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SOIL IMPROVEMENT WITH JET-GROUT COLUMNS: A CASE STUDY FROM THE 1999 KOCAELI EARTHQUAKE

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ABSTRACT

Soil improvement methods have been widely used to reduce the potential for liquefaction-related damages in sandy soils and strain-related problems in soft clays. The procedures and techniques used in the design of improved soil have been continuously improved. Filed case history data have always been crucial to refining such techniques and procedures.

The 1999 Kocaeli Earthquake (M=7.4) struck northwestern Turkey and caused significant damage in urban and industrial areas along Izmit Bay. The sites were subjected to ground motions ranging from about 0.10g to 0.42g. This paper presents the performance of the Ipekkagit Tissue Factory site in Karamursel at the southern waterfront of Izmit bay, where the soils were improved with jet-grout columns. The site is located just 4km south of the main fault rapture. In general the subsoil at the site consists of a 3 m thick stiff clay layer at top, followed by a series of low-to-medium dense sand and silt deposits. Below 9 m a stratum stiff-to-hard clays extends to the bottom of exploration depth of 32 m. The water table was found at a depth of 1.5 to 2 m. Jet-grout columns were installed to reduce anticipated static and earthquake induced settlements due to cyclic mobility of clays and to mitigate liquefaction in sands and silts considering the seismicity of the site, prior to the subject event. Maximum acceleration at the site reached to about 0.3g during the August 17, 1999 main shock, as estimated from the nearby recordings. Following the earthquake and significant after shocks, the authors investigated the site to document geotechnical field performance focusing mainly on the effects of soil improvement to the performance of the site and nearby structures. Observations showed that ground treatment by means of jet-grouting was effective in mitigating earthquake-related damages, especially relative to damages observed at nearby structures and sites of non-treated ground.

INTRODUCTION

The 1999 Kocaeli Earthquake (M=7.4) struck northwestern Turkey and caused significant damage in urban areas located along Izmit Bay. Following the earthquake and significant aftershocks, many authors investigated the affected area to document geotechnical field performance (Youd, Bardet and Bray, 2000). After this reconnaissance survey, further detailed studies were performed and their results were published on ground failure, geotechnical effects, foundation performance and performance of improved ground (Olgun et al., 2001; Martin et al., 2001, Sancio et al.,2002; Sancio et al., 2003). The implications of soil improvement and assessment of the performance of treated ground for Carrefour Shopping Center at Izmit located at the northern side of the fault rupture were previously reported (see Fig. 1). In this paper, the behavior of various units at the Ipekkagit Tissue factory located along the southern waterfront of Izmit Bay and southern side of the fault rupture are evaluated. The general lay-out of the site is given in Fig. 2. The subsoil was improved by means of jet-grout columns under

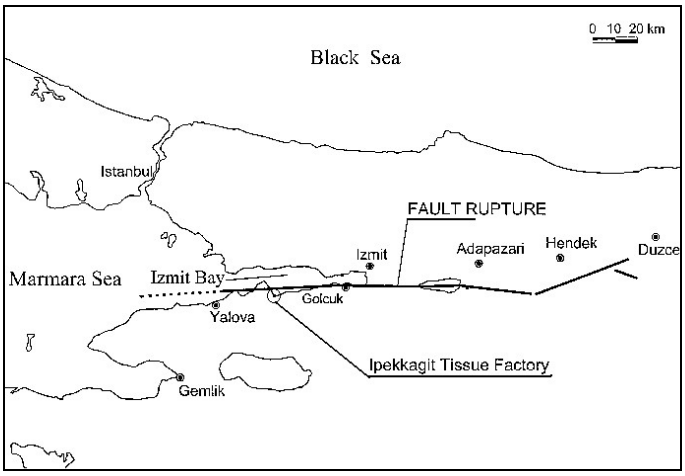

Figure 1. Location of the subject site and affected area of the 1999 Kocaeli Earthquake (after)

the PM3 Machine Building, Water Tanks and Reel Storage Buildings.

Maximum acceleration at the site reached about 0.3g during the main shock as estimated from nearby recordings and distance to the zone of energy release. The soils at the site consist of alternating layers of clay and sand with very high ground water level. No structural or ground damage occurred in investigated buildings founded on improved ground by means of jet-grout columns. However, visual inspection has revealed minor structural damage in the older buildings at the site and vicinity, where there was no soil improvement performed.

SOIL AND SITE CONDITIONS

Subsoil investigations performed for the subject site were available to the present study. Geotechnical data were obtained for the new extension to the Paper Machine Building No.3 (PM3), the Reel Storage Building, and two large water tanks. Construction of the Reel Storage Building and the Water Tanks was completed about one year before the Kocaeli Earthquake, and the PM3 Building was under construction during the event (see Figure 3). The soil investigations for these projects included ten borings with Standard Penetration Tests (SPTs) and 25 Cone Penetration Tests (CPT's). The penetration tests revealed alternating strata of medium-to-stiff clay and medium-to-dense sand to a depth of 32 m where the exploration was terminated (see Figure 4).

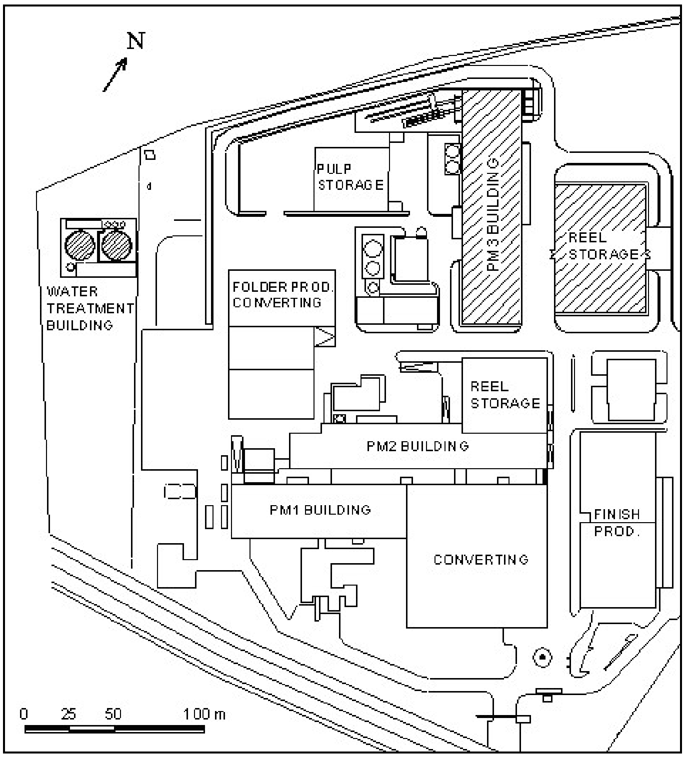

Figure 2. Ipekkagit Tissue Factory-site plan

At PM3 building location, a medium-to-stiff clay layer of medium plasticity extends from the ground surface to a depth of 3 m. Below the clay is a stratum of clean sand of medium density that extends from 3.0 m to a depth of 6.0 m. From 6.0 m to 9.0 m, a medium-dense silty sand layer is encountered. Below 9 m, a stratum of stiff-to-hard clay is found that extends to the bottom of the boring at a depth of 32.0 m. In some borings for this area, a medium dense sand layer was also found between the depths of 24 m and 27 m. The water table was found at a depth of 1.5 to 2 m. The PM3 soil profile can be considered representative of the entire plant site; however, specific soil data for the other structures were also available.

Figure 3. Water Tanks and PM3 building during construction

The soil profile at the water storage tanks varied slightly from that at the PM3 location. A clay stratum layer of medium stiffness and plasticity extends from the ground surface to a depth of approximately 4 m. Below the clay between the depths of 4 m and 10 m, a sand layer of medium density is found. Below the sand, a stiff-to-hard clay layer is encountered that extends from 10 m to the bottom of the boring at a depth of 20 m.

Subsoil conditions at the location of the Reel Storage Building were similar to those at the PM3 area. At the top, a medium-to-stiff clay stratum of medium plasticity is found. The depth to the bottom of this stratum is variable throughout the building area, ranging from 1.8 m to 4.5 m. From a depth of 4.5 m to 6.5 m, a gravelly sand layer is found in a medium-dense condition. A medium-dense silty sand layer is found between the depths 6.5 m and 8.5 m. Below 8.5 m, a stratum of stiff-to-hard clay extends to a depth of 18.0 m where a very dense sand layer is encountered.

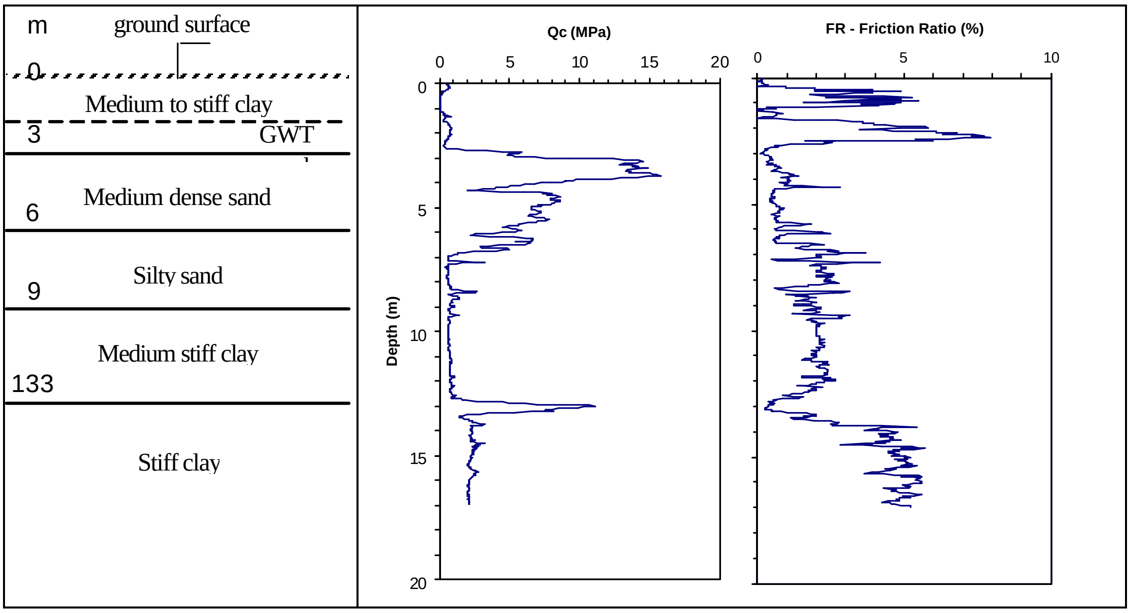

Figure 4. Subsoil Profile at the location of PM3 Building

FOUNDATION DESIGN AND SOIL IMPROVEMENT

The PM3 Building, being constructed at the time of the earthquake, is supported by a reinforced-concrete mat foundation. To improve the soils in this area, jet-grouted columns 12 m-long and 0.6 m in diameter were installed beneath the mat in a rectangular grid pattern. Center-to-center column spacing ranged from 1.2 to 2.4 m corresponding to an average area replacement ratio of a_r=0.10. Two additional rows of grouted columns were constructed around the perimeter of the building to provide additional safety against soil liquefaction, acting as containment structure to reduce the shear induced lateral displacements. These columns were 8.0 m long and spaced at 1.4 m center-to-center. The allowable axial capacity of each grouted columns under the mat foundation was estimated as 600 kN. The capacity was verified by means of pull-out tests on selected columns. Grout columns spacing and diameters were selected mainly on the basis of foundation loads, as no detailed analyses were made to modify the column patterns for liquefaction prevention: however, it was assessed at the time of the original design that the jet-grouted columns, with certain area replacement ratio and much higher stiffness compared to original soil, would significantly reduce liquefaction-related problems (Ozsoy, 2002). The lay-out of jetgrout columns at the location of PM3 Building is given in Figure 5.

Following jet grouting, CPTs were performed in the areas between the columns. Comparison of CPT soundings before and after jet-grout columns indicate that no significant increase in penetration resistance was achieved as seen in Figure 6, as would be expected, as the jet grouting process installs reinforcing columns but does not densify the in-situ soil. Comprehensive study was performed on the samples taken from the soilcrete by means of compression testing. Both the compressive strength and the modulus of the core samples taken from the soilcrete were measured. The measured average compressive strength value of soilcrete was 3.0 MPa and the shear modulus value was 2700 MPa. The modulus ratio, G_r of soilcrete to unimproved soil according to Ozsoy and Durgunoglu (2003) was in the order of 30.

The water tanks are supported by a mat foundation as well. Jet-grout columns 10.5 m length and 0.6 m in diameter were constructed beneath the mat. The columns were installed in a square grid pattern, with a 2.0 m center-to-center spacing for an area replacement ratio of a_r=0.07. The allowable axial capacity of jet grout columns of which 0.6 m in diameter was estimated at 700 kN which was verified by pull-out tests. The Reel Storage Building is supported by 4.0 m-wide strip footings. Jet-grouted columns 8.0 m in length and 0.6 m in diameter were constructed beneath the footings. The column spacing ranged from 1.2 m to 2.4 m and allowable axial capacity of each jet-grouted column was estimated as 450 kN.

The estimated cyclic shear stress ratio reduction factor K_G is about 0.27 for a_r= 0.10 and 0.33 for a_r= 0.07 for G_r value of 30 according to Ozsoy and Durgunoglu (2003). In other words, as a result of applied configuration and parameters, about 70% of the earthquake induced shear stresses was carried by the higher modulus jet-grouted columns.

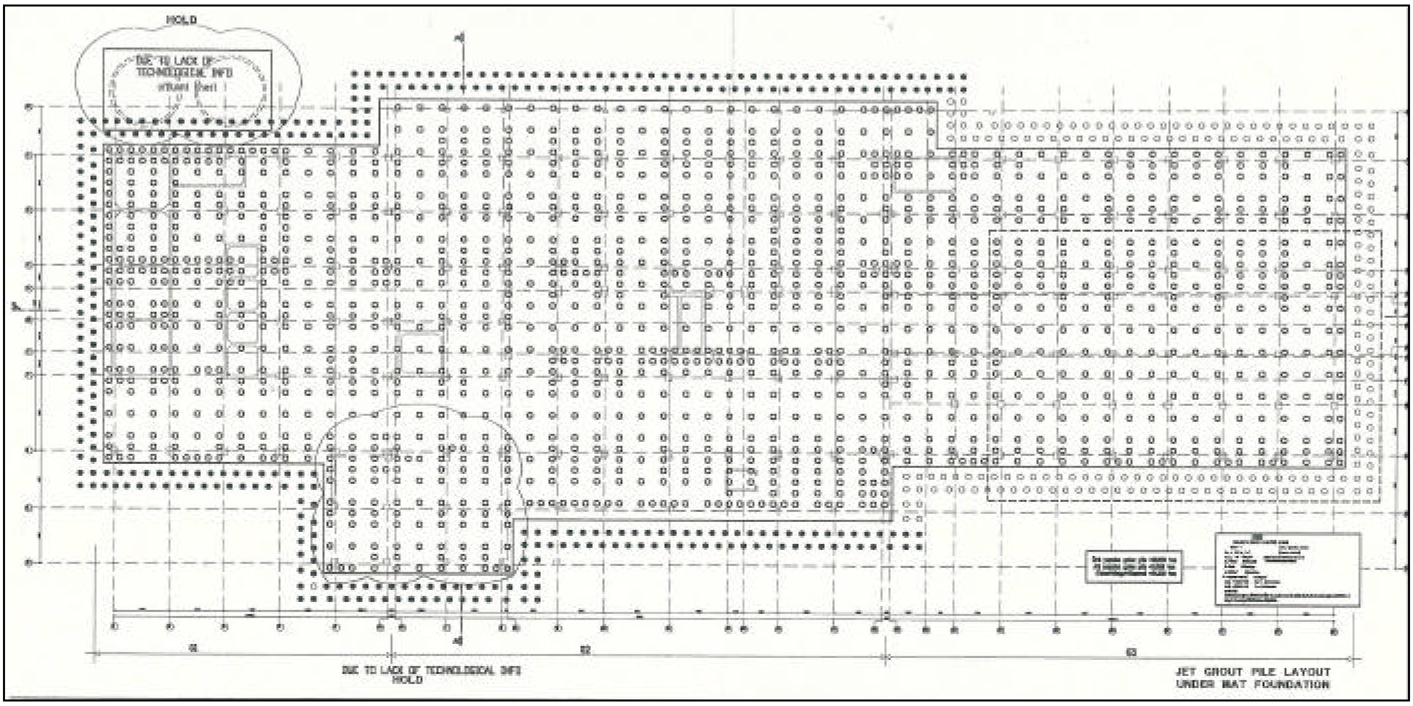

Figure 5. PM3 Building Jetgrout Lay-out Plan

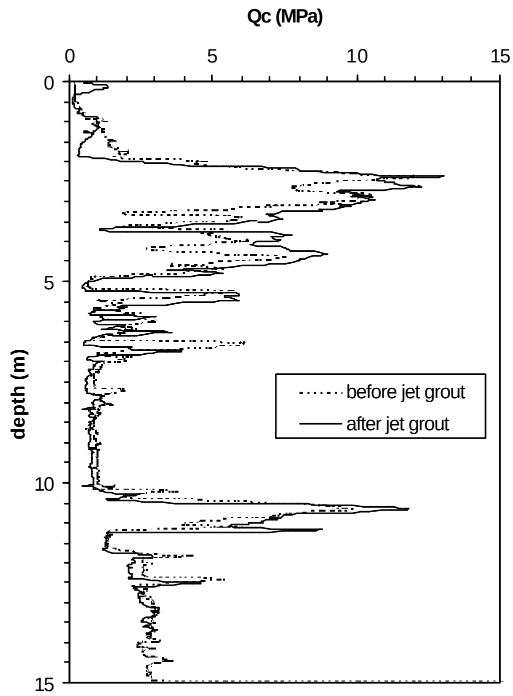

Figure 6. Comparison of CPT tip resistances before and after jet grout column construction

JET-GROUT PARAMETERS AND EQUIPMENTS

For the construction of the jet-grouting columns Tecniwell ancillaries and equipment were employed: one high pressure triplex pump mod. TW351(350HP), one complete automatic mixing plant TWM20 and 89 mm rods. Monitors with two 2 mm nozzles were used to inject at 50/55 Mpa a water/cement grout mixture with a W/C ratio by weight of 1:1. Quality control of the grout was ensured by the electronic weighting system installed on the mixing plant. The retrieval rod speed was about 55 cm/min and automatically controlled by electro/hydraulic valves. Rod rotation was 21 rev/min. These selected parameters were determined, prior to jet-grouting works, based on the detailed calibration tests at the site. The achieved design diameter of 60 cm was controlled by the measurement of perimeter of the selected columns.

FIELD PERFORMANCE DURING EARTHQUAKE

The shaking levels at the Ipekkagit plant site reached about 0.3g during the 1999 Kocaeli Earthquake (M7.4) as estimated from nearby recordings and distance to the zone of energy release. Following the event, a visual inspection of the plant revealed no major earthquake-related damages. All facilities remained operational during and after the earthquake. Only minor structural damage occurred in one of the older buildings (PM2 Building) where a heavy concrete facing element fell off the exterior of the building, and an interior reinforced-concrete column developed cracks about 1 cm-wide. The external damage to the building is shown in Figure 7. No structural damage occurred anywhere else at the plant. The foundation soils for the PM2 building were not improved; therefore, it could be stated that minor structural damage occurred at an area where the foundation soils were not improved.

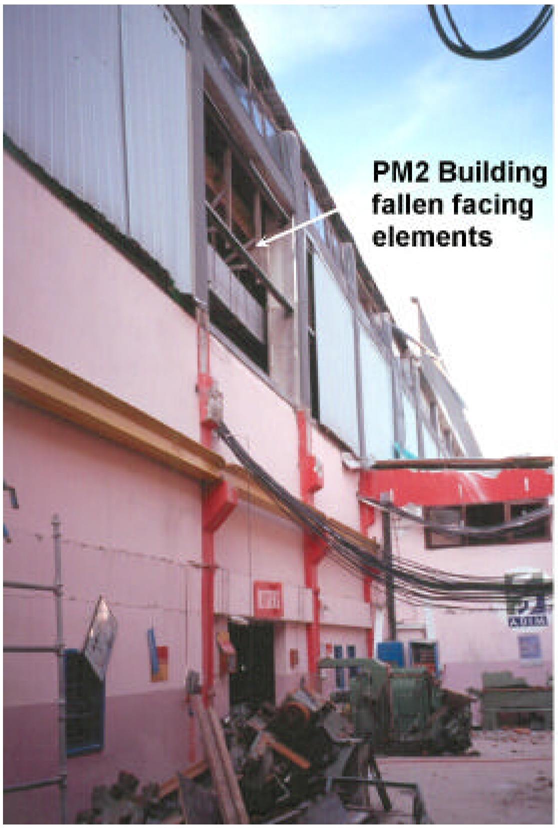

Figure 7. Photograph showing structural damages at PM2 Building due to falling of exterior panel.

No signs of liquefaction or surface ground movements were found anywhere at the plant. Surprisingly, there were also no liquefaction-related features found along the northern waterfront or at neighboring sites - all of which contained untreated liquefiable soils. The reason for the relative lack of liquefaction induced signs in this general area, given the high susceptibility of the soil and the close proximity of the fault rupture, is unclear. However, it is taught that limited displacements both induced by local liquefaction and cyclic mobility were taken place at a certain depth within lower sands and clays, and they were possibly masked by the presence of superficial silty clay formation as it was in the well documented case of Carrefoursa site in Izmit (Durgunoglu et.al., 2001).

CONCLUSIONS

1. It was shown that the jet-grouted soil improvement yielding an area replacement ratio of a_r=7-10% was effective against the possible damage induced under earthquake loading due to liquefaction and cyclic mobility potential of the subsoil
2. The limited structural damage was observed at the locations of nearby structures founded on untreated subsoil.
3. Possible liquefaction induced features on the ground were lacking possibly due to presence of superficial silty clays.

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