Geotechnical observations from the 2023 Kahramanmaraş EEFIT mission

By Orestis Adamidis, University of Oxford; Teoman Efeoglu, University of Bristol; Ozcan Gozenoglu, Arup; Joshua Jones, Aecom; Gopal Santana Phani Madabhushi, University of Cambridge; Yasemin Didem Aktas, UCL; and Emily So, University of Cambridge

Figure 1: Landslides and rockfalls close to Islahiye

1. INTRODUCTION

On February 6, 2023, two earthquakes struck eastern Turkey. The first in Pazarcık, Kahramanmaraş was of Mw 7.7 and the second in Elbistan, Kahramanmaraş, about nine hours later, of Mw 7.6.

The aftermath included significant loss of life – more than 59,000 confirmed deaths in Turkey and Syria – and serious damage to infrastructure and buildings – more than 120,000 collapsed or heavily damaged buildings.

This article describes important geotechnical observations made in March 2023, as part of the UK-based Earthquake Engineering Field Investigation Team (EEFIT) mission, which covered large areas around the approximately 300km long fault rupture.

They are categorised into four broad sections: landslides and rockfalls, surface feature interaction with structures, liquefaction and subsidence, and bridge foundations and approach structures. Implications for current seismic design practice are discussed at the end of the article.

Figure 2: Surface feature interaction with buildings in Gölbaşi, Adiyaman. All photos were taken along the same rupture feature

2. LANDSLIDES AND ROCKFALL

Multiple observations of landslides and rockfalls were made around Islahiye (*Figure 1*). A large landslide upstream of Değirmencik (*Figure 1a*) had blocked the local road as well as a stream that passed through the valley, creating a large reservoir (*Figure 1b*). Piping was visible through the natural dam (*Figure 1a*). The local authorities were alerted; they appeared unaware of the existence of the reservoir. Between Fevzipasa and Türkbahçe, an extensive, shallow slide failure mechanism was observed. Closer to Türkbahçe, a landslide had initiated on a rock cut made along the rail line and had blocked an approximately 60m section of the line (*Figure 1c*). Nearby, multiple rockfalls were observed, including a boulder of 6m by 5.5m by 4m (*Figure 1d*). Electricity, water and communication lines were visibly disrupted by rockfalls, with some rockfalls exhibiting runout distances in excess of 30m from the slope toe.

3. SURFACE FEATURE INTERACTION WITH STRUCTURES

Using the Maxar Open Data Program satellite data, the fault rupture was mapped over a length of approximately 300km. Here, surface feature interaction with buildings in the town of Gölbaşı, Adıyaman, is discussed. To the south west of Gölbaşı, the main fault segment rupture continued in an interrupted fashion towards the town. Lateral displacements consistent with a strike-slip fault rupture and with a magnitude of up to 2m were observed through satellite images. To the north east of Gölbaşı, a secondary east-west fault segment was identified. Close to the start of this segment, multiple parallel cracks were observed, at a steep angle to the secondary rupture. These cracks could have also been affected by spreading due to the vicinity of the site to a lake. Some characteristic photos along one of the observed cracks are shown in Figure 2. Based on privately provided borehole data, the first 20m from the surface in this location is made up of a mixture of gravelly sandy clay. By inspection and discussion with locals, all structures shown in Figure 2 had stiff raft foundations. The surface feature of Figure 2 was observed approaching a cluster of buildings through the shallow canal and road of Figure 2a. It then continued between two adjacent structures shown in Figure 2b, forcing a gap of 0.67m to open between them. Avoiding going through foundations, it continued past more buildings, damaging only lightweight structural components as shown in Figure 2c. Finally, in Figure 2d, the crack is seen diverting around the corner of a foundation, before continuing further. The kinematic constraint and increased stress imposed by the foundations along the inspected crack seem to have forced the surface feature to divert around the foundations of buildings, rather than go through them. As a result of the crack divergence, mostly rigid body displacements occurred, with structural damage remaining limited.

4. LIQUEFACTION AND SUBSIDENCE

Liquefaction was identified at three of the locations visited by the EEFIT team: the seafront of Iskenderun, the Orontes river, and Gölbaşı, Adıyaman.

In İskenderun, most of the seafront displayed several signs of liquefaction, including ejected sandy material, lateral spreading cracks and subsidence. The boulder seawall was displaced towards the sea and settlement was observed behind it, with ejected sandy material visible in some locations (*Figure 3a*). Sand ejecta along the Atatürk Boulevard park indicated widespread liquefaction. Lateral spreading cracks were visible throughout the inspected waterfront, with an average cumulative displacement towards the sea of more than 40cm (*Figure 3b*). Significant subsidence was observed in the districts of Yenişehir and Çay. Large parts of Atatürk Boulevard and its surrounding locations were under sea level at the time of inspection, including the İskenderun Anıt Meydanı square shown in Figure 3c. Settlement of up to 47cm was observed for a single-storey water management building within the liquefied zone at the seafront of Çay district (*Figure 3d*).

Widespread liquefaction was also identified all along the Orontes River, north east of Antakya. Two examples close to the village of Demirköprü are shown in Figure 4. Lateral spreading towards the Orontes was observed close to the historic masonry bridge and the school of Demirköprü, the yard of which is shown in Figure 4a. Ejected material was seen covering large parts of the surface around the Orontes river, to the west of

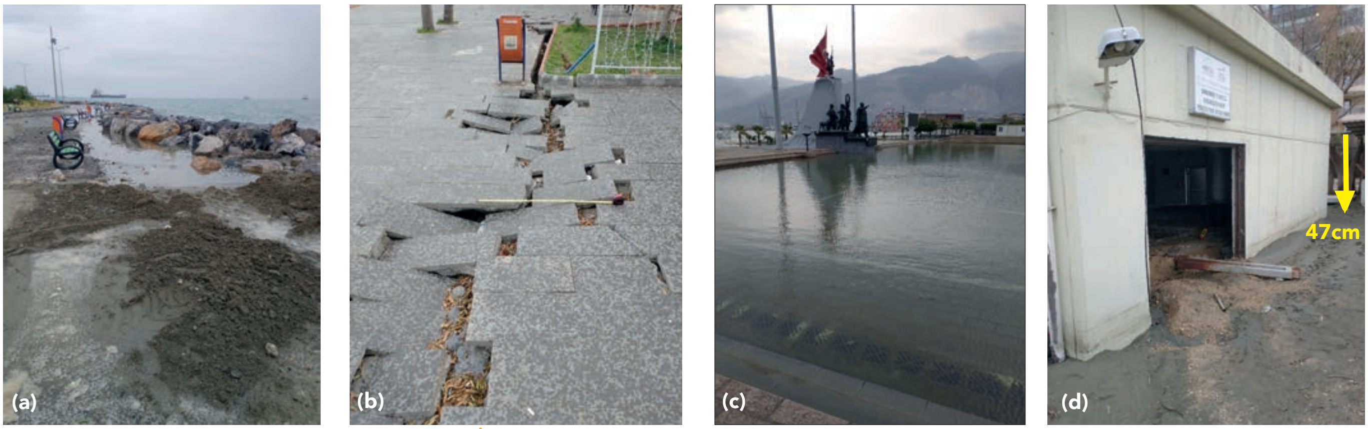

Figure 3 (above): Liquefaction and subsidence in İskenderun

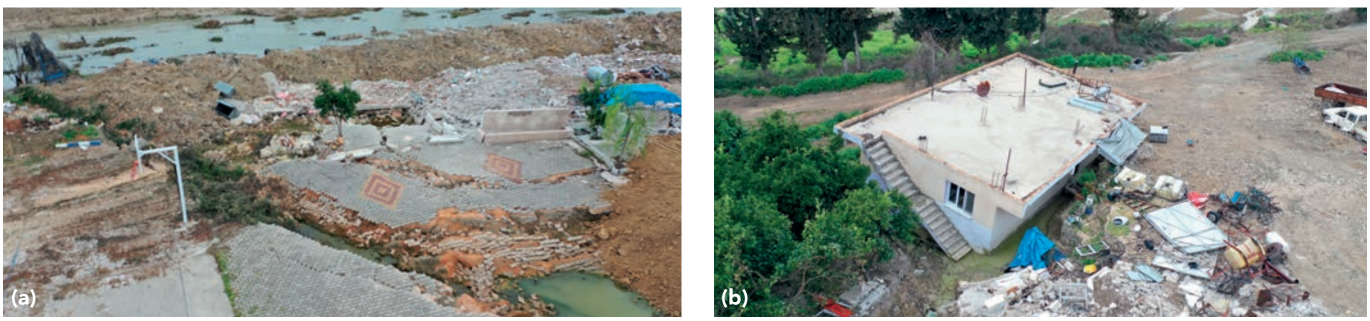

Figure 4 (above): Liquefaction and subsidence in İskenderun

Figure 5 (left and right): Liquefaction-related failures in Gölbaşı

Demirköprü. A shallow-founded structure within that zone is shown in Figure 4b, which experienced a settlement of 1.8m and rotation of 14° along its transverse direction, with no rotation measured along its longitudinal plane. A discussion with the owner indicated that the building had a reinforced concrete raft foundation. The side of the building away from the river settled more, indicating a deep scoop mechanism that encompassed the foundation. In the town of Gölbaşı, liquefaction within a part of the town was observed. The majority of the affected structures were founded on stiff raft foundations and experienced settlement of more than 1m (*for example, Figure 5a*) and in cases with a high aspect ratio, also significant tilting (*for example, Figure 5b*). Limited structural damage indicated a rigid body response for buildings, facilitated by the raft foundations and the soil softening due to liquefaction. Liquefaction in Gölbaşı affected structures within an urban setting, where structure-soil-structure interaction effects cannot be neglected (*Figure 5c*). ↺

Figure 6: Hatay stadium bridge inspection

Figure 7: Embankment between the villages of Evri and Çöçelli

5.BRIDGE FOUNDATIONS AND APPROACH STRUCTURES

Multiple bridges affected by the earthquakes were inspected during the EEFIT mission. Here, some information is given for the Hatay stadium bridge and the failure of an approach structure in Çöçelli.

The Hatay stadium bridge is a dual, five span beam bridge. Each span has a length of 27m. At the time of inspection, the bridge was closed due to heavy damage. Spreading cracks were observed on the western bank, with gaps up to 40cm (*Figure 6a*). The surface soil included fine grained, plastic material along with a proportion of gravel. No ejected material was visible. Pillars on the west bank rotated by up to 3.5°, with the foundations moving towards the river while the supporting beams impeded movement at their top. As a result, plastic hinges formed at the connections of pillars with the foundations (*Figure 6b*). On the eastern bank, which had a steeper slope, a slope stability failure was observed (*Figure 6c*), with the displacing soil pushing the pillars on that side and creating a "shadow" effect behind them (*Figure 6d*).

Finally, a failed approach embankment leading to an overpass bridge between Evri and Çöçelli was inspected (*Figure 7*). Longitudinal surface cracks in flat areas on both sides of the overpass bridge indicated a weak foundation soil. A hand held shear vane used on the surface layer verified its very low strength, giving 14kPa average peak shear strength and 3.5kPa average residual shear strength. Drone images revealed an extensive slope stability failure, with an extensive shear surface likely formed, passing through the soft soil below the embankment. The presence of a shallow canal facilitated the triggering of the failure mechanism towards one side by introducing an asymmetry. The displacements imposed by the failure mechanism were visible as a narrowing of the canal during the inspection.

6. CONCLUSIONS

This article presents some important geotechnical observations made by the 2023 Kahramanmaraş EEFIT reconnaissance mission. Landslides and rockfalls were inspected that indicated the potential for cascading hazards, including river blocking and lifeline disruption. Surface feature interaction with buildings was observed in Gölbaşı, which is a hazard not typically considered in seismic design. Liquefaction-related phenomena were a primary contributor to geotechnical damage. Liquefaction along the reclaimed seafront of Iskenderun demonstrates the need for better guidance in designing and performing land reclamation. The predominantly shallow-founded structures observed within liquefied zones suffered excessive settlement and tilting, indicating the need for better design of new structures and remediation for existing ones. Finally, liquefaction in the urban area of Gölbaşı demonstrated that structure-soil-structure interaction cannot be neglected.

7. ACKNOWLEDGEMENTS

This investigation was possible thanks to the Learning from Earthquakes: Building Resilient Communities Through Earthquake Reconnaissance, Response and Recovery project (EPSRC - EP/P025641/1 and EP/P025951/1).