FOUNDATION STRENGTHENING OF EXISTING BUILDINGS BY GROUTING; EITHER INJECTION OR SOIL REPLACEMENT

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ABSTRACT

Grouting is one of the major soil strengthening methods and it is economical and versatile too. The studies have been conducted around the foundations of low rise reinforced concrete buildings. They are built on problematic soils. A cement grout was injected near the columns, and the grouting holes were as much as seven meters deep around the basement level. The injection density was about 10m^2/borehole. The study proved that the uniaxial compressive strength and Young's modulus of the tested soils was remarkably improved. However, grouting caused a slight increase in the unit weight of the soils in the cases. Similarly, there was not a significant relationship between grouting pressure and the physical properties of grouted soil. Thin sections of the core samples were visualised under polarized light from crossed nicol prisms, which illustrated that soil has been replaced by cement and that the amount of voids is highly noticeable, which may explain why the unit weight was not considerably increased. Grouting caused soil replacement rather than soil densification in the silty sands and clayey sands. The practice has considerably increased uniaxial compressive strength and bearing capacity of the tested soils. It can be employed to form tough soils when foundations of existing buildings need strengthening.

Keywords: Soil strengthening, grouting, shallow foundation and Turkey

INTRODUCTION

Turkey has gained a valuable experience to construct earthquake resistant buildings and also inspecting existing buildings after the major earthquakes. In that context, the potential earthquake performance of a large number of existing buildings has been assessed, and the results indicated that a vast majority of them do not satisfy current building codes (Inel et al (2007), Kaplan et. al. (2006), Kaplan et. al. (2008).

Comprehensive readings about the strengthening of structures and foundations are available in the literature [UNDP/UNIDO (1985), FEMA (1997), D'Ayala & Charleson (2002), CEN (2003), Rai (2005).

Unsurprisingly, the soil conditions of the inspected buildings that were constructed before the enforcement of new building codes have not been examined in detail. Additionally, uncontrolled urban growth has increased, which has resulted in the increased instances of encountering problematic ground conditions practically in every country. These phenomena have contributed to the increase in the number of seismically weak buildings in Turkey. As such, action is required to strengthen the foundations of numerous buildings. The present studies were conducted in Denizli, which is called the capital of textile and travertine. The city is located in southwest Turkey where the horst-graben system is common and seismic activity is high due to normal faulting (Figure 1). The city is occupied by residential and commercial buildings up to ten stories in height, most of which were constructed over a short period of time (Akyol, 2002).

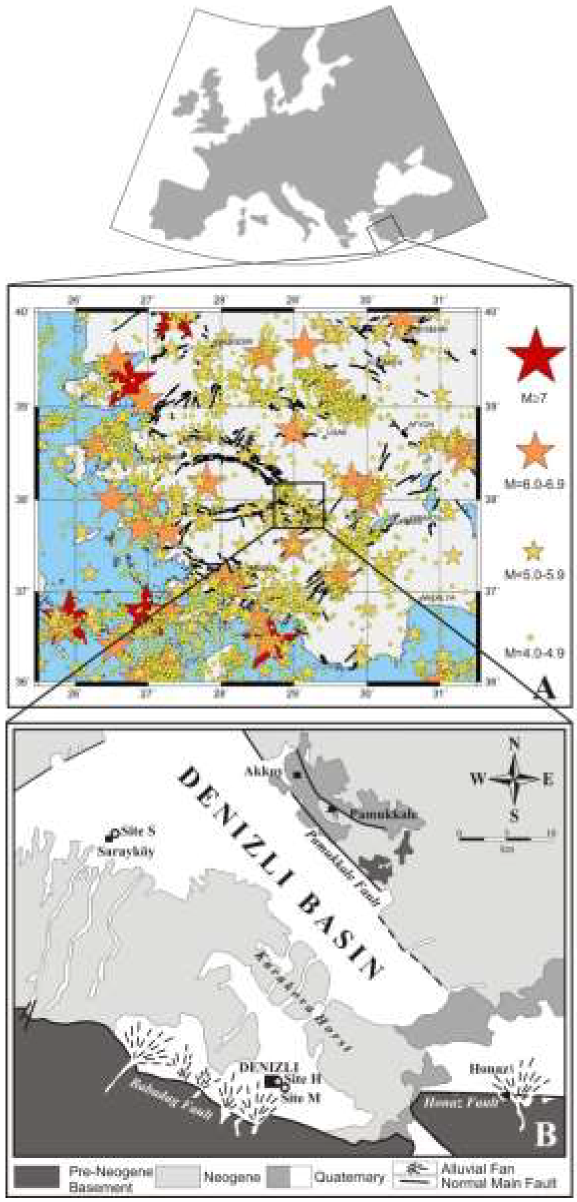

Figure 1: Location map of study area; A) earthquakes in the Aegean region [15], and B) a simplified geological map of the study area [16]

Compaction grouting has been employed to improve insufficient soil conditions by engaging densification and improving the bearing capacity and geomechanical properties of the soil. The operation also reduces water flow, and increases liquefaction resistance to seismic forces. This method is applicable to all type of soils, but the soil type and density certainly affect the amount of effort required (Warner, 2004). The term “grouting” is used to express injecting liquid material(s) into a geological formation (Byle & Borden 1995). In practical meaning, an appropriate grout material, i.e., commonly a water-cement mixture, is injected into loose soils and then densified (Tuncdemir, 2007 & Warner, 2004). The method is also very economic (Gallagher, 2000). Compaction grouting was employed in this study due to its feasibility in the study areas. In general speaking grouting fills voids around soil grains and it causes denser soils. When the grout pressure is high enough grout material forces soil particles to move, called soil replacement. In this circumstance grouting does not fill all voids which does not cause significant soil densification but still provides higher mechanical characteristics because of cement. In examined cases, compaction grouting has led to some soil replacement as well as densification. This type of application has dramatically increased the uniaxial compressive strength and Young's modulus of the soil without noticeable densification (Akyol, 2012).

MATERIAL AND METHOD

Three buildings at different sites, namely M, H and S as shown in Figure 1, were examined. The buildings are reinforced concrete type constructions with brick walls, and each is four stories in height and includes a basement storey. Two thirds of the basement stories are underground, and strip foundations were used in the construction of each building. The strips are 40cm in width and 60-80cm in height. The buildings at M and H have basements with a 650m^2 footprints, and the building at site S has a 450m2 footprint. The areas of the upper floor widen about 10%. The soil types ranged between GP (gravel-sand mixtures) and ML (inorganic silts and very fine sands) but mainly consisted of SC (clayey sand) and SM (silty sand) according to Unified Soil Classification System. The maximum and minimum values of SPT (number of blows for 30 cm penetration-N30) were 6 and 37, respectively. The average unit weight of the soils was 17.4kN/m3. The ground water depth varied between 1.2 and 3.8m (Figure 2).

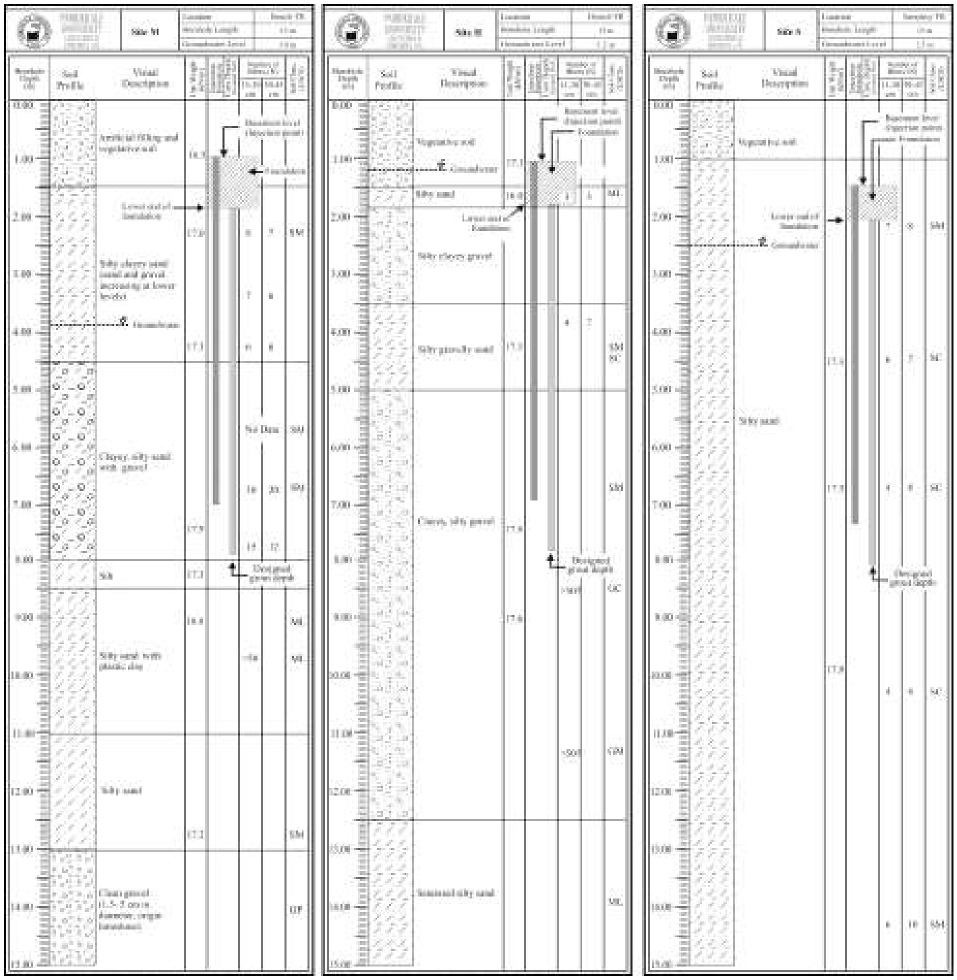

Figure 2: Borehole logs from the sites

A 1:3 ratio cement-water mixture was injected into the surrounding soil in most instances; rarely, other proportions (i.e., 2:3 and 1:1) were also used. The grouting was applied from bottom to top, and 25 kPa pressure increments were applied for every meter (Table 1).

Determining the pattern of injection boreholes was a rather complicated issue. A vast majority of the holes were positioned near the columns. Grouting holes up to 7 m in depth from the basement level were used. The injection density was about 10-12 m2/borehole. Rubright and Bandimere [2004] suggested that bentonite should make up less than 3% of the combined weight of the cement and that it may reach up to 5% only in extreme circumstances. Figure 3 illustrates the injected cement and bentonite at site M (i.e., 60,100 kg cement and 2,950 kg bentonite). In this study, a 4.9% bentonite to cement ratio was used. This is rather high and very close to the upper limit, but it was used because of the high fine content of the surrounding soils.

Table 1: Injection pressures in consolidation boreholes

Injection Level	Grouting Pressure
m	kpa
0.00 – 1.00	25

1.00 – 2.00	50
2.00 – 3.00	75
3.00 – 4.00	100
4.00 – 5.00	125
5.00 – 6.00	150
6.00 – 7.00	175

Verification boreholes were drilled to control grout quality and to obtain core samples (i.e., NX size) for testing (Figure 4). The uniaxial compression strength of the samples was measured, and their Young's modulus was calculated. Thin sections of the core samples were prepared in order to visualise the grout effects on the microscopic scale. The cement and soil grain interaction was clearly illustrated under polarized light from crossed nicol prisms.

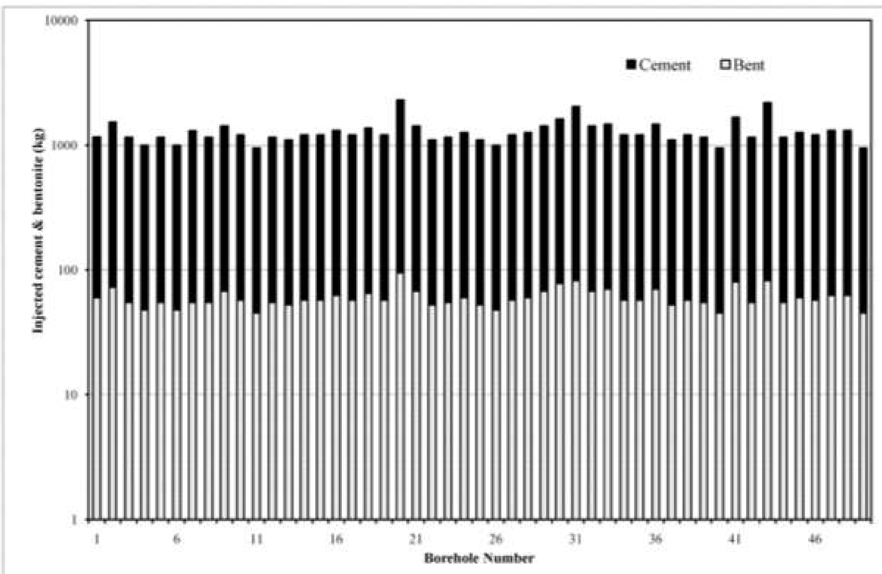

Figure 3: Sum of injected cement and bentonite at site M

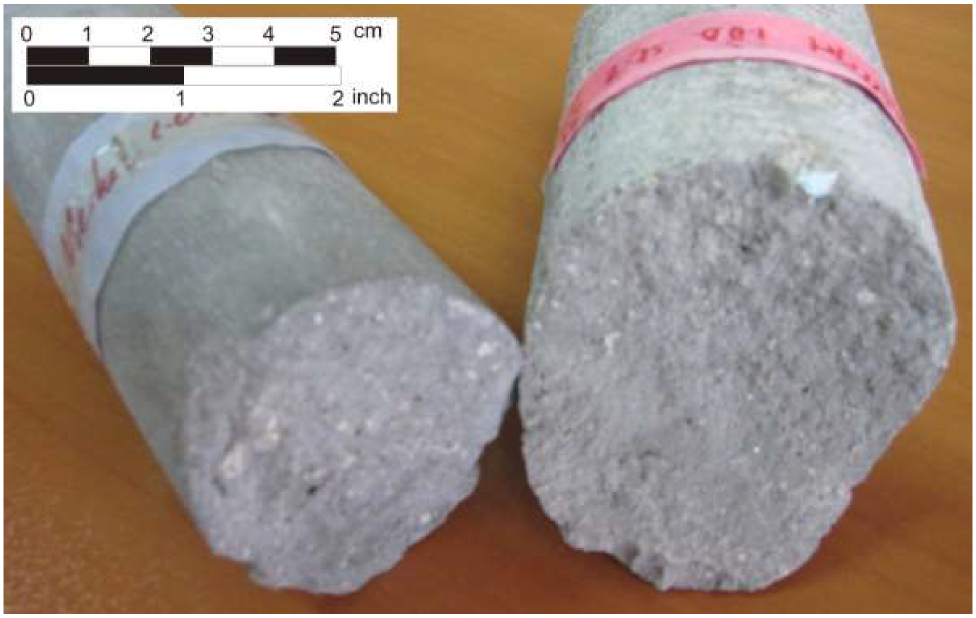

Figure 4: Some core samples of grouted soils

GROUTING AND SOIL STRENGTHENING

SPT were performed in natural soil and core samples, obtained from the grouted soil, were tested. To understand the grouting effects on mechanical properties of the soils, SPT values are need to be converted to qu (uniaxial compressive strength) and E (Young's modulus). The following equations were used for the parameters in this study;

qu =13.33*N (kPa) for sandy soils suggested by Sanglerat (1972),
E=250*(N+15) for saturated sands suggested by Bowles (1997).

The Young's modulus of the natural soils computed within the range of 5.3 MPa and 13 MPa.
The uniaxial compressive strength of the same ones varied between 79.98 kPa and 493.21 kPa.
The obtained core samples were tested, and the results are presented in Table 2. The uniaxial compressive strength varied from 18.6MPa to 35.4MPa, while the Young's modulus of the cores reached up to 51.2MPa. As evidenced by these results, both uniaxial compressive strength and Young's modulus have increased tremendously. The unit weights of the samples fall within a narrow range (17.1-19.9kN/m3) with an average of 18.3kN/m3. The average unit weight of the untreated soils was 17.4kN/m3; clearly, grouting did not increase the average unit weight dramatically in these cases.

A close relationship between the physico-mechanical properties and operational factors, like grouting pressure, has not been found. The evidence indicates that no significant relationship exists among these variables. In other words, soil densification, which was increased slightly by grouting, did not significantly impact the compressive strength and Young's modulus of the treated soils. Likewise, no distinct relationship between grouting pressure and unit weight or between compressive strength and Young's modulus was observed.

Thin sections of the core samples were visualised under polarized light from crossed nicol prisms in order to illustrate the soil and cement interaction (Figure 5). The white and colourful dots represent soil grains, whereas the black holes show the voids in the sample. The remaining area is cement. Figure 5a shows homogeneous mixture of cement paste and small size of soil grains. Small voids are approximately 10 to 30μm in diameter. Individual voids may reach up to 300μm in diameter as indicated in Figure 5b. Figure 5a and b prove that the soil has been replaced by cement and the amount of void is highly noticeable, which may explain why the unit weight is not significantly increased. Figure 5c and d display larger soil particles with different void sizes. The most desirable results are demonstrated in Figure 5c that are of soil and cement paste with very little voids. Figure 5d represents many single voids which are very close to each other. They were trapped among the soil particles and cement paste. Soil densification is more effective in last two samples especially in c. The excess amount of voids may clarify negligible increase of the unit weight.

Laboratory results and thin section pictures prove that grouting does not provide a remarkable soil densification but it causes soil replacement in the examined cases. The laboratory and in-situ data also suggest that high grouting pressure does not provide higher elastic modulus. The most important outcome is the increase of uniaxial compressive strength of the tested soils. The ultimate goal was achieved by maintaining high bearing capacity either by soil replacement or by densification. The practice can be employed to form tough soils with high bearing capacity when foundations of existing buildings need strengthening.

Table 2: Some physical and mechanical properties of the core samples

Site	Unit Weigth (kN/m3)	Uniaxial Compression Strength (MPa)	Elastic Modulus (MPa)	Grouting Pressure (kPa)	Depth (m)
S	17,5	24,5	33,1	25	2
S	17,1	25,2	34,1	75	3
S	17,7	23,5	31,7	25	1
S	17,6	29,6	40,0	100	4
S	17,5	31,2	42,2	100	4
S	18,4	18,6	25,1	25	1
S	19,9	21,9	29,6	50	2
M	17,8	23,3	33,2	75	3
M	18,5	24,5	62,4	150	6
M	17,9	25,1	48,7	125	5
M	18,5	31,6	54,0	150	6
M	18,0	19,7	47,5	50	2
M	17,8	27,2	61,9	150	6
M	17,9	35,4	51,2	125	5
M	18,4	25,1	60,8	125	5

M	17,6	23,3	50,8	150	6
H	18,0	24,9	26,8	150	6
H	18,3	22,8	35,2	150	6
H	17,6	20,8	33,6	100	4
H	18,2	27,1	27,8	125	5
H	18,5	21,4	25,8	150	6

CONCLUSIONS

The studies reinforced concrete buildings with brick walls and strip foundations on three different sites were conducted. All of the buildings are seated mainly on SC and SM soils with high water tables. A 1:3 ratio cement-water mixture was injected near the columns, and the grouting holes were up to 7m deep around the basement level. The injection density was about 10-12m^2/borehole. The utilized bentonite to cement ratio was about 4.9%; although this is rather high, it was used because of high fine content of the surrounding soils.

The average SPT (N30) value of the soils before grouting was 12-15. The lab results of the NX size core samples obtained from verification boreholes indicate that the Young's modulus was as much as 51.2MPa, while the uniaxial compressive strength was between 18.6MPa to 35.4MPa. The average unit weight of the untreated soils was 17.4kN/m3, and the subsequent grouting caused it to rise to 18.3kN/m3, which is certainly not a dramatic increase. Soil densification did not significantly affect the compressive strength or the Young's modulus in these cases. Similarly, no remarkable relationship was observed between the grouting pressure and the unit weight or between the compressive strength and the Young's modulus. Thin sections of the core samples were visualised under polarized light from crossed nicol prisms, which illustrated that small voids that were about 10-30μm in diameter were homogeneously distributed throughout the sample. Individual voids were rather large and reached up to 300μm in diameter. Additionally, the soil was replaced by cement, and the number of voids is rather large, which may explain why the unit weight was not considerably increased.

The most remarkable increased has been seen on the uniaxial compressive strength and the Young's modulus. When the maximum values were taken into consideration the uniaxial compressive strength bounced from 493.2kPa to 35MPa. Similarly the Young's modulus rose from 13MPa to 51.2MPa. These results show that cement grouting dramatically increases bearing capacity of fine sands either by soil replacement or by densification.

RECOMMENDATIONS

1. There is need to test and inspect the soil conditions before the buildings and enforcement of new building codes with adequate examination.

2. There should be adequate control of urban growth to avoid increased instances of encountering problematic ground conditions practically in every country as these phenomena have contributed to the increase in the number of seismically weak buildings.

3. Action is required to strengthen the foundations of numerous buildings not only in Turkey but also in other countries where earth quake is rampant.

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