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Measurement of Ground Deformation Induced by Liquefaction and Faulting in the Earthquake Area of the 1999 Kocaeli Earthquake

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ABSTRACT

This study was undertaken as the quantitative measurement of permanent ground deformation and associated strain fields induced by liquefaction and faulting resulted from the 1999 Kocaeli earthquake in Turkey. The permanent ground deformation was measured through aerial photogrammetry technique around the Sapanca Lake and the southern shore of Izmit Bay. For the purpose, aerial photographs taken before and after the quake were compared and the differences between these were interpreted as the liquefaction and /or faulting induced displacements.

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INTRODUCTION

Liquefaction of ground below ground water table is caused by the excess pore pressure due to shaking resulting from earthquakes or blasting. As a result the ground temporarily loses their strength and bearing capacity and it behaves as a viscous liquid rather than a solid. The actions in the soil, which cause liquefaction, are primarily shear waves. Liquefaction occurs in saturated soils, that is, soils in which the spaces between individual particles are completely filled with water [1]. The faults breaks appearing on the ground also produce ground deformation Damages and three dimensional displacements on the ground and structure which are caused by liquefaction and faulting after an earthquake can be determined by using photogrammetry and remote sensing data and methods.

Turkey is one of the most seismically active countries in the world and most of her damaging earthquakes are of inland-type. These earthquakes mostly result in permanent ground deformation as a consequence of faulting and liquefaction. Although the effect of faulting on the permanent ground deformation is known, the effect of liquefaction, which is called lateral spreading, became to be known after the 1964 Niigata earthquake. Liquefaction phenomenon was observed in almost all earthquakes occurred in Turkey when the reports of the past earthquakes are carefully examined. Nevertheless, it did not receive any attention until the recent March 13, 1992 Erzincan earthquake [2]. Furthermore, earthquakes having magnitude greater than 6 often results in surface ruptures due to earthquake faulting. Therefore, the ground deformation induced in large Turkish earthquakes represents almost the extreme conditions and it deserves a careful evaluation of ground deformation induced by both ground liquefaction and surface fault breaks.

The 1999 Kocaeli earthquake (also named by Eastern Marmara Earthquake) produced a fault break of more than 150km long and caused extensive ground liquefaction (Figure 1) [3]. The effect of liquefaction was quite extensive at Adapazarı and Sapanca Lake (Figure 2). A collaborative research project to measure permanent ground deformation due to liquefaction and faulting was initiated by Waseda University (Japan) and General Command of Mapping (Turkey) in 2001. Adapazarı, Sapanca Lake vicinity and south coast of Izmit Bay are the areas of interest in the project.

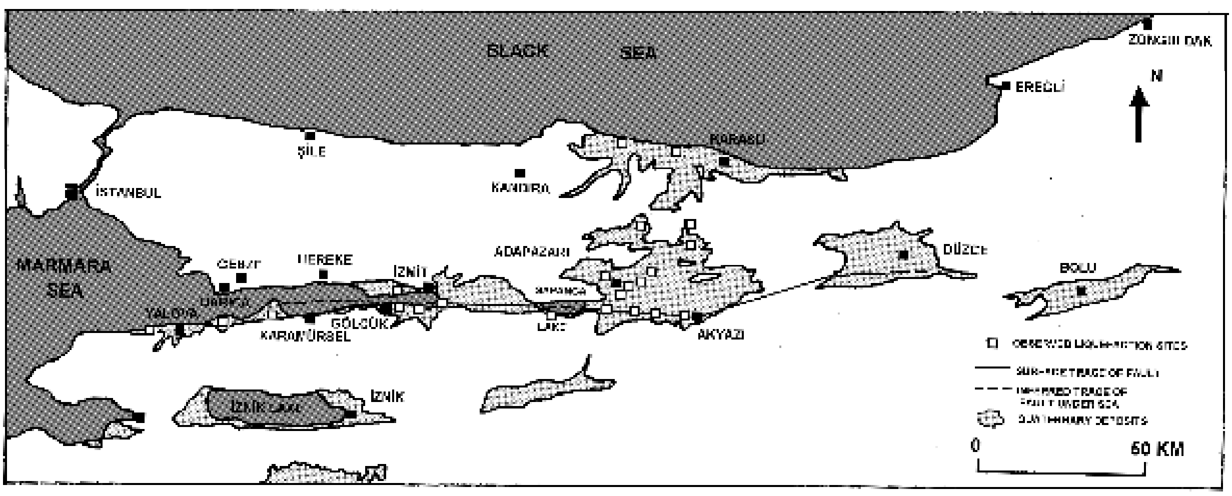

Figure 1. Liquefaction locations observed during Kocaeli earthquake of Aug. 17,1999

Figure 2: Examples of liquefaction in Adapazarı

The permanent ground deformations were measured through the aerial photogrammetry technique at several sites within the quake region as mentioned above. The three-dimensional coordinates of the common points on pre-post earthquake photographs were determined, and the differences between them are interpreted as the liquefaction and faulting induced displacements.

MEASUREMENTS AROUND THE SAPANCA LAKE

Geodetic surveying activities were carried out and aerial photographs were taken in 1:16.000 scale covering the areas Avcilar, Yalova, Izmit, Adapazari by General Command of Mapping on September 8th, 1999 after the Marmara earthquake.

While it is ideal to use aerial photographs pertaining to pre- and post-situation of earthquake in large scales (such as 1:5.000, 1:10.000) for determination of liquefaction, 1:35.000 scale aerial photographs taken in 1994 were to be used instead, as those of 1:16.000 scale taken in 1970 have no triangulation points. Although it seems a disadvantage to use small scale photographs, temporal resolution that is closest dates for the pre- and post-situation aerial photographs is especially preferred in the areas like Marmara region which have dense structuring.

Digital aerial triangulation measurements and block adjustments were implemented using scanned aerial photographs in 21 μm. Final products were 1:5.000 scale digital orthophoto maps, totally 860 sheets for the earthquake area. So, the exterior orientation parameters of all aerial photographs were already determined. 1:35.000 scale aerial photographs were also processed by means of analytical photogrammetric measurements for the revision of 1:25.000 scale topographic maps. That is why adjusted coordinates of tie points are available. Root mean square error of 6-8 μm. is normally acceptable for topographic mapping in GCM.

As many and well-distributed common points as possible have been selected on the aerial photographs for coordinate measurements. These points are on the features where artificial displacements are minimum, such as junction of roads, bridges and buildings.

Cartesian coordinates at 302 points have been measured in the photogrammetric models including north-coast of Sapanca Lake (Esme). Movement vectors have been calculated by means of coordinate differences of the common points. These vectors show a displacement implies with faulting in the east and southeast direction.

423 points have also been measured at the west corner of Sapanca Lake model. Obtained vectors do not show a unique direction. There is a similar movement with that of Esme in the north of the model, while sparse movement in the south of model because of varying soil structure and locating fault.

418 points have been measured in the area of Sapanca Otel. Displacement vectors have direction mainly to north, upward the Lake because of the liquefaction (Figure 3).

Results about the Sapanca Lake measurements can be seen in Table I.

TABLE I. SAPANCA LAKE AREA MEASUREMENTS AND RESULTS

SAPANCA LAKE AREA		<RESULTANT VECTOR (POST-PRE)(1999-1994)>			
AREA NAME	POINT NUMBER	DE (m)	DN (m)	DL (m)	DV (m)
SAPANCA OTEL	(418 points)				
Mean		0.410	0.835	1.460	-1.714
Detailed Measurement	(219 points)				
Mean_Detailed		0.467	1.207	1.778	-2.041
SAPANCA ESME	(305 points)				
Mean		2.351	-0.428	2.660	0.617
Detailed Measurement	(122 points)				
Mean_Detailed		2.575	0.193	2.849	0.762
SAPANCA LEFT SIDE	(423 points)				
Mean		0.608	0.291	3.036	0.602
Detailed Measurement	(50 points)				
Mean_Detailed		1.304	0.764	2.245	0.131
Detailed Measurement = Detailed Measurements at Coastline Area					

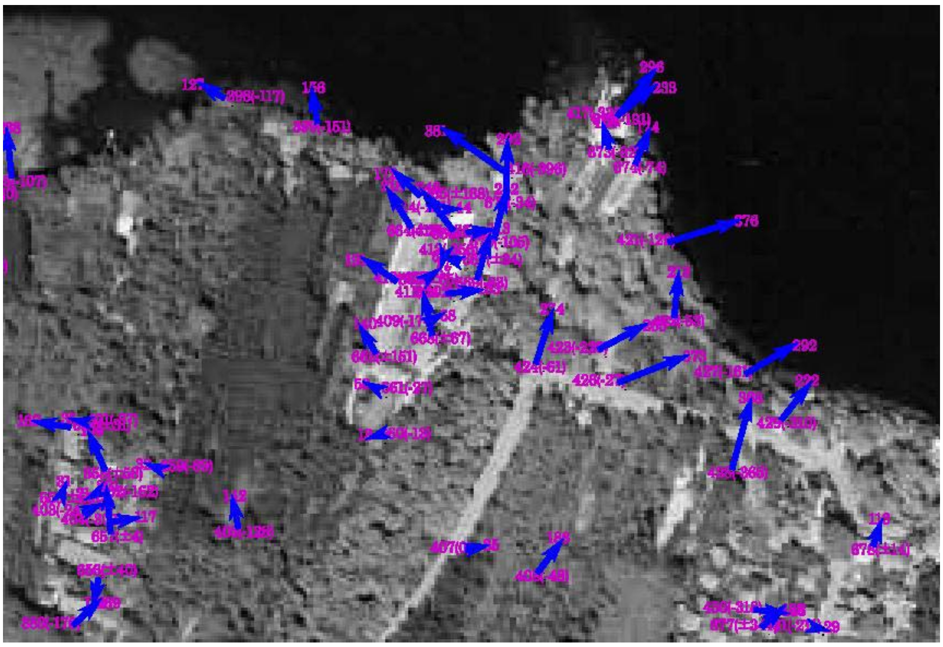

Figure 3. Displacement vectors around the Sapanca Hotel

Some other measurements were also implemented in eight different areas on the coastline of Izmit Bay (Figure 4) in addition to Sapanca Lake. Obtained results can be seen in Table II.

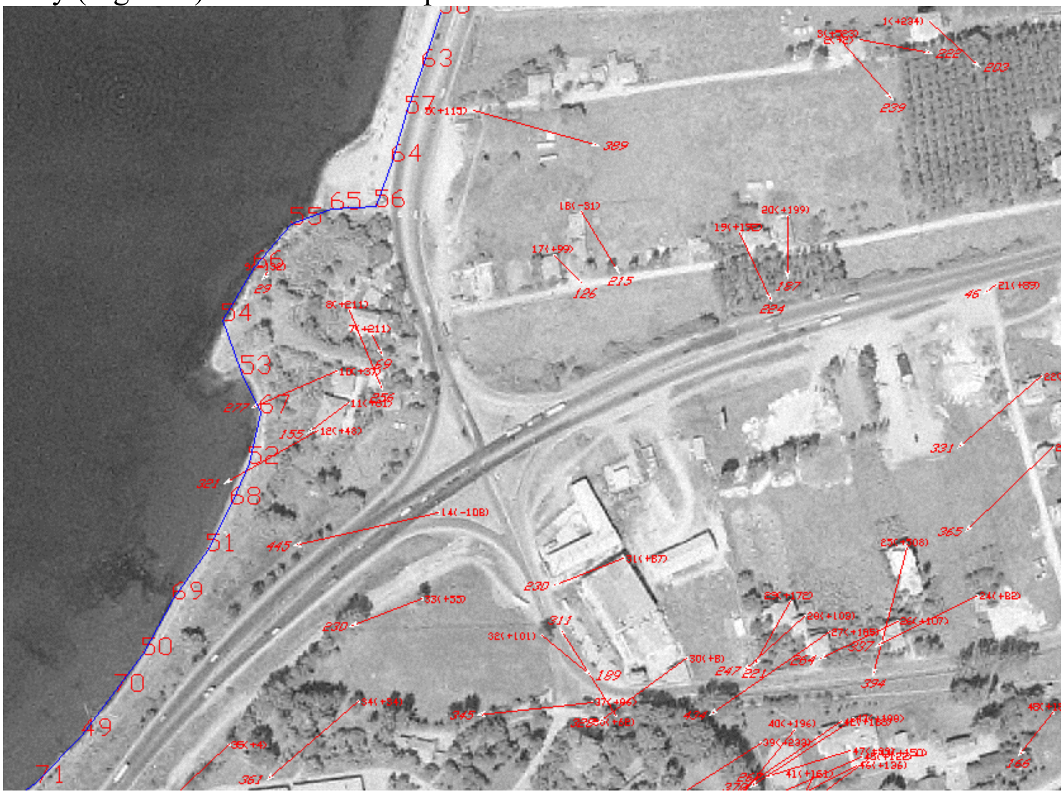

Figure 4. Displacement vectors at Basiskele

TABLE II. IZMIT BAY AREA MEASUREMENTS AND RESULTS

IZMIT BAY AREA		<RESULTANT VECTOR (POST-PRE)(1999-1994)>			
AREA NAME	**POINT NUMBER**	**DE (m)**	**DN (m)**	**DL (m)**	**DV (m)**
BASISKELE	(48 points)				
Mean		-1.389	-1.482	2.766	1.021
SEGMEN	(117 points)				
Mean		-1.064	-1.146	2.317	-0.132
GOLCUK	(92 points)				
Mean		-1.580	-1.259	2.440	-2.481
DEGIRMENDERE	(132 points)				
Mean		-1.354	-1.215	2.445	-0.602
HALIDERE	(66 points)				
Mean		-1.278	0.385	2.058	-1.454
ULASLI	(71 points)				
Mean		-0.438	-0.354	1.399	-0.680
HERSEK	(145 points)				
Mean		-2.069	-1.112	2.881	-1.505
YALOVA	(301 points)				
Mean		1.637	0.709	2.155	1.037

CONCLUSION

Earthquake dated 17th August 1999 has revealed that reliable and rapid information about the effects and affected areas is one of the vital issues. Photogrammetry and remote sensing methods and means provide rapid and reliable information sources. On the other hand, scientific activities on earthquake research can be classified based on geodesy-geology, photogrammetry-remote sensing and geographic information systems. Of these, geodesy and geology deals with plate motion and soil mechanics. GIS based methods provide information for rescue, determination of damaged structures, and rebuilding.

Photogrammetry and remote sensing based methods, in which aerial photographs, satellite images, SAR laser profiling data are used, provide wide opportunities for determination of ground displacement depending on resolution and measuring accuracy.

Aerial photographs can be used especially both in detailed analysis studies of the limited comprehensive earthquake effect areas and as a reliable data source for the reconstruction applications by means of orthophoto maps produced in the wide comprehensive effected areas.

On the other side, the laser scanners provide reliable information for the mentioned goals especially in the more limited effect areas more quickly than aerial photographs do. The laser scanners, which are not available in Turkey as for today and require a high cost for establishment, are the systems, of which developments have to be followed closely.

In earthquakes that affect very wide areas like Marmara earthquake, the landsat satellite images are used as a suitable data source abroad, though recently in Turkey. The components, which affect reliability and accuracy, are;

- The images that will be used for determination of changes have to be taken in a limited time range and in the same part of the year, and
- These sensor images have to collect data with the same view angle and resolution.

Based on the aerial photogrammetric evaluations conducted for five sub-areas along the southern coast of the Sapanca Lake, displacement vectors determined confirm the site observations, which were done at liquefaction areas. It is also noted that towards the south part of Sapanca town, where liquefaction has not been observed, some displacement vectors were also determined. These vectors indicate some displacement contributing to the main deformations due to liquefaction induced lateral spreading along the coast of the lake. On the contrary to these, displacement vectors at the northern part of Sapanca Lake, particularly at the north of Esme town, are parallel to the fault, which caused the earthquake. At this part of the site no liquefaction has occurred, and therefore, it can be concluded that the permanent ground deformation is higly associated with the movement of the fault. This part of the study is considered to be valuable for further geotechnical assessments which will be carried out at the second phase by the geotechnical group.

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