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GROUND CHARACTERIZATION OF CANAKKALE CITY CENTER FROM A LIQUEFACTION POINT OF VIEW

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ABSTRACT

This paper presents the results of an extensive ground characterization study carried within the context of a Horizon 2020 Project, "Liquefact". The project aims to develop a low-accuracy liquefaction risk map for European countries based on past liquefaction occurrences and existing geological, geotechnical and seismological information. This risk map will be validated and/or optimized after performing site-specific, localized analyses in four regions denoted as "testing sites". In this context, Canakkale city center was selected as the test site in Marmara Region by Istanbul University team and ground characterization was performed from a liquefaction point of view. Canakkale city center is founded on loose, saturated sand and silts and is characterized by a high seismic hazard and therefore fullfills the criteria as a test site. Within the context of the study, pre-existing studies carried out in the region were first collected and evaluated. The areas which were susceptible to liquefaction were determined and six study areas in the test site were selected accordingly. A complementary investigation campaign was then planned for these six study areas taking into account that the data will be used in liquefaction assessment studies. Ground characterization focused on coarse-grained soils including clean sands, silty-sands and non-plastic sandy-silts deposits in view of the susceptibility of these geomaterials to liquefaction. This paper summarizes these complementary studies carried out in the region, gives examples from the evaluations that were made in one of the study areas and evaluates the findings from a soil characterization point.

Keywords: LIQUEFACT, Liquefaction, Canakkale, Ground Characterization, Turkey

1. INTRODUCTION

Istanbul University has been involved in a Horizon 2020 Project entitled "LIQUEFACT: Assessment and mitigation of liquefaction potential across Europe: a holistic approach to protect structures/infrastructures for improved resilience to earthquake-induced liquefaction disasters". The project is funded by the EU within the H2020–DRS 2015 call (Research Innovation Action) and addresses the mitigation of risks to Earthquake Induced Liquefaction Disasters (EILD) events in European communities with a holistic approach. The notable outcomes of the project have been defined as European liquefaction hazard GIS mapping framework, new simplified structural vulnerability assessment methodology, liquefaction mitigation planning framework, urban community resilience model framework and an overall integrated software toolbox (www.liquefact.eu).

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In the project, it was targeted to construct a low-accuracy liquefaction risk map for European countries based on past liquefaction occurrences and existing geological, geotechnical and seismological information. This risk map will then be validated and/or optimized after performing site-specific, localized analyses in four regions denoted as "testing sites". In order to fulfill the requirements for construction of the map, four test sites were chosen in European region to perform ground characterization using novel techniques and advanced methodologies by in situ and laboratory tests. Within this work package, Istanbul University had the responsibility to carry out a site investigation in Marmara Region and in this context, a test site was selected in Canakkale city center in Marmara Region. The data from pre-existing soil investigation studies was gathered in the first stage and evaluations were made. Based on these evaluations, six study areas in the test site were chosen and complementary tests were carried out in these areas taking into account the needs for liquefaction analyses. This paper presents the complementary studies carried out in the region, gives examples from the evaluations that were made in one of the study areas (Study Area 2) and evaluates the findings from a soil characterization point of view. The details are given in Ozcep et al. (2017).

2. CANAKKALE TEST SITE: LOCATION AND IMPORTANCE

Performing site-specific, localised analyses in four selected testing sites was within the scope of the work packages in LIQUEFACT project. This work package was entitled as "*Report on ground characterization of the four areas selected as testing sites by using novel techniques and advanced methodologies to perform in situ and laboratory tests*" and the information gathered in this section will be used in establishing microzonation studies that shall be performed. In this context, a test site in Marmara Region was selected as by the Istanbul University Team.

Marmara Region is one of the most populated areas in Turkey and according to 2009 numbers, the population is more than 23 million, which makes about a quarter of the total population. This region is also the first ranking region in the country in terms of social-economic issues. One of the most destructive earthquakes in Turkey occurred on August 17, 1999. It is known as Kocaeli earthquake for the province where the epicenter was located. Official magnitude estimates for the earthquake was 7.4 on the moment scale and a very large area, more than 10000 km^2 was affected by the earthquake. Figure 1 shows the Marmara Region, together with the Kocaeli-Sakarya and Yalova areas which were affected by the 1999 earthquake. Intensive and numerous post-earthquake investigation campaigns were carried out by several national and international teams in Adapazari, Kocaeli (Golcuk) and Yalova areas and several publications were made. In this context, liquefaction phenomenon in these areas was studied to the most rigorous level and important contributions were made to the relevant literature. Especially Adapazari liquefaction has been very well documented in the literature and the extent of liquefaction and the liquefaction criteria have been well established. In this context, it was decided by Istanbul University project team that additional study in Adapazari or Yalova would not add much to the liquefaction literature and therefore Canakkale City Center, which is founded on loose, saturated sand and silts and characterized by a high seismic hazard, was selected as the test site. Figure 1 presents the Canakkale city center as the "study area".

Figure 2 shows the boundaries of the test site, which is about 11 km^2. Canakkale city center fulfils all the criteria to be selected as a test site because of the following reasons. The study area is in the first degree earthquake zone according to Turkish Earthquake Design Code (2007). Saros and Ganos faults, which are in the most western part of the Marmara Region pass through Canakkale City and are about 40 km to the selected test site. Gokcaada fault is also close to the test site and is extending into the Aegean Sea towards Greece. As a consequence of these two faults, a high earthquake risk is prevalent in the area. The historical earthquakes in the region are also shown in Figure 1. Another reason is that suitable soil conditions for liquefaction occurrence and high groundwater table prevail in the area.

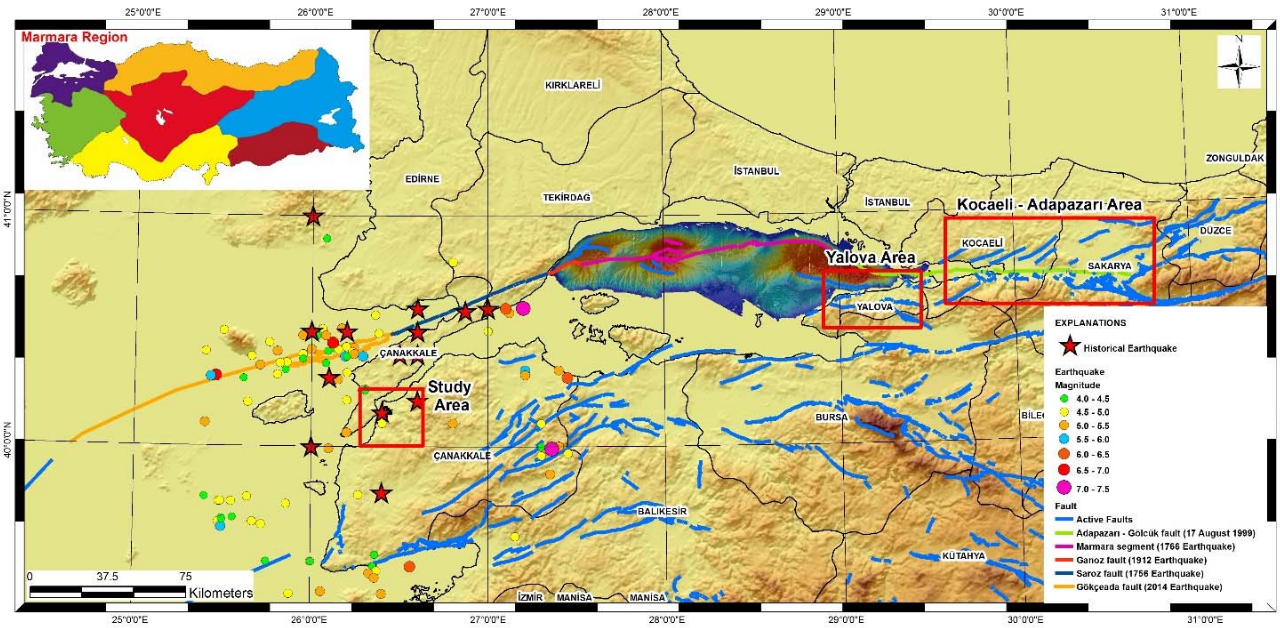


Figure 1. Marmara Region, past earthquakes, study area and the active faults in the region

Figure 2. Boundaries of Canakkale city test site

3. OBJECTIVES OF GROUND CHARACTERIZATION STUDIES

The main objective of ground characterization at the four European testing sites was defined to "develop a geological-geotechnical model of a territory of limited extension, yet sufficiently large, to allow performing microzonation for liquefaction susceptibility. Ground characterization shall focus on coarse-grained soils including clean sands, silty-sands and non-plastic sandy-silts deposits in view of the susceptibility of these geomaterials to liquefaction."

In the first stage of the study, existing available data providing subsurface geological information up to a depth of at least 20 m from the ground surface was collected and stored. In this context, all the previous information available for Canakkale city center from governmental offices and private companies were investigated. As a result of this investigation, the data came from two main sources. The main data came from a detailed site investigation carried out for Canakkale Municipality, which will be cited as Canakkale Municipality Report (2013) hereafter. This report was written by Buyuksarac et al. (2013), based on the soil investigation tests made by Canakkale Municipality. The aim of this site investigation was to carry out a microzonation study for development issues to be utilized by the local planning authorities. The second source of data was from a soil investigation report which was carried out by a private company (Geosan, 2008). Collected data was first checked for the accuracy and reliability and then stored and managed in a georeferenced framework. In this context, a Geographical Information System (GIS) was developed and used throughout the project.

Pre-existing data showed that Canakkale city center included liquefaction prone areas due to river meander points, estuarine deposits, alluvial ridges and reclamation fills. Appropriate number of relevant geolithological cross-sections were defined in order to provide the spatial distribution of the liquefiable formations. Based on the present information, a 3D engineering geological subsoil model was developed as given in Figure 3 and geometries of unconsolidated deposits, location of geological or seismic bedrock roof were mapped and age of unconsolidated deposits were presented. Pre-existing data showed that there are lithological units of Quaternary (Holocene) soil deposits in the test site and soil lithology consisted of six different soil types. These are; Artificial fills/top soil, clean sands (SP, SW) (Holocene, Alluvium), plastic silts and clays (ML, MH, CL, CH) (Holocene, Alluvium), silty sands and sands (SW-SP-SC-SM) (Holocene, Alluvium), clay, claystones and limestone (Miocene-Pliocene, Alcitepe Formation) and claystone, sandstone (Miocene, Gazhanedere Formation) (Canakkale Municipality Report, 213). An example lithology map at a depth of 5 m is shown in Figure 4. The data showed that first 15 meters of the subsoil consisted of mainly clean sands, sands and silty sands, with intrusions of plastic silts and clays. From a liquefaction susceptibility view, artificial fills, top soils, clean sands, sands and silty sands should be investigated further. Plastic silts and clays are less susceptible to liquefaction and Miocene-Pliocene claystone and limestones and Miocene sandstone are not liquefiable units. Based on the soil lithology, it can be concluded that a large portion of the area consists of liquefiable soils to a considerable depth, as deep as 20 or 25 m.

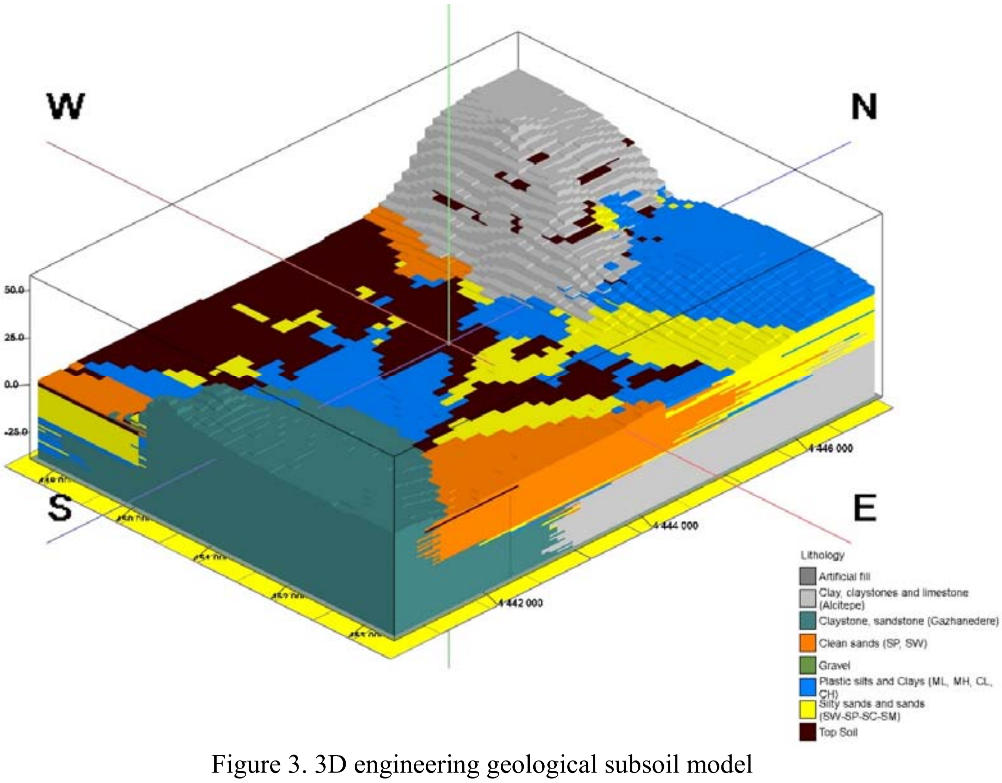


Figure 3. 3D engineering geological subsoil model

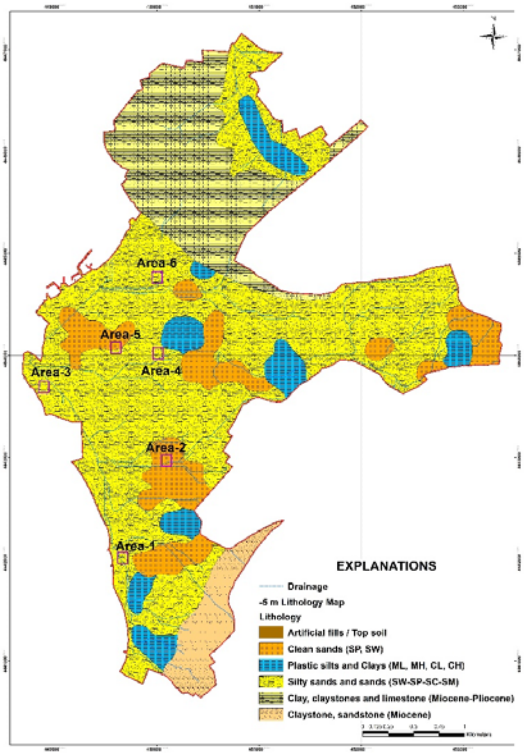


Figure 4. Lithology map of the test site at a depth of -5 m

Based on the evaluation of the present data, a complementary field study was planned and performed in selected six areas which are shown in Figure 4. These six study areas were chosen so that they were representative of different soil profiles in the test site. The complementary test study aimed to provide rigorous and reliable data for the liquefaction analyses, which would be carried in further stages of the project. Table 1 tabulates the extent of the field and laboratory tests carried out within the context of complementary field studies.

Table 1. Complementary tests carried out in the areas

Area	**Tests**
1, 2, 3	SPT, DMT, SCPT, downhole seismic, PS-logging, seismic refraction, 2D-ReMi, MASW, microtremor, H/V Nakamura prospecting, 2D resistivity, resonance acoustic profiling (RAP)
4, 6	SPT, CPTu, MASW, resonance acoustic profiling (RAP)
5	SPT, SCPT, MASW, resonance acoustic profiling (RAP)
City center	2D resistivity (for deep investigation of bedrock and aquifer characteristics)
All areas	Laboratory tests; sieve analysis, hydrometer, consistency limits, resonant column test (RCT), torsional shear test (TST), dynamic simple shear (DSS) tests

The main frame of the study was as follows; the depth of investigation was selected as 25-30 m, since the consequences of soil liquefaction are particularly detrimental when the liquefiable layers are located in the upper 15 to 20 m from the ground surface. For lithostratigraphic reconstruction to obtain a well-constrained subsoil model, borehole logs are required, therefore carefully controlled boreholes were opened in these six locations. SPT tests with energy measurements were carried out. CPT tests were performed to define the subsoil continuously and the results were compared with the observations obtained from the boreholes. Marchetti Dilatometer, DMT tests were carried out for additional ground characterization. Non-invasive and invasive geophysical tests were applied to assess the heterogeneity of soil formations. These tests included SCPT, downhole seismic, PS-logging, seismic refraction, 2D-ReMi, MASW, microtremor (H/V Nakamura), 2D resistivity and resonance acoustic profiling (RAP). The RAP, which is new developing technique (still not validated) was used for obtaining the groundwater (mostly aquifer) and bedrock level and the results were compared with the conventional techniques. Shear wave velocities were obtained by different techniques and the results were compared. Laboratory tests were carried out to determine the grain size distribution, Atterberg Limits and moisture content of potentially liquefiable layers. Dynamic soil testing was carried out including resonant column tests, torsional shear tests and cyclic direct simple shear tests. Scope of these tests was to measure the low-strain and large-strain dynamic properties of soils. As well known, undisturbed samples from the sandy soils can only be achieved through very expensive techniques such as soil freezing and more recently gel-push sampling. It was not possible to get undisturbed samples from sandy soils in our study. However careful reconstitution of the samples were carried out in the laboratory and Resonant column test (RCT), torsional shear test (TST), and cyclic direct simple shear (DSS) tests were carried out within the context of complementary testing. The dynamic laboratory tests also showed that the liquefaction susceptibility of the clean sands and silty sands were high, however, results obtained in laboratory testing are not presented in this paper due to space limitations. At the final stage of the field and laboratory studies, a comprehensive evaluation of the data was made and will be presented here.

4. COMPLEMENTARY TESTS CARRIED OUT IN STUDY AREA 2

In this section, the results of the complementary tests carried out in Study Area 2 will be presented and evaluations will be made. Similar evaluations were also carried out for other study areas. In study area 2, seismic (refraction, MASW, ReMi profiles), 2D-Resistivity profile, microtremor measurements, downhole seismic measurement, RAP and PS logging measurements were performed. Locations of field testing and sketch of geophysical measurements carried out in the area are given at Figure 5. Data obtained from borehole (BH-A-2), SCPT, DMT and geophysical tests are also presented in this section.

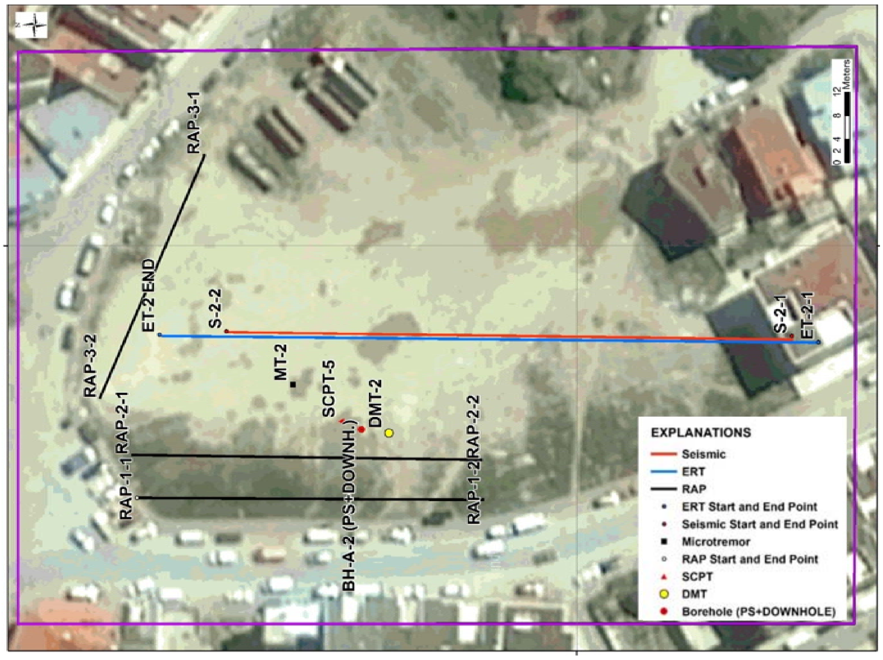


Figure 5. General view of study area 2

Table 2 presents the soil profile based on SPT and SCPT tests in study area 2. Field tests which were carried out to a depth of 25 m showed that the soil profile consisted of sands, silty sands and clays. Shear wave velocities measured by SCPT as seen in Figure 6 revealed that the velocities were about 200 m/s to a depth of 20 m. The results of the DMT test is presented in Figure 7. The results of geophysical tests are presented in Figure 8 and 9. In this area, seismic refraction, 2D-ReMi and MASW measurements were taken in the same line. The results of V_p model and tomography including X-T graph are shown in Figure 8 and Figure 9. V_s velocity section is given in Figure 10.

Table 2. Soil profile based on borehole, SPT and SCPT tests in study area 2

BH-A-2	N1,60
0.0 - 2.0 SANDY FILL	11
2.0 - 5.0 SANDS	11
5.5 - 12.0 SILTY SANDS	13
12.0 - 19.0 SILTY SANDS	13
19.0 - 22.3 CLAYS- SILTS-SANDS	13
22.3 - 25.5 CLAYS	6

SCPT - A-2	qc (MPa)	Dr (%)	Su (kPa)
0.0 - 3.0 FILL	-	-	-
3.0 - 7.0 SANDS	8	70	-
7.0 - 12.0 SANDS	5	55	-
12.0 - 19.0 SILTS, SILTY SANDS	2	-	100

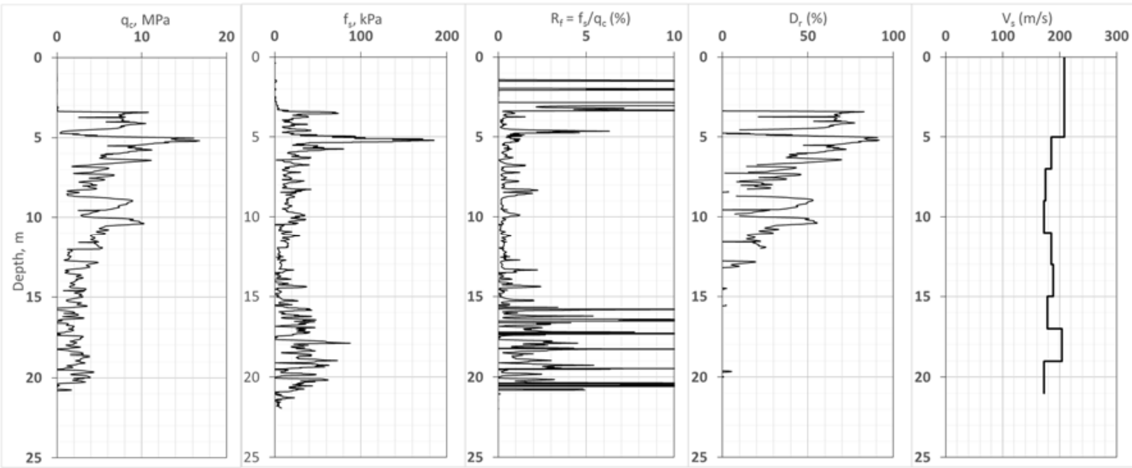


Figure 6. SCPT test results at study area 2

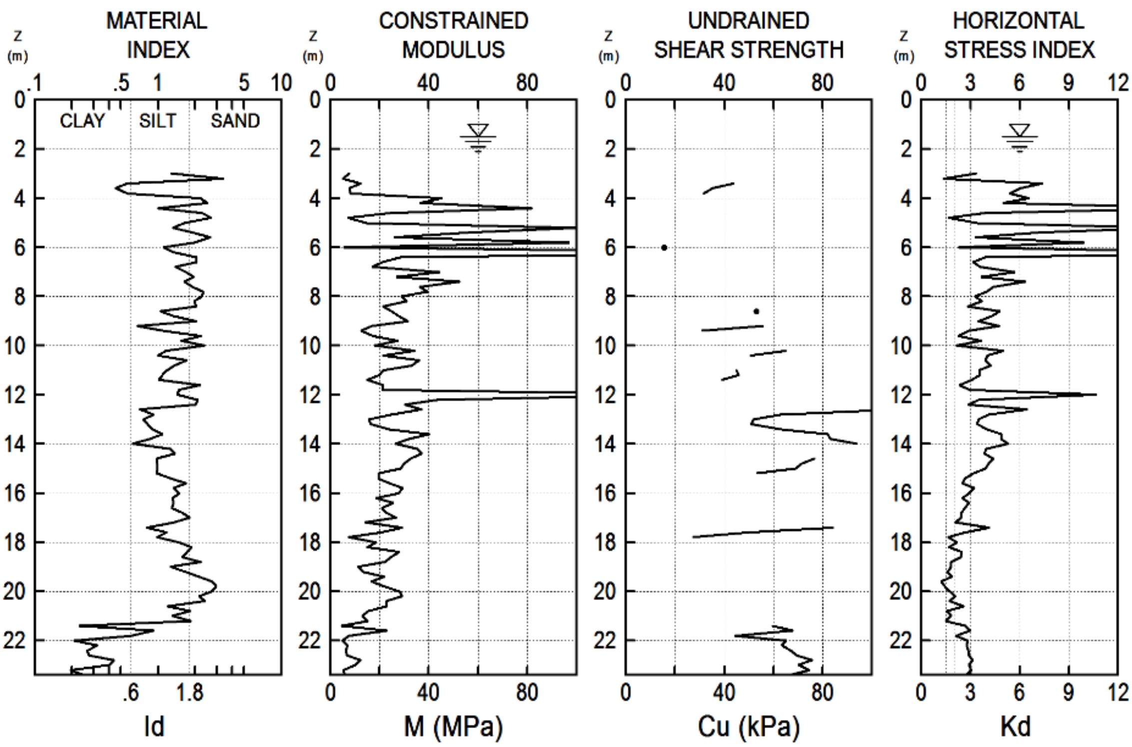


Figure 7. DMT test results at study area 2

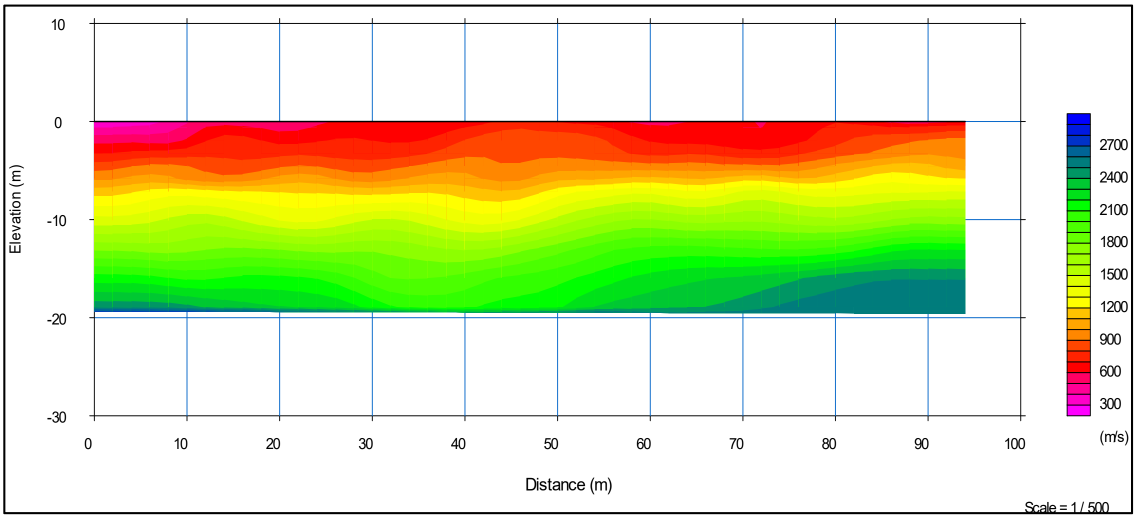


Figure 8. Seismic-2 (Study area 2) V_p Tomography X-T Graph and V_p Tomography Result

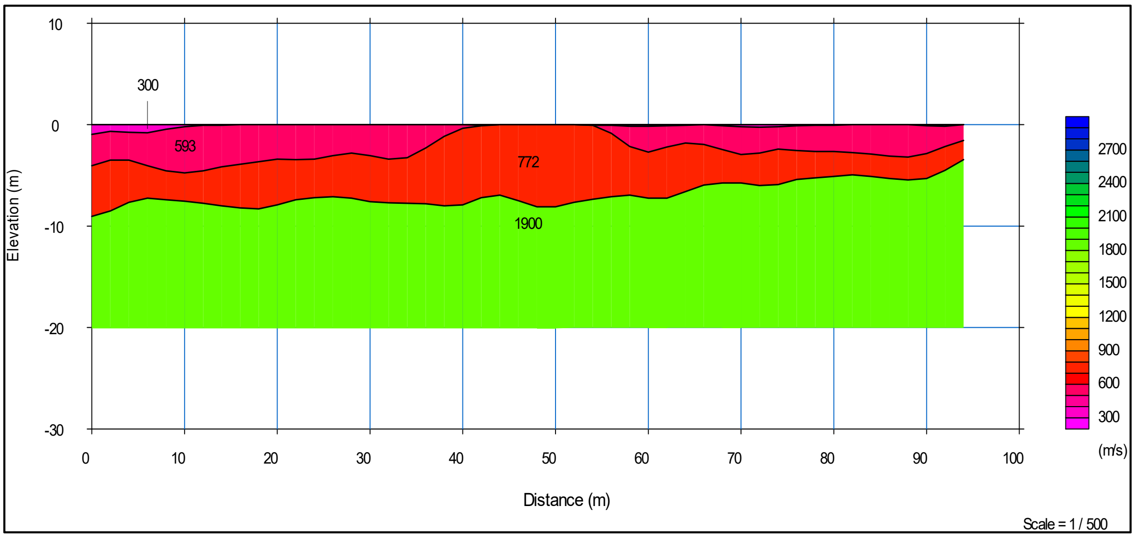


Figure 9. Seismic 2 (Area 2) V_p Model X-T Graph and V_p Model Result

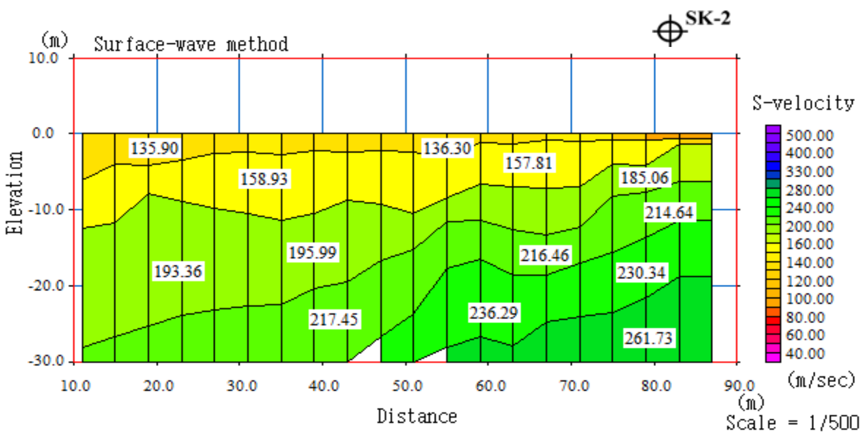


Figure 10. Seismic 2 (Study area 2) V_s Section

2D-Resistivity measurements consisted of 112 electrodes with 1 meters electrode spacing. Dipole-Dipole, Wenner and Schlumberger electrode configurations were used in 2D-Resistivity study. 2D-Resistivity results are presented in Figure 11. The field testing also included a downhole seismic test which was performed in the borehole to a depth of 20 meters in the borehole. PS logging measurement was also performed down to 21.5 meters of depth in the borehole. These results were evaluated together with shear wave measurements in the following section.

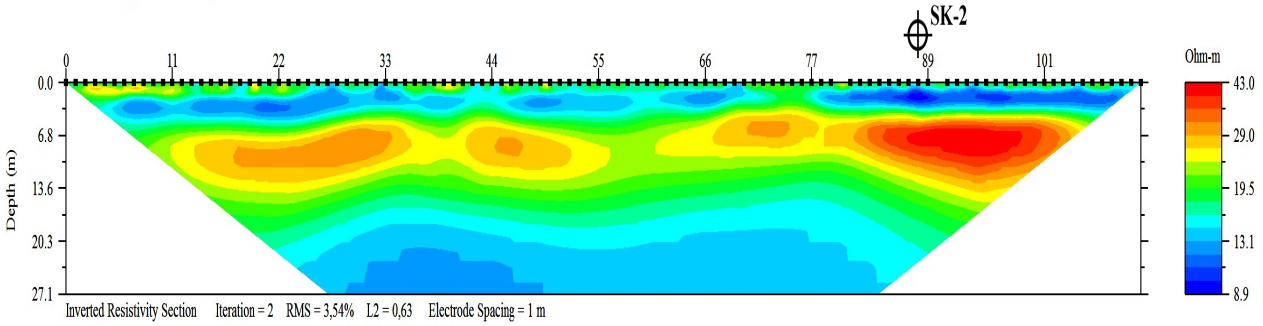


Figure 11. ET-2 (Study area 2) 2D-Resistivity Result (Dipole-Dipole+Wenner+Schlumberger)

Method of Resonance Acoustic Profiling (RAP) refers to a category of geophysical methods for studying and using the information for the natural physical fields, namely-own acoustic vibrations of the earth strata Zuykov (2001). The frequency range of the studied acoustic signals-from fractions to tens of thousands of Hertz, which can be attributed RAP method to geoacoustics section. The data from RAP (Resonance Acoustic Profile) carried out in this area is given below in Figure 12.

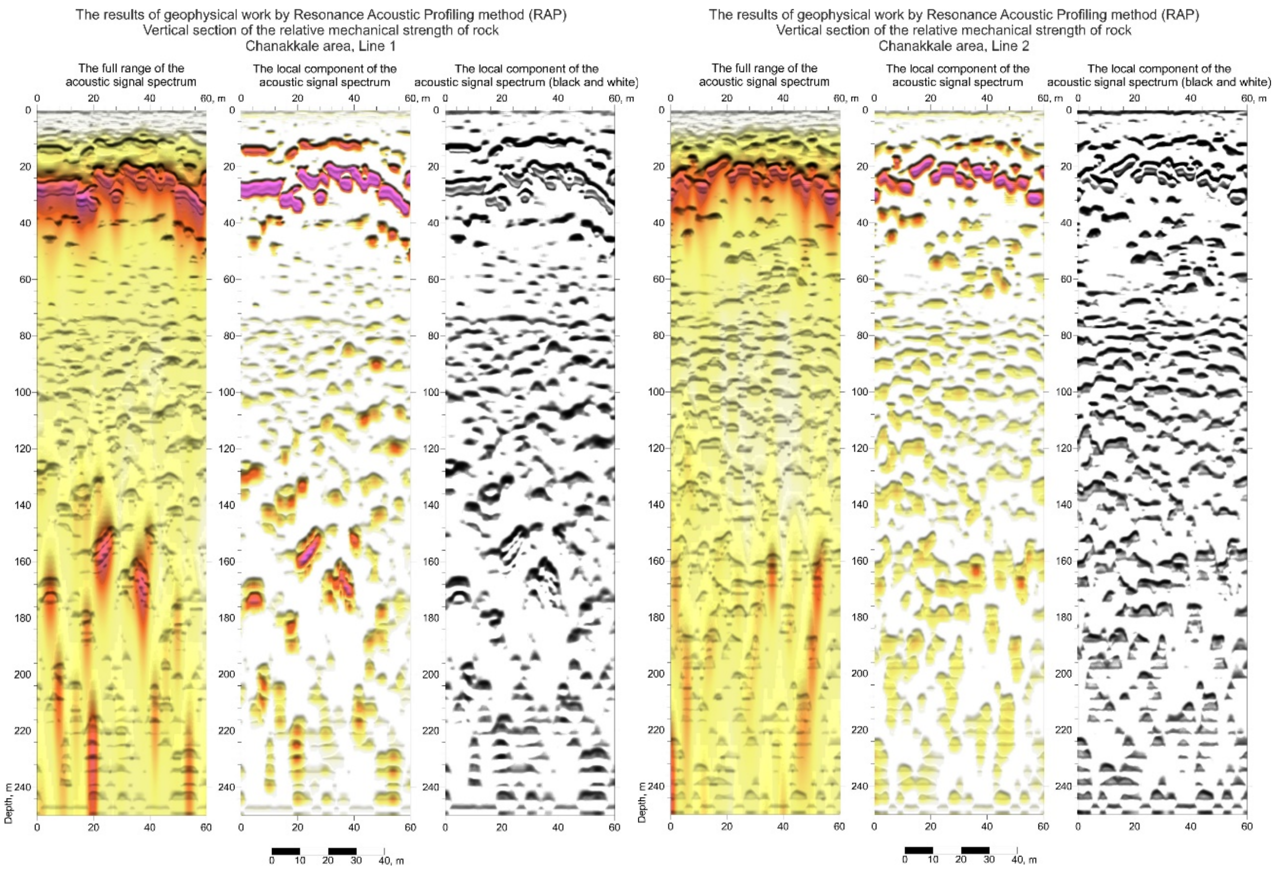


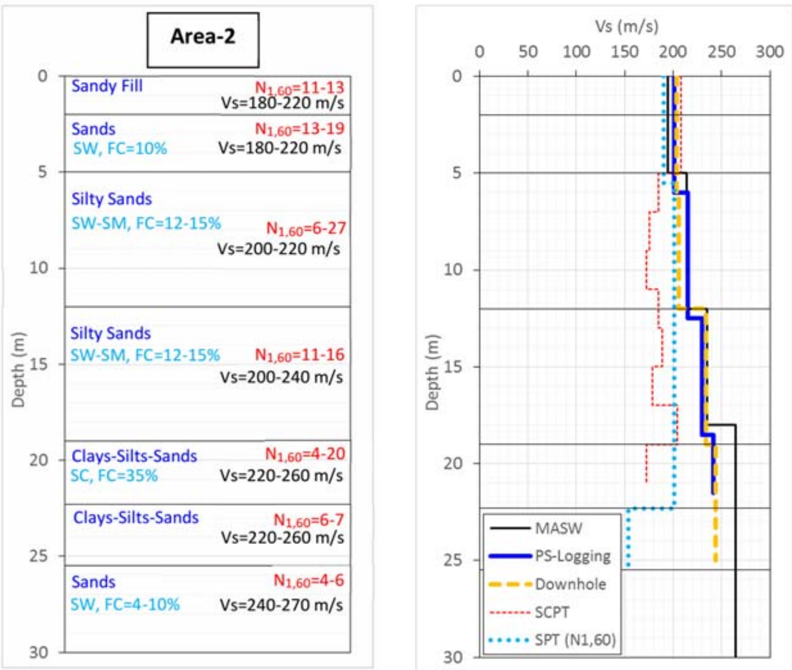
Figure 12. RAP profiles in study area 2

5. GEOTECHNICAL CHARACTERIZATION IN STUDY AREA 2

Information obtained in the complementary studies were summarized for study area 2 as in Figure 13. Figure 13a shows the general soil profile in the area. In the first 30 m, the corrected SPT values ($N_{1,60}$) are low ranging from 2 and 27. Shear wave velocities are between 150 m/s to 270 m/s. Soil types are sands, silty sands, clays, silty clays, fills and sand-silt-clay mixtures. Fine contents values range from 4% to 35 % and therefore low fine contents are dominating in the area. Soil classes in the test site including study area 2 can be listed as SP-SM, SP, SM, ML, SW, SW-SM, SC. It should be recalled that these soil classes are highly liquefiable. Figure 13b compares the shear wave velocities measured by; MASW, PS-Logging, Downhole, SCPT and shear wave velocities calculated based on $N_{1,60}$ values. In this context, Equation 1 given by Ohta and Goto (1978) for Quaternary Alluvial deposits was used.

$$V_s=82.1x(N_{1,60})^{0.35} \tag{1}$$

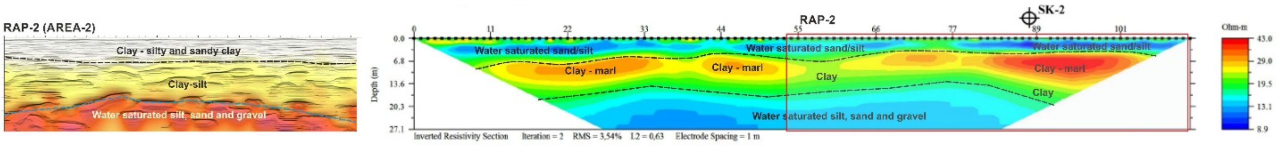
Figure 13b shows the shear wave velocities measured in the area. In the first 10-15 meters, the shear wave velocities were about 200 m/s. There were increases in shear wave velocities with depth, however in all cases, shear wave velocity values were lower than about 300 m/s. In terms of liquefaction consideration, all the sites were susceptible to liquefaction based on shear wave velocities. Figure 13b also compares the shear wave velocities measured with different methods. Shear wave velocities measured by geophysical tests (PS-logging, downhole, MASW) were consistent with each other and those calculated by SPT values were found to be generally consistent with those measured from geophysical tests (PS-logging, downhole, MASW). Therefore based on the results of this study, the validity of Ohta and Goto (1978) equation for Quaternary Alluvial deposits has been proven. However, shear wave velocities measured by SCPT did not give similar values with geophysical methods. This was valid for majority of the readings.



(a) (b)

Figure 13. Summary of the information obtained in the complementary studies a) Soil profile and measured field and laboratory values b) Comparison of shear wave velocities

The results also showed that RAP technique which has been implemented as a developing one surprisingly fit the outputs obtained with resistivity and deep boreholes to define the bedrock level. This is shown in Figure 14. Resistivity and RAP both indicated that there was groundwater in the sand and gravel layers which underlie the clayey layers (at about 20-25 m depth) which caused artesian pressures. There were hints about this artesian pressure during borehole opening and SPT and CPT tests.



(a) (b)

Figure 14. Comparison of cross sections obtained with a) RAP technique and b) field tests including resistivity

At the last stage of the study, soil profiles were redrawn for the Canakkale test site using the data obtained in the complementary investigation campaign. Figure 15 shows a typical cross section including study area 2. This figure shows that Canakkale test site was found to consist of a subsoil profile, majority of which is dominated by silty sands and sands. There are also layers and spots of clean sands. The whole area was characterized by low SPT numbers and low shear wave velocities. Fine percent of the soils encountered varied in the profile, but were low in general. At about 20 m depths, plastic silts and clays were encountered in most of the boreholes. A gravel layer lied beneath this layer.

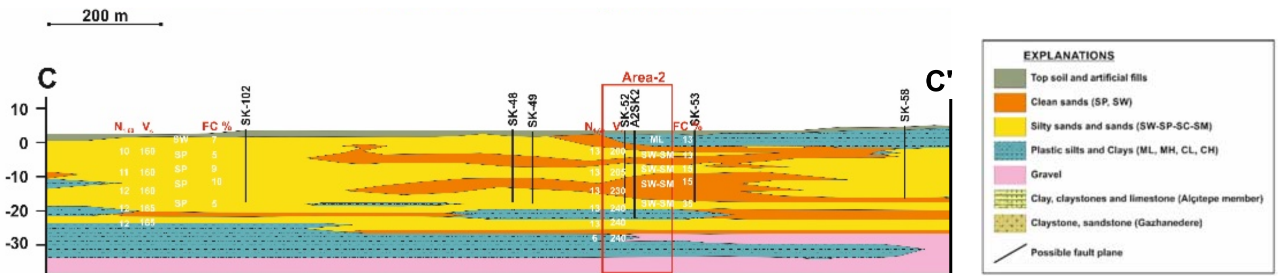


Figure 15. A cross section in Canakkale test site

6. CONCLUSIONS

This paper presents the results of a ground characterization study carried within the context of a Horizon 2020 Project, “Liquefact”. Istanbul University team has the responsibility to carry out a site investigation in Marmara Region, so that further liquefaction analyses could then be carried out. In this context, the test site was chosen as Canakkale city center. The city center is prone to high earthquake risk in the future and the city center is founded on mostly saturated loose granular material and therefore is a liquefaction prone area. Further investigation in this region will have important outcomes which will help in securing human life and prevent economical losses in the area in case of an earthquake.

An evaluation of the pre-existing data and the detailed complementary testing revealed that Canakkale test site consists of a subsoil profile, majority of which is dominated by silty sands and sands. There are also layers and spots of clean sands. Soil classes can be listed as SP-SM, SP, SM, ML, SW, SW-SM, SC. The dynamic laboratory tests also showed that the liquefaction susceptibility of the clean sands and silty sands were high. Based on all these solid and reliable information taken from the study areas in Canakkale test site, it was clear that the study areas are highly susceptible to liquefaction. The profiles which has been determined by boreholes, CPTs, and DMT’s were verified by the geophysical methods. The RAP technique which has been implemented as a developing one gave promising results. Shear wave velocities measured with different methods were compared and evaluations were made. The results obtained in Canakkale test site will then be used in further stages of the project, using both conventional and novel techniques.

ACKNOWLEDGEMENTS

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