

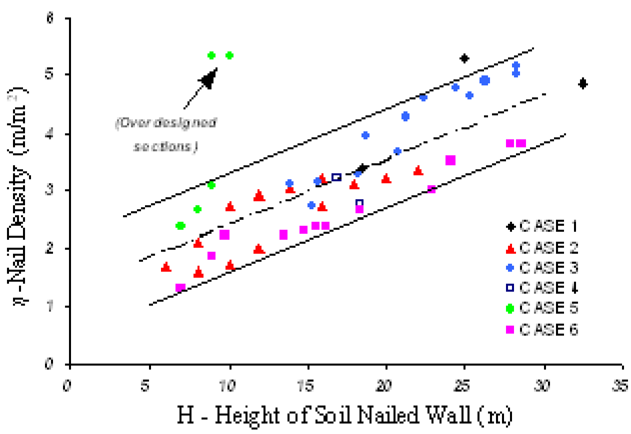

Figure 9. Nail density vs. height

By the analysis of the data given in Table 2, lateral displacements, δ_h, performance ratio, P_r, average nail length, L, and nail density, η and the height of the soil nailed wall were developed and presented in Figures 6 through 9. From these figures the following observations and evaluations are done for the soil nailed walls constructed in greywacke formation:

- It is seen that the linear increase in lateral displacement with the height of the wall is valid up to a certain height. The change in slope occurs at various heights and sooner for the weaker claystone than the stronger silicified sandstone case. Similar observation was made previously by Durgunoglu *et al* (2003)
- The performance ratio, P_r, for the greywacke formation is within the range of $1x10^{-3}$ to $3x10^{-3}$, depending in the nature of the lithological unit of the formation. For the strongest silicified sandstone with E_m=250 MPa, $P_r \sim 1x10^{-3}$, on the other hand for weakest claystone $P_r \sim 3x10^{-3}$ with E_m=50 MPa. It maybe seen that these values tend to increase after 25m for the case of sandstone and 15m for the case of claystone.
- Average nail length, L, increases linearly with the height of soil nailed wall. The average nail length that could be utilized is about L=5 to 8m for H=10m and L=8 to 11m for H=20m.
- Nail density, L/S (m/m^2) also increases linearly with the height of the soil nailed wall. It is about 1.6 to 3.2m/m^2 for H=10m and 2.8 to 4.4m/m^2 for H=20m.
- From figures 8 and 9 it is seen that two sections from case 5, Tepe Shopping Mall, are overdesigned since they have noticeably long average nail lengths considering the small soil nailed wall heights. However, excessive nail lengths implemented on these sections have no or little effect on the lateral displacements or performance ratios as can be seen from the figures 6 and 7.

5 CONCLUSIONS

Soil nailing is a very versatile excavation retaining system for deep excavations in urban areas surrounded by major structures and infrastructures provided that limiting lateral displacements are not exceeded.

Using conventional methods of design, Federal Highway Administration (2003) and previously developed charts for estimating lateral displacements or performance ratio may be misleading in deep soil nailing applications

Monitoring and modern numerical analysis based design and application for such deep soil nailed walls are of primary importance.

ACKNOWLEDGEMENT

We would like to thank to ZETAS Zemin Teknolojisi A.S. for providing all the pertinent data for the soil nail walls case studies presented in this paper.

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