

Case History for Ground Improvement Against Liquefaction Carrefoursa Shopping Center – Izmit, Turkey

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ABSTRACT: An earthquake of magnitude $M_w=7.4$ occurred along the North Anatolian Fault on August 17, 1999 in Turkey. The epicenter was located in Izmit area, near the town of Golcuk. The Carrefoursa Shopping Center, under construction at the time, is located in Izmit, approximately 5 km from the fault rupture. Peak ground accelerations near the site were estimated in the range of 0.2g during the earthquake. The soil profile consists of recent marine sediments with shallow ground table. To reduce anticipated settlements in soft cohesive soils, the site was preloaded and prefabricated wick drains were installed. Jet-grout columns were also installed to provide increased bearing support and to mitigate the effects of anticipated liquefaction. It was concluded that the soil improvement measures were effective in preventing liquefaction-related damages. The site also provided the rare opportunity to measure the earthquake-induced settlement of an unimproved liquefiable sand layer by means of magnetic extensometers installed before the event.

1 INTRODUCTION

The Kocaeli Earthquake of August 17, 1999 occurred in north-western Turkey with a magnitude of $M_w=7.4$. The event caused significant damage within the Marmara region, especially along the waterfront of Izmit Bay. The earthquake occurred along the North Anatolian Fault with a right lateral strike-slip fault mechanism. Accelerometer recordings in Izmit indicate that the peak horizontal ground acceleration levels reached about 0.2g during the main shock.

The Carrefoursa Shopping Center is located in Izmit, approximately 8 kilometers from the earthquake epicenter, and 5 km from the fault rupture; see Figure 1. The shopping center, under construction at the time, was subjected to strong ground shaking during the $M_w=7.4$ main shock of the Kocaeli Earthquake. The earthquake caused liquefaction-related damages in the vicinity of the site, including settlements, sand boils, and lateral spreading. Soil improvement was performed at the shopping center site to reduce anticipated large settlements in soft cohesive soils and to mitigate liquefaction-related ground damage from loose sands. Parts of the site was preloaded with surcharge fills and wick drains were installed to improve the clayey soils. Jet grout columns were also installed across the site to provide extra bearing support and prevent liquefaction of the loose sandy soils. At the time of the main earthquake, jet grouted columns had been installed in the area of the main supermarket building, but column construction had not yet been completed in the proposed parking areas.

Following the earthquake, field reconnaissance indicated that no liquefaction-related damage occurred at the portions of the site treated with jet grout columns.

However, significant liquefaction-related settlements occurred in adjacent areas that were not yet treated. Further, settlement monitoring devices present at the time of the earthquake provided the rare opportunity to measure the liquefaction-induced settlement of an untreated sandy soil stratum.

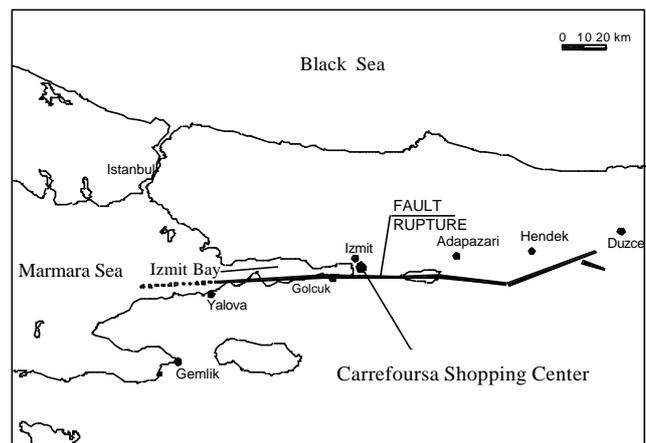


Figure 1. Location of Carrefoursa Shopping Center

2 FACILITIES

The Carrefoursa complex covers an area of about 55,000 m² and was designed to house a shopping mall (Supermarket Building) and two-story parking garage (Parking Structure) as shown in Figure 2.

Lot C, located along at the northern end of the site, is a proposed expansion area that currently serves as a parking area. The structures were designed for shallow foundations resting on improved ground.

It can be seen that the supermarket building is located at the eastern end of the site and consists of two sections. Block A is a steel structure covering an area of approximately 10,750 m². The foundations of Block A are isolated spread footings connected with tie beams resting on jet grout columns. Block B, which is also a steel structure encompassing an area of 4,850 m², is supported by a mat foundation resting on jet grout columns.

The two-story parking structure covers an area of 14,000 m² and is located at the western end of the site. The structure consists of prefabricated reinforced concrete structural elements.

The foundations of the parking garage are isolated spread footings connected with tie beams resting on jet grout columns. Column spacings of the parking structure vary between 8.0 meters and 32.0 meters, with slab-on-grade bearing pressures of 10 kPa and column loads of between 110 kN and 1900 kN.

3 SUBSOIL INVESTIGATIONS AND SITE CONDITIONS

The Carrefoursa site, located along the eastern shore of Izmit Bay, is underlain by Quaternary aged marine sediments. The site is at low elevation (< +3 m), only minimal local relief.

4 FOUNDATION ENGINEERING EVALUATIONS

4.1 Bearing capacity

Based on the geotechnical data shown in Figure 3, the allowable soil pressure for shallow foundations (without consideration of settlements), was estimated at $q_{all}=75$ kPa, using a safety factor of 3.0 against bearing capacity failure.

4.2 Settlements

For the parking structure and Lot C, an additional 1.5 m thick fill was necessary to be built to reach the design elevations. There-

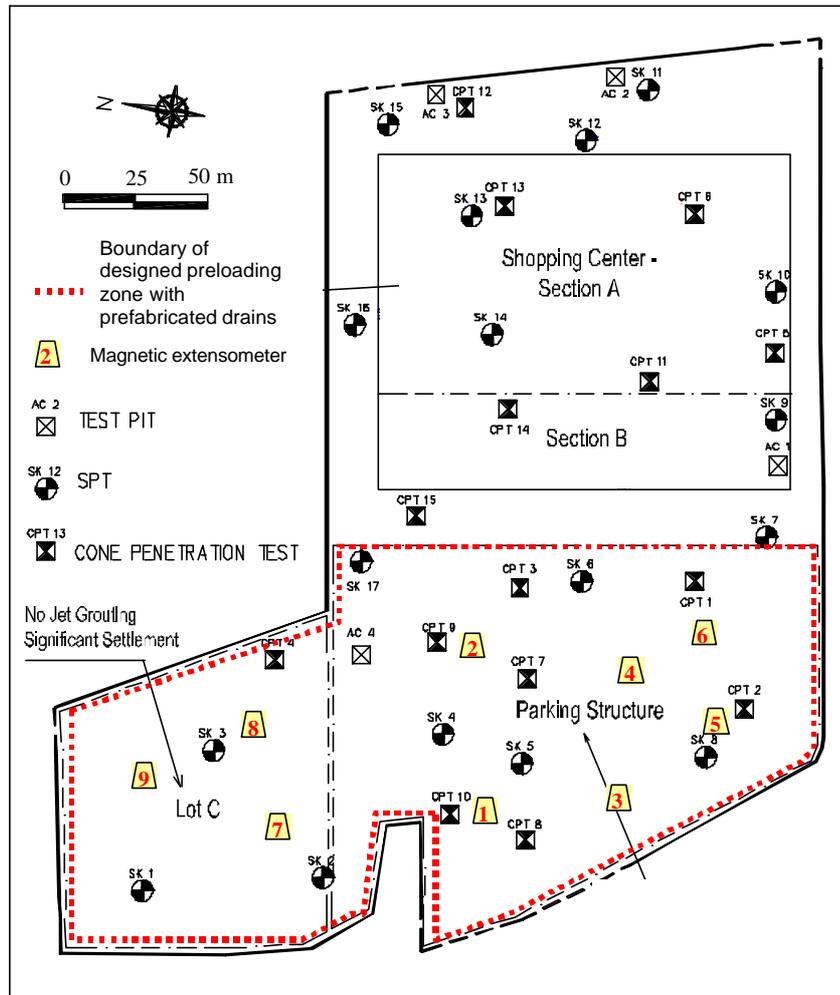


Figure 2. General lay-out of the shopping center and preliminary soil investigation locations

Subsoil investigations for the proposed facilities included Cone Penetration Testing (CPT), Standard Penetration Tests (SPT), and trial pits (Zetas, 1998). The locations of the investigations are shown in Figure 2.

The site is underlain by a gravelly sand fill that 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 silty sand is encountered at a loose-to-medium density. The thickness of this sand layer ranges from 4 m to 1 m across the site. Below the sand, is a layer of medium silty clay that extends from 10 m to a depth of more than 30 m, where the exploration was terminated. The ground water table was found within 2.6 m of the ground surface throughout the site. A representative geotechnical profile is shown in Figure 3.

fore to reduce anticipated large settlements in the underlying clayey soils, the site was to be preloaded with a 3-m thick sandy fill.

Time rate calculations for the clayey soils indicated that 20 and 85 years would be required to achieve 50 percent and 90 percent consolidation, respectively. To accelerate the pre-load consolidation period, prefabricated wick drains were recommended with design spacings of 100 cm to 200 cm, and effective drain diameters of 5.5 cm.

4.3 Liquefaction analysis of the site

A simplified liquefaction analysis for the site was performed using the SPT and CPT data as recommended by Idriss (1998).

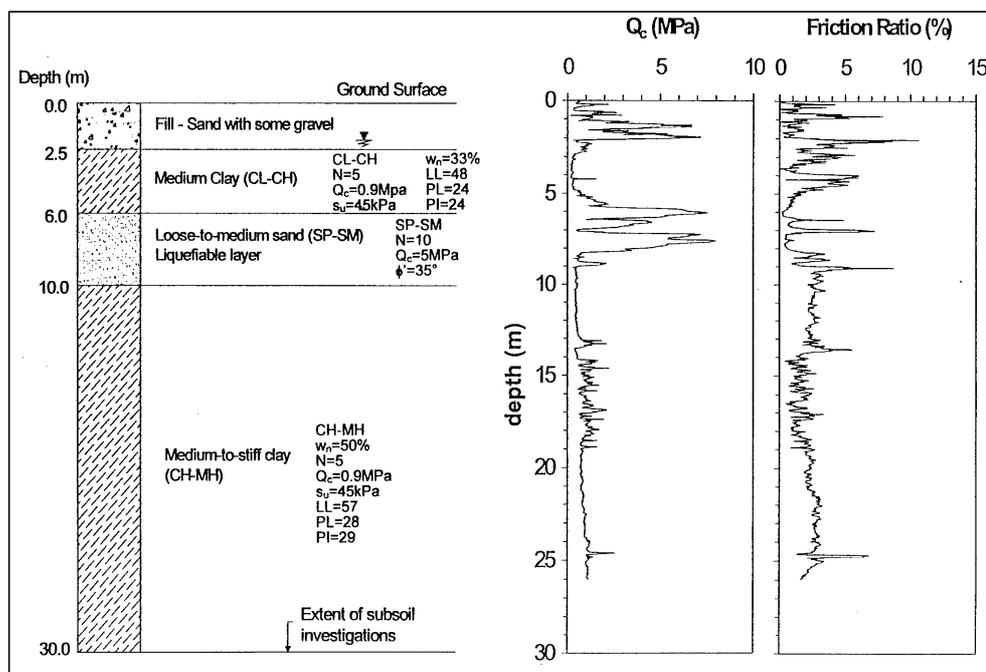


Figure 3. Typical geotechnical section

A more detailed analysis, using the CPT, was made by Durgunoglu (1999) using the method suggested by Stark and Olson (1995).

For the analysis, peak accelerations in rock were estimated using attenuation relationships based on distance from the North Anatolian Fault. Magnitude was determined from prior seismological investigations that assumed a characteristic earthquake for the area. Peak accelerations at the ground surface were estimated by modifying the bedrock accelerations using the procedure given by Idriss (1998) for soft soil sites. Estimated cyclic stress ratios in the loose sand layer were found to be as high as 0.5 for the selected design ground motions of $M=7.5$ and $0.5g$. It was estimated that the critical limit values of corrected tip resistance against liquefaction were $q_{c1}=15$ MPa for clean sands and $q_{c1}=11.5$ MPa for silty sands. To relate the fine content of soil layers with the friction ratio, the correlation chart suggested by Suzuki (1995) was utilized. From this method, the zones with $R_f < 1\%$ and $q_{c1} < 11.5$ MPa were considered liquefiable. Using the criteria, all CPT records were examined and the suspect zones were identified. It was found that a high potential for liquefaction exists for the sand stratum having an approximate thickness of 3.0 m throughout the site. Based on the results of these analyses, soil improvement was recommended to mitigate liquefaction risk.

5 SOIL IMPROVEMENT

The combination of jet grouting and pre-loading with prefabricated wick drains was found to be the most feasible solution for providing required foundation support in the soft clays as well as mitigating the anticipated liquefaction problem considering the locally available technologies. Jet grout columns 60 cm diameter were proposed for installation beneath the foundations as well as beneath the slabs-on-grade. The boundary of the preloading zone with prefabricated drains is shown in Figure 2. Magnetic extensometers were also installed at nine different locations within the pre-loaded zones to monitor settlements in the soft silty clay (Figure 2). Additional details of the soil improvement work for each area of the site are provided in the following sections.

5.1 Supermarket Building Area

Block A of the Supermarket Building rests on isolated spread footings, while Block B is supported by a mat foundation. For this area, no preloading was planned, taking into account the consolidation effects of an earlier fill that was present at this section for more than ten years.

Jet grout columns were constructed to improve bearing support and reduce settlements of the clay, and to increase liquefaction resistance of the underlying loose sand deposit. Jet grout columns were installed in primary and secondary grids of rectangular pattern to provide blanket treatment beneath the structure. The columns in the primary grid are 0.6 m in diameter with a center-to-center spacing of 4.0 m. These columns extended to a depth of 9.0 m from the ground surface. The secondary grid consisted of shorter, 2.5-m long grouted columns installed in between the primary columns with a center-to-center spacing of 2.0 m to further increase the liquefaction resistance of the sand stratum (about 2.5 m thick in this location) by means of solidification. The short secondary columns were installed only within the sand stratum, extending from a depth of 6.5 m to 9.0 m in this area.

In addition to the primary and secondary grids, 9.0 m long jet grout columns of 0.6 m diameter were also installed at each spread footing location in Block A. Groups of two and four jet-grouted columns were installed beneath the exterior and interior footings, respectively.

5.2 Parking Structure Area and Lot C.

The soils in the area of the Parking Structure and Lot C were improved in a manner similar to those in the Supermarket Building Area. The parking structure is founded on shallow isolated footings, with a slab poured between the footings to tie the foundation system together. No structures were initially planned for Lot C, however the soil improvement was designed in anticipation of future development. For the Parking Structure and Lot C, it was proposed to first implement preloading with prefabricated drains, to achieve the consolidation settlement in the clayey soils. Following preloading and removal of surcharge fill, jet grout columns were installed to support structural loads and provide addi-

tional soil stiffness and reduction of liquefaction potential. The Parking Structure area and Lot C were surcharged with a 3.0 m high sand fill. Wick drains 20 m long were installed at 2.5 m spacings for the Parking Structure, and at a 3.0 m spacing for Lot C. Magnetic extensometers, with a series of circular magnetic anchors, were installed to monitor settlements at different depths. At the Parking Structure area, the surcharge fill had been removed and jet grout column construction has begun, when the main shock of the Kocaeli Earthquake $M_w=7.4$ occurred.

Jet grout columns were designed to be installed throughout the parking structure in primary and secondary grids to provide blanket treatment for the area. The primary grid consisted of 0.6 m diameter jet grout columns to be installed with a 2.2 m center-to-center spacing under the footings (four columns per footing in general) and with an 8.0 m center-to-center spacing under the slabs. The columns extended from the ground surface to a depth of 9 m into the lower medium clay stratum. The secondary grid with a 4.0 m center-to-center spacing included shorter columns that penetrated only the liquefiable sand layer, which is about 3 m thick in this area of the site. Similar short jet grout columns with a 2.0 m center-to-center spacing were also designed to be installed to mitigate the liquefaction risk for Lot C.

For quality control of jet grout column construction, in-situ pile integrity, pull-out tests, column diameter measurements, and unconfined compression strength tests on core samples were performed. Compressive strength values varied between 1.4 MPa and 6.7 MPa with an average value of 2.9 MPa for the samples obtained from 7 day-old jet grout columns. Other specifics of the jet grout column construction are provided in Table 1.

Table 1. Details of jet grout column construction

Jet grout system	Jet-1
Number of nozzles	2
Nozzle size	2 mm
Rods lifting speed	50 cm/min
Rods rotation speed	20 rev/min
Injection pressure	450 bar
Water/cement ratio	1/1

6 OBSERVED FIELD PERFORMANCE AND STATUS OF CONSTRUCTION DURING THE $M_w=7.4$ KOCAELI EARTHQUAKE

6.1 Construction Status

To provide a clearer understanding of the findings of the field reconnaissance, the status of the construction of the shopping center facilities at the time of the 17 August 1999 earthquake is summarized below. While reviewing these notes, it may be helpful to examine Figure 2:

- At supermarket building Block A, subsoil improvement and foundation construction had been completed and erection of steel framework was almost completed.
- At supermarket building Block B, subsoil improvement and foundation construction had been completed while the erection of steel framework was underway.
- At the parking structure section, the preloading fill was removed and subsoil improvement with jet grout column construction was partially completed.
- At Lot C, the preloading fill was still in place and no jet grout columns were installed yet.

6.2 Earthquake-Induced Settlements

Visual field inspections following the earthquake indicated that no structural damage occurred in the Supermarket Building (Block A and B) and no noticeable settlements or ground damages were observed anywhere at the site except in the Lot C area where the surcharge fill was still in place and part of parking structure area that were not yet treated. The ground surface in the Parking Structure area was completely inundated with water fol-

lowing morning of the earthquake. Both Lot C and the Parking Structure area were treated with wick drains that penetrated the underlying sand stratum. However, following the removal of surcharge fill, settlement observation was ceased for the parking structure zone and therefore it was not possible to monitor the induced settlements by the earthquake for this section.

Following field inspection, it was concluded that the observed surface water originated from the wick drains due to earthquake-induced pore pressure build-up in the sand layer. Three settlement measuring devices were in place at Lot C zone during the earthquake. By comparing pre- and post-earthquake readings, the earthquake-induced settlement of the sand layer could be closely determined. A typical records from one of the three magnetic extensometers installed at Lot C, are presented in Figure 4.

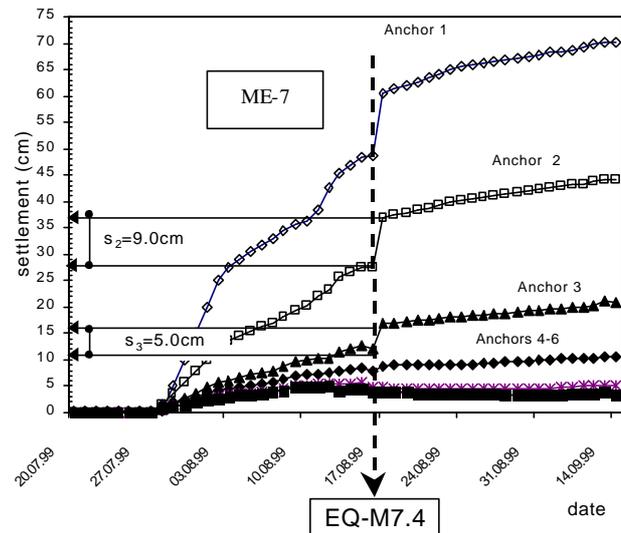


Figure 4. Time dependent settlement readings from magnetic extensometer at Lot C

Simplified methods of analyses were proposed in the literature for estimating settlements in saturated sand deposits subjected to earthquake shaking. Tokimatsu and Seed (1987) and Ishihara (1993) have developed empirical charts to estimate the vertical settlement subsequent to an earthquake.

Each of the three installed magnetic extensometers consisted of five magnetic anchors installed at five-meter vertical intervals. During the quality control tests, 10 CPT tests were performed at Lot C area prior to jet grouting on 30/09/2001. CPTs 8, 9 and 10 were located closest to settlement columns 7, 9, and 8 respectively. The variation of tip resistance (q_c), and friction ratio (R_f) values with depth for a typical CPT data is shown in Figure 5. The estimated sand layer thickness for each CPT location ranged from 1.1 m to 1.5 m based on the soil classification procedure developed by Roberston (1988). To estimate the earthquake-induced settlement within the untreated sand layer, the difference between the settlement values recorded by anchors 2 and 3 were calculated. The elevation of anchors 2 and 3 do not correspond to the top and bottom of the sand layers (the anchors were installed in clayey and silty soil layers located about 2.5 m above and 1 m below the sand layer, respectively). Therefore, the estimated earthquake-induced settlements in the sand should be considered maximum values, as it is conceivable that a portion of the measured settlements may have occurred within the over- and underlying finer-grained soils. It is believed however, that the vast majority of the settlements measured between anchors 2 and 3 were from the sand layer. Based on this methodology, it is estimated that up to 4.0 to 4.5 cm of earthquake-induced settlement, corresponding to about 2.9 to 3.6% volumetric strain, respectively, occurred in the sand stratum.

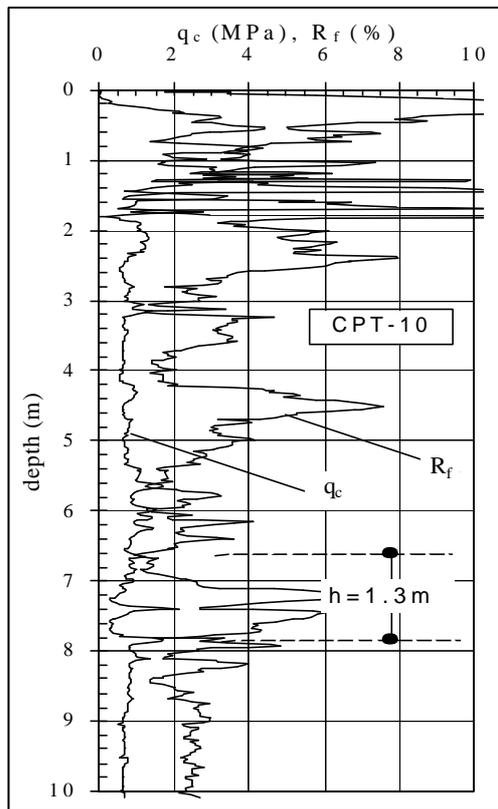


Figure 5. Typical CPT data from September, 1999 at Lot C, after the main shock, before the construction of jet grout columns

For purposes of comparison, existing settlement methods from the literature were used to assess predictive capability as determined by how closely they predicted the actual settlements. In using the CPT data for this purpose, the thin layer influence was considered as recommended by Robertson and Fear (1995), and a correction factor for cone resistance was also used in the calculations. Based on this methodology, Ishihara's procedure (1993), estimated about 4.8 cm of settlement. In order to compare the results from two in-situ tests, SPT blow count values obtained from boreholes made at Lot C are utilized and, Tokimatsu and Seed's procedure yielded an estimated average settlement of 4.6 cm. The results are summarized in Table 2 and plotted in Figure 6 for the purpose of comparison. For this site, it can be seen that both Ishihara's method utilizing CPT data and Tokimatsu and Seed's method utilizing SPT data provided close estimates for the observed settlements.

Table 2. Comparison of estimated settlements

Procedure	Predicted Settlement (average value- cm)	Observed Settlement (average value- cm)
Ishihara (1993)	4.8	4.2
Tokimatsu and Seed (1987)	4.6	

6.3 Earthquake-Induced Ground Damage

Liquefaction is often accompanied by the development of sand boils. However the development of sand boils is a complicated and somewhat random process depending on the magnitude of the excess pore pressure; the thickness, density, and depth of the zone of excess pore pressure; and the thickness, permeability, and intactness of any soil layers that overlay the zone of high excess pore pressure (Kramer, 1996).

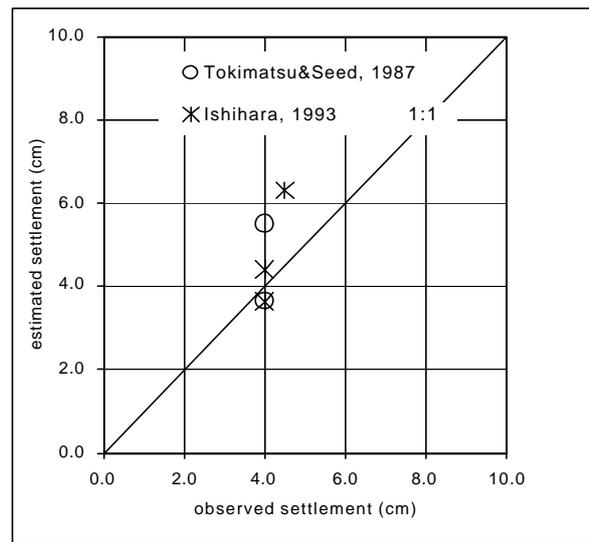


Figure 6. Comparison of estimated settlements

Observations immediately following the earthquake of August 17, 1999 revealed that, within and/or in the close vicinity of the Carrefoursa site neither sand boils, nor any surficial ground damage occurred. Ishihara (1985) examined the soil conditions associated with various liquefaction-related damage reports and produced estimates of the thickness of the overlying layer required to prevent level-ground liquefaction-related damage as shown in Figure 7. Considering that approximately a 6.0

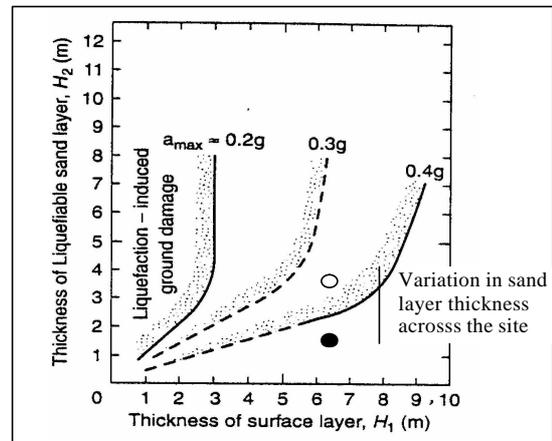


Figure 7. Conditions for occurrence and nonoccurrence of ground damage (After Ishihara, 1985; Adapted from Kramer, 1996)

m thick layer of "unliquefiable soil" overlays the 1.5 m thick liquefiable sand layer at Lot C section, non-occurrence of surface manifestation is expected according to Ishihara as shown with the full circle in Figure 7.

Considering that the liquefiable sand layer thickness reaches to 4.0 m, Carrefoursa site is still within the "no ground damage" zone as presented by the open circle on Figure 7. It is also informative to note that Lot C and partly parking structure sections were the only area at the complex that had not been improved with jet-grouted columns prior to the earthquake. 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 and the adjacent improved areas, it has been demonstrated that the jet-grouted columns have been effective in reducing liquefaction

susceptibility and liquefaction-related settlements of the sand layer.

7 CONCLUDING REMARKS

The principal conclusions drawn from this study are:

1. Conditions appropriate for liquefaction were present at the Carrefoursa Shopping Center site. A loose sand layer 3.0 m in thickness was found to be liquefiable under relatively low levels of accelerations.
2. During the August 1999 earthquake, the Supermarket Building section of the site were treated with jet grout columns while Lot C and partly parking structure sections were untreated. This provided an opportunity to observe the performance difference of unimproved and improved sites against liquefaction.
3. Settlements of up to 4.5 cm occurred in the area where the sand layer was untreated, while no liquefaction related settlements were observed within the areas treated with jet grout columns. Lot C and partly parking structure sections were the only areas at the center that had not been improved with jet grout columns at the time of the quake. All other areas had been improved with jet grout columns to reduce liquefaction susceptibility.
4. Both Ishihara's method utilizing CPT data and Tokimatsu and Seed's method utilizing SPT N values provided close estimates for the observed settlements.
5. No ground failure in the form of sand boils or ground cracks were observed anywhere at the site. Considering that approximately 6.0 m thick "unliquefiable soil" overlays the 1.5 m thick "liquefiable" sand layer at Lot C, the absence of surface manifestation of liquefaction is expected according to Ishihara.
6. Jet grout columns were effective in mitigation of liquefaction and liquefaction-related settlements of the loose sand stratum.

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