Reconnaissance survey on geotechnical damage caused by February 6, 2023, Kahramanmaraş Earthquake, Türkiye

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Key Facts
- Hazard Type: Earthquake
- Date of the disaster: February 6th, 2023
- Location of the survey (Lat. Lon., name or address): Islahiye, Tepehan, Iskenderun, Antakya, Golbasi, Kahramanmaras
- Date of the field survey (if any): March 29th – April 2nd 2023
- Survey tools (if any): Drone, Digital camera, GPS, Laser rangefinder, Microtremor
- Key findings: landslides, liquefaction, inundation, settlement, embankment failure

Key Words : *Kahramanmaras Earthquake, geotechnical damage, liquefaction, lateral spread, landslide, inundation, settlement*

1. INTRODUCTION

A major earthquake of Mw 7.7 with a focal depth of 8.6 km has struck Pazarcık, Kahramanmaraş, Türkiye (epicenter: 38.288N, 37.043E) on February 6, 2023 at 4:17 (1:17 GMT)[1)]. A second major earthquake of Mw 7.6 with a focal depth of 7.0 km in Elbistan, Kahramanmaraş (epicenter: 38.089N, 37.239E) followed 9 hours later at 13:24 (10:24 GMT) (Fig. 1). A large aftershock of Mw 6.4 followed on February 20 with a focal depth of 21.73 km in Hatay (epicenter: 36.037N, 36.021E). As a result of these earthquakes 11 cities with a total population of 14,013,196 people have been affected.

These earthquakes have led to loss of 50,783 lives and also great economical losses by the devastation of several structures[2, 3]. A geotechnical reconnaissance team supported by the Japan Society of Civil Engineers and the Japanese Geotechnical Society took part in the survey led by the Architectural Institute of Japan. This report summarizes the observations of the geotechnical team.

The recorded strong motions given in this report belong to the first earthquake with Mw 7.7 at Pazarcik, Kahramanmaras. In Fig.1 locations covered in the reconnaissance study are marked with red circles, while the epicenters of the 6th February Earthquakes are marked with stars on the Türkiye Earthquake Hazard Map, which is accessible on AFAD[4] website with active faults marked by active fault study of MTA[5].

The reconnaissance survey was carried out with the schedule given in Table 1.

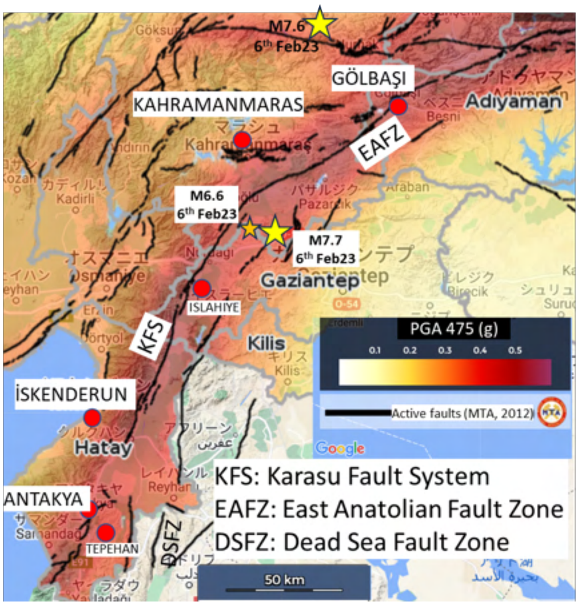


Fig. 1 Türkiye Earthquake Hazard Map of the region covered in this study with epicenters of the 6th February earthquakes (after AFAD[4], Active faults by MTA (2012)[5]).

2. REGIONAL GEOLOGY AND TOPOGRAPHY OF THE AFFECTED AREA

The affected region lies in the southeastern part of Türkiye. The general topography of the region is a valley surrounded by uplifted mountains from Kahramanmaraş to Antakya, where the Amanos mountains with pre-Cambrian to Eocene rock units located to the west, Southeastern Anatolian Mountain range with Cretaceous to Miocene rock units to the east, and the Baer-Bassit range predominantly with Cretaceous ophiolite and Miocene rock units to the south. The residential areas heavily affected are located in the units that belong to the Quaternary in the graben, which generally consists of alluvial fans, alluvium, and basaltic compound volcanic rocks. Due to Arabian and African tectonic plates and Anatolian block intersect in this region, various topographic features such as river valleys, mountain ranges and plateaus are formed with high seismicity. In this region, East Anatolian Fault Zone (EAFZ), Dead Sea Fault Zone (DSFZ) and Karasu Fault System (KFS) are the main fault zones[6)7].

Table 1 The schedule of reconnaissance survey.

Date	Damage, city
29/03 /2023	Damage to road embankment, Highway O-52
30/03	Reclaimed land and Cay Neighbourhood in Iskenderun District, Hatay
31/03	Rockfall and landslide dam in Islahiye Landslide at Tepehan, Altinozu District, Hatay Antakya District, Hatay
01/04	Golbasi district, Adiyaman Damage to the road and retaining structure on the Malatya-Golbasi Yolu
02/04	Onikisubat and Dulkadiroglu Districts, Kahramanmaras

3. GEOTECHNICAL RELATED DAMAGES IN THE AFFECTED REGION

In this section the geotechnical related damages observed in the affected region is reported, starting from the cities visited at the north of the region moving to the south and observations made along the road is summarized.

(1) Golbasi District, Adiyaman

Golbasi is a district of Adiyaman City, located in the southeastern part of Türkiye with a surface area of 784 km^2 at an altitude of 866.8 m above sea level. While early research has interpreted the formation of Golbasi basin as a pull apart structure or a fault wedge basin, in a recent study it was discussed that the basin is an abandoned large faulted valley[8]. Suitability of the Golbasi district as a settlement area was reported by Akil et al.[9] by discussing geological and geotechnical properties in the region. As a result of their study, two main regions are classified in the district as Quaternary alluvium and swamp sediment region, where the settlement is allowed in the alluvium region with precautions such as detailed ground investigation at each parcel and designing foundation accordingly. In this region, some parts were classified as medium level for susceptibility to liquefaction, where groundwater level was high (1-3 m below ground level (bgl)) and deposited with medium-dense sands and gravelly soils. Additionally, it was stated that in case a structure is built on such an area, then the foundation should be designed to withstand effects of liquefaction or soil improvement should be performed.

Fig. 2 Tilted houses in Golbasi, Adiyaman due to effect of liquefaction (37.79035N, 37.6519E).


Fig. 3 Tilted houses in Golbasi, Adiyaman due to effect of liquefaction (37.787739N, 37.643769E).


Fig. 4 Parked cars crashed under the settled building (37.787861N, 37.643083E).


Fig. 5 A sample of ejected soil (37.788194N, 37.642861E).

During our survey, we observed many settled and tilted midrise buildings as typically shown in Fig.2 and Fig.3, due to the effect of liquefaction and bearing capacity loss. The largest observed settlement was about 1.5 m, which resulted in parked cars crashed under the 1st floor balcony level (Fig.4). Another structure with a 0.8 m thick mat foundation tilted until it leaned against the neighboring building. Ejected soil (Fig.5), which was mainly reddish-colored silt and clay was also observed with a plasticity index of 17.7. Additionally lateral spread in the region surrounding the Golbasi lake was observed.

It was not only the old buildings, but several newly built structures also experienced similar types of tilting and subsidence related damages. The region is classified as suitable for a settlement with earthquake hazard precautions, meaning that adequate soil investigations before construction and adequate design and construction of a foundation accordingly is desirable. Since the observations in the region showed the existence of ground with liquefaction potential, these precautions listed above should be followed strictly for the future structures.

(2) Onikisubat and Dulkadiroglu District, Kahramanmaras

Kahramanmaras city located in the central southeastern region of Türkiye, is a tectonic-based basin with the central region of city located on the quaternary alluviums dominantly, which are mainly composed of loose textured and cementless gray/light gray, gravel, sand, and silt, with a thickness reaching up to 300 m. Groundwater level in the central region of the city vary between 0-15 m bgl, begin relatively higher in the southern part of this region[10,11].

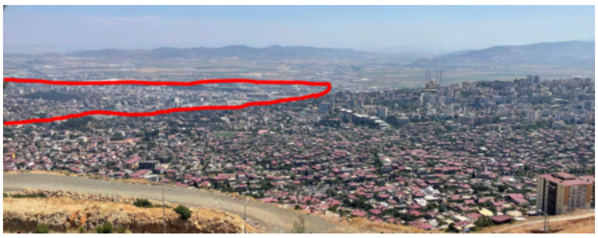


Fig. 6 A view of plain and hilly region of central Kahramanmaras (from a hill at 37.60141N, 36.91263E).

Fig. 6 is a view of Dulkadiroglu and Onikisubat Districts (from a hill at 37.60141N, 36.91263E) that forms the central part of Kahramanmaras City. Although both districts were affected by the earthquake, more severity was observed in the area circled with a red line, which is located on the plain region. Being the central part of the metropolitan city, this region was as densely populated as the hilly region on the right side of the photo. Since several structures have either collapsed or demolished due to being heavily damaged, which resulted in clear observation of the different damage levels in the plain and the hilly area. Although it is hard to conclude that the damages are due to the ground effect only, it is clear that ground effect contributed to the damage level observed in the region.

Fig. 7 A well-performed reinforced earth retaining wall with a damage occurred during the demolishing works of heavily damaged building nearby (37.57320N, 36.91964E).

The photo of the damaged region given in Fig. 7 was taken at Ebrar housing estate consists of 12 blocks, of which 8 totally collapsed and 4 heavily damaged, each block with 10 floors with 4 flats each floor (total of 320 flats totally collapsed). Tobita et al.[12] reported that the dominant period of this damaged site was about 0.24 s, longer than any other sites they measured in Dulkadiroglu and Onikisubat Districts. Although the reinforced earth retaining wall performed well during the earthquake, the damage seen in the photo happened during the demolishing works of the heavily damaged buildings.

(3) Landslide in İslahiye

Fig. 8 shows a landslide triggered by the earthquake which resulted in formation of a natural dam at Degirmencik Creek Basin in Islahiye. Observations were made by a drone at a bauxite mine, which is on the top of the mountain where the landslide had happened. This basin is primarily composed of Paleozoic dolomites, Mesozoic limestones, and Quaternary slope debris-cone, alluvial, and basalt units[13]. The altitude in the landslide region is around between 550 m to 1084 m above the sea level.

Nearest recording at Station 2718 around 3 km distance from the landslide is shown in Fig. 9 and maximum recorded acceleration is 654 cm/s^2. Both

Fig. 8 Landslide at Degirmencik Creek Basin in Islahiye, Gaziantep (37.00537N, 36.59151E).

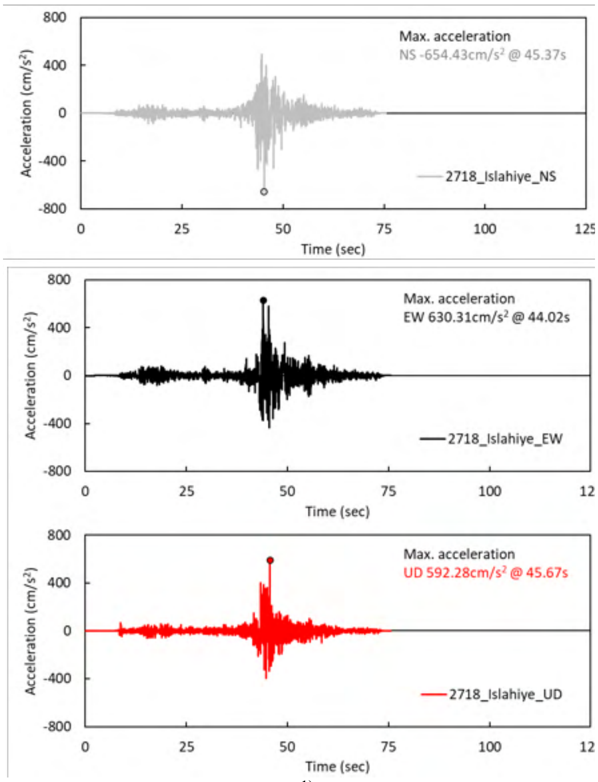


Fig. 9 Recorded strong motion[1] at Station 2718 (37.00777N, 36.6266E).

Fig. 10 Rockfall in Idilli (36.99072N, 36.57813E).

the road and the stream between Idilli and Degirmencik neighborhood was blocked with the landslide and a natural dam lake was formed. Since there is a risk of flooding The General Directorate of State Hydraulic Works (DSI) opened a spillway and the 15 m water level decreased to 6 m within five months[14)].
In Idilli, rockfall was also observed as shown in Fig. 10 at around 2 km distance from the abovementioned landslide and the observed type of rock was dolomite.

(4) Iskenderun District, Hatay

Iskenderun is a port town of Hatay province located in southern Türkiye with town center at a 4 m altitude. In Iskenderun, the general ground formation is Quaternary alluviums including silt and sandy layers with liquefaction risk[15)].

The main road called Ataturk Boulevard sits on the reclaimed area in the coastal region of the town. As shown in Fig. 11 this road is inundated after the earthquake due to severe ground settlement and damage to the lifelines underneath with liquefaction. Additionally, water coming out of the manholes and local residents removing water with pumps from the basement of the buildings was observed. Lateral spread and several ejected sands were also observed in this area. In Fig. 12 cracks on the road around the manholes are observed in longitudinal direction to the seaside. Seven months after the earthquake there were TV reports showing the region was still inundated[16)].

The collapsed structure in Fig. 13 was a structure consisting of two blocks, which was completed in 2019. First block collapsed by the effect of the first earthquake, while the second block lost the stairs and totally collapsed by the effect of the second earthquake[18)]. A ground investigation in this region reported that the ground is mainly formed of quaternary silty sand and sandy clayey silt, which is formed

Fig. 11 Inundation of Ataturk Boulevard in Iskenderun (36.59280N, 36.16768E).

Fig. 12 Cracks along Ataturk Boulevard in Iskenderun due to lateral spreading.

Fig. 13 A collapsed structure in front of Ramada hotel in Iskenderun (36.58899N, 36.17712E), photo on the left taken after first earthquake[17)], photo on the right during the survey.

Fig.14 Sidewalk damage with the effect of liquefaction (36.58954N, 36.17355E).

Fig.15 An example of tilted buildings in Cay Neighborhood, Iskenderun (36.587222N, 36.176639E).

due to abrasion, weathering, erosion and sedimentation of the Miocene claystone, sandstone and conglomerate in the region. Ground profiles of boreholes generally consist of fill up to 1.5 m deep, followed by silty sand layer up to 20 m deep, and groundwater level is 1 m bgl with high salt content. The predominant ground periods are reported to be 0.64 to 0.7s with Vs30 being 239 to 263 m/s[19].

At several locations sidewalk damage with liquefaction was also observed (Fig. 14). Additionally, there were differential settlements and tilting of several structures (Fig. 15).

(5) Antakya District, Hatay

Antakya district (shaded with yellow in Fig. 16 based on Emre et al. (2012)[20]) is located to the east and west of the Asi River, in the valley that continues south after crossing the Amik Plain. The boundaries between the mountainous areas in the north, composed of rocks with different geological ages, and the plain is represented by the faults (Fig. 16). The region located between the Asi River through the skirts

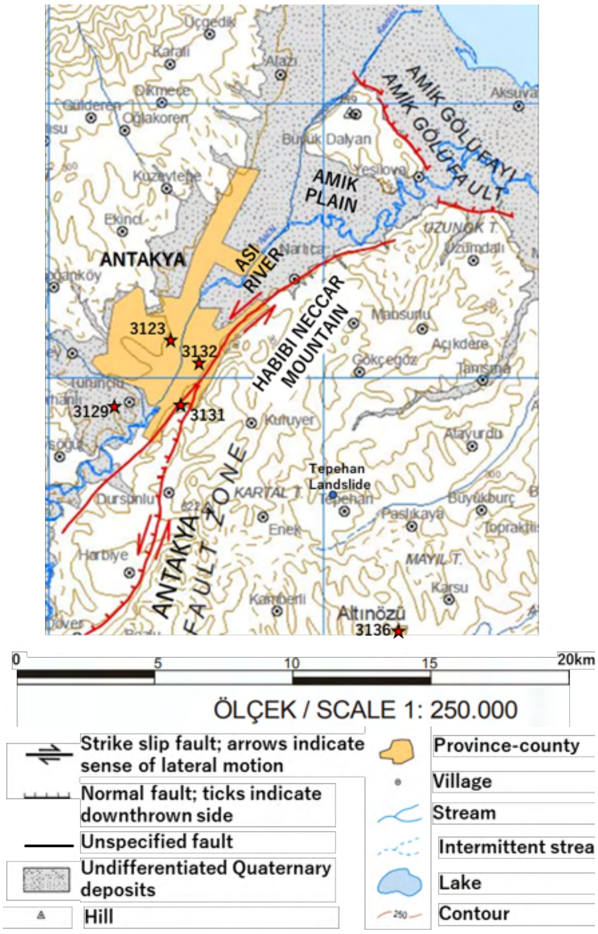


Fig. 16 Location of Antakya City and active faults in the region[20] with the location of the strong motion stations (marked with a red star).

of Habibi Neccar Mountain (its steep slopes vary between 100 and 250 m in height) is called Old Antakya, while the region on the west of Asi River, the gently sloping hilly areas have an elevation ranging from 100 to 130 m and consist of Pliocene sediments, called New Antakya. Average altitude of the city is around 80 m[21].

Over et al.[22] has reported a borehole in New Antakya region, consisting of 0-2m bgl landfill, 2-4m bgl silt with sand and clay, 4-17m bgl sand with silt and sand, with groundwater around 3m bgl averagely and located at a region where natural period of the ground is less than 0.2 s. Fig. 17 shows the heavily damaged structures near the borehole location. Tobita et al.[12] reported that H/V spectral periods were 0.03 sec and 0.14 sec at Figs. 17 a and b, respectively.

(a)

(b)

Fig. 17 Heavily damaged buildings in Antakya; (a) 36.19846N, 36.15393E (b) 36.20186N, 36.16133E.

The values of the natural periods are favorable for structures in terms of earthquake engineering; however, the observed heavy damage rate might be due to the basin effect causing localized amplifications of surface waves, which will be clarified with further detailed studies.

Several structures in Antakya were either totally collapsed or heavily damaged (Fig. 17) and the removal of debris was under effect during the survey. Similar to Kahramanmaras, damaged structures were concentrated in the plain and the damage rate was decreasing through the hilly region. Yet, it is difficult to conclude that the observed damage was only due to ground effect, but it did clearly contribute to the high damage rate. Since the effect was similar in both Kahramanmaras and Antakya, rather ground being the only reason to the damages, an appropriately

Table 2 Maximum absolute acceleration of recorded strong motion at Antakya[1].

Station	Location	Maximum absolute acceleration (cm/s^2)		
		NS	EW	UD
3123	36.15973E, 36.21423N	652	581	840
3132	36.17159E, 36.20673N	501	508	356
3131	36.16328E, 36.19121N	356	354	146
3129	36.13430E, 36.19117N	1161	1198	716

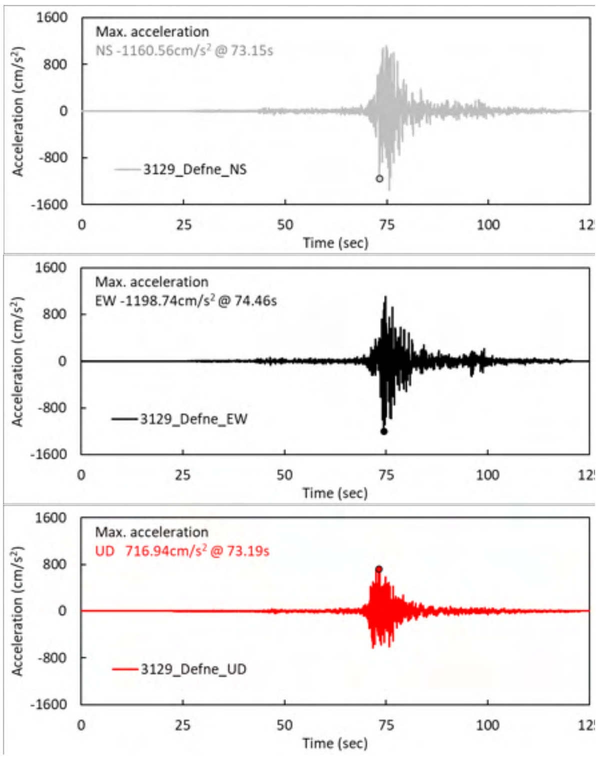


Fig. 18 Recorded strong motion[1] at Station 3129 (36.19117N, 36.6266E).

designed and constructed structure taking into account the ground conditions that they are built on, could be the main reason for the increased damage rate.

A list of the maximum absolute accelerations recorded in the region and the time history of Station 3129 are given in Table 2 and Fig. 18, respectively. While highest maximum absolute accelerations were observed in the basin region (i.e. Stations 3123, 3129), getting closer to the mountain region (i.e. Stations 3132, 3131) maximum absolute accelerations were smaller.

(6) Tepehan, Altinozu District, Hatay

In Tepehan, a large slope failure at an olive field was observed (Fig. 19). In this region, Tepehan formation is mainly represented by sandstone and clayey limestone[23]. The weathered surface of the sandstones within Tepehan Formation is light grayish-brown, while the freshly broken surface is yellowish-beige in color, which was also observed as shown in Fig. 19 during the survey.

The unit is generally loosely cemented, with calcium carbonate ($CaCO_3$) acting as the cementing material. Locals have recovered several fishbone fossils after the landslide from the freshly cut layers. The thickness of the Tepehan Formation is reported to vary between 200 to 500 m and the formation is identified as Middle Miocene[24].

Fig. 19 A close up of top part of Tepehan landslide (36.1609N, 36.2211E)

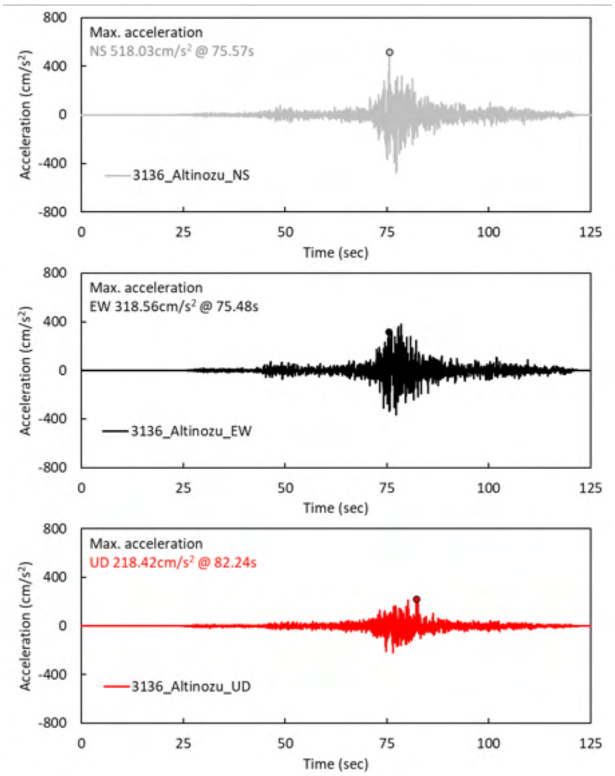


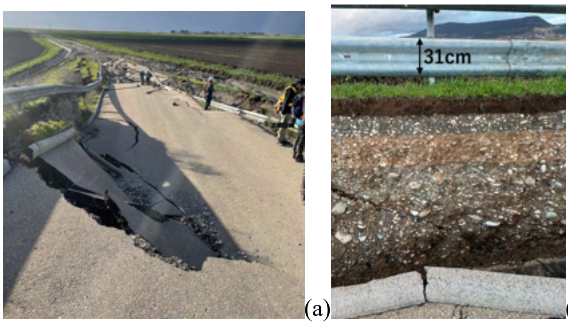
Fig. 20 Recorded strong motion[1] at Station 3136 (36.11593N, 36.24722E)

The hills surrounding the landslide are quite mild slopes and the slope of the landslide was approximately 4°. The landslide affected 500 m long and 100 to 150 m wide region and soil blocks moved while retaining their shapes, which are similar features observed in 2008 Aratozawa landslide[25]. Hence the landslide may have occurred due to the presence of a weak thin layer almost parallel to the surface which is weakened with the effect of the earthquake and resulted in soil blocks above to move while retaining their shapes.

Although there was not any station at the landslide location, the nearest station is Station 3136 (location shown in Fig. 16) in Altinozu, at 5.49km southeast of the Tepehan landslide. The recorded strong motion at this station is shown in Fig. 20.

(7) Observations in between cities on the road

Approach embankment of an overpass bridge crossing the O-52 highway between Gaziantep and Nurdagi experienced a severe settlement damage at both north and south side of the highway. The settlement damage at the north side of the highway is shown in Fig. 21(a), and the cross-section of the embankment became visible at the north side with the settlement of the road is shown in Fig. 21(b). This damage is considered to have happened with the lateral spreading of the embankment as a result of liquefaction of its foundation ground, which resulted in its severe settlement. In fact, a 15 m wide water channel running along the embankment at a 5 m distance had around 10 m decrease in its width.



(a) (b)

Fig. 21 (a) Settlement damage of the embankment observed during the survey (37.28379N, 37.11392E) (b) a cross-section of the embankment

The strong motion recorded at Station 4615, which is about 11.7 km north of the damaged embankment is given in Fig. 22 with maximum absolute accelerations of 585 cm/s^2 NS and 657 cm/s^2 UD.

In Fig. 23 already repaired road embankment, which was reported to be damaged during the earthquake[26] and the damage of retaining wall on the Malatya-Golbasi Road is shown. This damage is possibly due to the liquefaction induced lateral spread towards Goksu stream running along the road embankment.

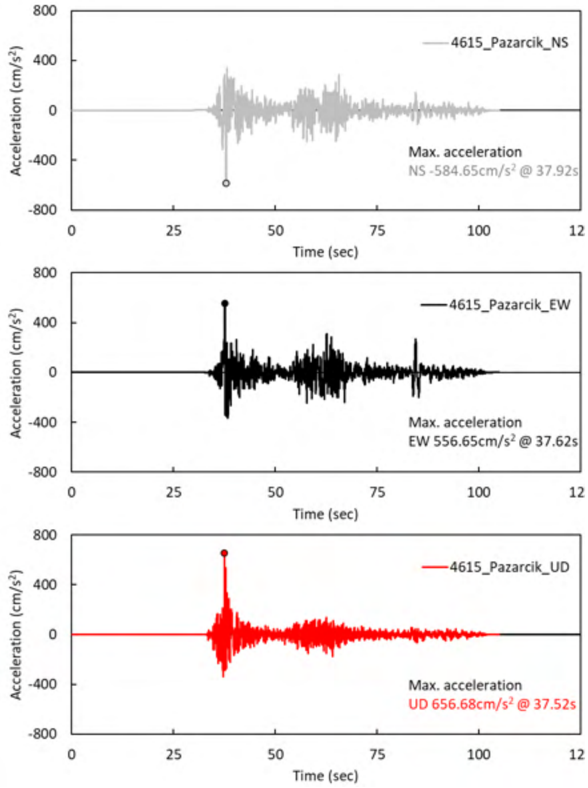


Fig. 22 Recorded strong motion1) at Station 4615 (36.7088N, 37.1123E)

Fig. 23 On the Malatya-Golbasi Road: already repaired road embankment and damage of retaining wall (37.86332N, 37.76760E)

4. CONCLUSIONS

In this paper, a summary of the observations made by the geotechnical members of a collaborative reconnaissance team of researchers and engineers from Japan and Türkiye who conducted a survey from March 28 to April 2, 2023 are reported. The findings during this survey are as follows:

1. In Golbasi and Iskenderun, liquefaction induced settlement and tilt of structures, lateral spread, and sand boils are observed.
2. In Kahramanmaras and Antakya, concentra-

tion of building damage in the plain region is observed, while there was a less damage rate in the hilly region. Although change in damage rate can be attributed to the ground conditions, it is difficult to conclude this as the only reason for the damages. However, the importance of appropriately designed and constructed structures by taking into account the ground conditions that they are built on can be clearly emphasized depending on these observations.

3. In Islahiye, formation of a natural dam due to the landslide and mitigation for the removal of water in the formed lake is observed. Since there are settlements downstream, this landslide dam should be monitored against the breaching risk.
4. In Tepehan, a landslide of a gentle slope occurred in a vast area. Since the soil blocks moved without losing their shapes, the possibility of a weak layer parallel to the ground surface is discussed.
5. Several road embankments were damaged by the earthquake. In particular, damages were observed on the road embankments where a water channel/river running alongside the road, which were caught in the liquefaction-induced lateral spreading of their foundation.

These findings provide valuable lessons learnt and shed a light on the mechanism of earthquake related damages on the geotechnical structures. Additionally, vulnerabilities can be detected by taking these findings as a basis to prepare cities to be more resilient towards seismic risks.

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