Chapter 2. Earthquake and Damage

2.1 Source Characteristics and Ground Motion

2.1.1 Source Model

The 1999 Kocaeli earthquake that struck the western Turkey was a complex rupture characterized by a right lateral strike-slip fault with a moment magnitude of 7.4. The earthquake was produced by the western part of the North Anatolian fault east of the Marmara sea. Approximately 130km of surface rupture was observed (CNRS-INSU, IPGP, Istanbul Technical University). To understand the kinematic rupture process of the earthquake, a kinematic inversion of the source was performed using the strong motion stations shown in Figure 2.1.1 (Sekiguchi and Iwata, 2000). The fault model used for the inversion is also shown in that figure. As we can see the fault model follows approximately the fault surface break.

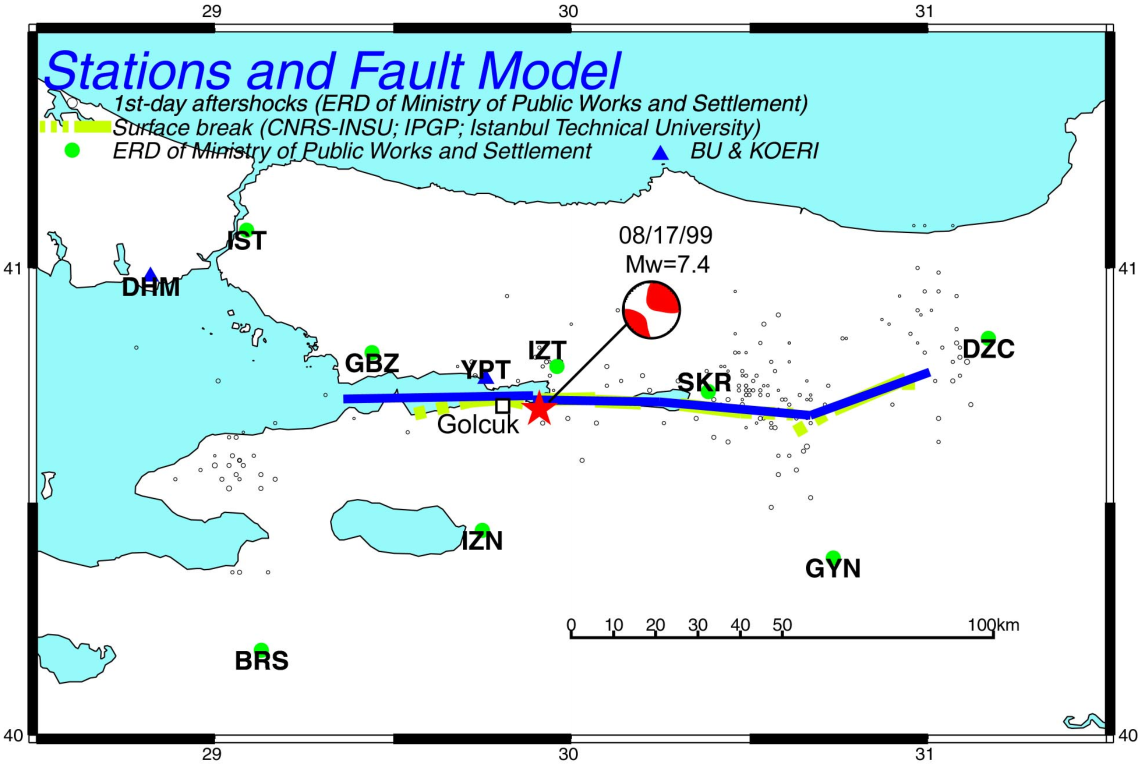

Figure 2.1.1. Surface break and fault model of the 1999 Kocaeli earthquake. The strong motion stations used for the kinematic source inversion are shown (Sekiguchi and Iwata, 2000).

The final slip solution shows three patches of large slip, the first one localized in the bottom of the fault, 10km west of the hypocenter. The second one 15km to the east of the hypocenter at the bottom of the fault and the third one localized in the upper part of the fault 40km to the east of the fault. These three patches correspond to asperities Nos. 1, 2, and 3 as shown in Figure 2.1.2. We also can appreciate that the maximum slip of the fault was approximately 9 meters localized in the largest asperity 10km to the west of the hypocenter (asperity No. 1).

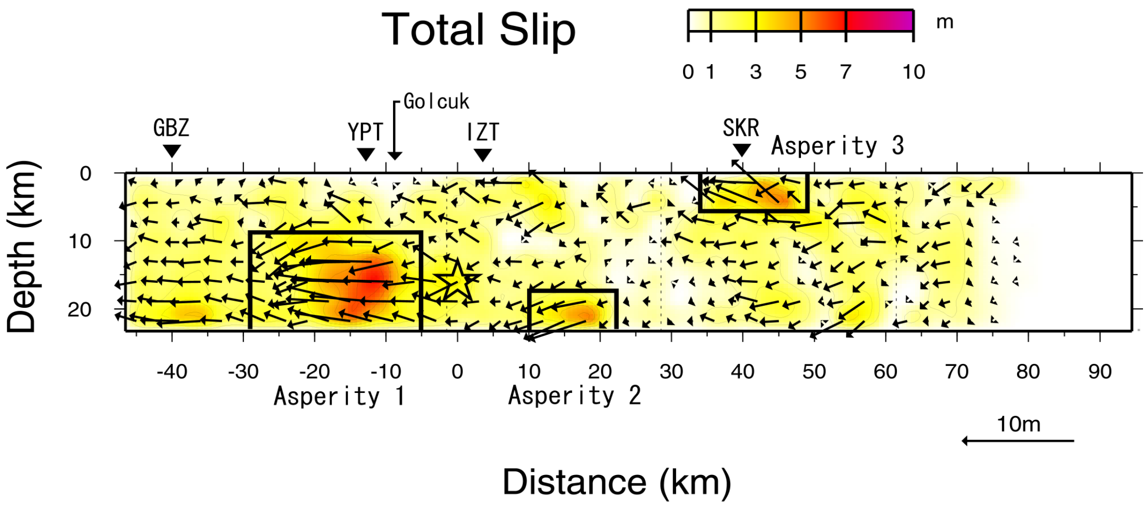

Figure 2.1.2. Kinematic model of the 1999 Kocaeli earthquake. Final slip distribution (Sekiguchi and Iwata, 2000). The hypocenter is shown by a star. Horizontal distance is measured from the hypocenter. Arrows denote final slip vector.

2.1.2 Ground Motion Estimation Methodology

We will explain the methodology that is being applied to make the ground motion estimation for the Kocaeli earthquake which takes into account the main factors that contribute to the ground motion generation namely the source complexity, the propagation and the local amplification of the seismic waves. The basic idea is to produce ground motions in a broadband frequency range (0.1-10Hz) in order to be able to compare the simulated ground motions with the observed damage distribution. One of the target regions is the heavily damaged city of Golcuk where no ground motion recordings from the mainshock are available.

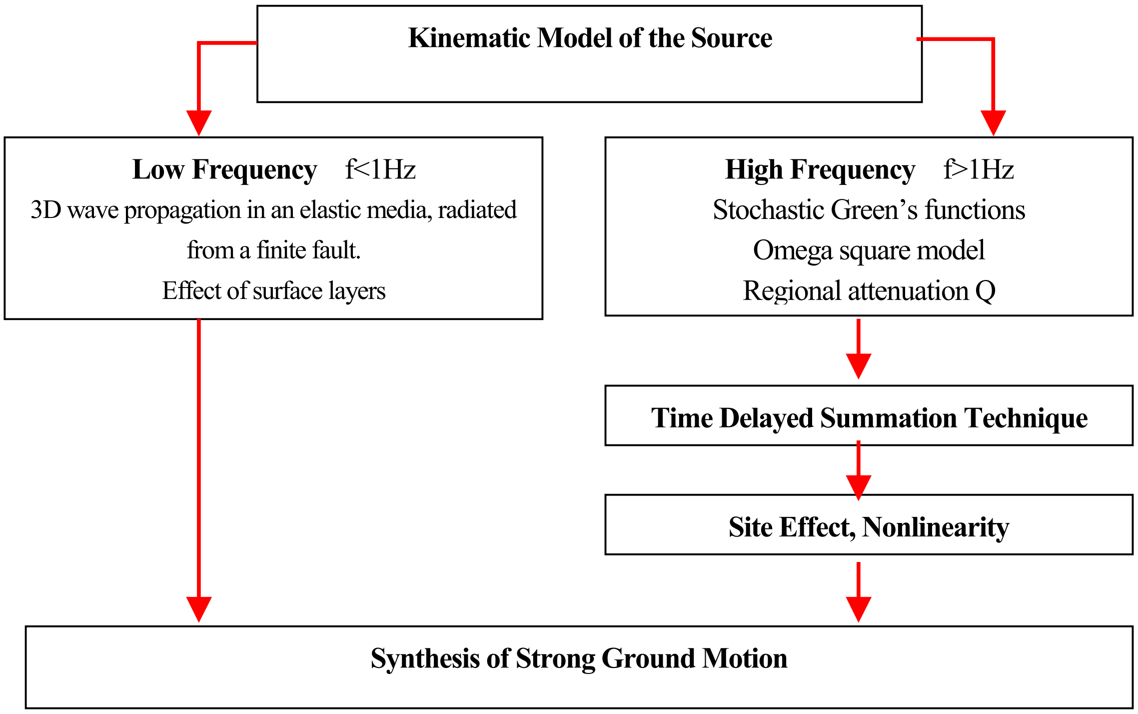

Figure 2.1.3. Flowchart for the broadband estimation of ground motion (Hybrid technique).

The procedure to be applied is a hybrid ground motion simulation, which consists in the generation of ground motions in low frequency (<1Hz) and high frequency (>1Hz) bands (Figure 2.1.3). The low frequency part of the ground motion is calculated from the radiation of seismic waves from a simplified asperity model (Figure 2.1.2) propagating in a 3D elastic media. For this purpose, Discrete wave number method for a 3D elastic wave propagation in a layered media will be applied (Bouchon, 1981). The high frequency motion generation uses the idea of the empirical Green's function technique (Irikura, 1983), which consists in using recordings from small events (aftershocks) in order to reproduce the ground motion from a large event (mainshock). For that purpose, the scaling relation of the source spectra and the source parameters together with an appropriate selection of the small event must be considered. For regions like Golcuk city, where no appropriate recording of aftershocks is available, the seismograms of the small event are generated stochastically in such a way that they follow an omega square model and a regional attenuation relationship (Boore, 1983). After that the same summation technique used in the empirical Green's function method is applied. Finally the amplification of the seismic waves and the nonlinearity effect of subsurface layers should be included to get the ground motion at a specific site. The final motion is obtained as a summation of the low and high frequency parts obtained before.

2.1.3 General Ground Motion Features

It is interesting to observe the waveforms corresponding to stations located close to the fault trace (few kilometers) like SKR and YPT. We can see from Figure 2.1.4 that the velocity waveforms show a very simple one or two pulse shape, which is actually related with the radiation of seismic waves from the nearest asperity to each station. In the case of station SKR, most of the contribution to the ground motion at that site could come from asperity No. 3, and for station YPT, the main contribution is from asperity No. 1. The previous characteristic was actually observed during the Hyogoken-Nanbu earthquake where 1-3s pulses in the records at the heavily damaged zone in Kobe, where produced by the forward directivity effect from the asperities located in the Kobe side (Kamae and Irikura, 1998). In the case of stations SKR and YPT, the duration of the pulses is approximately 6s, and assuming a rupture velocity of 3km/s, it gives a size for the main asperity of 20km, which is approximately the size of the main asperity obtained from the kinematic model in Figure 2.1.2. It is also interesting to compare the velocity waveforms of SKR and YPT with that of IZN. The IZN station which is located about 40km from the fault trace does not show the impulsive characteristic of the near field waveforms.

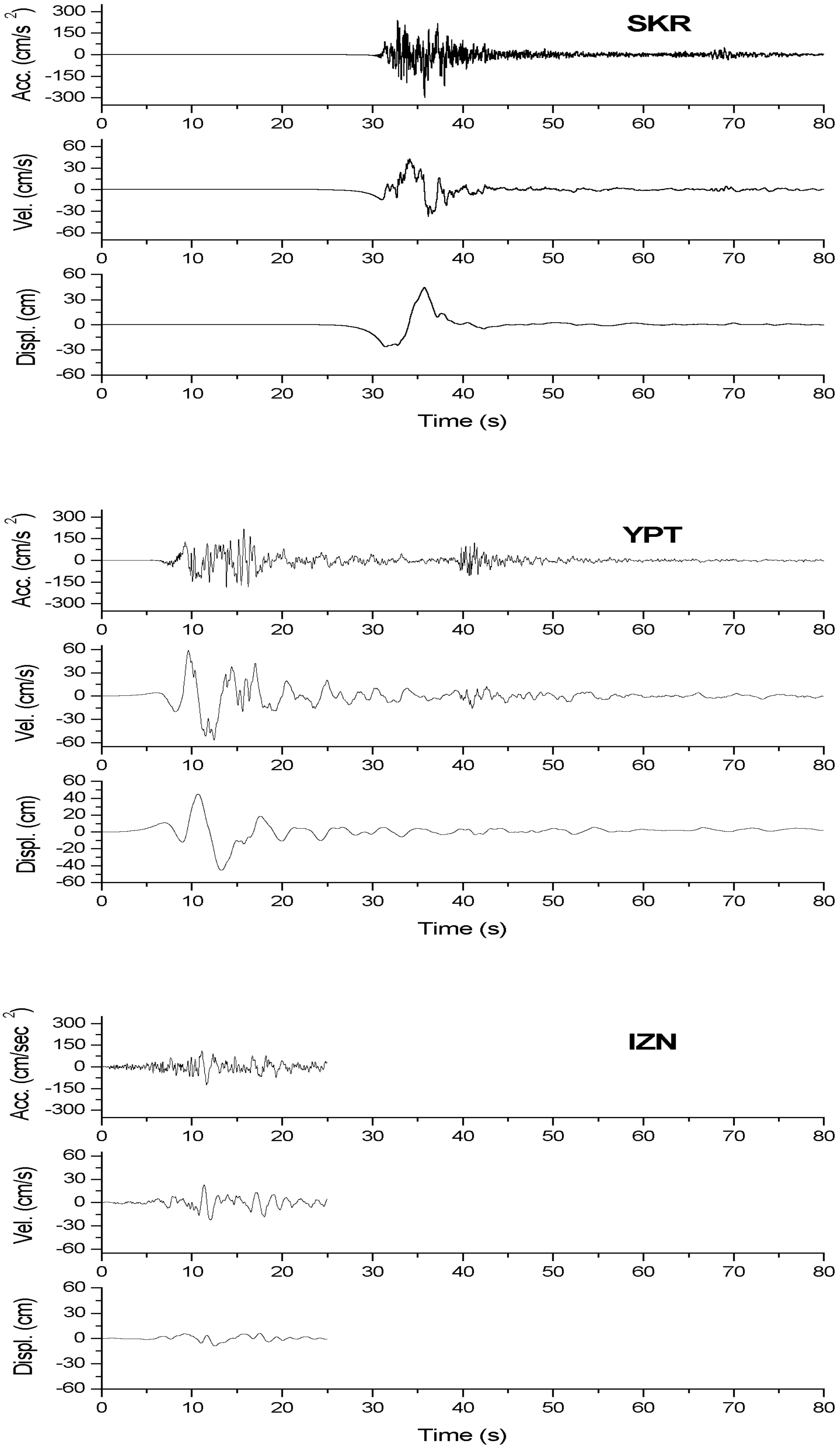

Figure 2.1.4. Acceleration, velocity, and displacement waveforms for the EW component of the SKR, YPT, and IZN stations. The waveforms were band-passed filtered between 0.1 and 10 Hz.

2.1.4 Summary

A fault rupture model that is so-called the kinematic model (Sekiguchi and Iwata, 2000) for the 1999 Kocaeli, Turkey earthquake is reviewed. With in the model proposed, the importance of the forward directivity effect radiated from the main asperities is shown from a preliminary observation of the recordings at the vicinity of the fault. This directivity effect coupled with the site amplification at Golcuk city can explain the heavy damage observed within the region. Secondly, introduced is the so-named hybrid simulation procedure for the broadband estimation of ground motion based on the kinematic model of the source.

Further studies are needed to determine the ground motion at the heavily damaged zone of Golcuk during the quake. We would like to extend our research to evaluate the ground motions at Golcuk utilizing the proposed hybrid technique to explain the contribution of the source to the ground motion. The generated ground motions can be utilized for the damage analysis on the buildings discussed in Chapter 5.

Acknowledgements

The author would like to thank Dr. Haruko Sekiguchi, Geological Survey of Japan, and Dr. Tomotaka Iwata, Disaster Prevention Research Institute, Kyoto University, who kindly provided the source model of the 1999 Kocaeli earthquake.

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2.2 Building Damage

From the point of view of building damage during Kocaeli earthquake, most of them seem to be caused by the characteristic structures of Turkish buildings. We will begin with summarizing the structural features of Turkish buildings, and try to review actual damages by survey results.

2.2.1 Structural Feature of Buildings

Overview of Structural Feature

Most of apartment or private house is made of reinforced concrete, which is from 3 to 7 stories in height (see Photo 2.2.1). Some of older construction, which is one or two stories in height, is built as wood framed structure with masonry wall. A majority of the residence building collapses in first story due to the poor structure, so-called soft-first story (Photo 2.2.2). To keep the open space for the usage of commercial, warehouse or parking at the first floors, infill walls often luck in the first story. First story is often set back from the street in the front (Photo 2.2.3), which comes from former Turkish regulations. In commercial district, interval of buildings is rarely kept (Photo 2.2.4). A majority of basement type is spread foundation. Reinforcing bars are sometimes exposed from top floor, for alterations of adding upper floors.

Structural Elements

In most building, hollow clay block (Photo 2.2.5) or solid block is used as the material for infill wall. Reinforced bar are not used in the block wall. Recently, formed concrete block have became more common. Earthquake resisting walls are rarely used in typical residence buildings. Most of the column has rectangular cross section (Photo 2.2.6), and the aspect ratio is often quite large, such as 25cm by 60cm. Long side of rectangle is generally arranged along same direction, and the tendency is shown remarkably in commercial building than residence building. They are often placed in partition with infill walls. Columns are not always placed on the grid pattern. Details of the reinforcement, as observed in columns, beams, slabs and those joints, are relatively poor (Photo 2.2.7). To give an actual example, concrete confinement lack in the columns and at the beam-column joints, splice length is insufficient, usage of 90 degrees hooks, etc. Most of slabs are type of “flat-slab” which are not supported by girder or beam. Some of slabs are type of infill slab made from hollow brick and reinforced concrete (Photo 2.2.8).

Materials and Construction

Hollow clay block usually used as material for infill wall. Recently, formed concrete block become more common. By the observation on concrete of collapsed members, quality of concrete seems to be relatively poor. A majority of concrete is mixed on construction site by the use of a concrete mixer machine. Ready-mixed concrete is not common for residence buildings. We measured the compressive strength of concrete, in four residence buildings constructed in Golcuk, Sapanca and Adapazari (Photo 2.2.9). Schmidt Hammer (the measuring capacity is 10 to 70 MPa) was used to measure the compressive strength. The test results are shown in Table 2.2.1. Generally, estimated value from the Schmidt Hammer test greatly depends on the assumed age of the material. In the reconnaissance, we could not exactly check the year those buildings were built. Therefore, the values are indicated for surmised age of material. Assumed strength from the tests were between 12 and 22 MPa. Details of the reinforcement are relatively poor. By the investigation, observed details of reinforcement were summarized as follows, longitudinal reinforcement with 18ф plain bar, usage of 90 degrees hooks, insufficient splice length, transverse hoops typically spaced at 25 to 30 cm, lack of concrete confinement in the columns and at the beam-column joints, cover concrete less than 10mm (Photo 2.2.10), etc.

Table 2.2.1. Compressive strength of concrete measured by Schmidt Hammer (in MPa).

	Golcuk	Golcuk	Sapanca	Adapazari
Supposed Age of Concrete	No damage	No damage	No damage (Under construction)	Collapse
28days	21.5	24.0	21.5	22.7
100days	16.8	18.7	16.8	17.7
300days	15.0	16.8	15.0	15.9
1000days	14.0	15.6	14.0	14.8
3000days	13.5	15.1	13.5	14.3
10000days	12.2	13.7	12.2	13.0

Notes: Bold frame indicates the assumed value correspond to the age of concrete. The age of concrete was surmised by appearance of each building. The equation Fc = 13R - 184 (The Society of Material Science, Japan) was used to estimate the compressive strength Fc from rebound value R.

Summaries of Turkish Design Codes

In Turkey, most recent codes were issued in 1975 and 1997. The 1975 code is an adaptation of the Uniform Building Code (UBC) in California, and it contains detailing requirements, such as 135-degree hooks in column hoops and cross ties, denser transverse reinforcement at member ends and within the joints, strong-column and weak-beam design concepts. Most of the damaged region lies in the highest seismic zone (seismic zone 1) in Turkey, so buildings constructed after 1975 can be expected to be highly earthquake resistant. However, amount of damaged buildings were observed to be constructed after 1975. This fact means that the earthquake-resistive details and design philosophies, expressed in the code, did not accompany construction practice.

Photo 2.2.1. Mid-rise residence building under construction in Avcilar (Refer to color Photo 1).

Photo 2.2.2. Residence building collapsed at first story in Adapazari (Refer to color Photo 2).

Photo 2.2.3. Set back lower story of residence building in Avcilar.

Photo 2.2.4. Commercial buildings close each other in Golcuk.

Photo 2.2.5. Hollow clay block for infill wall, Yalova (Refer to color Photo 3).

Photo 2.2.6. Rectangular cross-section column of commercial building, Golcuk.

Photo 2.2.7. Reinforcement bar in collapsed column of building, Adapazari.

Photo 2.2.8. Flat infill slab in commercial building, Avcilar.

Photo 2.2.9. Schmitt hammer test at residence building, Sapanca.

Photo 2.2.10. Exposed reinforcing bars of column and beam, Sapanca.

2.2.2 Results of Surveys

Reconnaissance was performed in the district of Avcilar, Istanbul, Yarimca, Derince, Izmit, Yalova, Degirmendere, Golcuk, Adapazari, and Sapanca, during the period of 28 Sep. to 2 Oct., 1999.

Overview of Building Damage in Each District

As of 12 September 1999 the results of the damage assessment, totaled up by OCHA (1999), are shown in Table 2.2.2. The table indicates that Kocaeli (including Izmit, Golcuk) and Sakarya suffered serious disaster also in building damage. When we consider the factors of disaster concentration of these district, location nearby the epicenter or concentration of population do not seem to be the only factors for the serious damage. In our investigation, most of building damage was observed in the south coast of Marmara Sea like Yalova, Degirmendere and Golcuk, and also in Adapazari. Those districts are located along seismic fault that caused the earthquake (Photos 2.2.11-13). In the north coast of Marmara Sea, some damages were observed in a factory and a port facility. In a factory of chemical industries located in Yarimca, damage on bridge piers, cooling towers, pipelines, research laboratories and residence building were observed (Photo 2.2.14). Among those damages, the hardest building damage was moderate. In a port facility of Derince, a warehouse collapsed by a fallen crane and subsided backfill soil were observed. The crane fall were supposed to be caused by the ground depression or pile collapse (Photo 2.2.15). In Istanbul, any remarkable building damage was not observed. However, in Avcilar, borders on Istanbul on the northeast, some collapsed mid-rise buildings were found in places (Photo 2.2.16). The dispersed distribution of building damage was supposed to be due to soil condition.

Observed Damage

As remarkably observed in Golcuk and Adapazari, spatial distribution of building damage was supposed to be affected by the ground structure and liquefaction. A large number of buildings suffered serious damage that was constructed in improper site, such as on active faults and in areas of high liquefaction potential. Generally speaking, however, the high damage ratio might be due to the structural features mentioned above, rather than the strong motion characteristics. A majority of the residence building collapses in soft first story (Photo 2.2.2). To give considerable factors of the cause, following factors seem to be the major factor of collapse process: 1) soft story without seismic resistant wall; 2) poor confinement reinforcement in beam-column joints; and 3) heavy load against weak first story. Generally, most of residence building perform alterations of adding upper floors without strengthen the existing structure. Another typical pattern of whole building collapse is “pancake collapse”. The majority of the collapse seems to be due to the failure of a certain story, and that caused layer collapse of other stories (Photo 2.2.17).

Table 2.2.2. Building damage assessment (As of 12 September 1999).

District	Destroyed	Moderately Damaged	Lightly Damaged
Bolu	3,226	4,782	3,233
Bursa	32	109	431
Eskisehir	70	32	204
Istanbul	3,614	12,370	10,630
Kocaeli	23,254	21,316	21,481
Sakarya	20,104	11,381	17,953
Yalova	10,134	8,870	14,459
Total	60,434	58,860	68,391

Photo 2.2.11. Collapsed first story of residence building in Aydinkent.

Photo 2.2.12. Submerged buildings and ground depression in Golcuk.

Photo 2.2.13. Collapsed buildings caused by ground failures in Adapazari (Refer to color Photo 4).

Photo 2.2.14. Damaged columns and walls in piloti of residence building, Yarimca (Refer to color Photo 5).

Photo 2.2.15. Warehouse damaged by crane fall, Derince Port.

Photo 2.2.16. Residence buildings next to collapsed building in Avcilar.

Photo 2.2.17. Pancake collapse of residence building,
Yalova-Golcuk (Refer to color Photo 6).

2.2.3 Summary

Survey on building damage was performed in the district of Avcilar, Istanbul, Yarimca, Derince, Izmit, Yalova, Degirmendere, Golcuk, Adapazari, and Sapanca. The results of survey can be concluded as follows; 1) Most of the building damage seems to be due to the poor structural configuration and poor detail of structural elements, rather than the strong motion characteristics. 2) Poor construction practice also gave rise to poor performance of structure. As for the middle and small-scale residence building, quality of material and construction seemed worse than large one. 3) A large number of buildings suffered serious damage that was constructed in improper site, such as on active faults and in areas of high liquefaction potential. 4) Structural performance described in the 1975 code was not insufficient for the earthquake. However, earthquake-resistive details and design philosophies in the code did not accompany construction practice.

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2.3 Ground Failure

Ground failures occurred during the 1999 Kocaeli earthquake, Turkey, were widely distributed and caused damage to buildings, structures, and lifelines in the region between Adapazari and Yalova. The most remarkable ground failures in the region were fault scarp and soil liquefaction. Fault scarp was observed in several areas, for example, in Golcuk, Sapanca, and Adapazari. Soil liquefaction was observed in several areas along the earthquake fault within a band of about 10km. In particular, the most remarkable damage due to soil liquefaction was observed in Adapazari, where is about 6km away from the fault scarp on the northern block. Besides, Adapazari is on a sedimentary basin in landlocked area located to about 50km from Black Sea, and very few case of such liquefaction in landlocked area has been reported in the past earthquakes. In this chapter, fault scarp, soil liquefaction, and their damage to buildings and structures are reported considering mainly of relations between conditions of structural damage and those of ground failures. One of the authors was a member of the Reconnaissance Team of AIJ (Architectural Institute of Japan) for this Turkey earthquake, therefore, some of the ground surveys and their results shown in this chapter are also of those by the AIJ Team.

2.3.1 Outline of Surveys

Ground surveys were performed in the following three districts in Turkey: 1) Kavakli district in Golcuk; 2) southern shores of Lake Sapanca; and 3) central part of Adapazari, from 11th to 13th, Sep. 1999. Ground failures and damage to foundations of buildings were searched in each district on foot, and their locations were marked on maps. Building damage due to ground failures, for example, settlement and inclination of building, relative displacement between building and ground, were measured, and some of them were recorded.

Additional surveys were conducted in the same area as mentioned above from 18th to 20th, Mar. 2000, about seven months after the main shock. The movement of the water front line in Golcuk and Lake Sapanca was measured, and building damage due to ground failures in the northern part of Adapazari was recorded. The results of the both two surveys can be summarized as below.

2.3.2 Results of Surveys

Kavakli District, Golcuk

Kavakli district is in the northeast area of Golcuk, where is between Ataturk main street and the coastline. Figure 2.3.1 shows a schematic map of Kavakli district. Fault scarp was observed on ground at several sites in the district (for example, Photo 2.3.1), and its traveling direction is roughly shown in Figure 2.3.1. Maximum vertical and horizontal gaps of the fault scarp in this district were about 2m and 1.5m, respectively. This ground scarp in the district might be due to the sub-fault, because its traveling direction (mainly northwest-southeast) could be deferent from that of the main-fault (east-west direction) as shown in Figure 2.3.1. The main-fault was investigated and/or estimated by several research institutes, for example, by Bogazici University, Istanbul, Turkey (http://www.koeri.boun.rdu.tr/). Around a site shown in Photo 2.3.1, most of buildings on the lower side, i.e., the northern side, of the fault scarp were undamaged or damaged slightly, although even some buildings on the upper side, i.e., the southern side, of the fault scarp were collapsed.

In this district, a gymnasium with pile-foundation was just located on and was damaged due to the fault scarp (Figure 2.3.1). The pile-foundation of the building was exposed due to vertical gap of the fault scarp (Photo 2.3.2). Photo 2.3.3 shows the head part of the exposed piles arranged at the northeast corner of the building foundation. In the photo, the head part of the left-side pile was damaged, and its failure mode could seem to be shear one. These observations suggest that the failure on the pile-head could be caused due to horizontal gap of the fault scarp. On the other hand, the upper structure of the building had less serious damage, except shear cracks on three columns of the building. Namely, this gymnasium on the fault scarp was caused severe damage

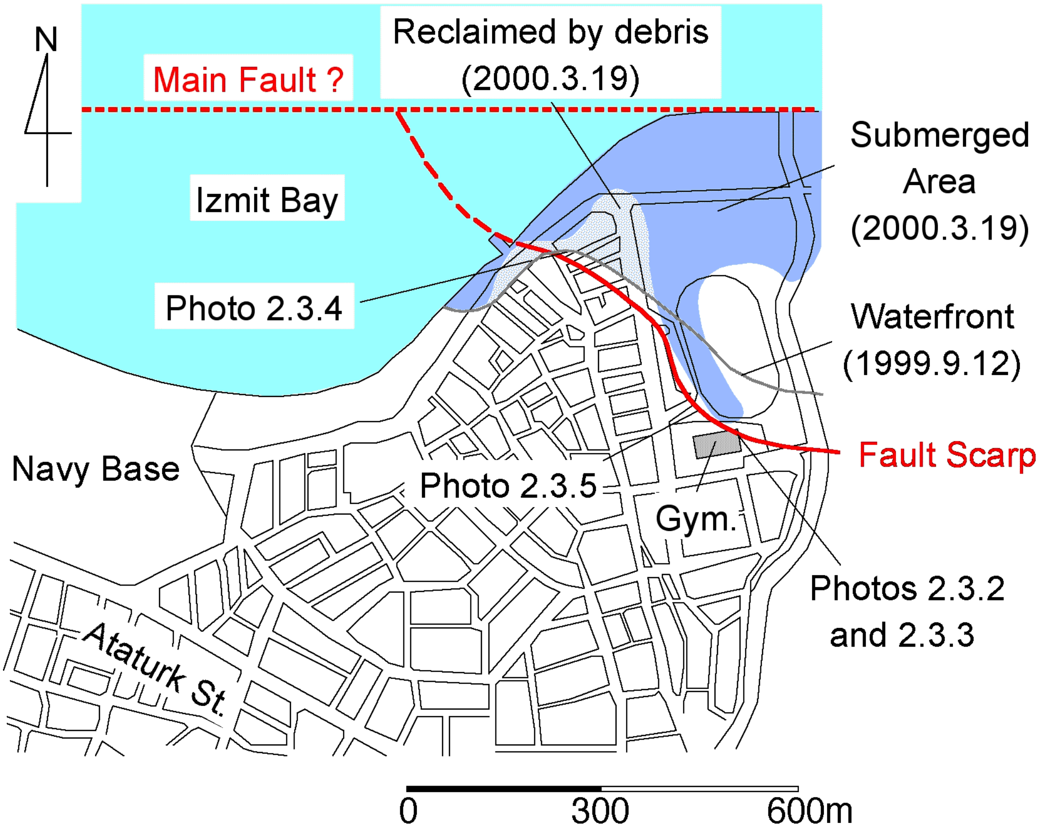

Figure 2.3.1. Schematic plan of Kavakli district, Golcuk.

on the head part of pile-foundation only.

Most of the area on the northern side, which is the lower side, of the fault scarp was submerged. The submerged area is also shown in Figure 2.3.1. This submerged area could be enclosed by the main- and sub-faults as shown in the figure, suggesting that the ground subsidence on the northern side of the fault scarp might be caused due to horizontal displacements of the both two faults. Besides, depressions of ground were observed at several sites near the coastline. In Photo 2.3.4, the ground just under the two reinforced concrete framed buildings subsided about 3m and was submerged. However, the structural damage and inclination were hardly found on the both buildings. On the other hand, a reinforced concrete framed building located in the vicinity of the buildings was collapsed, and the ground just under the building could not be seen as it subsided. This trend might be similar to that observed around the fault scarp stated above.

After seven months, the extent of the submerged area was smaller than that in Sep. 1999. The location of waterfront moved seaward as shown in Figure 2.3.1. The eastern area of the field in the stadium was not submerged; on the other hand, the western area was submerged as shown in Photo 2.3.5. Moreover, the eastern residential area of the stadium, which was submerged in Sep. 1999, was almost dry. According to comments of local residents, the waterfront line moved seaward about one month ago.

Photo 2.3.1. Fault scarp in Kavakli district, Golcuk, Sep. 1999 (Refer to color Photo 7).

Photo 2.3.2. Exposed pile-foundation of a gymnasium in Kavakli, Golcuk, Sep. 1999 (Refer to color Photo 8).

Photo 2.3.3. Damaged pile-head of a gymnasium in Kavakli district, Golcuk, Sep. 1999 (Refer to color Photo 9).

Photo 2.3.4. Depression of ground under buildings in Kavakli, Golcuk, Sep. 1999 (Refer to color Photo 10).

Photo 2.3.5. Fault rupture and submerged field in Kavakli district, Golcuk, Mar. 2000 (Refer to color Photo 11).

Southern Shores of Lake Sapanca

Figure 2.3.2 shows a rough sketch of a small community located on the southern shores of Lake Sapanca. Most of the lakefront area in this community subsided and was submerged. Some breaks could be observed on ground, and these might be due to fault (sub-fault) difference.

In the vicinity of the lakefront, several settled and/or inclined buildings could be observed. For instance, the building (hotel) shown in Figure 2.3.2 subsided and inclined to the lakeside and its 1st floor was submerged (Photos 2.3.6 and 2.3.7, on Sep. 1999). This building consists of two-ridges of annex and old mansions, and a roofed passage between the both mansions fell down during or after the earthquake. Except the above damage, any damage could not be observed in the superstructure material of this building.

Photo 2.3.8 shows a relative displacement between ground and building, on Sep. 1999, which was a residential house with a mat type foundation. This residential house was located to the shores of Lake Sapanca as shown in Figure 2.3.2. Maximum horizontal gap occurred between ground and the building was about 2m wide. In Photo 2.3.8, some boundaries where ground had touched the building before the earthquake could be observed on the wall of the building, and no damage could be found in the upper structure. These suggest that ground might move to the lakeside (left-side in Photo 2.3.8) and subsided during or after the earthquake and that this relative displacement might be caused due to both or either of liquefaction and lateral spreading of the ground.

A swimming pool, which is 25m long, is located close to the above residential house as shown in Figure 2.3.2. According to some neighborhood, there was information that the swimming pool was filled with water before the earthquake, however, most of the water in the pool had gone elsewhere after the earthquake. Although some cracks, maybe due to fault scarp, were observed at an edge of the swimming pool side, no damage and no water leak could be observed on the pool itself. This might suggest that predominant period of ground motions during the earthquake at the site was very long and that magnitude of amplitude of the motion was very large, when the information was true.

After seven months, the extent of the submerged area was larger than that in Sep. 1999. The extended submerged area is also shown in Figure 2.3.2. The waterfront moved toward inland by several meters. The hotel as shown in Photo 2.3.6 was submerged as shown in Photo 2.3.9. According to comments of local

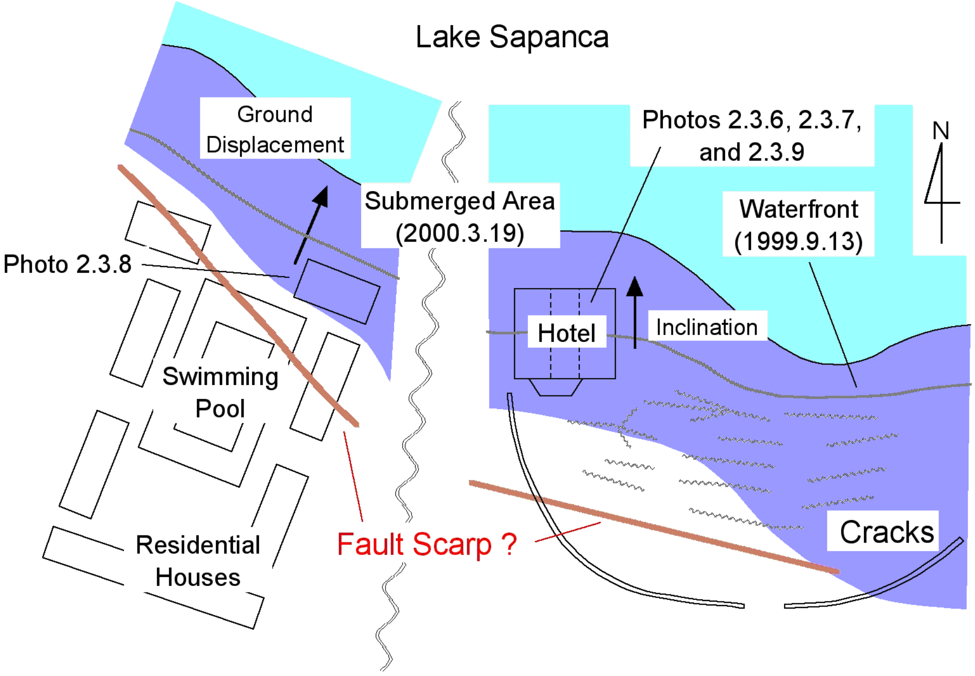

Figure 2.3.2. Rough sketch of a small community on the southern shore of Lake Sapanca (Refer to color Figure 1).

residents, the water level of the lake was rising, because the amount of the water intake supplied to cities around the lake was decreasing. However, the amount of the waterfront movement in this area was larger than that in other area along the lake. The extension of submerged area on the southern shores of Lake Sapanca might be due to not only the rise of water level in the lake, but also the change in ground surface configuration because of lateral spreading of the ground.


'99 9 13

Photo 2.3.6. Submerged hotel located on the shore of Lake Sapanca, Sep. 1999 (Refer to color Photo 13).


'99 9 13

Photo 2.3.7. Submerged 1st floor of Sapanca Hotel, Sep. 1999 (Refer to color Photo 14).


'99 9 13

Photo 2.3.8. Relative displacement between ground and building in Sapanca, Sep. 1999 (Refer to color Photo 15).


'00 3 13

Photo 2.3.9. Submerged hotel located on the shore of Lake Sapanca, Mar. 2000 (Refer to color Photo 16).

Central Part of Adapazari

Adapazari is in an alluvium plain formed by River Sakarya on a sedimentary basin, and central part of the city is located to about 50km apart from Black Sea. The most remarkable damage in this district was settlement and inclination of building and up-heave of ground around the building (for example, Photo 2.3.10). Many cracks on pavement were also observed, and they could be caused due to ground deformations. Remarks of sand boils could be observed at a few sites in the district. Besides, at a few sites in this district, shallow ground water level could be confirmed in a trench that might be caused due to relative horizontal displacement between two buildings. Based on the above observations, it is suggested that these ground failures could be due to liquefaction of subsurface soils.

Ground surveys were performed in the areas shown in Figure 2.3.3, and ground failures, for example, settlements and/or inclinations of buildings, observed in the survey areas are marked on the figure. The results of twice survey, Sep. 1999 and Mar. 2000, are shown in this figure. Based on the figure, it is suggested that ground failures could be observed concentrically at several local sites in the areas. In this district, furthermore, the Reconnaissance Team of the Japanese Geotechnical Society (JGS) also performed ground surveys and detailed investigations on building damage. The outlines of liquefied and nonliquefied areas estimated by the JGS Team (JGS, 2000) are shown in Figure 2.3.4 comparing with the results of our surveys. Based on the estimated results by the JGS, the liquefied area with a band of several hundred meters could be surrounding the nonliquefied area where was located around the railway station shown in Figure 2.3.4. Based on our survey results, however, ground failures could be observed at the several local sites in the nonliquefied area estimated by the JGS. In fact, as reported by the JGS, spatial variations of ground failures were indistinct at several sites in this district, so it might be hard to distinguish clearly between liquefied and nonliquefied areas. Therefore, it is suggested that both our and the JGS results should be inspected and be re-compiled based on further detailed surveys in future.

Many buildings, that settled or inclined, had less serious structural damage on their upper structures. Settlements of buildings were more remarkable than the inclinations. However, a few buildings inclined to a large extent. For example, a four-storied reinforced concrete framed building (hereby called Building A), which was located in the northeast side of the crossing of Sakarya Street and Izmit Street shown in Figure 2.3.4, inclined about 60 degree to the short side direction of the building (Photo 2.3.11). There was information that the inclination of the building was about 30 degree immediately after the main shock and it increased up to about 60 degree in the following 10 days. The foundation was a mat type and its embedding depth was about 80 cm. Subsurface soils under the foundation consisted mainly of gravel and sand. The building was located near a borderline between liquefied and nonliquefied areas estimated by the JGS (see Figure 2.3.4).

A few buildings, which settled or inclined, had serious damage on their superstructure. For example, a five-storied reinforced concrete framed building (hereby called Building B), which was located in Orta district, the north side of Ankara Street shown in Figure 2.3.4, subsided and inclined, and up-heave of ground around the building were observed as a result (Photo 2.3.12). These ground failures could be due to liquefaction of subsurface soils as stated above. On the other hand, the building was also damaged on the top of a column of 1st floor (Photo 2.3.13). At present, we cannot understand when the column was damaged during the earthquake, before or after soil liquefaction. To understand this matter, more detailed investigations and examinations might be required.

Settlements of the buildings in liquefied area ranged from several ten-centimeters to 1.5m. For example, a six-storied reinforced concrete framed building (hereby called Building C), which was located at the southeast corner of Sakarya Street and Izmit Street shown in Figure 2.3.4, settled by about 1 m without any structural damage on the upper structure (Photo 2.3.14). There was no information regarding foundation of the building. In the northwest side of the crossing of Sakarya Street and Izmit Street, many collapsed buildings were observed. On the other hand, in the southwest side of that crossing, damage to buildings seemed to be slight.

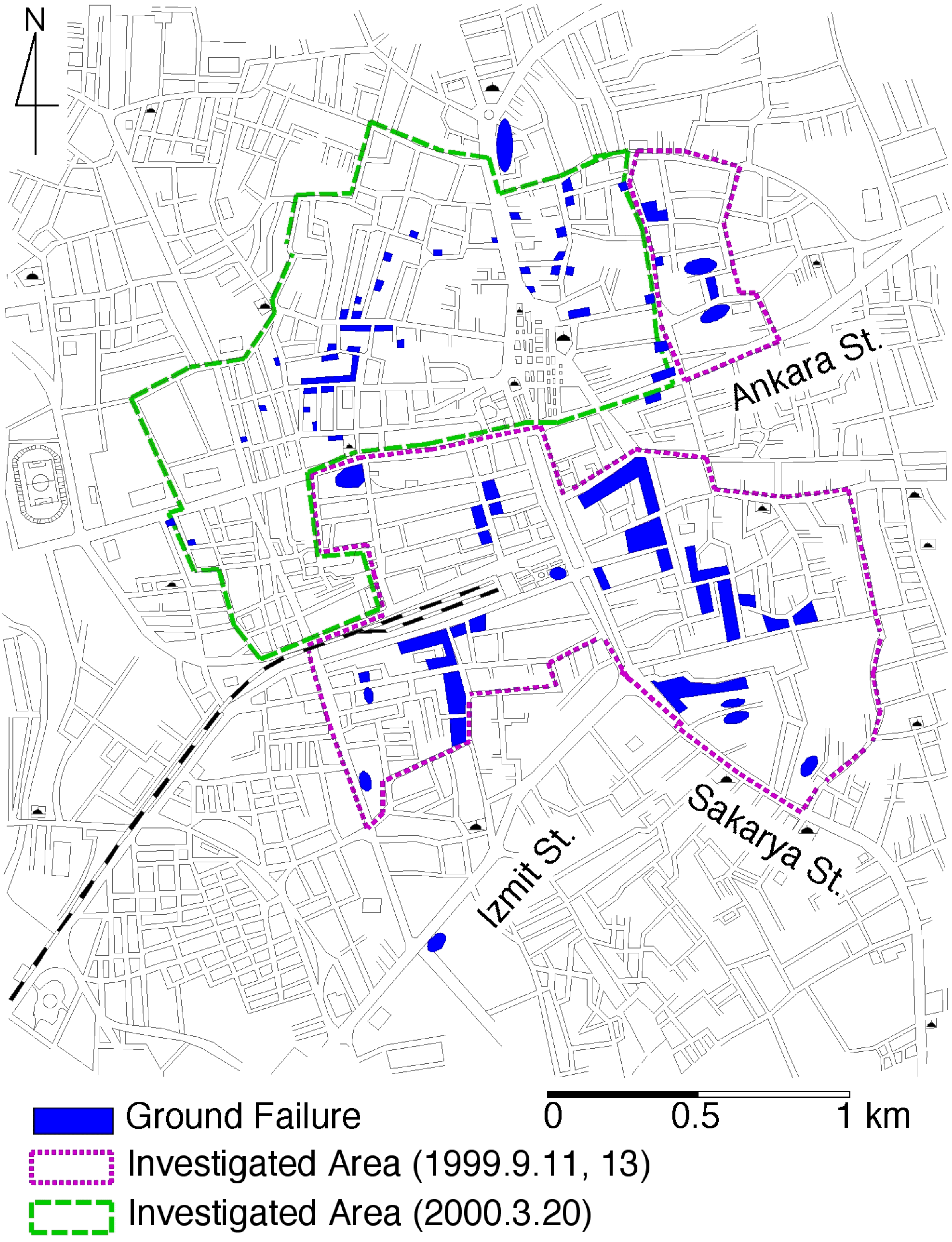

Figure 2.3.3. Map showing investigated areas and locations of ground failures in Adapazari.

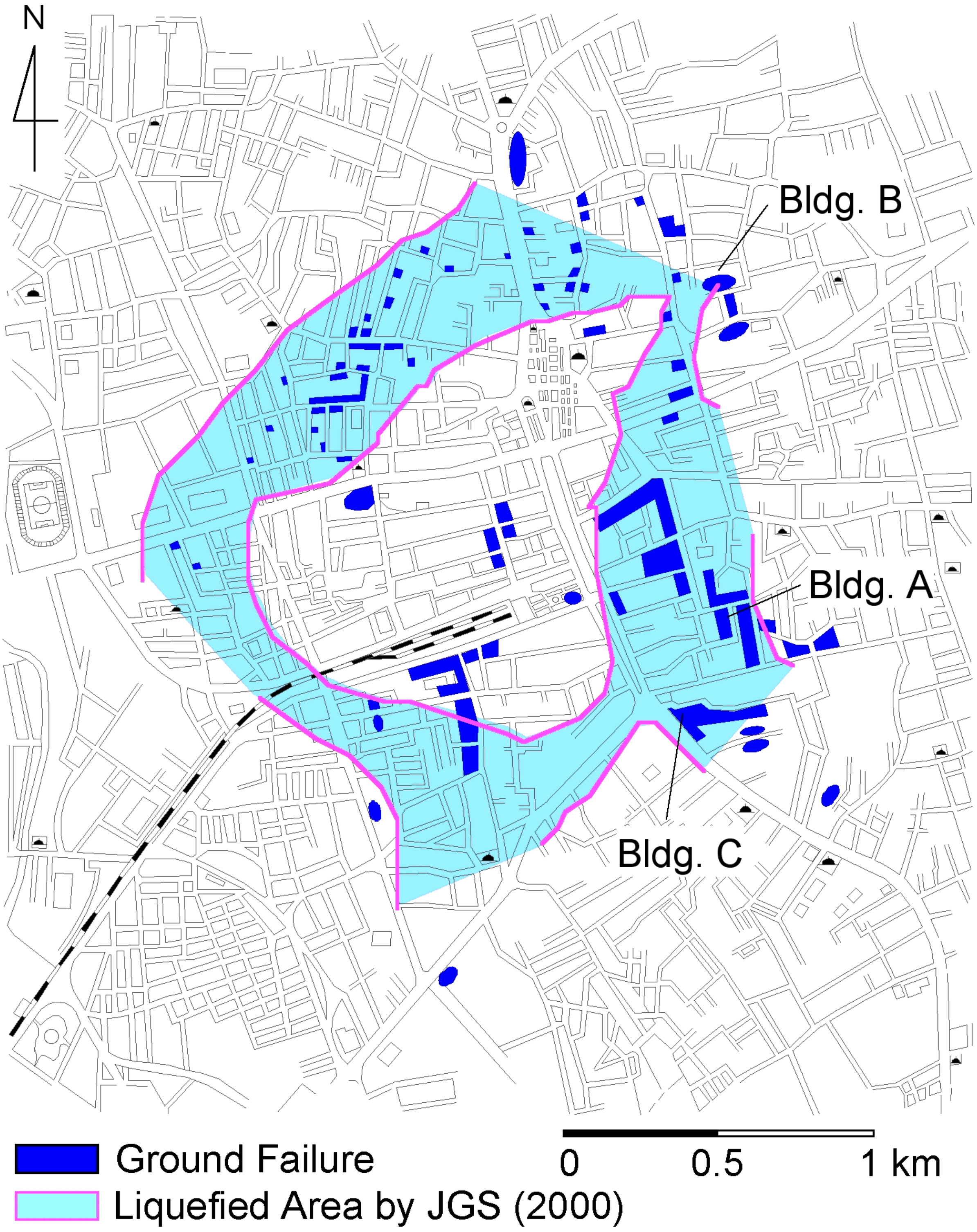

Figure 2.3.4. Map showing ground failures and estimated liquefied areas in Adapazari (JGS, 2000).

Photo 2.3.10. Up-heave of ground in Adapazari, Sep. 1999.

Photo 2.3.11. Inclination of Building A in Adapazari, Sep. 1999 (Refer to color Photo 12).

Photo 2.3.12. Inclination of Building B in Adapazari, Sep. 1999.

Photo 2.3.13. Damaged column of 1st floor of Building B in Adapazari, Sep. 1999.

Photo 2.3.14. Settlement of Building C in Adapazari, Sep. 1999.

Based on the results of detailed investigations on building damage by the JGS, it is suggested that number of stories and foundation width of building could have a significant effect on settlement and tilt angle of the building. Of course, the above our observations on building damage are in good agreement with that trend reported by the JGS. Considering these observations and suggestions stated above and also the results of recent studies on local site effects, it is indicated that source and path of seismic motion, sedimentary basin structure, subsurface soil condition, and building and foundation information are all quite important in order to understand mechanism of damage to soils and foundations in Adapazari region. This indication could apply to soil and building damage in the other region.

2.3.3 Summary

Ground surveys were performed in Kavakli district in Golcuk, southern shores of Lake Sapanca, and central part of Adapazari, to investigate damage to buildings due to fault scarp and soil liquefaction during the 1999 Kocaeli Earthquake, Turkey. The results of surveys in the three districts can be concluded as follows: 1) In Golcuk, most of structures on the lower side of the fault scarp and ground depressions were undamaged or damaged slightly, although even several structures on the upper side of those were collapsed; 2) The gymnasium located on the fault scarp in Golcuk was damaged on the head part of pile-foundation only; 3) Ground failures observed in Sapanca might be caused due to either or all of liquefaction, lateral spreading of subsurface soils, and the fault scarp on ground; 4) The extent of the submerged area changed after seven months of the main shock; 5) Adapazari was damaged heavily due to soil liquefaction, which could be observed concentrically at several local sites; 6) Spatial variations of ground failures were indistinct at several sites in Adapazari, so it might be hard to distinguish clearly between liquefied and nonliquefied areas. Therefore, it is suggested that both our and the JGS results should be inspected and be re-compiled based on further detailed survey in future; and 7) Source and path of seismic motion, sedimentary basin structure, subsurface soil condition, and building and foundation information could be all quite important in order to understand mechanism of damage to soils and foundations.

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Reference

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