Earthquake Engineering Research Institute
Dedicated to reducing earthquake risk

MIDDLE EAST TECHNICAL UNIVERSITY
Earthquake Engineering Research Center

Geotechnical Aspects of February 6, 2023 Kahramanmaraş-Türkiye Earthquake Sequence (M_w=7.8 and M_w=7.6)

Prof. Dr. Kemal Onder Cetin

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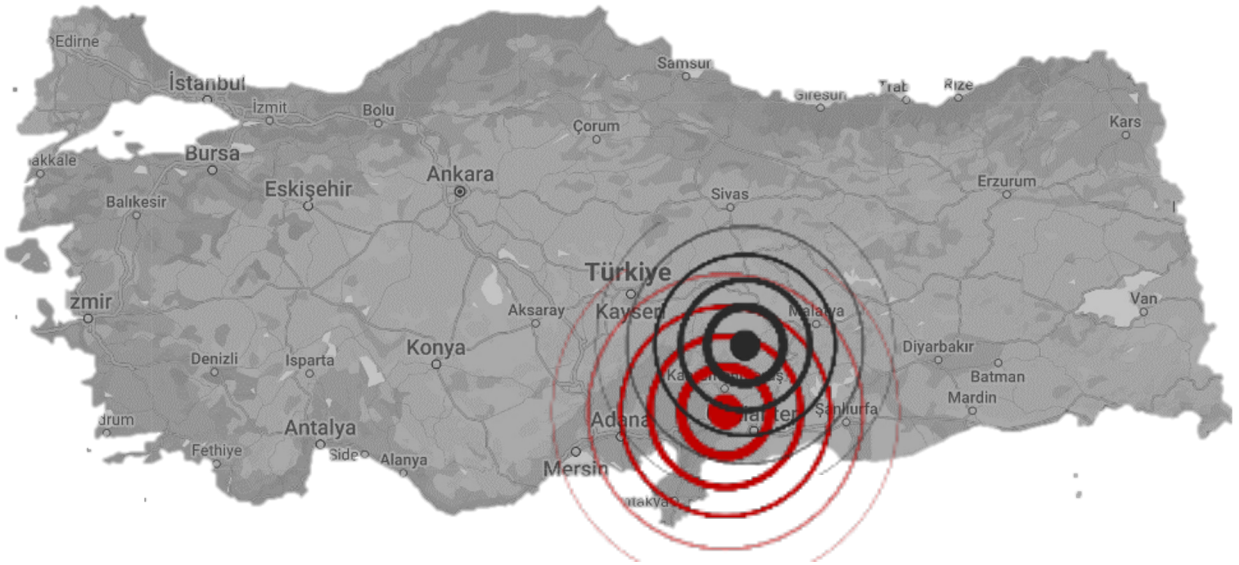

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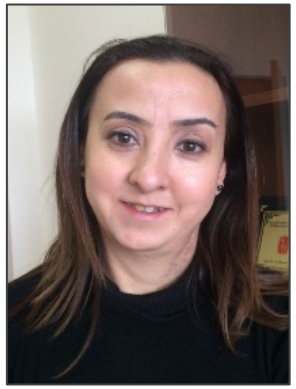

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PhD Candidate
Soner Ocak

Dr. Kristin Ulmer

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MSc Hayri Güzel

and MANY MORE...

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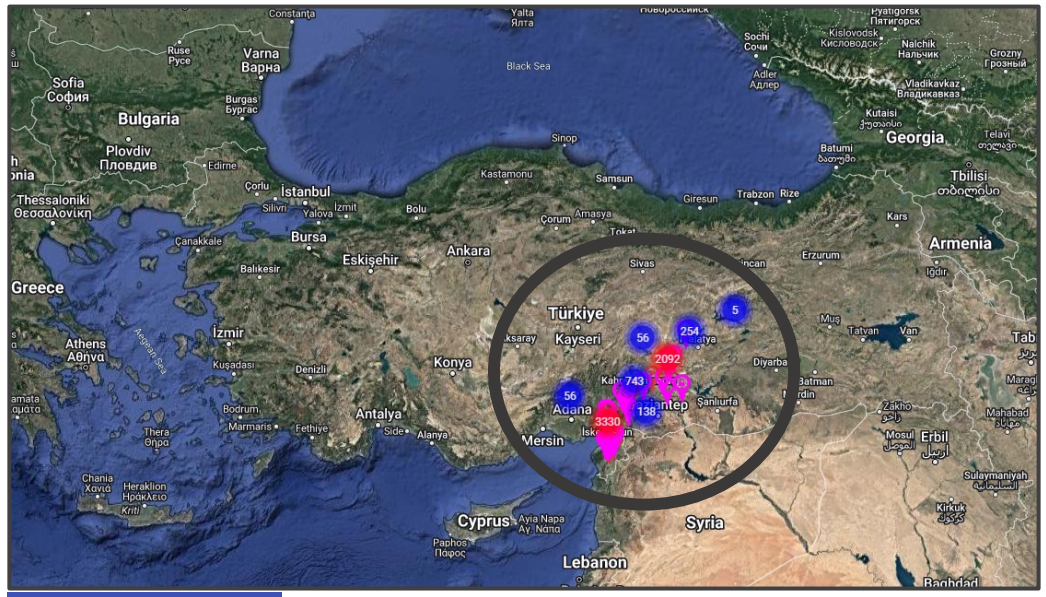
Alaa Elsaid

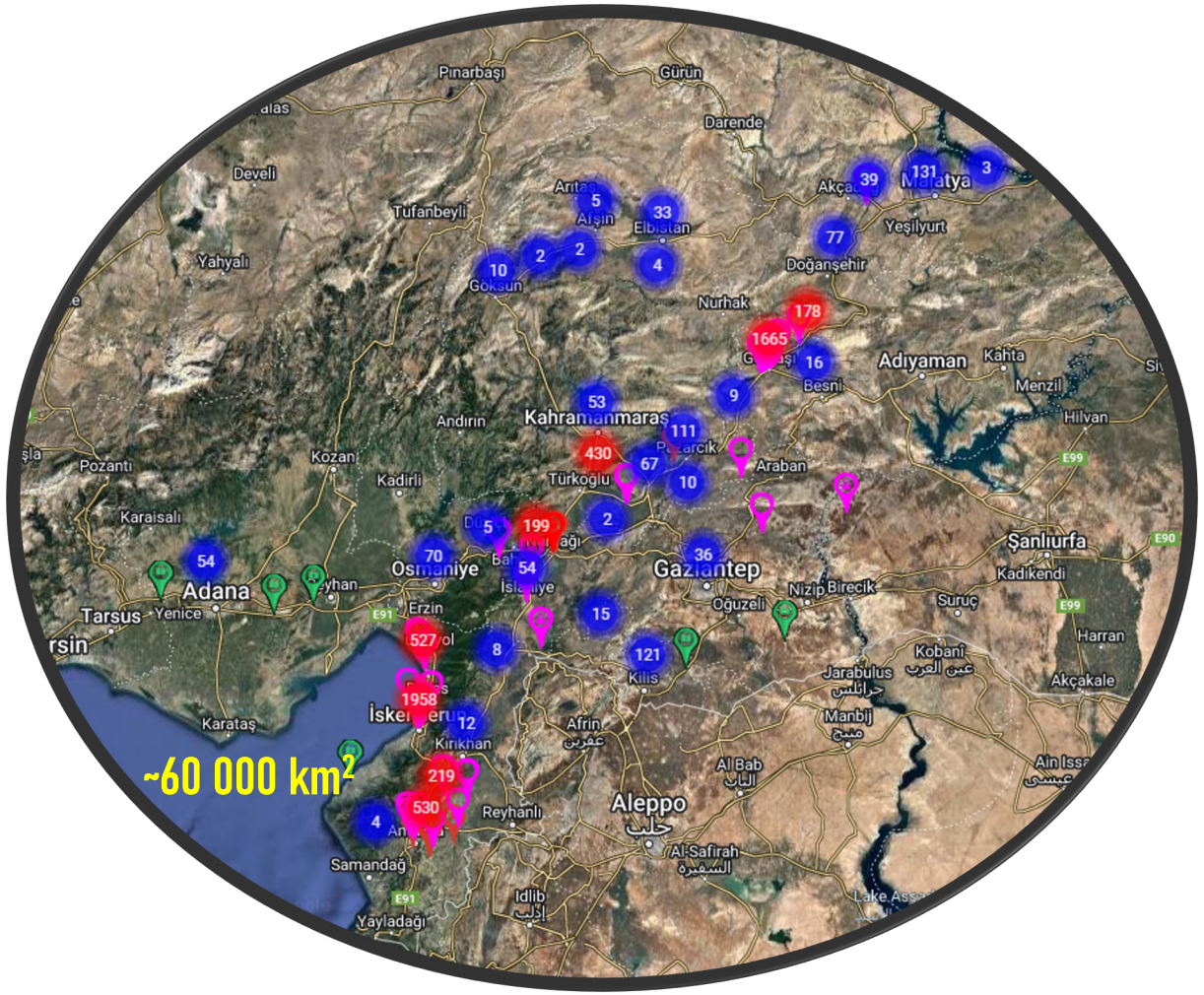
PhD Candidate
Ahmed Al-Suhaily

PhD Student
Arda Şahin

Geo-Reconnaissance Route



SAHAGÖZÜ



PRESENTATION OUTLINE

- INTRODUCTION
  - Brief Statistics
  - Tectonic Setting
  - Fault Rupture Mechanisms and Strong Ground Motion Characteristics
  - Rupture Velocity/Directivity/Site Effects

- GEOHAZARDS
  - Seismic Soil Liquefaction Sites
    - Free Field Liquefaction Sites
    - Manisfestations by :
      - Building Foundations
      - Ports and Harbours
      - Hydraulic Structures/ Eartfill and Rockfill Dams
      - Bridges
      - Airports

- GEOHAZARDS (Cont'd)
  - Lateral spreading - Inundation
  - Landslides and Rockfalls
  - Permanent Ground Displacements / Deformations
    - Fault Offsets
    - Deformations at:
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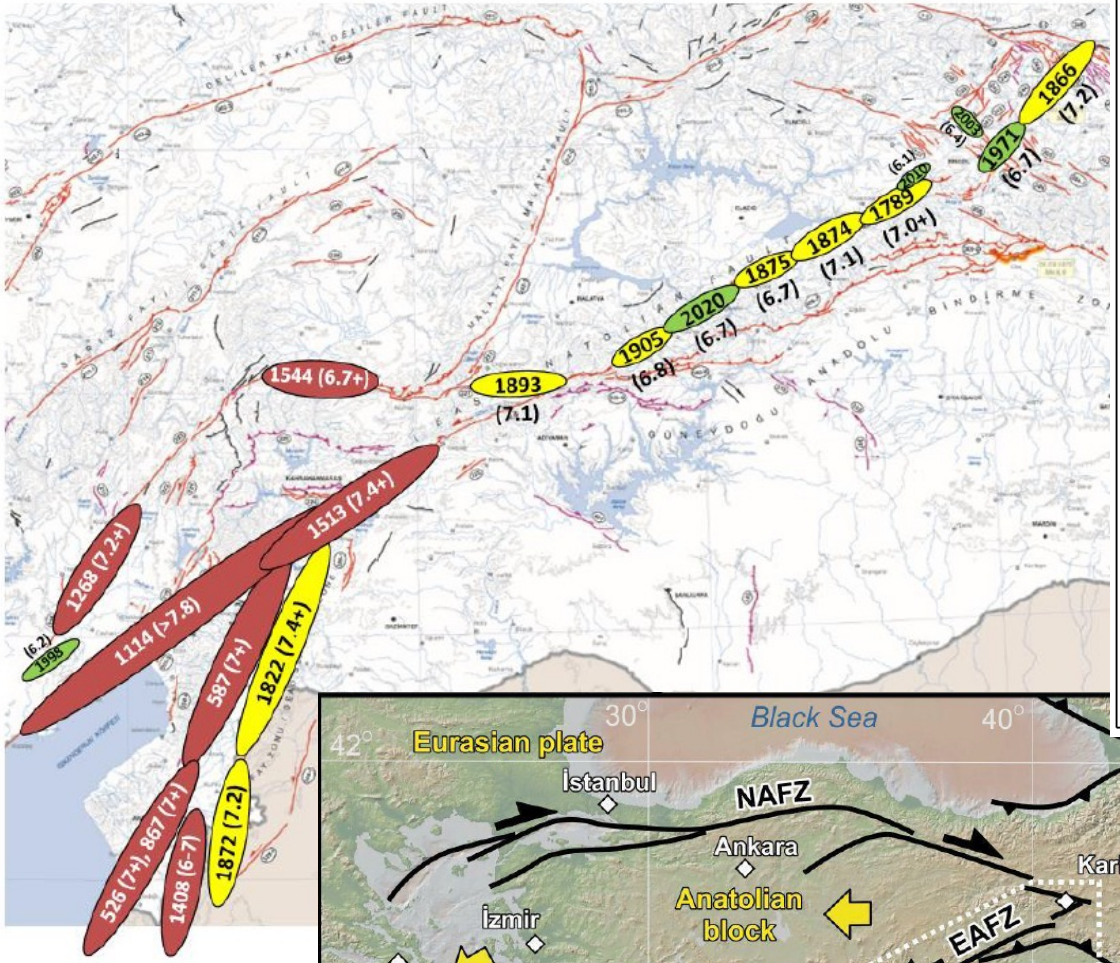
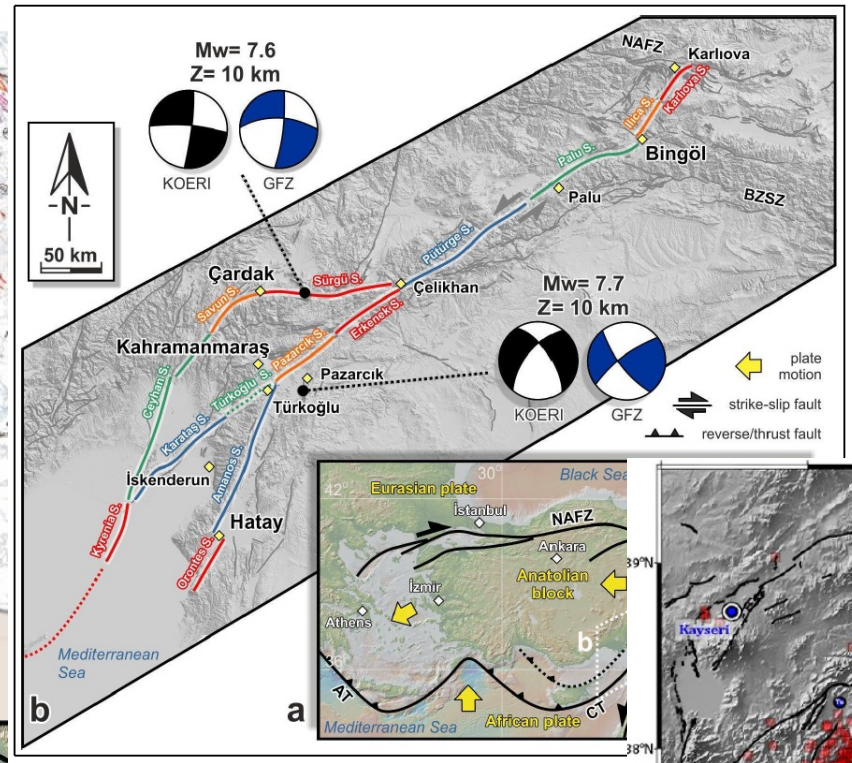
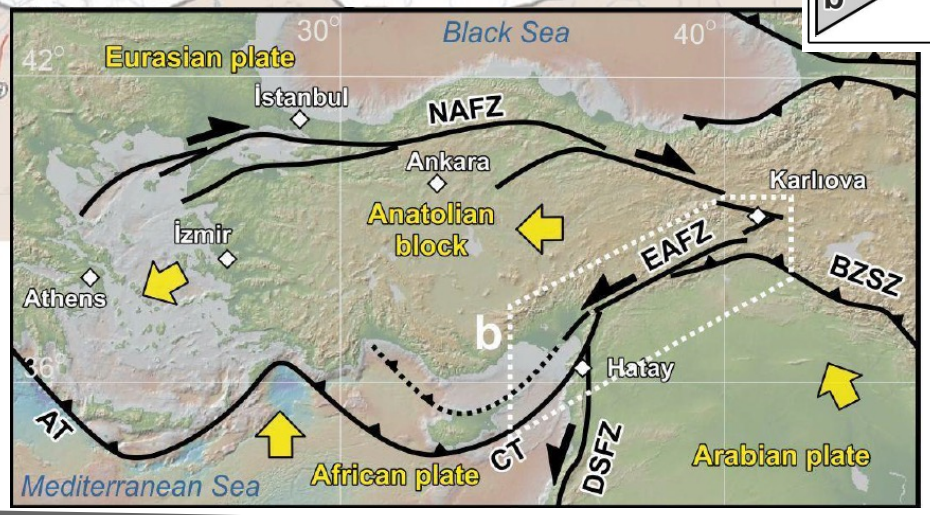
      - Earthfill and Rockfill Dams

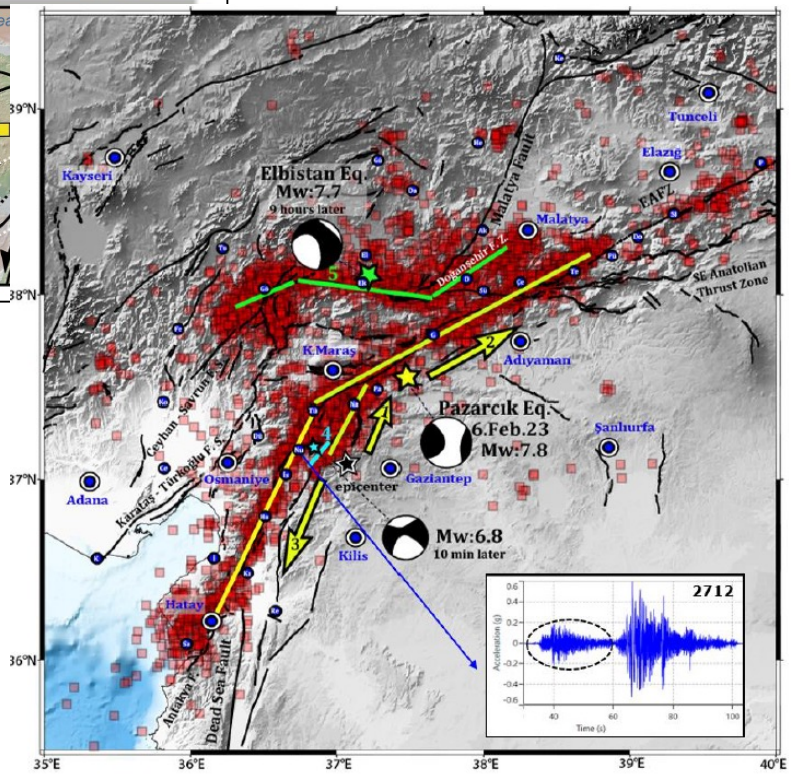
- LESSONS OFFERED AND CONCLUSIONS

Seismotectonic Setting









Adapted from Chapter 3 of Özacar et. al. (2023) ; Cetin et. al. (2023)

Fault Rupture Mechanisms: Likely Scenarios

RESEARCH

Science

NATURAL HAZARDS

Supershear triggering and cascading fault ruptures of the 2023 Kahramanmaraş, Türkiye, earthquake doublet

Chunmei Ren[1]†, Zexin Wang[1]†, Tuncay Taymaz[2], Nan Hu[3], Heng Luo[1], Zeyan Zhao[1], Han Yue[1]*, Xiaodong Song[1,4]*, Zhengkang Shen[5,1], Haoyu Xu[1], Jianghui Geng[6], Wei Zhang[3], Teng Wang[1], Zengxi Ge[1], T. Serkan Irmak[7], Ceyhun Erman[2], Yijian Zhou[8], Zhen Li[1], Hang Xu[1], Bonan Cao[1], Hongyang Ding[1]

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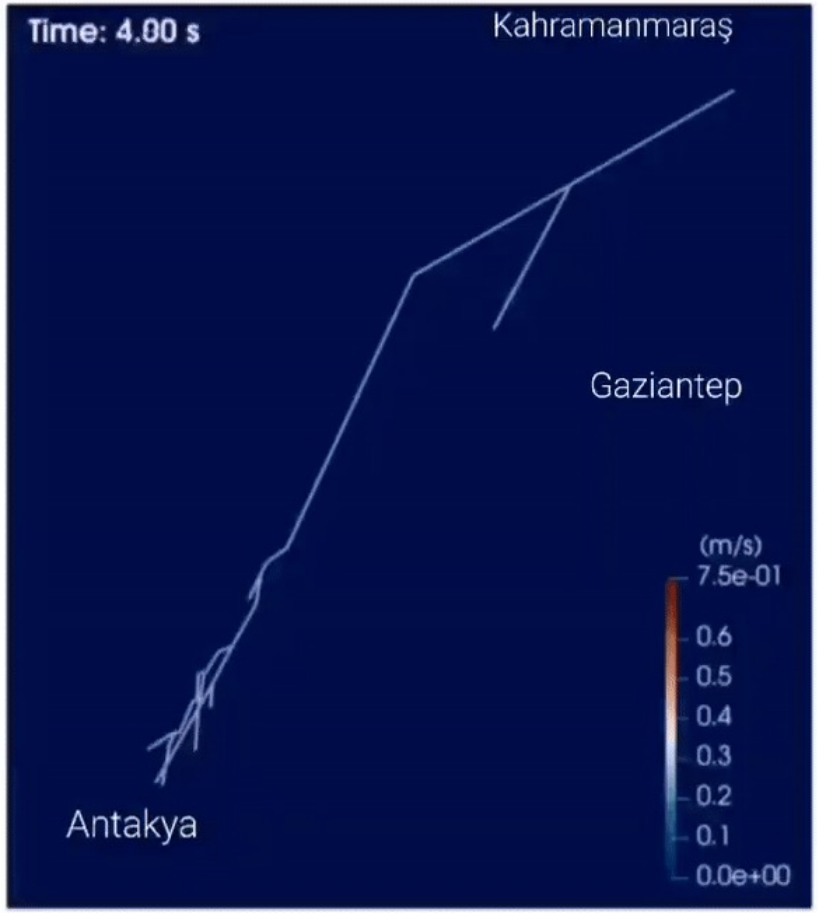
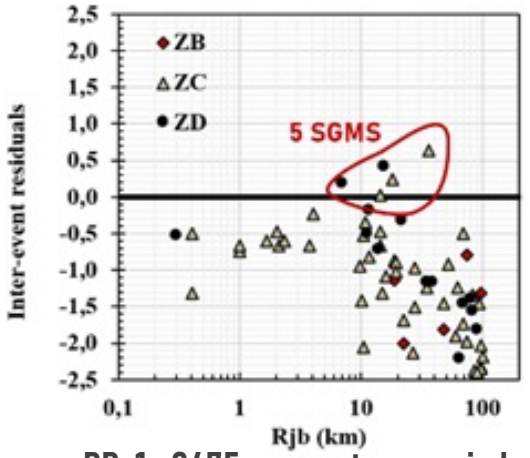
[8] Department of Earth and Planetary Sciences, University of California, Riverside, CA, 92521, USA

Ren et al. (2023) Supershear triggering and cascading fault ruptures of the 2023 Kahramanmaraş, Türkiye, earthquake doublet

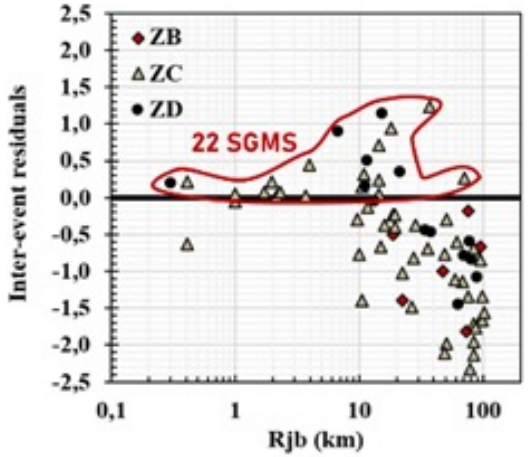


Abdelmeguid et al. (2023) – Dynamics of episodic supershear in the 2023 M7.8 Kahramanmaras/Pazarcik earthquake, revealed by near-field records and computational modeling

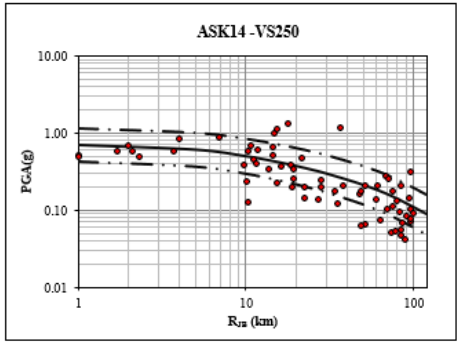
Sttrong Ground Motion Characteristics: Pazarcık Event

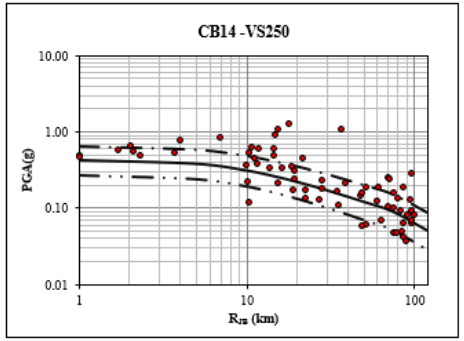


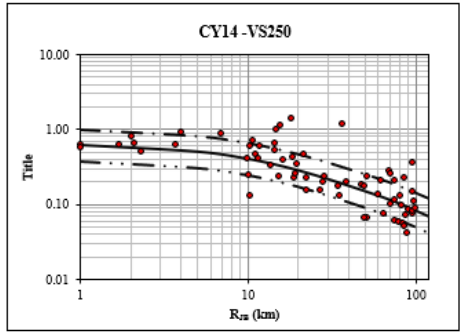
DD-1 : 2475 year return period

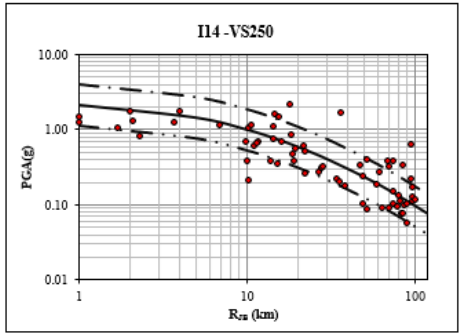


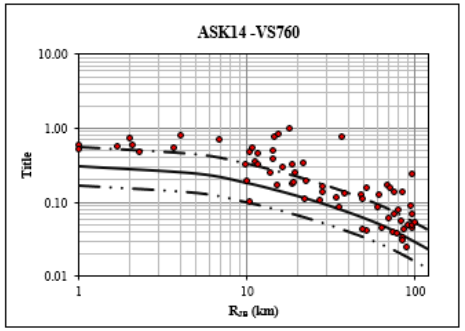
DD-2 : 475 year return period

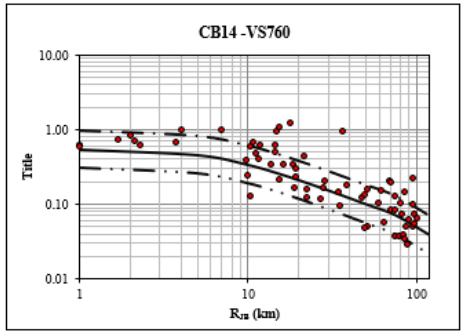


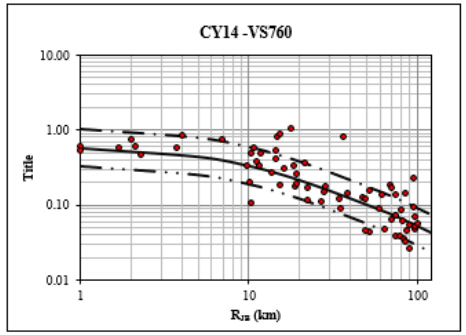


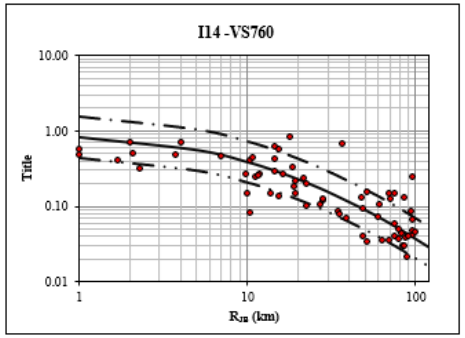




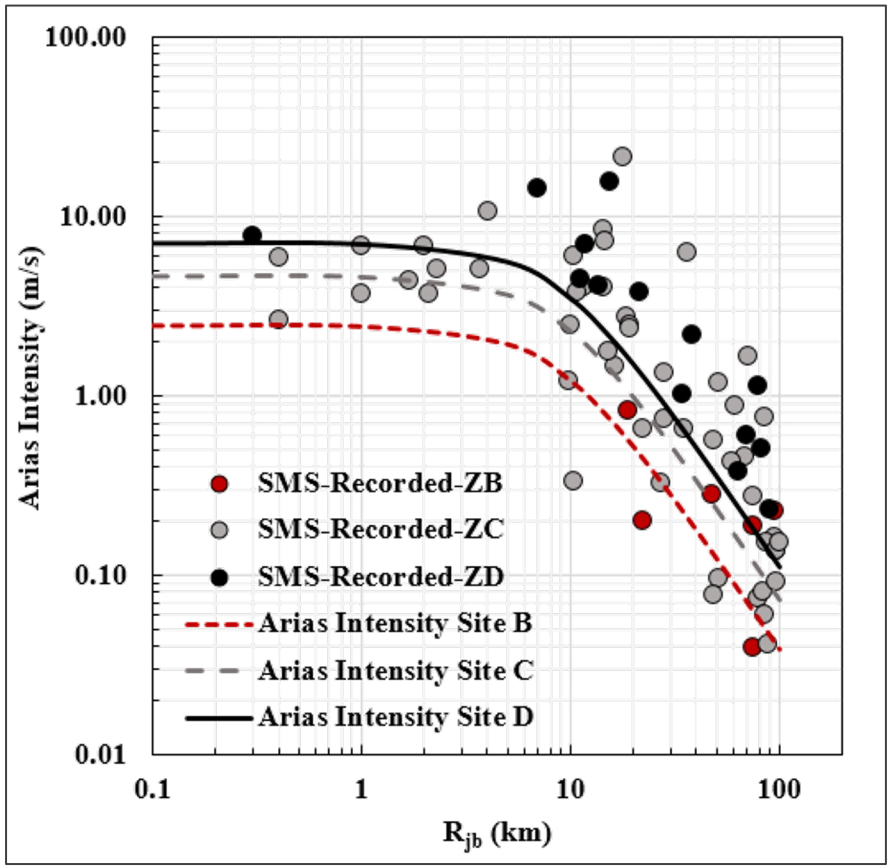




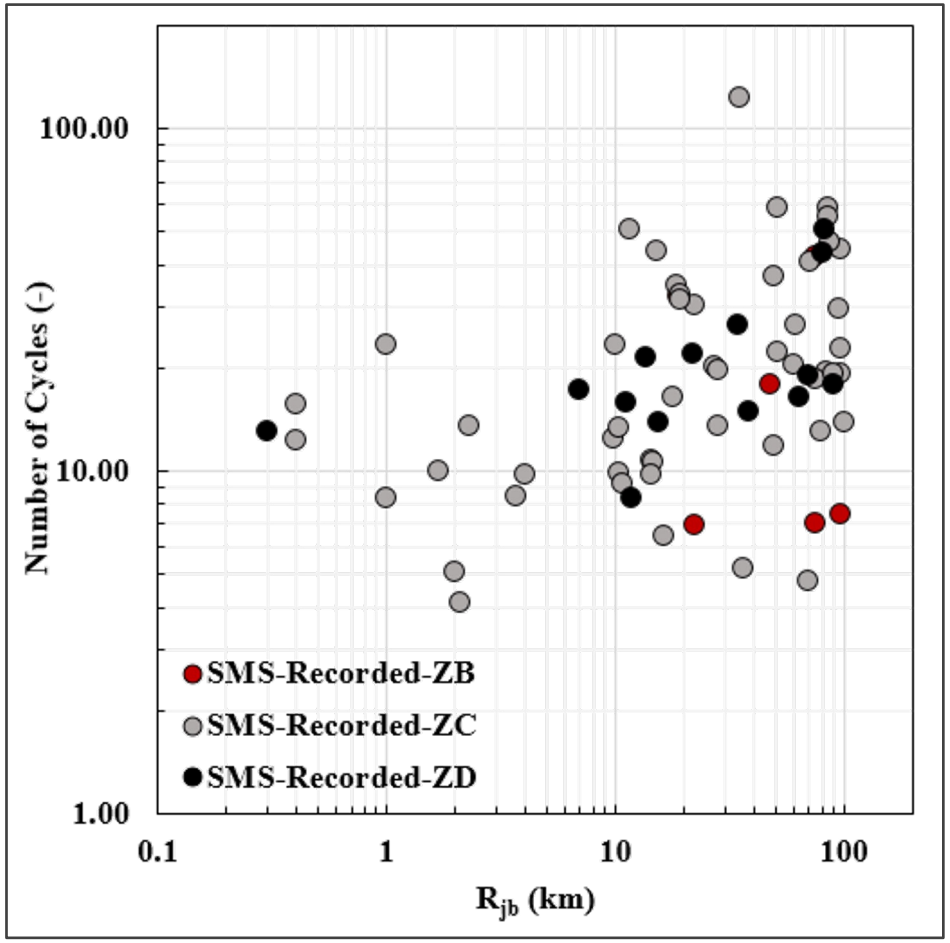




Strong Ground Motion Characteristics

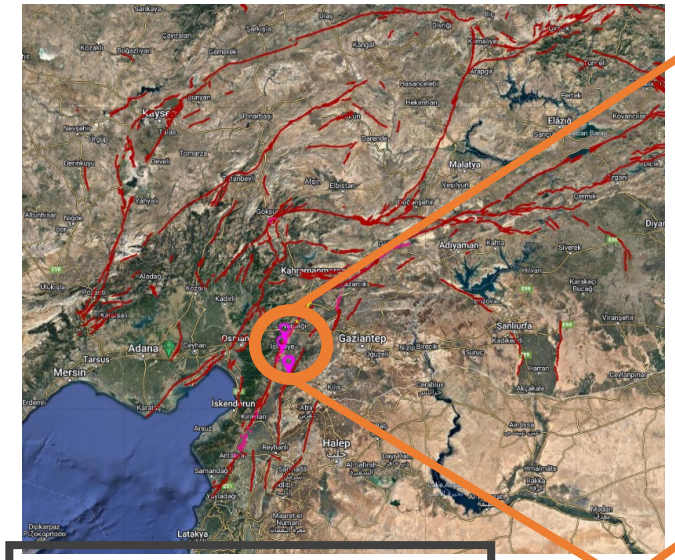


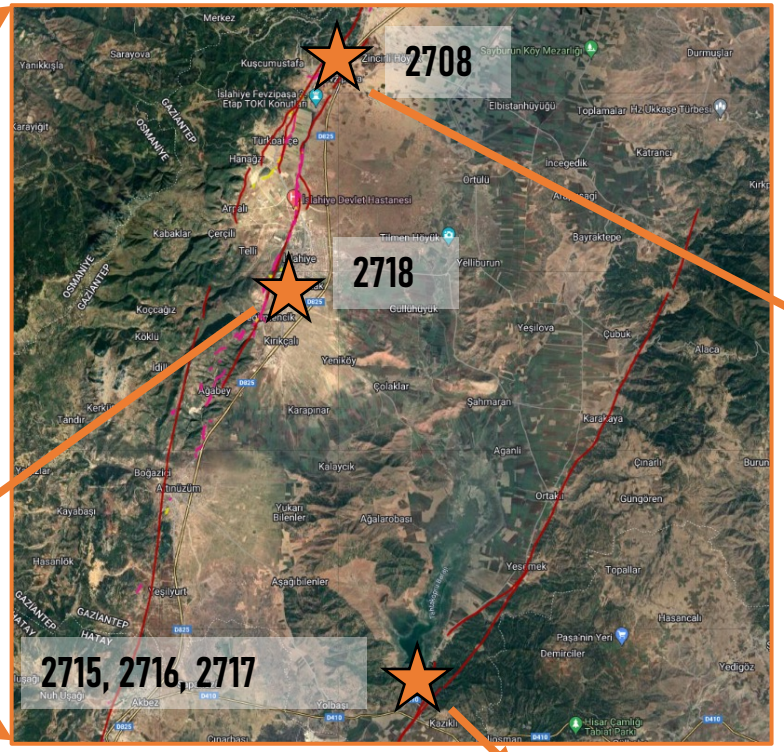
Compared to: Travasarou, Thaleia, Jonathan D. Bray, and Norman A. Abrahamson. "Empirical attenuation relationship for Arias intensity." *Earthquake engineering & structural dynamics* 32.7 (2003): 1133-1155.

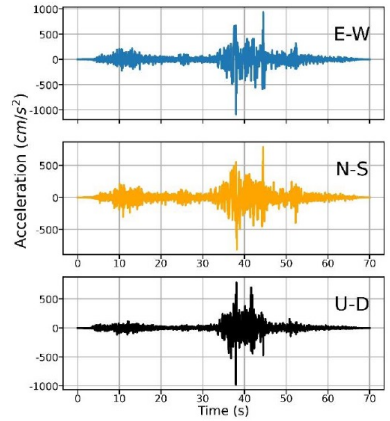


Assesed as outlined in Cetin et al. (2021)
Cetin, K. O., Altinci, E., and Bilge H. T., (2021). Probability-based assessment of number of equivalent uniform stress cycles. *Soil Dynamics and Earthquake Engineering,* 143, 106583

Rupture Velocity / Directivity/ Site Effects

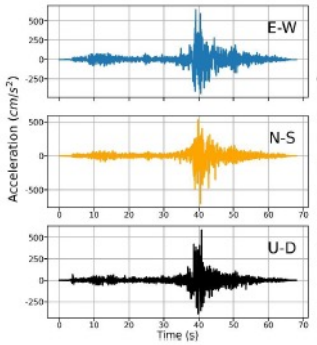


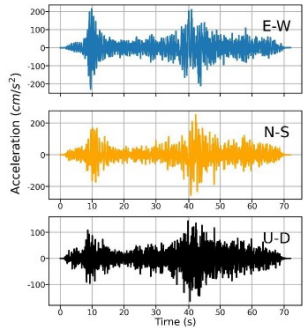




PGA_y = 1.09 g
PGA_d = 0.98 g
R_{rup} = 4.0 km

PGA_y = 0.70 g
PGA_d = 0.58 g
R_{rup} = 1.7 km

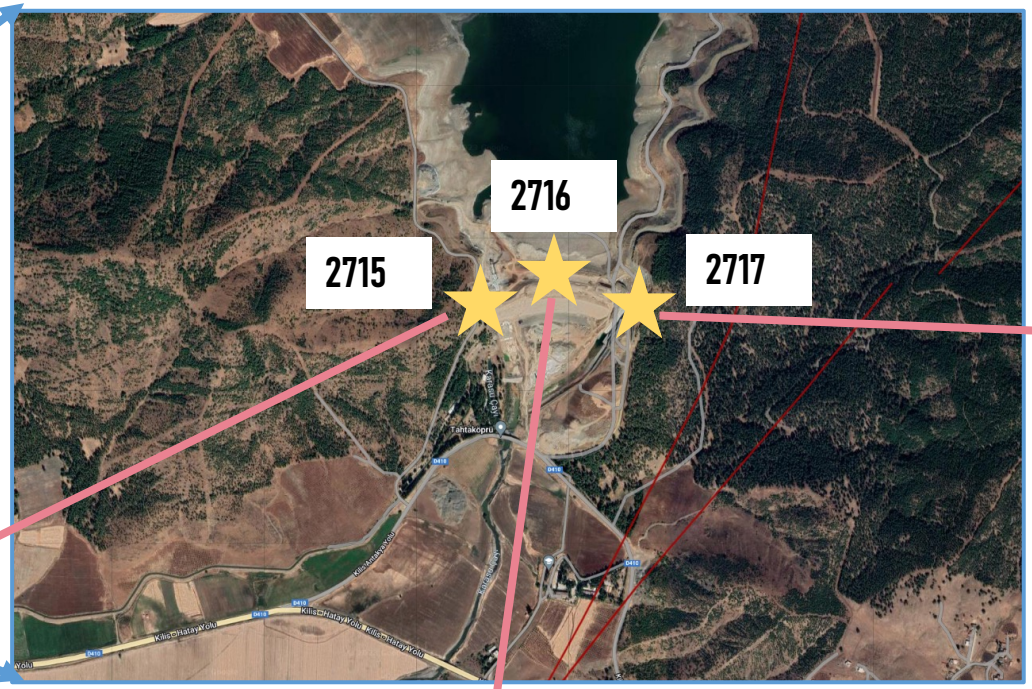


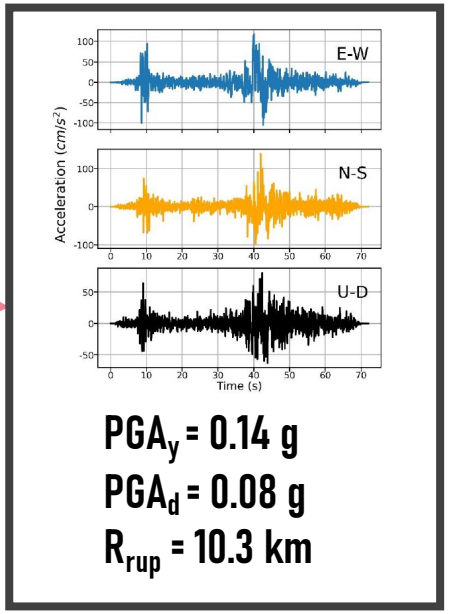


PGA_y = 0.14 – 0.46 g
PGA_d = 0.08 - 0.16 g
R_{rup} = 9.8 - 10.3 km

İslahiye, Gaziantep

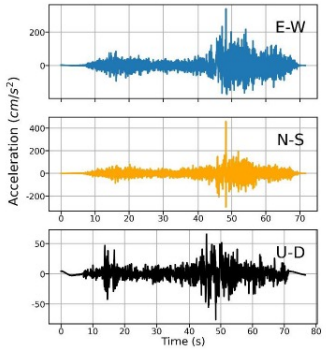
Rupture Velocity / Directivity / Site Effects

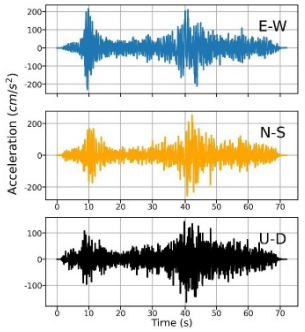




PGA_y = 0.14 g
PGA_d = 0.08 g
R_{rup} = 10.3 km

PGA_y = 0.46 g
PGA_d = 0.08 g
R_{rup} = 9.8 km

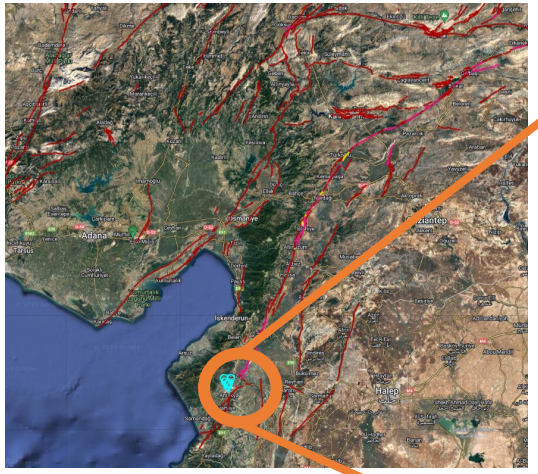


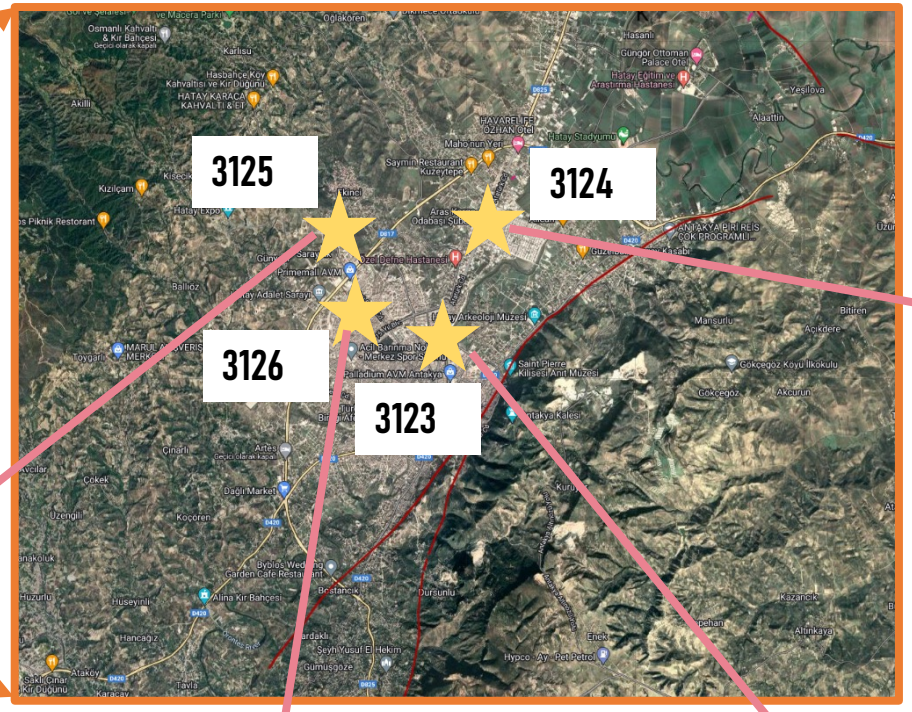


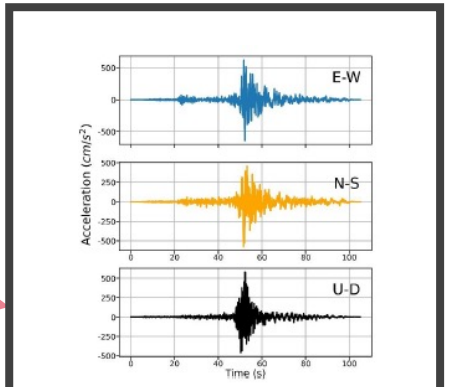
PGA_y = 0.26 g
PGA_d = 0.16 g
R_{rup} = 10.0 km

İslahiye, Gaziantep

Rupture Velocity / Directivity / Site Effects

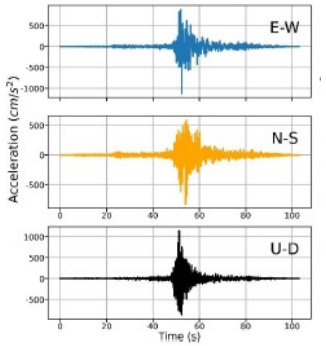


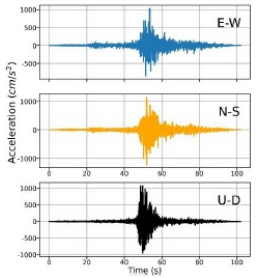




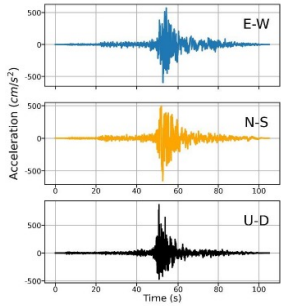
PGA_y = 0.64 g
PGA_d = 0.58 g
R_{rup} = 11.7 km

PGA_y = 1.12 g
PGA_d = 1.14 g
R_{rup} = 14.6 km





PGA_y = 1.21 g
PGA_d = 1.07 g
R_{rup} = 15.4 km



PGA_y = 0.66 g
PGA_d = 0.87 g
R_{rup} = 14.4 km

Antakya, Hatay

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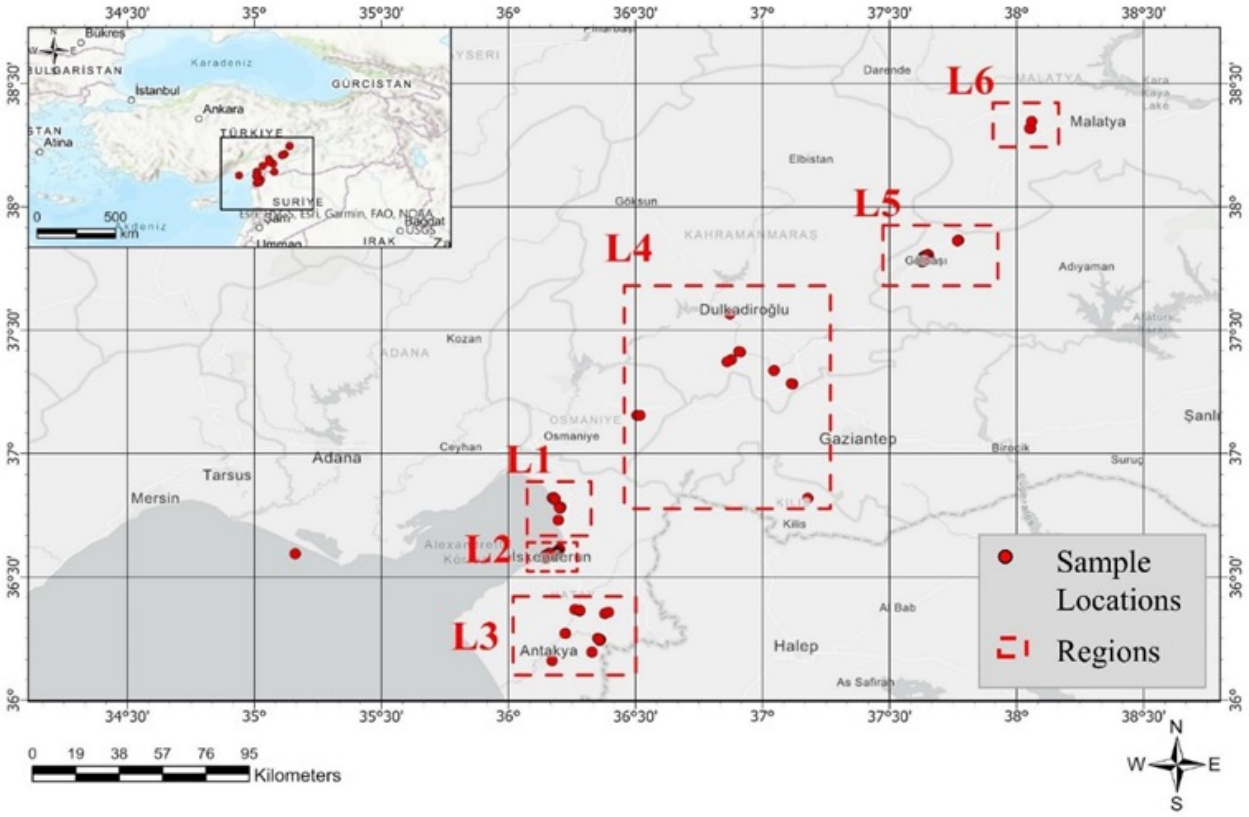
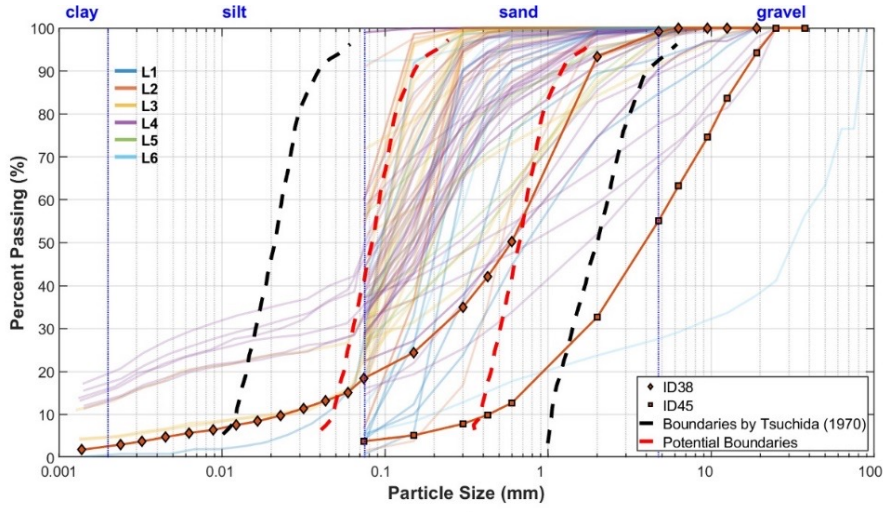
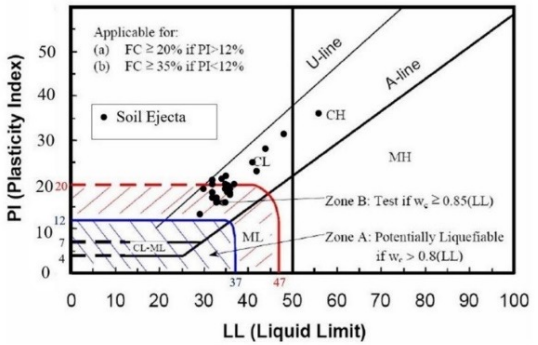
Seismic Soil Liquefaction Manifestations





a)



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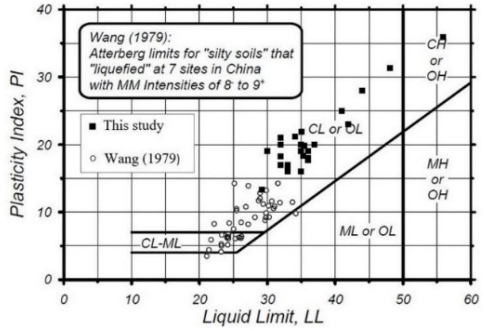

c)

Seismic Soil Liquefaction Manifestations

Bulletin of Earthquake Engineering
https://doi.org/10.1007/s10518-024-01875-3

S.I. : FEBRUARY 6, 2023, KAHRAMANMARAŞ-TÜRKİYE EARTHQUAKES

Soil liquefaction sites following the February 6, 2023, Kahramanmaraş-Türkiye earthquake sequence

Kemal Onder Cetin[1,2] · Berkan Soylemez[1] · Hayri Guzel[1] · Elife Cakir[1]

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Abstract
Seismically induced soil liquefaction was listed as one of the major causes of damage observed in the natural and built environment during the 2023 Türkiye-Kahramanmaraş earthquake sequence. Reconnaissance field investigations were performed to collect perishable data and document the extent of damage immediately after the events. The sites with surface manifestations of seismic soil liquefaction in the form of soil ejecta, excessive foundation and ground deformations were identified and documented. The deformations were mapped, and samples from ejecta were retrieved. The ejecta samples were predominantly classified as sands with varying degrees of fines. Laboratory test results performed on liquefied soil ejecta revealed that the fines-containing liquefied ejecta samples are mostly classified as low plasticity clays (CL). Most of CL soil type ejecta were retrieved from Gölbaşı–Adıyaman region. The liquid limits of these samples varied in between 32 and 38%, their plasticity index values were estimated in the range of 16–23%. Surprisingly, two ejecta samples with plasticity indices higher than 30% were retrieved from Hatay airport, one of which was classified as high plasticity clay (CH). The majority of the fine-grained ejecta samples fall either on "Zone B: Testing Recommended" region of the Seed et al. (Keynote presentation, 26th Annual ASCE Los Angeles Geotechnical Spring Seminar, Long Beach, CA, 2003) susceptibility chart. Moreover, 12 out of 74 samples fall outside the susceptible limits defined by Seed et. These preliminary results suggest that clayey soils can produce liquefied ejecta when subjected to cyclic loading. Detailed site investigation and laboratory testing programs are ongoing to further investigate this rather unexpected response. Until their findings become available, the liquefaction susceptibility of silty-clayey soils' mixtures is recommended to be assessed conservatively with caution.

Keywords Liquefaction · Grain size · Atterberg limits · Low plasticity · Kahramanmaraş earthquake · Susceptibility

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Springer

Cetin et al. (2024) – Soil Liquefaction Sites Following the February 6, 2023, Kahramanmaras-Turkiye Earthquake Sequence (Bulletin of Earthquake Engineering, published)

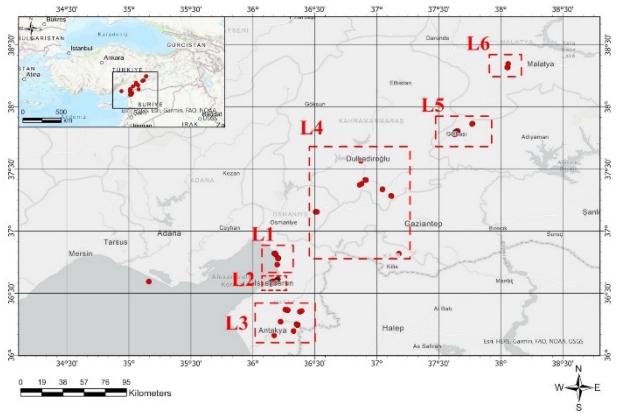


Table 2 A summary of the site coordinates and soil classification characteristic of the ejecta samples from Region A

Sample ID #	Latitude (°)	Longitude (°)	Color	USCS Soil Type	Gravel Content (%)	Sand Content (%)	Fines Content (%)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Uniformity Coefficient C_U	Coefficient of Curvature C_C
14	36.782708	36.205458	Brown	SM	1.0	58.5	40.5	<0.075	<0.075	0.12	-	-	-	-	-
15	36.821216	36.174943	Dark Brown	SP	0.3	97.0	2.7	0.09	0.15	0.21	-	-	-	2.3	1.2
16	36.821368	36.174806	Dark Brown	SP	0.0	94.8	5.2	0.09	0.16	0.24	-	-	-	2.7	1.2
[illegible]	36.812778	36.181332	Black	SP	7.1	88.7	4.2	0.14	0.26	0.45					1.1
															0.9
															1.0
															-
															-

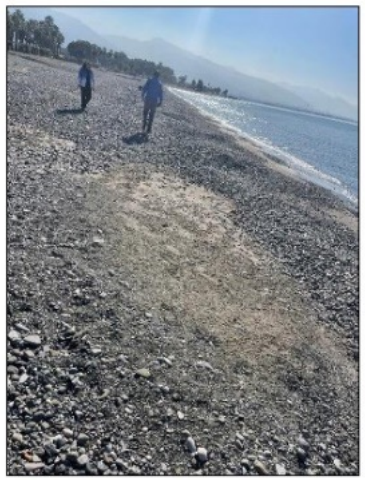
Table 3 A summary of site coordinates and soil classification of the samples from Region B

Sample ID #	Latitude (°)	Longitude (°)	Color	USCS Soil Type	Gravel Content (%)	Sand Content (%)	Fines Content (%)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Uniformity Coefficient C_U	Coefficient of Curvature C_C
3	36.593344	36.185508	Gray	ML	0.0	9.1	90.9	<0.075	<0.075	<0.075	NP			-	-
8	36.597441	36.192487	Black	ML	0.0	45.2	54.8	<0.075	<0.075	0.08	NP			-	-
9	36.597441	36.192487	Black	-	0.1	43.4	56.4	<0.075	<0.075	0.08	-	-	-	-	-
22	36.589542	36.176742	Black	SM	0.0	74.9	25.1	<0.075	0.09	0.18	NP			-	-
[illegible]	36.590614	36.173581	Black		0.0	60.9	39.1	<0.075	<0.075	0.17				-	-
														2.6	1.2
														-	-
														-	-
														-	-

Table 4 A summary of site coordinates and soil classification of the samples from Region C

Sample ID #	Latitude (°)	Longitude (°)	Color	USCS Soil Type	Gravel Content (%)	Sand Content (%)	Fines Content (%)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Uniformity Coefficient C_U	Coefficient of Curvature C_C
1	36.350516	36.379327	Light Brown	SC or SM	0.0	78.3	21.7	<0.075	0.09	0.13	-	-	-	-	-
2	36.350916	36.379327	Light Brown	SC or SM	0.0	83.2	16.8	<0.075	0.11	0.19	-	-	-	-	-
4	36.362648	36.280920	Light Brown	SC	3.0	64.2	32.8	<0.075	0.07	0.53	32	11	21	-	-
5	36.350916	36.379327	Brown	SM	0.0	72.2	27.8	<0.075	0.08	0.15	NP			-	-
6	36.362648	36.280920	Light Brown	CH	0.0	28.4	71.6	<0.075	<0.075	<0.075	56	20	36	-	-
7	36.363890	36.283064	Brown	CL	8.5	39.7	51.8	<0.075	<0.075	0.19	48	17	31	-	-
10	36.350916	36.379327	Brown	ML	0.0	45.3	54.7	<0.075	<0.075	0.08	NP			-	-
11	36.362648	36.280920	Light Brown	SC	1.5	71.3	27.2	<0.075	0.13	0.64	30	11	19	-	-
13	36.364562	36.281468	Light Brown	SC or SM	0.7	64.4	34.9	<0.075	<0.075	0.24	-	-	-	-	-
51	36.194480	36.321980	Grayish brown	CL	1.0	41.0	58.0	<0.075	<0.075	0.08	44	16	28	-	-
57	36.195355	36.328872	Yellowish brown	SC or SM	0.0	78.4	21.6	<0.075	0.12	0.24	-	-	-	-	-
58	36.2451	36.35865	Light Brown	SM	0.0	72.0	28.0	<0.075	0.08	0.11	NP			-	-
59	36.24509	36.35864	Brown	SM	0.0	77.3	22.7	<0.075	0.09	0.12	NP			-	-
60	36.24507	36.35866	Light Brown	SM	0.0	75.2	24.8	<0.075	0.08	0.11	NP			-	-
61	36.24506	36.3581	Light Brown	SC or SM	0.0	74.9	25.1	<0.075	0.08	0.12	-	-	-	-	-
62	36.24527	36.35794	Light Brown	SM	0.0	81.2	18.8	<0.075	0.09	0.16	NP			-	-
68	36.245145	36.357975	Brown	SM	0.0	59.6	40.4	<0.075	<0.075	0.09	NP			-	-
														2.5	1.2
														12.7	1.3
														-	-
														-	-

Seismic Soil Liquefaction Manifestations: Free Field Liquefaction Sites



a) 36.8188°N, 37.1777°E

b) 36.60346°N, 36.19299°E

c) 36.36449°N, 36.281483°E

d) 36.245061°N, 36.358097°E

e) 37.337105°N, 37.045719°E

f) 37.788863°N, 37.650141°E

g) 37.782958°N, 37.635994°E

h) 37.78166°N, 37.62913056°E

j) 37.780522°, 37.628813°E

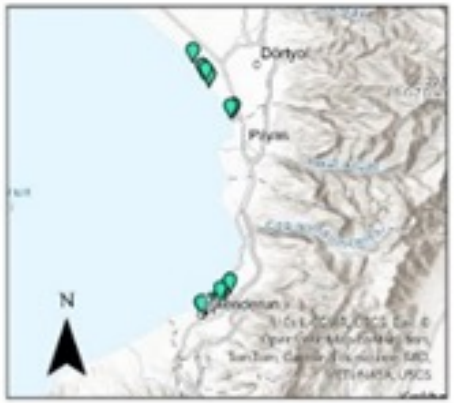
Free-field soil ejecta sites at a) Payaş Dörtyol-Hatay coastal line, b) A Port facility in İskenderun, c) İskenderun-Hatay, d) Demirköprü-Hatay, e) Emiroğlu-Kahramanmaraş, f, g, h, and j) Gölbaşı-Adıyaman after Kahramanmaraş Earthquakes

Seismic Soil Liquefaction Manifestations: Free Field Liquefaction Sites

Free-field soil ejecta sites at Demirköprü-Hatay, Kumlu-Hatay and Gölbaşı-Adıyaman after Kahramanmaraş Earthquakes

Seismic Soil Liquefaction Manifestations: By Building Foundations

37.786694°N 37.632338°E



36.5901°N 36.1774°E

37.788°N 37.6432°E

37.788°N 37.642°E

37.788°N 37.642°E

a) Gölbaşı-Adıyaman

36.5907°N 36.179°E

36.590°N 36.179°E

36.592°N 37.170°E

b) İskenderun-Hatay

Liquefaction-induced settlement observed at a) Gölbaşı-Adıyaman, and b) İskenderun-Hatay

Seismic Soil Liquefaction Manifestations: By Building Foundations

Liquefaction-induced settlement observed at Gölbaşı-Adıyaman

Seismic Soil Liquefaction Manifestations: at Harbours and Ports

a) 36.6036°N 36.19248°E

b) 36.596698°N 36.193048°E

c) 36.82067°N 36.17367°E

d) 36.5936°N 36.176°E

e) 36.5934°N 36.175°E

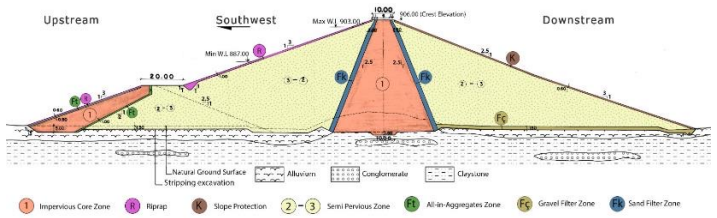
f) 36.593°N 36.175°E

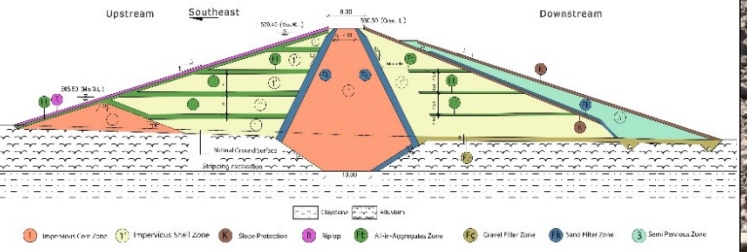
Liquefaction-induced deformations at port facilities in, b) Limak Port in Iskenderun, c) Fishery Warf, d, e, and f) Iskenderun State Harbor

Seismic Soil Liquefaction Manifestations: at Harbours and Ports

Liquefaction-induced deformations at a private port in İskenderun and Fishery Warf

Seismic Soil Liquefaction Manifestations: at Hydraulic Structures





a) 37.319°N 38.051°E

b) 37.156°N 36.514°E

EARTHQUAKE SPECTRA
The Professional Journal of the Earthquake Engineering Research Institute

Cetin et al. (2024) – Performance of Hydraulic Structures During February 6, 2023 Kahramanmaraş-Türkiye Earthquake Sequence (Earthquake Spectra, under review)

Performance of Hydraulic Structures During February 6, 2023 Kahramanmaraş-Türkiye Earthquake Sequence

Kemal Onder Cetin[a], Faik Cuceoglu[a,b], Bilal Umut Ayhan[a,c], Sefa Yildirim[a,b], Seckin Aydin[b], Sarper Demirdogen[b,d], Yasemin Er[a,b], Ayhan Gurbuz[e] and Robb Eric S. Moss[f]

ABSTRACT

The February 6 2023, Türkiye-Kahramanmaraş earthquake sequence affected 140 dams, and most of them are located within Joyner and Boore, R_{jb} distance of 50 km. The dams were subjected to moderate to high levels of seismic intensities such that the peak ground accelerations (PGA) at a comparable distance from the fault rupture were estimated to vary between 0.1 to 1.3 g and 0.15 to 0.45 g during the Pazarcık and Elbistan earthquakes, respectively. Although all dams could maintain the water retaining capabilities, some of them suffered from moderate to large permanent deformations, and the water levels at two of these dams, namely Sultansuyu and Arıklıkaş, were lowered in a controlled manner, as a part of the emergency response of meditation. Following the day of these earthquakes, all hydraulic structures in the influence zone were surveyed, and findings were reported in this study. Findings revealed that earthfill and rockfill dams were observed to be more significantly damaged than the concrete dams at smaller R_{jb} and high PGA shaking zones. Additionally, permanent displacements consistently increase with the transverse section height.

Keywords: Hydraulic structures, Earthquakes, Permanent displacement, Site reconnaissance, Seismic performance

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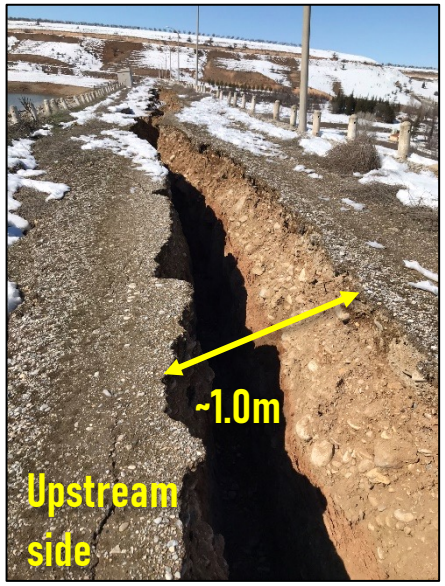
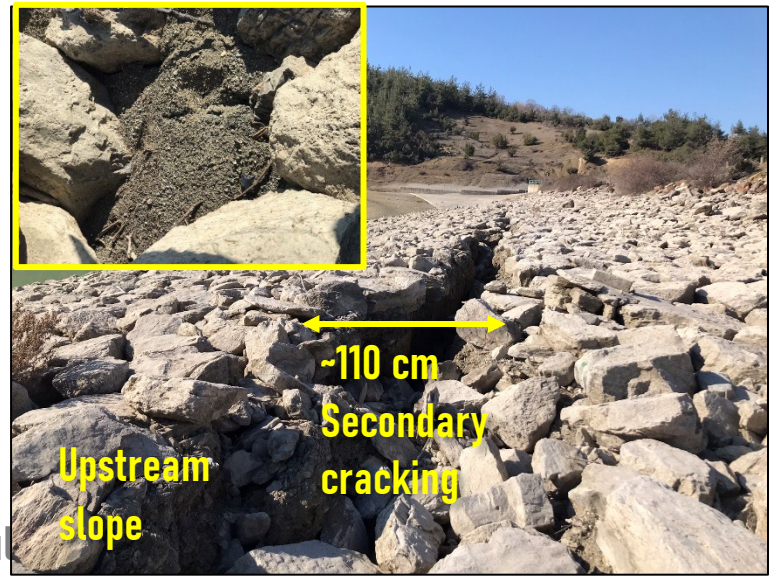
[c] Istanbul Bilgi University, Eminyettepe, Kazım Karabekir Cd. No: 2/13, 34060 Eyüpsultan/Istanbul, Türkiye
[d] Gazi University,Celal Bayar Blv:, 06570, Maltepe/Ankara, Türkiye
[e] Cal Poly,San Luis Obisqo, CA 93401, USA

Surface manifestation of liquefaction observed at a) Sultansuyu Dam and b) Arıklıkaş Dam

Seismic Soil Liquefaction Manifestations: at Hydraulic Structures



Sultansuyu Dam



Arıklıkaş Dam

estation of liquefaction observed at Su

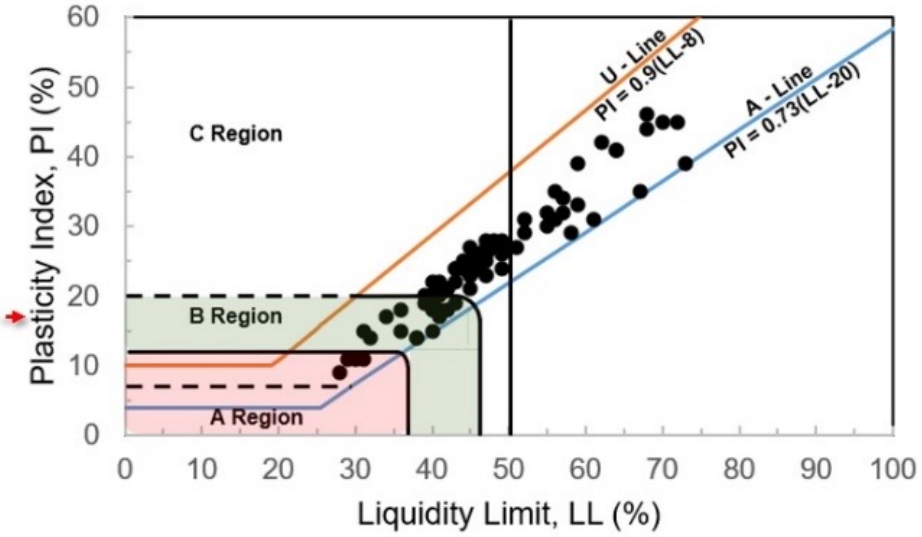
Seismic Soil Liquefaction Manifestations: at Demirköpü Bridges

a) 37.319°N 38.051°E

b) 36.2456°N 36.3573°E

c) 36.2456°N 36.3573°E

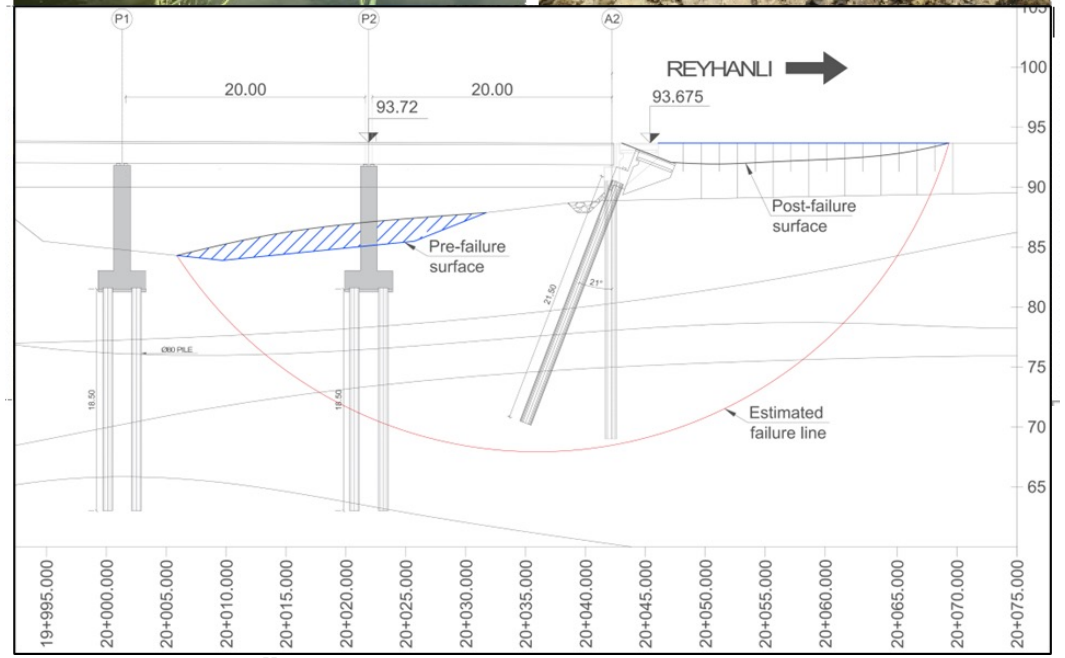
d) 36.245097°N 36.358647°E

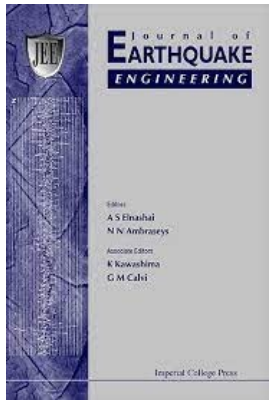


e)

Surface manifestation of liquefaction observed at Demirköprü Bridge

Seismic Soil Liquefaction Manifestations: at Demirköprü Bridge





1 **Liquefaction-induced Failure of Demirköprü Bridge Pile Foundation and**
2 **Retaining System Following the February 6 Kahramanmaraş Earthquake**
3 **Sequence**

4 Soner OCAK[a,c] and Kemal Onder Cetin[b,c*]

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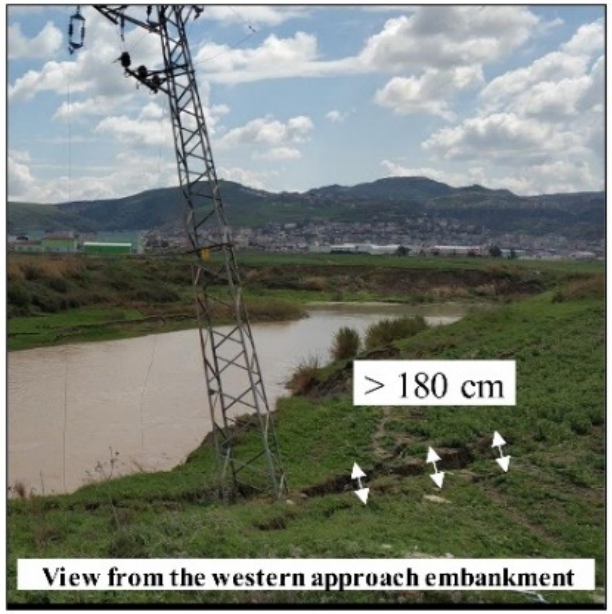
9 ID: 0000-0003-0540-2247

Surface manifestation of liquefaction observed at Demirköprü Bridge

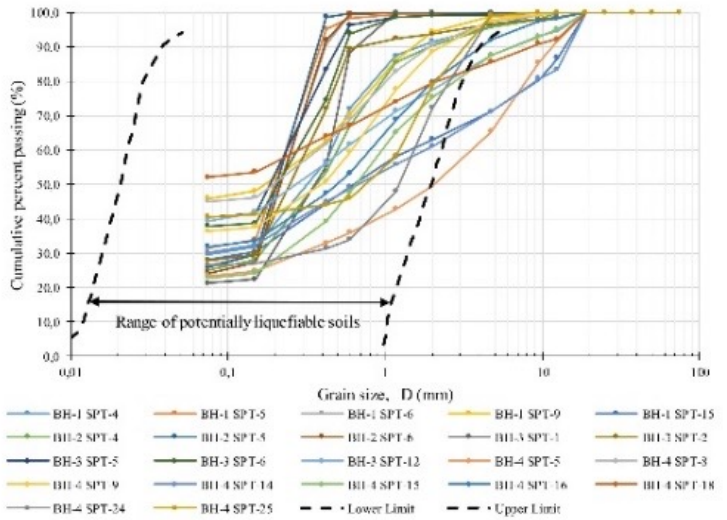
Seismic Soil Liquefaction Manifestations: at Karasu Bridges



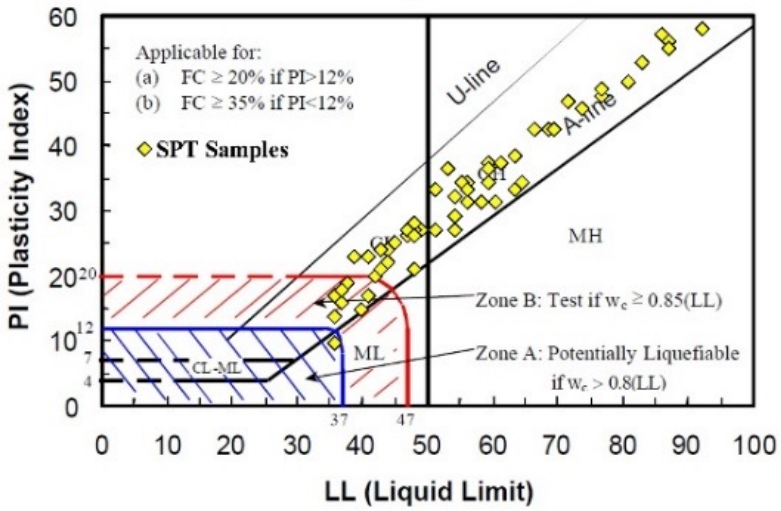
a)

b)

c)



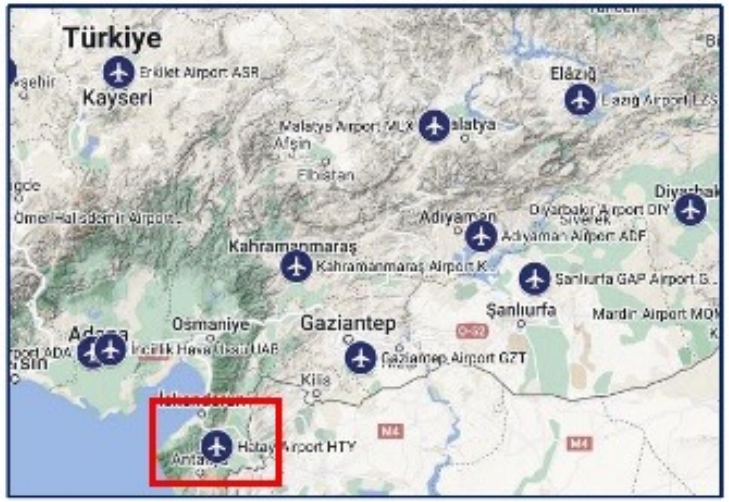
d)



e)

Surface manifestation of liquefaction observed at Karasu Bridge

Seismic Soil Liquefaction Manifestations: at Hatay Airport



a) Airports located in the region

b) 36.3645°N 36.2815°E

c) 36.3645°N 36.2815°E

d) 36.3646°N 36.2815°E

e) 36.3645°N 36.2814°E

f) 36.3645°N 36.2814°E

Surface manifestation of liquefaction observed at Hatay Airport

Seismic Soil Liquefaction Manifestations: at Hatay Airport

Surface manifestation of liquefaction observed at Hatay Airport

PRESENTATION OUTLINE

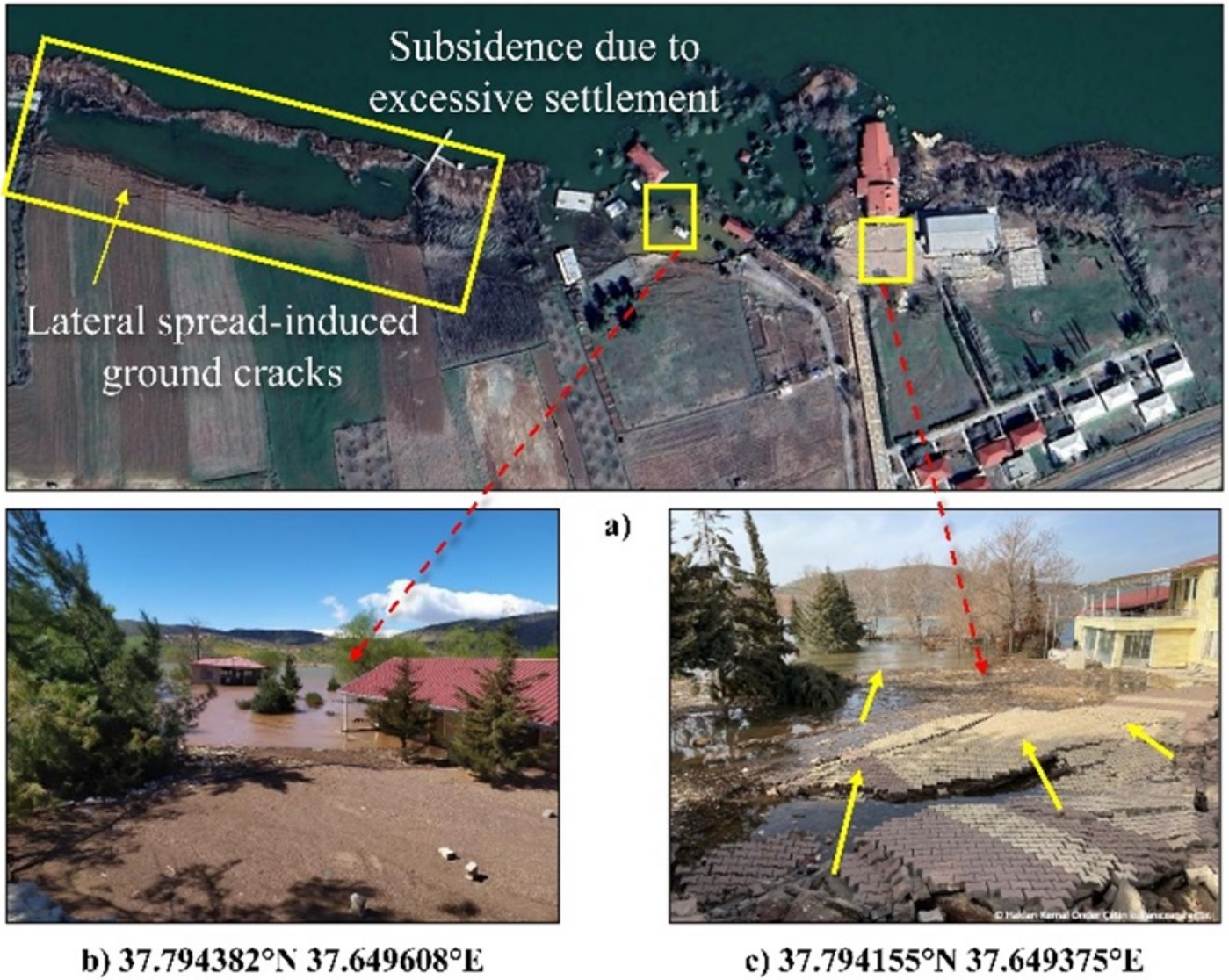
- INTRODUCTION
  - Brief Statistics
  - Tectonic Setting
  - Fault Rupture Mechanisms and Strong Ground Motion Characteristics
  - Rupture Velocity/Directivity/Site Effects

- GEOHAZARDS
  - Seismic Soil Liquefaction Sites
    - Free Field Liquefaction Sites
    - Manisfestations by :
      - Building Foundations
      - Ports and Harbours
      - Hydraulic Structures/ Eartfill and Rockfill Dams
      - Bridges
      - Airports

- GEOHAZARDS (Cont'd)
  - Lateral spreading - Inundation
  - Landslides and Rockfalls
  - Permanent Ground Displacements / Deformations
    - Fault Offsets
    - Deformations at:
      - Retaining Structures
      - Earthfill and Rockfill Dams

- LESSONS OFFERED AND CONCLUSIONS

Lateral Spreading and Inundation



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Lateral spreading and subsidence observed in Gölbaşı-Adıyaman adapted from Cetin et al. (2024)

Lateral Spreading and Inundation

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Lateral spreading and subsidence observed in Gölbaşı-Adıyaman adapted from Cetin et al. (2024)

Lateral Spreading and Inundation

a) 37.794382°N 37.649608°E

b) 36.603663°N 36.191988°E

c) 36.597333°N 36.191885°E

d) 36.592063°N 36.176013°E

e) 37.794382°N 37.649608°E

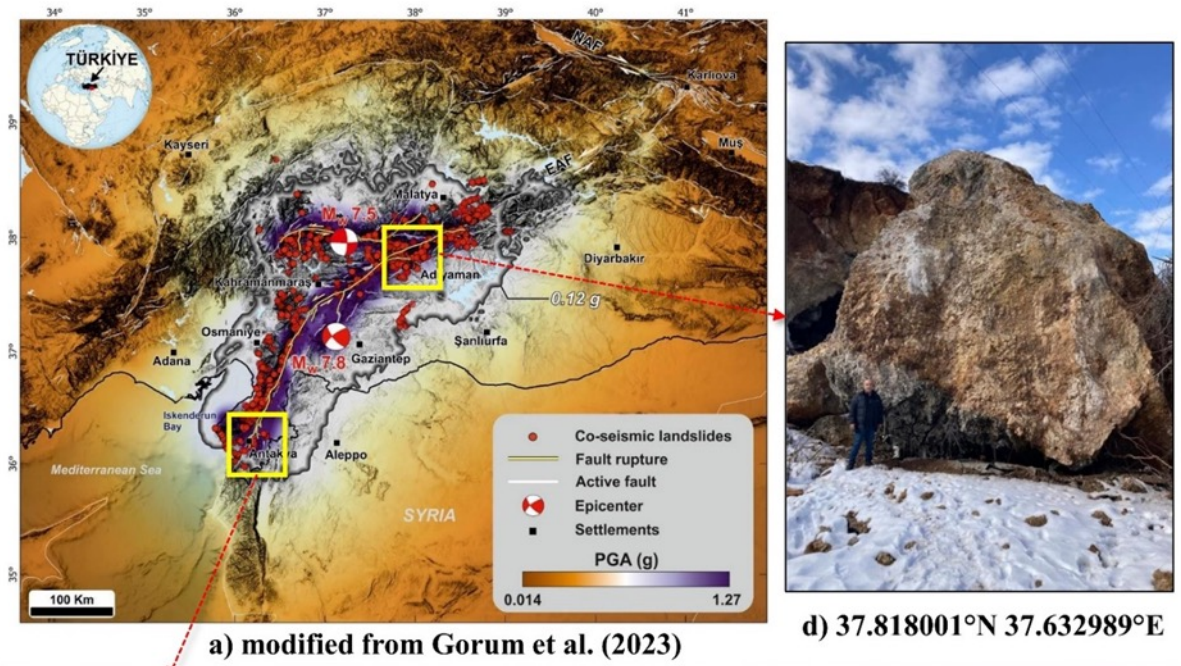
f) 36.592516°N 36.172822°E

Lateral spreading observed in Hatay-İskenderun

Lateral Spreading and Inundation

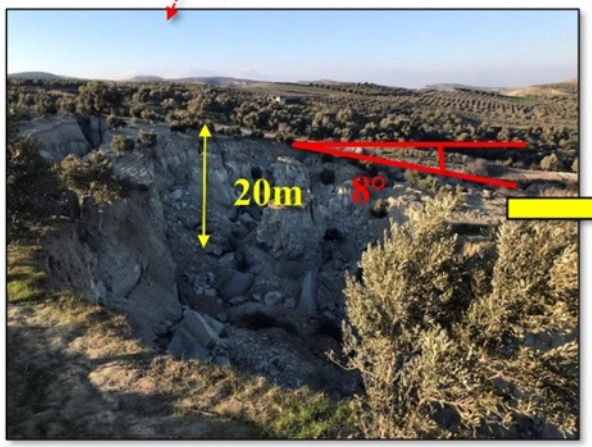
Lateral spreading observed in Hatay-İskenderun

Landslides and Rockfalls



a) modified from Gorum et al. (2023)

d) 37.818001°N 37.632989°E



b) 36.16130°N 36.22024°E

c) 36.18559°N 36.23610°E

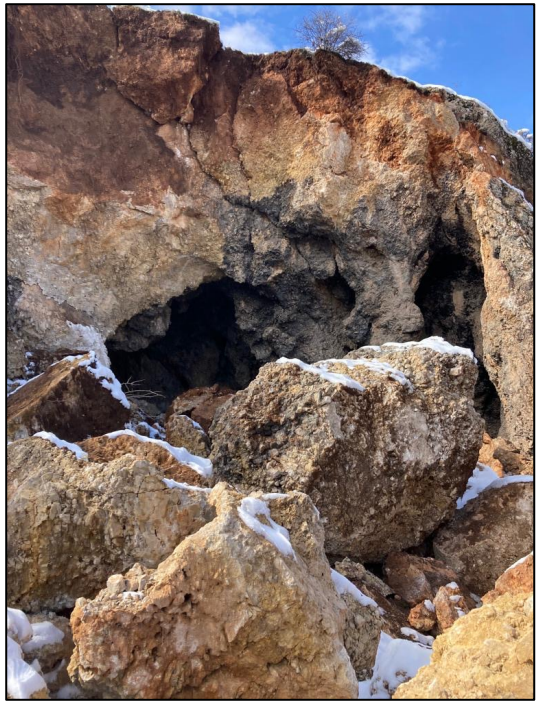
- A total of 3673 coseismic landslides associated with these events
- Over 90% of mapped landslides occurred within a 20-km-wide zone along the fault rupture.

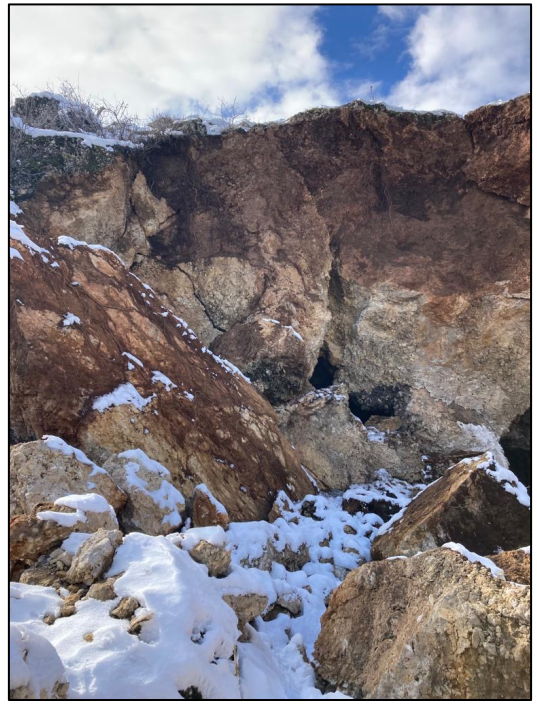
a) Spatial distribution of coseismic landslides overlain by the Kahramanmaraş Earthquakes fault rupture and PGA recordings for M>5.5 modified from Gorum et al. (2023),

b, c) transitional slide in Tepehan Village, and

d) rockfalls reported in Karamağara-Gölbaşı

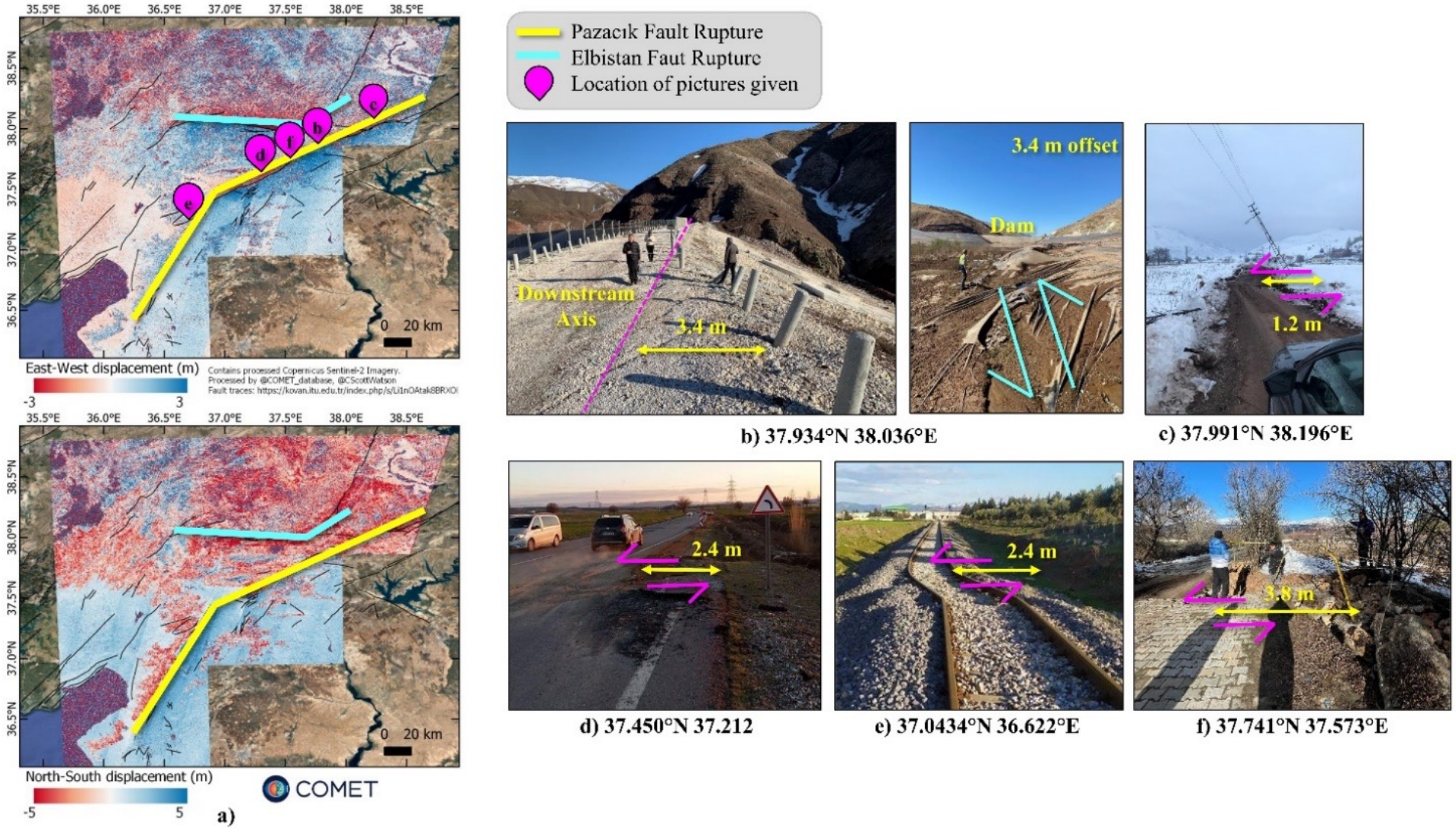
Landslides and Rockfalls





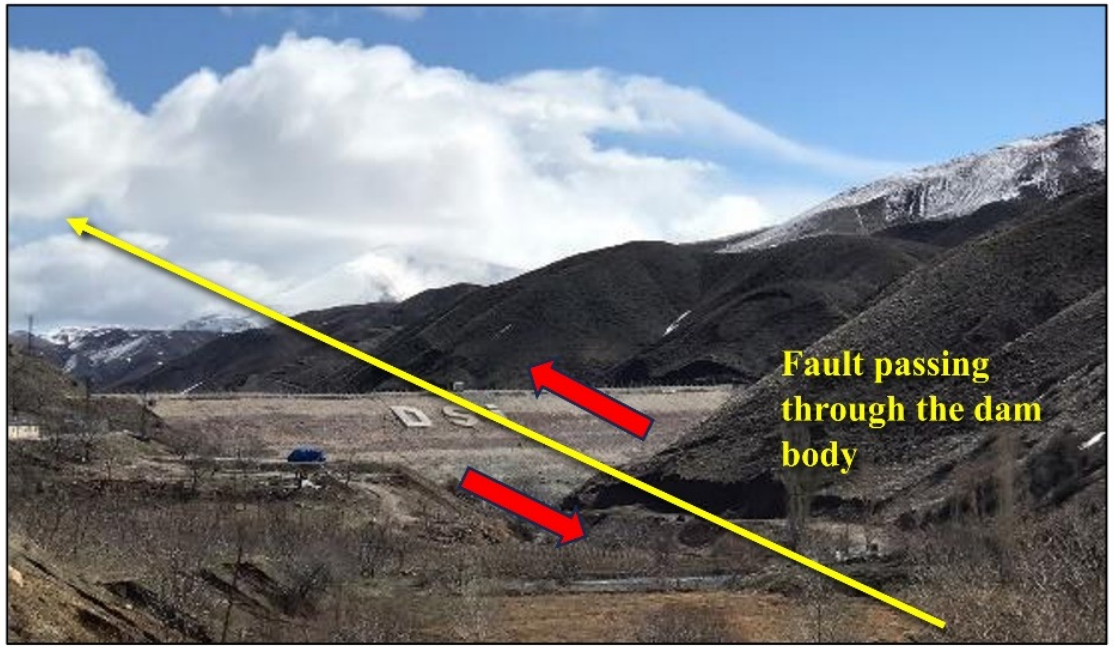
Landslide observed in Tepehan-Hatay and Rockfalls observed in Karamağara-Gölbaşı-Adıyaman

Permanent Ground/Soil Displacements and/or Deformations: Fault Offsets



a) Sentinel-2 deformation analyses provided by COMET after Cetin and Ilgac (2023), b) fault offsets mapped b) across the Erkenek Dam, in c) Çelikhan, d) Pazarcık, e) Islahiye, and f) Balkar

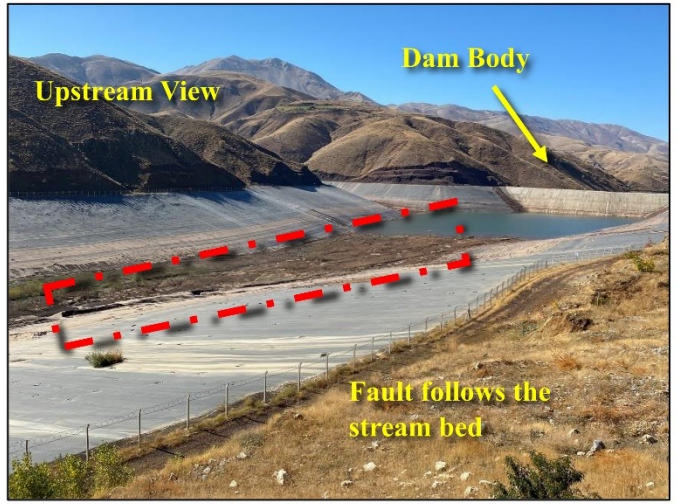
Permanent Ground/Soil Displacements Deformations: Fault Offsets



a)

b)

c)



d)

e)

Erkenek Dam

Permanent Ground/Soil Displacements Deformations: at Retaining Structures

Gölbaşı-Adıyaman

a) 37.86332°N 37.7675°E

b) 37.86332°N 37.7675°E

Gölbaşı-Malatya Highway

Malatya-Gölbaşı Highway

c) 37.90435°N 37.8117°E

d) 36.684°N 36.218°E

Ceyhan-İskenderun Highway

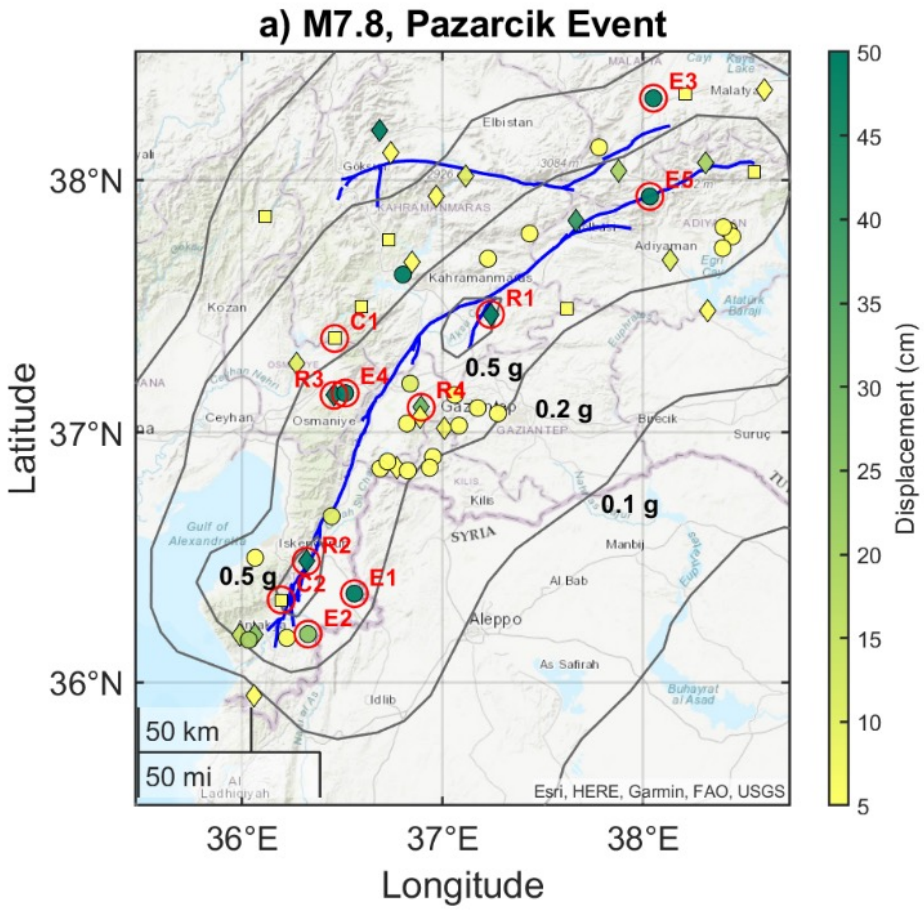
Retaining wall performance after the Kahramanmaraş Earthquakes: a) Stonewall, b) Cantilever, c, and d) anchored walls

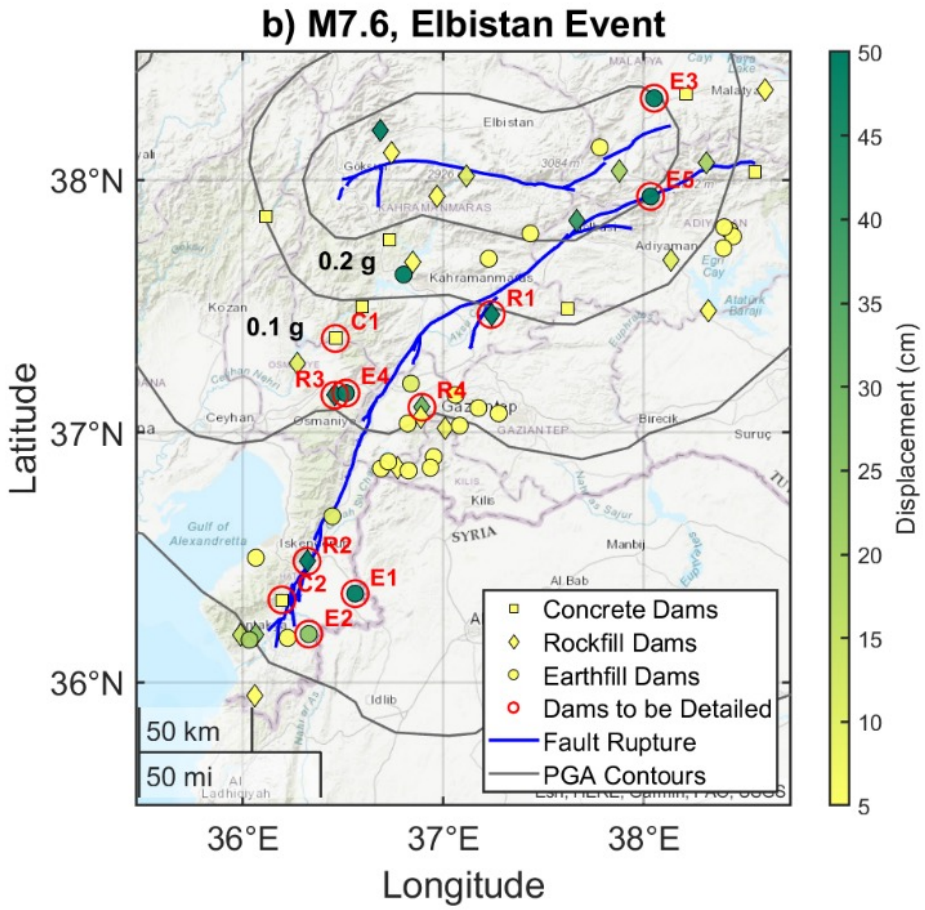
Permanent Ground/Soil Displacements Deformations: at Retaining Structures

Malatya-Gölbaşı Highway

Bahçe-Osmaniye

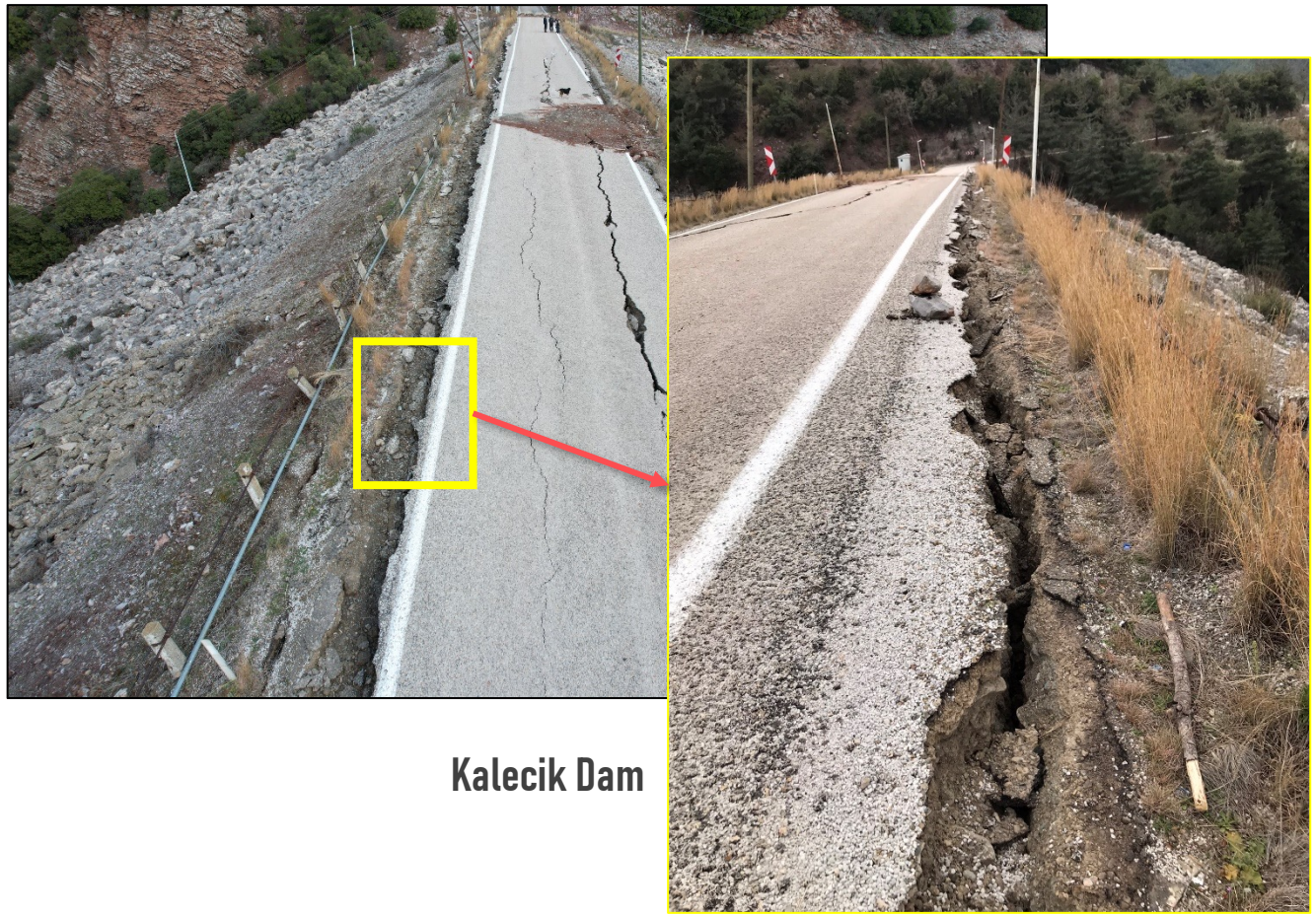
Permanent Ground/Soil Displacements Deformations: at Earthfill and Rockfill Dams





Reyhanlı Dam

Permanent Ground/Soil Displacements Deformations: at Earthfill and Rockfill Dams



Kalecik Dam

Kurtlusoğuksu Dam

Permanent Ground/Soil Displacements Deformations: at Earthfill and Rockfill Dams

Kartalkaya Dam

PRESENTATION OUTLINE

- INTRODUCTION
  - Brief Statistics
  - Tectonic Setting
  - Fault Rupture Mechanisms and Strong Ground Motion Characteristics
  - Rupture Velocity/Directivity/Site Effects
- GEOHAZARDS
  - Seismic Soil Liquefaction Sites
    - Free Field Liquefaction Sites
    - Manisfestations by :
      - Building Foundations
      - Ports and Harbours
      - Hydraulic Structures/ Eartfill and Rockfill Dams
      - Bridges
      - Airports
- GEOHAZARDS (Cont'd)
  - Lateral spreading - Inundation
  - Landslides and Rockfalls
  - Permanent Ground Displacements / Deformations
    - Fault Offsets
    - Deformations at:
      - Retaining Structures
      - Earthfill and Rockfill Dams
- LESSONS TO LEARN AND CONCLUSIONS

Lessons to Learn and Conclusions

- The February 6, 2023 Kahramanmaraş-Turkiye Earthquake sequence yielded valuable and unique lessons for the earthquake and geotechnical engineering community, particulary in the following areas:

A. Seismic Hazard Assessment:

- Source Characterization: The sequence highlighted the importance of considering the possibility of multiple fault segments rupturing within a short timeframe, which may not have been adequately accounted for in seismic hazard assessments.
- Ground Motion Prediction Equations (GMPEs): It revealed discrepancies between the predicted and recorded ground motion intensities, especially in proximity to the fault rupture, emphasizing the need for improved GMPEs.

B. Geohazards:

- Fault Displacements: The earthquake sequence demonstrated significant fault displacements, underscoring the need for resilient design and planning in seismically active regions.
- Seismic Soil Liquefaction:
  - Instances of liquefaction-induced bearing capacity failures and ground deformations highlighted the vulnerability of structures built on liquefiable soils.
  - Clayey soils with PI > 20 % produced ejecta in Gölbaşı-Adıyaman and at Hatay Airport.

Lessons to Learn and Conclusions

- The February 6, 2023 Kahramanmaraş Earthquake sequence yielded valuable and unique lessons for the earthquake and geotechnical engineering community, particulary in the following areas:

B. Geohazards:

- Landslides and Rockfalls: The widespread occurrence of landslides and rockfalls emphasized the need for comprehensive slope stability assessments and mitigation measures. 92 lives lost due to landslides and rockfalls. Probabilistic assessment of seismically induced landslides and rockfalls needed

- Permanent displacements in embankments and earthfill and rockfill dams subjected to high intensity shaking. A valuable database to update our current post-seismic permanent displacement predictive models.

- Stone gravity walls performed poorly under high seismic demands. Well-designed and constructed reinforced earth walls performed exceptionally well.

- The filter zones in earthfill and rockfill dams typically consist of liquefiable sand and gravel. Inadequate compaction in these zones lead to liquefaction and concentrated displacements at filter interfaces.

Çok Üzgünüz!

15 Million Residents were affected,
Over 50,000 lives lost,
650,000 residential units unoccupiable
100 Billion dollar economical loss

Deeply Sad...