From Simulations to Safety: Interdisciplinary Approaches for Urban Seismic Resilience in Türkiye

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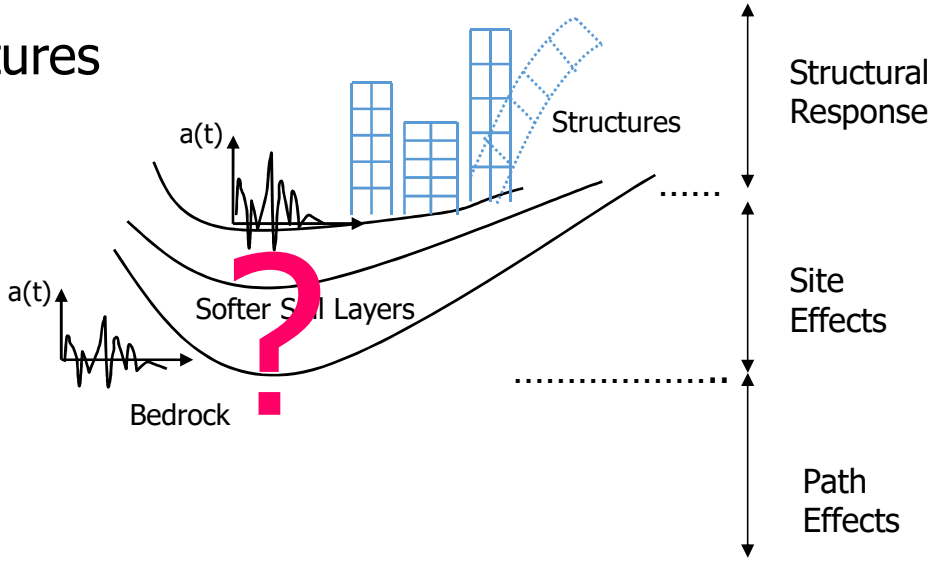
INGV Roma

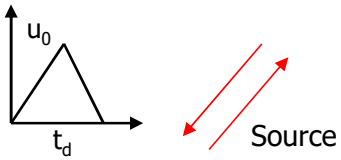
Mathematical Modeling of Earthquakes

Three main issues (by Seismo. Soc. of Amer. 1906):

1. the physical earthquake event itself (when, where, how)
2. the associated ground motions
3. the effect on the structures

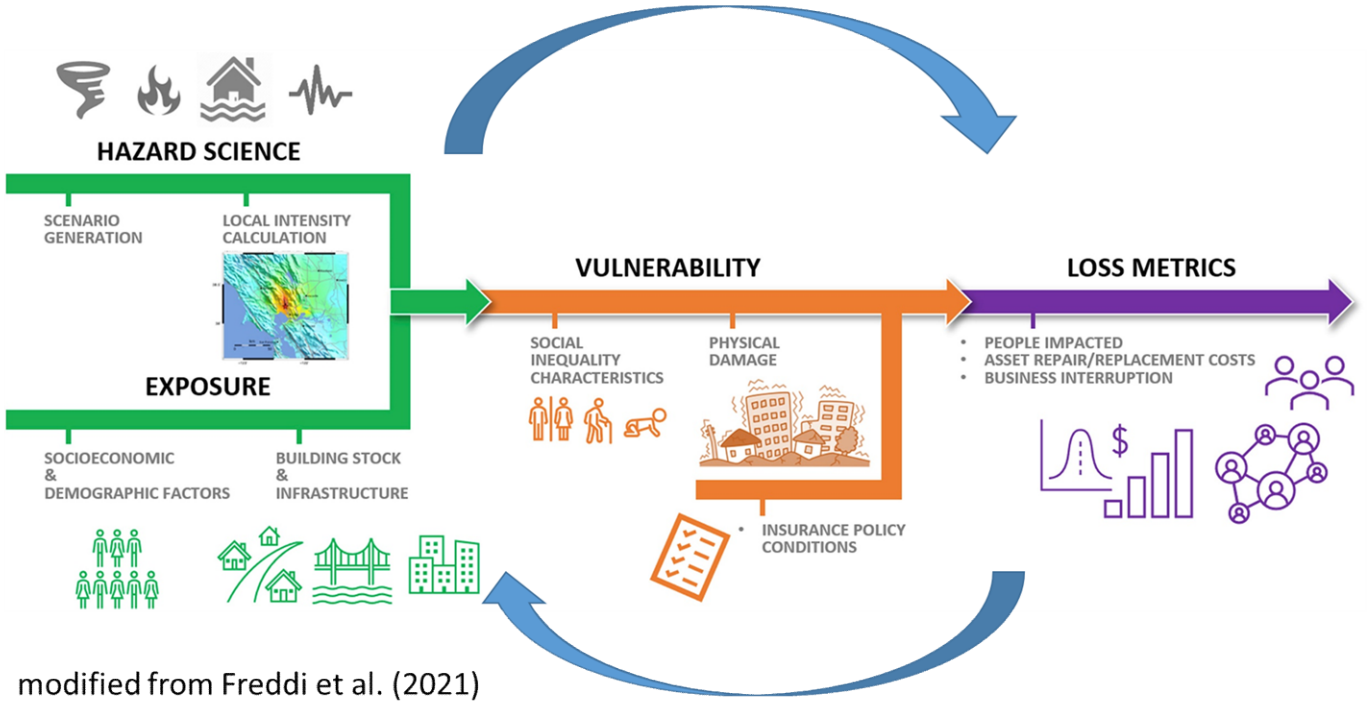
Integrated Approaches!





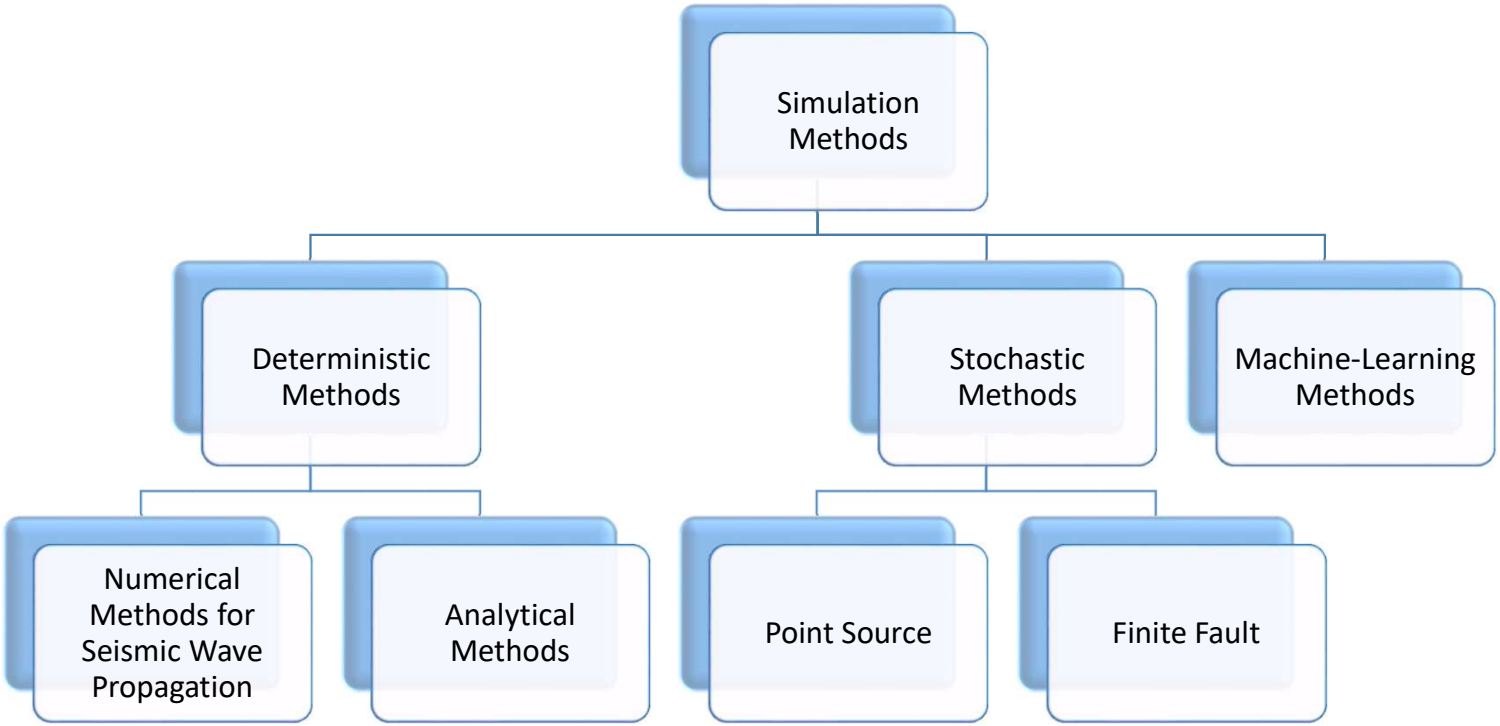
Motivation

Seismic Resilience



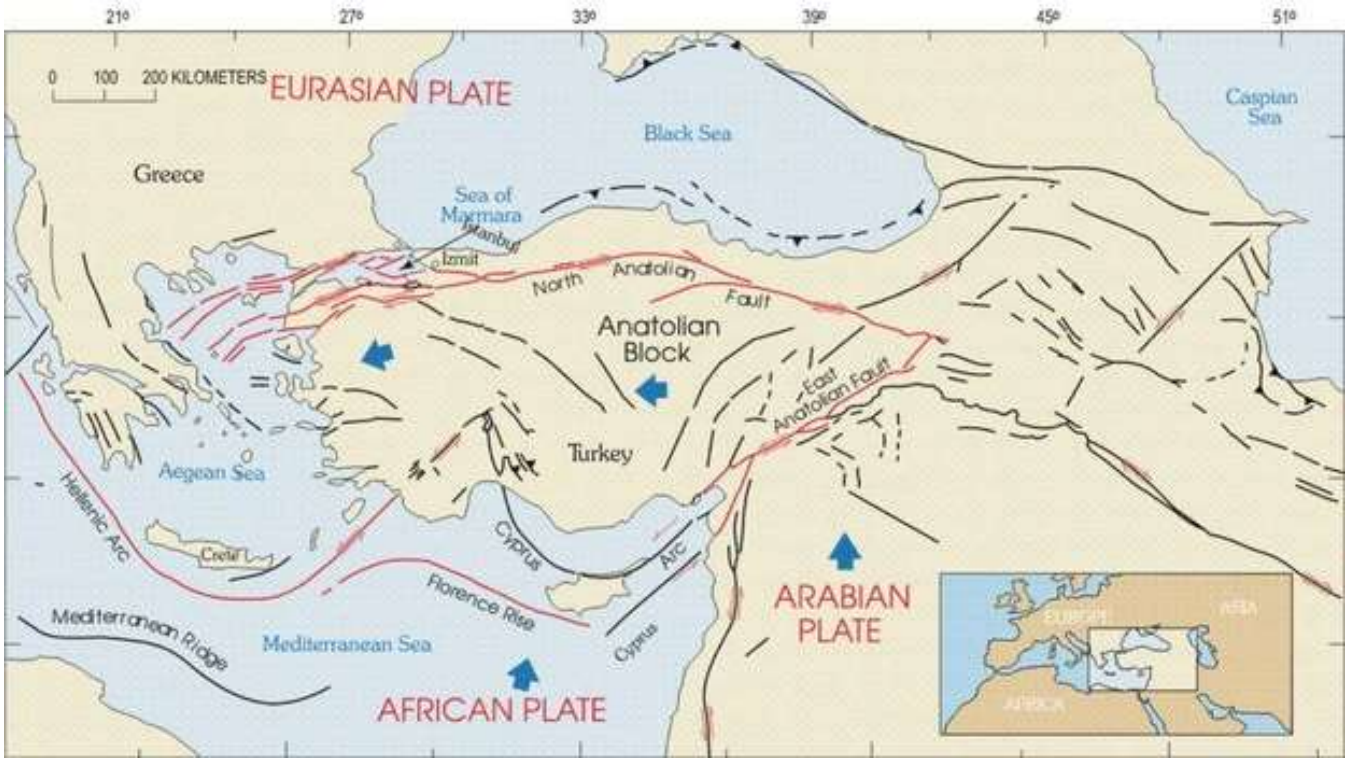
modified from Freddi et al. (2021)

Simulation Approaches



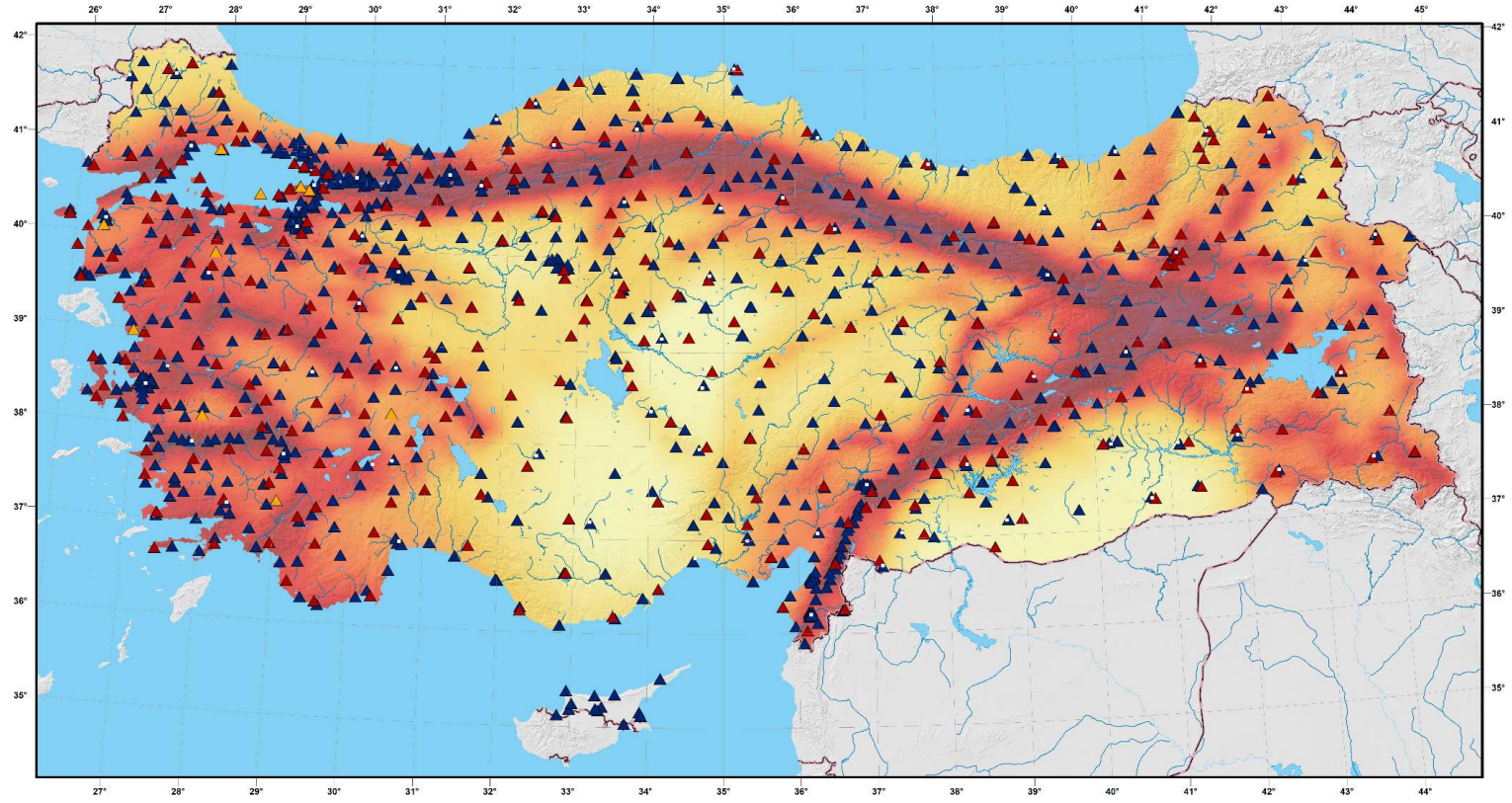
Use of Simulations for Earthquake Engineering Purposes in Turkiye (and Italy)

Turkey: Tectonic setting



Holzer et al. (2000)

Station Network in Turkey



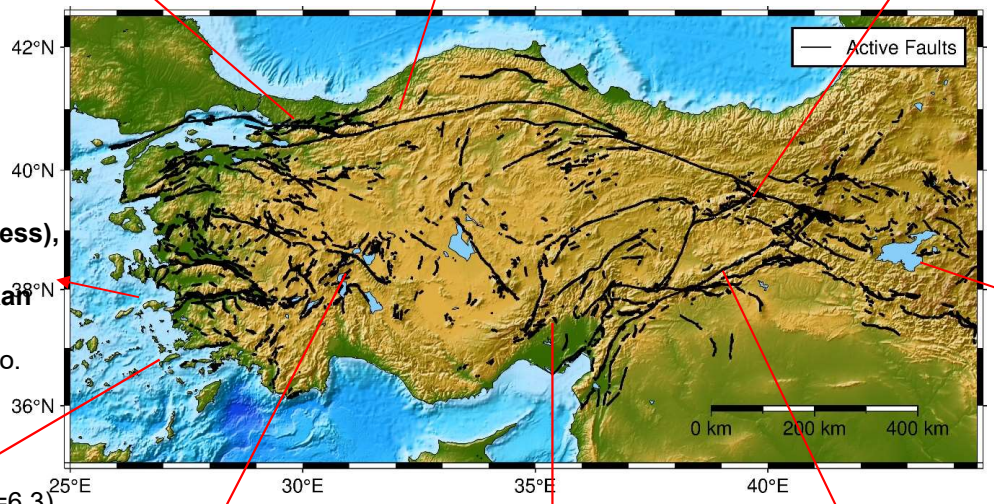
/

Ground Motion Simulation Efforts in Turkey for events with M>6

1999 Kocaeli (Mw=7.4)
1. Yalçınkaya (2012), Sto.

1999 Duzce (Mw=7.2)
1. Ozmen et al (2020), Hyb.
2. Tanırcan et al (2017), Det.
3. Ugurhan and Askan (2010), Sto.

1992 Erzincan (Mw=6.6)
1. Sisman and Askan (in progress), Hyb.
2. Askan et al. (2013), Sto.



2020 Samos (Mw=7.0)
1.Askan et al. (in progress), Hyb.
2. Karimzadeh and Askan (2024), Sto.
3. Akinci et al. (2021), Sto.

2011 Van (Mw=7.1)
1.Zengin and Çaktı (2014), Sto.
2.Gallovic et al. (2013), Hyb.
3.Akinci and Antonioli (2013), Sto.

2017 Bodrum-Kos (Mw=6.3)
1.Tanırcan and Yelkenci-Necmioglu (2020), Sto.

1998 Ceyhan (Mw=6.3)
1.Yalçınkaya (2005), Sto.

2020 Elazıg (Mw=6.8)
1.Altindal, Askan, Karimzadeh (in progress), Sto.
2.Cheloni and Akinci (2020), Sto.

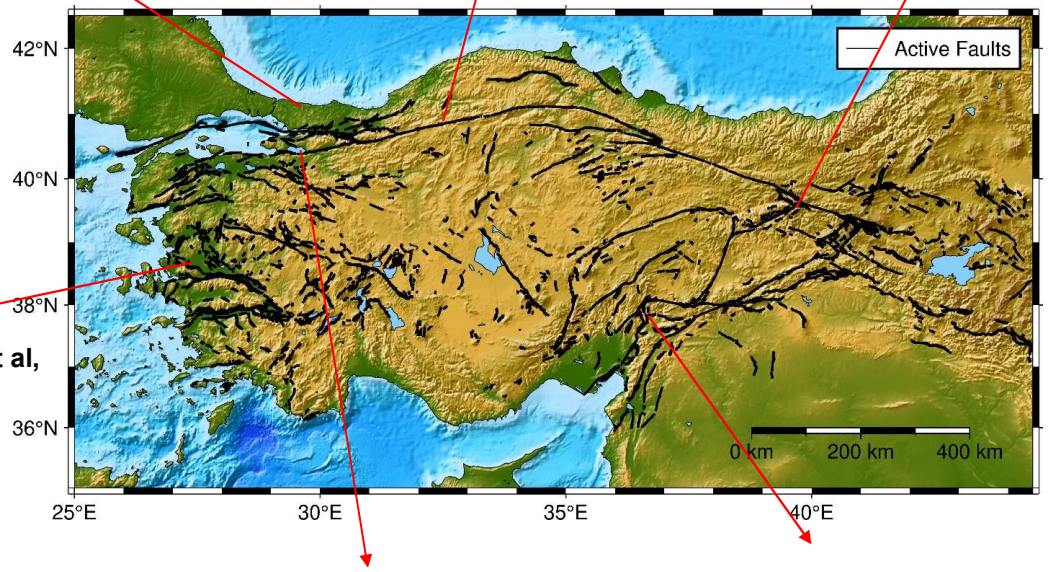
2002 Cay (Mw=6.6)
1. **Can, Askan, Karimzadeh (2021), Sto.**

Ground Motion Simulation Efforts in Turkey for Scenario Events

Istanbul and Kocaeli region:
1. Zhang et al (2021), Det.
2. Infantino et al (2020), Hyb.
3. Sahin et al (2018), Det.
4. Ansal et al. (2009), Sto.
5. Sorensen et al. (2007), Hyb.
6. Goto et al. (2005), Det.

Duzce:
1. Karimzadeh and Askan (2019), Sto.
2. Ugurhan et al. (2011), Sto. & Hyb.

Erzincan:
1. **Karimzadeh and Askan (2019), Sto.**
2. **Karimzadeh and Askan (2018), Historical eq, Sto.**



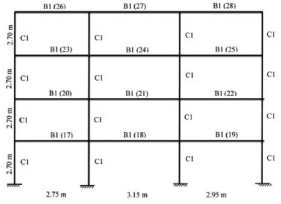
Izmir:
1. Albayrak, Askan et al, (in progress), Hyb.

Bursa:
1. Unal, Askan, Kestel (2017), Sto.

Antep and Maras:
1. Arslan-Kelam et al. (2021), Sto.
2. Altindal, Askan et al. (in progress)

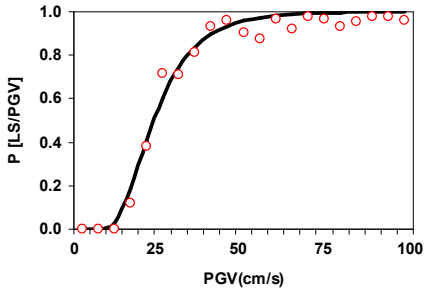
Use of Simulated Ground Motions in Earthquake Engineering Applications (2010- present)

Nonlinear Response History Analyses

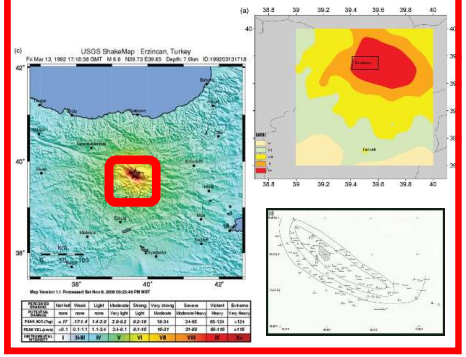


(SDOF, MDOF, base-isolated str, liquid storage tanks)

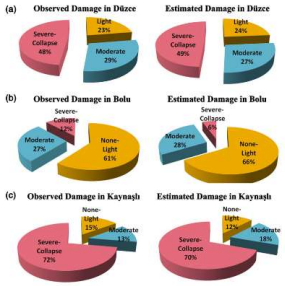
Generation of Fragility Curves



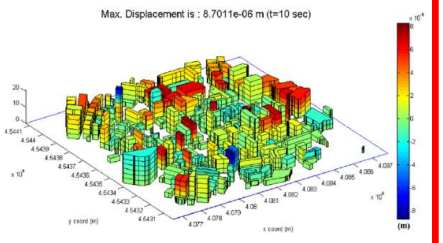
Validations with MMI Maps



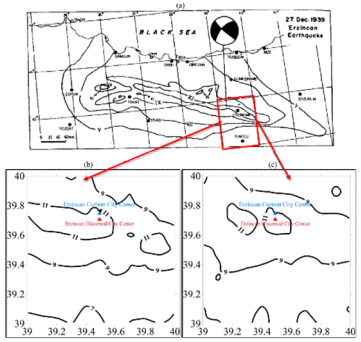
i) Damage and Loss Modeling
ii) Insurance premiums



City-scale Modeling



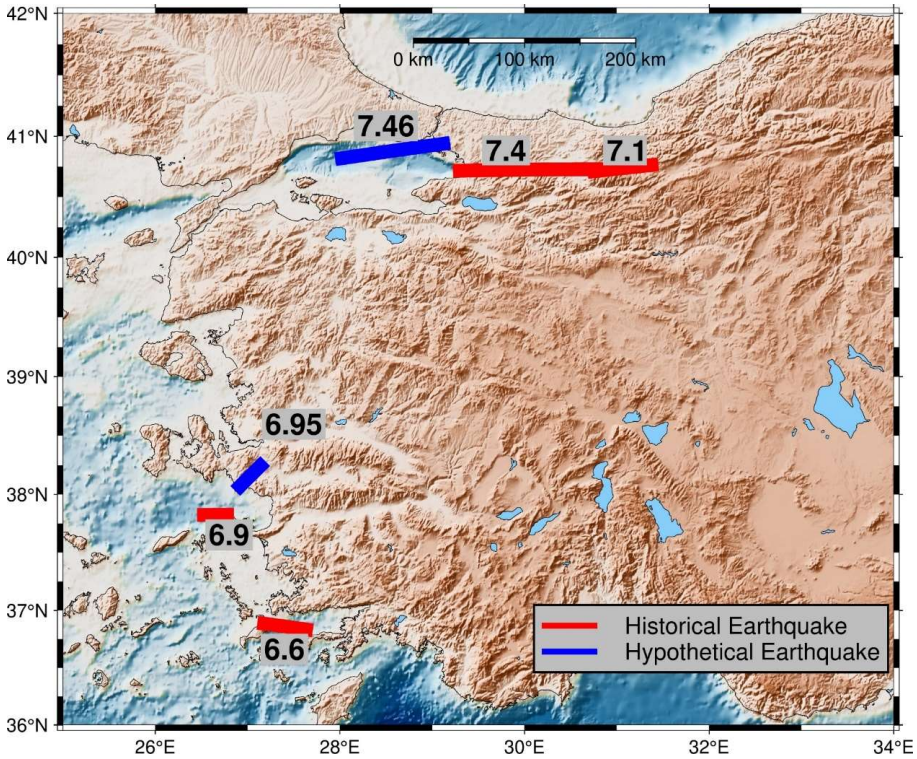
Historical Earthquakes

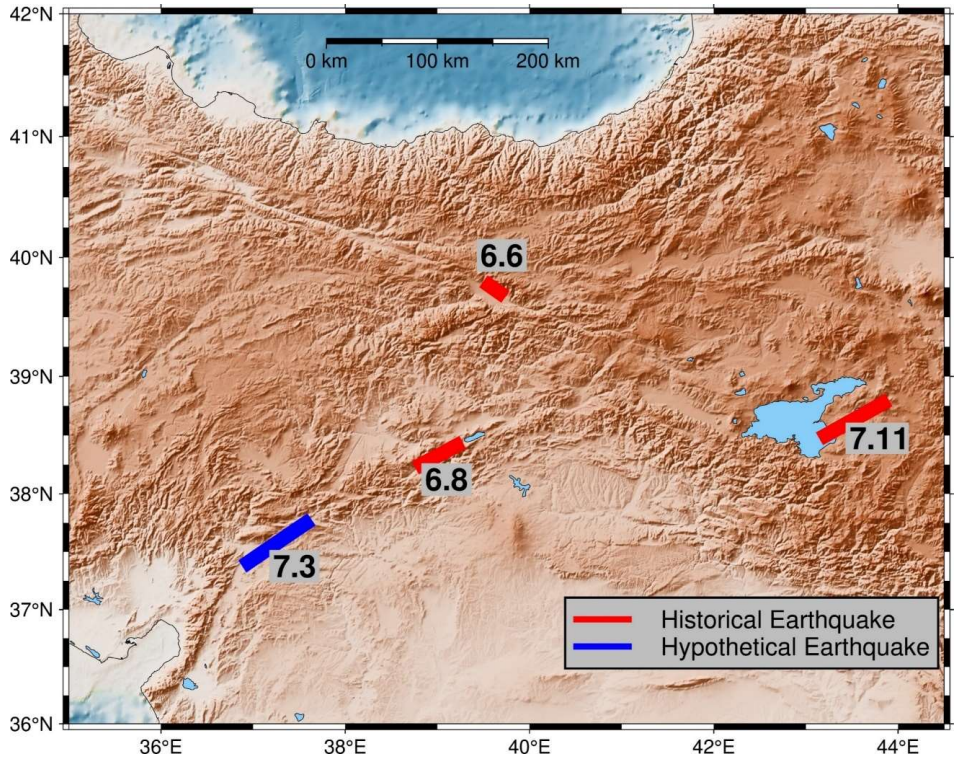


References:

Askan et al. (2024)
Altindal and Askan (2024, 2023)
Arslan-Kelam et al. (2022)
Karimzadeh, Kadas, Askan, Yakut (2021)
Ozsarac, Karimzadeh, Askan, Erberik (2021)
Uckan, Umut, Sisman, Karimzadeh, Askan (2018)
Karimzadeh, Askan, Erberik, Yakut (2018)
Azari Sisi,Askan, Erberik (2017)
Unal, Askan, Selcuk-Kestel (2017)
Sahin, Sisman, Askan and Hori (2017)....
...Ugurhan and Askan (2010)

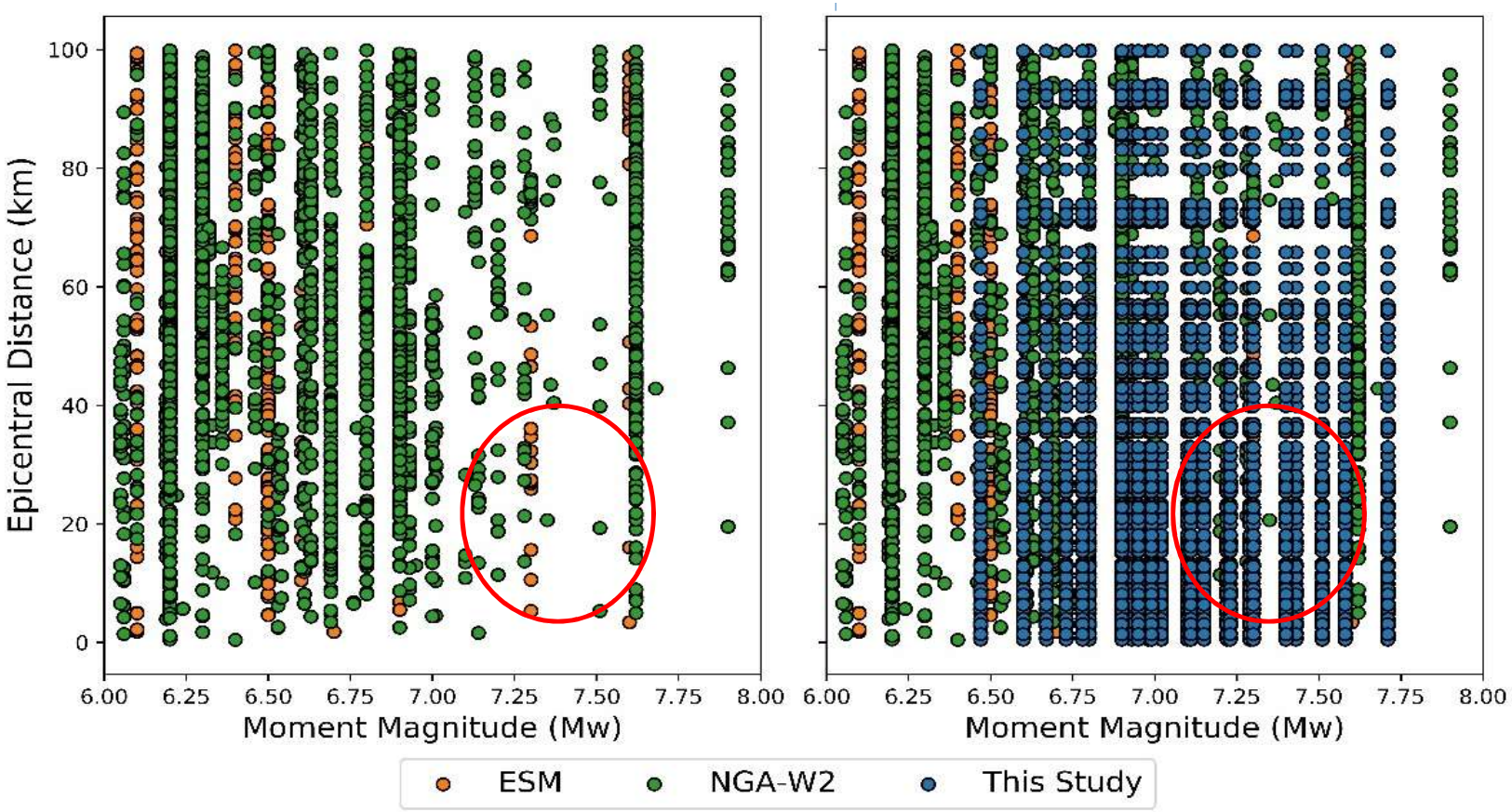
A Recent Simulated SGM Database for Tr





Altindal and Askan, 2023 (JoS)

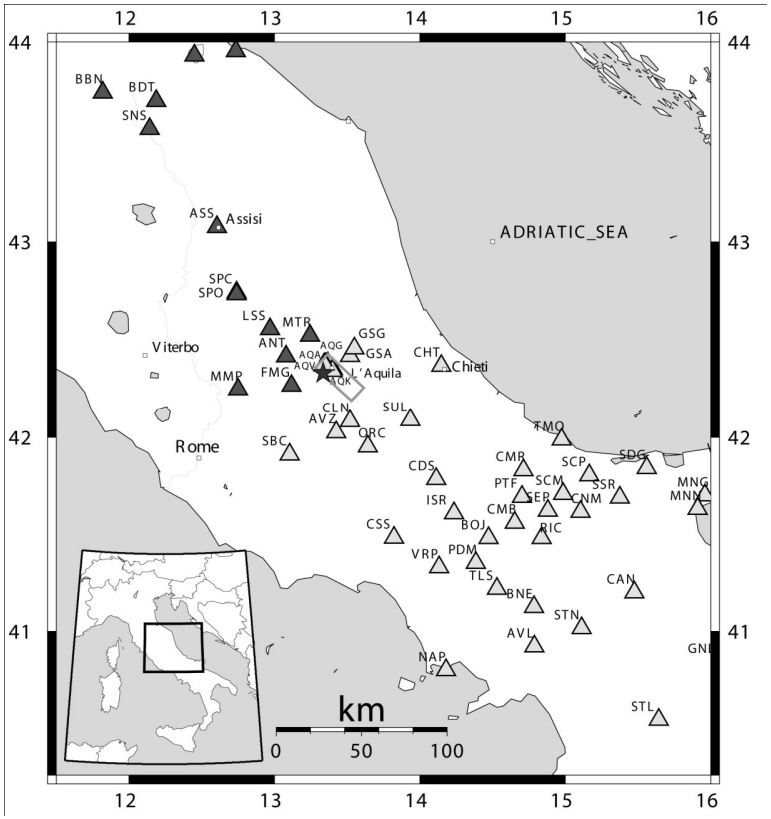
A Recent Simulated SGM Database for Tr



bability
tribution is
ived in Altindal
d Askan (2022)

Altindal and Askan, 2023 (JoS)

I. Use of Simulated Motions for NRHA of MDOF Building Models

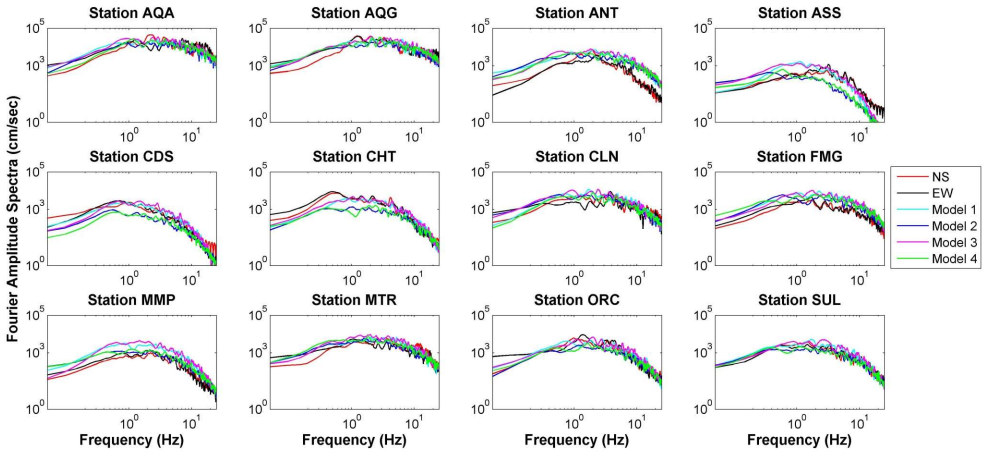


* High frequency simulation of 2009 Laquila eq with 4 different models

* with Akinci and Malagnini, INGV Rome and G. Ameri

(Karimzadeh, Askan, Yakut, and Ameri, 2017, SDEE)
(Ugurhan, Askan, Akinci, and Malagnini, 2012, BSSA)
(Ameri, Gallovič , and Pacor, 2012, JGR)

I. Use of Simulated Motions for NRHA of MDOF Building Models



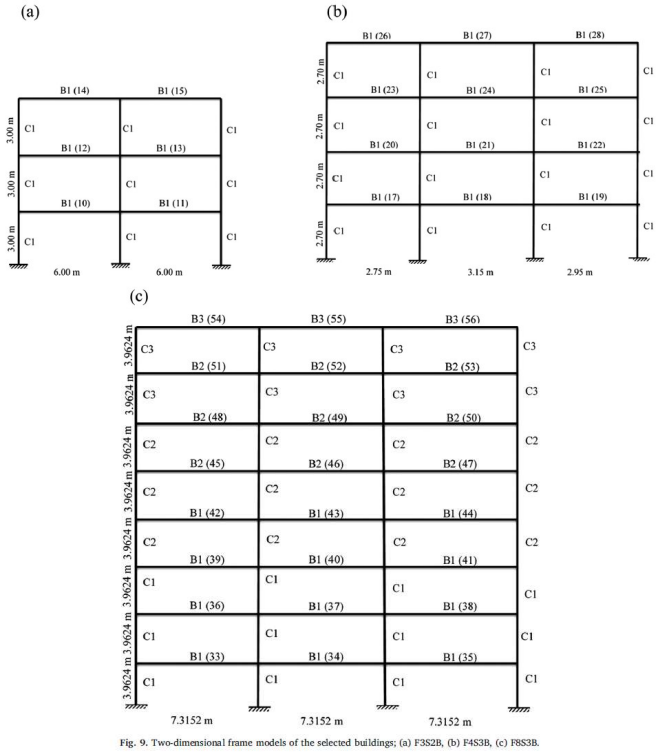
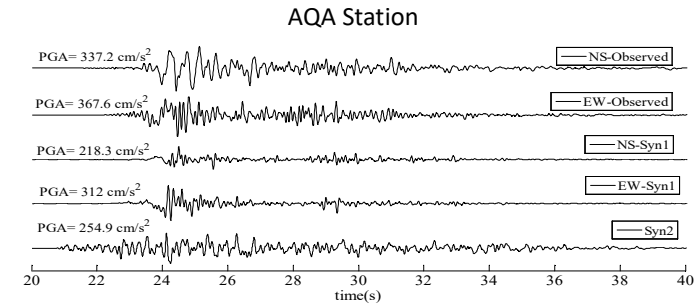


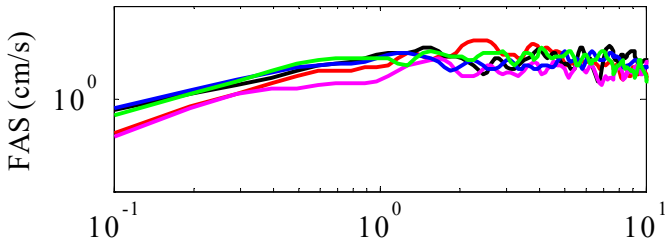
Fig. 9. Two-dimensional frame models of the selected buildings; (a) F3S2B, (b) F4S3B, (c) F8S3B.

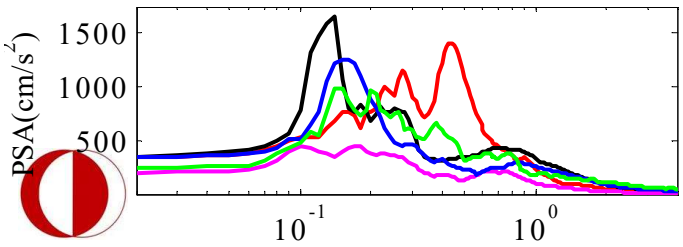
(Karimzadeh, Askan, Yakut, and Ameri, 2017, SDEE)
(Ugurhan, Askan, Akinci, and Malagnini, 2012, BSSA)
(Ameri, Gallovič , and Pacor, 2012, JGR)

I. Use of Simulated Motions for NRHA of MDOF Building Models

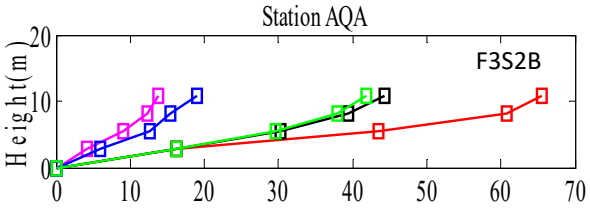
Task 1. Ground motion simulation

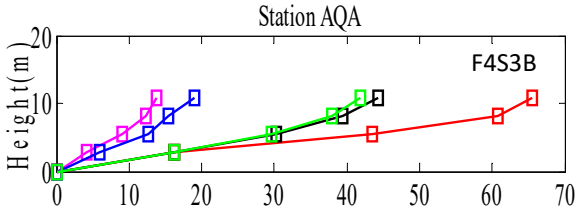


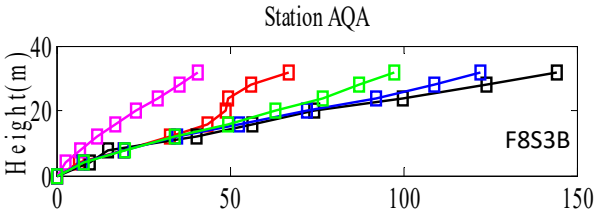


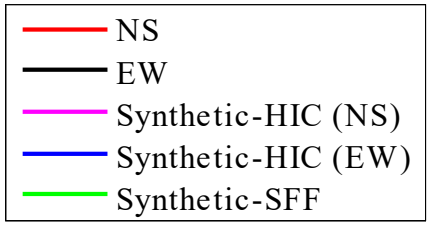


Task 2. Structural response evaluation









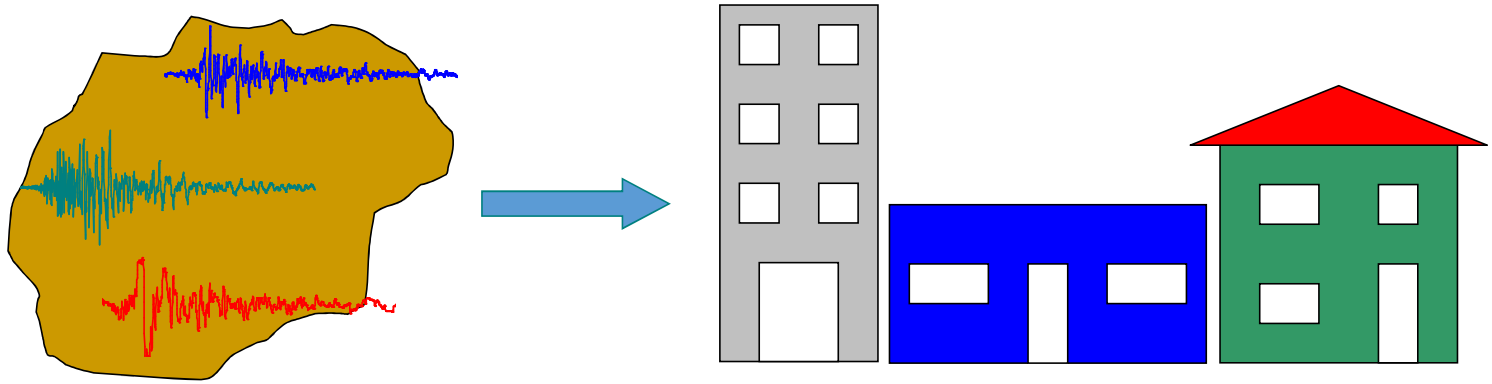
$$Misfit_{FAS} = 1/n_f \sum_f |\log(FAS_{syn}(f)/FAS_{obs}(f))|$$

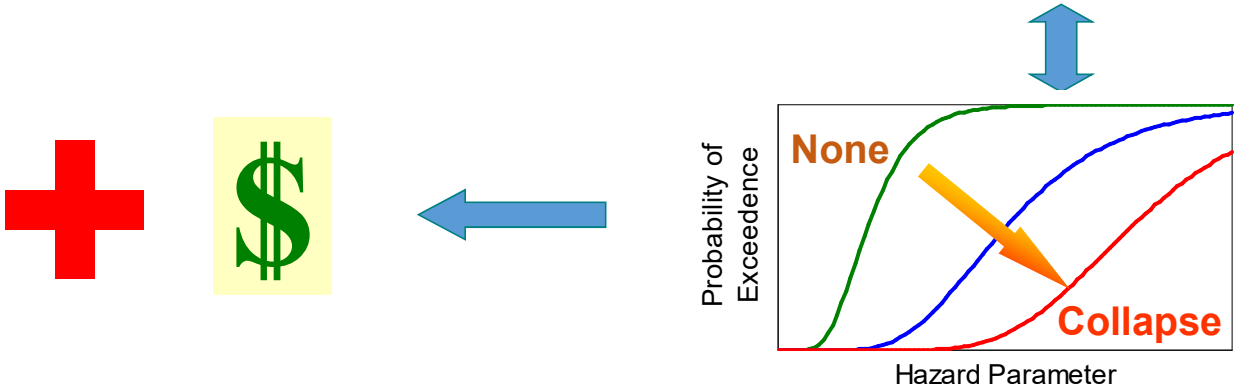
$$Misfit_{RS} = 1/n_T \sum_T |\log(RS_{syn}(T)/RS_{obs}(T))|$$

$$Misfit_{NR} = 1/n_s \sum_{s=1}^{n_s} |\log(NR_{syn}(s)/NR_{obs}(s))|$$

(Karimzadeh, Askan, Yakut, and Ameri, 2017, SDEE)

II. Damage and Loss Modeling in Urban Regions with Simulated Motions





III. City-scale Loss Modeling using Simulated Motions: Erzincan Example

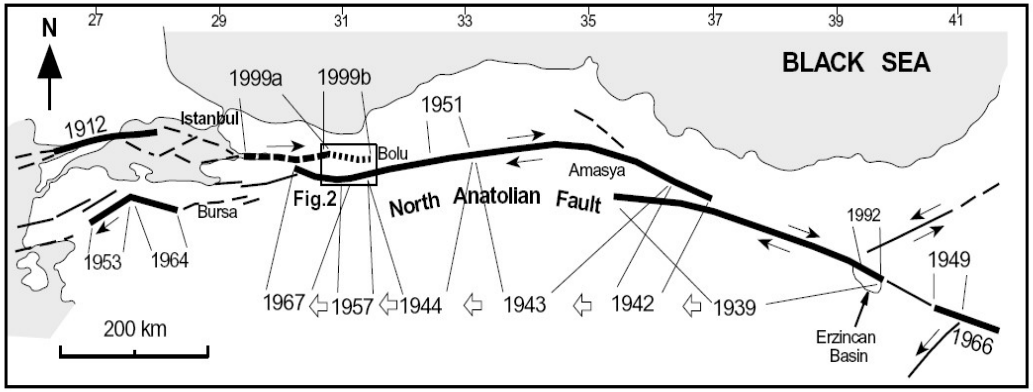
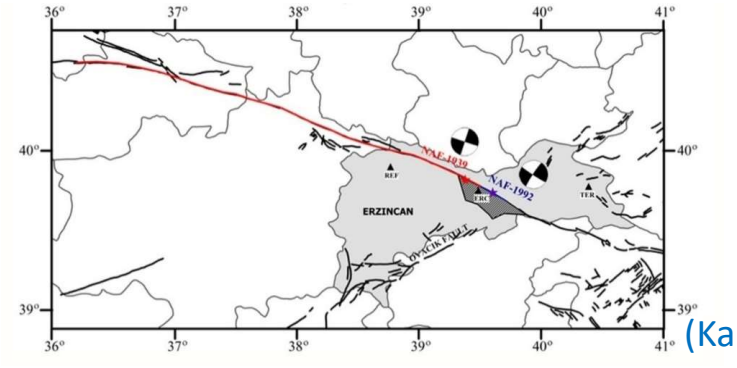
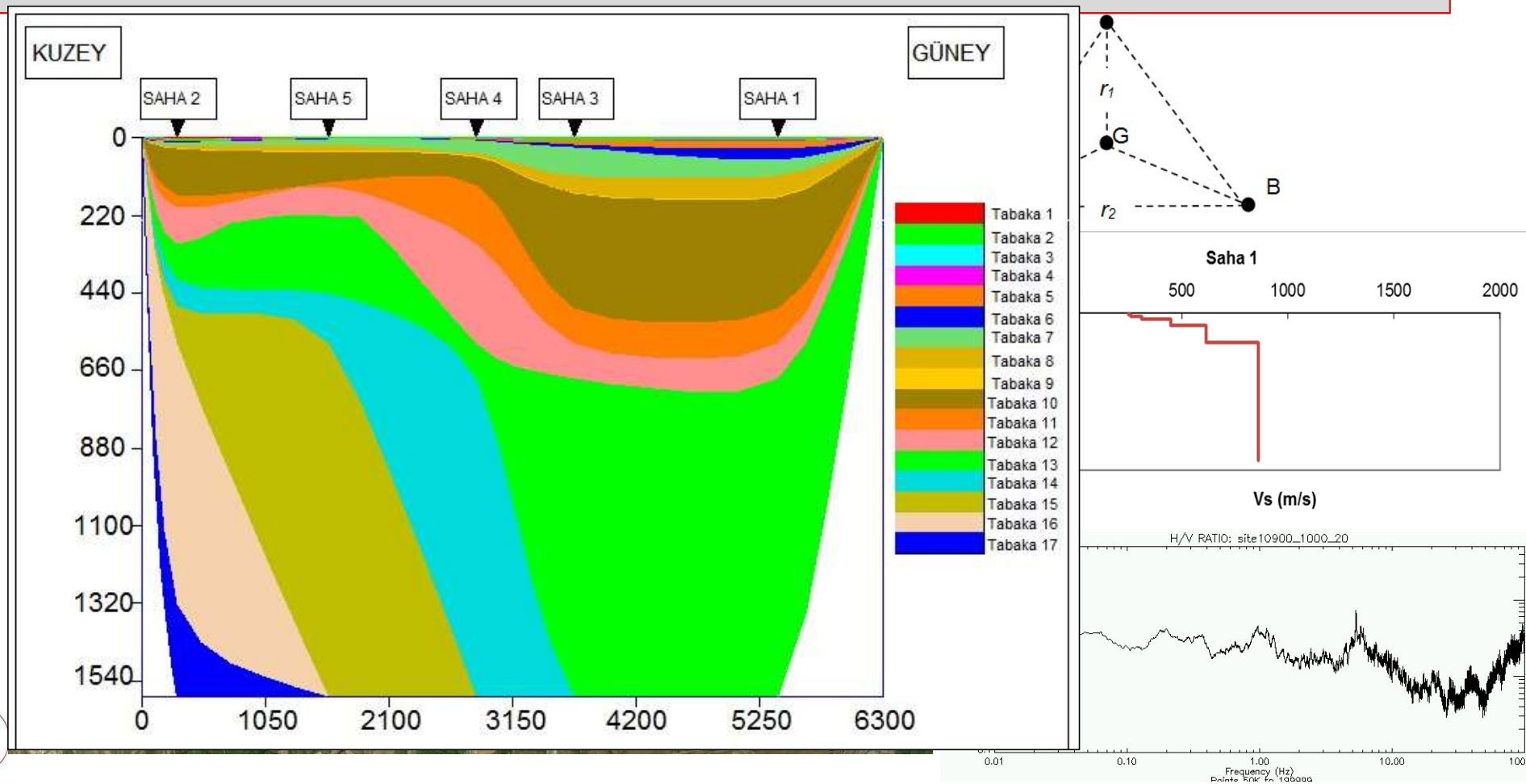


Figure 1. The westward migrating earthquakes since 1939 along the North Anatolian fault.



(Karimzadeh, Askan, Erberik and Yakut, 2018)

III. City-scale Loss Modeling using Simulated Motions: Erzincan Example



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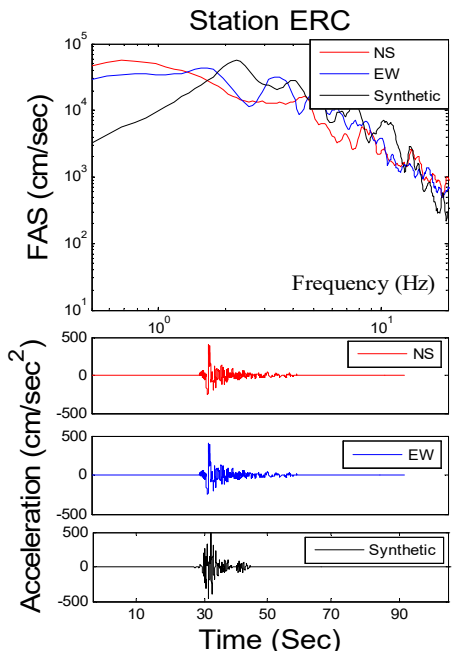
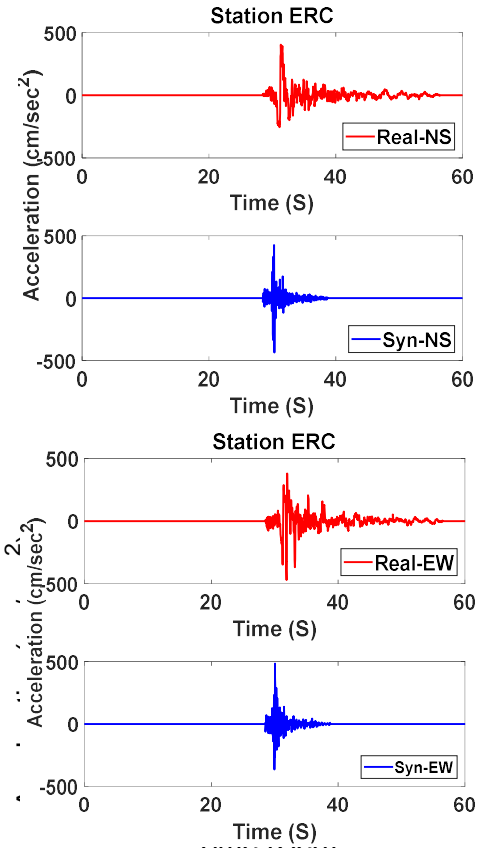
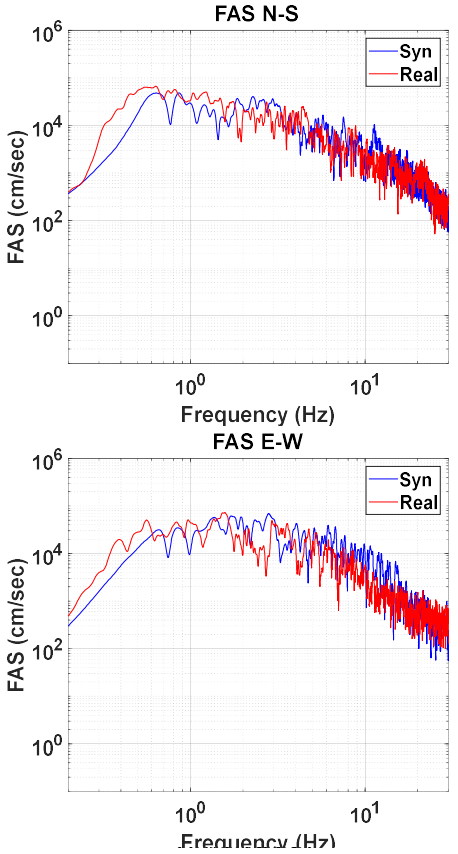
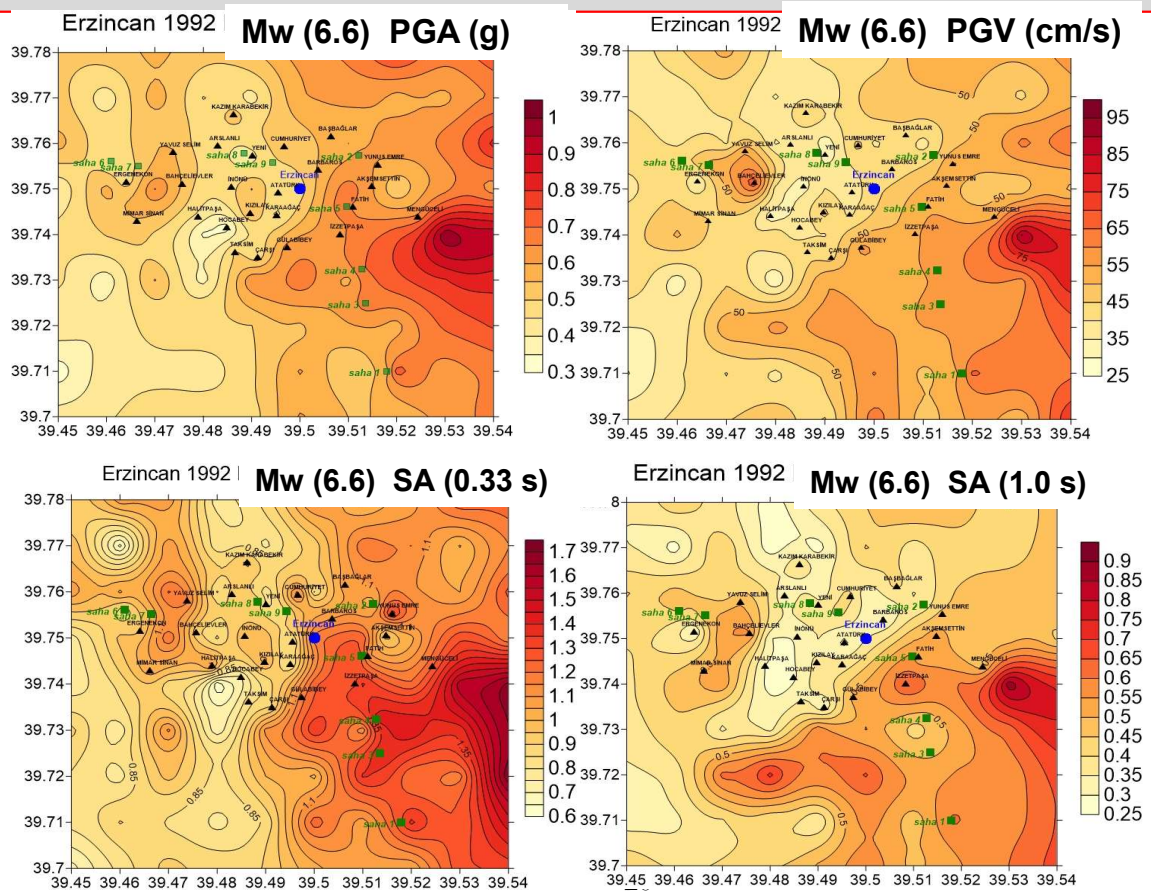




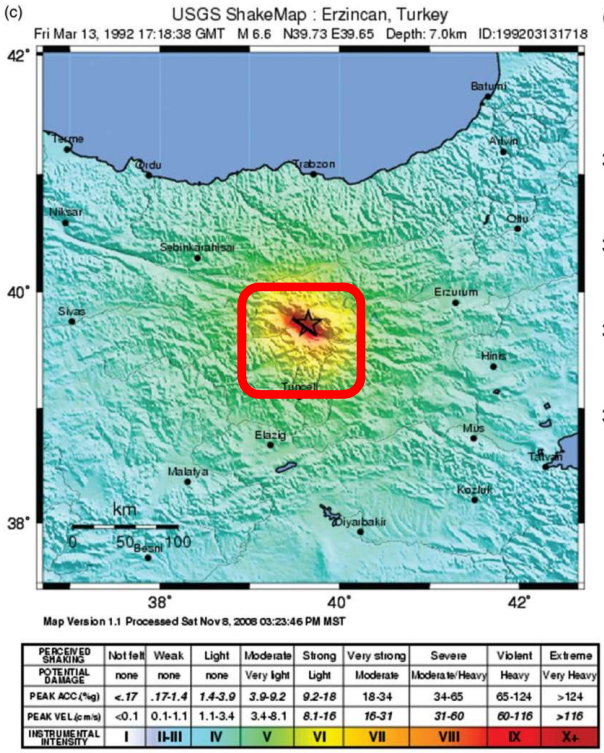


III. City-scale Loss Modeling using Simulated Motions: Erzincan Example

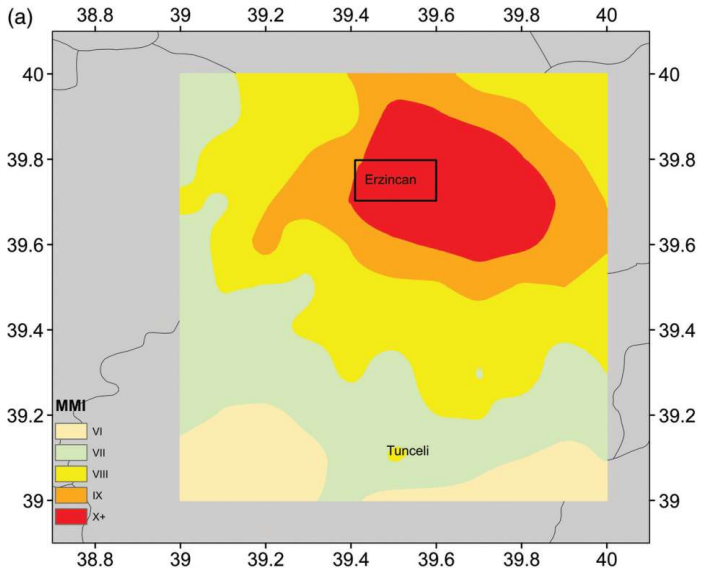


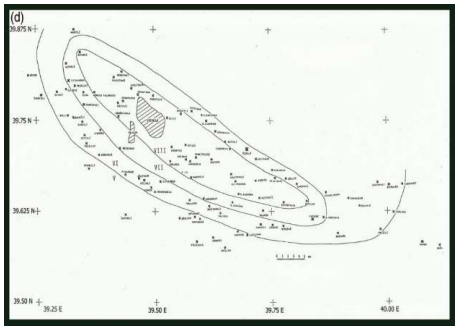
(Karimzadeh, Askan, Erberik and Yakut, 2018)

III. City-scale Loss Modeling using Simulated Motions: Erzincan Example



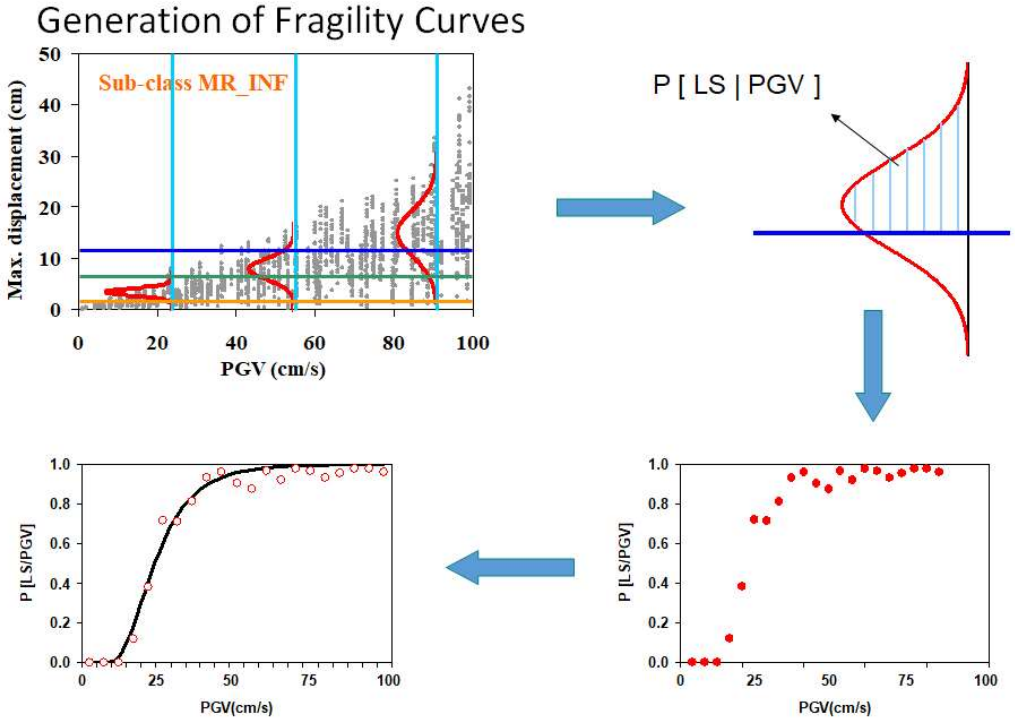
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+





III. City-scale Loss Modeling using Simulated Motions: Erzincan Example

- On site structural classification: 12 RC, 9 Masonry sub-classes
- Dynamic properties of each sub-classes (period, ductility, etc)
- Monte-carlo sampling
- Detailed nonlinear analyses within OPENSEES platform



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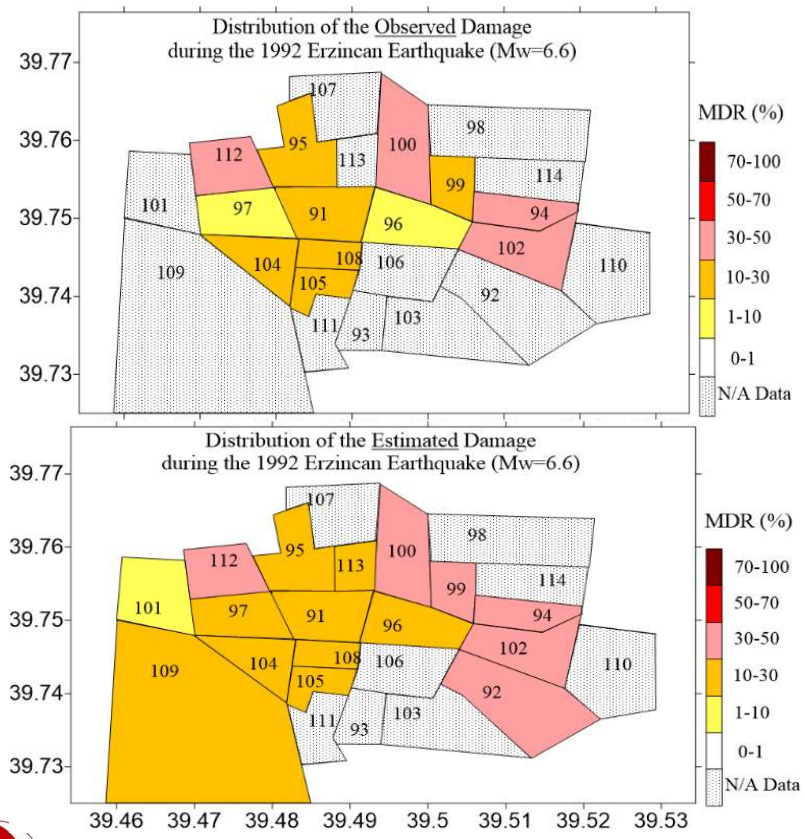
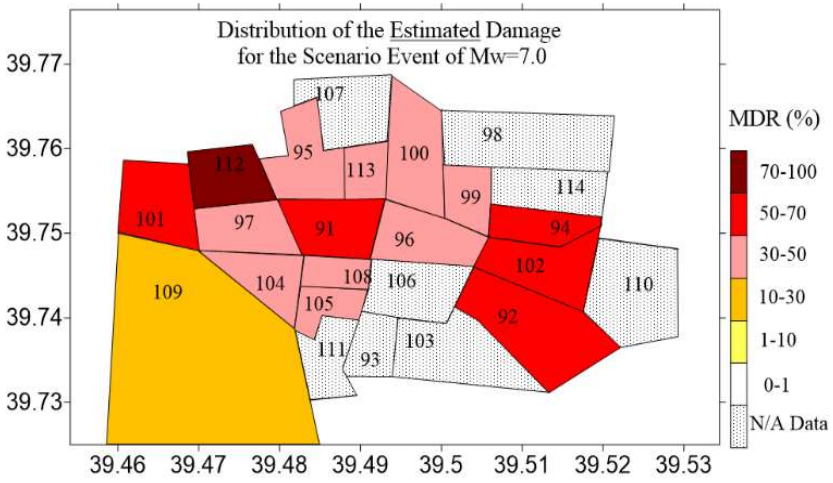
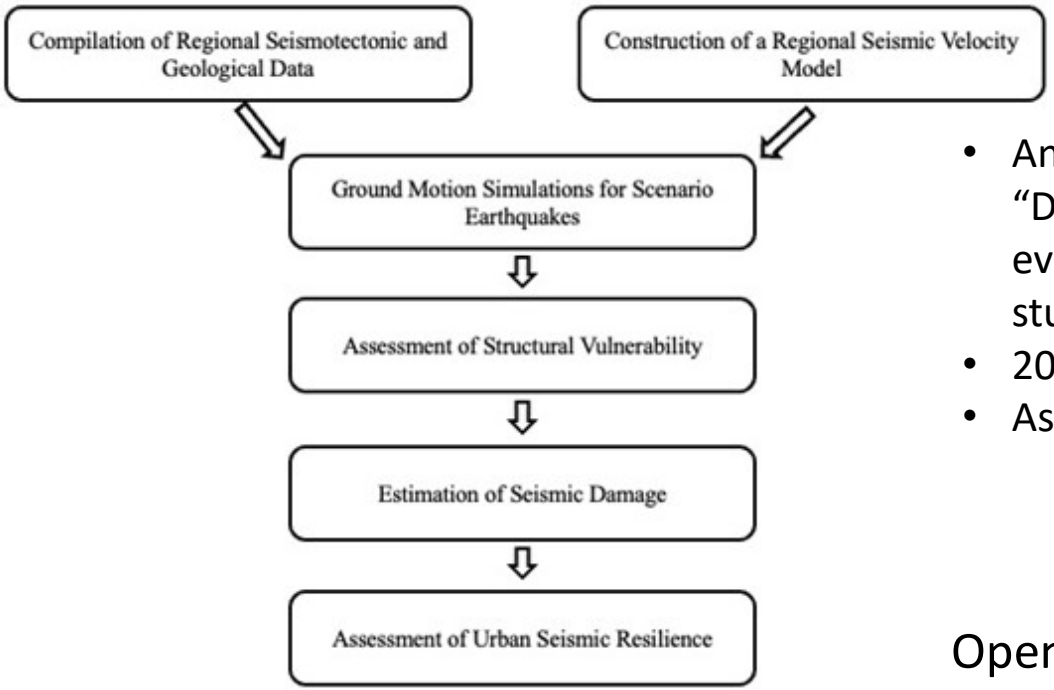
III. City-scale Loss Modeling using Simulated Motions:Erzincan Example





(Karimzadeh, Askan, Erberik and Yakut, 2018)

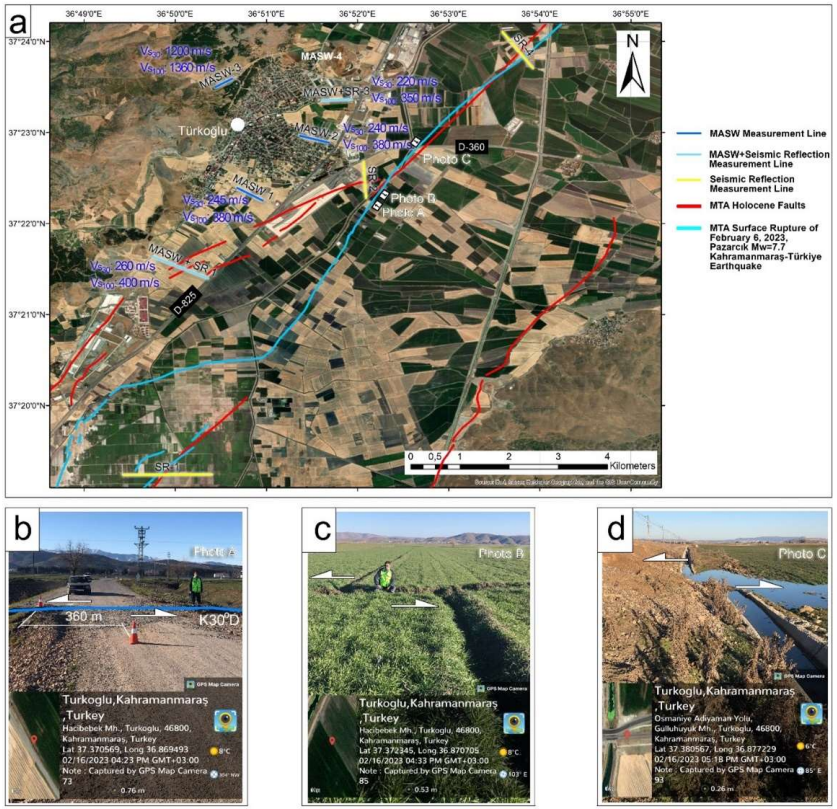
IV. City-scale Loss Modeling using Simulated Motions: Kahramanmaras Example



- An AFAD-funded national project entitled "Development of a method for urban resilience evaluation: Türkoğlu, Kahramanmaraş case study"
- 2021-2023
- Askan et al. 2025 (Eq Spectra)

Open Access →

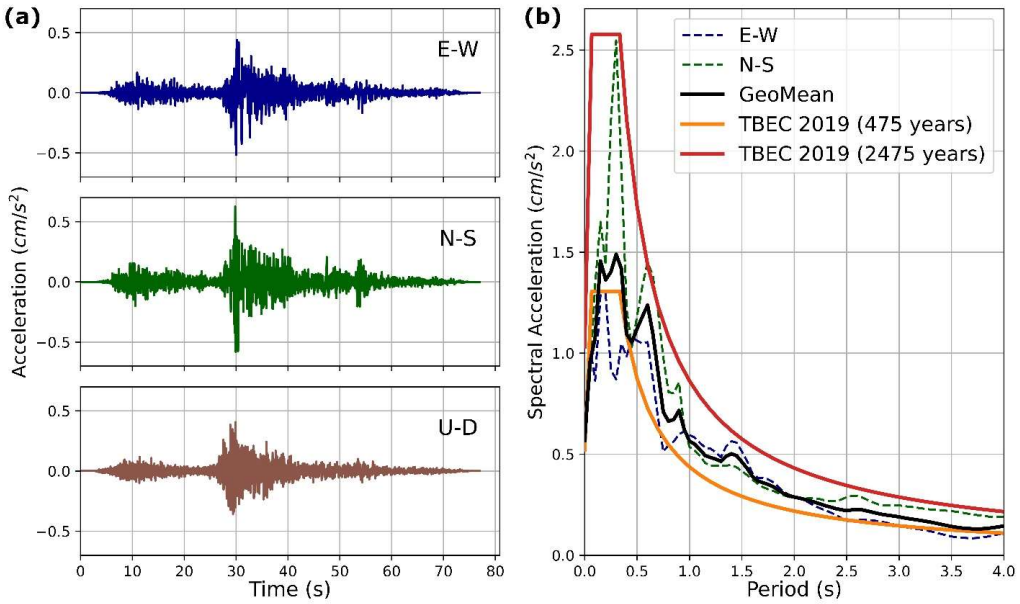
IV. City-scale Loss Modeling using Simulated Motions: Kahramanmaras Example

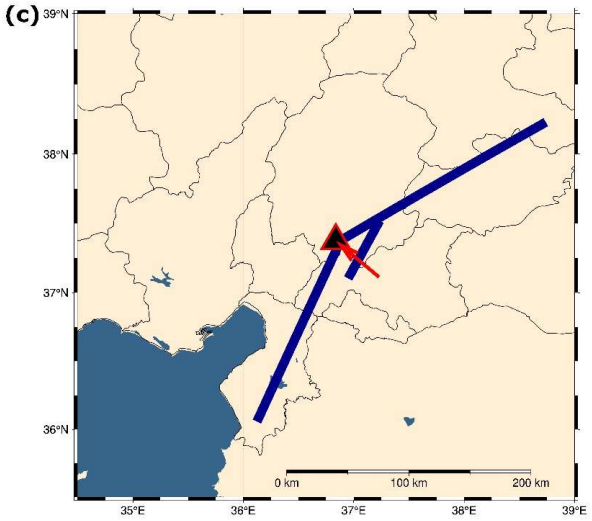


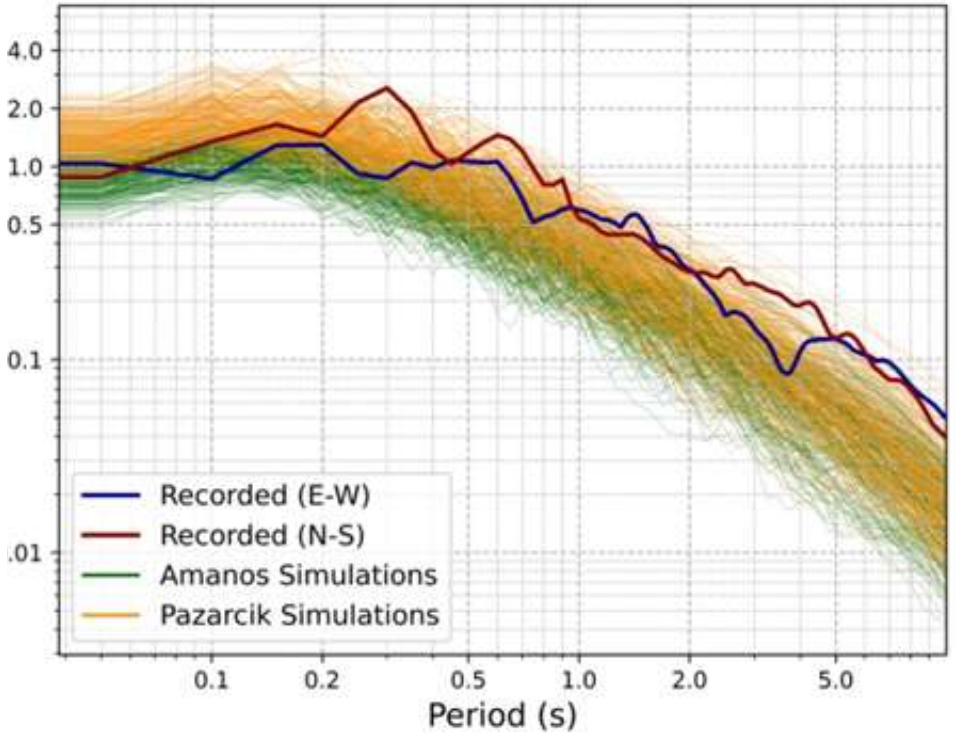
Method	Line Length (m)	Channel Count	Geophone Spacing (m)	Vs_{30} (m/s)	Vs_{100} (m/s)
MASW-1	480	48	10	245	380
MASW-2	480	48	10	240	380
MASW-3	312	48	5	1200	1360
MASW + SR-1	480	48	10	260	400
SR-1	720	144	5	---	---
MASW+ SR-3	480	48	10	220	350
SR-3	480	144	3	---	---
SR-1	1440	144	10	---	---
SR-2	740	144	5	---	---
SR-4	880	144	5	---	---

- Site characterization in 2022
- MASW, SR

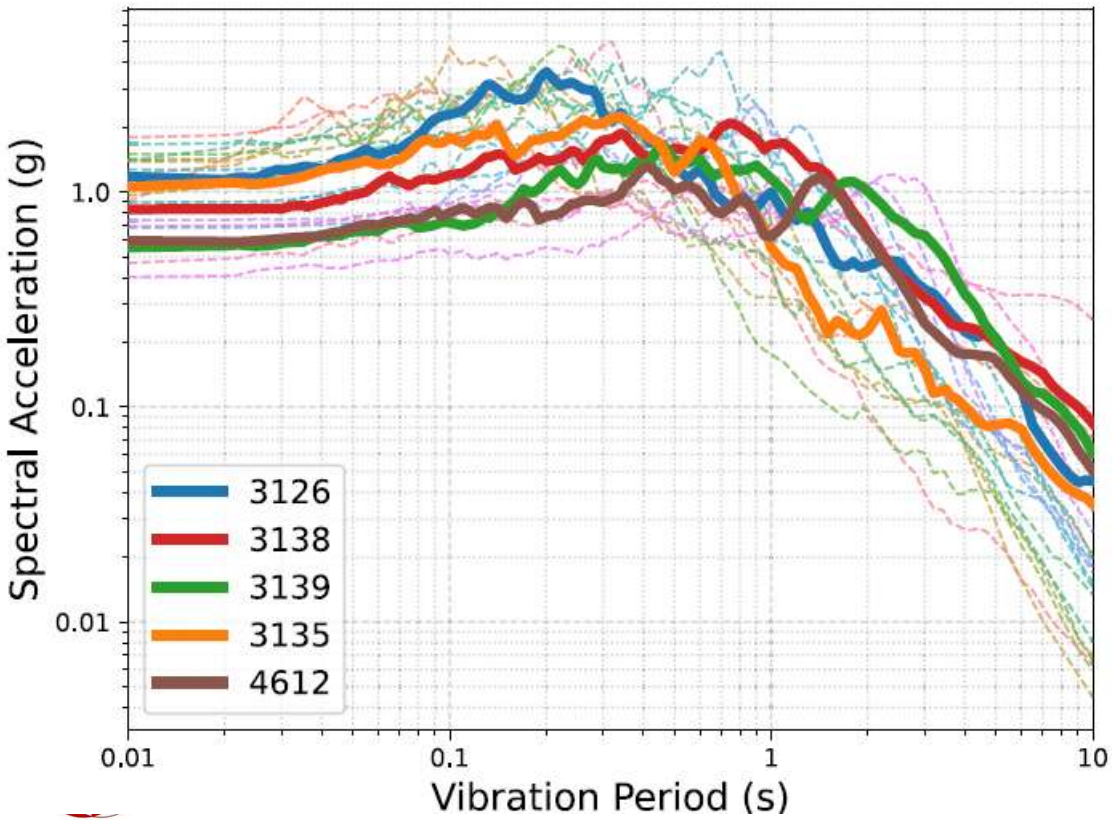
g using Simulated Example



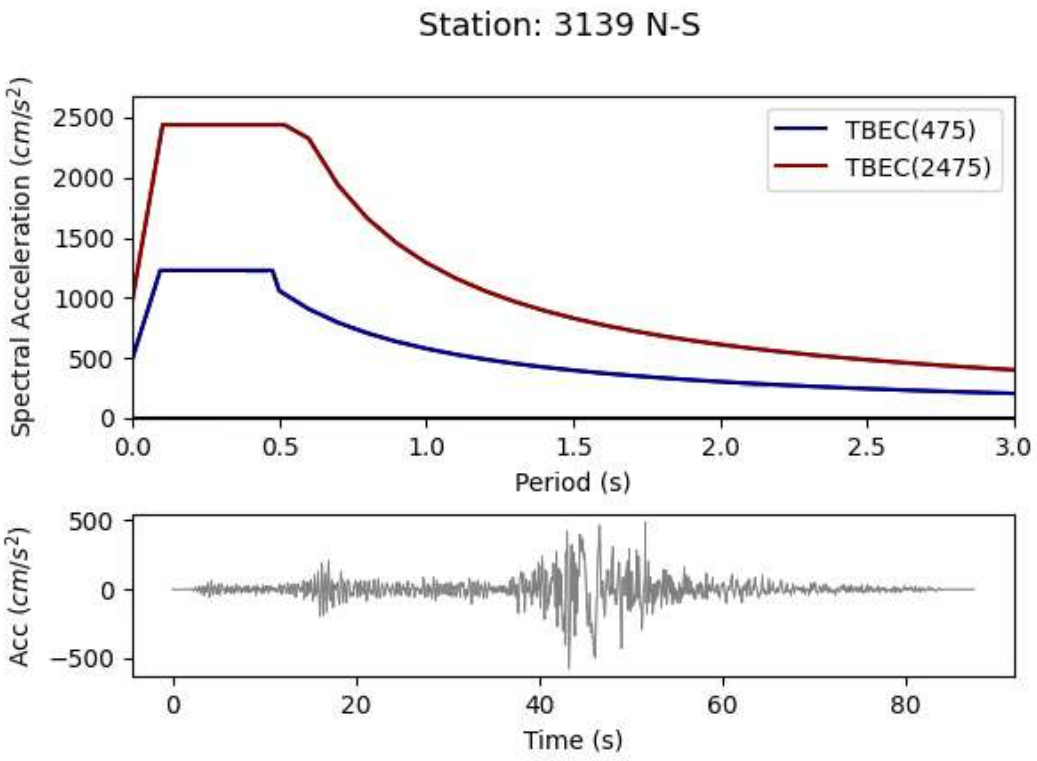




How large were the ground motions?

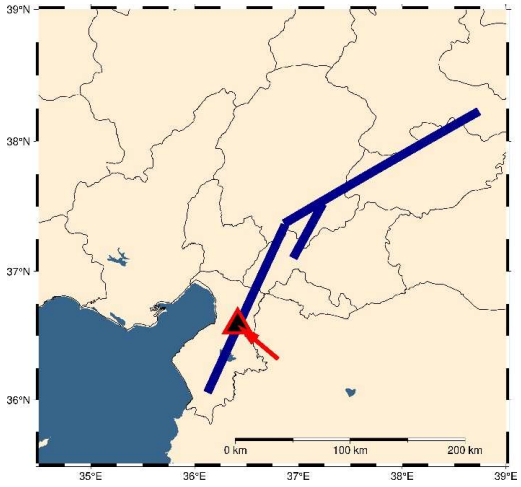


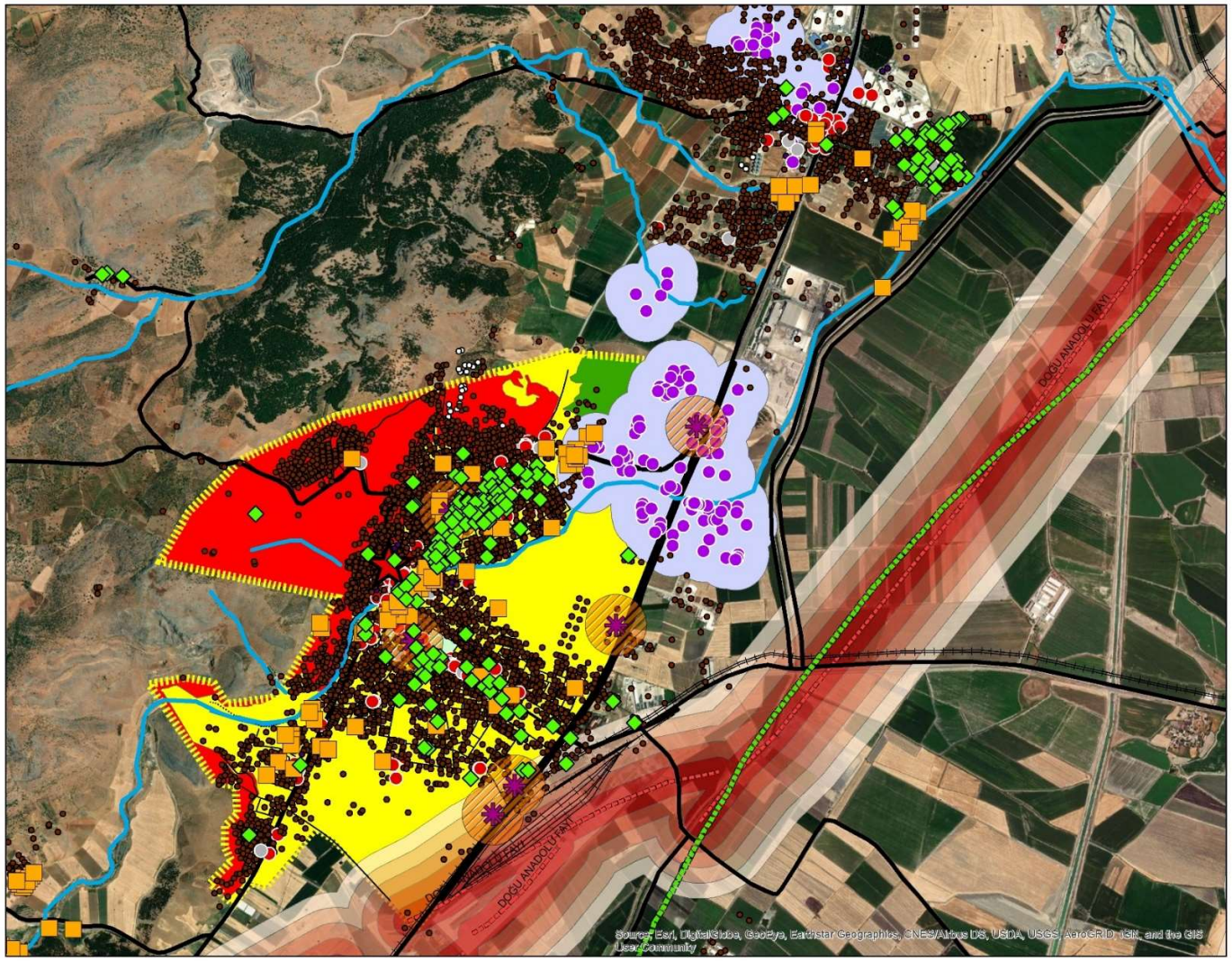
How large were the ground motions? Example for recorded motions of M 7.8 event



Abdullah Altindal & Aysegul Askan (METU, 2023)

- Station 3139 is located in Kırıkhan, Hatay
- Very broadband RS



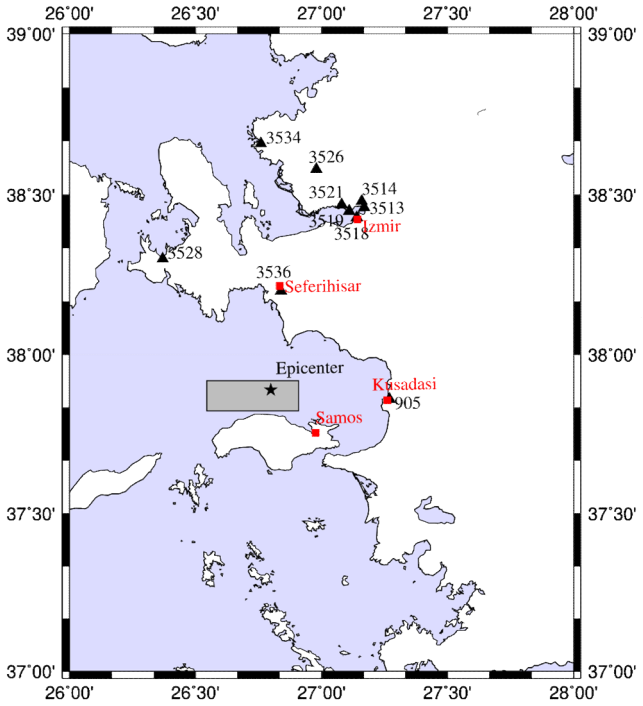


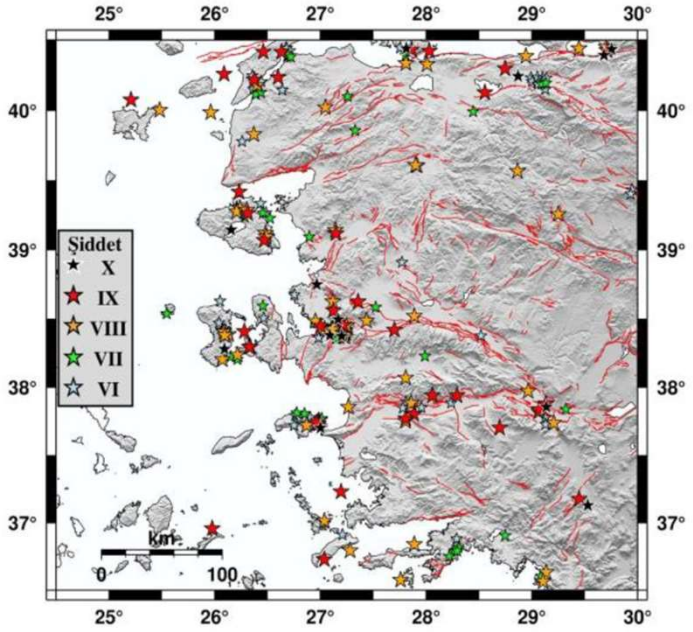
Data Sources: ArcGIS Satellite Map 2024 (ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, AeroGRID, IGN, and the GIS User Community. 1/25000 Scale Development Plan (2011), Emre, Ö., Duman, T.Y., Özalp, S., Elmacı, H., Olgun, Ş. ve Şaroğlu, F., 2013, Açıklamalı Türkiye Diri Fay Haritası (MTA 2013 Active Fault Lines). Ölçek 1:1.250.000, Maden Tetkik ve Arama Genel Müdürlüğü,

Summary

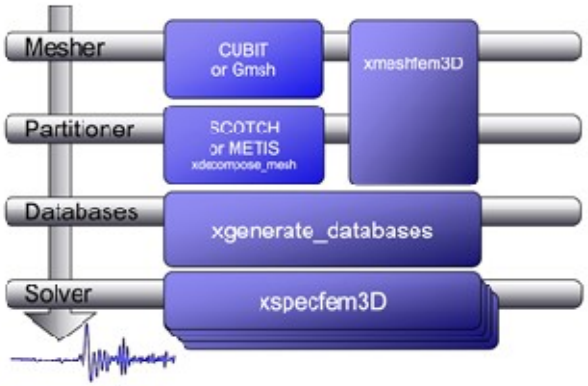
- This national project had started two years before the 2023 earthquakes.
- There was not sufficient time to implement the findings of the project in practice to mitigate the well-identified risks.
- Yet, the entire experience shows how important it is to study seismic resilience in regions of seismic gaps.
- Naturally, this region is not the only seismic gap in Turkiye or in the world.
- Similar multidisciplinary studies should be performed in regions with high seismic hazard and risk along with historical earthquakes with long return periods. It is critical to study in advance the potential effects of large events

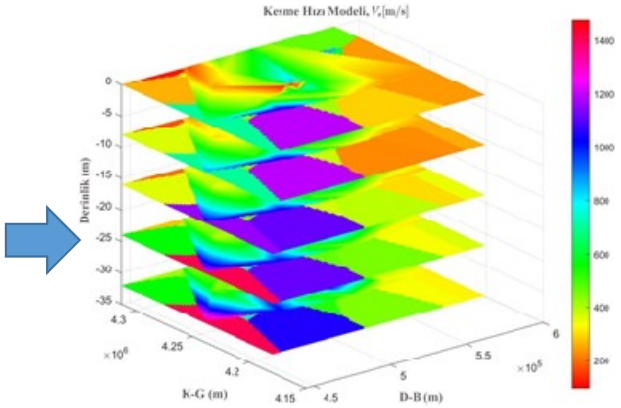
V. City-scale Loss Modeling using Simulated Motions: İzmir Example

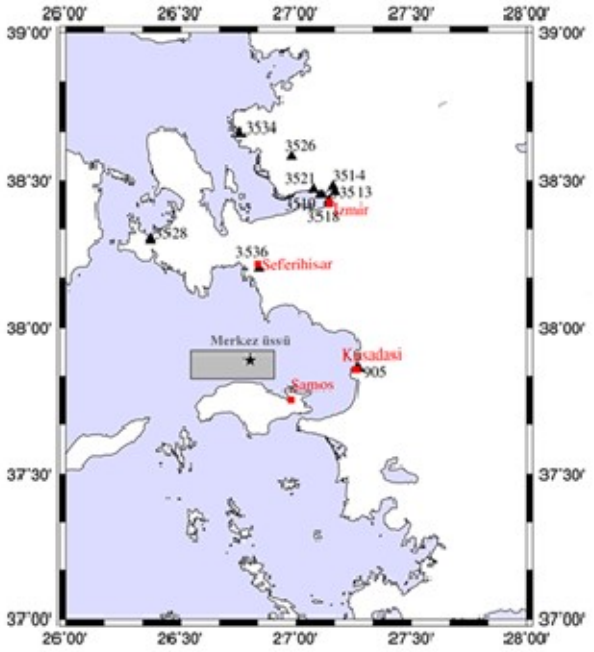


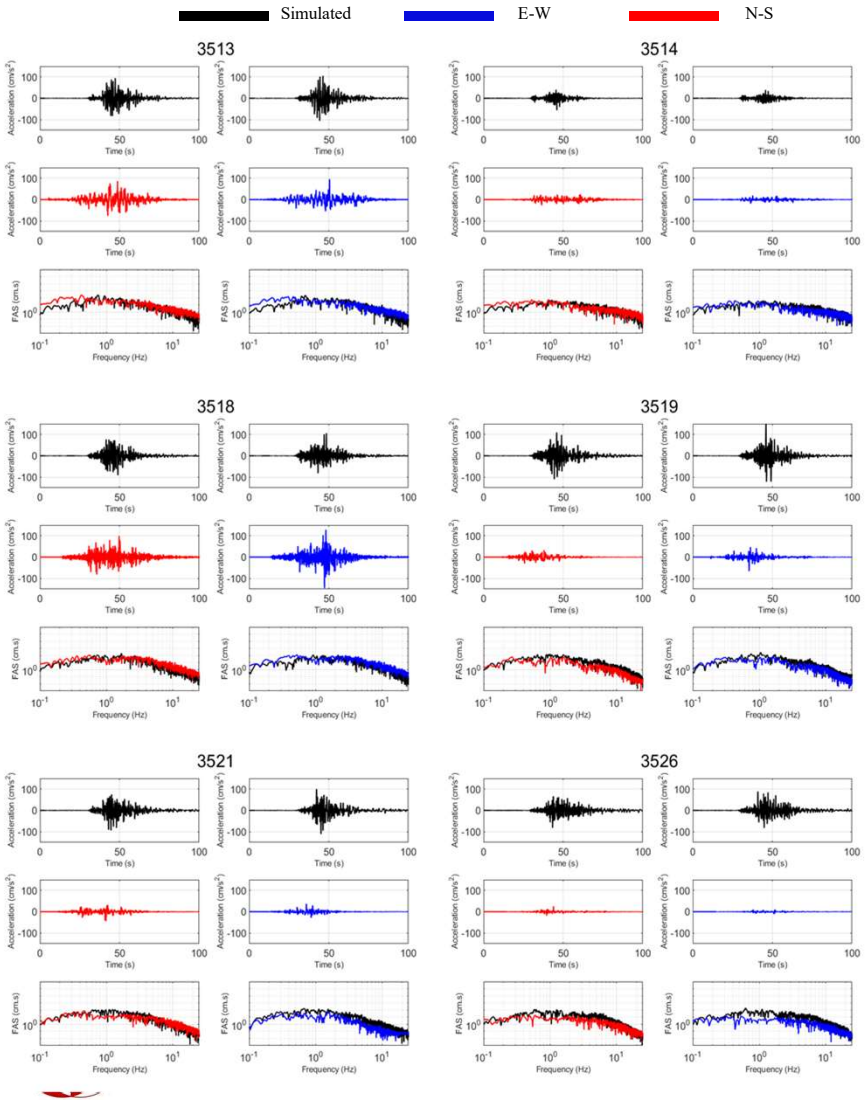


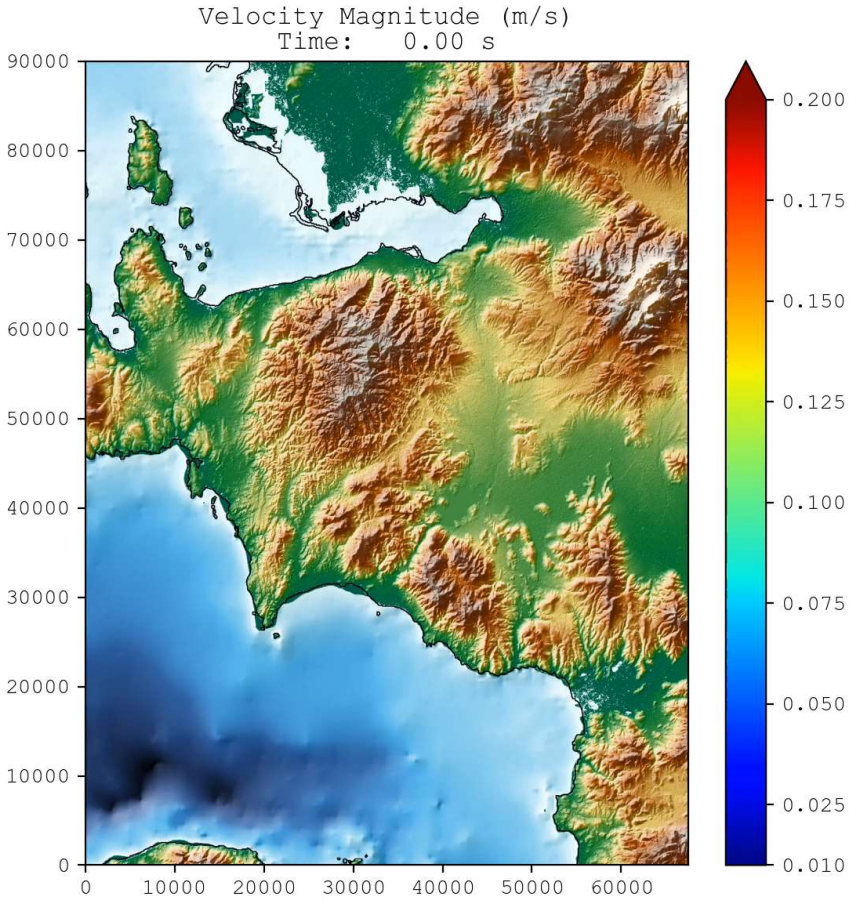
V. City-scale Loss Modeling using Simulated Motions: İzmir Example



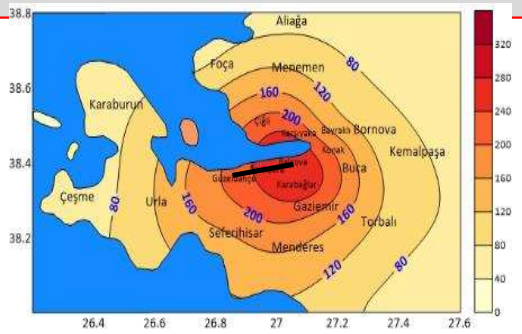


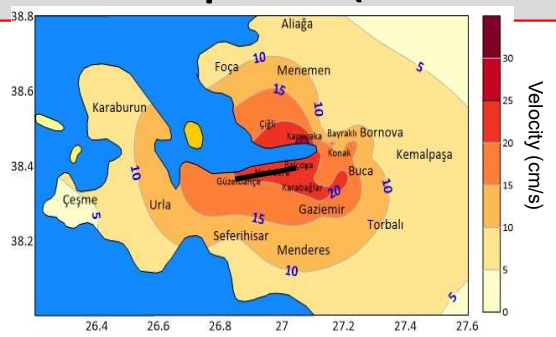


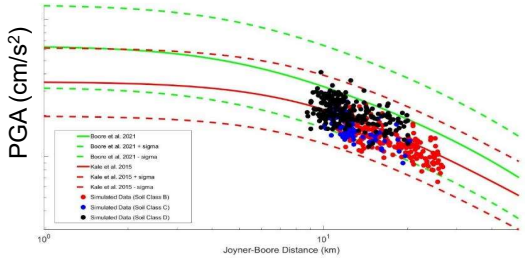

Simulated
E-W
N-S
3513
3514
3518
3519
3521
3526
Acceleration (cm/s²)
Time (s)
FAS (cm.s)
Frequency (Hz)

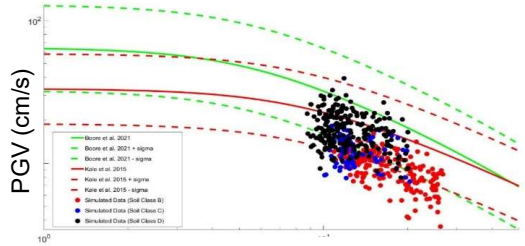

Velocity Magnitude (m/s)
Time: 0.00 s
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
10000
20000
30000
40000
50000
60000
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.010

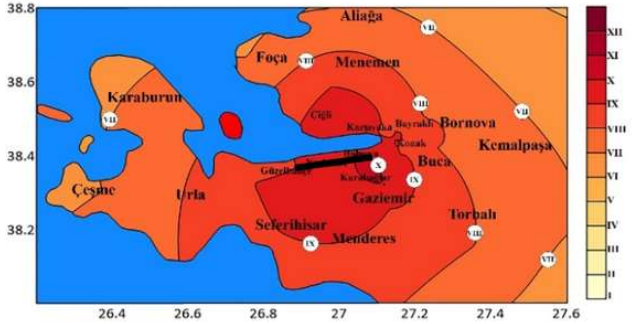
VI. City-scale Loss Modeling using Simulated Motions: İzmir Example (M6.6 on İzmir fault)

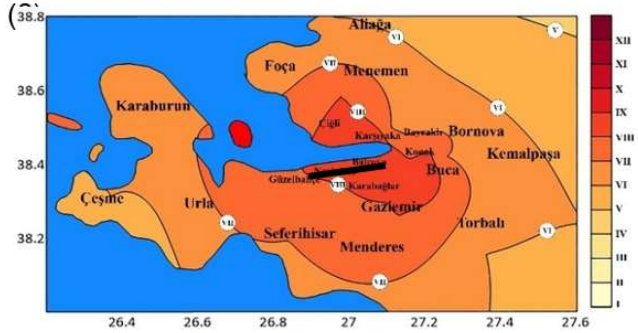






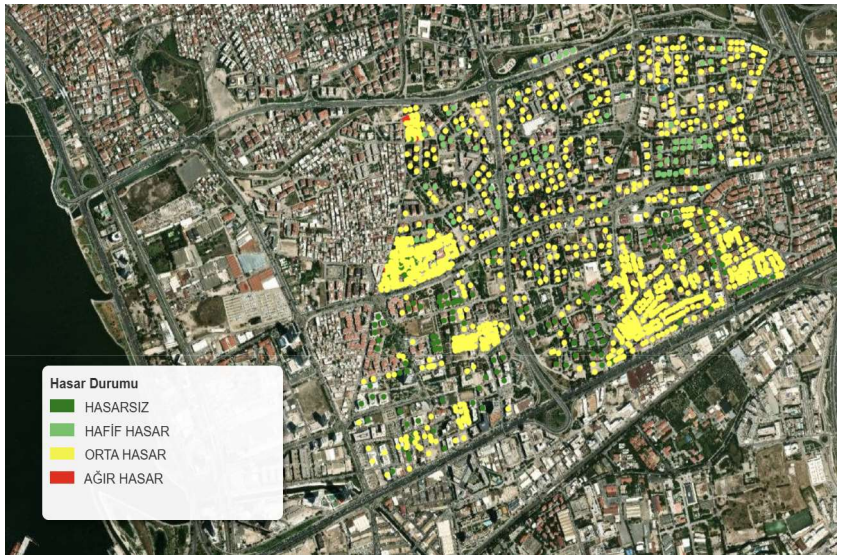




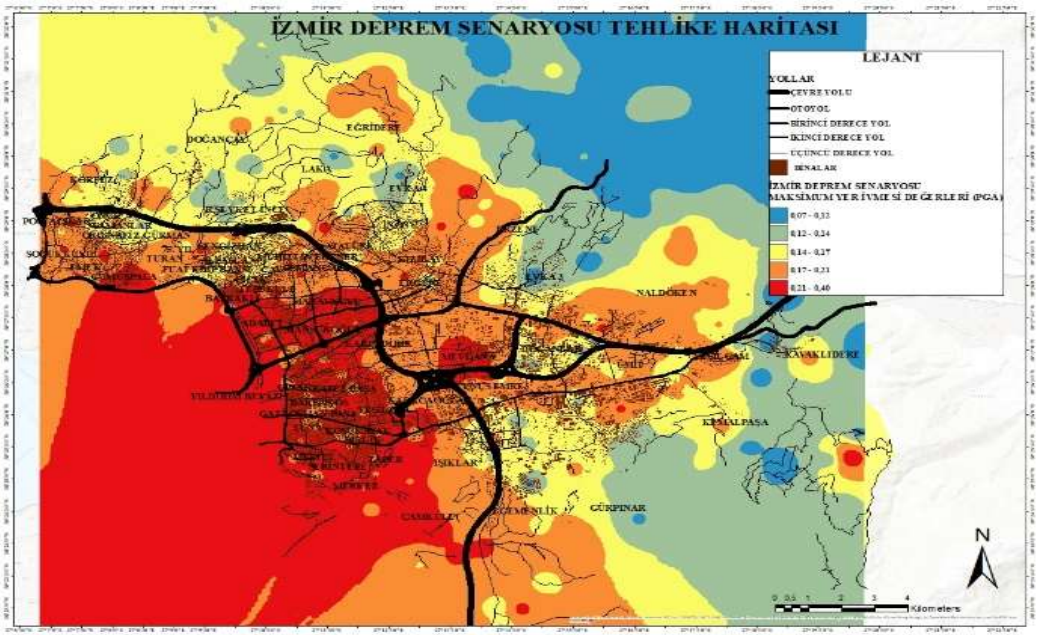


VI. City-scale Loss Modeling using Simulated Motions: İzmir Example (M6.6 on İzmir fault)

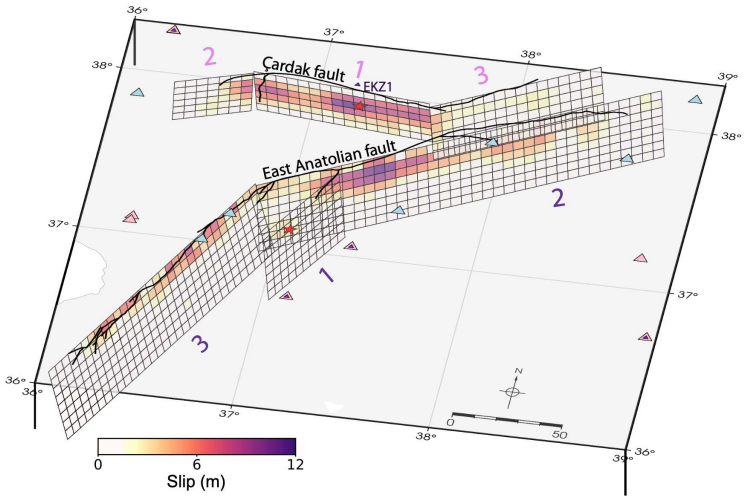
Physical Vulnerability: Damage State Distribution



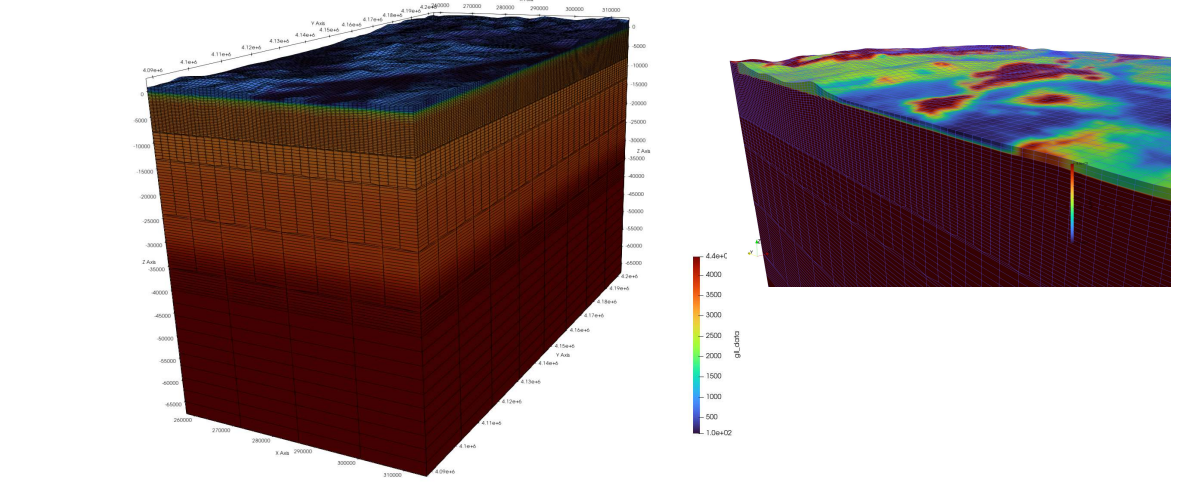
Social Vulnerability and Urban Planning

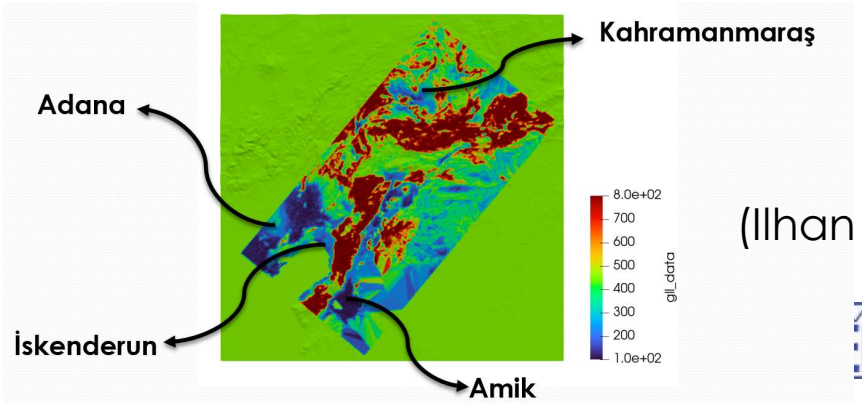


Physics-based Simulations of 2023 Kahramanmaraş earthquakes (ongoing MSc thesis of Bartu Bilgen)



(Goldberg et al., 2023)



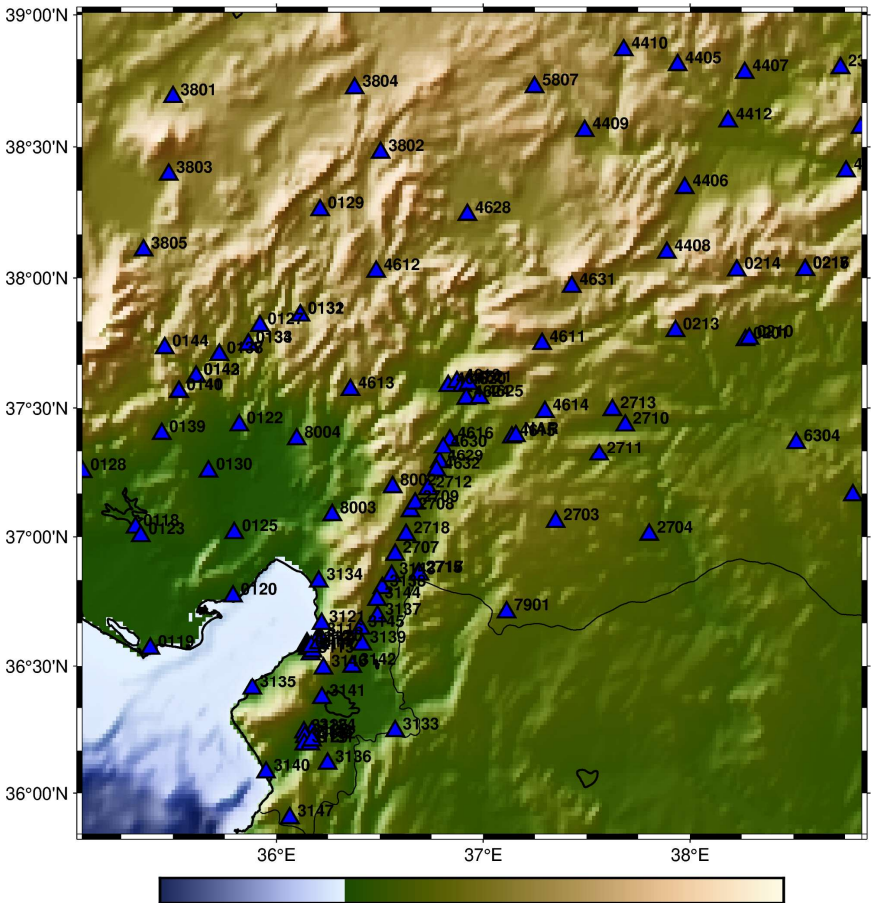


(Ilhan et al., 2025)

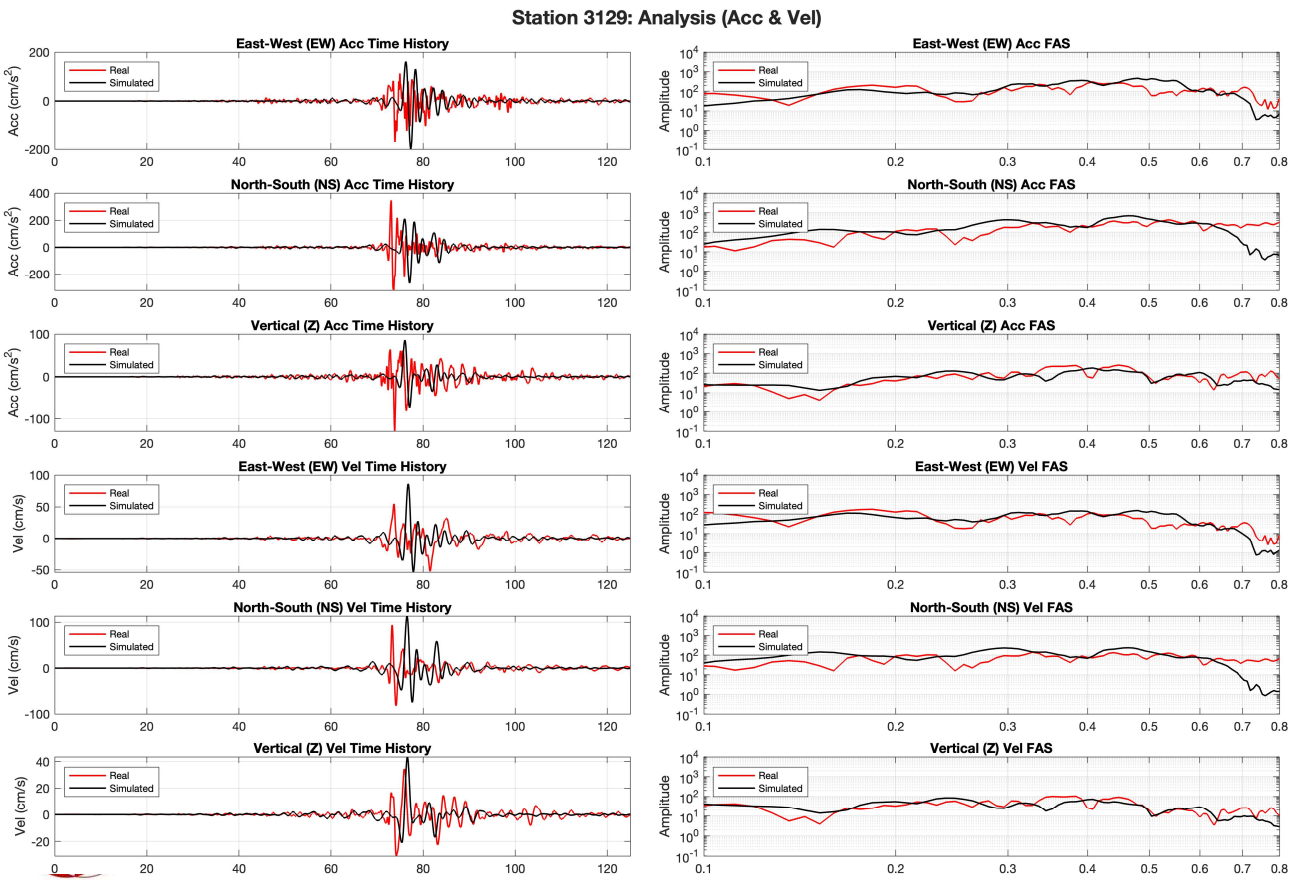
Physics-based Simulations of 2023 Kahramanmaraş earthquakes (ongoing MSc thesis of Bartu Bilgen)

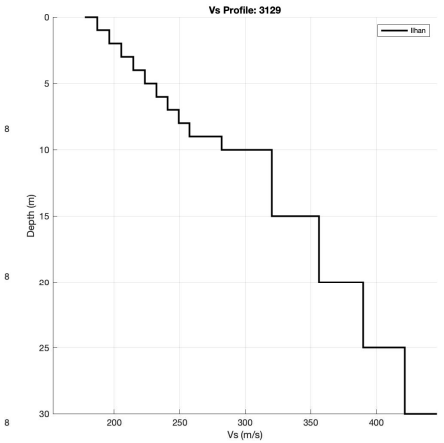
Computational Summary

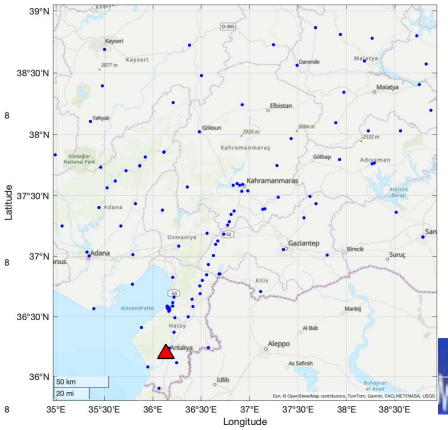
- 18 GPUs (P100): 22 hours 32 mins
- dt = 0.0008 s (250 s total, 312500 timesteps)
- Total number of elements without CPML: 6068800
- Total number of elements with CPML: 7084800
- Total number of DOFs: 1177651734
- Tomo resolution:
  - dx=dy=450 m
  - dz=100 m



Physics-based Simulations of 2023 Kahramanmaraş earthquakes (ongoing MSc thesis of Bartu Bilgen)







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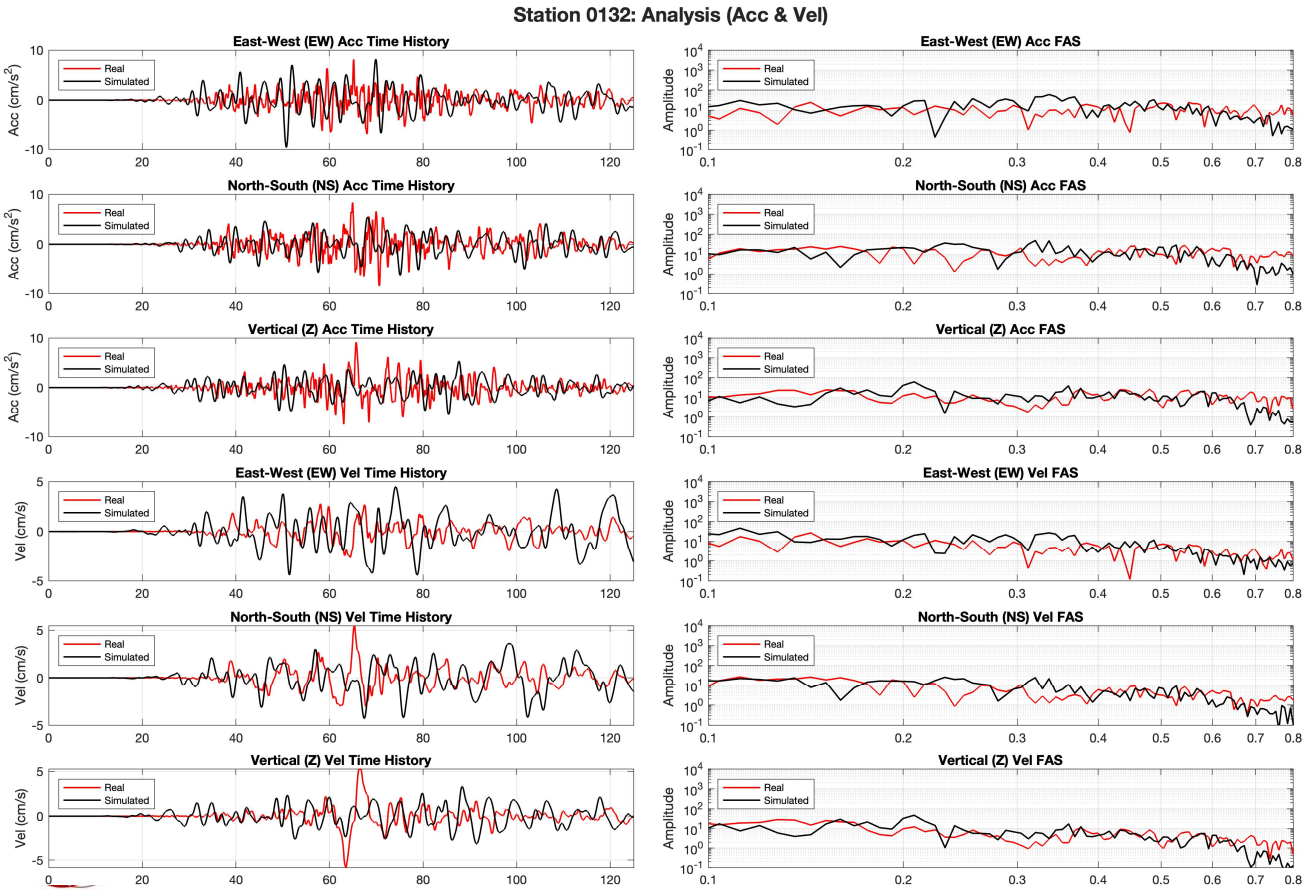
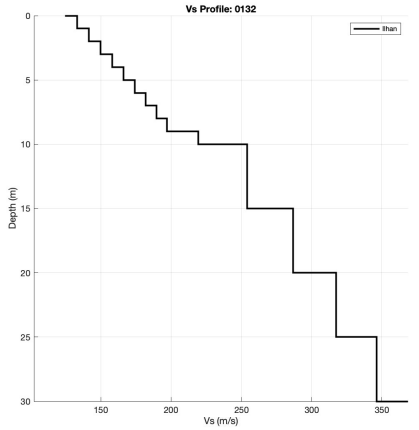
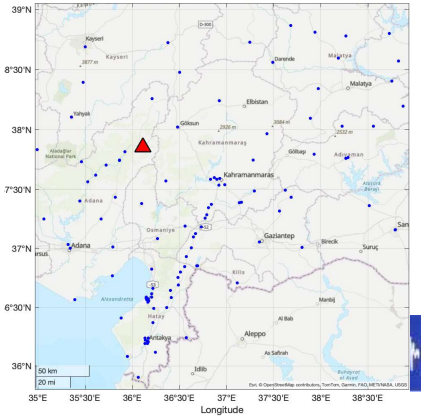
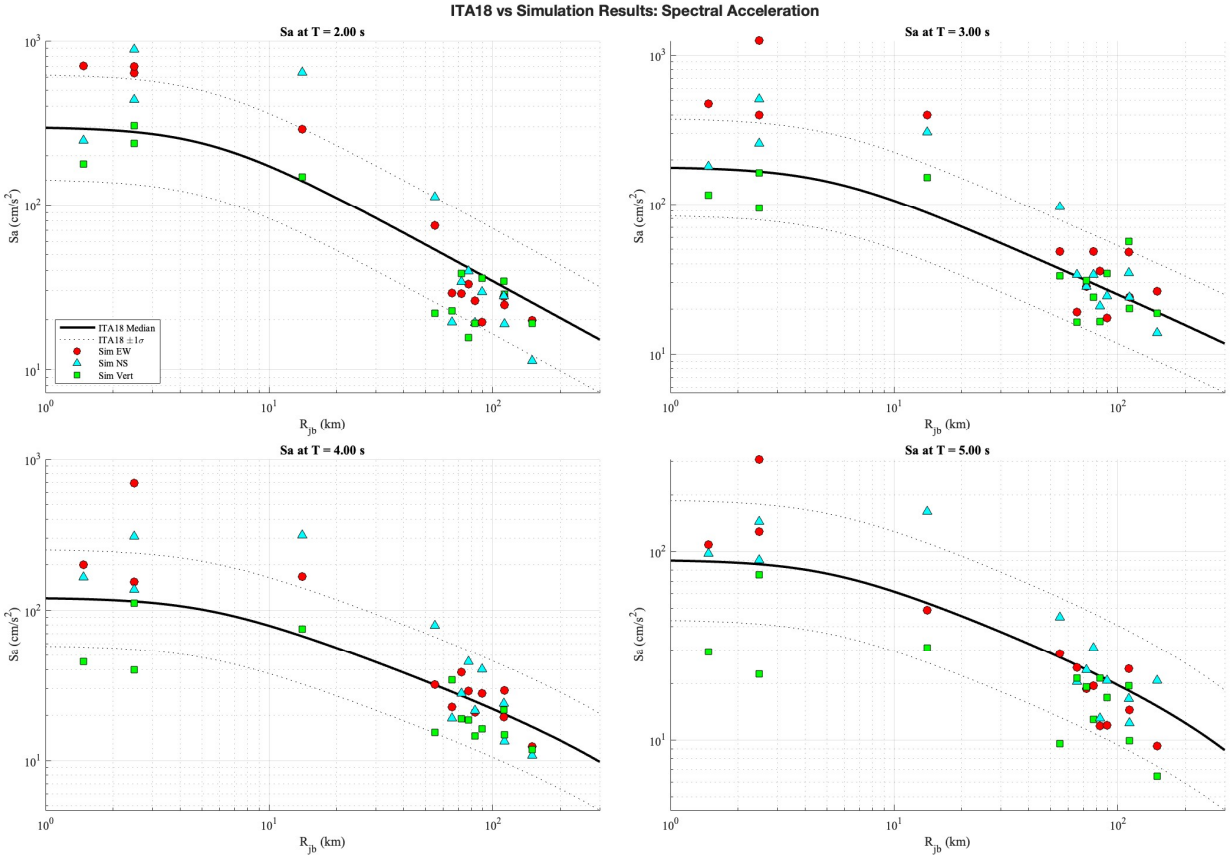




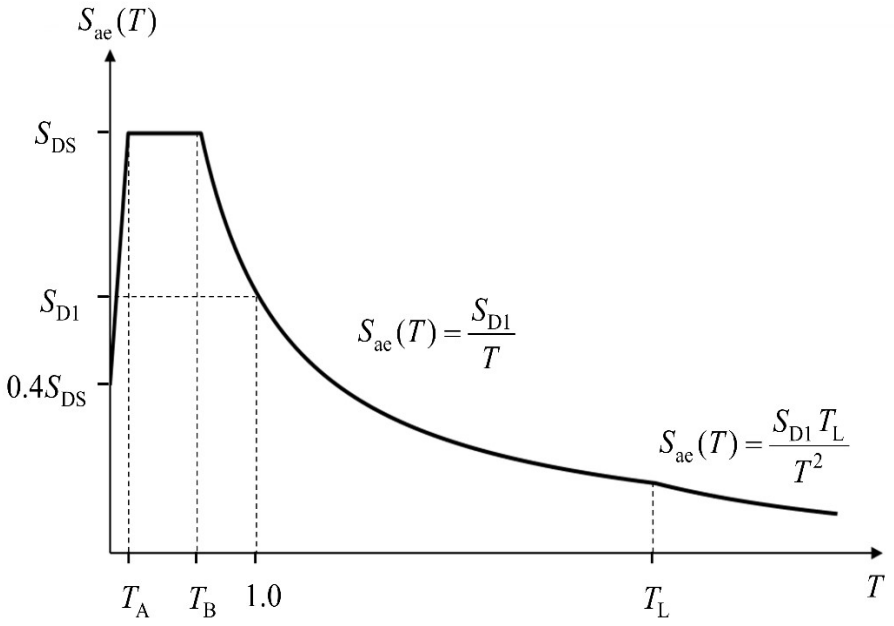


Physics-based Simulations of 2023 Kahramanmaraş earthquakes (ongoing MSc thesis of Bartu Bilgen)



Implications for Future: Code and Design Spectra

- Long periods
- Basin effects
- NF effects
- Site amplifications
- Liquefaction updates



Turkish Building Earthquake Code (TBEC, 2018)

Ongoing Challenges and Future Tasks

- velocity models (in progress at most locations)
- source models for moderate size earthquakes
- building databases!
- validation of event-based records
- uncertainty analyses
- need for simulated ground motion databases (Altindal and Askan JoS, 2023)
- Global databases (COSMOS Sim WG!)
- Encourage real engineers to use simulated motions!

Ongoing Challenges and Future Tasks

- Multi-disciplinary approach (extending also to social sciences and economics)
- High-quality data → Accurate and precise modeling → Risk reduction!
- Continuity of the link between research and practical earthquake engineering
- Similar types of damage!
- Memory effect (2010–2020 Elazığ earthquakes)
- Digital Twins, Machine Learning, and Multi-disciplinary Simulations on Supercomputers
- Multi-hazard scenarios
- Supervision in the field!
- Organic bonds between science, practicing engineers and local administrations

METU EERC

ESC2026: Looking forward to seeing you all in Istanbul

https://www.esc2026.org

ABSTRACT SUBMISSION
DEADLINE: March 15!

Thanks and Contact

Thanks to all of my graduate students and colleagues and funding sources, who
- not only helped with all of these studies
- but also had to deal with my enthusiasm for research.

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aaskan@metu.edu.tr

Reference publications:
https://scholar.google.com/citations?user=Ok5p600AAAAJ&hl=en

https://blog.metu.edu.tr/aaskan/publications