Soil Nailing Practice in İstanbul

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ABSTRACT

Soil nailing as a retaining system for excavations and slopes is a widely accepted method in countries where the seismic activity is the main concern. Considering the increasing demand for deep excavations in connection with extensive land utilisation within densely populated areas and as a result of increasing value of land, the economy and construction speed of soil nailing has made the method an outstanding alternative for both temporary and permanent excavations in İstanbul, where the main lithological unit is alternating claystone, siltstone and sandstone known as greywacke formation. In this paper the remediation studies for a retaining structure that has failed during the deep excavation of a high rise hotel building in İstanbul are summarized. The failure mechanism has been investigated and design considerations have been evaluated in terms of stability and safety. A retaining system with soil nailing has been chosen for the remedial design. Instrumentation and monitoring has been implemented during the application of remedial measures and the most economical engineering solution has been applied with safety.

1. INTRODUCTION

A sudden failure has occurred in a tieback retaining wall during the deep excavation of a high rise hotel building in İstanbul. The depth of the excavation base is planned to be 20.5m, whereas the failure took place when the excavation was at 16.0m depth. The plan of the failed retaining system is shown in Figure 1. The sliding block covered the entire wall with a length of 80 meters, the main scarp extending to 15 meters behind the wall.

The failure mechanism has been investigated and design considerations have been evaluated in terms of stability and safety. A back analysis has been performed using the available geotechnical parameters on a typical cross section and it has been determined that maximum capacity of the elements of the tie back retaining wall has been exceeded with the drop of the peak shear strength parameters to residual values.

A proper soil nailed retaining system has been designed according to the evaluations of the geotechnical conditions and failure geometry. Stability analyses have been performed in the design of the nailed wall. Nail lengths have been optimized by evaluating the location of critical sliding surfaces along the wall. Lateral deflections have been monitored with inclinometers during construction and the proposed system has been applied with safety.

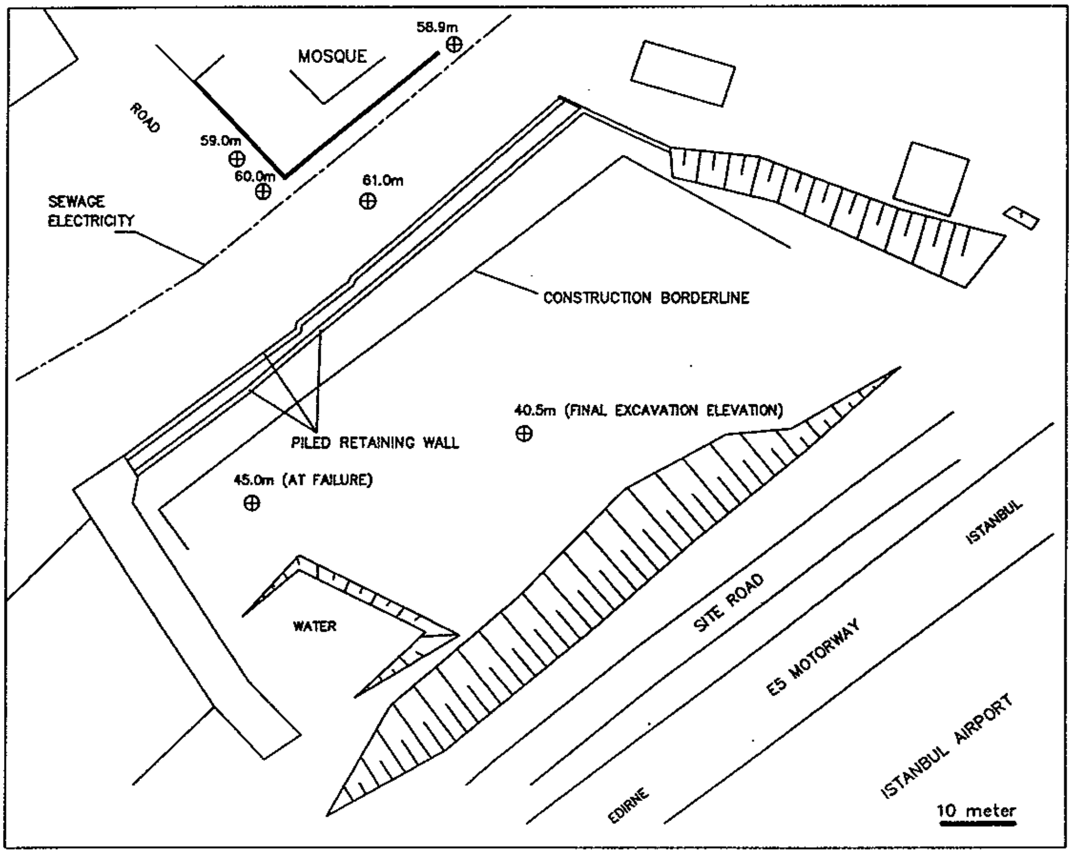

Figure 1. Site Plan

2. INITIAL RETAINING SYSTEM AND INVESTIGATIONS

The governing strength parameters and the design considerations of the initial project have been checked to determine the failure mechanism, taking into consideration that the failure geometry exhibited a systematic pattern, covering the entire retaining wall. The present soil formation consists of sedimentary deposits. Erratic layers of clay, marn and sand are present at the top; limestone overlying overconsolidated clay is present below this covering surface. Geotechnical parameters that were proposed in the design are summarized in Table I.

Table I. Geotechnical Parameters (Toğrol, 1993)

Soil	c′ (kPa)	ϕ' (deg)	γ_n (kN/m^3)
clay, marn, sand layers	0	26.5	18
marn, limestone	10	37.5	19
overconsolidated clay	40	22.0	18

The tieback wall was designed as the retaining system for the foundation excavation of a high rise hotel building. The retaining system consists of intersecting bored piles of ϕ 80 cm diameter, tied back with two rows of 20.0m long anchors. The initial ground elevation prior to excavation is 61.0m and the elevation of the final excavation base is 40.5m, creating a depth of 20.5m. A typical cross section and failure geometry is shown in Figure 2.

A sudden failure has occurred in the system described above when the excavation was at elevation 45.0m, corresponding to 16.0m depth. The failure covered the entire wall length of 80 meters, extending to 15.0m behind the wall. All of the anchors supporting the piled wall have shown to fail, some pulled out from the soil, some broken by the tendons. Resulting in damage to some neighboring structures and breaking sewage pipes and electricity cables, whole material in this zone slided into the excavation area.

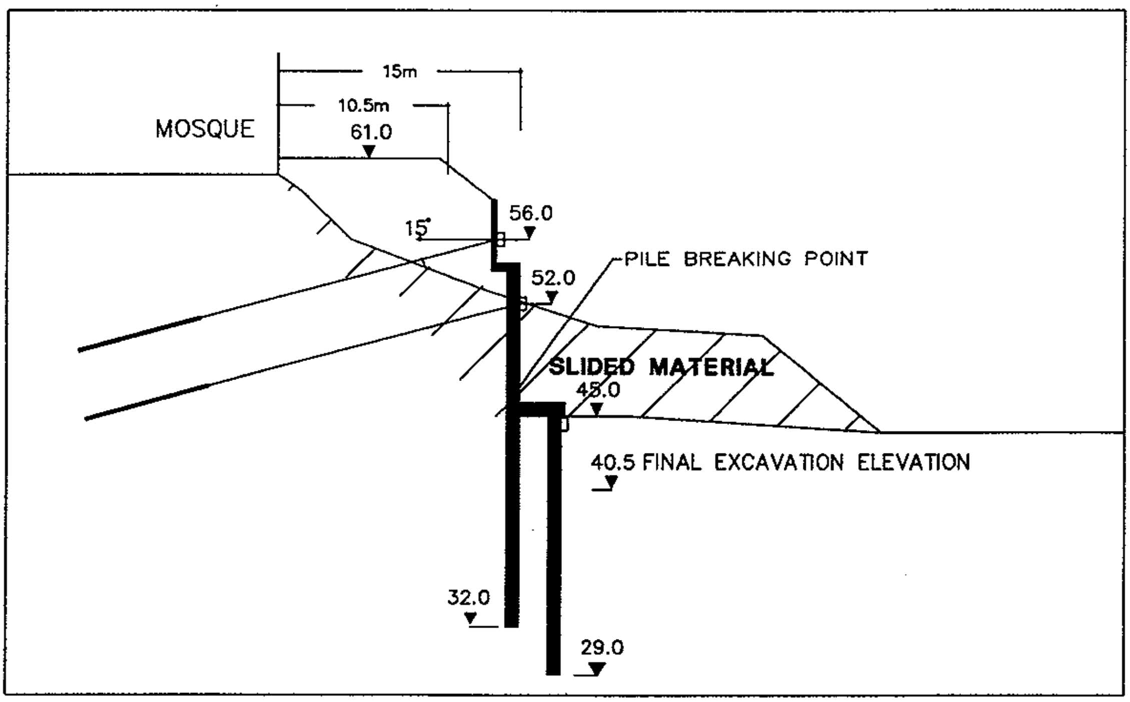

Figure 2. Typical Cross Section of Tieback Retaining Wall and Failure Geometry

The forces expected to develop on the elements of the tieback wall have been investigated by performing a back analysis on a typical cross section, using the available parameters. The backcalculated forces have been evaluated by comparing the forces expected to develop on the retaining wall with maximum capacities. Possible scenarios of failure have been checked to determine the failure mechanism. The results of the analyses are summarized below in Table II.

Table II. Element Forces Back-calculated Using Available Parameters

Element	**Calculated Force-Moment**	**Allowable-Maximum Values**
1st row anchorage	653 kN/anchor	450 kN-650 kN (all.-max.)
2nd row anchorage	550 kN/anchor	450 kN-650 kN (all.-max.)
Toe support system	400 kN/m	3000 kN/m
Pile section moment	257 kNm/pile	365 kNm - 512 kNm (all.-max.)
Support beam moment	199 kNm	not critical

It has been determined from the performed analyses that, even though the geotechnical parameters used in the design were valid, forces exceeding the allowable capacity are expected to develop on the elements of the tieback wall. Finally it has been determined that the intrusion of water and decomposition resulted an initial sliding movement. With this initializing movement, the shear strength of overconsolidated clay dropped from peak values to residual values and the stresses in the anchors increased to values exceeding the maximum capacity, resulting with failure (Durgunoğlu, 1995).

3. REMEDIAL PROJECT

After the studies performed to determine the failure mechanism and with the evaluations of the geometrical configuration of sliding, a soil nailed wall starting behind the slided slope as seen in Figure 3, has been designed as the remedial project. The nailed wall consists of two stages extending from elevation 45.0m to 60.0m. The nails are located with 2.0m horizontal spacing. The final excavation depth which is below the base of the nailed wall is designed to be achieved by using the unbroken piles remaining from the initial project.

Stability analyses have been performed both for the nailed wall and overall sliding. The optimum nail length is determined with the evaluation of possible slip surfaces along the wall. Two critical sliding

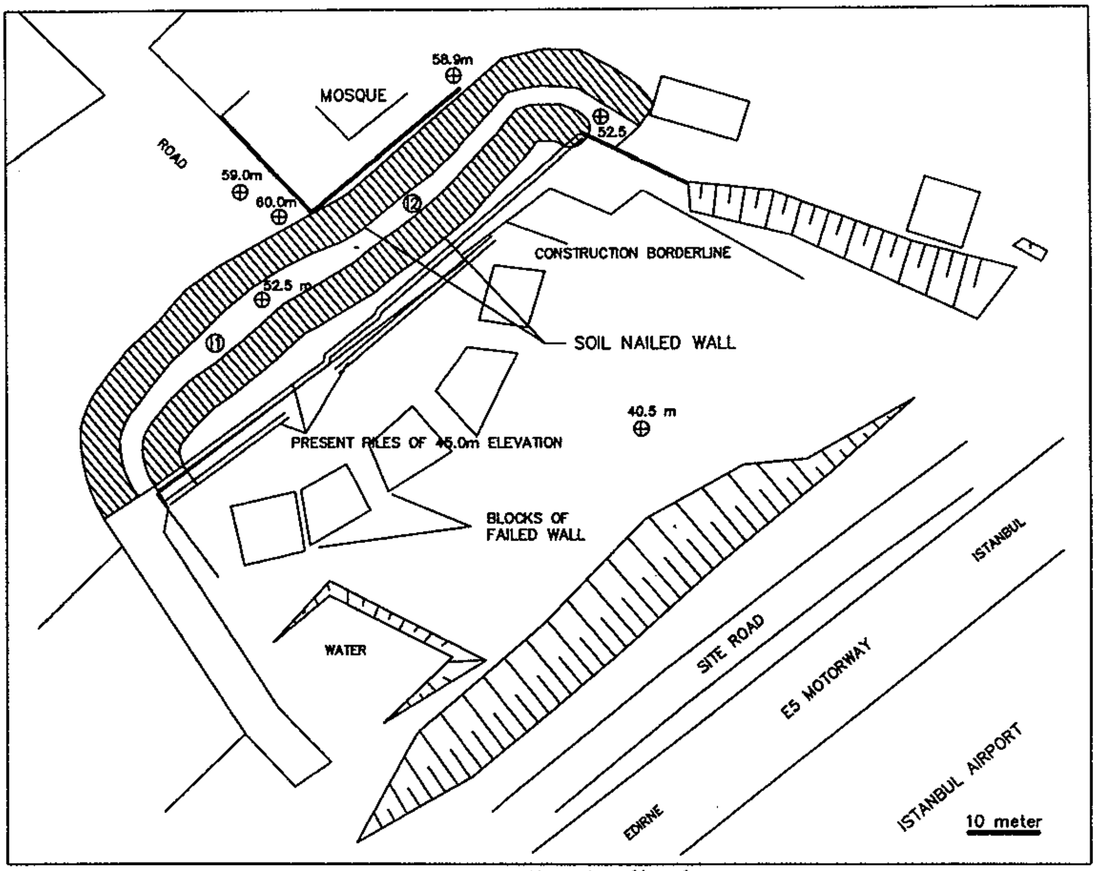

Figure 3. Soil Nailing Application

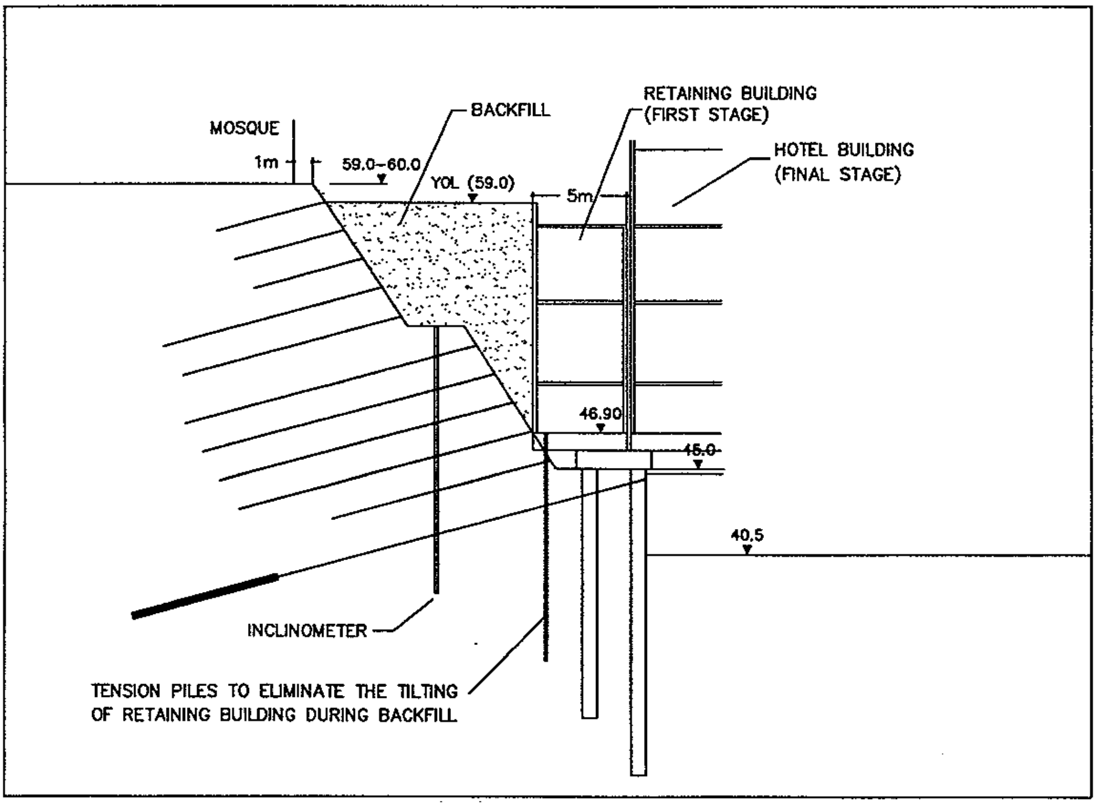

Figure 4. Final Cross Section of Nailed Wall

surfaces have been checked using the residual parameters assuming the cohesion value dropped to zero. One of these surfaces is the shallow sliding surface intersecting the toe of the slope. The nail lengths have been optimized with the evaluation of this surface. Alternatively the deep sliding surface passing under the piles been checked and it has been determined that it was not critical in terms of statical and earthquake conditions.

The building construction started following the completion of the excavation supported by soil nailing. At the first stage, the part of the hotel building 5.0m wide has been constructed to enable the excavation area to be backfilled so that the neighboring road could be opened to traffic. The top of the piled wall has been tied back with additional anchors to withstand the overturning moments due to the backfill and the initial stage building. Moreover, micro piles of ϕ 15cm diameter and 20.0m length with 1.0m spacing have been installed to the base of this 5.0m wide building section to support the building for the overturning moments, as shown in Figure 4 .

4. INSTRUMENTATION

It was determined from the performed analyses that the shear strength parameters of the subsoil had dropped to residual values due to sliding. The deformations during the excavation were expected to rise to values critical for neighboring structures, due to the presence of a preslided surface and the drop in soil shear strength. Two inclinometers were installed at 52.5m elevation at the berm of the nailed wall to monitor the lateral movements during excavation. The location of the inclinometers along the wall are shown in the plan showing soil nailing application. The second stage of the nailed wall that has been monitored is completed in five excavation stages. The lateral deflections measured with two inclinometers for each excavation step are shown in Figure 5.

Several sliding surfaces have been detected during the excavation and construction processes. It is seen from both inclinometer readings that, sliding has started 3.0-3.5m below the berm at the first excavation stage, but this movement has stopped at location of inclinometer 1, in the proceeding excavation steps. In the following excavation stages, a surface located at 7.0 m depth has started to move at location of inclinometer 1. The deflections at inclinometer 2 location have continued to increase at depth 3.5 m to values measured larger than the first inclinometer. The measured deflections have shown to be in good agreement with the sliding surfaces proposed in the design procedure of the nailed wall.

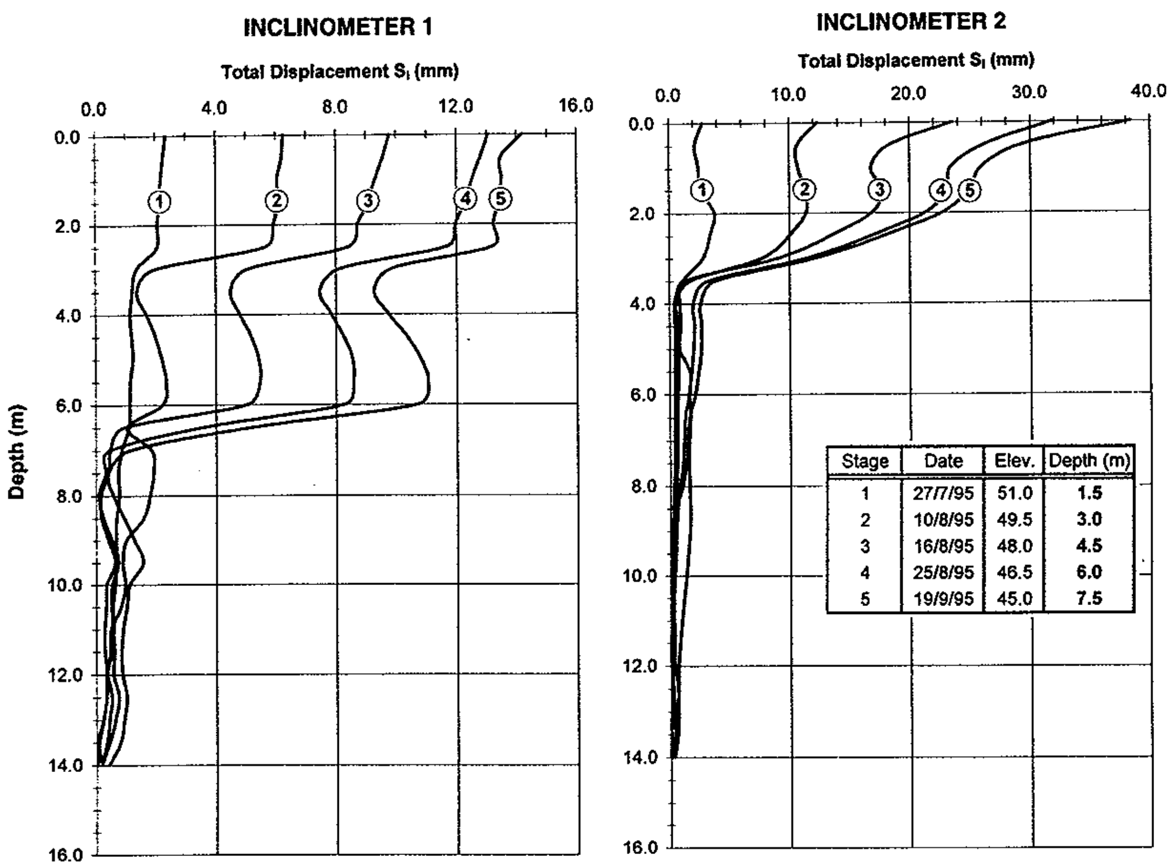

Figure 5. Monitoring Results

The ratio of deflections measured during excavations to corresponding wall heights are summarized in Table III. The lateral deflections measured are in ranges between 0.2 to 0.5 percent of wall height. These values are in good agreement with the ones proposed in the literature (Elias and Juran, 1989) for deflections required for full mobilization of nail forces and measurements at recent soil nailing applications in İstanbul (Özsoy, 1996).

Table III. Excavation Stages and Lateral Wall Movements

Excavation Stage	Elevation (m)	Wall Height - H (m)	Lateral Movement - D (mm)		D / H (x 1000)	
			I1	I2	I1	I2
1	51.0	1.5	2.4	2.8	1.6	1.9
2	49.5	3.0	6.3	12.3	2.1	4.1
3	48.0	4.5	9.8	23.6	2.2	5.2
4	46.5	6.0	13.1	31.8	2.2	5.3
5	45.0	7.5	15.4	38.4	2.1	5.3

5. CONCLUSION

The remediation studies after a retaining structure failure are outlined. Analyses have been performed to determine the failure mechanism and it has been decided that failure occurred since the anchor forces were exceeded with the drop of strength parameters from peak to residual values.

A retaining system with soil nailing has been designed and constructed as a remedial measure with the evaluation of subsoil condition and failure geometry. Soil nailing as a flexible retaining system can conform to the surrounding ground and withstand greater total and differential ground movements in all directions. Therefore, smaller earthquake coefficients could be utilized in the design of this flexible retaining system which made nailing very cost effective compared to alternative rigid tieback systems. The lateral movements of the nailed wall has been monitored with inclinometers during the excavation and construction process. The measured deflections have shown to be in the ranges of the ones proposed in the literature for this type of formation. The most economical engineering solution has been applied with safety with the application of instrumentation and monitoring.

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