
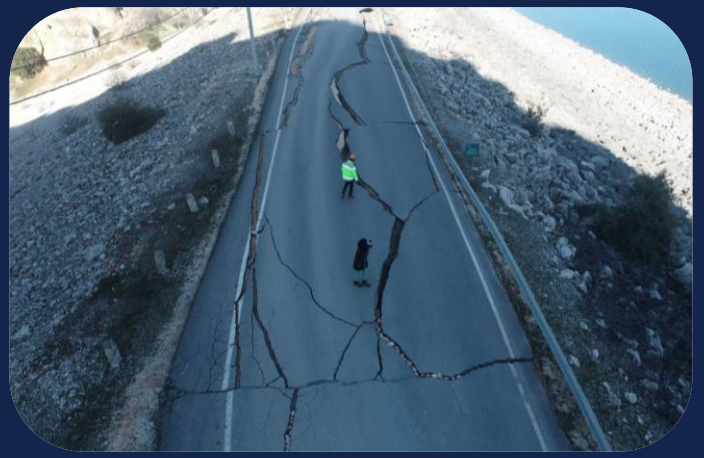


Geotechnical Problems Caused by the 2023 Kahramanmaras - Turkiye Earthquakes

Professor Tugce Baser, Dr. Ozgun Alp Numanoglu, and Professor Okan Ilhan

March 31st, 2023

The Grainger College of Engineering
Civil & Environmental Engineering

Schnabel ENGINEERING
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Ankara Yıldırım Beyazıt Üniversitesi

Collaborators

Recon Team

- Professor Tugce Baser (University of Illinois Urbana – Champaign), Dr. Ozgun Numanoglu (Schnabel Engineering), Serhat Erinmez (i4Works Corporation)

- Deployed on February 12th

Collaborators

- Professor Youssef Hashash – (University of Illinois Urbana – Champaign)

- Professor Onur Pekcan (Middle East Technical University, Founder of i4Works Inc and SiteEye)

- Professor Okan Ilhan (Yildirim Beyazit University)

- Professor Guney Olgun (Missouri University of Science and Technology)

What Does This Presentation Include?

- Details of the coverage the recon team achieved
- Brief intro to tectonics of the area and some ground motion parameters and site effects
- Comparison of ground motions with the design codes
- Geotechnical Observations
  - Performance of dams
  - Large-scale liquefaction and liquefaction evidence collected at Iskenderun
  - Large-scale earthquake-induced landslides
  - Adana case
  - Cascading events

What is NOT Included in this Presentation but Available?

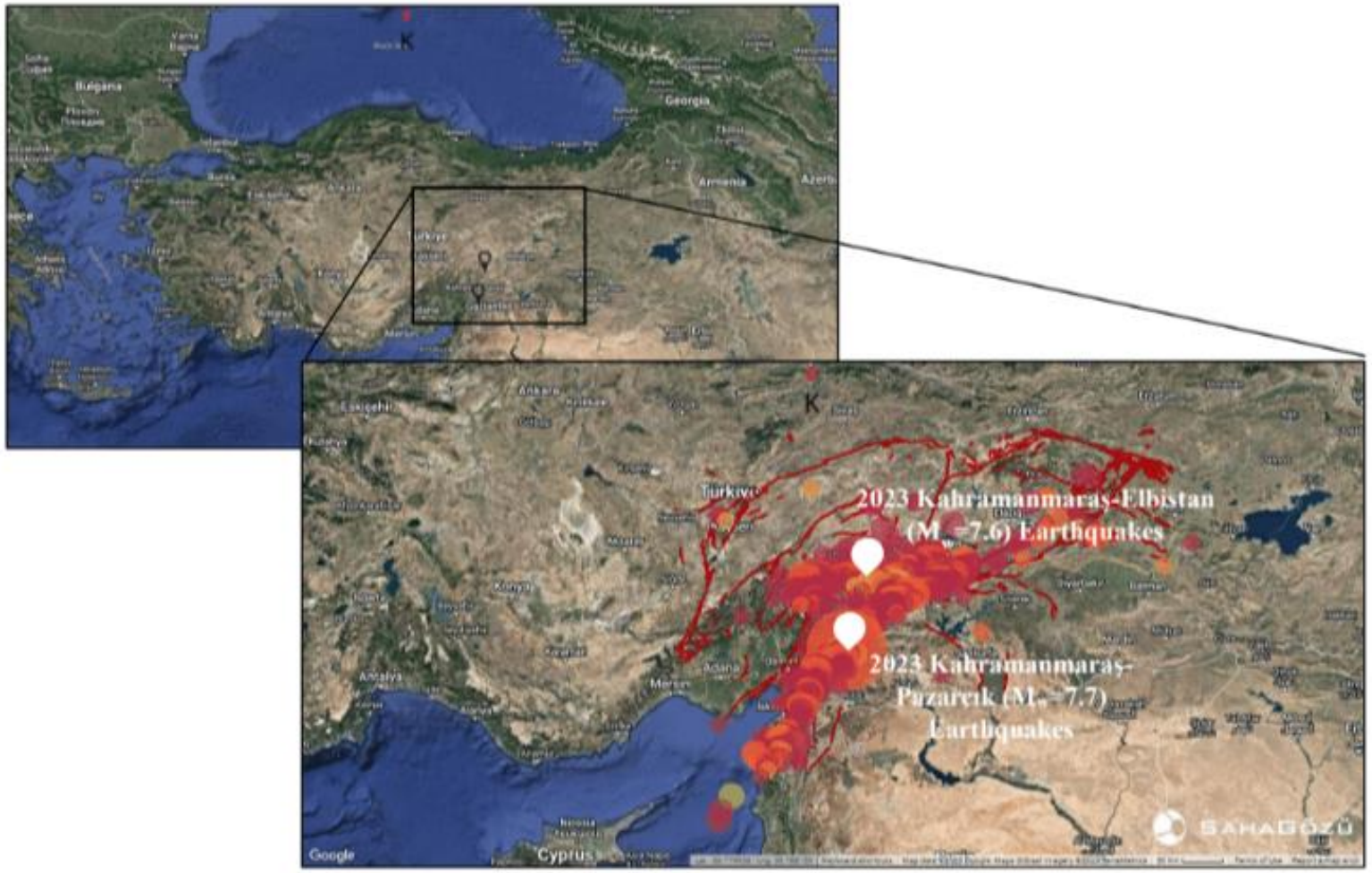
- Detailed tectonic settings and historical events

- Impacts of the earthquakes in Syria (This earthquake also hit Syria)

Further details to the content presented herein can be found at:

Turkiye Earthquake Reconnaissance and Research Alliance: Resonnaissance Report on February 6, 2023, Kahramanmaras – Pazarcik (Mw = 7.7) and Elbistan (Mw = 7.6) Earthquakes

Map of Turkiye and Epicenter of Earthquakes



- 3 major quakes within 9 hours with focal depths ranging between 5 and 9 km
- The earthquakes ruptured the East Anatolian and Dead Sea faults.
- More than 10,000 aftershocks

Figure from: https://www.researchgate.net/publication/369093645_Reconnaissance_Report_on_February_6_2023_Kahramanmaras-Pazarcik_Mw77_and_Elbistan_Mw76_Earthquakes

Immediate Aftermath of the Quakes

- 11 Cities and more than 13 million people were impacted by the events
- Causalities are around 50,000 with additional 100,000 or more injured
- The Turkish Enterprise and Business Confederation estimated $80 billion cost for reconstruction not including the impacts on the local business

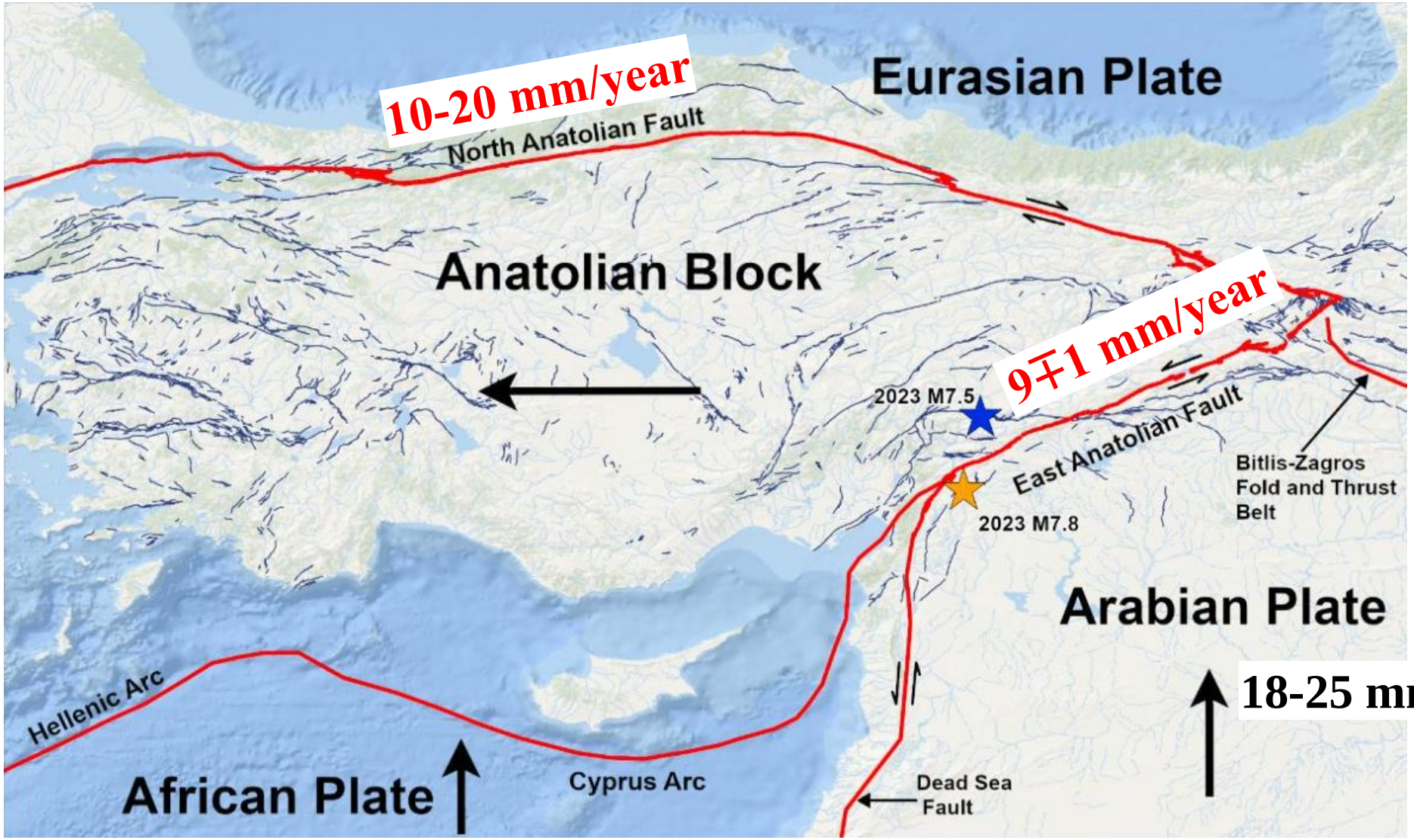
Overall Map and Reconnaissance Coverage

- Covered areas include the City of Adana, Pazarcik (Kahramanmaras), Hatay (including Antakya and Iskenderun), Osmaniye and Gaziantep (including Islahiye and Nurdagi)

Drone Technology used during the Reconnaissance

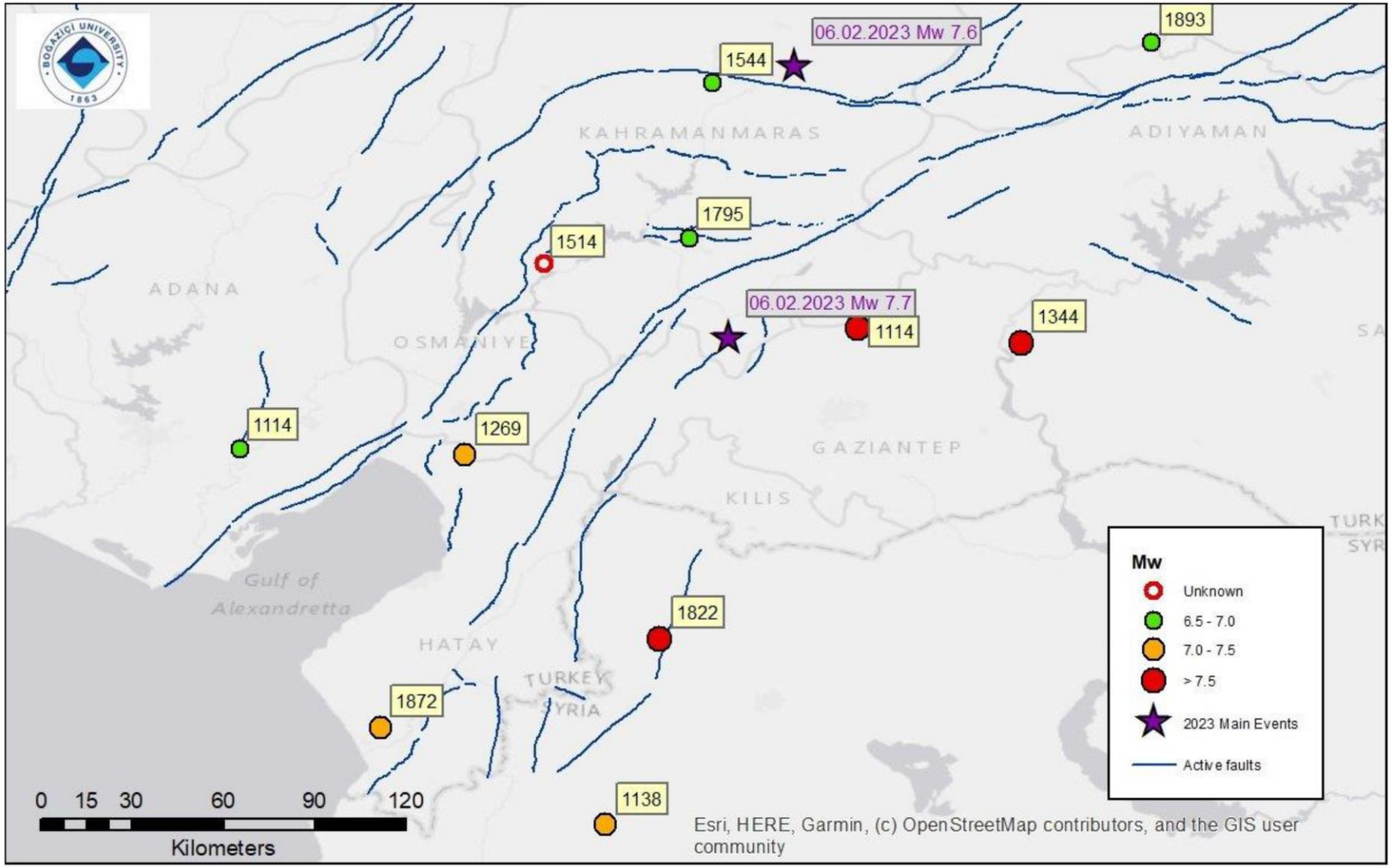
- Recon team used 3 different size drones to gather photos and videos during the recon.
- The drones were provided voluntarily by i4Works Inc.
- All the data was uploaded to SiteEye software and readily available for the members.

Tectonic Setting (Retrieved from USGS, Emre et al. 2018)



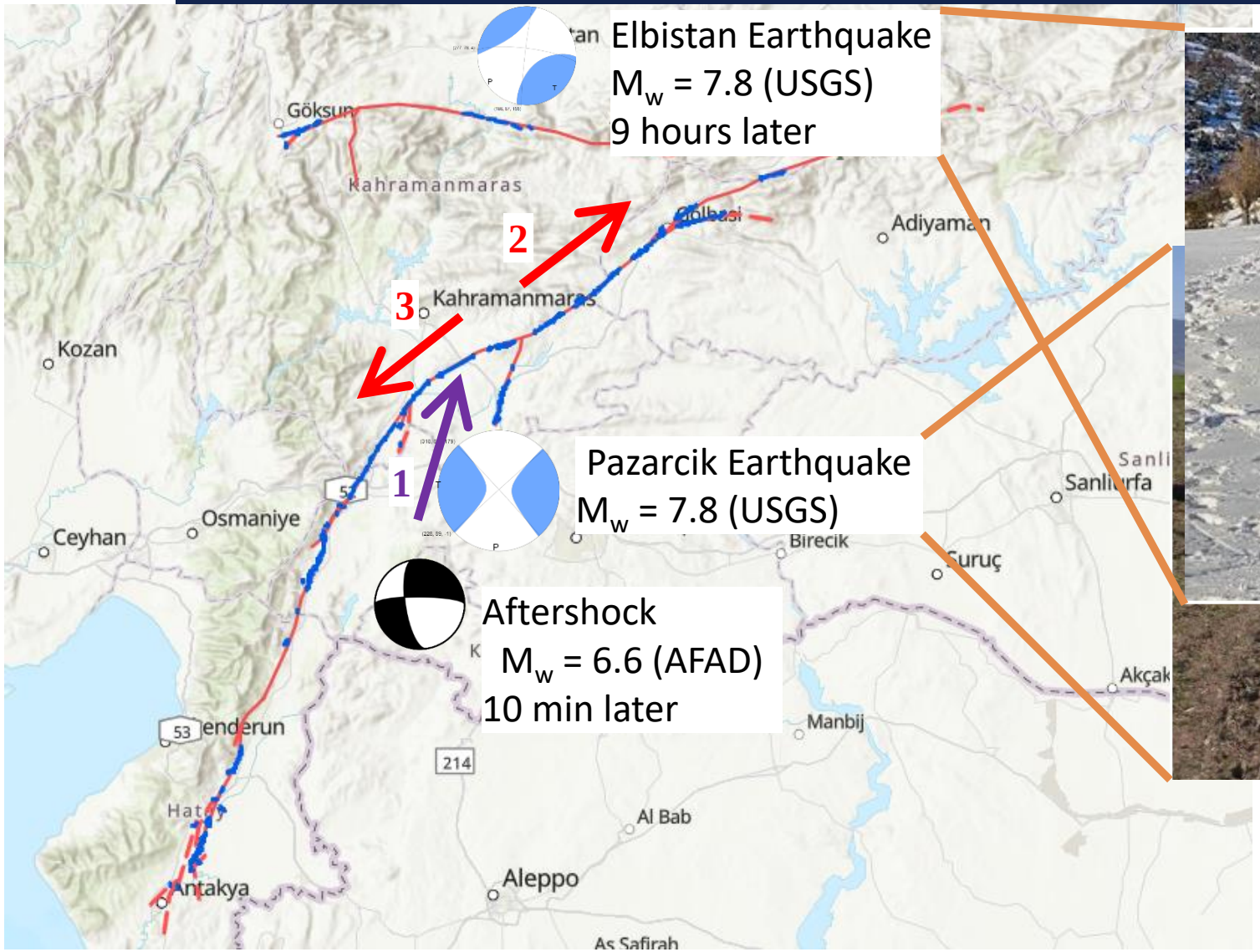
Nalbant et al. (2002)

Tectonic Setting: Historical Events



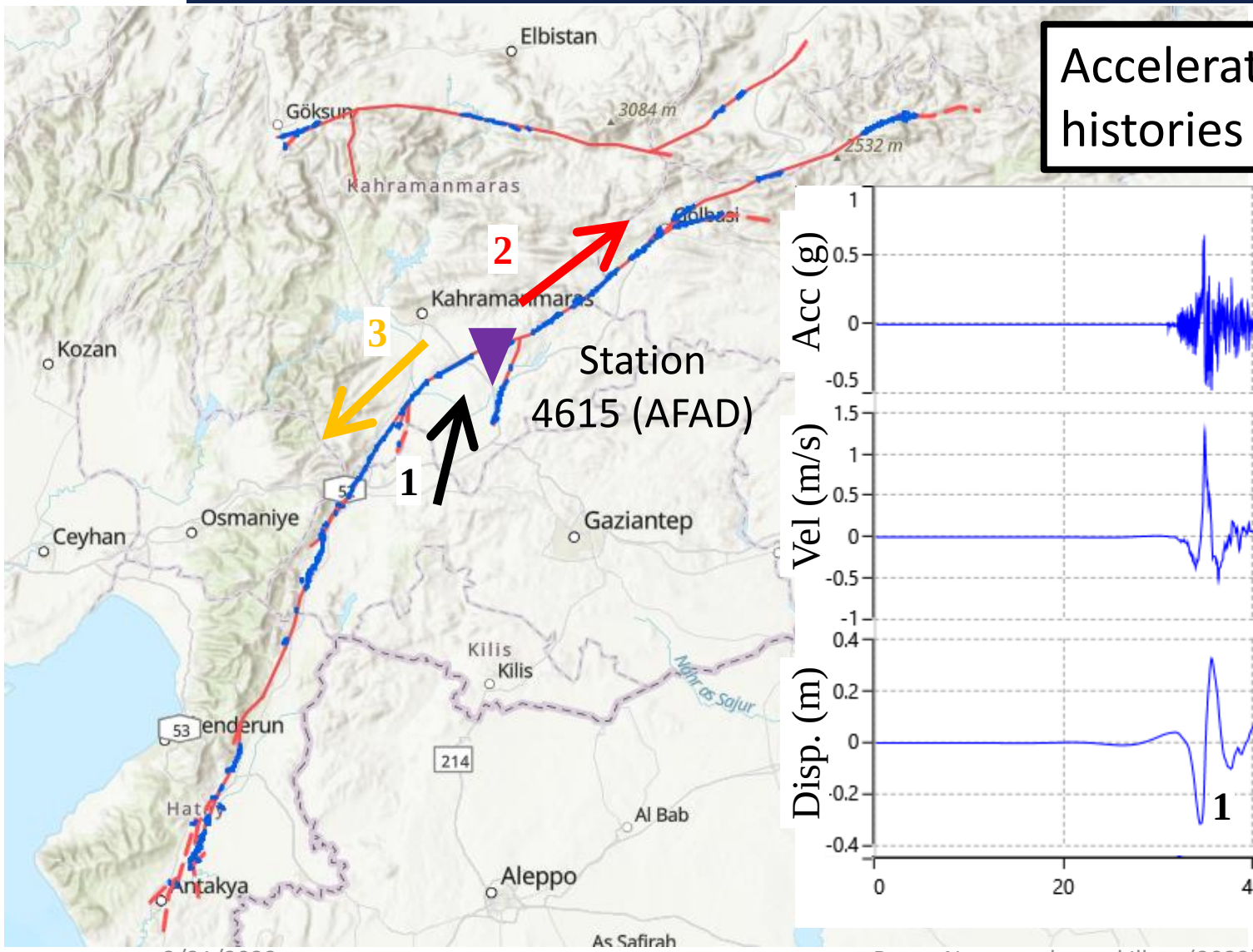
Şeşetyan et al. (2023)

6th February 2023 Earthquakes: Earthquake Mechanism

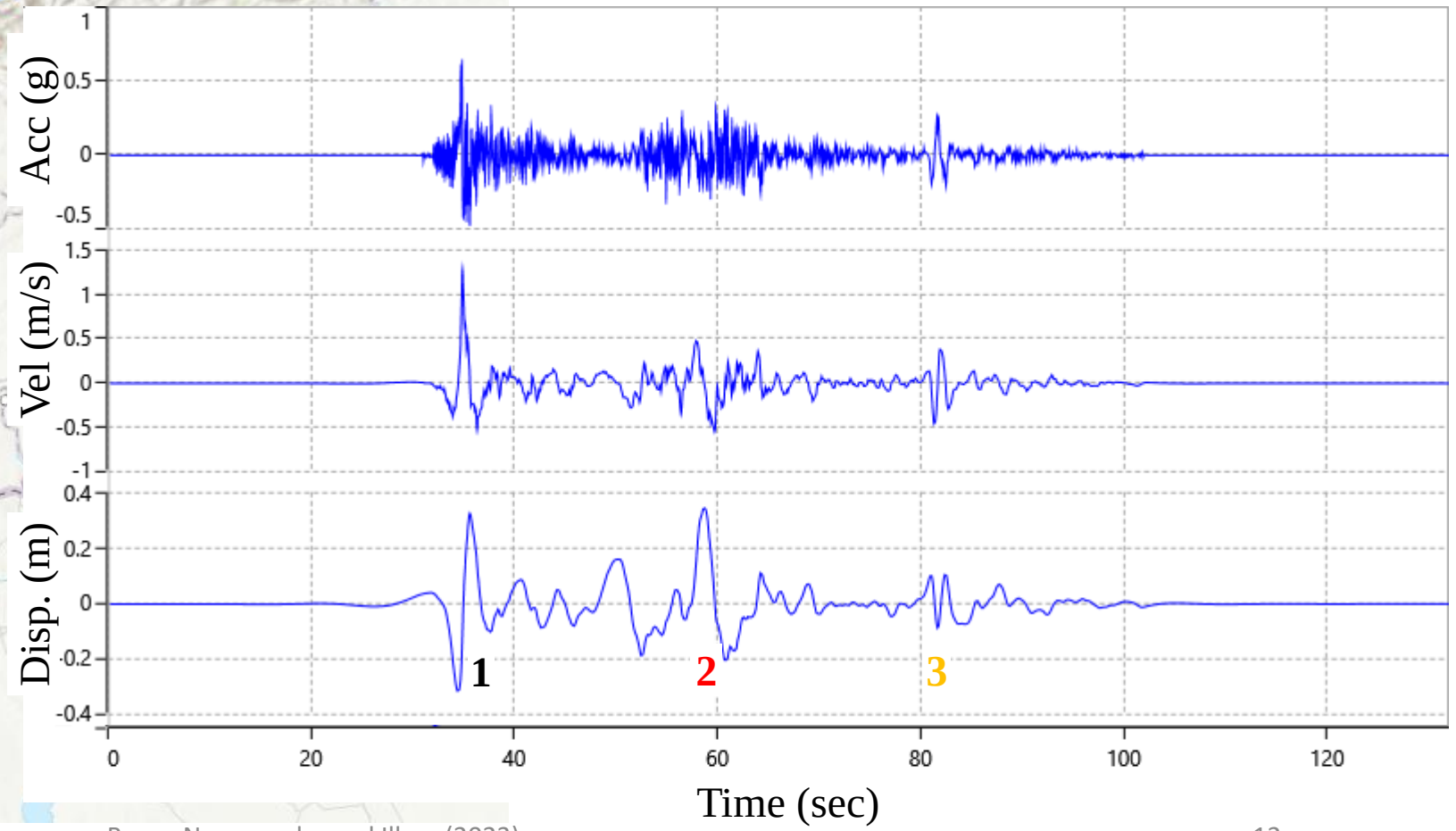


USGS
AFAD (Disaster and Emergency Management Presidency of Turkey)
Çetin and Gülerce et al. (2023)

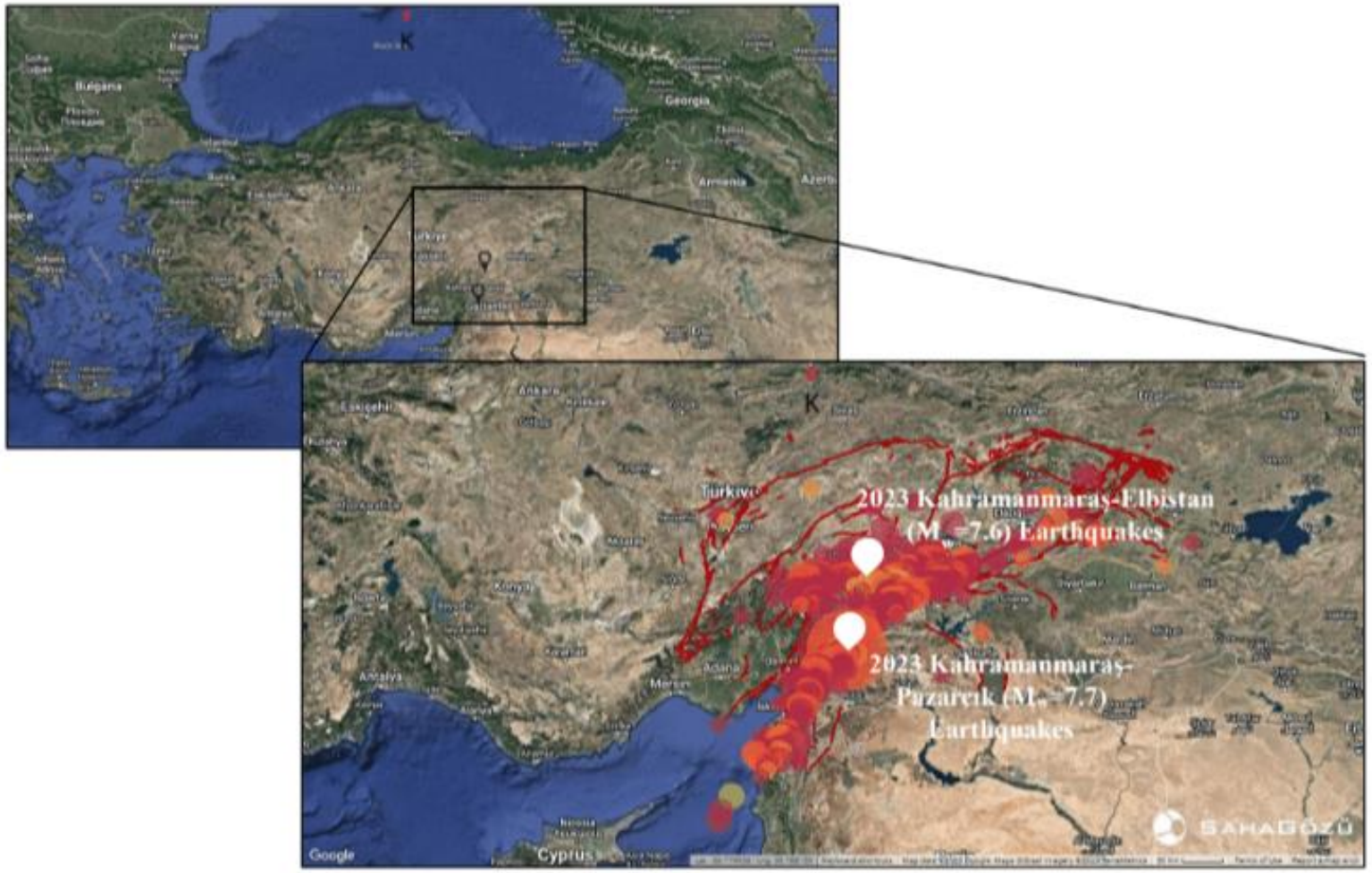
6th February, 2023 Earthquakes: Earthquake Mechanism



Acceleration, Velocity and Displacement time histories recorded at Station 4615 (AFAD).



Map of Turkiye and Epicenter of Earthquakes



- Maximum ground acceleration of 1.23g in Antakya, and 0.65g at Kahramanmaras
- Up to 2g spectral accelerations at T = 1 s

Figure from: https://www.researchgate.net/publication/369093645_Reconnaissance_Report_on_February_6_2023_Kahramanmaras-Pazarcik_Mw77_and_Elbistan_Mw76_Earthquakes

Aftermath of the Quakes (Not Including Syria - Aleppo)

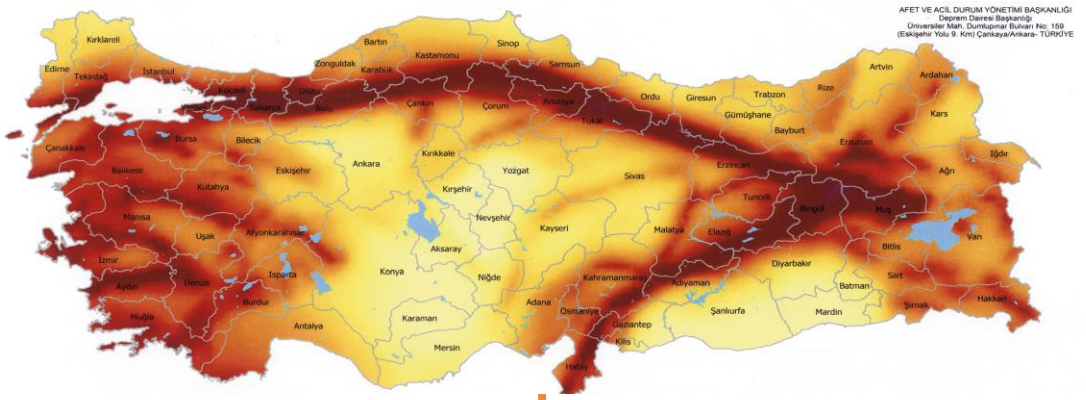
[Map of the proviences that experienced damage after the 2023 Gaziantep-Kahramanmaraş earthquakes - 2023 Turkey–Syria earthquake - Wikipedia]

6th February 2023 Earthquakes: Strong Groung Motion Recordings

M_w = 7.5 Pazarcik Earthquake was recorded by 268 stations of AFAD available Turkish Strong GM Database.

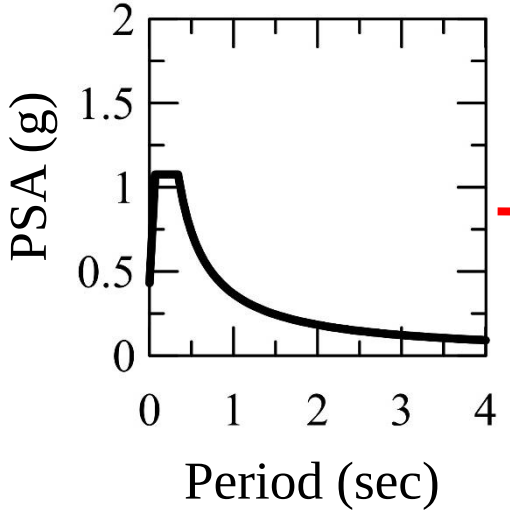
6th February 2023 Earthquakes: Comparison with Turkish Building Code Design Spectra

Turkish Building Code (2019) Seismic Hazard Map



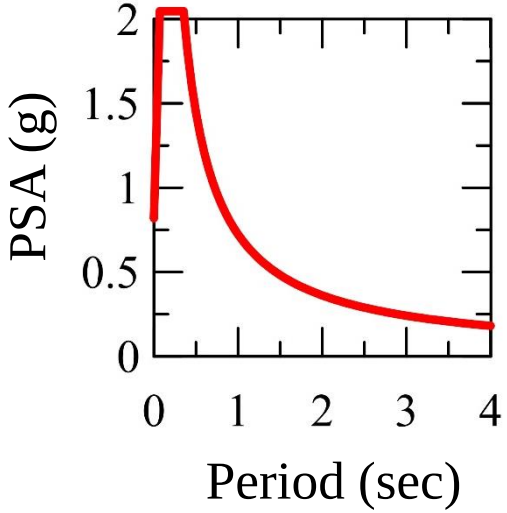
- How do the spectral acceleration of strong GM data recorded during February 6th, 2023, Earthquakes compare with Turkish Building Code Design Spectrum?
- Site Effects?

Relative to reference condition of (V_{S30} = 760 m/s)



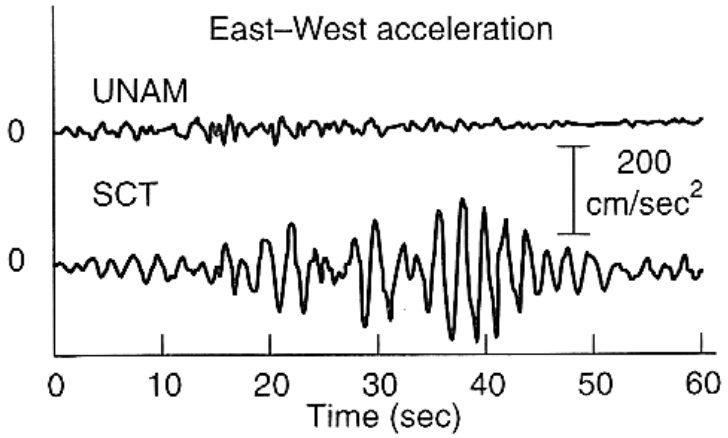
$$S_{DS} = S_S F_S$$
$$S_{D1} = S_1 F_1$$

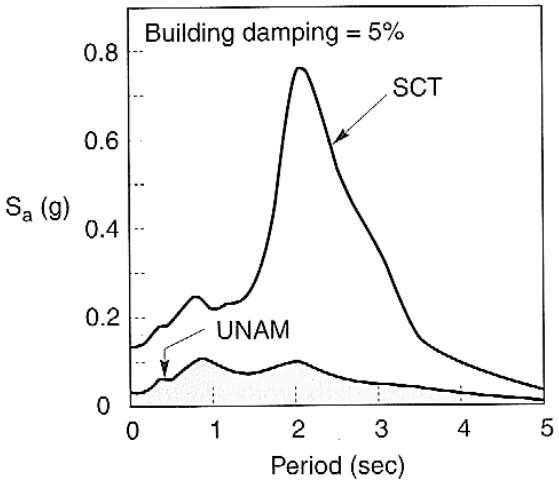
Site Effects

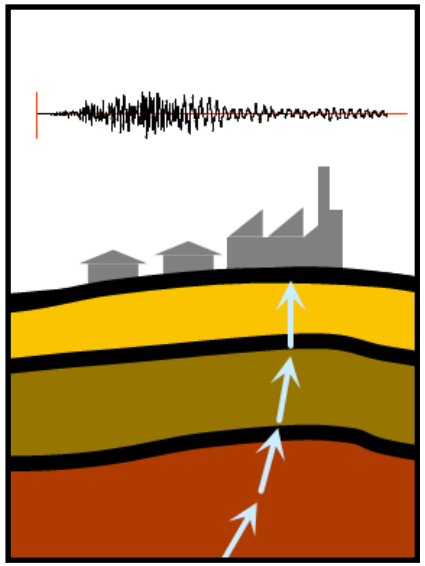


Site Effects through **site factors**

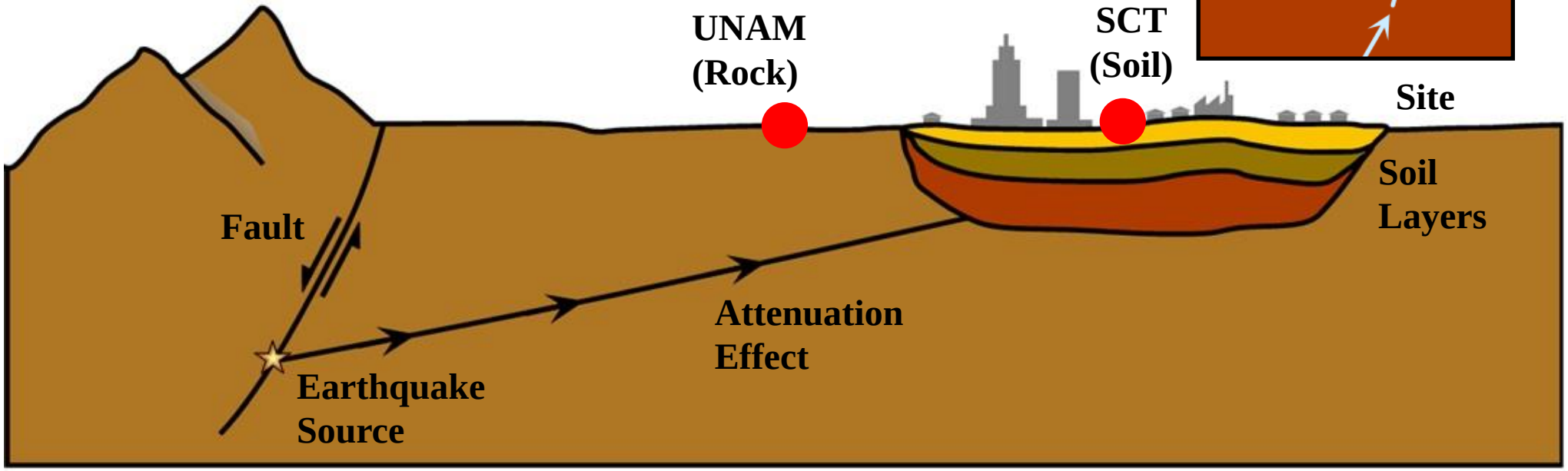
Site Effects: Definition



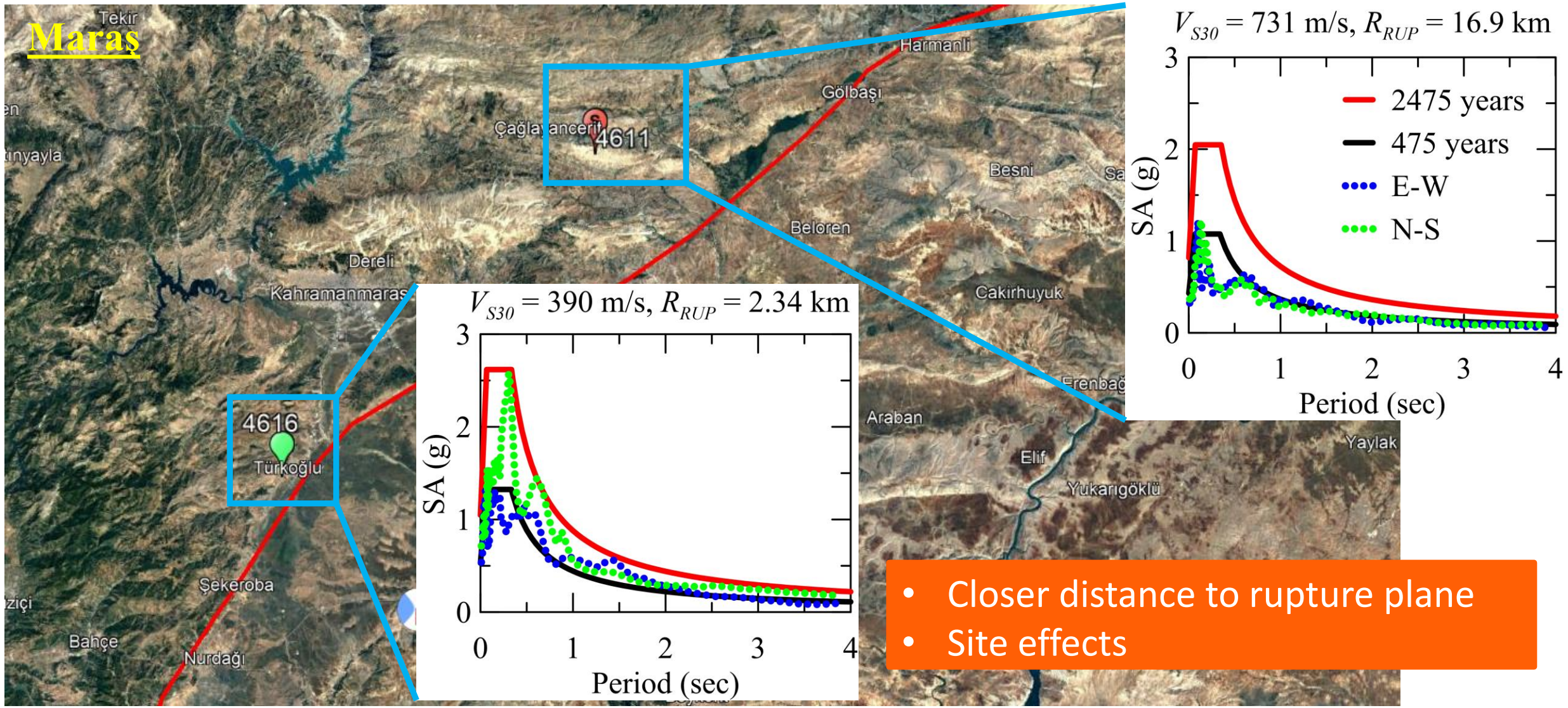




Site Effect

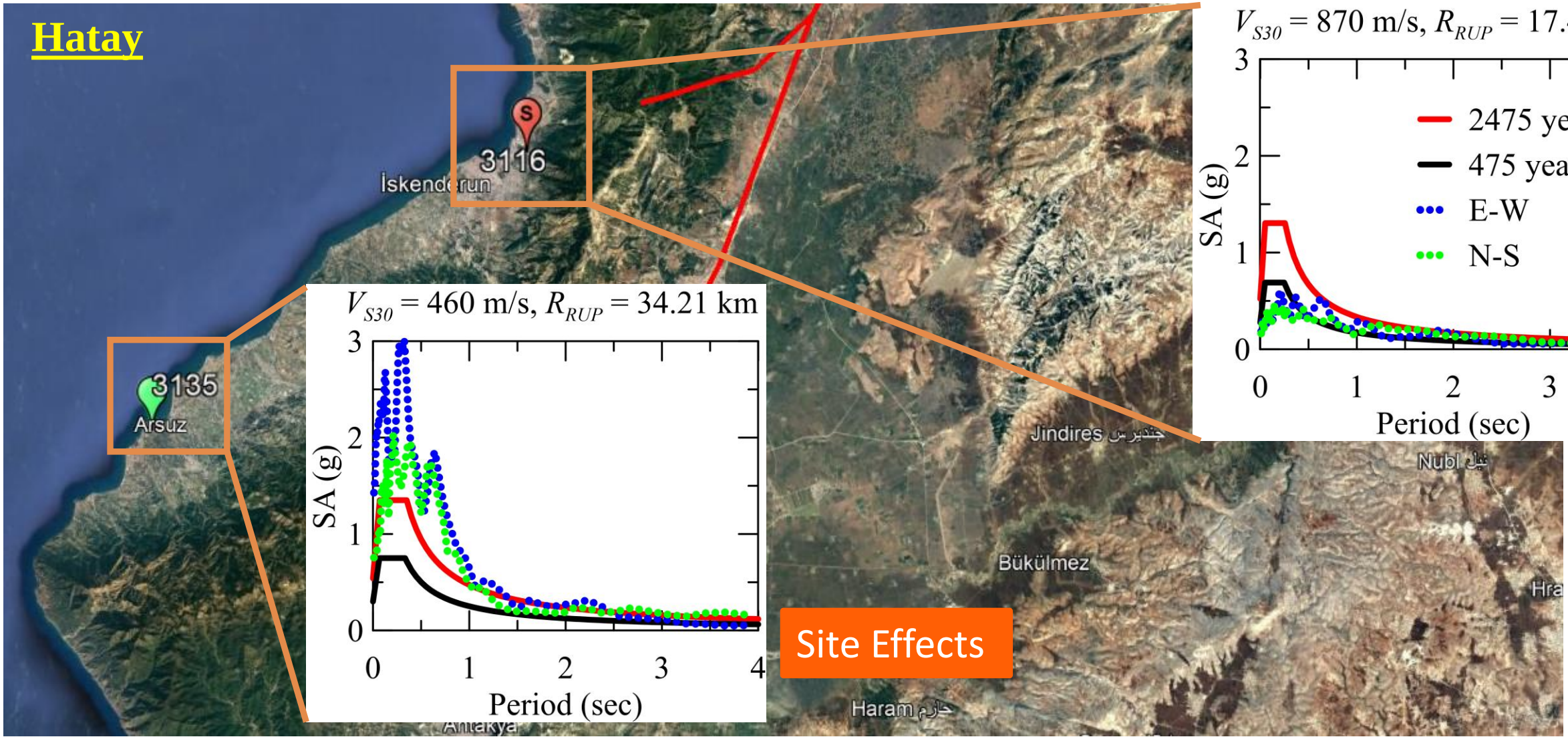


6th February 2023 Earthquakes (M_w = 7.8): Comparison with Turkish Building Code Design Spectra

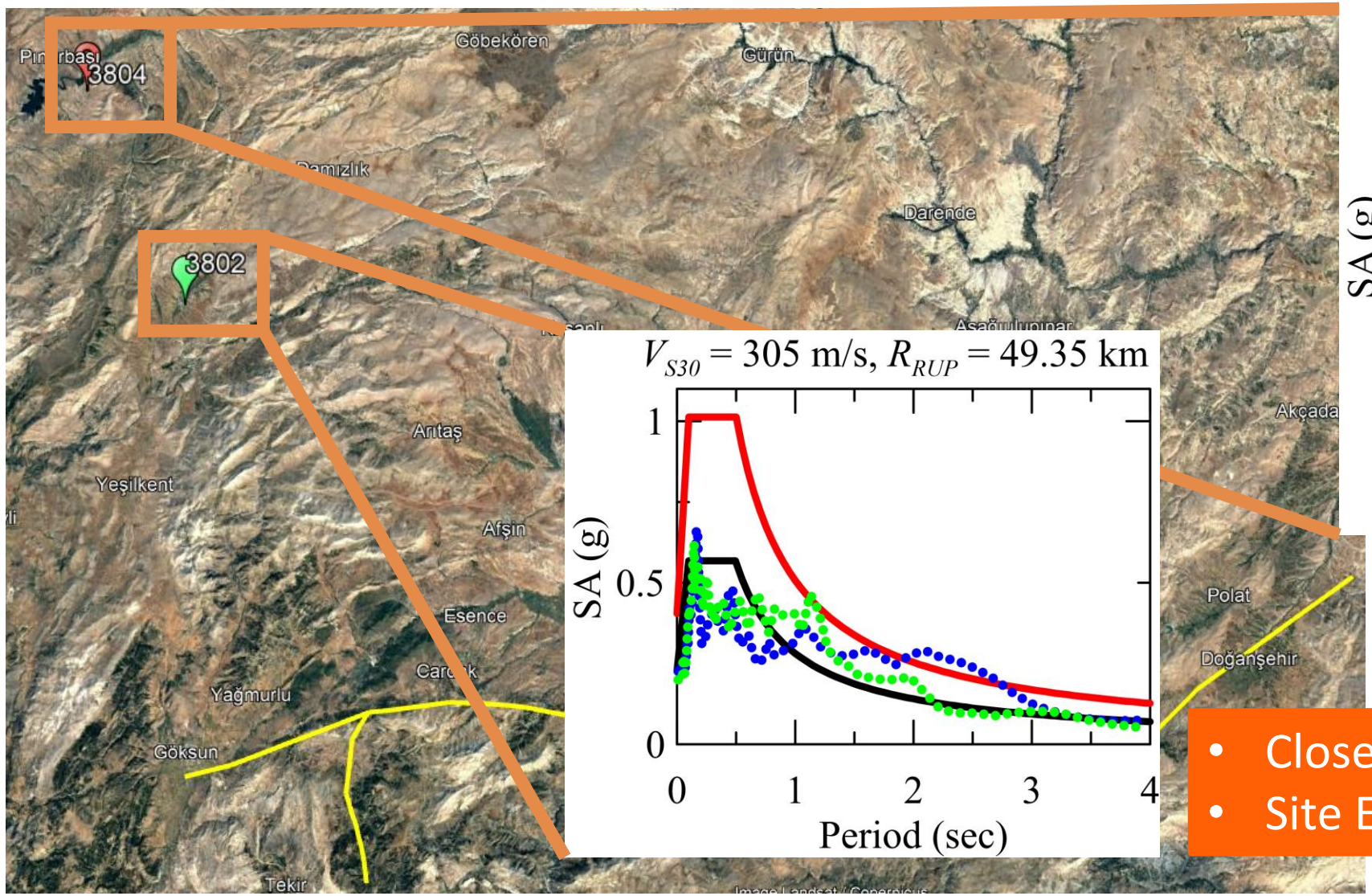


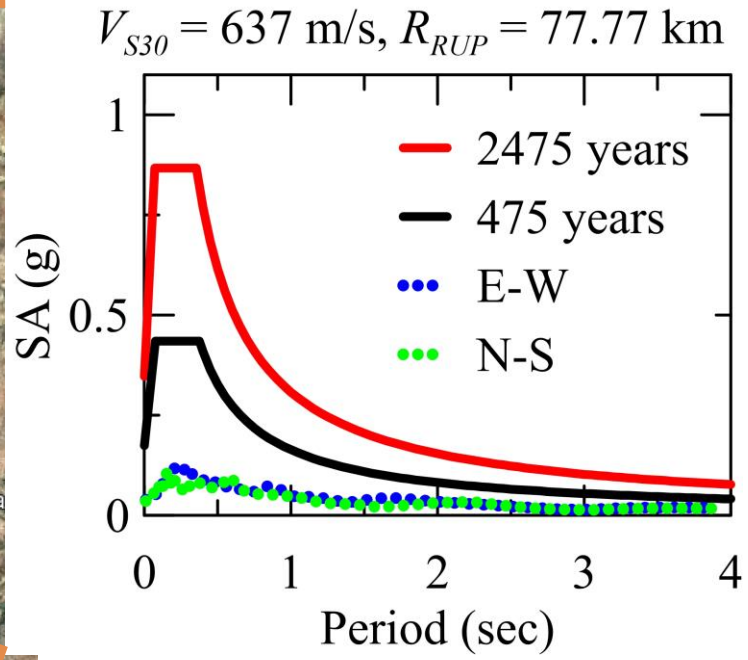
- Closer distance to rupture plane
- Site effects

6th February 2023 Earthquakes (M_w = 7.8): Comparison with Turkish Building Code Design Spectra



6th February 2023 Earthquakes (M_w = 7.5): Comparison with Turkish Building Code Design Spectra



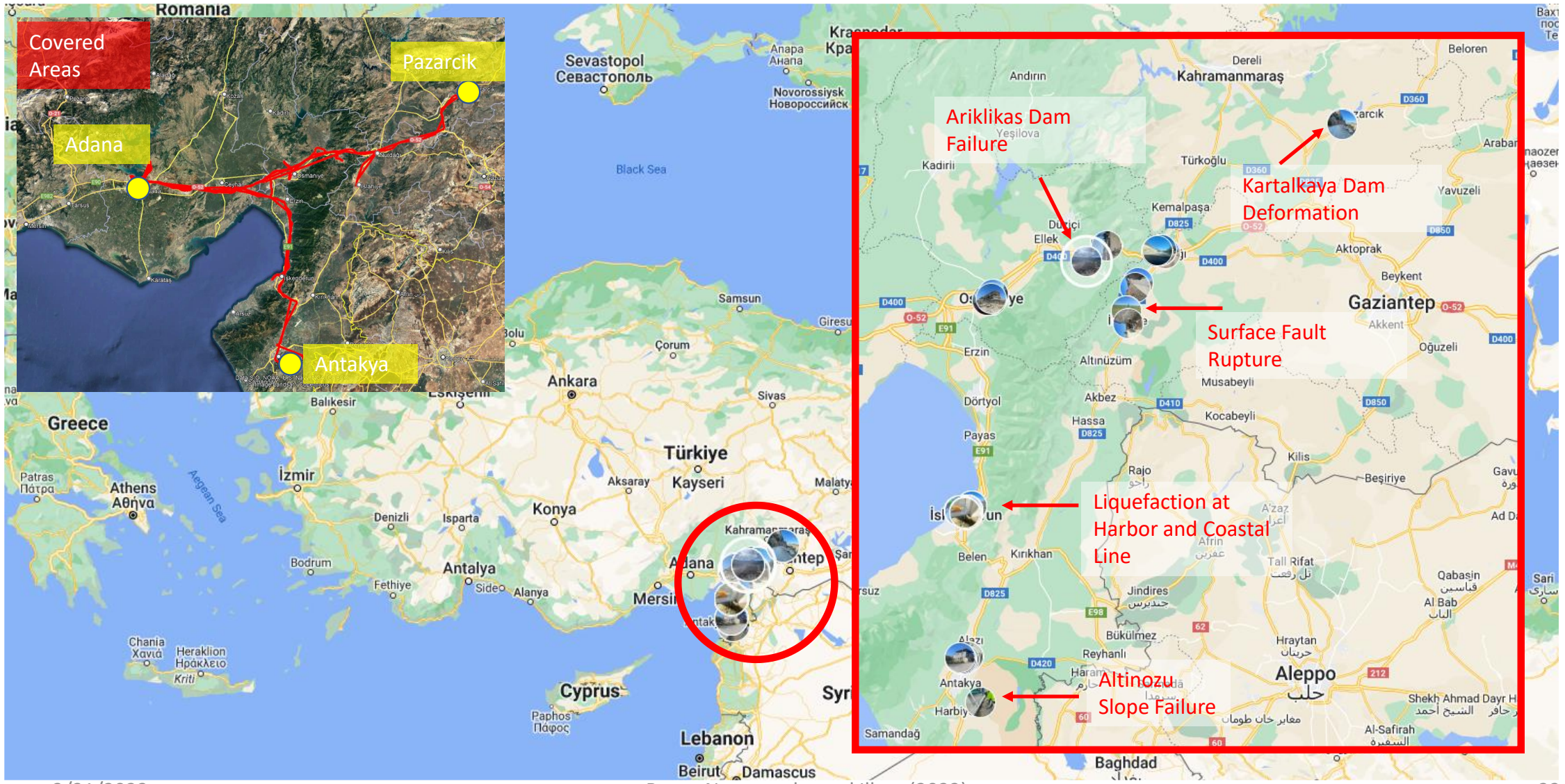


- Closer distance to rupture plane
- Site Effects

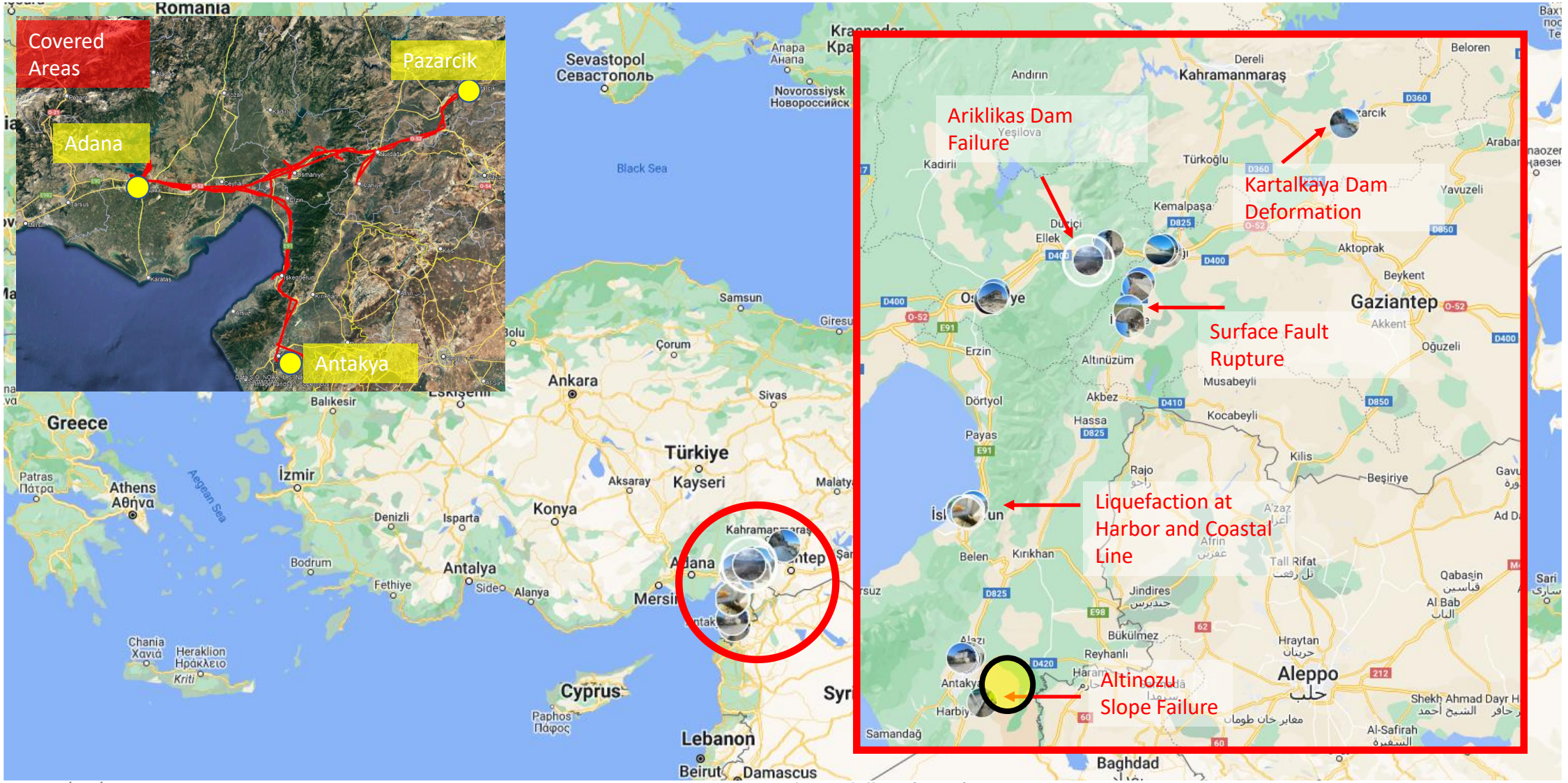
Intermediate Conclusions – Ground Motions

- Two large-magnitude earthquakes (Mw = 7.8 and Mw = 7.5) and aftershocks
- Spectral accelerations for some stations were observed to exceed the design spectra of Turkish Earthquake Building Code (TEBC, 2019) for return period of 2475 years.
- Significant site effects
- Next Steps: Re-evaluation of current seismic hazard analysis in TEBC (2019)Region-specific site factors

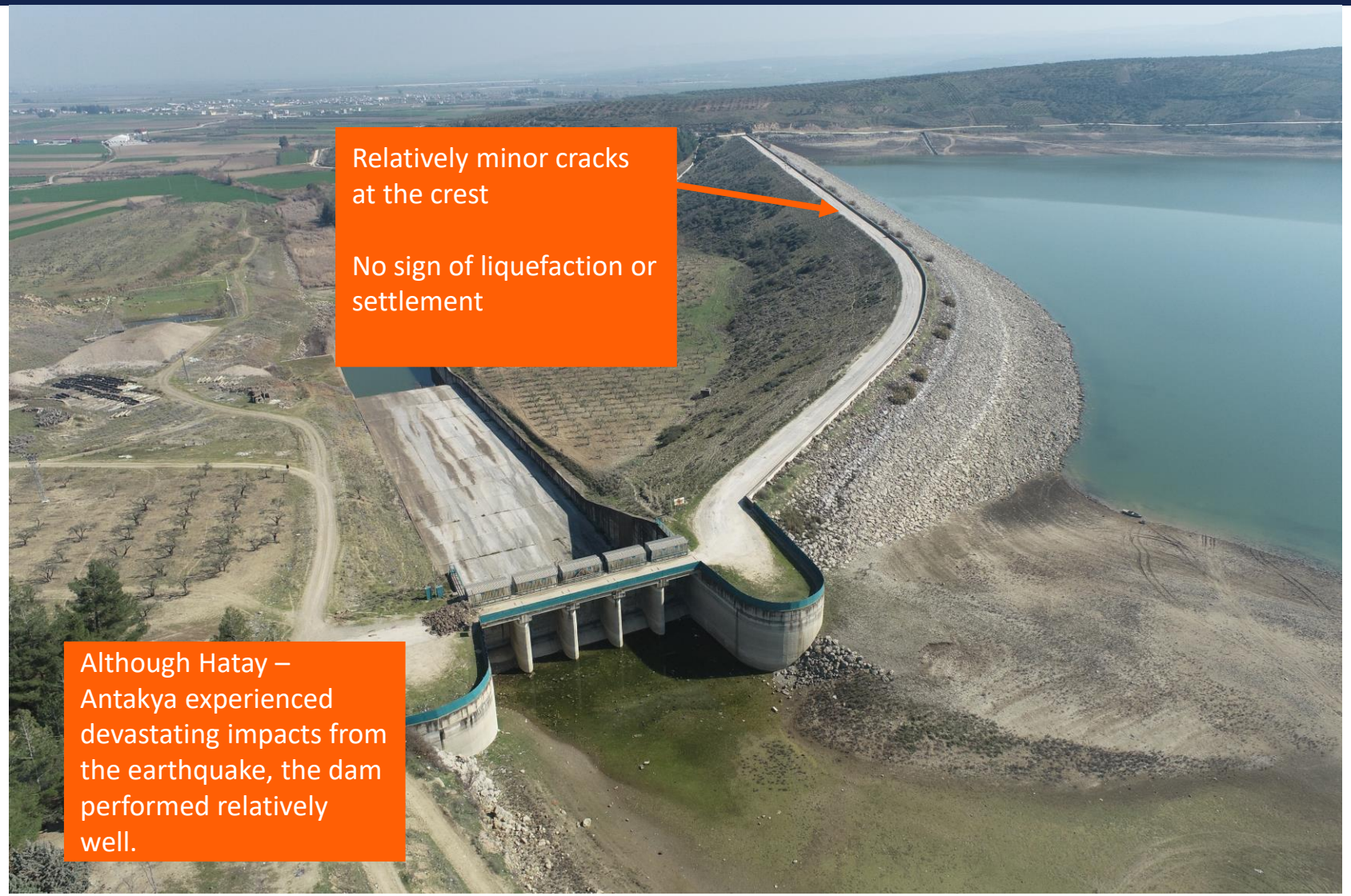
What Did We Find within Geotechnical Engineering Scope?



Yarseli Dam - Hatay



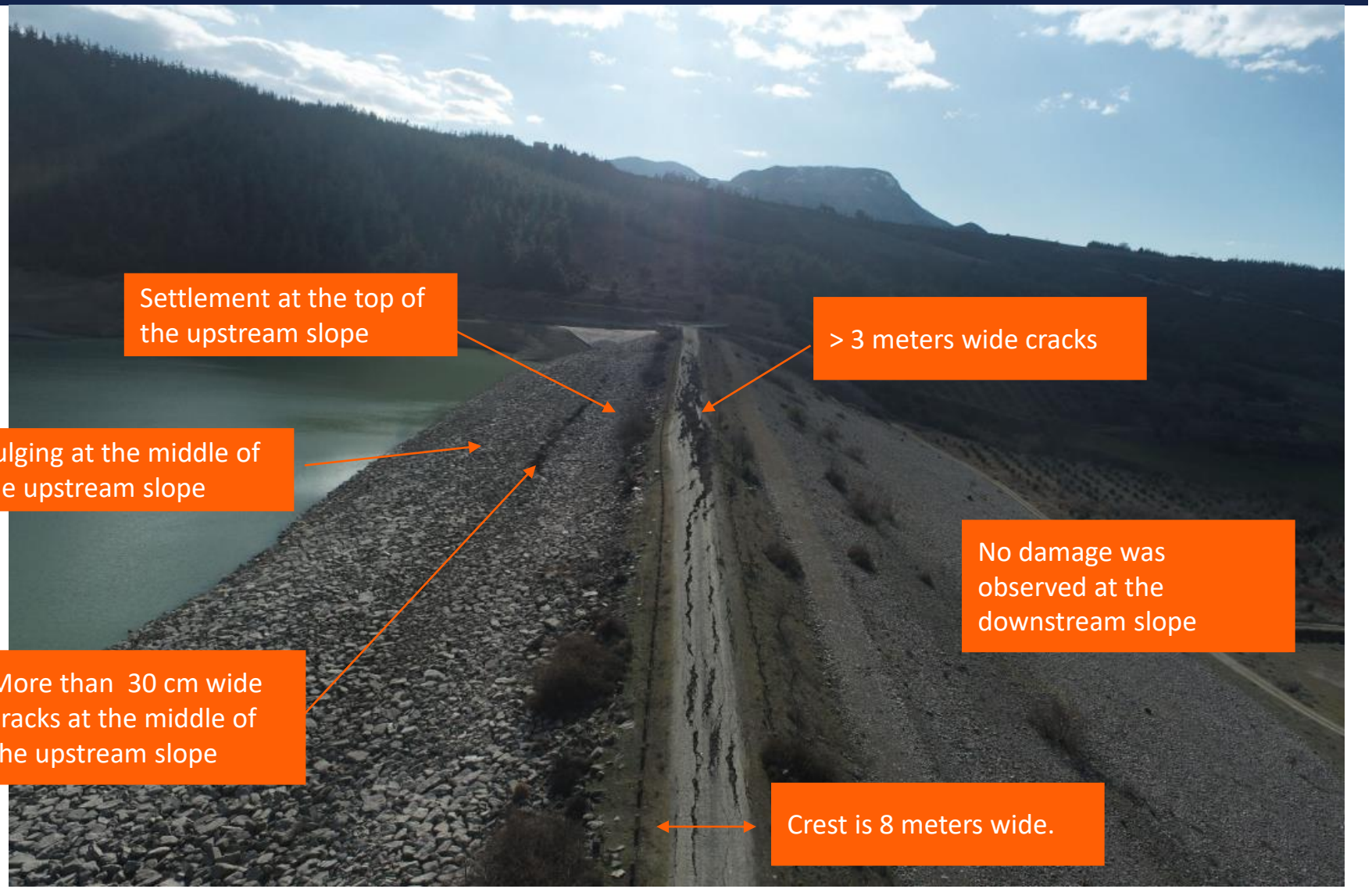
Yarseli Dam – Relatively Good Performance



Ariklikas Dam Failure

Ariklikas Dam - Osmaniye

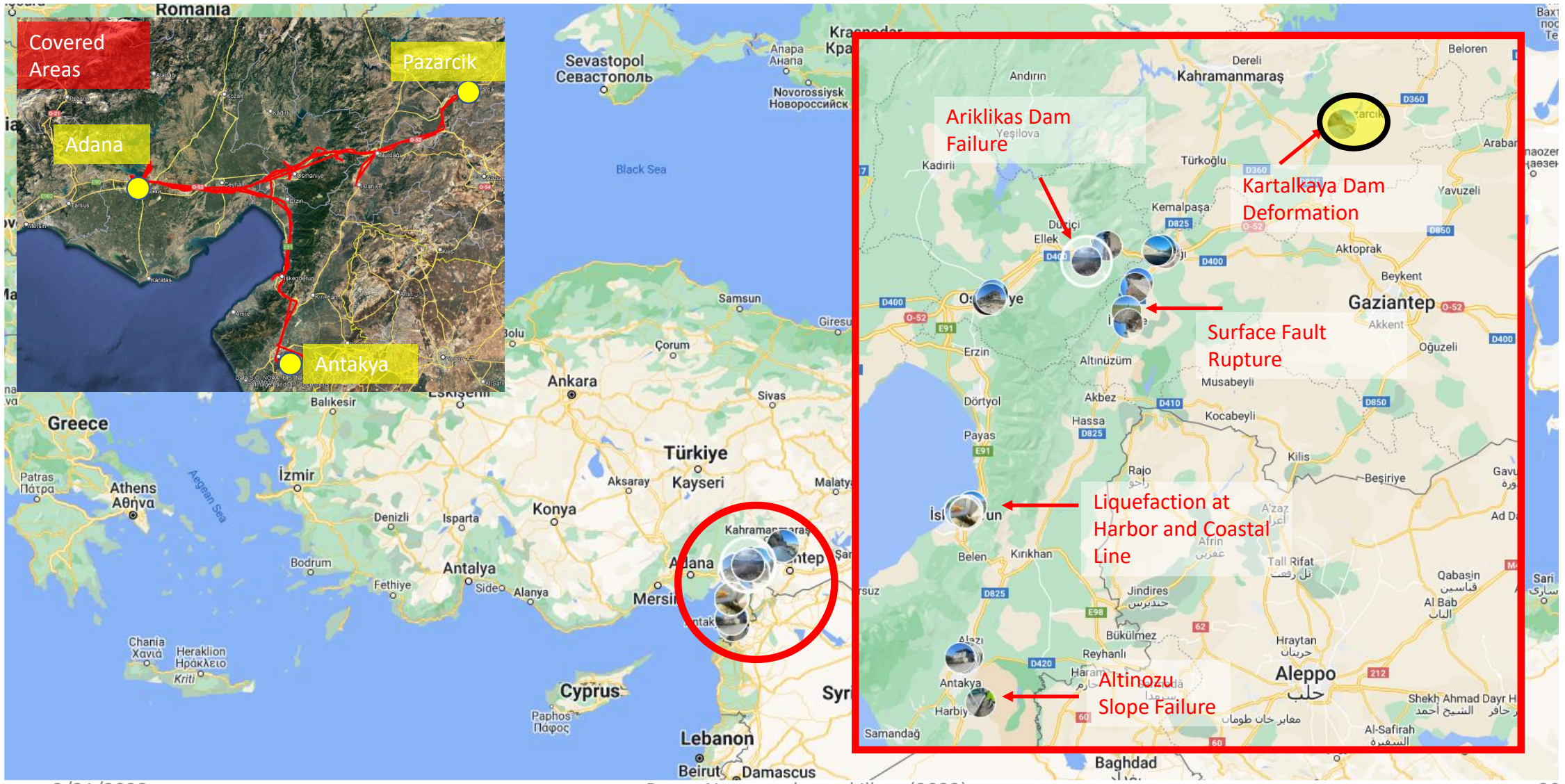
Ariklikas Dam - Osmaniye



Ariklikas Dam - Osmaniye

Ariklikas Dam - Osmaniye

Kartalkaya Dam Deformations



Kartalkaya Dam- Pazarcik, Kahramanmaras

Kartalkaya Dam- Pazarcik, Kahramanmaras

Kartalkaya Dam- Pazarcik, Kahramanmaras

Intermediate Conclusions – Performance of Dams

- Some dams performed very well whereas some other performed poorly during the quakes
- Further study is required to identify the key aspects that led to poor performance of certain dams and good performance of others

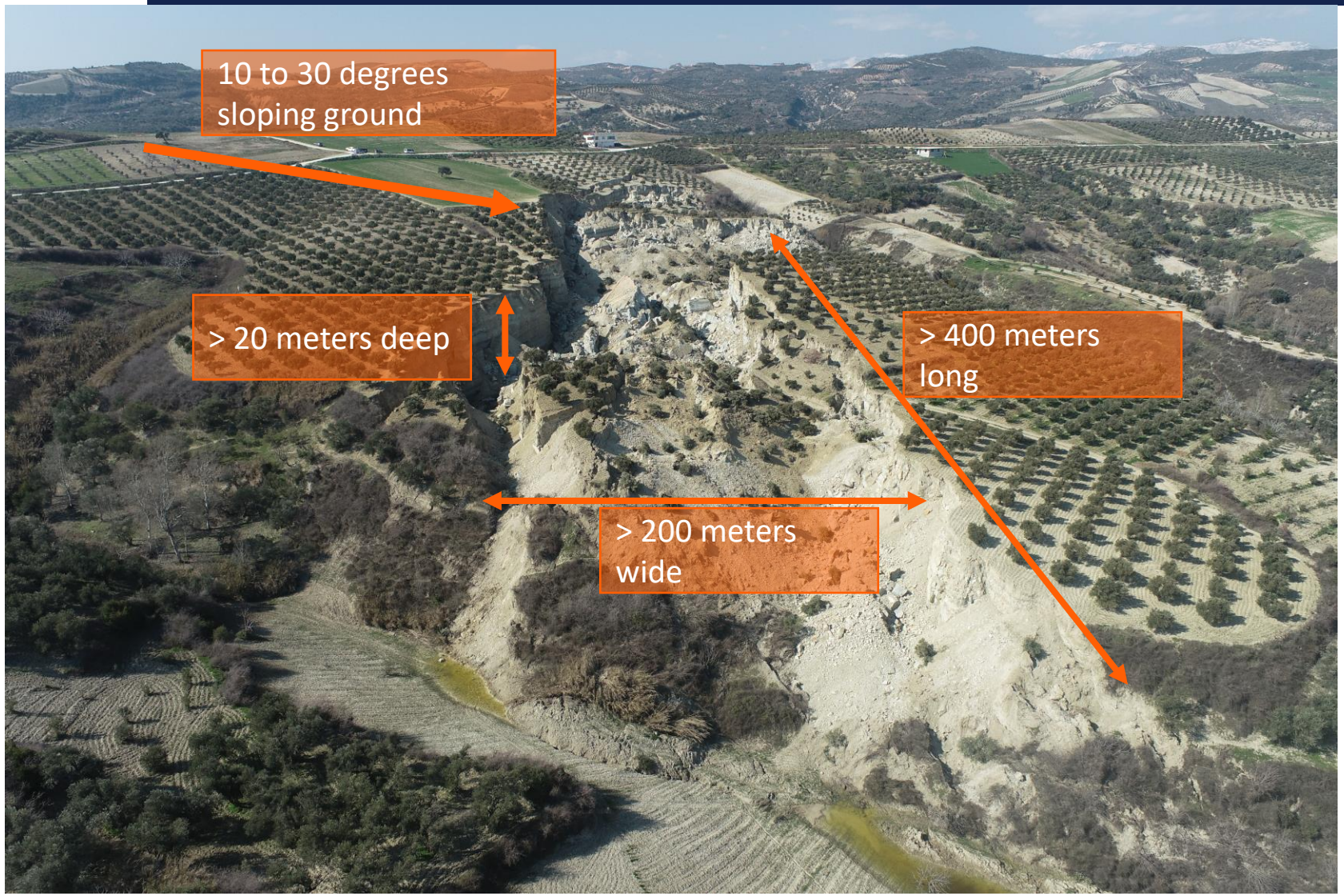
D825 Highway – Landslide near Railroad

D825 Highway – Landslide near Railroad

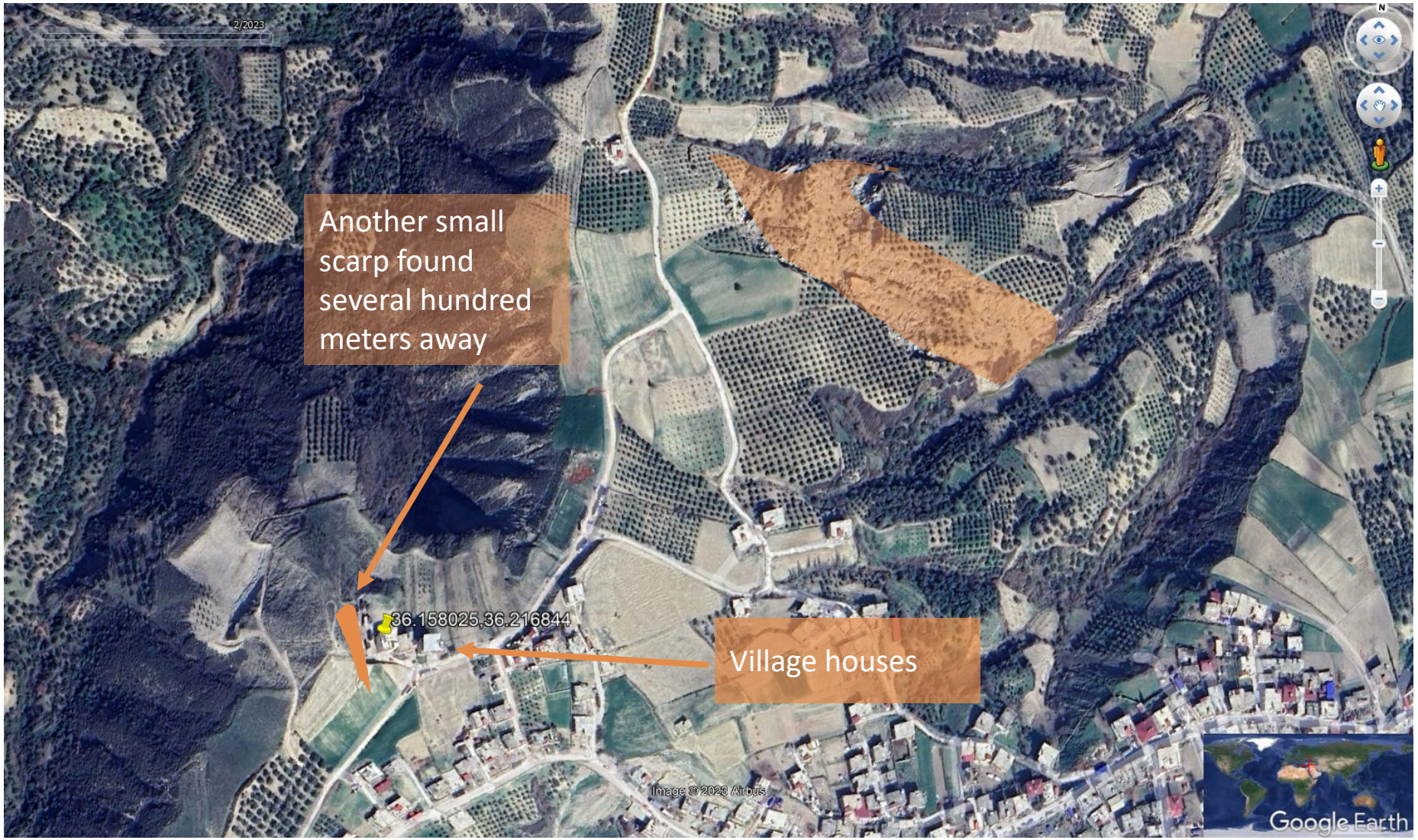
Altinozu Landslide

Altinozu Landslide

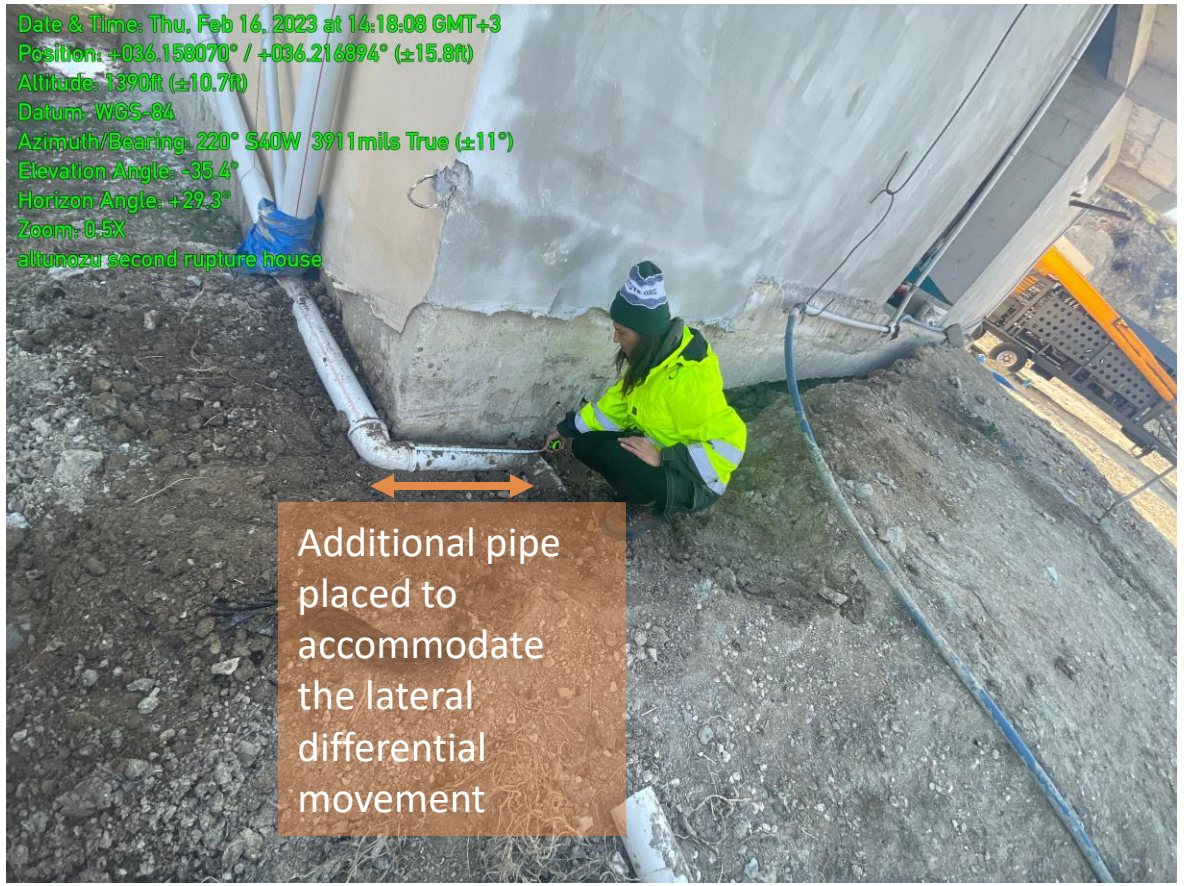
Altinozu Landslide



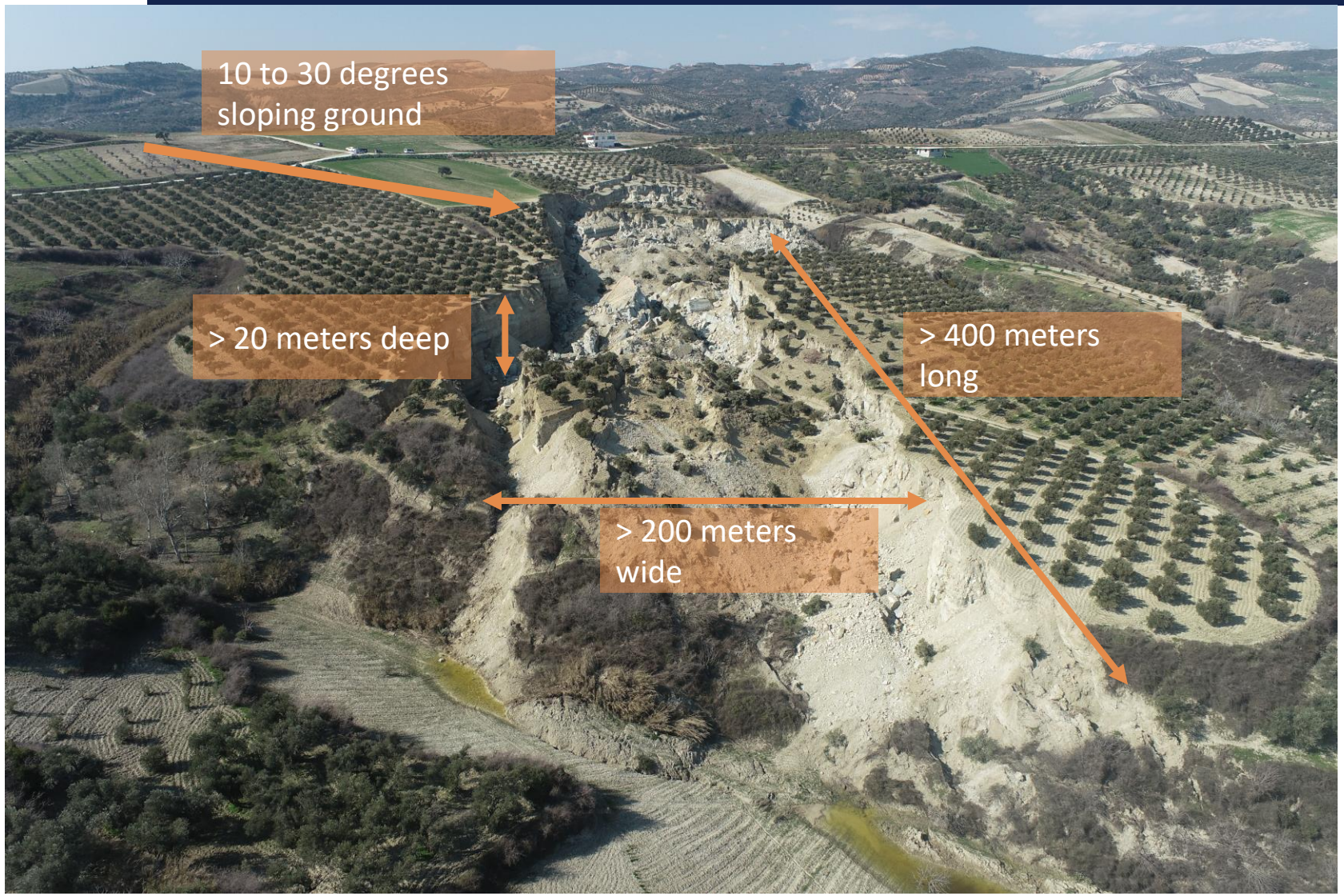
Altinozu Landslide



Village Houses Trapped between Two Landslides (or One?)



Altinozu Landslide



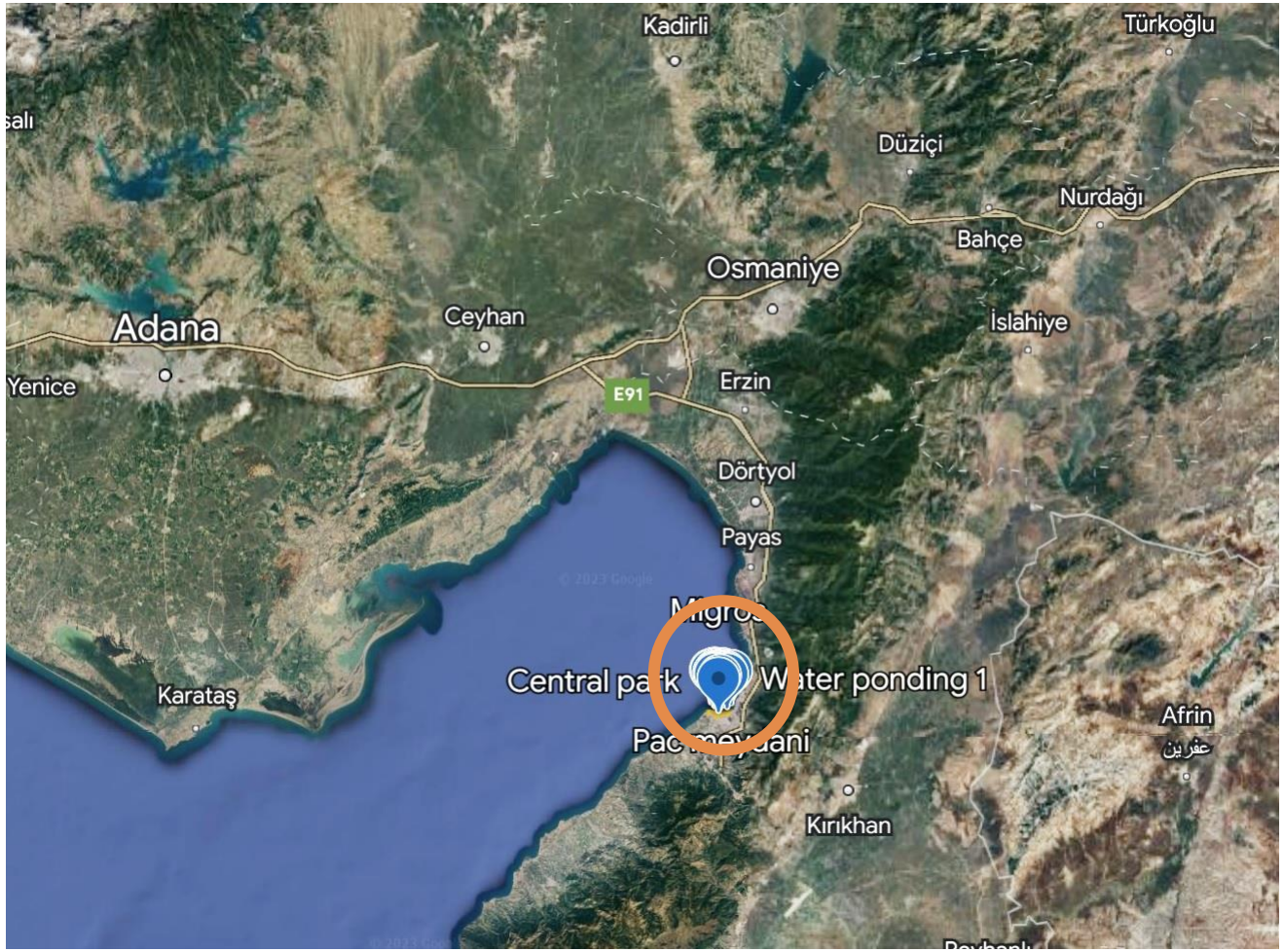
- Already mobilized slope?
- Heavy rainfalls right before the earthquake
- Mobilization after the earthquake (e.g., aftershocks, creep, new earthquakes?)

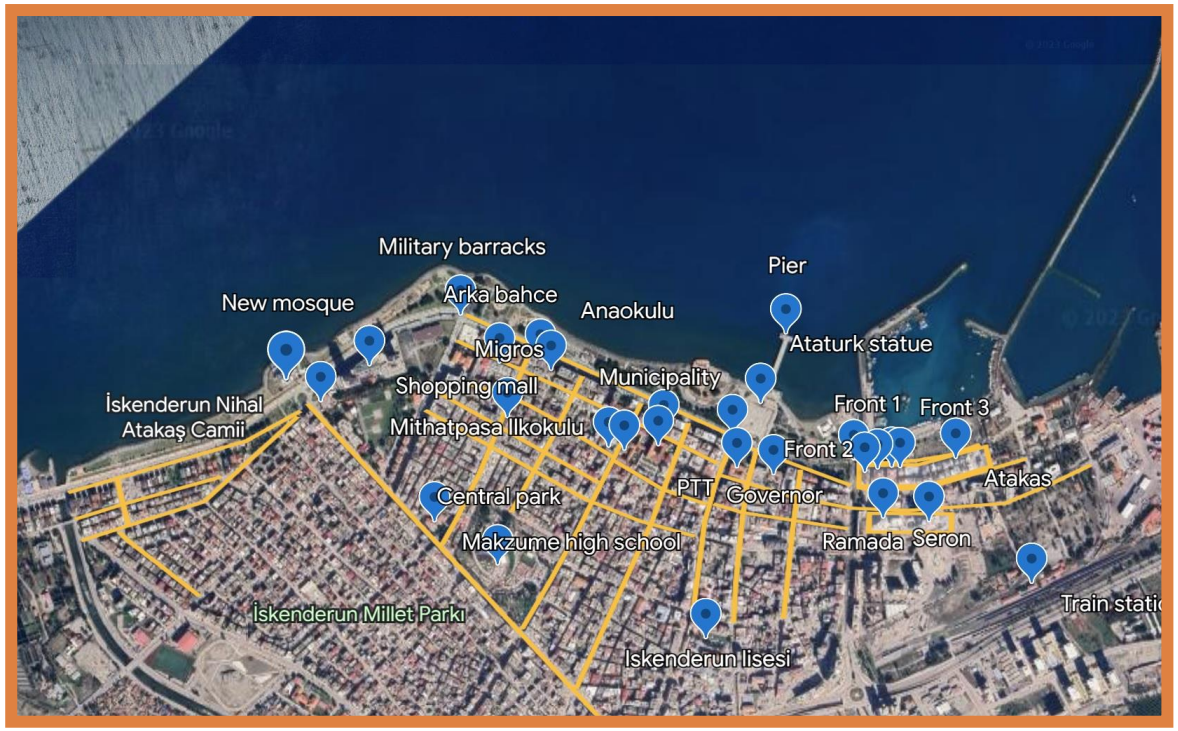
Intermediate Observations and Discussions– Altinozu Landslide

- Was the slope already moving before the earthquake?
- Heavy rainfall right before the earthquake. The sequence of events took place at the area indicates series of extreme events
- Mobilization after the main slip (e.g., aftershocks, new earthquakes, creep type continuation of the slope movement?)
- How will this landslide impact the locals living in the area?

Ground Subsidence in Iskenderun

Iskenderun Coastal Line (Reclaimed Areas) – Liquefaction Manifestation





Iskenderun Coastal Line (Reclaimed Areas) – Liquefaction Manifestations

Iskenderun Coastal Line (Reclaimed Areas) – Liquefaction Manifestations

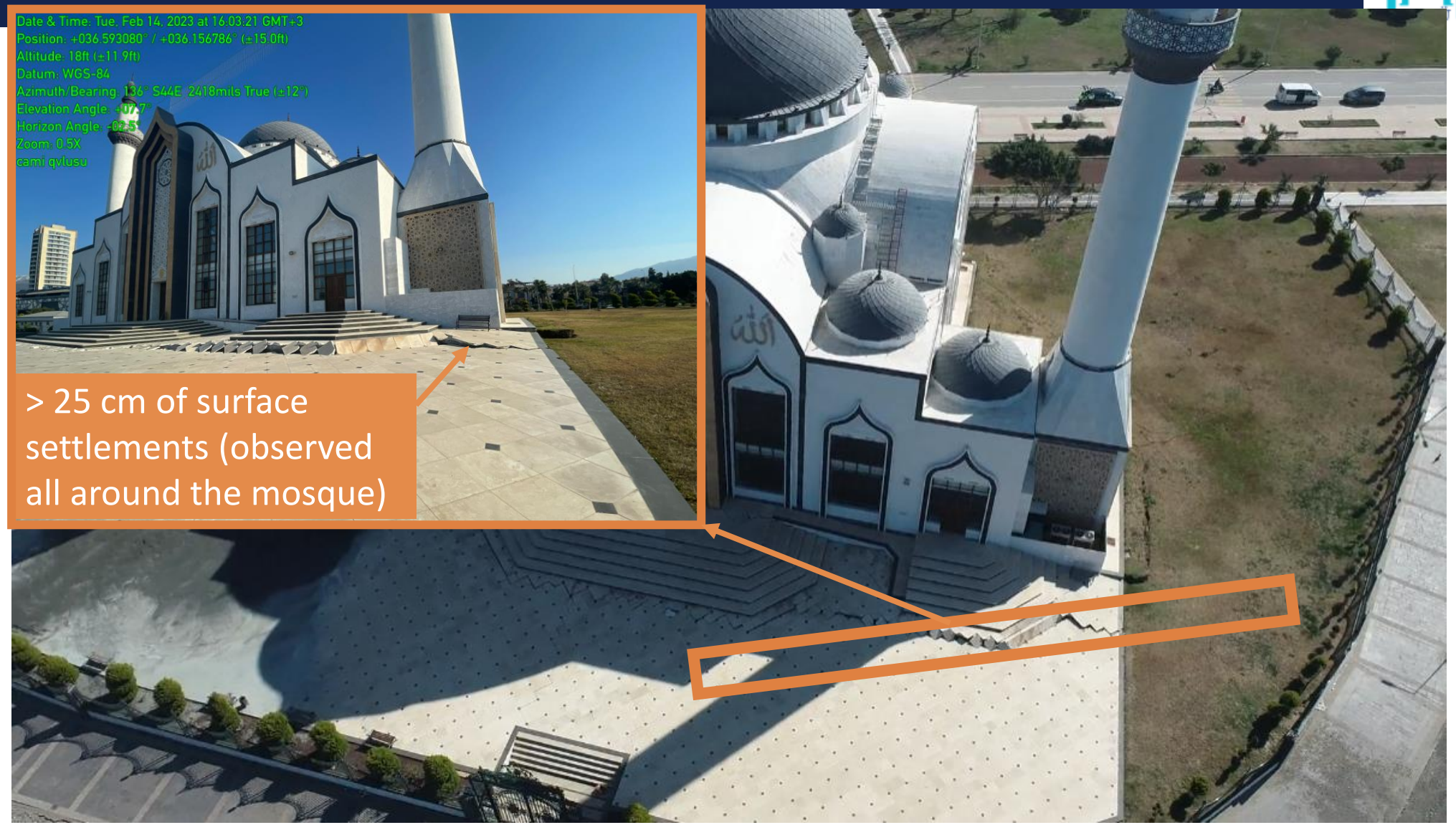
Iskenderun Coastal Line (Reclaimed Areas) – Sand Boils

Near-free field widespread liquefaction was observed at the reclaimed areas.

Iskenderun Coastal Line (Reclaimed Areas) – Sand Boils / Sand Eject

Iskenderun Coastal Line (Reclaimed Areas) – Lateral Spreading

Iskenderun Coastal Line (Reclaimed Areas) – Differential Settlement

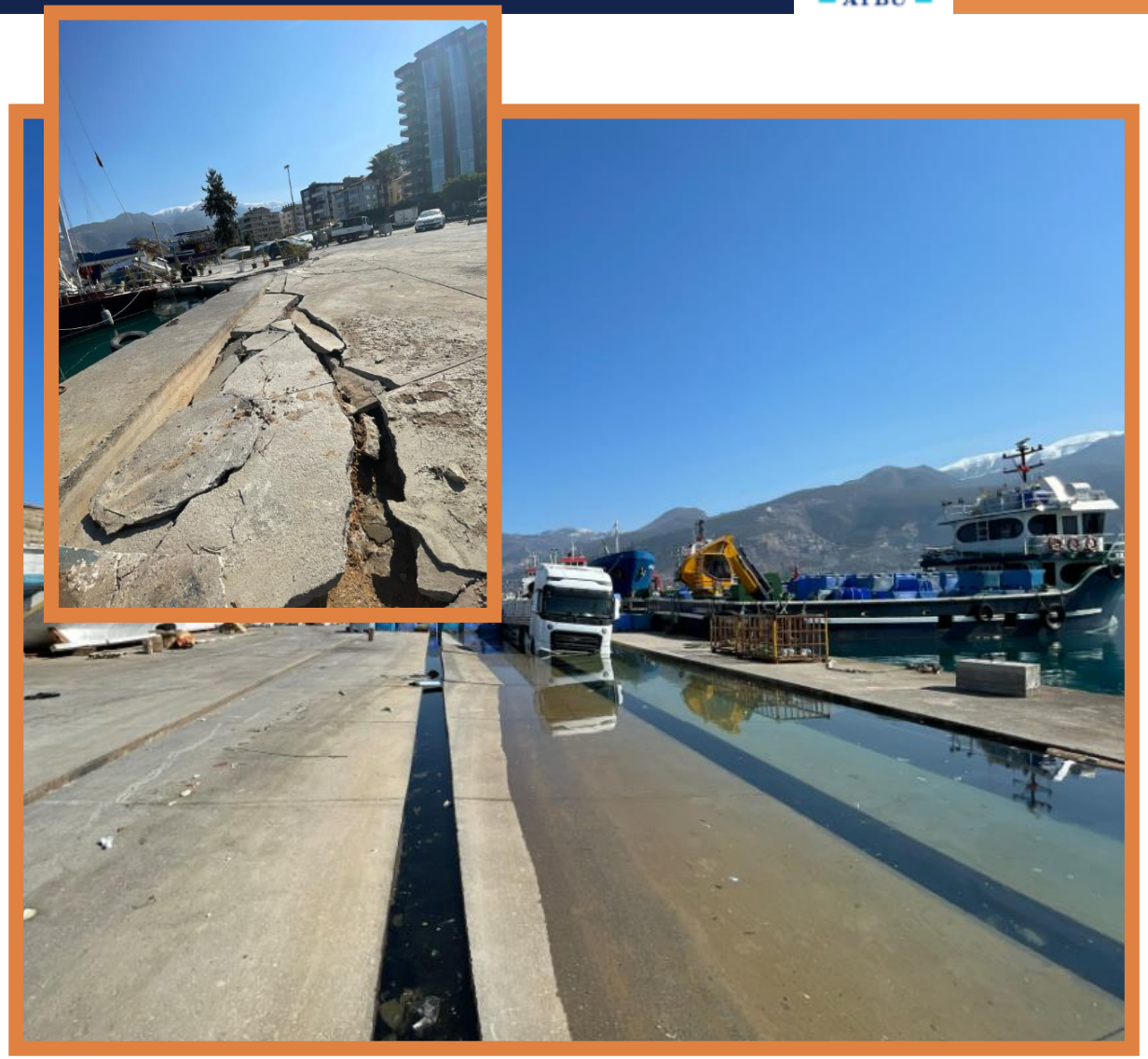


Iskenderun Coastal Line (Reclaimed Areas) – Lateral Spreading

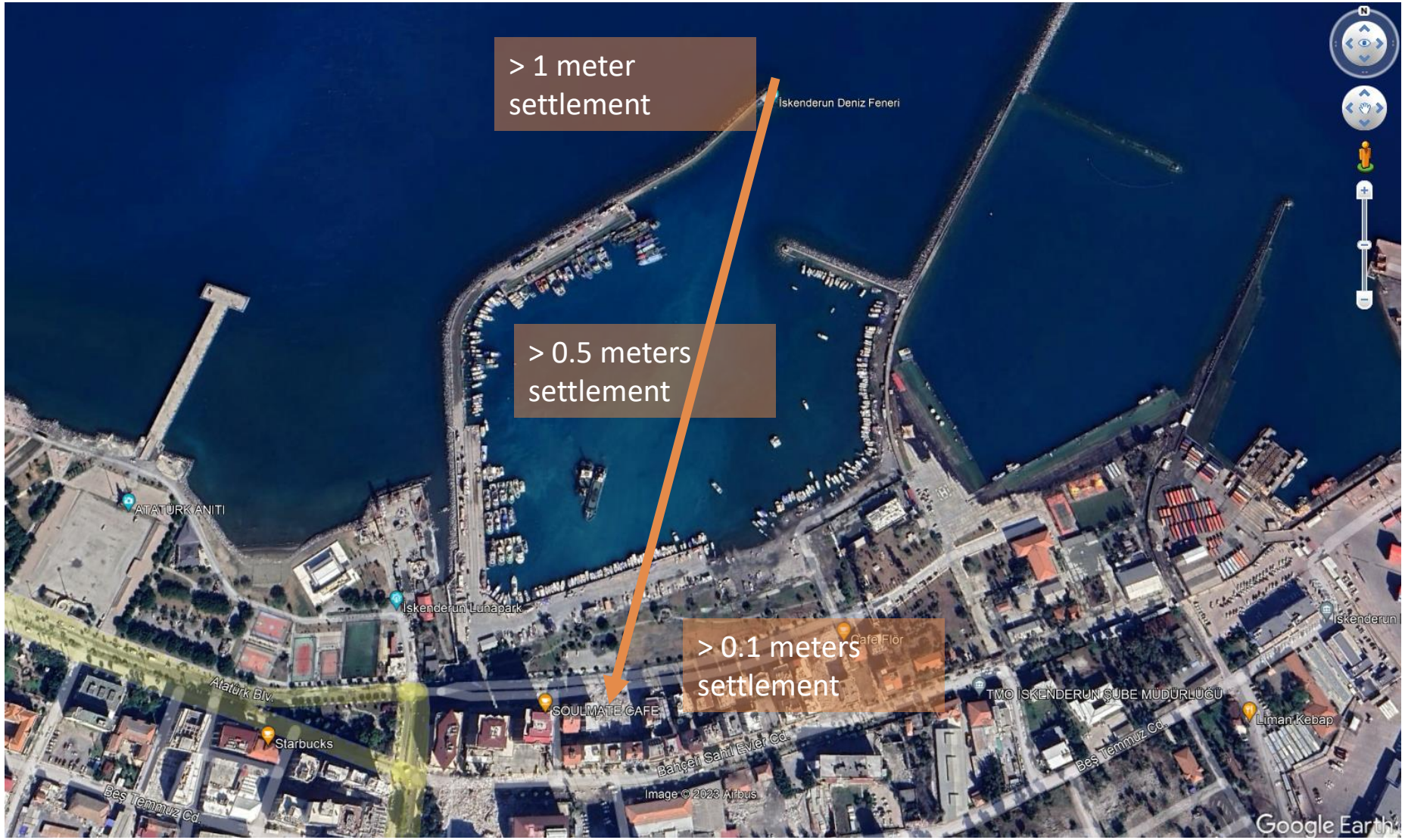
Iskenderun Coastal Line (Reclaimed Areas) – Differential Settlement

Iskenderun Coastal Line (Reclaimed Areas) – Iskenderun Dock

Iskenderun Coastal Line (Reclaimed Areas) – Iskenderun Dock



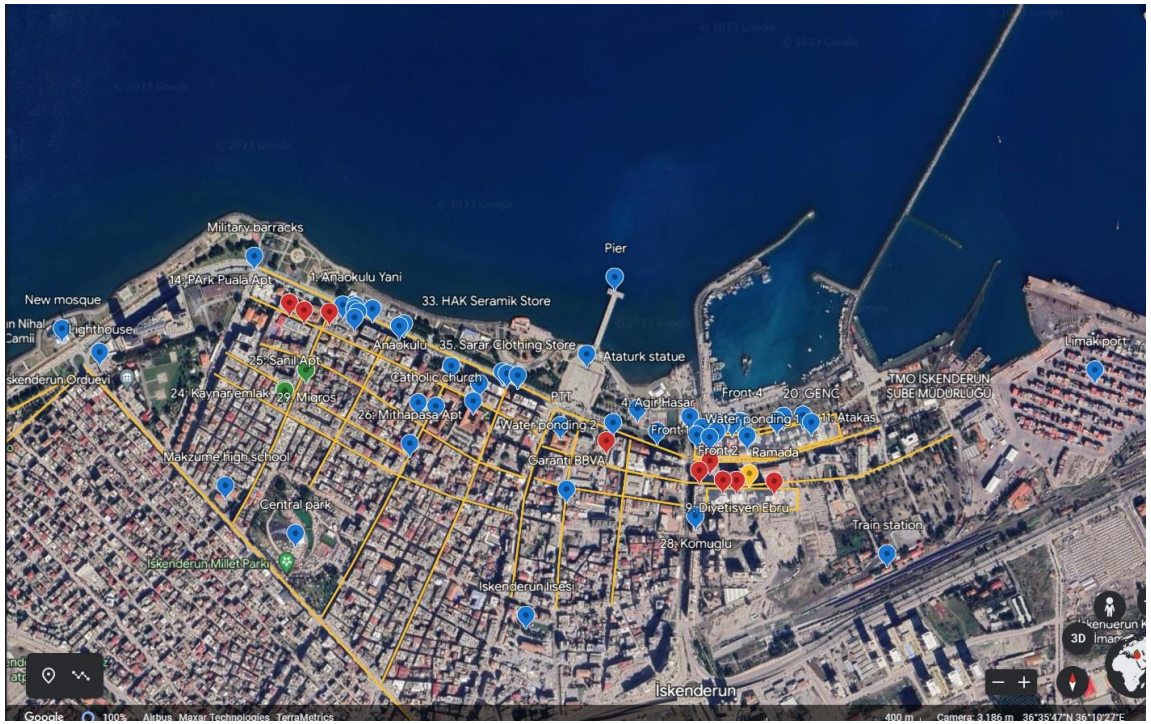
Iskenderun Coastal Line (Reclaimed Areas)



Iskenderun


Stable
Tilted
Iskenderun District
Stable
Total Collapse
Total Collapse
Total Collapse
RAMADA

Iskenderun Building-Foundation Performance



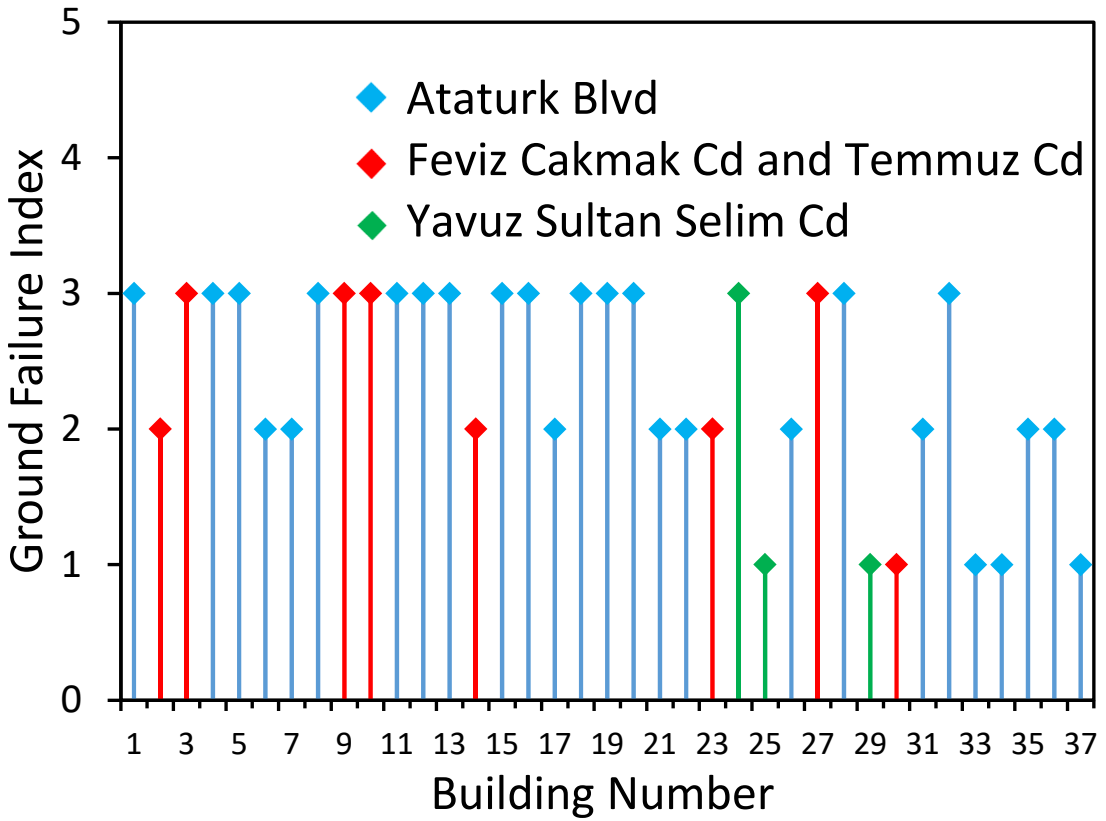


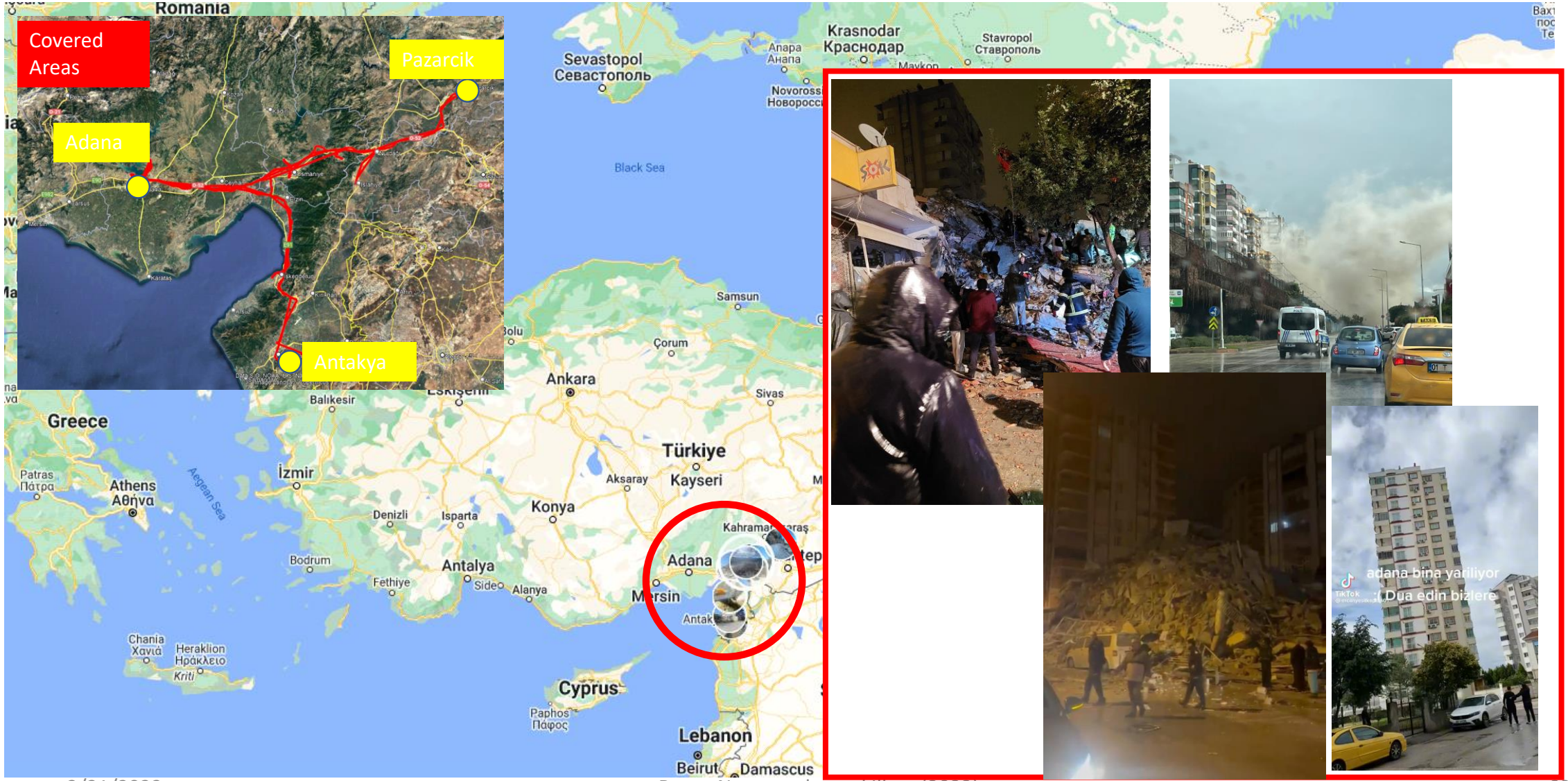
Table 8.3. Ground Failure Index.

Index	Description	Interpretation
GF0	No Observable Ground Failure	No settlement, tilt, lateral movement, or boils
GF1	Minor Ground Failure	Settlement, $\Delta < 10$ cm; tilt of > 3-story buildings < 1°; no lateral movements.
GF2	Moderate Ground Failure	$10 < \Delta < 25$ cm; tilts of 1–3°; small lateral movements (< 10 cm)
GF3	Significant Ground Failure	$\Delta > 25$ cm; tilts of > 3°; lateral movements > 25 cm.

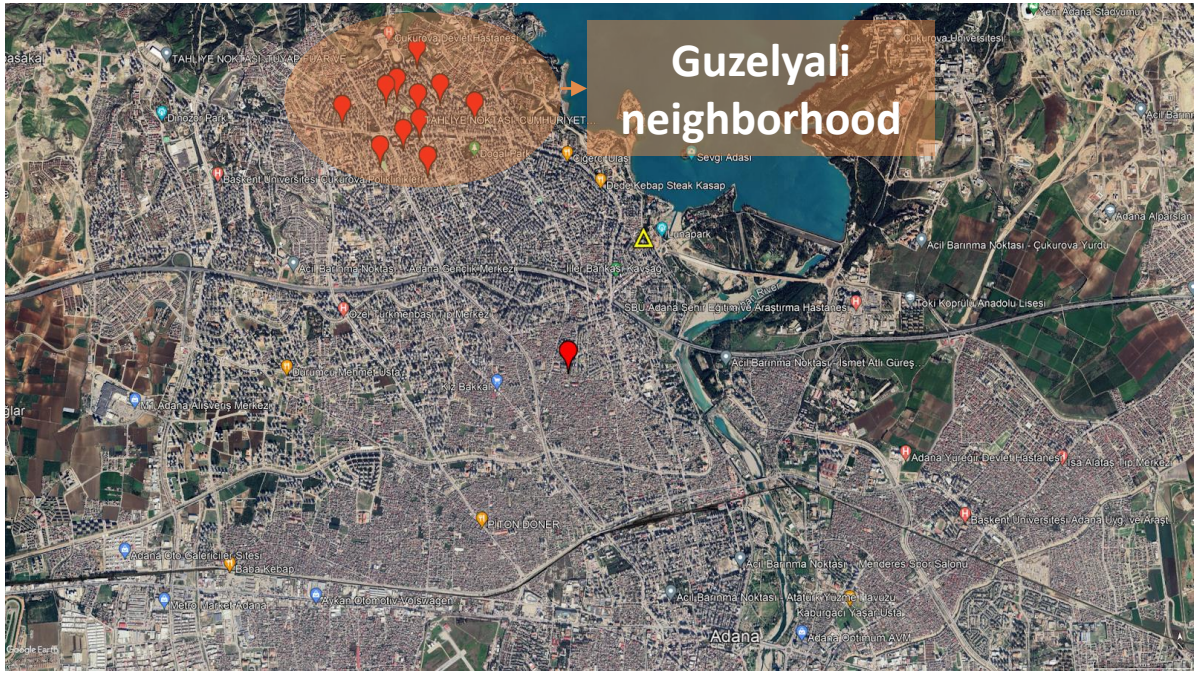
Intermediate Conclusions - Iskenderun

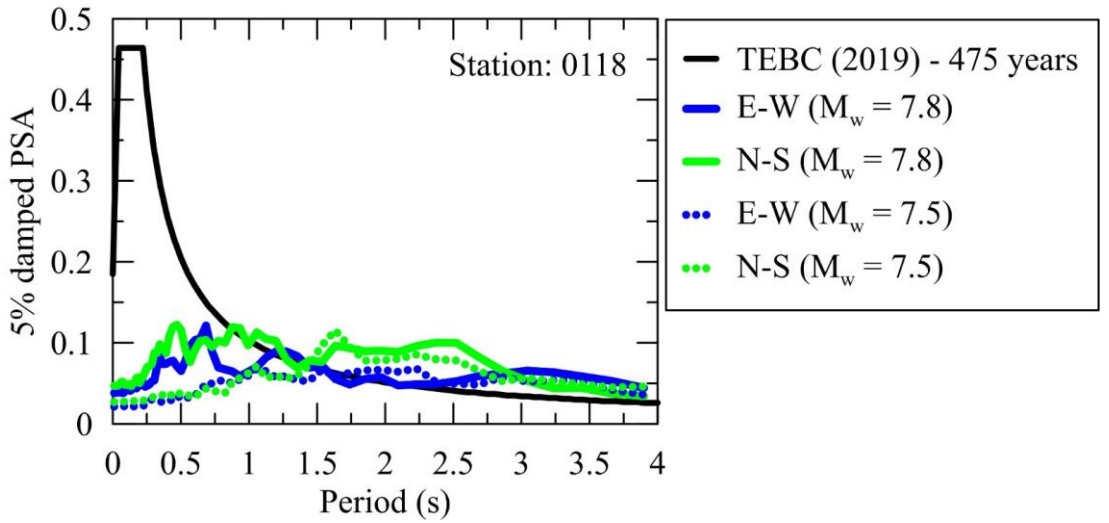
- Widespread liquefaction
- Liquefaction occurred both at near-free field and at soil-structure interaction cases
- Settlements vary between 20 cm up to 150 cm and largest settlements occur at the edges of the Iskenderun dock (might be related to thickness of reclamation material)
- Lateral spreading with 5 cm to 25 cm displacements was measured around the coastal line

ADANA: A Puzzling Case History



ADANA: A Puzzling Case History





- 12 residential buildings with more than 10 stories catastrophically collapsed resulting in 1,000 deaths
- 3800 buildings red tagged to be demolished
- Collapsed buildings in a specific neighborhood of Adana, 11 of these buildings laid within an area less than a kilometer radius
- Distant to the earthquakes and **weak ground motions (~0.05g)** close to the area with the collapsed buildings

of the Extents of the Impacts

Flash floods in Sanliurfa, Adiyaman, Hatay Source of the mud?

NASA's Goddard Space Flight Center **identified more than 100 landslides**, including several in the valley near Sarıseki, using **high-resolution data** from Planet Labs.

Baser, Numanoglu, and Ilhan (2023)

Conclusions

- Further investigation is necessary to better understand the widespread liquefaction occurred at Iskenderun, Hatay.
- Systematic evaluation of the dams is valuable to understand the mechanisms and parameters played a role on some dams experiencing severe damages whereas the others performing relatively well
- Altinozu landslide is required monitoring of the slope movement (if any) in case of a progressive failure
- Although not shown in this presentation explicitly, site amplification evidence is strong in this event and needs to be further studied.
- At the same location, some buildings performed very well and the other had total collapse, thus, parametric evaluation is valuable to understand the reasons behind good performance versus total collapse.
- Adana case is attributed to the lack of technical expertise on earthquake-resistant design, poor construction practices and **possibly an unforeseen seismic amplification in this area**.

Unknowns remain

- Was Altunozu slope already moving? Contribution of rainfall or seismic loading?
- Settlements in Iskenderun caused by reconsolidation and/or lateral movement?
  - Why some buildings performed well why others collapsed or settled significantly?
- Overlooked cascading events: Climate change acting as a stressor on the earthquake induced failures
  - Mechanisms of flooding events in Sanliurfa, Adiyaman, Iskenderun, and Hatay
- Adana: Site amplification caused by the stratigraphy? (Handere formation overlained by quaternary carbonate conglomerate)

THANK YOU.

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