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LIQUEFACTION INDUCED LATERAL SPREDING IN THE 1999 KOCAELİ EARTHQUAKE, TURKEY: CASE STUDY AROUND THE HOTEL SAPANCA

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SUMMARY

The Kocaeli earthquake of August 17, 1999 with a magnitude of 7.4 induced permanent deformation of ground due to both liquefaction and faulting and resulted heavy damage to both superstructures and infrastructures. This research study was undertaken as the first quantitative measurement of permanent ground deformation and associated strain fields induced by ground liquefaction in Turkey. The permanent ground deformation was measured through the aerial photogrammetry technique developed by Hamada at several sites within the earthquake stricken region. Among them, the area around the Sapanca Vakıf Hotel was chosen and investigated in this article. In the vicinity of the hotel, 14 new boreholes were drilled in addition to the existing boreholes by Iller Bank of Turkey. A series of analyses on the liquefaction susceptibility of the area was carried out by using a method by Japan Roadway and Bridges Society [1]. The permanent ground displacements were estimated according to a method proposed by Hamada and Wakamatsu [2]. Then the estimations are compared with theoretical predictions and the existing data from sites obtained in the earthquakes in Japan. These outcomes from the Sapanca Vakif Hotel area are compared with the existing data from the earthquakes in Japan and it is found that they are quite similar to each other. Estimations based on seismic coefficient values of 0.3 and 0.4 are quite consistent with each other.

INTRODUCTION

Turkey is one of the most seismically active countries in the World and most of her damaging earthquakes are of in-land type. These earthquakes mostly result in permanent ground deformation as a result of both faulting and liquefaction. Although the effect of faulting on the permanent ground deformation is known, the effect of liquefaction on permanent ground deformation, which is called *lateral spreading,* became to be known after the 1964 Niigata earthquake. Hamada et al. [3] carried out the first quantitative measurements of permanent ground deformation due to liquefaction. This work was extended to other earthquakes in Japan, Philippine and USA.

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The Kocaeli earthquake of August 17, 1999 with a magnitude of 7.4 induced permanent deformation of ground due to both liquefaction and faulting and resulted heavy damage to both superstructures and infrastructures. This example provides an important case study for earthquake engineering communities in Turkey, Japan, and USA as well as in other countries, and it was an urgent requirement for quantifying the permanent ground deformation and associated strain field in relation to the damaged assessment of buildings and infra-structures. This research study was undertaken as the first quantitative measurement of permanent ground deformation and associated strain fields induced by ground liquefaction in Turkey. It is considered that the result will be of great significance to the tri-lateral collaborative research project among institutes from Turkey, Japan and USA to investigate the relation between the damage to buildings and infra-structures and resulting strain fields in association with geological and geotechnical conditions of ground. In this collaborative research program, the permanent ground deformation was measured through the aerial photogrammetry technique developed by Hamada et al. [3] at several sites within the earthquake stricken region. Among them, the area around the Sapanca Vakıf Hotel was chosen and investigated in this article. In the vicinity of the hotel, 14 new boreholes were drilled in addition to the existing boreholes by Ýller Bank of Turkey. A series of analyses on the liquefaction susceptibility of the area was carried out and the permanent ground displacements were estimated. Then the estimations are compared with theoretical predictions and the existing data from sites obtained in the earthquakes in Japan.

DAMAGED DUE TO LIQUEFACTION AND LATERAL SPREADING

Liquefaction was widely observed and caused severe damage to structures in the region between Adapazari and Yalova. Liquefaction phenomenon was widespread for a length of 120 km almost along the earthquake fault break. Some liquefaction was also observed along the shore of Black Sea. The general distribution of the ground fissures and sand boils are evidently observed in Adapazari City, along the Sakarya River up to the Black Sea coast, Akyazi, the southern shores of the Sapanca Lake and Izmit Gulf as far as Yalova whenever saturated Quaternary loose deposits exist (Figure 1). The incidents of sand and silt volcanoes, sand blows were clearly visible at various localities. However, the most devastating effects of liquefaction was observed in Adapazari city which was about 6 km away from the fault break on the northern block and in the southern shore of the Sapanca Lake. The liquefaction observed in the vicinity of Hotel Sapanca was spectacular and the hotel building sank and moved towards the lake (Figure 2a). The general trends of the eruption fissures were systematically parallel to the shore with an orientation of N75W (Figure 2b).

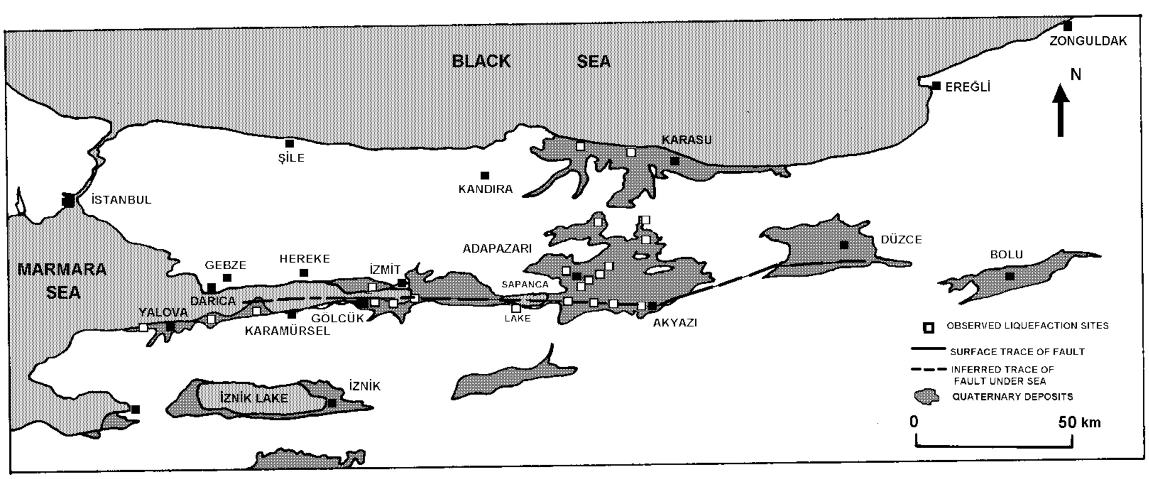


Figure 1. Liquefaction locations observed during the 1999 Kocaeli earthquake (after Aydan et al. [4])

(a) (b) (c)

Figure 2. (a) Flooded Sapanca Vakıf Hotel due to lateral spreading along the southern shore of the Sapanca Lake, and (b) lateral spreading and fissures in the vicinity of this hotel.

AERIAL PHOTOGRAMMETRY MEASUREMENTS

Figure 3 shows the map of Sapanca town and the location of Sapanca Vakif Hotel. The area used in aerial photogrammetry measurements was 5 km in EW direction and 4 km in NS direction. The aerial photographs were taken from the site in 1994 and 1999 before and after the earthquake and their scales were 1:35.000 and 1:16.000, respectively. As for measurements points, the manholes and tree roots were taken as points on the ground while the roof, bridges and poles were used as points off the ground. The three-dimensional coordinates of the common points on pre-post earthquake photographs were determined and their differences are interpreted as the liquefaction induced displacements using the method proposed by Hamada et al [3]. The error in aerial photogrammetry measurements was estimated to be about 50-60 cm. After the preliminary aerial photogrammetry measurements, the region shown in Figure 4 was investigated in detail and this area was also subdivided into 5 sub-regions as shown in Figure 4. Figure 5 shows the ground displacements in Area 1, Area 2 and Area 3 and the locations of the boreholes, which are described in the next section.

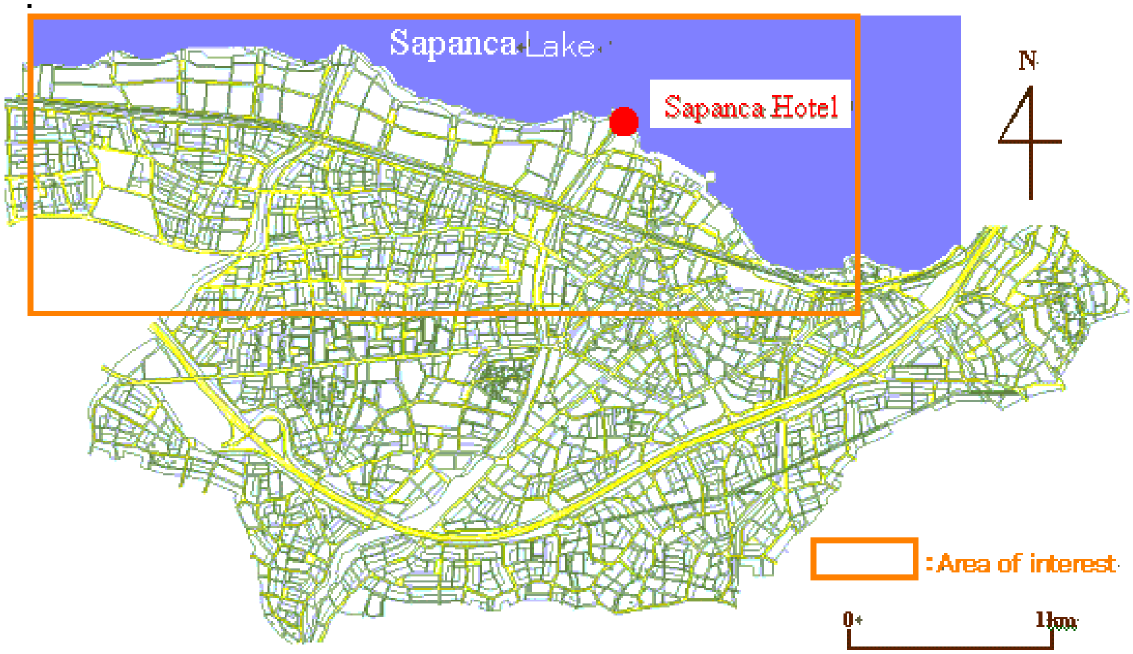


Figure 3. The map of Sapanca and the area of interest.

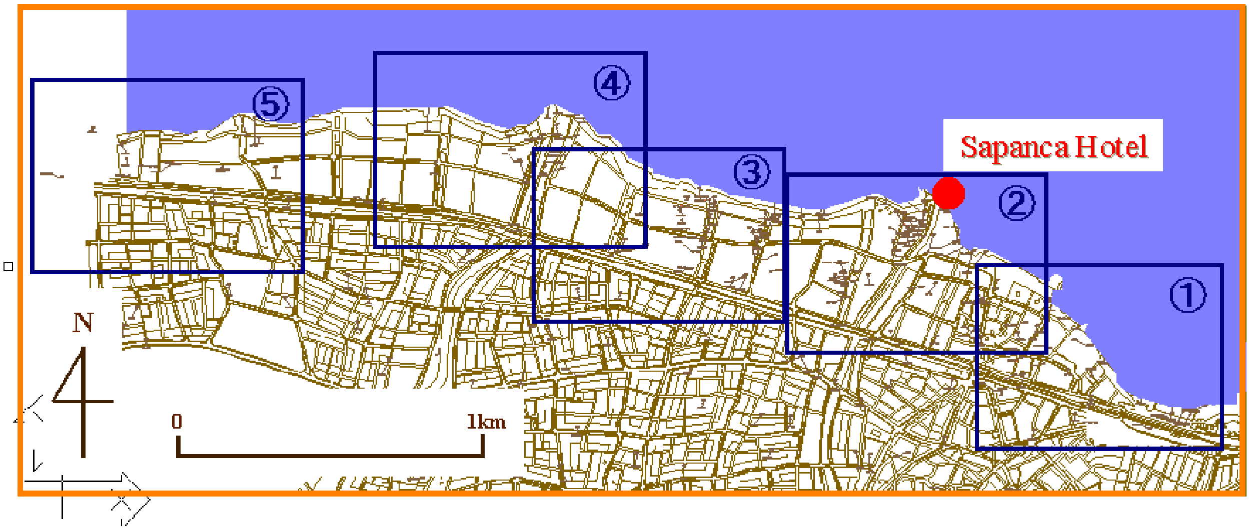


Figure 4. Sub-divisions of the area of interest.

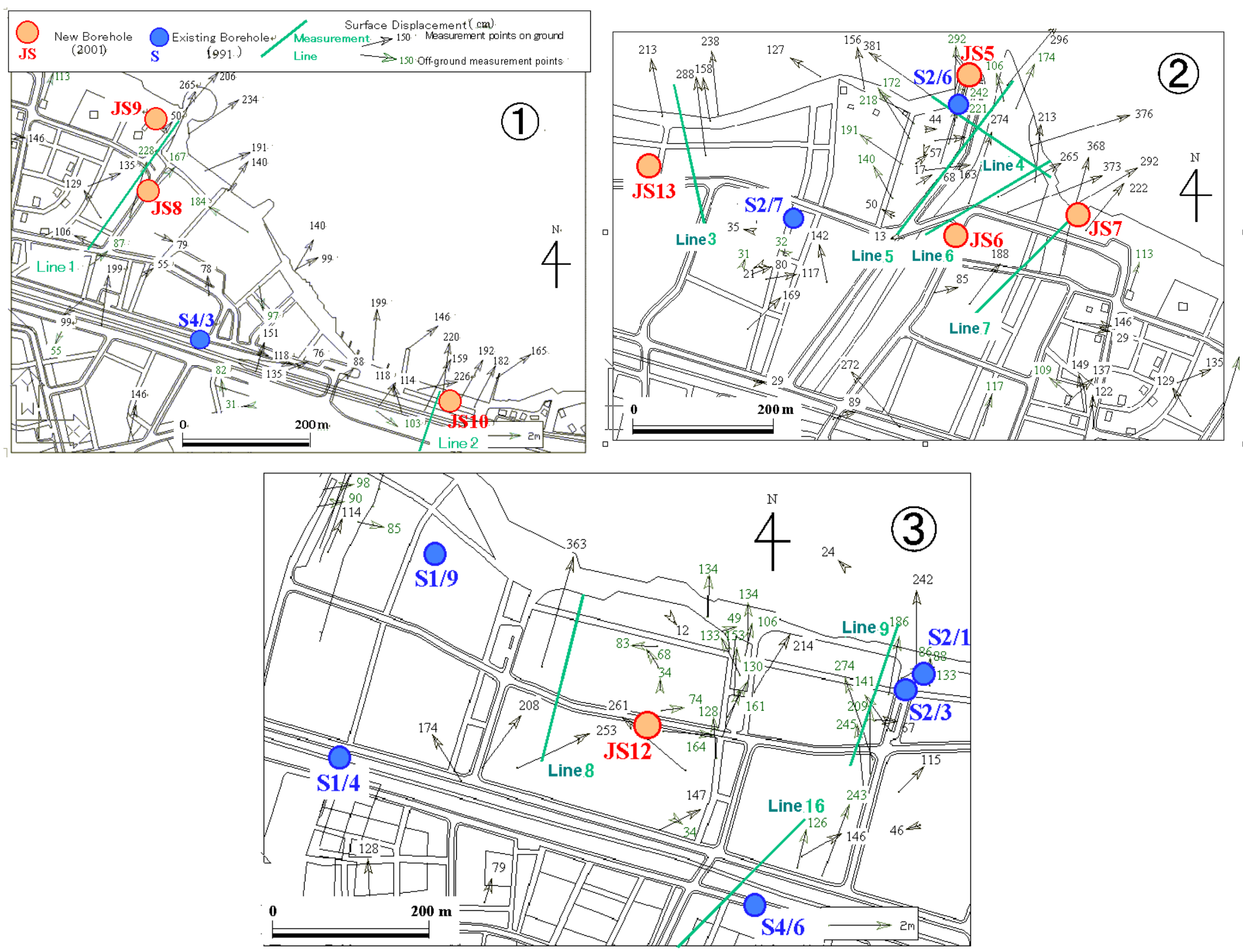


Figure 5. Ground displacement vectors of lateral spreading and locations of the boreholes in Areas 1 to 3.

GEOTECHNICAL CONDITIONS

Iller Bankası of Turkey [5] has already drilled boreholes for the sewage network of Sapanca town municipality. These boreholes are denoted with capital “S” in the respective figures. 14 new boreholes up to a depth of 10 m below the ground surface were drilled in the area of interest. Depth of the groundwater level was generally shallow and it was less than 2 m below the ground level. Figure 6 illustrates the ground conditions based on the borehole data in Areas 1, 2 and 3. The ground was broadly classified into five subgroups, namely, artificial fill, organic soil, sandy soil, silty soil, gravelly soil. The soil conditions differ from east to west. While the ground mainly consists of sandy and gravelly soils in the east (Areas 1 and 2), the silty and clayey soil became dominant in west (Areas 4 and 5). Furthermore, the gravelly soil becomes thicker as the distance from the shore increases. Table 1 shows the measured ground displacement in the closed vicinity of boreholes. When the location of measurement points does not coincide with the borehole, the displacement of the borehole corresponds to the ground displacement of the nearest measurement point within the perimeter of 50 m of the borehole.

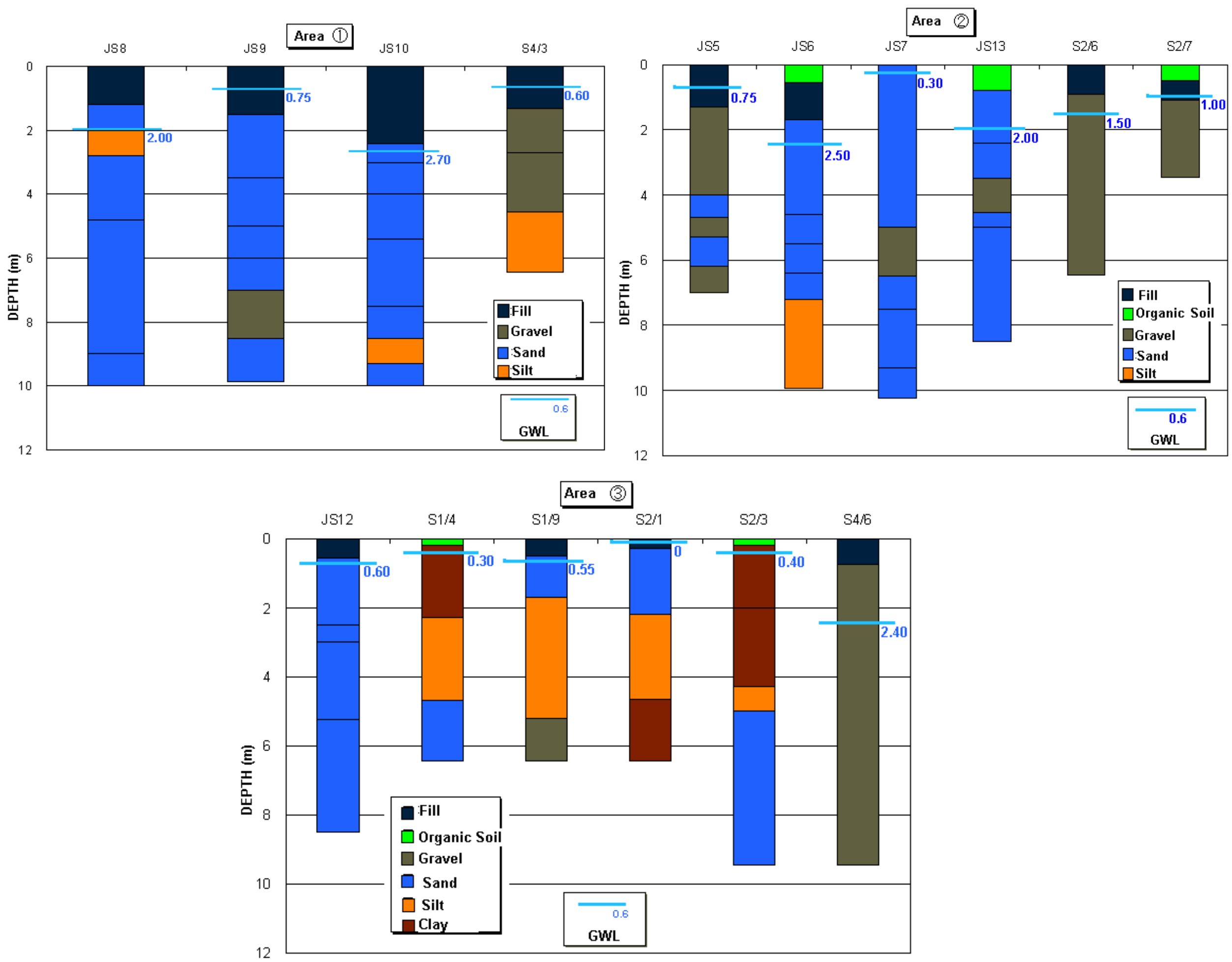


Figure 6. Ground conditions in Areas 1 to 3.

LIQUEFACTION SUSCEPTIBILITY ANALYSES

Liquefaction analyses were carried our according to a method proposed by Japan Roadway and Bridges Society [1]. Liquefaction analyses were performed at 15 boreholes and the liquefaction resistance factor denoted as F_L is computed at each borehole. In computing liquefaction resistance factor F_L the following assumptions are made.

Table 1. Computed thickness of liquefaction layers at each borehole.

Boring No.	Boring Year	Line No.	Area No.	Displ. (m)	Depth of GWT (m)	Total liquefied layer thickness (m) Seismic Coeff. 0.3	Total liquefied layer thickness (m) Seismic Coeff. 0.4	Gradient (%)
JS14	2001	15	5	4.79	0.80	0.00	1.65	2.12
JS5	2001	4	2	3.81	0.75	5.05	6.25	2.04
S2/6	1991	4	2	3.05	1.50	1.50	1.50	2.04
JS7	2001	7	2	2.94	0.30	4.75	7.43	1.44
S1/7	1991	12	4	2.19	1.00	1.40	1.40	1.36
JS8	2001	1	1	2.16	2.00	3.75	4.73	2.02
JS9	2001	1	1	2.06	0.75	5.83	9.05	2.02
S1/13	1991	10	4	1.50	1.40	1.08	2.58	1.69
S2/3	1991	9	4	1.47	0.40	1.35	1.35	1.47
S2/1	1991	9	4	1.37	0.00	1.90	1.90	1.47
JS3	2001	13	4	1.37	1.02	1.75	2.98	0.20

(1) The liquefiable soil should satisfy the following requirements:

- i) Groundwater depth is less than 10 m below the ground surface and the soil is fully saturated.
- ii) Fine content ratio is less than 35%, plasticity index I_P should be less than 15.
- iii) Mean grain diameter D_{50} is less than 10 mm and the content of soil, whose grain size is smaller than 1 mm, is less than 10%.

(2) The liquefaction resistance factor F_L is computed from the following formula and if it is less than 1, the ground is assumed to be liquefiable.

$$F_L = R / L \quad (1)$$

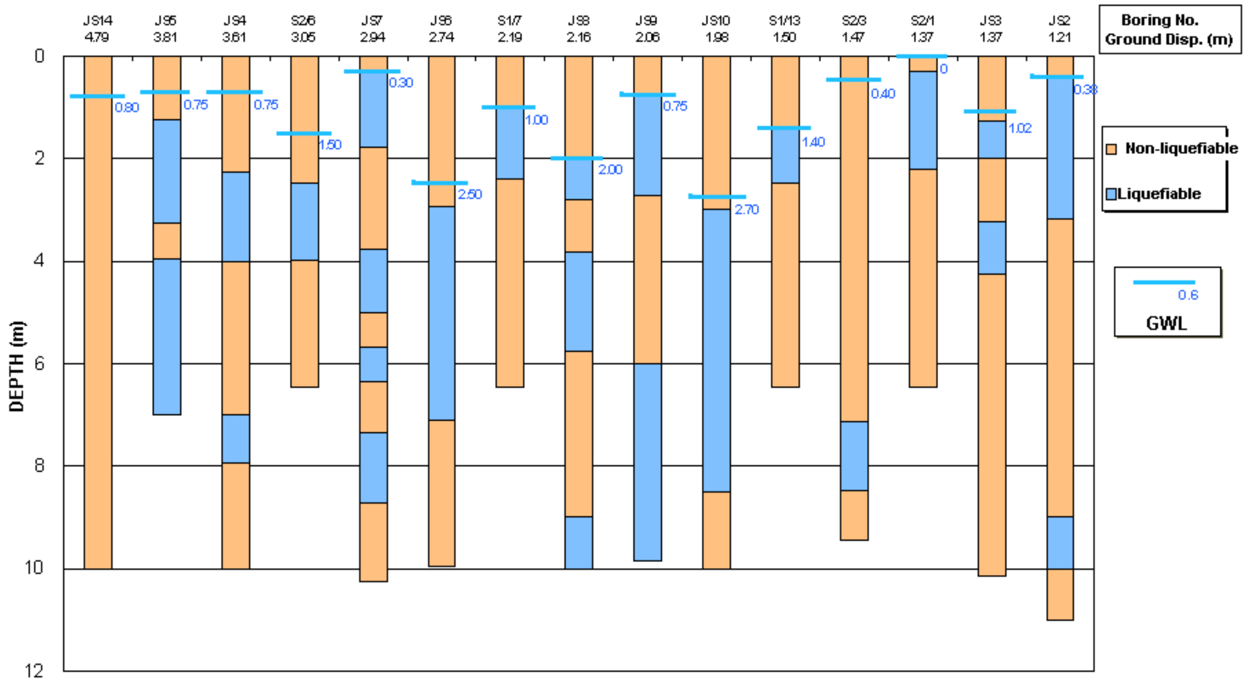
Where R and L are the resistance estimated from SPT value with the consideration of fine content and disturbance estimated from horizontal acceleration, total and effective vertical stresses, respectively.

The maximum horizontal ground acceleration imposed from the bedrock into the liquefiable ground was estimated from the empirical relation proposed by Aydan [6] for the firm ground and bedrock.

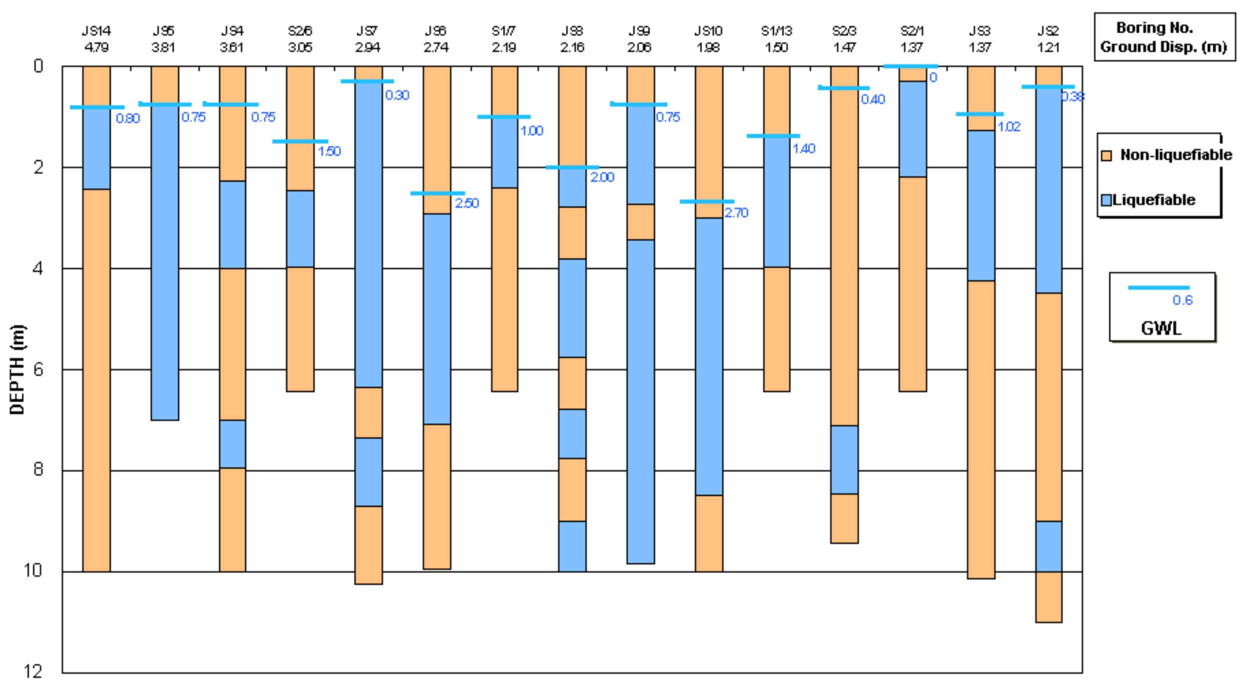
$$a_{\max} = 0.56e^{-0.025R}(e^{0.9M_s} - 1) \quad (2)$$

Where R and Ms are hypocenter distance and surface magnitude of the earthquake, respectively. The maximum ground acceleration on bedrock was estimated as 294 gal from the above relation for the parameters of the 1999 Kocaeli earthquake. The peak ground acceleration was 407 gal at Adapazarı station of the Turkish National Strong Motion Network. Therefore, the values are taken as the base accelerations in liquefaction analyses.

Figures 7a and 7b show the results of liquefaction analyses for seismic coefficients of 0.3 and 0.4, respectively. The total thickness of liquefiable layer at each borehole for two different seismic coefficient values was also given in Table 1. As seen from this table, the thickness of liquefiable layer increases at each borehole as the seismic coefficient increases. At boreholes JS7 and JS9, the thickness of liquefiable layer is greatest and it is about 9 m. However, there is almost no liquefaction at JS14 for seismic coefficient value of 0.3 in-spite of very large ground displacement at this location.



(a)



(b)

Figure 7. Computed thickness of liquefiable layers at each borehole for seismic coefficients of 0.3 (a) and 0.4 (b).

LATERAL SPREADING ANALYSES AND COMPARISONS

The gradient of ground in the vicinity of boreholes along lines shown in previous figures is given Table 1. Figure 8 illustrates how the gradient of the ground was determined. The boreholes JS10, JS6, JS2 and JS4 were omitted in the lateral spreading analyses, as their topography was complex. The maximum distance from the lakeshore was taken as 100 m for lateral spreading analyses. Table 1 also gives the ground conditions and thickness of liquefiable layer together with measured ground displacement. The ground displacement at each borehole was estimated by using a method proposed by Hamada et al. [3] Hamada and Wakamatsu [2]. The details of the analyses can be found in master theses by Inuzuka [7] and Kanıbir [8]. Figures 9a and 9b compare the measured and estimated ground displacement for two different seismic coefficients, respectively. In the same figure, data from earthquakes in Japan are also plotted and compared with the data from Sapanca. It is of great interest that, the data from Turkey and Japan are remarkably similar to each other.

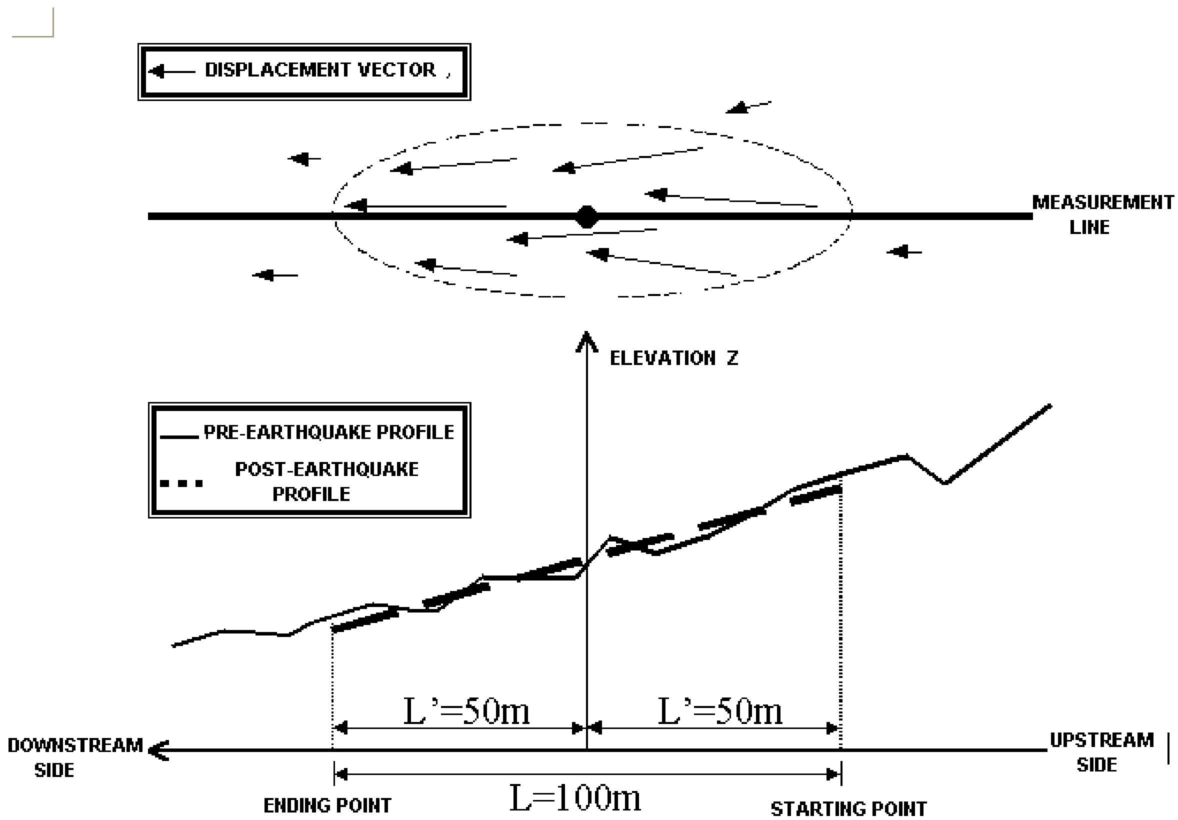
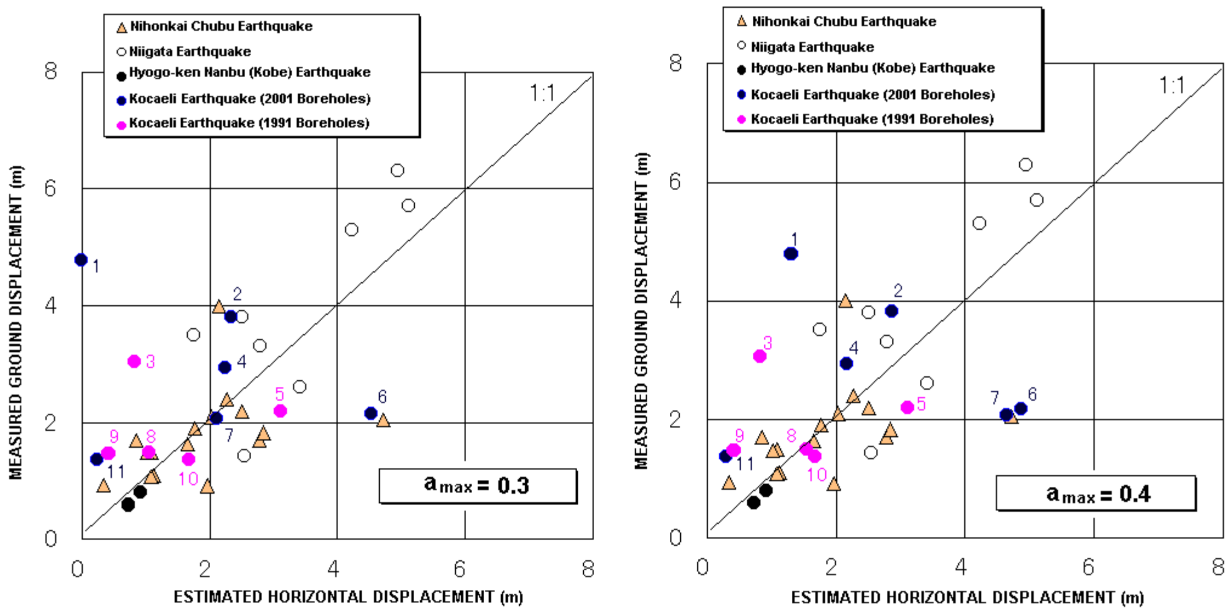


Figure 8. The procedure used for determining ground gradient.

CONCLUSIONS

The authors carried out a research project with the collaboration of General Command of Mapping of Turkey on the liquefaction induced lateral spreading and related damage in the region from Adapazarı to Yalova, caused by 1999 Kocaeli earthquake. This article presents preliminary outcomes of this research for Sapanca Vakıf Hotel area. These outcomes are compared with the existing data from the earthquakes in Japan and it is found that they are quite similar to each other. Estimations based on seismic coefficient values of 0.3 and 0.4 are quite consistent. These analyses are also applied to other areas in the research area and they will be presented in subsequent publications.



(a) (b)

Figure 9. Comparison of measured and estimated ground displacement of Sapanca with data from the earthquakes in Japan for seismic coefficient 0.3 (a) and 0.4 (b).

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