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Geotechnical Aspect of Damage In Adapazari City During the 1999 Kocaeli, Turkey, Earthquake

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ABSTRACT

This report summerizes detailed investigation on the structural damage and its geotechnical condition in the Adapazaý City, Turkey, during the 1999 Kocaeli earthquake by the reconnaissance team of the Japanese Geotechnical Society. Damages to individual buildings were investigated along several streets in the downtown area. A little rough investigation was made almost all downtown area, in which damages were classified by its cause, i.e., inertia force or soil liquefaction. These investigations as well as hearing investigation and areal investigation by means of helicopters made clear the area where there was an island a few hundred years ago by which the name of Adapazarý, i.e., ada (island) + pazarý(market), came from. In addition, the damage in the AdapazarýCity is shown to be strongly affected by the ground condition because damage caused by liquefaciton was observed only outside the old island and areas where significant structural damage was observed were concentrated near the boundary between the old riverbed and island.

INTRODUCTION

The Kocaeli earthquake of August 17, 1999 brought significant damage in the Izmit Bay area, Turkey, and its vicinity. Damage in Adapazarý City was one of the most severe ones; many houses and buildings were collapsed, settled or tiled. We visited this city as the first reconnaissance team from the Japanese Geotechnical Society (JGS). The damage to buildings seems interesting from the point of view of the earthquake geotechnical engineering because two areas; area whose damage is caused by inertial force and area whose damage is caused by soil liquefaction. We, therefore, made a detailed investigation in this city especially focusing on the damage to buildings and occurrence of liquefaction. The complete report of this investigation is published from JGS (2000) as a part of the reconnaissance report by two reconnaissance teams from JGS, which is summarizes in this paper.

Fig. 1. Areal views of Sakarya River

GEOLOGICAL CONDITION

The name of Adapazarýcomes "from two words, i.e. "ada" and "pazarý'. The former means island and the latter market. According to the hearing investigation, the town was an island about 150 years ago, and there were markets in the island, as indicated in the name of the city; boat was used for the transportation between the island and nearby areas. Area covered by water has been filled by the flood that has occurred nearly every two years by the Sakarya river (Fig. 1) that runs east of the city at present and flows into the Black sea. About one-third or a quarter of the city area remained as marsh about 50 years ago. At present, almost all the area are developed to be flat area and marsh is seldom seen. As indicated in this history, surface soil of the city is very young Holicene soil developed for recent 200 years. The water table is generally high to be about 1 to 3 meters and it may come near the ground surface in summer.

Beside the filled area, the geology is generally Pleistocene material as shown in Fig. 2. The thickness of the surface deposit is estimated to be about 200 m in the downtown area (Onalp, 1999). Surrounding the city area, there are high lands where baserock outcrops. An acceleration record was obtained on one of such bedrock in the south of the city. The peak acceleration in the EW direction is 407cm/s^2. After the

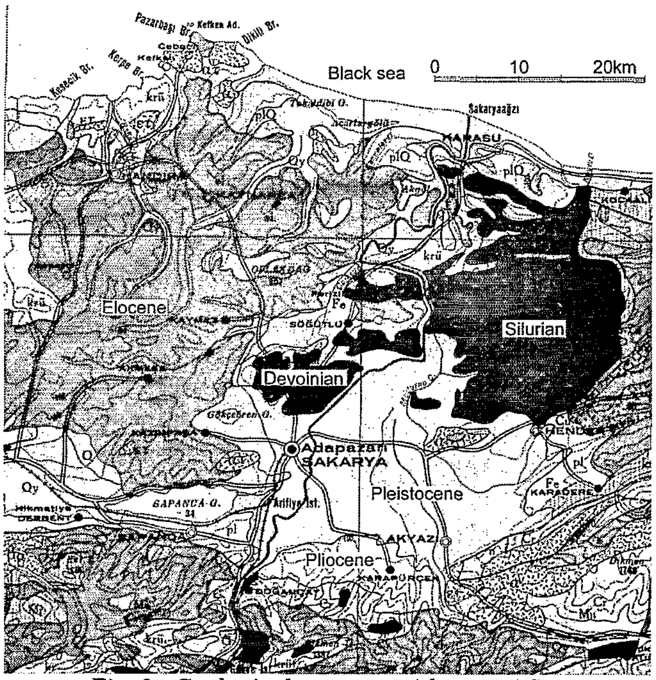


Fig. 2. Geological map near AdapazarýCity

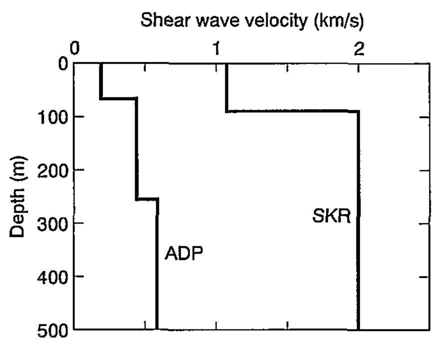


Fig. 3. S-wave velocity identified from microtremor measurement

earthquake, Kudo et al. (1999) conducted microtremour measurement in order to obtain the shear wave velocity structure at the strong motion observation site as well as a downtown site. The result is shown in Fig. 3. There is a discontinuity of the shear wave velocity at bout 250 m deep at the downtown site, which may be consistent with the hearing investigation. They, however, pointed that the shear wave velocity at the downtown is quite different with that at the strong motion observation site even at very deep depth; shear wave velocity at the ground surface of the strong motoin observation site is larger than 1km/s whereas that in very deep point is still about 500 m/s at the downtone site. This indicates that evaluation of the ground shaking in the downtown area from the earthquake record is difficult because there is no common base layer.

Figure 4 shows the map in the downtown of the AdapazarýCity, in which various informations obtained by the reconnaissance are overdrawn. The dark gray shading indicates the liquefied area, which will be discussed later. Several borehole data are obtained out of this area, some of which is shown in Fig. 5. The I-5 point is located west of the map along the Cark Cadesi in

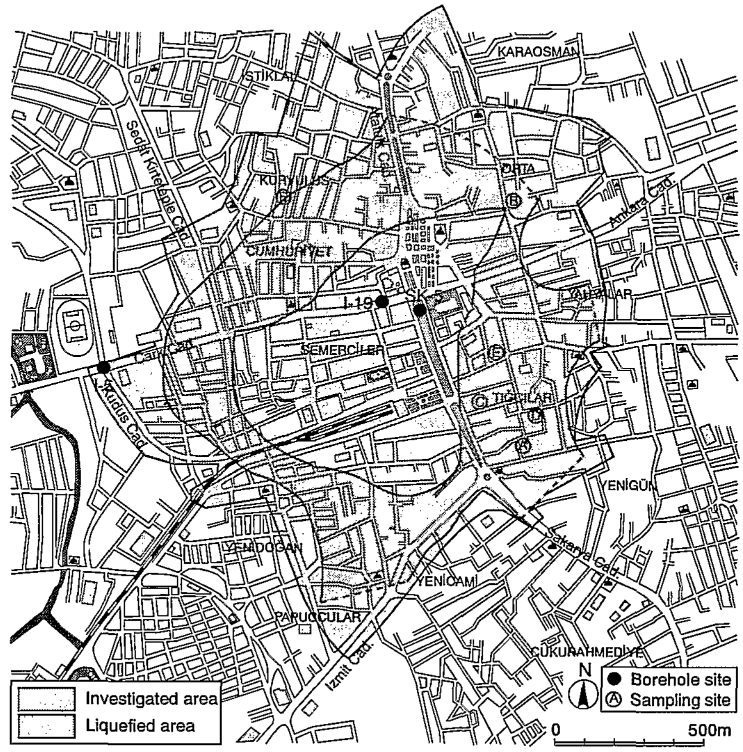


Fig. 4. Map of Downtown Adapazarý. Investigated area, site of borehole investigation, sand sampling, and liquefied area are shown

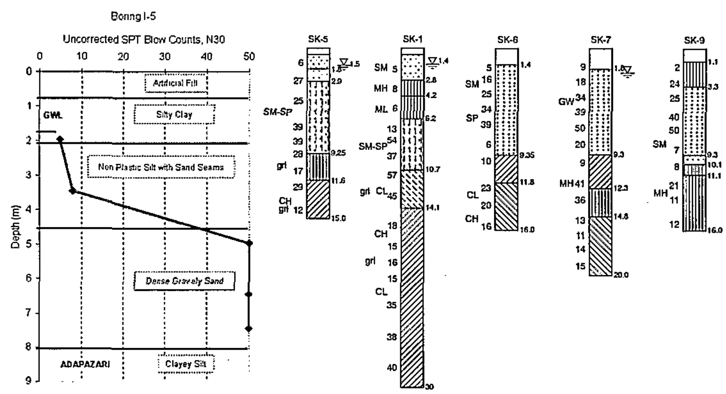


Fig. 5. Drilling log

Fig. 4 (Erken, 1999). Water table is about 1.8 m below the ground surface. There exist fill with 1 m thickness and silty clay layer with 1 m thickness. Non-plastic silt with 2 m thick that includes lens shaped sand exists beneath them. Then there exists dense gravely sand with more than 50 SPT-*N* value. The right hand drilling logs in Fig. 5 are obtained close to the station (the name SK-5 is used to indicate the location in Fig. 4) (Onalp, 1999). Although they are located close by, the data fairly scatters. The surface layers are made of silt and sand, but SPT-*N* values are considerably large, which may be the reason why liquefaction did not occur at this site.

Since data in the liquefied area was not obtained, sand samples were taken at the liquefied area. Fig. 6 shows grain size distribution of the samples. Sites where samples were taken are shown in Fig. 4 as notation A to F with circle. Among these samples, A to E are samples taken from sand boils, therefore

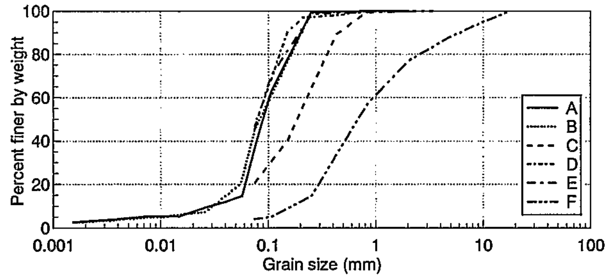


Fig. 6. Percent finer by weight

liquefied material. The sample at point F is excavated sand at the water supply construction site, therefore may not be related to liquefaction. Grain size distributions are nearly identical in the liquefied site except B. The average grain size D_{50} is fairly small to be a little less than 0.1mm; the sand is classified to be fine sand close to silt. The grain sizes are concentrated around D_{50}, therefore it is easy to liquefy. The D_{50} at B is about 0.2 mm which is about two times larger than the other sand, but it is also easily liquefiable sand.

RESULT OF INVESTIGATION

Three types of investigation as well as hearing investigation were made in order to grasp the relationship between the damage to buildings and geotechnical condition. The first one is areal investigation by means of helicopters, which gives general information of the damage in the city. The second one is rough investigation in order to grasp the general feature of the damage. The third investigation is detailed investigation to all buildings along the street.

Rough investigation: general feature of damage

The rough investigation was conducted in wide area including the downtown area of the city, which is shown in Fig. 4 as light gray shading. Many of the buildings in this area are RC building with 3 to 6 stories. Their foundations are generally spread foundation penetrated 0.5 to 1.2 m deep into the ground. There are residential houses with 1 to 2 stories in this area, too.

There are a few exceptions from the typical structural type according to the hearing investigation. The PTT building that is located near SK-5 site in Fig. 4 has pile foundation with 80 cm diameter and 25 m long. A 2-storied parking lot also has pile foundation (location is not known). The Agricultural Bank building that is located south of PTT building has a basement floor and is penetrated about 4.5 m. These structures were survived from the earthquake.

Looking at the damages in the investigated area, damage can be classified into two types. The first one is totally or partially collapsed building because of the failure of the column as typically shown in Fig. 7. These damages are supposed to be caused by inertia effect of the earthquake shaking, therefore will be referred to be an inertia type damage hereafter. Another type is tilt and/or settlement of the building as typically shown in Fig. 8. Soil liquefaction may be the predominant reason of this kind of damage, which will be referred as a liquefaction type damage hereafter. It is also noted that there are many

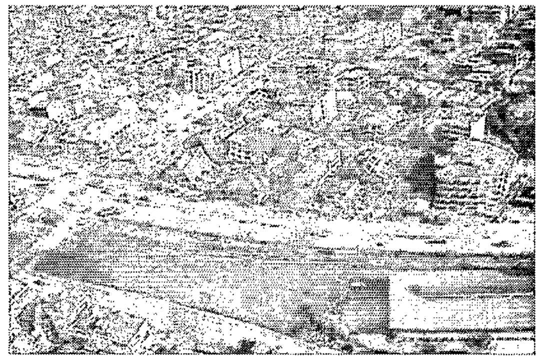


Fig. 7. Damage to buildings by inertial force.

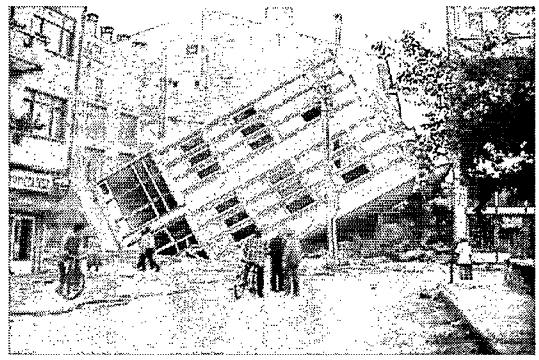


Fig. 8. Damage caused by soil liquefaction.

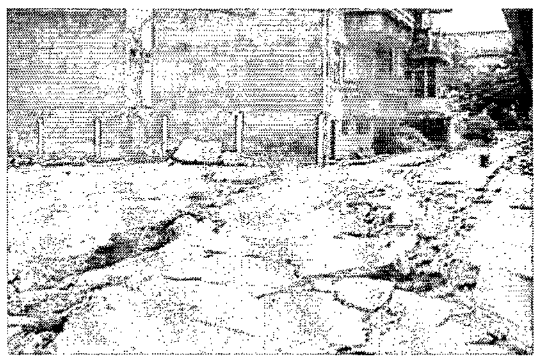


Fig. 9. Damage caused by large ground fissure

buildings that did not or hardly damaged as shown later.

There are clear differences between the areas where inertia type and liquefaction type damages are observed. In the area where inertia type damage is predominant, tilted or settled building without structural damage was hardly seen. On the other hand, there is little inertia type damage in the area of liquefaction type

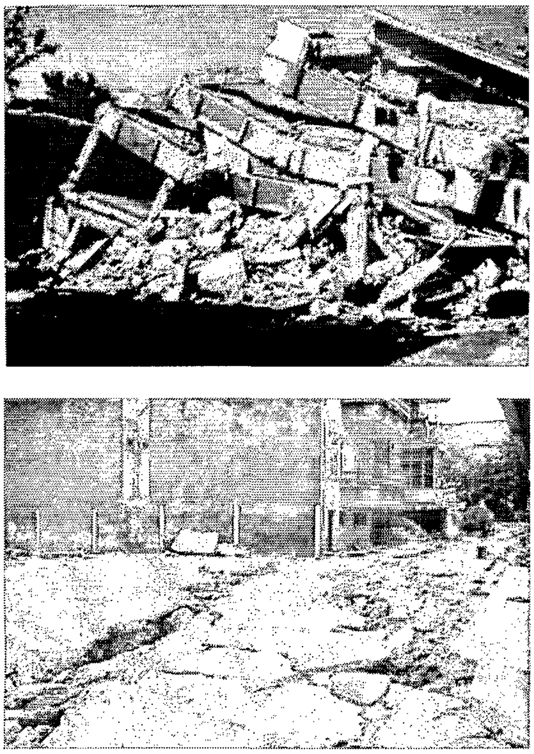


Fig. 10. Typical inertia type damage. Pancake crash (top) and soft first story collapse (bottom).
damage.

A typical feature in the liquefied area is that clear proof of the occurrence of liquefaction such as sand boil was not frequently observed. We, however, supposed that liquefaction type damage was caused by soil liquefaction. The reason why sand boils is not much will be discussed by another paper in the same Workshop. According to the detailed and rough investigation of the city area, the area with liquefaction type damage is found to exist surrounding the downtown. The area is shown in Fig. 4 as dark gray shaded area. Inside this area is a non-liquefied area, which is supposed to be the old island from which the name of the Adapazarýcame.

Liquefaction type damage was especially severe in the north of Cark Cadesi and east of Sakarya Cadesi. Wide cracks runs crossing the road damaging buildings on it as shown in Fig. 9 in the north of Cark Cadesi. A building tilted for more than 60 degrees as shown in Fig. 8. It is noted that tilt of this building was about 30 degrees on the day next to the earthquake and increases to present state taking for about 10 days. Settlement of the buildings was very large near this building. Sewage pipelines were going to replace in the Izmit Cadesi at the time of our visit, which indicates that ground deformation was significant in this area. These areas were supposed to be the old riverbed of the Sakarya River.

Inertia type damage was frequently observed in the non-liquefied area. Fig. 10 as well as Fig. 7 shows typical damage of the inertia type damage. This types of damage was especially severe along the road running to the EW direction

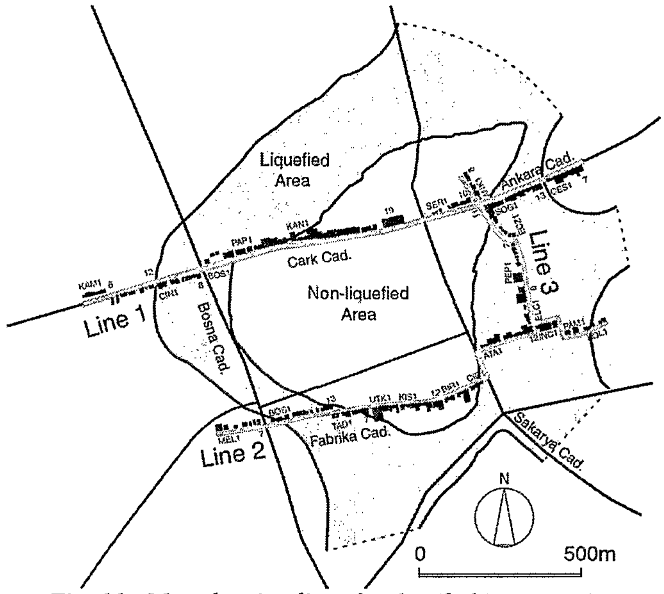


Fig. 11. Map showing lines for detailed investigation

such as Cark, Fabrica and Izmit Cadesi. These areas can also be said to be located adjacent to the liquefied area. Irregular ground configuration between liquefied and non-liquefied sites may be the reason of the localization of severe inertia type damage.

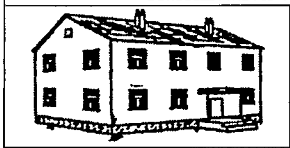
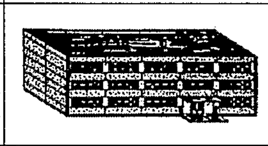
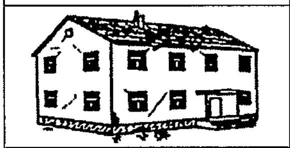
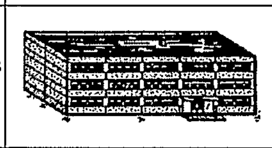
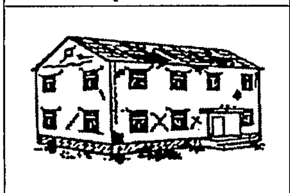
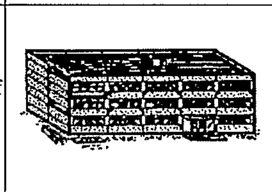
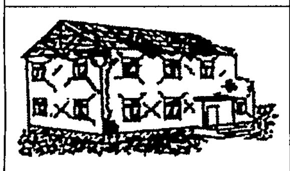
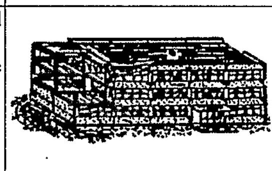
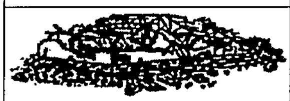
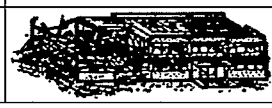
<u>Detailed investigation: characteristics of damage to buildings</u>

Investigation of all buildings was conducted along three lines shown in Fig. 11. Structural dimensions such as size of plan and number of stories, settlement, tilt and damage level were measured and evaluated. 192 building were investigated in total. Elevations of investigated buildings are schematically drawn in Fig. 11. Since one side of the road was generally investigated, the buildings are drawn on the side where original building exists.

Classification of damage to buildings was based on the European Macro-seismic Scale (EMS98) following to the investigation by reconnaissance team from Architectural Institute of Japan (AIJ, 1999) who conducted detailed survey in Gölcük City nearly the same time. Damage is classified into five levels for masonry structures and RC structures. Level 1 is negligible to slight damage, level 2 is moderate damage, level 3 is substantial to heavy damage, level 4: very heavy damage, and level 5 is destruction. Fig. 12 shows the schematic figures showing the classification.

Figure 13 shows the result of damage investigation along three lines; damage level, maximum settlement and angles of tilt in the EW and NS directions are shown in terms of the distance from west or south end of each line.

No severe damage was found in the west end of Line 1 (Cark Cad.) for about 200 m. Damage suddenly becomes significant near Bosna Cad. where many 3 to 5 storied buildings were significantly damaged. There is strong contrast of damage

Classification of damage to masonry buildings		Classification of damage to buildings with reinforced concrete	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of building in very few cases.		**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Fine cracks in plaster over frame members or in walls a the base
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.		**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partition, gable walls		**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Cracks in columns and beam column joints or frames at the base and at joints of coupled walls. Spalling of concrete cover buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.		**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction (very heavy structural damage)** Total or near total collapse.		**Grade 5: Destruction (very heavy structural damage)** Collapse of ground floor or parts (e.g. wings) of buildings.

(a) Masonry buildings (b) Reinforced concrete

Fig. 12. Classification of damage to buildings

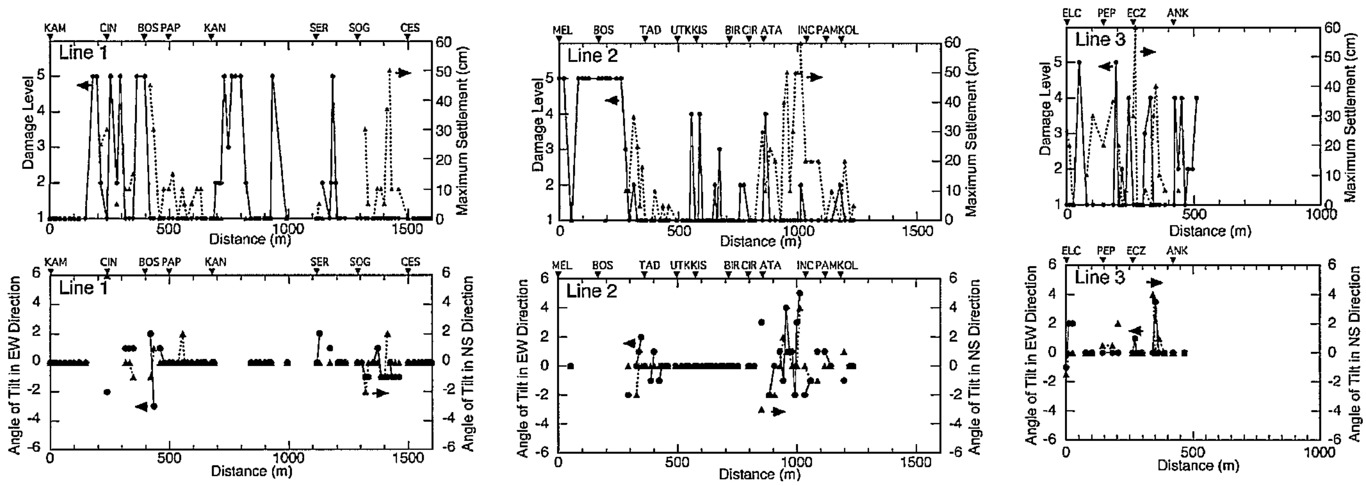


Fig. 13. Result of detailed damage investigation

between both side of road from Bosna Cad. to KAN1 point. Buildings in the north of the road are severe liquefaction type damage, whereas buildings in the south of the road are severe inertia type damage as shown in Fig. 14. Structural damage was hardly observed from KAN1 to Line 3 crossing the Sakarya Cad. Buildings again suffered damage in the east of Line 3. The damage is liquefaction type damage without any structural damage. Structural damage was not observed in the east end of Line 1.

Damage from the west end to Bosna Cad. along the Line 2 (Fabrika Cad.) was one of the severe one. Almost all buildings except one timber house were collapsed by first story failure or complete failure as can be seen in Fig. 7, where Fabrika Cad. runs horizontally, and 15, and is classified to be damage level 5. Damage, then, becomes moderate and liquefaction type damage comes to be seen; this area is classified as liquefied area. Small damages were observed from the east of the liquefied area to Sakarya Cad. Liquefaction type damage suddenly appears east of Sakarya Cad. Buildings with 4 to 6 stories were settled for10 cm to 1 m. Center of the road and ground between two buildings was heaved up and ground cracks were frequently observed. Examples of damage in this area are shown in Figs. 8 and 16.

South of Line 3 belongs to liquefied area. Buildings settled 5 - 35 cm and tilted 0 - 2 degrees except two buildings whose upper structures were damaged. In other words, damage to structural members was hardly observed for the tilted or settled buildings. Liquefaction type damage was not observed in the north of Ankara Cad., but damage to structural members was sometimes observed.

DISCUSSION

Figure 17 shows the relationship between the damage level and number of stories. Numbers beside each solid circle is a sum total of data that belongs to each dot, and numbers on the top and in the right of the figure are sum total of each classification. Here, number of stories of zero indicates that it is not known because it completely collapsed. In total, 14 buildings are included in this classification. It is, however, sure that number of stories of these building is not small such as 1 or 2; they are probably 4 or more. Two features can easily be obtained from this figure. The first one is that number of buildings with middle damage level is smaller than that with small and large damage levels. It is natural that it is smaller than that with small damage, but not natural that it is smaller than that with large damage. This probably comes from the brittle structural members of the building. The building directly goes to complete failure in brittle structures when earthquake load exceeds the structural load carrying capacity. The second feature is that severely damaged structure is concentrated in 3 to 5 storied buildings.

Figure 18 shows the relationships between damage level and settlement of the buildings. Here, settlement of -10 cm indicates the buildings whose actual settlement was not observed partly because the structure is completely collapsed and partly because evaluation was difficult. Number of this classification is written in the figure. There is clear tendency of the settlement. Large amount of settlement can occur only when damage level is small. In other words, buildings that settled did not suffer severe structural damage. It is noted that some damage in damage level 2 to 4 was caused even by soil liquefaction. Tilt of buildings sometimes stops by hitting the neighboring building, in which case structural members in both building sometimes damaged. Moreover, tilt of building itself sometimes becomes the cause of the structural damage. Considering these situations, it can be concluded that building damaged by soil liquefaction did not suffer large inertia force. The separation between liquefied and non-liquefied area shown in Figs. 4 and 11 is justified by this figure.

Figure 19 shows the relationships between average tilt and average settlement versus number of stories in the liquefied area. Average settlement is about 10 cm for 2 and 3 storied buildings. It increases to 20 cm for 4 and 5 storied buildings. These values are fairly smaller than past experience such as Niigata City during the 1964 Niigata earthquake, Japan, and Dagupan City during the 1990 Luzon Earthquake, Philippines.

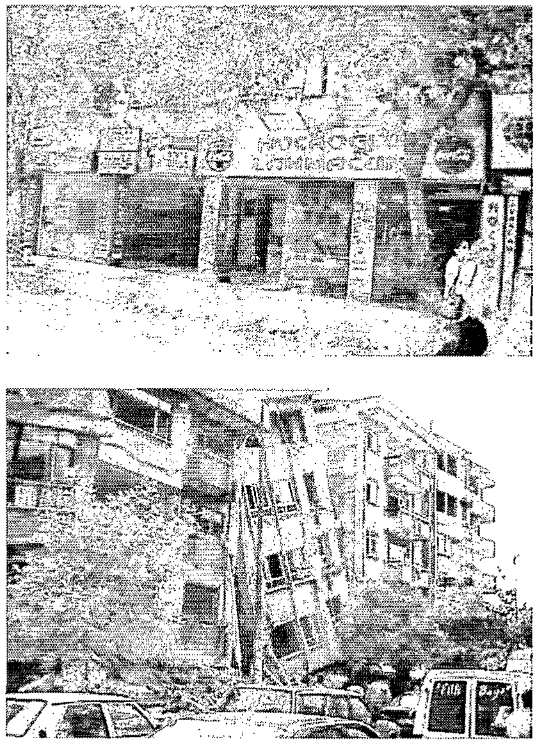


Fig. 14. Contrast of damage between the north side (top) and south side (bottom) of Cark Cadesi.

Fig. 15. Damage to building on Fabrika Cad.

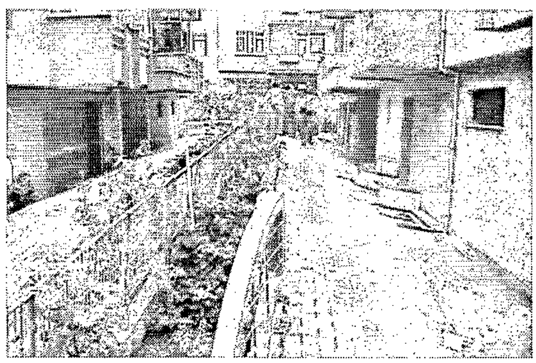


Fig. 16. Heaving between buildings

The smaller sand boils may be related to this fact. The tilt of buildings is about 1 degree regardless the number of stories and regardless the direction. Structural type such as wooden and RC does not also affect the tilt of buildings.

Figure 20 shows the relationship between foundation width and angle of tilt. Although data scatters, the tendency that tilt becomes larger as foundation width becomes smaller is clearly observed.

SUMMARY

Detailed investigations were made on the damage to buildings and geotechnical condition in the Adapazarý City. It is found that downtown area is separated into the non-liquefied area and liquefied area surrounding the non-liquefied area. Liquefied area is supposed to be old riverbed of the Sakarya River and non-liquefied area was an island from which the name of the city, Adapazarý, came from.

Severe damage to buildings caused by inertia effect is concentrated along the road running the EW direction or areas adjacent to the liquefied area, which indicates the effect of complicated geotechnical condition between liquefied and non-liquefied areas. Buildings in the liquefied area settled or tilted, but did not suffer severe structural damage causing failure of structural members. The amount of tile and settlement is affected by the number of stories and size of foundation although data sometimes scatters. They are fairly small compared with the past experience, which may be related to the fact that sand boil was seledom observed in the liquefied area.

Observed fact strongly indicates that structural damage is affected by the surface ground condition. More investigation is encouraged to conduct especially in order to find the reason why inertia type structural damage concentrated in the non-liquefied area adjacent to the liquefied area and why settlement and tilt is smaller than that in past expericences.

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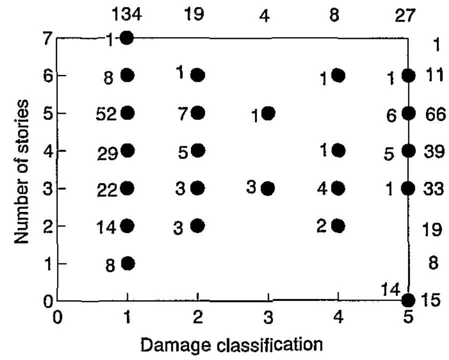

Fig. 17. Relation between number of stories and damage classification

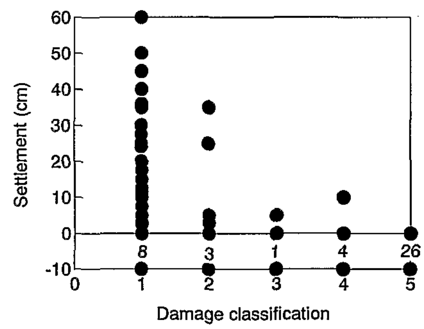

Fig. 18. Relation between settlement and damage classification.

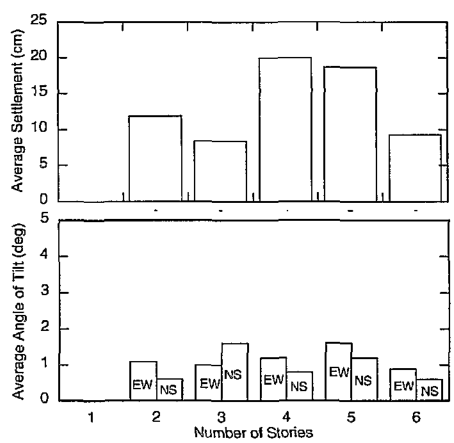

Fig. 19. Effects of number of stories on settlement and tilt of buildings in liquefied area

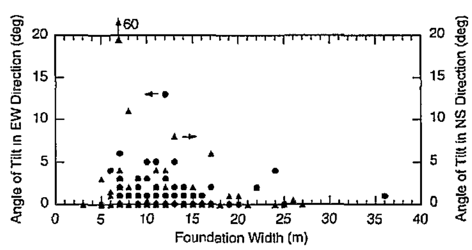

Fig. 20. Relation between angle of tilt and foundation width of buildings in liquefied area