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GEOTECHNICAL ASPECTS OF DAMAGE IN ADAPAZARI CITY DURING 1999 KOCAELI, TURKEY EARTHQUAKE

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ABSTRACT

Reported are the results of a detailed investigation of the structural damage and its geotechnical condition in the Adapazari City, Turkey, during the 1999 Kocaeli earthquake by the Japanese Geotechnical Society Reconnaissance Team. Damage to individual buildings was investigated along several streets in the downtown area. A regional investigation was made of an area larger than the downtown area, in which damage to buildings and houses was classified by cause, i.e., inertia force or ground deformation. These investigations as well as hearing investigation and aerial investigation by means of helicopters made clear the area where there was an island a few hundred years ago from which the name of Adapazari, i.e., ada (island) + pazari (market), came from. In addition, the damage in the Adapazari City is shown to be strongly affected by the ground condition because damage caused by liquefaction was observed only outside the old island and areas where significant structural damage was observed were concentrated in the nonliquefied area near the boundary between the old riverbed and island.

Key words: earthquake damage, ground deformation, Kocaeli earthquake, liquefaction (**IGC**: E8)

INTRODUCTION

The Kocaeli earthquake of August 17, 1999 brought significant damage to the Izmit Bay area, Turkey and its vicinity. Over 15,000 people were killed and about 24,000 people were injured. About 120,000 buildings and houses were irreparably damaged; among these about 5000 were very seriously damaged or completely collapsed, and about 600,000 people lost their living places.

Damage in Adapazari City was one among the most severe. The city is located about 40 km east of the epicenter and about 5 km north of the fault. Many buildings and houses collapsed, subsided or tilted. The authors visited this city about 20 days after the earthquake as the first Japanese Geotechnical Society Reconnaissance Team, and believed that damage to buildings and houses in this city was strongly related to the geotechnical conditions, because damage differed markedly according to area as described in the following. In order to confirm this impression, three different kinds of investigation were conducted in the downtown area of the city. These were rough investigation by means of aerial view from a helicopter, regional investigation to classify the damage pattern, and detailed investigation on individual building and house. Results of these investigations are summarized in this paper.

GEOLOGY AND TOPOLOGY IN ADAPAZARI CITY

The name of Adapazari came from two words, i.e. "ada" and "pazari". The former means island and the latter market. According to the hearing investigation, the town was an island about 150 years ago, and there was a market in the island as indicated by the name of the city; a boat was used for the transportation between the island and nearby areas. The area covered by water was filled by floods of the Sakarya River that occurred nearly every two years. About one-third or a quarter of the city area remained as marsh about 50 years ago. At present, almost all of the area has been developed into a flat area and marsh is seldom seen. The water table is generally high at about 1 to 3 meters and it may come near the ground surface in the rainy season.

At present, two rivers run near the city from south to north. The Sakarya River runs on the east side of the city and flows into the Black Sea (Photo. 1). The Cark River, which runs on the west side of the city, flows out from the Sapanca Lake and into the Black Sea. Because the

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Photo. 1. Aerial view of Sakarya River running east of Adapazari

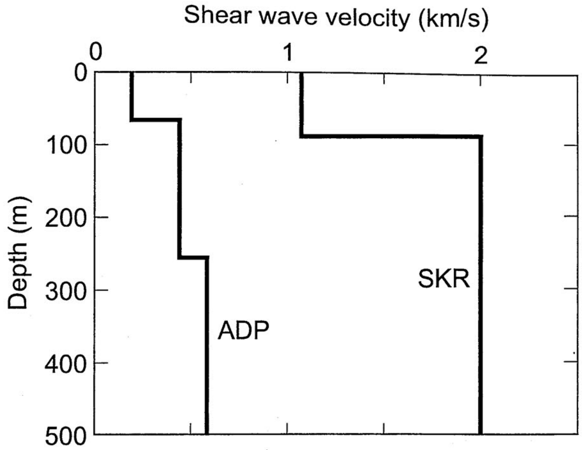


Fig. 2. Shear wave velocity identified from microtremor measurement

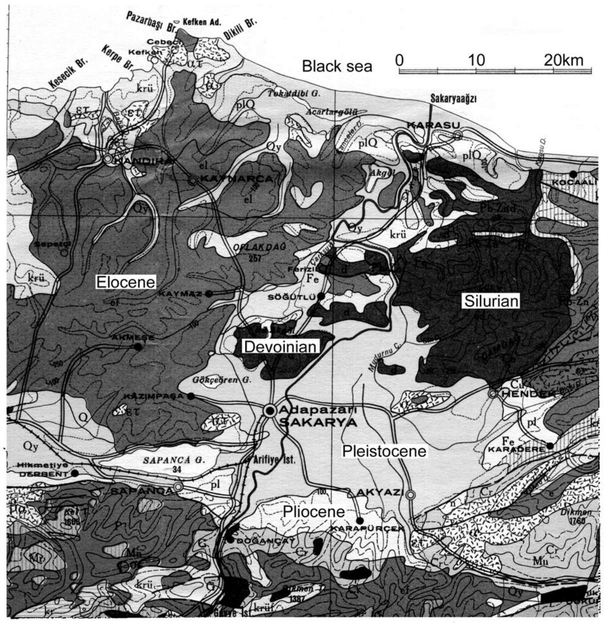


Fig. 1. Geological map near Adapazari City

Sakarya River is much wider than the Cark River, the present town area is supposed to be an alluvial plain formed by the Sakarya River.

Figure 1 shows a geological map of the city. The city is on the Sakarya Plain and is located about 50 km from the Black Sea. The elevation of the city is about 30 m. The city area is nearly a flat plane, but bedrock outcrops out of the city. Figure 2 shows shear wave velocity structures obtained from microtremor measurement (Architectural Institute of Japan Reconnaissance Team with Bogaziçi University, Istanbul Technical University, Middle East Technical, 1999). Here, site SRK is the strong motion observatory southwest of the city where rock outcrops. Site ADP is located in the significantly damaged area northeast of the city. The shear wave velocity of SKR is more than 1 km/s even at the ground surface, whereas shear wave velocity at the ground surface at ADP is about 200 m/s. Moreover, shear wave velocity even at 250 m deep is still a little larger than 500 m/s at ADP, which is much smaller than that at the ground surface of SRK. The thickness of the surface deposit is estimated to be larger than 300 m.

Figure 3 shows a map of the downtown area of Adapazari with information that will be explained later. Borehole data along the Cart Cadesi, one of the main streets in the city, is shown in Fig. 4 (Erken, 1999), which was obtained during the construction of sewage lines. The I-5 site is located in the west and site I-19 is located near the city center. The water table is about 1.8 m below the ground surface at the I-5 site. A one meter thick fill overlays a silty clay layer of 1 m thickness. Non-plastic silt with 2 m thick that includes lens shaped sand exists beneath them. Then there is a dense gravely sand whose SPT-*N* value is greater than 50. Here, the SPT test is conducted based on the ASTM standard. The water table is a little larger than 1 m at the I-19 site. Soil above GL-2 m seems to be the same as the I-5 site. There are sand layers with SPT-*N* values of 20 to 40 below it. Then, there is dense gravel layer whose SPT-*N* value is greater than 40.

Figure 5 shows borehole data at the city center (Onalp, 1999). These sites are located close to each other, and are also close to site I-19 (*see* Fig. 3 where only site SK-5 is shown among the sites from Fig. 5). Soil profiles at these sites are similar to each other, although there are small differences. The water table is about 1.5 m. There is a silty sand to gravelly sand layer up to about 10 m deep beneath the fill, whose SPT-*N* value is fairly large. A soft silty clay layer overlays it at sites SK1 and SK9. There is a clay layer beneath the sand layer whose SPT-*N* value is also large.

Damage to buildings caused by soil failure was observed over a widespread area as described later, but borehole data from these areas was not obtained. Sand samples were taken in these areas, whose grain size distribution is shown in Fig. 6. The sampled sites are shown in Fig. 3 as notation A to F with circle. Among these, A to E are taken from sand boils, and are therefore liquefied sand. On the other hand, the sample at point F is excavated sand at the water supply construction site. Grain size distributions are nearly identical in the liquefied sand

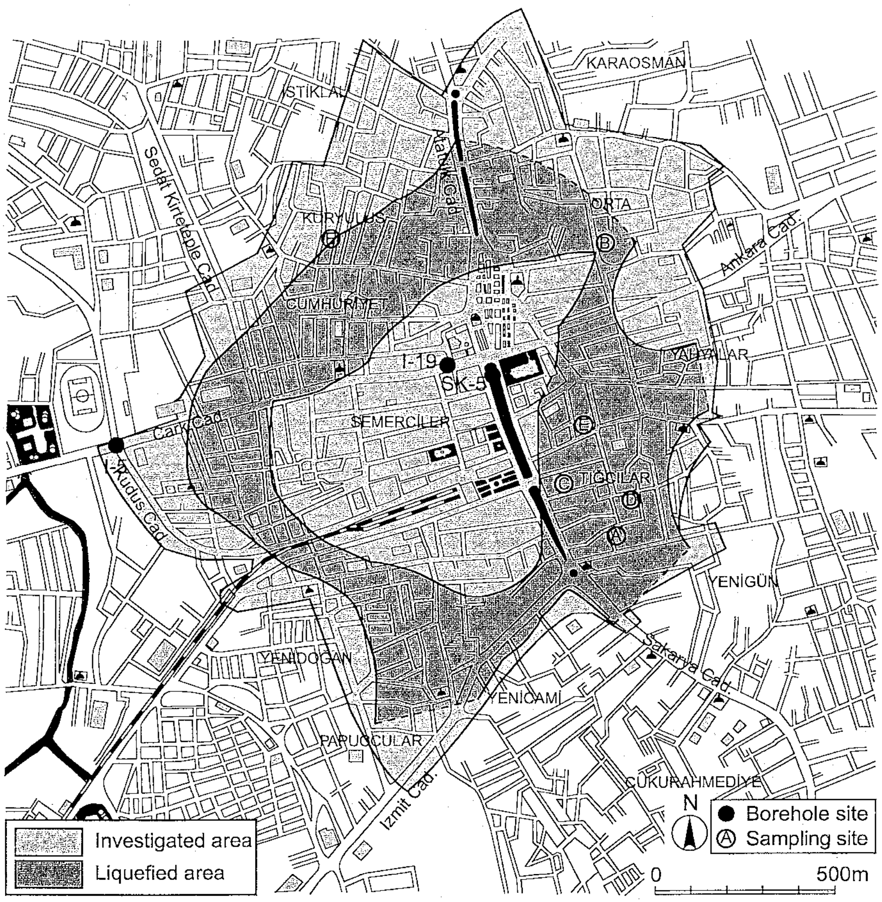


Fig. 3. Map of downtown Adapazari: Investigated area, site of borehole investigation, sand sampling, and liquefied area

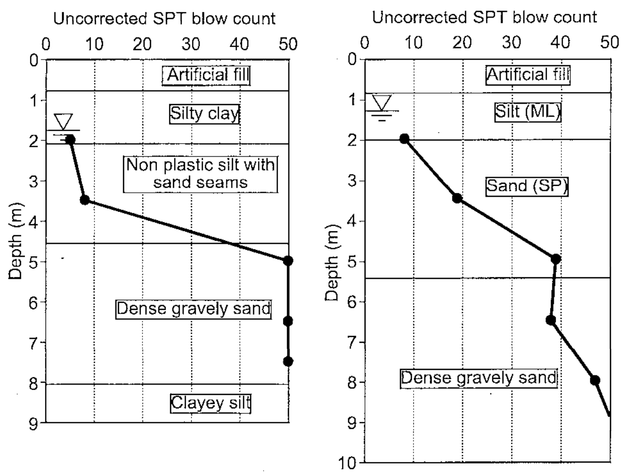


Fig. 4. Drilling log along the Cark Cadesi (Modified from Erken, 1999)

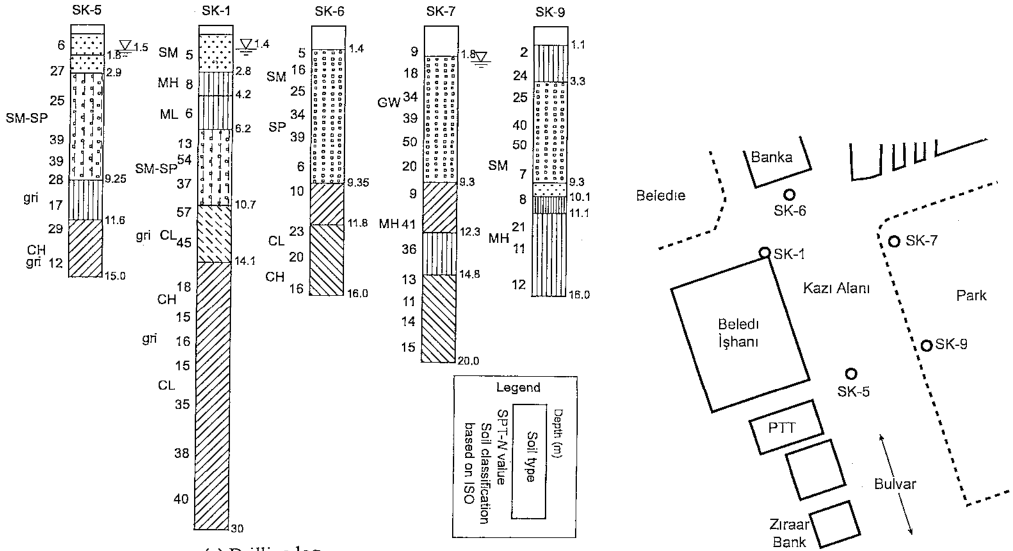
except site B. The average grain size D_{50} is small at a little less than 0.1 mm. Considering that fines may be lost during sand boiling, the sand may be classified as fine sand close to silt. The grain sizes are concentrated around D_{50}, which indicates that these sands are easy to liquefy. Average grain size D_{50} at B is about 0.2 mm, which is about twice as large as the other sand, but this is also easily liquefiable.

CHARACTERISTIC FEATURE OF DAMAGE

In order to grasp the characteristic feature of the damage to buildings and houses, a regional investigation was conducted in the area including the downtown area of the city, which is shown in Fig. 3. Locations of typical damage are shown by capital letters A to O, which will be referred to later. A detailed investigation, i.e., investigation of individual buildings, was conducted in Lines 1 to 3 in Fig. 7.

Almost all (more than 95%) of the RC buildings with 3 to 6 stories are spread foundation penetrating between 0.5 and 1.2 m under the ground. Photograph 2 shows an example of the arrangement of the reinforcing bars for the foundation beam. Two buildings are known to be a pile foundation and survived the earthquake damage. They are PTT Building (piles are 80 cm in diameter and 25 m in length; *see* Fig. 5(b) for location), and 2-story Parking Lot (locations not known). Agricultural Bank Building (shown as Ziaar Bank in Fig. 5(b)), has an underground floor, and therefore the spread foundation is about 4.5 m deep; it was not damaged. The relationship between the damage and foundation type is not known at present.

Settlement and tilt of buildings were frequently seen, as shown in Photos. 3 and 4, for example. Heaving, subsidence of the ground, and damage to pavement were ob-



(a) Drilling log (b) Location of site

Fig. 5. Drilling log north from station (Modified from Onalp, 1999)

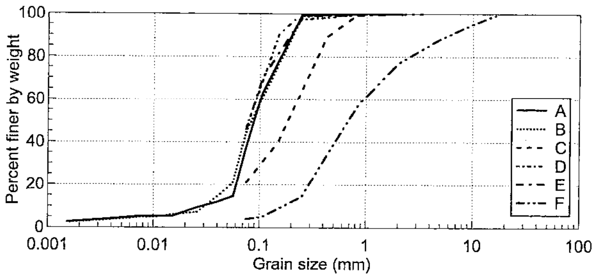


Fig. 6. Percent finer by weight: Locations of A to F are shown in Fig. 3

served around and between sunk or tilted building; examples are shown in Photos. 5, 6 (site C), 7 (site D) and 8 (site E). Thick deposited sand boils were observed between two buildings or between the crack of wall and heaved-up floor in some places; examples are shown in Photo. 9 for Site F. Sand boil was not frequently observed apart from at these and some other sites, although settlement and tilt were frequently observed. This damage seems to have been caused by soil liquefaction, but the reason why sand boil was rare is not clear, mainly because there is no borehole data. The term liquefaction will be used hereafter, however, although there is no clear evidence in the whole area.

The results of the regional investigation are shown in Fig. 3 as liquefied and nonliquefied areas, in which a liquefaction area is identified by settlement and tilt of buildings and houses. There is a nonliquefied area at the center of the map in the downtown area, and a liquefied area surrounding this area is several hundreds meters wide. Two regions are bounded by the line running northeast from the intersection between the Cark Cadesi and Bosna Cadesi in the north, and the line running north-northeast and west-northwest from the intersection between the Izmit Cadesi and Sakarya Cadesi in the east and southwest, respectively.

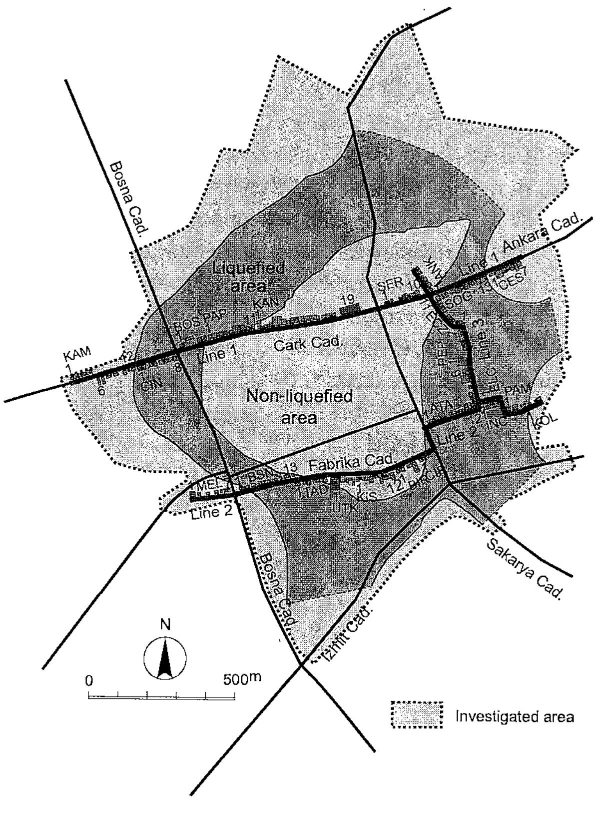


Fig. 7. Map showing lines for detailed investigation

Several fissures run from southwest to northeast to the north of the Cark Cadesi (site G in Photo. 10), and the ground spreads laterally towards the southwest. Significant ground deformation was observed to the east of the Sakarya Cadesi, at Site B (Photo. 3) and Site H (Photo. 11). Settlement of the building and damage to pavement and road were significant along the Izmit Cadesi as

Photo. 2. Bar arrangement of foundation beam at Site A

Photo. 3. Tilted building at Site B

Photo. 4. Tilted building at Site C

shown in Photo. 12 (site I). These areas are supposed to be old swamp or riverbed of the Sakarya River.

Photo. 5. Heaving caused by settlement at Site C

Photo. 6. Ground distress at Site C

Photo. 7. Ground heaving at Site D

Damage to Building in Liquefied Area

Buildings in the liquefied area may have tilted or sunk, but superstructure was seldom damaged. Buildings that tilt more than 2 degrees were frequently observed in the areas northwest of the fissures shown in Photo. 10, and east of the Sakarya Cadesi as shown in Photos. 3 to 4, and Photo. 13 (Site J). Damage to buildings due to leaning of the adjoining building was sometimes observed as shown in Photo. 14 (Site K).

Photo. 8. Damage to pavement at Site E

Photo. 9. Boiled sand between buildings at Site F

Photo. 10. Damaged by lateral spreading at Site G

Settlement of buildings is relatively small in areas other than the above-mentioned area. A dense configuration of buildings, which may have a relatively larger foundation width in total, a thin liquefied layer, and large fines contents may be the reason. It is also worth mentioning that damage to the superstructure was small in buildings that sank and tilted, but floor slabs lifted and were damaged when no reinforcing bar was installed or when stiffness was low, as shown in Photo. 15 (Site L).

Photo. 11. Damage to building and pavement on the east side of Sakarya Cad. (Site H)

Photo. 12. Damage at Site I in Izmit Cad.

Photo. 13. Settlement of building at Site J

Damage to Building in Nonliquefide Area

Structural damage was concentrated in the nonliquefied area. Typical damage patterns were collapse of the first story column, collapse of the first story that resulted in the total collapse of the building, and total collapse, as shown in Photos. 16 (Site M) and 17 (Site N). Damage to superstructures was also seen in the boundary

Photo. 14. Damage to adjoining building by tilted building at Site K

Photo. 17. Damage due to soft first story at Site N

Photo. 15. Damage to floor slab by settlement of foundation at Site L

Photo. 18. Tilted building in demolished buildings at Site P

Photo. 16. Pancake crash of multi-stories at Site M

between the liquefied and nonliquefied areas and even inside the liquefied area, as shown in Photos. 14 (Site K) and 18 (Site O).

Structural damage was concentrated along the road running in the east-west direction in the same area. Buildings along the Izmit Cadesi, Cark Cadesi and Fabrika Cadesi are examples of this kind. Building along these streets had openings in the east-west direction, therefore strength in this direction was small. It is worth noting that, in the Izmit Cadesi, although 5-story buildings collapsed at every door, damage was much smaller in the building that sank. Damage was also smaller for buildings with only a few stories even if settlement was not observed.

DETAILED INVESTIGATION

A detailed investigation was conducted along three lines, Line 1, 2, and 3, in Fig. 7, in which the liquefied area is overdrawn. Line 1 runs along the Cark Cadesi and Ankara Cadesi, Line 2 runs along the Fabrika Cadesi and its extension, and Line 3 runs north from the building that tilted 60 degrees on Line 2. Lines 1 and 2 run in the east-west direction, whereas Line 3 runs in the north-south direction between Line 1 and Line 2. Buildings north of the road were investigated along Lines 1 and 2, and those west of the road were investigated along Line 3. If there were no buildings on these sides or the degree of damage was difficult to evaluate because of demolition, buildings on the other side of the road were investigated. Investigations were conducted from west to east along Lines 1 and 2 and from south to north in Line 3.

Following the procedure in the past (Architectural In-

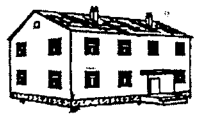
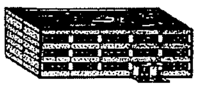
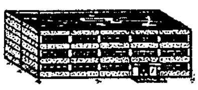
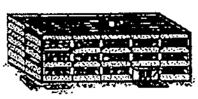
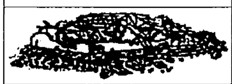
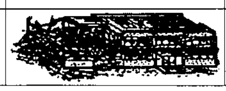
Classification of damage to masonry buildings		Classification of damage to buildings with reinforced concrete	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones 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.

Fig. 8. Classification of damage to buildings (EMS98)

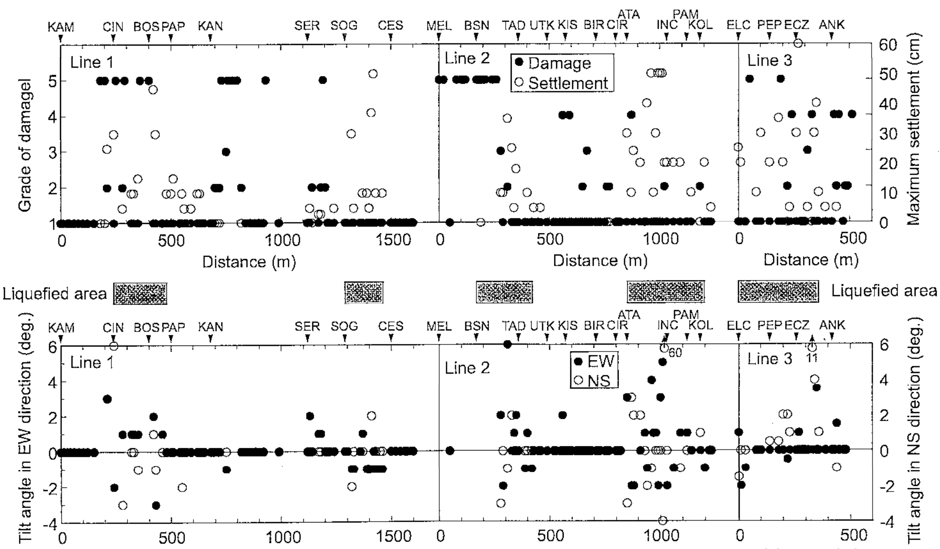


Fig. 9. Results of detailed damage investigation

stitute of Japan Reconnaissance Team with Bogaziçi University, Istanbul Technical University, Middle East Technical University, 1999), structural type, number of stories, shape of plan, degree of damage, settlement and tilt were evaluated for each building. Moreover, if damage to buildings was severe on the opposite side, they were also evaluated. Figure 7 shows the location and rough plan shape of the building. Each building is named by three letters of the alphabet, a number, and further letter. The first three letters are generally the first three characters of the street name that are used to indicate rough location of the building. The number is the sequential number. The final letter indicates the side of the building when the fundamental rule described above is not used; S, E and N are south, east and north of the road, respectively. This last letter is not shown in Fig. 7 because it is easy to distinguish.

Degree of damage was evaluated based on the Europe-

Photo. 19. Cark Cad. (from lower center to upper left)

Photo. 21. Building leaning on adjacent building (KAM11)

Photo. 20. Ankara Cad. (from upper center to lower left)

Photo. 22. Pavement around foundation on the north side of Cark Cad. (BOS5)

an Macro-seismic Scale (EMS98), the same as the AIJ Reconnaissance Team (Architectural Institute of Japan Reconnaissance Team with Bogaziçi University, Istanbul Technical University, Middle East Technical University, 1999), which is shown in Fig. 8 for masonry and reinforced concrete buildings. Damage is classified into five grades: 1, negligible to slight damage; 2, moderate damage; 3, substantial to heavy damage; 4, very heavy damage; and 5, destruction. The results of the investigation are summarized in Fig. 9, and detailed data is shown in the appendix. Here, data of the tilt angle for the building in which story failure occurred is omitted.

Investigation along Line 1

Photographs 19 and 20 are aerial photographs along the investigated lines; buildings KAM10 to KAM19 are shown in Photo. 19 and SOG1S to SOG12S are shown in Photo. 20.

Damage to the superstructure and settlement and tilt of the building were hardly observed about 200 meters from the west end of the Cark Cadesi (KAM1 to KAM9S). Then, the damage pattern suddenly changed and damage to buildings became significant. It is noted, however, that not a few RC buildings with 3 to 6 stories survived without severe damage although many 3 to 5 story buildings were completely collapsed. As shown in Fig. 9, buildings with less damage in structural members had a tendency to sink and tilt more. Buildings that were damaged because of the complete collapse of the neighboring building were also seen as shown in Photo. 21.

Three buildings, BOS1 to BOS3, that were located just after crossing the Bosna Cadesi collapsed in the superstructure, and were already demolished at the time of investigation, apart from the building BOS1, which faced the Bosna Cadesi as shown in Photo. 17. Settlement of the foundations of the other two buildings is not known. Buildings north of the demolished building sank, but suffered no damage to their superstructure, and were chosen for BOS2 and BOS3. Most of the buildings on the south side of the road were significantly damaged and were demolished. Damage to structural and nonstructural members was hardly observed but settlement and tilt were observed for the surviving buildings in these areas (Photo. 18).

The damage pattern was quite different on both sides of the street from BOS4 to PAP9. Pavement was damaged in many places, as shown in Photo. 22, and many buildings sank about 10 cm, but damage to the su-

Photo. 23. Damage to buildings on the south of Cark Cad.

Photo. 25. Fabrika Cad. (from center right to upper left)

Photo. 24. Damage to building on the north side of Cark Cad. (KAN10)

Photo. 26. Kadirhoca Sok. (from center to lower left)

perstructure was hardly observed in the north side of the road. In contrast to this, buildings collapsed because of the first story failure, as shown in Photo. 23. Settlement was sometimes difficult to evaluate because the ground surface was covered with collapsed material, but it seemed not to have occurred. Collapse of this kind continued to the building in front of PAP9 along Line 1.

Structural damage, settlement and tilt were hardly observed from PAP10 to KAN5 on both sides of the street. Then, the damage pattern changed again. Significant damage caused by the first story failure was observed in 4 buildings among the 5 from KAN6 to KAN10 (*see* Photo. 24) on the north side of the street, whereas no building suffered significant damage on the south side of the street.

Damage to structural members and settlement and tilt of the building were absent or hardly observed in the east of the previous region to about 150 m in the Ankara Cadesi after passing the Sakarya Cadesi (KAN11 to SER10), except two buildings that fell down. This region is classified as a nonliquefied area. The region for 200 meters from the intersection with Line 3 (SOG1S) is classified as a liquefied area. Many buildings between SOG1S to SOG13S sank or tilted without damage to their superstructures. Settlement was generally between 5 to 10 cm with several exceptions of SOG3S, SOG9S, and SOG10S whose settlements were more than 30 cm. Damage to the floor caused by lifted-up ground was significant, as shown in Photo. 15 for SOG9S and SOG10S. Both damage to superstructure and settlement and tilt of foundation were not observed for at least 100 m to the west from this point.

Investigation along Line 2

Photographs 25 and 26 are aerial photos showing Line 2. Buildings MEL1 to MEL7 are taken from the right of Photo. 25, and then buildings from BOS1 are shown after crossing the Bosna Cadesi. Sakarya Cadesi runs from the upper-left to lower-right direction in Photo. 26, and buildings ATA1 and ATA8 can be seen.

Buildings from MEL1 to BOS5 that were located along the western side on the Fabrika Cadesi were classified as grade 5 damage except for one wooden house. They completely collapsed (pancake crash) or collapsed due to failure of the first story that has wide openings. This area is one of the most significantly damaged areas and many buildings collapsed, as shown in Photos. 25 and 27.

Damage to superstructure became small from BOS8. Instead of structural damage, settlement and tilt of the

Photo. 27. Damage to building on Fabrika Cad. (MEL6)

Photo. 28. Tilted building on Fabrika Cad. (BSN10)

building appeared from BOS8 to TAD7S, which may have been caused by soil liquefaction. Settlement reached 35 cm at maximum between BOS8 and BOS13, and was less than 10 cm between TAD1S to TAD7S. Correspondingly, tilt of the building was larger in buildings BOS8 to BOS13. Photograph 28 shows the most tilted building, with a tilt of 6 degrees to the east; the western side of the foundation lifted up 22 cm.

East of this, the area from the Sakarya Cadesi along Line 2 is classified as a nonliquefied area. Structural damage was observed in several weak RC buildings among UTK1S to CIR3, but neither structural damage nor settlement and tilt were observed in other buildings.

Photo. 29. Settlement of building (ATA12)

Photo. 30. Heaving between buildings (ATA11–12)

The damage pattern suddenly changed when entering the liquefied area after passing the Sakarya Cadesi. Buildings with 4 to 6 stories sank from several tens of centimeters to 1 meter, and tilted significantly, as shown in Photo. 29. Road and ground between the buildings lifted up and cracks appeared in many places. Photograph 30 shows the lift-up of ground between ATA11 and ATA12. A 4 story building (ATA13) that was located at the intersection between Line 2 and Line 3 tilted 60 degrees and sank up to 3 m, as shown in Photos. 31 and 32. Tilt of this building was 30 degrees in the morning of the day after the earthquake, and it took about 10 days to tilt another 30 degrees. Tilt stopped when it fell on the adjoining brick fence and building. Settlement and tilt became smaller east from this point.

Investigation along Line 3

Photographs 33 and 34 show aerial photos along Line 3. In Photo. 33, ECZ2E to ECX11E (SOG1S) are shown from the left, and buildings north from ANK1E after passing the Ankara Cadesi are also shown. The Ankara Cadesi is shown in the bottom right corner, and buildings from ANK3E are shown in the upper-right direction in Photo. 34. The center of the photograph is a mosque that failed because of the structural damage. An area with sig-

Photo. 31. Overturned building (ATA13)

Photo. 32. Exposed foundation of ATA13

Photo. 33. Central part of Line 3 (from left to right)

nificant damage is seen north from the mosque.

Eleven RC buildings from ELC1 to PEP7 sank 5 to 35 cm and tilted 0 to 2 degrees (Photo. 35), apart from two buildings. Damage to superstructure was not observed for the sunk building. Two exceptions were 2 story and 3 story wooden houses, among which a 3 story house was about to collapse, as shown in Photo. 36. Settlement was not observed in these wooden houses.

Photo. 34. North side of Line 3 (from lower right to center)

Photo. 35. Settlement of building (PEP2)

Among buildings from ECZ1E to ECZ11 along the Ankara Cadesi, 5 story RC buildings sank 5 to 60 cm and tilted 3 to 4 degrees at maximum, as shown in Photo. 37. Settlement was not observed, on the other hand, for light 1 story buildings and 3 story wooden buildings, although one 3 story wooden building was about to collapse. After crossing the Ankara Cadesi, buildings between ANK1E to ANK8E did not sink nor tilt, apart from one building. Instead of settlement and tilt, weak buildings that were damaged in the superstructure were frequently seen.

Photo. 36. Damage to wooded houses (PEP7)

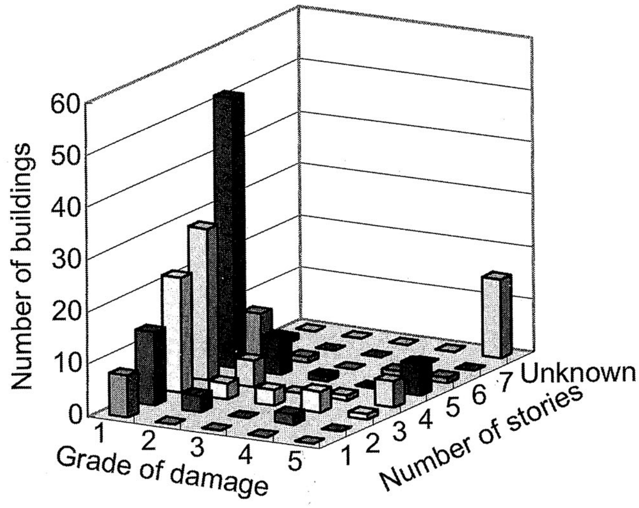


Fig. 10. Relationship between grade of damage and number of stories

Photo. 37. Tilted buildings (ECZ9E)

DISCUSSION

Figure 10 shows the relationship between the grade of damage and number of stories obtained in the detailed investigation. Totally 197 buildings and houses were investigated. Numbers of buildings that belongs to each classification are 134, 19, 4, 8, and 27 for grades 1 to 5, respectively, and numbers of buildings are 8, 19, 33, 39, 66, 11 and 1 for 1st story to 6th story, respectively. The number of stories is not known for 14 buildings with grade 5 damage because they had completely collapsed. This number, however, is sure not to be as small as 1 or 2 stories; it must be 4 or more. Two features can easily be seen from this figure. The first is that the number of buildings in the middle grade of damage is smaller than in grade 5 or the number destroyed, which is unusual compared with past experiences. 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 maximum load carrying capacity of the building. The second feature is that severely damaged buildings are concentrated in 4 to 5 story buildings, whereas buildings in the middle grade of damage are concentrated in 3 story buildings. This may be related to the predominant period of the ground shaking and predominant period of buildings.

Figure 11 shows the relationship between the grade of damage and settlement of the building. Here, "unknown" indicates that exact evaluation of the settlement was difficult mainly because collapsed building fell down on the foundation or the ground was covered by wreckage of the collapsed buildings nearby; however, the authors have the feeling that settlement did not occur from the possible inspection. It is also noted that damage with grade 2 to 4 can occur even in the liquefied area if an adjoining building falls down onto the building, as seen in Photo. 21; this is not a rare case. Considering this, large settlement is said to occur only when the grade of damage is small. In other words, buildings that sunk did not suffer damage to superstructure. This tendency can

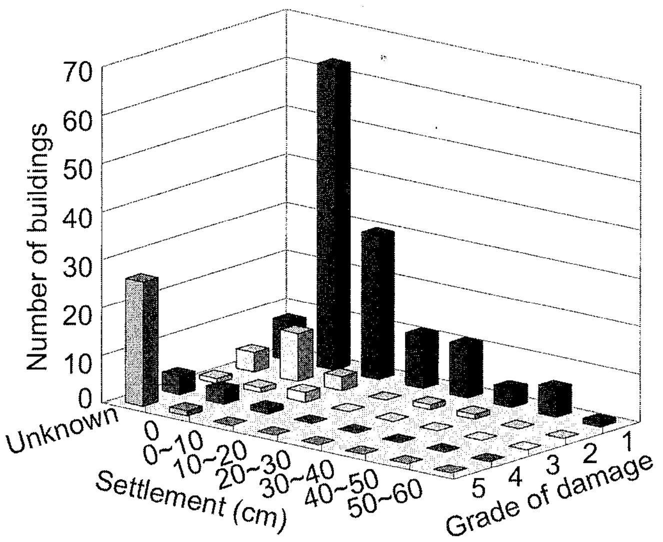


Fig. 11. Relationship between settlement and grade of damage

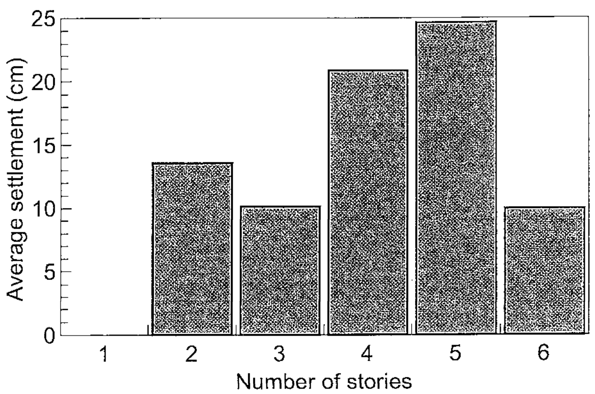


Fig. 12. Effects of number of stories on settlement of buildings in liquefied area

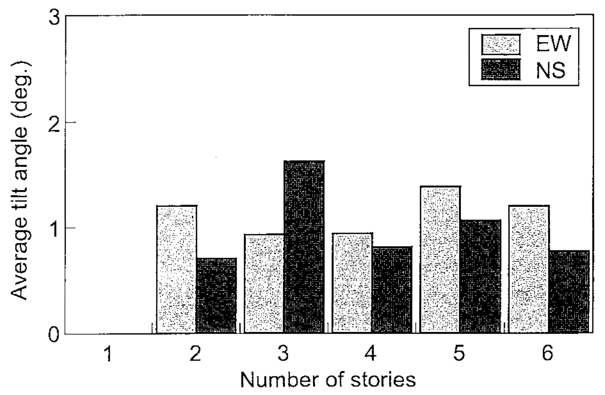


Fig. 13. Effects of number of stories on tilt of buildings in liquefied area

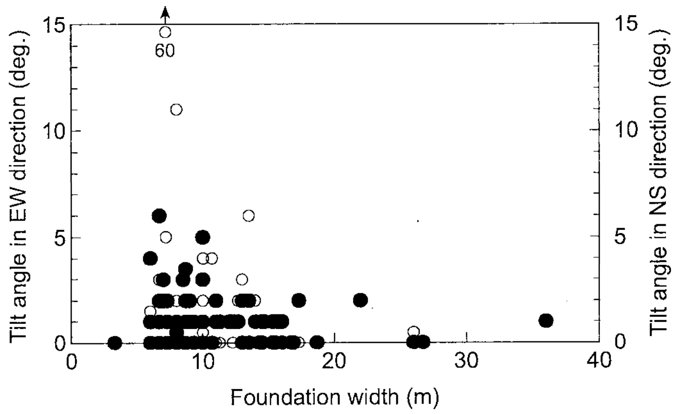


Fig. 14. Relation between angle of tilt and foundation width of buildings in liquefied area

also be seen in Fig. 9 in which the larger grades of damage mainly occurred out of the liquefied area. This also justifies the classification of the city area into liquefied and nonliquefied area.

Figure 12 shows the relationship between average settlement and number of stories, and Fig. 13 shows that between the average tilt and number of stories in the liquefied area. Here, data of the building that tilted 60 degrees is not counted in calculating the average tilt because this case is considered to be an exception. Average settlement is about 10 cm for 2 and 3 storied buildings. This increases to more than 20 cm for 4 and 5 storied buildings. These values are somewhat smaller than past experience such as in Niigata City (The Building Research Institute, 1965) during the 1994 Niigata earthquake, Japan, and Dagupan City (Tokimatsu et al., 1994; Wakamatsu et al., 1992) during the 1990 Luzon earthquake, Philippines. Tilt of buildings is about 1 degree regardless of the number of stories and direction, except for 1 story buildings in which tilt was not observed. Structural type such as wooden house and reinforced concrete building does not affect the tilt of the building.

Figure 14 shows the relationship between the angle of tilt and the foundation width. Aspect ratio is frequently used in this kind of comparison, but, as shown in the appendix, width of the building perpendicular to the road cannot be frequently observed mainly because buildings were built without space. Instead of the aspect ratio, therefore, width of the building in the direction of road is used in Fig. 14. Although the data is scattered, there is a clear tendency that tilt becomes larger as foundation width becomes smaller. There is no significant difference between the EW and NS directions.

CONCLUDING REMARKS

Various investigations were made on the damage to buildings and houses, and on geotechnical conditions in the Adapazari City. The downtown area can be separated into a nonliquefied area and a liquefied area surrounding it. The liquefied area is supposed to be the old swamp or riverbed of the Sakarya River and the nonliquefied area was an island from which the name of the city, Adapazari, came.

Severe damage to buildings caused by inertia effect is observed only in the nonliquefied area. This was concentrated along the road running in the EW direction and in the nonliquefied area adjacent to the liquefied area. Buildings in the liquefied area settled or tilted, but superstructure did not suffer severe damage causing the failure of structural and nonstructural members. The amount of tilt and settlement is affected by the number of stories and size of the foundation on average. Settlement and tilt are relatively small compared with the past large liquefaction experience such as in the 1964 Niigata earthquake and thc 1990 Luzon earthquake, which may be related to the fact that the sand boil was seldom observed in the liquefied area.

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

ACKNOWLEDGEMENT

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Appendix. Summary table of damage investigation of buildings

Name	F	ST	DM	SET (cm)	TLR (deg.)	TLP (deg.)	WD (m)	DP (m)	Comment
Line 1-1 (8, Sept.)									
KAM1	3	W	1	0	0	0	9	7	
2	2	W	1	0	0	0	13.5	12	
3	1	W	1	0	0	0	10	10	
4	1	W	1	0	0	0	20	8	
5	2	W	1	0	0	0	17	10	
6S	3		1	0	0	0	6	22	Change investigate site to south of road.
7S	3		1	0	0	0	6	22	
8S	2		1	0	0	0	18	8	
9S	2		1		0	0	18	8	
									Road.
10S	?		5	?	CP	CP	?	?	
11S	4		5	?	4E	5F	4.5	6	Tilted.
12S	5		2	25	3E	3F	14	8	Building KAM11S fell down to KAM12S.
									Cinar Sk.
CIN1S	5		1	20–30	2W	6F	13.5	17	
2S	?		5	?	CP	CP	?	?	
									Road is covered by collapsed building.
3S	3		2	5	1E	3B	10	12	
4S	?		5	?	CP	CP	?	?	
5S	6		1	5–10	1E	0	14	12	
6S	6		1	10	1E	0	11	?	
7S	4		1	10–15	1E	1B	16	8	
8S	?		5	?	CP	CP	?	?	
									Bosna Cad.
BOS1	5?		5	?	3E	8F	12	13	Buildings that faces to road demolished.
2	4		1	45	2E	1F	11	8	Buildings that faces to road demolished.
3	4		1	30	3W	1B	10	8	
									Road.
4	3		1	0	1E	0	16	16	Building DOS3 fell down to DOS4. Float up about 10 cm.
5	5		1	0–10	0	0	13	18	
									Papatya Sokok.
PAP1	5		1	10	0	0	10.5	14	Damage rand = 5 in the opposite side of road up to PAP10. Generally 5F.
2	6		1	10–15	0	0	16	15	
3	1	S	1	0	0	0	14	?	
4	5		1	5–10	0	2B	7	12	
5	5		1	5	0	0	9.5	?	Damage between road and building is severe.
6	6		1	0	0	0	11	?	10 cm spacing between pavement and building.
7	5		1	5	0	0	25	?	
8	5		1	10	0	0	20	?	Degree of damage 5 terminates here in the opposite side of road.

(continued)

Name	F	ST	DM	SET (cm)	TLR (deg.)	TLP (deg.)	WD (m)	DP (m)	Comment
9	5		1	5–10	0	0	12	?	Degree of damage is 1 in the building opposite to road (2 story).
10	1	W	1	0	0	0	4.5	?	There is damage in the opposite side of road.
11	2	W	1	0	0	0	12.5	27?	Damage between road and building is severe.
									Kanara Sokak.
KAN1	5		1	0	0	0	13.5	27	
2	5		1	0	0	0	4.5	?	Degree of damage is 1 in the building opposite to road. No settlement.
3	5		2	0	0	0	10	?	
4	5		2	0	0	0	7	?	
5	5		2	0	0	0	10	?	
6	6?		5	?	2W	5F	16	30	First story collapsed. 6th floor is light.
7	5		3	?	1W	0	14	30	
8	5?		5	?	2W	3F	12	20	First story collapsed. Degree of damage is 1 in the building opposite to road. No settlement.
9	4?		5	?	5E	0	13	13	First story collapsed. Degree of damage is 1 in the building opposite to road. No settlement.
10	5?		5	?	1W	5F	27	20	First story collapsed. Degree of damage is 1 in the building opposite to road. No settlement.
11	5		2	0	0	0	18	?	Slight structural damage. Damage to column facing KAN10.
12	5		1	0	0	0	18	?	
13	5		1	0	0	0	18	?	Partial damage to the building in the 6 story building opposite to road.
14	5		1	0	0	0	9	16	
									Narrow road.
15	5		1	0	0	0	13.5	12	
16	5		1	0	0	0	14	12	
17	5		1	0	0	0	5	?	Light 5th story. Partial damage to the building opposite to road.
18	?		5	?	CP	CP	?	?	
									Road.
19	6		1	0	0	0	65	25	
									Bul var-Sakarya Cad.
Line 1-2 (10, Sept.)									
SER1	5		1	0	0	0	12.0	4.0	
2	5		1	0–5	2E	0	4.7	5.3	Tilt.
3	5		2	0	0	0	6.0	9.3	
4	5		1	3?	1E	0	4.0	9.3	
5	3		2	3?	1E	0	2.0	4.0	Light penthouse added on.
6	?		5	?	CP	CP	?	?	
7	4		2	?	0	0	7.3	12.7	Nearly no settlement.
8	5		1	?	0	0	4.3	?	Nearly no settlement.
9	7		1	?	0	0	19.3	10.7	Light roof floor.
10	6		1	5?	0	0	11.3	14.7	Damage to surface.
SOG1S	5		1	?	0	0	16.9	20.7	About 10 cm settlement.
2S	3		1	?	0	0	14.3	?	About 10 cm settlement.

(continued)

Name	F	ST	DM	SET (cm)	TLR (deg.)	TLP (deg.)	WD (m)	DP (m)	Comment
3S	2		1	25–30	1W	2B	12.7	?	
4S	2		1	5	1W	0	8.0	10.7	
5S	2		1	0	0	0	16.7	10.7	
6	3		1	10	1E	0	16.0	?	
7	3		1	10	1W	1B	9.3	?	
8	3		1	5	1W	1B	15.7	?	
9	3		1	35–37	1W	2F	6.7	?	
10S	4		1	50	0	0	9.3	?	Roof floor added. Lift-up of earth floor significantly.
11S	3		1	5–10	1W	0	7.3	?	
12S	6		1	?	1W	0	15.3	?	Nearly no settlement.
13S	2	W	1	5–10	1W	0	14.7	15.3	
									Cesme Meydani Cad.
CES1S	5		1	0	0	0	24.0	6.7	
2S	5		1	0	0	0	24.0	?	
3S	5		1	0	0	0	14.7	?	
4S	5		1	0	0	0	11.1	?	
5S	5		1	0	0	0	15.6	?	
6S	5		1	0	0	0	7.3	28.0	
7S	5		1	0	0	0	14.7	16.7	
Line 2-1 (10, Sept.)									
MEL1	5		5	?	6W	1B	18.7	20	
2	?		5	?	CP	CP	12.7	13.3	
3	2	W	1	0	0	0	10.7	8.0	
4	?		5	?	18W	12F	14.7	12.0	
5	4?		5	?	11W	9F	7.3	12.0	
6	4?		5	?	18E	2B	8.0	16.0	
7	?		5	?	CP	CP	8.7	16.0	
									Bosna Cad.
BSN1	?		5	?	CP	CP	8.0	7.3	
2	5		5	?	13E	1B	12.0	7.3	
3	3		5	0	3E	2B	10.0	?	
4	?	W	5	?	CP	CP	2.7	?	
5	4		5	?	5E	4F	12.7	12.0	
6	?	W	5	?	CP	CP	14.7	12.0	
7	5?		5	?	4E	3F	24.0	12.0	
8	3	W	3	0–10	2E	3B	6.7	7.3	
9	4		1	0–10	2W	0	7.3	10.0	
10	5		2	35	6E	1B	6.7	10.7	Left side float up 22 cm.
									Road.
11	5		1	25	0	2F	10.0	11.3	

(continued)

Name	F	ST	DM	SET (cm)	TLR (deg.)	TLP (deg.)	WD (m)	DP (m)	Comment
12	5		1	5	1E	0	7.3	12.0	
13	5		1	5–18	2E	0	17.3	8.0	
									Road.
TAD1S	5		1	0	0	0	18.7	12.0	Roof floor is light.
2S	3		1	0	1W	0	8.7	?	Semisubterranean.
3S	5		1	10–5	1E	0	12.3	14.7	
4S	4		1	0	1W	0	11.3	10.7	
5S	5		1	5	0	0	9.3	?	
6S	3		1	0	0	0	10.7	?	
7S	4		1	5	0	0	10.0	15.3	Roof floor is light penthouse.
UTK1S	5		1	0	0	0	27.3	41.3	Partially 4 story.
2S	4		1	0	0	0	16.7	15.3	
3S	4		1	0	0	0	8.0	16.7	
4S	3		1	0	0	0	8.0	?	
5S	4		4	0	2E	0	6.0	24.7	First story column yield.
KIS1S	4		1	0	0	0	10.7	14.0	
2S	3		1	0	0	0	6.0	?	
3S	2	W	4	0	0	0	7.3	?	
4S	3		1	0	0	0	11.3	?	
5S	4		1	0	0	0	12.0	21.3	
6S	3		1	0	0	0	7.3	?	
7S	3		1	0	0	0	7.3	?	
8S	4		2	0	0	0	8.7	26.7	
9S	4		1	0	0	0	4.7	15.3	
									Narrow road.
10S	3		3	0	0	0	5.3	16.0	First story column residual deformation.
11S	5		1	0	0	0	6.7	16.0	
12S	5		1	0	0	0	13.3	26.7	
									Road.
BIR1S	3		1	0	0	0	7.3	12.0	
2S	4		1	0	0	0	12.0	7.3	
3S	4		1	0	0	0	8.0	13.3	
									Road.
4S	3		1	0	0	0	8.7	11.3	
5S	2		2	0	0	0	7.3	?	
6S	4		2	0	0	0	16.7	37.3	

(continued)

Name	F	ST	DM	SET (cm)	TLR (deg.)	TLP (deg.)	WD (m)	DP (m)	Comment
Line 2-2 (8, Sept.)									
CIR1	4		1	0	0	0	10	?	
2	4		1	0	0	0	9	?	
3	5		1	0	0	0	19	5	
									Sakarya Cad.
ATA1	6		1	5–30	3E	3F	7	7	Ground surface lifted up 20 cm, and manhole in front float up.
2	3		4	10	2W	3F	13	4.5	Road lifted up 10 cm. 1st floor tilts.
3	5		1	24	2W	2F	22	15	
4	4		1	5–20	0	2F	13.5	22	
									Road.
5	2	W	1	0	1E	0	8	9	Degree of damage is 1 in opposite side 4 story building. Large settlement.
6	4		1	30–40	1W	2B	14	15	Degree of damage is 1 in opposite side 5 story building. Large settlement.
7	2	W	1	50	4E	1B	6	6	Significant tilt. Degree of damage is 3 in opposite side 5 story building. Large settlement.
8	3		1	10	1E	1B	12.5	8	Degree of damage is 1 in opposite side 4 story building. Large tilt.
9	3		1	30	1E	0	8	?	
10	5		1	30–50	2W	0	7	24	
11	5		1	30–50	3E	0	8.5	25	Surrounding road lifted up 30 cm, especially between 11 and 12.
12	5		1	30–50	5E	4B	10	7	Surrounding road lifted up 30 cm.
13	4		2	fell	60N	5B	7.2	11	Embedment 1 m. Maximum settlement is 3.4 m.
									Turn right at next corner.
INC1S	4		1	20	2W	0	9	9	
2S	5		1	10–20	1W	1B	36	20	
3S	5		1	20	1E	1B	12	19	Roof floor just to collapse.
									Pamuk Sokak.
PAM1	4?		1	0	1E	0	14.5	12	
2	4		1	10	0	0	15.5	16.5	
									Kol Sk.
KOL1	6		2	0	0	1F	14.5	9	
2	3		1	20	1W	1B	9	9	
									Roof floor only collapsed.
3	1	W	1	0	0	0	7.5	7	
4	4		1	5	0	0	12	9	
Line 3 (10, Sept.)									
ELC1	4		1	25	1.5S	1B	6.0	?	North of ATA13.
2	4		1	20	0	2F	8.7	?	
3	4		1	0	0	1F	11.3	11.3	
4	?		5	?	CP	CP	13.3	5.3	
5	4		1	10	0	0	26.7	?	
6	4		1	30	0	0	16.0	?	

(continued)

Name	F	ST	DM	SET (cm)	TLR (deg.)	TLP (deg.)	WD (m)	DP (m)	Comment
PEP1	5		1	20	0.5N	0	26.0	?	
2	4		1	35	0.5N	0	10.0	?	
3	?		5	?	CP	CP	4.7	?	
4	4		1	20	2N	0	7.3	?	
5	2	W	2	0	2N	0.5F	8.0	?	
6	5		1	5	1	0	10.0	?	
7	3	W	4	?			8.0	?	1st floor just to collapse.
ECZ1E	5		1	30	0	0	3.3	?	
2E	5		1	60	0	1B	10.0	?	
3E	1		1	0	0	0	8.7	?	
4E	1	W	1	0	0	0	8.7	?	
5E	1	W	1	0	0	0	6.0	?	
6E	3		3	5	0	0	6.7	?	
7E	3	W	4	0	11S	0	8.0	?	1st floor just to collapse.
8E	5		1	30	4N	0	10.7	?	Large amount of sand boil between 8E and 9E.
9E	5		1	40	0	3.5B	8.7	?	
10E	5		1	10	1N	0	15.3	?	
11E	5		1	5	0	0	20.7	?	Building is same with SOG1S.
ANK1E	2		1		0	0	4.7	?	
2E	2		4		0	0	2.7	?	
3E	4		2	5	1S	1.5B	13.3	?	
4E	3		4		0	0	4.7	?	
5E	2	W	1		0	0	12.0	?	
6E	3		2		0	0	6.0	?	
7E	2		2						
8E	6		4						

Note. F: Number of story, ST: Structural type (RC is not written), DAM: Grade of damage, SET: Settlement, TLT: Tilt in direction of road, TLP: Tilt in direction perpendicular to road, WD: Width in the direction of road, DP: Width in the direction perpendicular to the road. CP: Collapse, F: Tilt to front, B: Tilt to back, Blank line indicates road or spaces between buildings.