Improved ground performance during the 1999 Turkey earthquakes

Exécution au sol améliorée pendant les tremblements de terre 1999 de la Turquie

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ABSTRACT: Following the August 1999 Kocaeli, Turkey Earthquake (M_w=7.4) and the November 1999 Duzce, Turkey Earthquake (M_w=7.2), the authors performed investigations in the affected area to document geotechnical field performance. These studies focused on investigating improved soil sites. Two of these sites are selected for presentation in this paper. One of the sites is a commercial construction site partly treated with jet grout columns against liquefaction. Jet grouted columns prevented possible liquefaction, whereas liquefaction was observed at untreated portions of the site. The other site involves two reinforced earth walls constructed with steel strips and compacted granular backfill. These walls performed well suffering minor damage although they were subjected to severe shaking and fault rupture related ground displacements. It was found that ground treatment was generally effective in mitigating earthquake-related damages.

RÉSUMÉ: Après août 1999 Kocaeli, tremblement de terre de la Turquie (M_w=7.4) et novembre 1999 Duzce, le tremblement de terre de la Turquie (M_w=7.2), les auteurs a exécuté des investigations dans la zone affectée pour documenter l'exécution géotechnique de zone. Ces études se sont concentrées sur étudier les sites améliorés de sol. Deux de ces sites sont choisis pour la présentation en cet article. Un des sites est un chantier de construction commercial en partie traité avec des colonnes de coulis de gicleur contre la liquéfaction. Les colonnes scellées au ciment de gicleur ont empêché la liquéfaction possible, tandis qu'on a observé la liquéfaction aux parties non traitées du site. L'autre site implique deux murs renforcés de la terre construits des bandes en acier et granulaires compacts remblayent. Ces murs ont exécuté le dommage mineur bien de souffrance bien qu'ils aient été soumis à la secousse grave et rupture de défaut a associé les déplacements au sol. On l'a constaté que le traitement au sol était généralement pertinent dans des dommages tremblement de terre-connexes d'atténuation.

1 INTRODUCTION

An earthquake of magnitude M_w=7.4 struck northwestern Turkey in August 17, 1999 resulting in significant structural destruction and loss of life. Peak accelerations up to 0.3g were measured on rock at close distances to the fault. Another earthquake to the east of the unruptured segment of the fault occurred in November 12, 1999 with magnitude M_w=7.2. Both of these earthquakes are associated with the North Anatolian Fault, a prominent geologic structure which extends for over 1300 km through northern Turkey. North Anatolian Fault is a right lateral strike slip feature that has been very active in the historic times and is similar to San Andreas Fault of California in terms of average annual slip rate, typical earthquake depths and regional crustal structure. This paper summarizes the key observations of improved ground and reinforced soil structure performances during these earthquakes. Two case studies are presented in detail.

Six soil improvement sites were identified and investigated. The sites mostly included industrial and commercial developments that were previously improved against liquefaction. Location of the sites and the fault rupture setting of the August earthquake are shown in Figure 1. Soil improvement methods at these sites included jet grout columns, stone columns, preloading fills with wick drains. Several reinforced soil structures were identified including reinforced earth walls and soil nailed excavations.

Preliminary observations showed that ground treatment was generally effective in mitigating liquefaction-related damages, especially relative to damages observed at nearby sites of untreated ground. Sites treated with stone columns and jet grout columns for liquefaction prevention showed little to no damage, compared to significant settlements and sand boils at untreated areas. Also, the reinforced earth walls of Arifiye overpass performed well despite being subjected to significant shaking and large ground displacements. One reinforced earth wall of 8 m height collapsed during the Duzce earthquake. Preliminary analyses indicate that lack of adequate foundation support and overall stability problems were the key factors contributing to this failure. Site investigations and detailed analyses of these sites are in progress and will be reported consequently in upcoming publications.

2 CARREFOUR CASE STUDY – JET GROUT COLUMNS AGAINST LIQUEFACTION

Carrefour Shopping Center is located in the city of Izmit, approximately 8 km from the earthquake epicenter, and 5 km from the fault rupture. Peak ground accelerations in this area were in the range of 0.2g. The soil profile consists of recent marine sediments with alternating strata of medium clay and loose sand (Zetas 1998). The soils were improved to increase bearing support for shallow foundations and reduce liquefaction potential of the sand layers.

Buildings at the complex were in the early phases of construction when the earthquake occurred. Data from geotechnical investigations and instrumentation, installed for construction settlement monitoring made possible the detailed assessment of the seismic performance of the site and the effectiveness of soil improvement.

Of particular importance, this site provided the rare opportunity to measure the settlement of a liquefiable sand layer subjected to strong ground shaking. The observations also allowed a qualitative comparison between the seismic performance of an improved section of the site relative to an adjacent unimproved area.

As shown in Figure 2, the site covers an area of about 55,000 m^2 and will house two main facilities. A large supermarket is being built at the eastern end of the site, and a parking garage will be constructed at the opposite end. Both structures will be supported on shallow foundations on improved ground.

Geotechnical field investigations included seventeen Standard Penetration Tests (SPTs), fifteen Cone Penetration Tests (CPTs), and four test pits. Irregularly placed sandy-gravely fill extends from the ground surface to a depth of about 2.5 m. The fill is underlain by a medium clay stratum that extends from a depth of 2.5 m to 6.0 m. Below the clay, a stratum of fine-to-silty sand is

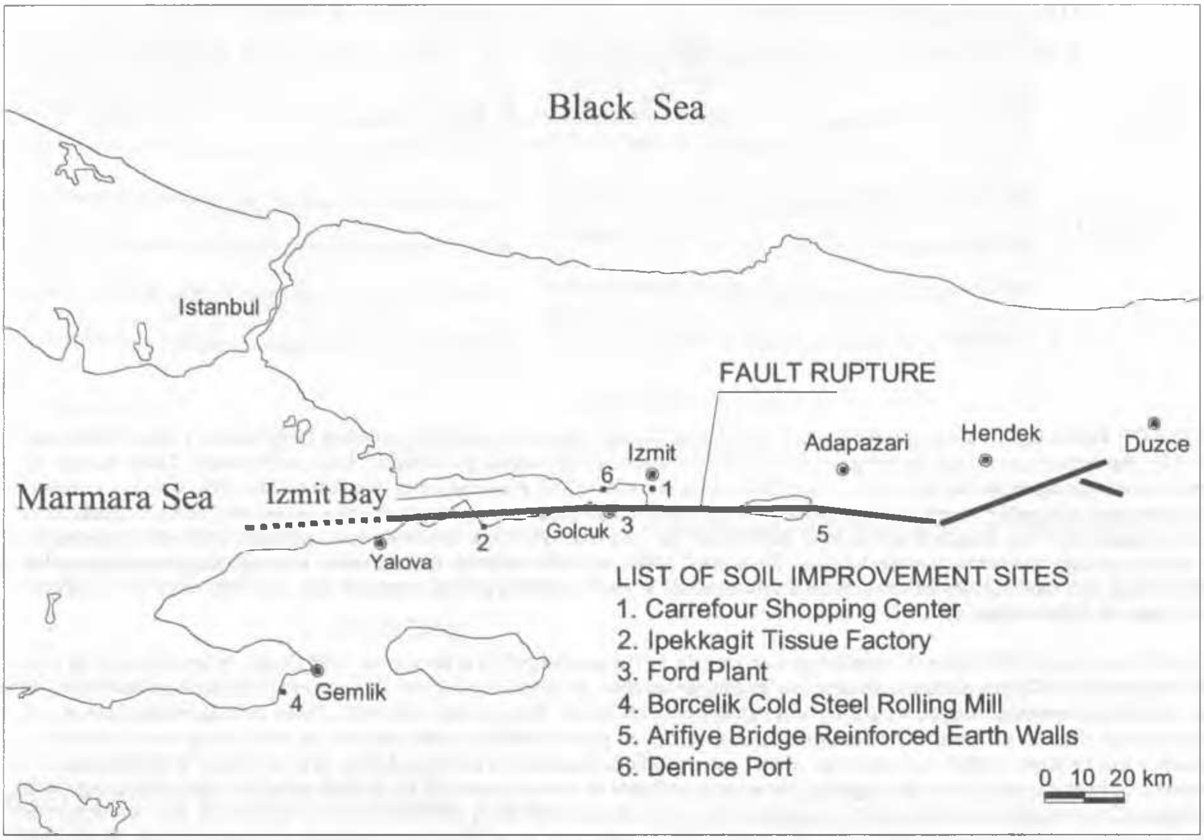

Figure 1. Map of affected area and site locations

encountered in a loose-to-medium dense condition. The thickness of this sand layer ranges from 2 m to 4 m across the site. Penetration data indicate that this layer is liquefiable under strong ground shaking. Below the sand, a second stratum of medium silty clay is encountered that extends from 10 m to a depth of more than 30 m where the exploration was terminated. The ground water table is found within 2 m of the ground surface throughout the site. A CPT sounding typical of the site is given in Figure 3.

The structures at the shopping center are to be founded on shallow footings and mats. The primary foundation design issues were large anticipated settlements and bearing problems in the clay, along with liquefaction of the loose sand layer. Surcharge fills and jet grouting were used to improve the soils across the entire site. Spacing, treatment depth, and construction details varied from location to location due to differing soil conditions and foundation configurations. With the exception of the Lot C area and part of Parking Structure area, all ground improvement had been completed and the foundations recently constructed when the earthquake struck.

2.1 *Supermarket Building Area*

This is a one story building covering an area of approximately 15,600 m^2. Section A of the building will rest on isolated spread footings, while Section B is to be supported by a mat foundation. The soils in both sections were preloaded with a 3.5 m-high fill that was present at the site before construction for a substantial period of time.

In addition to preloading, jet-grouted columns were constructed to improve bearing support and reduce settlements of the clay, and to increase liquefaction resistance of the underlying sand layer. A primary and secondary grid of columns was installed in a rectangular pattern to provide blanket treatment. The columns in the primary grid were 0.6 m in diameter with a center-to-center spacing of 4 m. These columns extended from the ground surface to a depth of 9.0 m. The secondary grid consisted of shorter, 2.5 m-long jet grouted columns that were installed in between the primary columns to further increase the liquefaction resistance of the sand stratum (about 2.5 m thick in this location). The secondary columns penetrated only the sand stratum, extending from a depth of 6.5 m to 9.0 m.

2.2 *Parking Structure Area*

The soils in this area were improved in much the same manner as those for the supermarket area. The parking area has an area of about 14,000 m^2. The structure is to be founded on shallow isolated footings, with a slab poured between the footings to tie the foundation system together. The site was surcharged with a 3.3 m-high sand fill and 20 m-long wick drains were installed at a 2.5 m spacing to speed up consolidation of the clay. The surcharge was removed after consolidation was complete and was not in place at the time of the main shock.

Jet-grouted columns were installed throughout the parking area in primary and secondary grids to provide blanket treatment for the area. The primary grid of 0.6 m-diameter grouted columns was installed in a rectangular pattern with a 2.5 m-center-to-center spacing. The columns extended from the ground surface to a depth of 9 m into the lower medium clay stratum. The secondary grid included shorter columns that penetrated only the liquefiable sand layer, which is about 4 m thick in this area of the site. In addition to the primary and secondary grids, jet grout columns were installed directly under each footing for the parking structure. Jet-grouted columns were in place in parts of this area at the time of the earthquake.

2.3 *Lot C Area*

Lot C is located adjacent to the Parking Structure and encompasses an area of 4,160 m^2. No structures were initially planned for this section, but the soils were being improved in anticipation of future development. Similar to the other treated areas, Lot C was surcharged with a 3.3 m-high fill and 20 m-long wick drains were installed. Settlement columns were installed to monitor settlements at several depths within the soil profile. The surcharge fill was in place during the earthquake, and settlements of the clay strata were being monitored on a regular basis. Jet-grouted

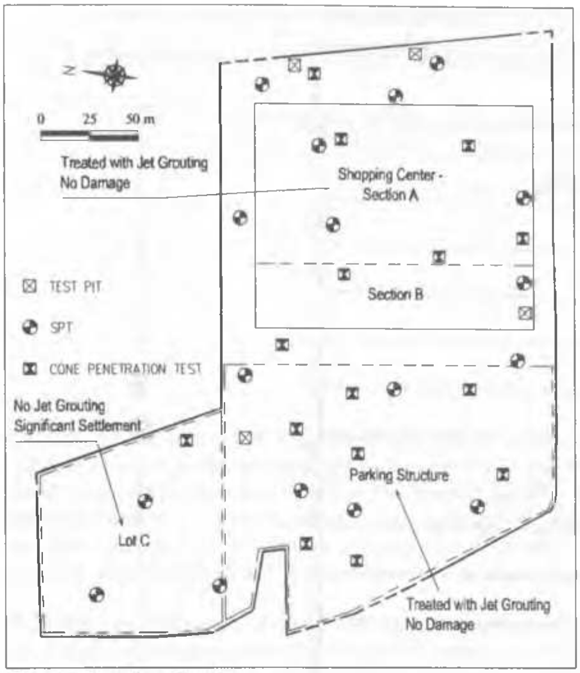

Figure 2. Carrefour site plan

columns had not yet been installed.

2.4 *Observed Field Performance during Earthquake Loading*

The steel framework for the supermarket building and the foundations for the parking garage were in place at the time of the earthquake. Visual field inspections following the earthquake indicated that no structural damage occurred in the supermarket building and no noticeable settlements or ground damages were observed anywhere at the site except in the Lot C Area and part of Parking Structure Area that were not yet improved. Site personnel reported that parts of Parking structure area that were not yet treated with jet grout columns were inundated with water the morning following the earthquake. It may be remembered that this area was treated with wick drains that penetrated the underlying sand stratum, and a surcharge fill was still in place. Following field inspection, it was concluded that the observed surface water originated from the wick drains due to earthquake-induced pore pressure buildup in the sand layer. It is fortuitous that settlement measuring devices were in place at Lot C during the earthquake. By comparing pre- and post-earthquake readings, the earthquake-induced settlement of the sand layer could be closely estimated. It was found that 80 mm of settlement occurred in the sandy layers.

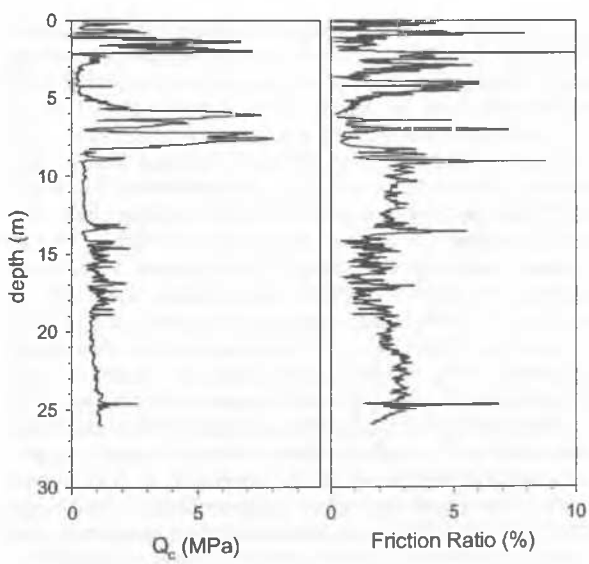

Figure 3. Typical CPT sounding from Carrefour site

Lot C and parts of Parking Structure area were the only areas at the complex that had not been improved with jet-grouted columns. All other areas had been improved with both primary and secondary grids of grouted columns to reduce liquefaction susceptibility. Based on the differences in performance between the unimproved areas and the adjacent improved areas, the jet-grouted columns appear to have been effective in reducing liquefaction potential and liquefaction-related settlements of the sand layer.

3 ARIFIYE REINFORCED EARTH WALLS

The Arifiye Bridge overpass was constructed in 1988, and consists of four simply-supported spans resting on approach abutments and three mid-span pier supports (Reinforced Earth 1999). The wing walls of the northern approach abutments were constructed using Reinforced Earth technology. The site is situated within a deposit of Quaternary alluvial sediments. Alternating layers of medium clay and dense sand are present in the soil profile, and the water table is located at a depth of about 5 m. The abutments were supported on piles, and the RE walls and approach fills rested on natural ground.

The RE walls were 10 m high and of conventional design, consisting of square, interlocking reinforced-concrete panels as facing elements. The panels were 150 cm x 150 cm in frontal area, and the reinforcing elements were ribbed, galvanized steel strips with a cross section of 40 mm x 5 mm. Typically four strips were used per panel at a horizontal spacing of 90 cm. The backfill soil was of good quality, consisting of sand and gravel that was compacted in lifts during wall construction. A cross section of the double wall abutment at its highest is given in Figure 4. A reinforced-concrete culvert of 4.8 m width passed beneath the RE wall. The culvert is located in a creek channel that runs beneath the site. Settlement or possibly internal collapse of this culvert led to significant vertical movements in the wall. Four spans of the bridge collapsed in a "saw-tooth" manner due to lateral displacements of the piers and abutments, along with inadequate beam seat widths. However, the RE walls remained intact and experienced relatively little damage. A nearby unreinforced embankment suffered heavy damage.

The closest accelerometer was located about 10 km away in Adapazari where the maximum accelerations were measured at 0.4g. The soil conditions at the bridge site however, are different than those found at Adapazari, and less localized amplification would be expected. It is thought that the accelerations at the Arifiye Bridge were probably in the range of 0.3g. In addition to significant shaking, ground displacements near the RE walls were very large, as the surficial fault rupture passed between the northern abutment and the center pier.

Maximum horizontal and vertical ground displacements near the northern wall were estimated at 350 cm and 45 cm, respectively. These movements were inferred from the measured displacement of a buried pipe that was ruptured by the fault about 50 m from the wall. In addition to fault-related lateral movement, up to 25 cm of vertical movement occurred in the section of the wall overlying the culvert. The culvert appears to have settled during the earthquake, probably due to the presence of soft and/or liquefiable creek bed sediments. The resulting differential wall settlement caused the facing panels to become separated and misaligned, which allowed spillage of some backfill material. The maximum out-of-plane panel displacement was 5 cm. The differential wall movement may have also been related to the fact that the culvert created a discontinuity in foundation conditions beneath the wall.

The most notable overall observation was the relative lack of significant damage to the RE walls despite being subjected to strong ground shaking and large displacements. In stark contrast to this behavior, a conventionally-constructed approach embankment located about 250 m from the RE walls suffered heavy damage during the earthquake, experiencing settlements of more than 1 m. The good performance of the RE walls is thought to be particularly meaningful in demonstrating the seismic stability of conventionally-constructed walls of this type.

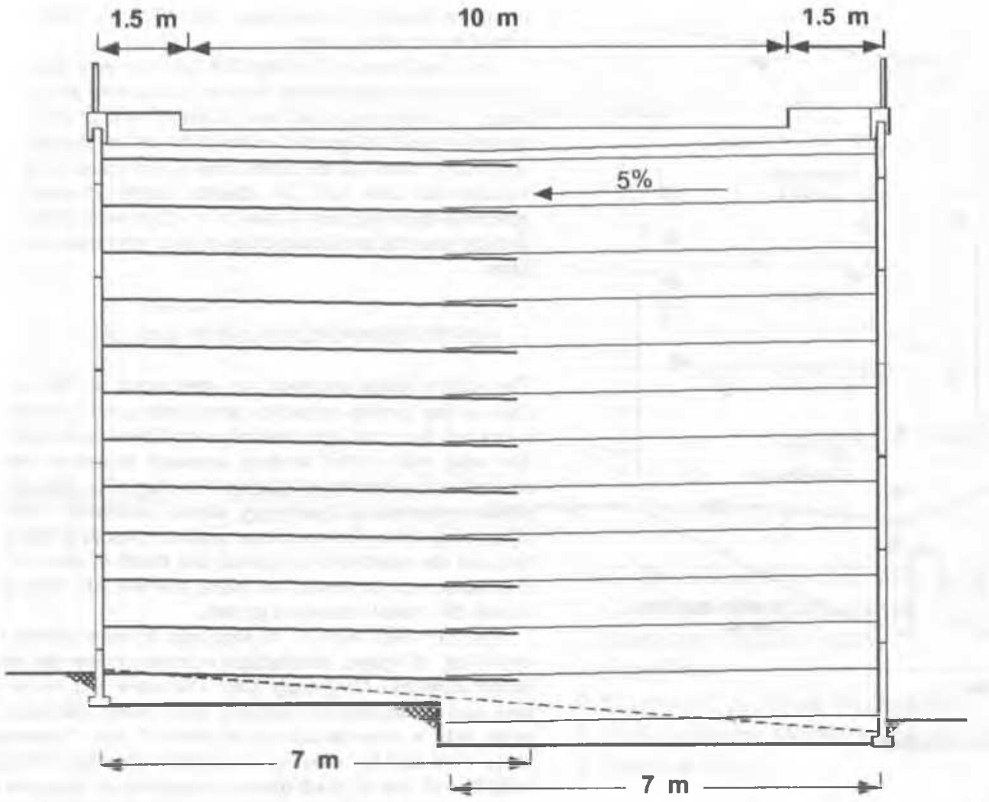

Figure 4. Cross section of the Arifiye Reinforced Earth Walls

4 SUMMARY AND CONCLUSIONS

Following the 1999 earthquakes in Turkey (M_w=7.4 and M_w= 7.2) the authors performed investigations in the affected area to document geotechnical field performance at improved soil sites. Two sites of particular interest involved a commercial construction site partly treated with jet grout columns for liquefaction prevention, and two reinforced earth walls constructed with steel strips and compacted granular backfill. In general, these sites performed well and the soil treatment was effective in limiting damages.

A summary of key observations from the sites is provided below:

- Jet grout columns were effective during the earthquake in preventing liquefaction.
- Stone columns were effective in preventing liquefaction related damage.
- Wick drains effectively drained the ground water up to the surface and relieved excess pore pressures in sandy layers that developed as a result of cyclic shearing.
- Provided drainage (i.e. wick drains) possibly prevented liquefaction-related ground damage (i.e. sand boils), but did not prevent consequent settlements in the sandy layers.
- Reinforced earth walls with adequate foundation support and no global instability problems performed well.

Additional, more refined studies and analyses are needed to better evaluate the findings.

5 ACKNOWLEDGEMENTS

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REFERENCES

Reinforced Earth, TAI Group (1999). Reinforced Earth Structure Performance in Izmit - Adapazari, Turkey, Visual Inspection Report, August 1999, Istanbul.

Zetas Earth Technology Corporation. (1998). Izmit Carrefour Commercial Center, Factual Report, March/24/1998, Istanbul, Turkey.