Earthquake Insights Seminar: Unveiling Discoveries and Preparedness Strategies

Lessons Learned from the M7.8 Türkiye Earthquake of 6 February 2023

October 13, 2023

We would like to acknowledge that we reside on the unceded traditional territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) Nations.

General Agenda

TIME	TITLE
1:00 - 1:05	Opening Remarks
1:05 - 2:00	Technical Session
2:00 - 2:20	Break
2:20 - 3:20	Technical Session
3:20 - 3:40	Break
3:40 - 4:20	Technical Session
4:20 - 4:50	Panel Discussion
4:50 - 5:00	Concluding Remarks

Certificate of Attendance

Participants who are both registered and in attendance will receive a Certificate of Attendance for 3.5 Professional Development Hours (PDH) from UBC.

Please confirm and submit your details in order to receive your PDH certification.

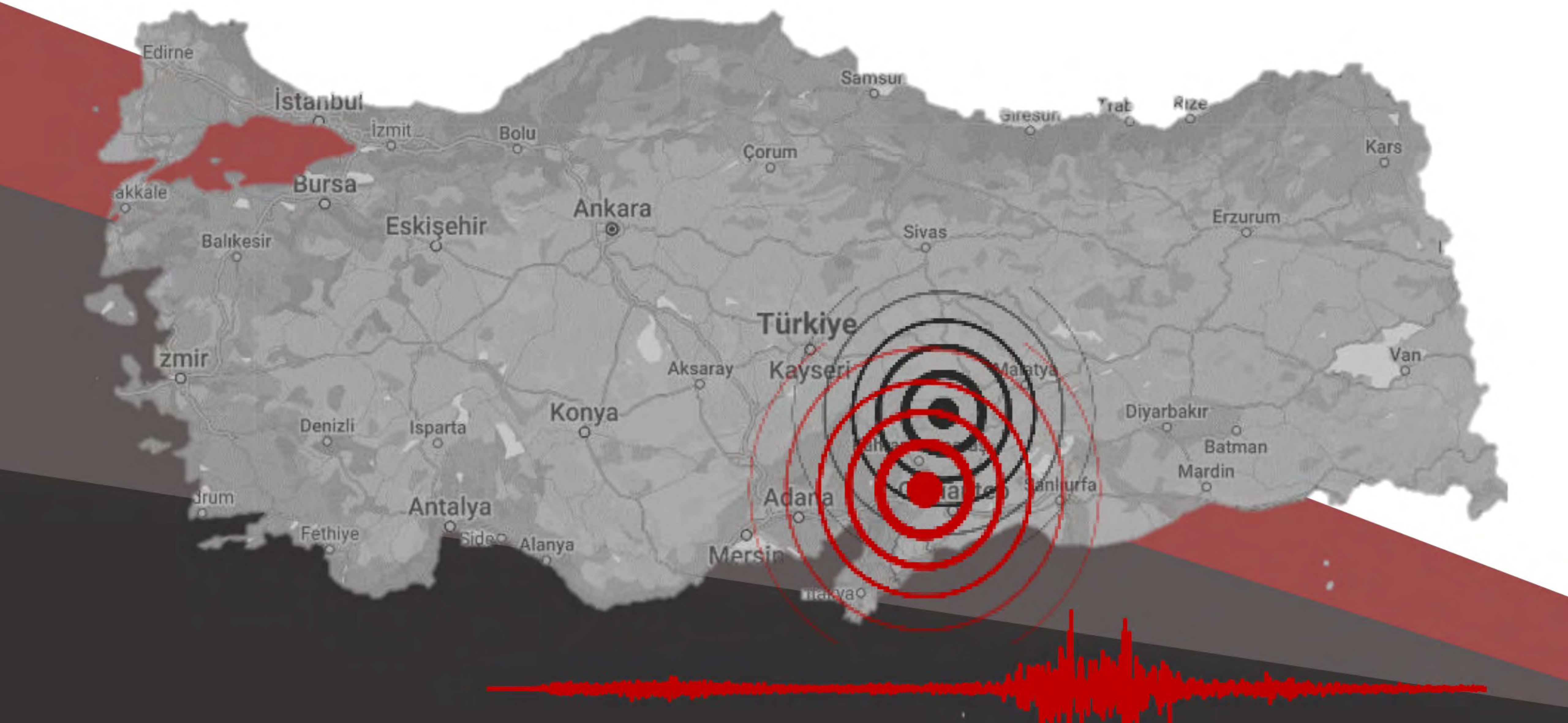
engineering.ubc.ca/COA

Opening Remarks

Mr. Hüseyin Emrah Kurt, General Consul of Türkiye

1. Introduction

Tony T.Y. Yang, Ph.D., P.Eng., F.CAE, Professor, UBC
Alemdar Bayraktar, Visiting Professor, UBC



Dedicated to the lives lost during the 2023 Türkiye Earthquake
& the effort to mitigate lives lost in future earthquakes.

Team:

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Acknowledgement:

UBC APSC

SEABC certificate program

CAE

THE UNIVERSITY OF BRITISH COLUMBIA
Engineering
Faculty of Applied Science

STRUCTURAL ENGINEERS ASSOCIATION
SEA
BRITISH COLUMBIA

Certificate in Structural Engineering Program

CAEES ACGPS

All local contacts in Türkiye:

Ali Gemci, Director of Urban Planning of Onikişubat Municipality; Ali Gül, Headman of Hacilar Village; Ali Osman Coşkun, Hüseyin Sünnetçioğlu, Abdulmutalip Barubay, Sedat Humartekin in BRY and GNR Altyapı Inc.; Alpay Atmaca, Engineer in Osmaniye State Hospital; Bülent Haksal, Director of Disaster Coordination of Gaziantep Municipality in Nurdağ; Eflahun Yıkıcı, Guard in Kartalkaya Dam in Pazarcık; Engin Özer, The deputy mayor of Antakya Municipality; Enver Kaya, Controller in the Kartalkaya Dam; Erdoğan Emrah Hatunoğlu, Director of Foreign Relations of Kahramanmaraş Municipality; Halil Satıcı, Manager of Social Affairs of Gaziantep Municipality in Nurdağ; Hasan Ay, District Director of National Education in Kırıkhan; H. Abdullah Dinç, Head of Industrial Vocational High School in Kırıkhan; İbrahim Hızyolu, Director of Disaster Coordination of Gaziantep Municipality in Islahiye; Kemal Topçu, Head of 75. Yıl Kindergarten in Kırıkhan; M. Fatih Tosyalı, Mayor of İskenderun Municipality; Metin Çiftçi, Site Manager of the Tunnel and Bridge in Gölbaşı; Muharrem S. Bilgiç, Project Coordinator in Intek Inc. in Islahiye; Mürsel Koçer, Head of Osmaniye State Hospital; Rüstem Keleş, General Secretary of Kahramanmaraş Municipality; Sait Bayraktar, District Director of National Education in Hassa; Osman Tuğrul Adıgüzel, Head of Bahçe High School in Bahçe; Özgür İspir, Representative of Chamber of Civil Engineering in Elbistan; Uğur Pekmez, Pekmez Inc. in Kahramanmaraş; Uğur Yücel, Architect in Gölbaşı; Yusuf Dedeoğlu, Head of Hacılar Middle School in Hassa;

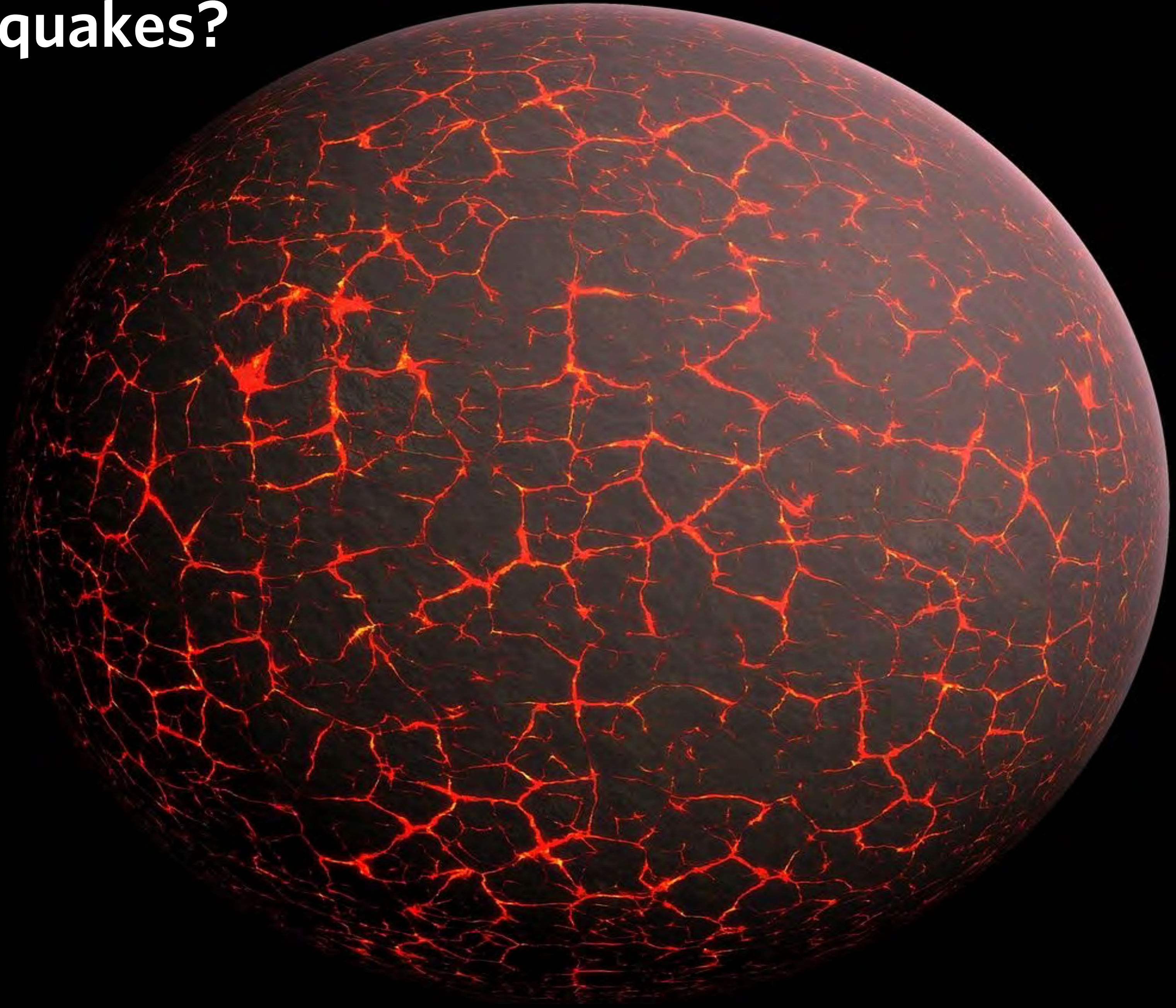
Why earthquakes?

- Earth was formed about 4.5 billion years ago.

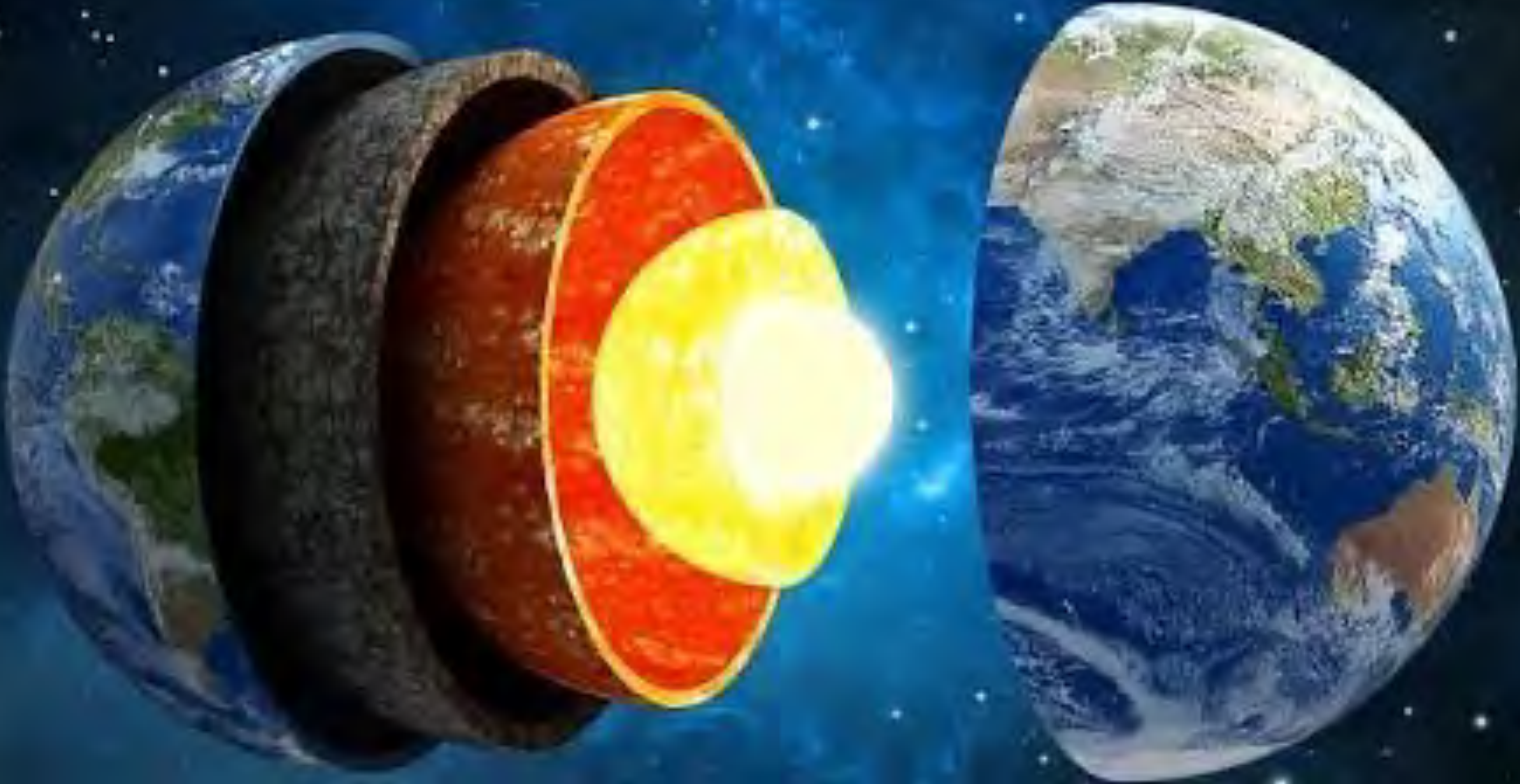
Why earthquakes?

National Geographic

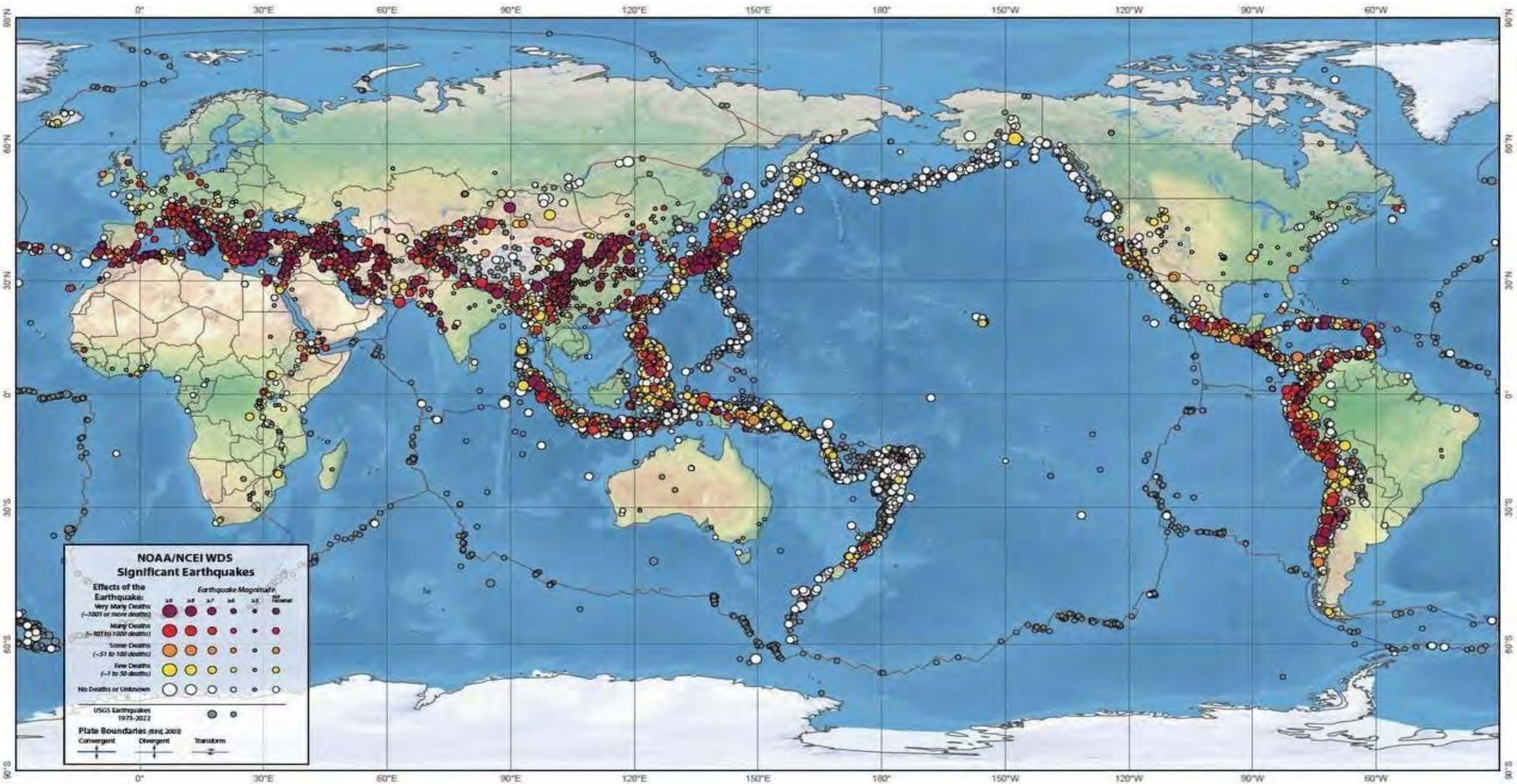
Why earthquakes?



Why earthquakes?



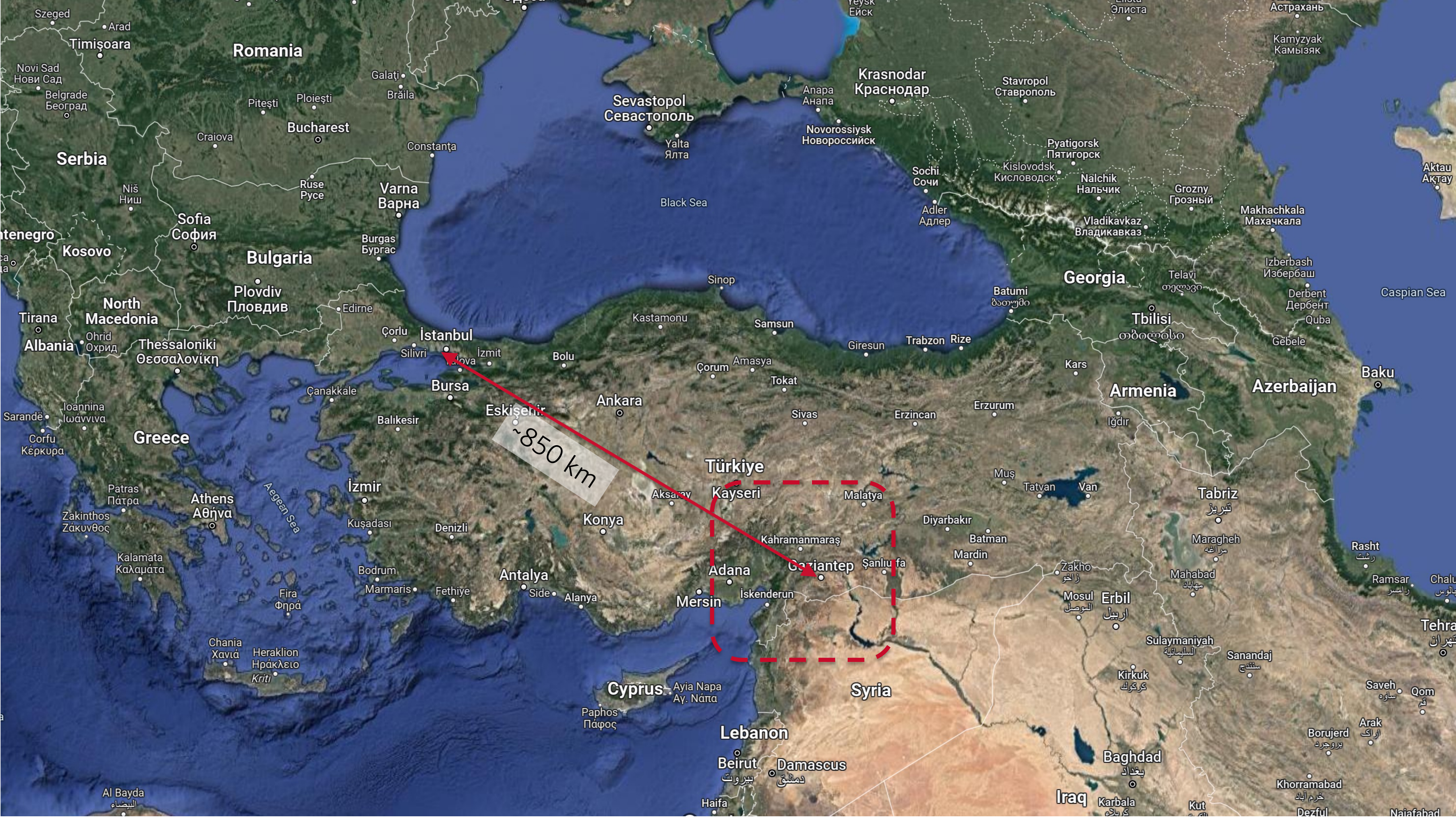
Past earthquakes:

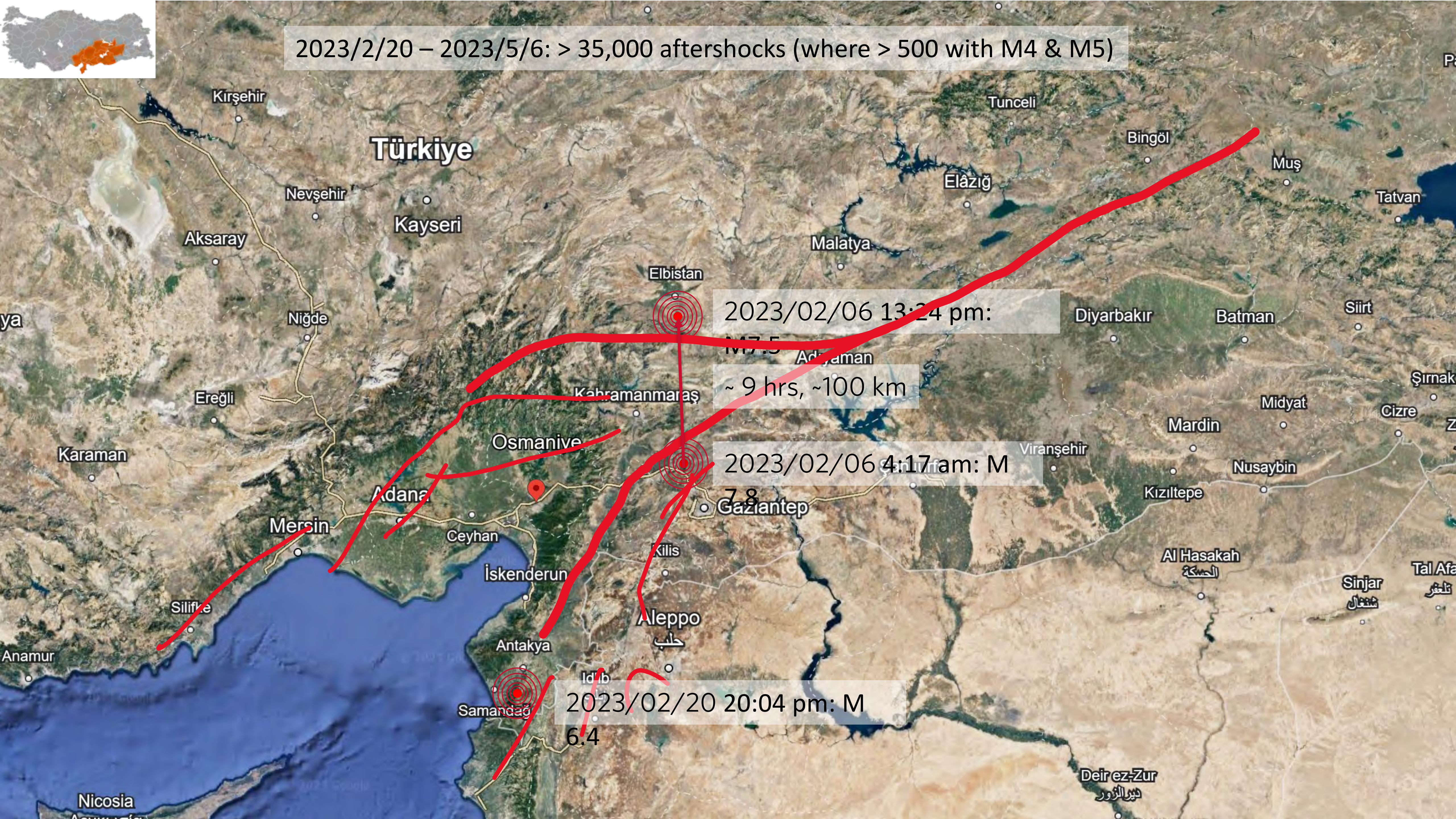


Patterson Cylindrical Projection

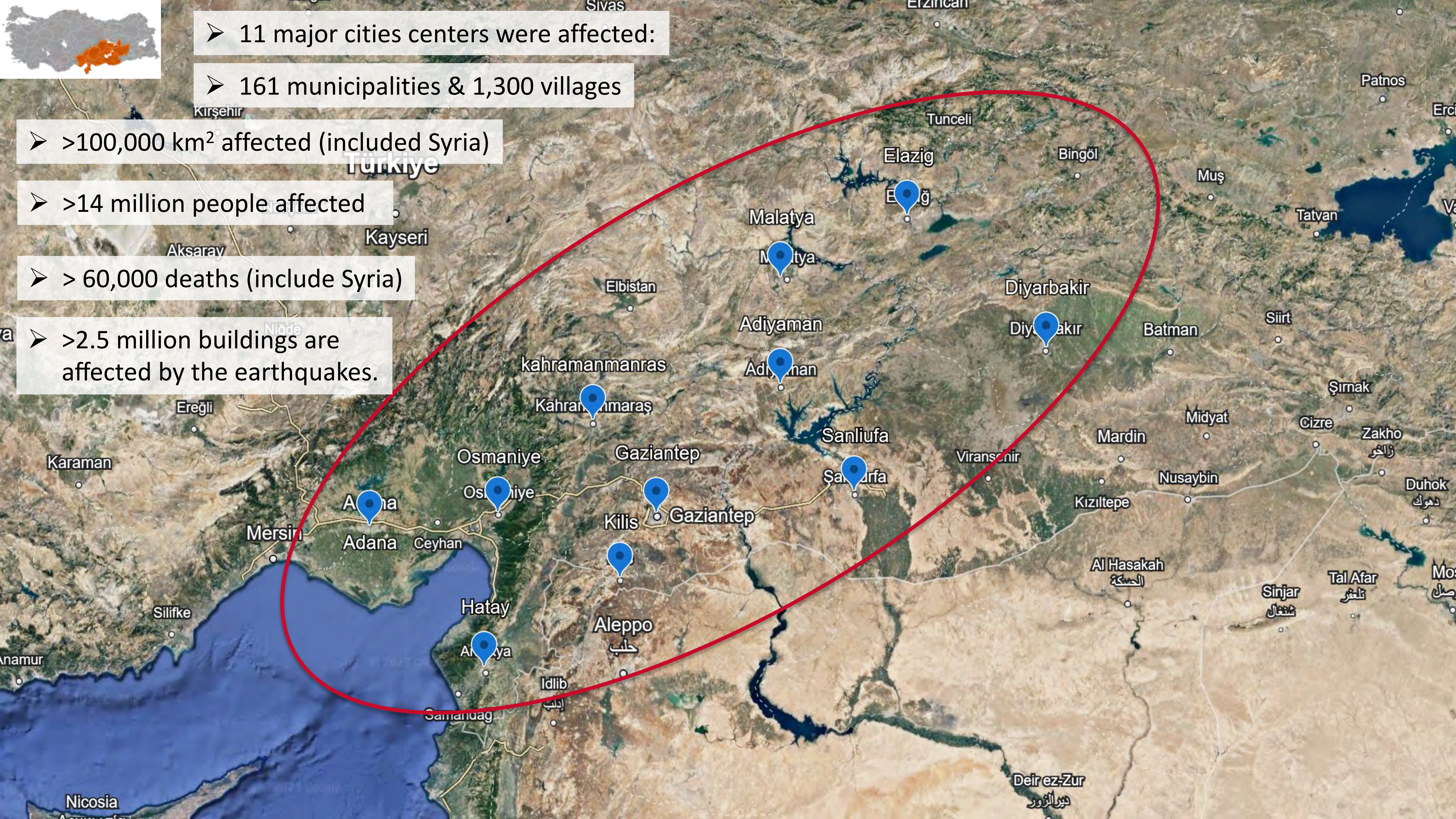
Symbol drawing order: more deaths on top of fewer deaths; smaller magnitude earthquakes on top of larger magnitude earthquakes.

March 2022


~850 km
Romania
Serbia
Bulgaria
Kosovo
North Macedonia
Albania
Greece
Türkiye
Georgia
Armenia
Azerbaijan
Syria
Lebanon
Iraq
Cyprus
Black Sea
Caspian Sea
Aegean Sea
İstanbul
Bursa
Eskişehir
Ankara
İzmir
Konya
Antalya
Kayseri
Malatya
Kahramanmaraş
Gaziantep
Şanlıurfa
Adana
Mersin
İskenderun
Diyarbakır
Batman
Mardin
Sivas
Erzincan
Erzurum
Samsun
Sinop
Trabzon
Tbilisi
Baku
Bucharest
Sofia
Athens
Beirut
Damascus
Baghdad
Mosul
Erbil
Tabriz
Krasnodar
Sevastopol


2023/2/20 – 2023/5/6: > 35,000 aftershocks (where > 500 with M4 & M5)
2023/02/06 13:24 pm: M7.5
~ 9 hrs, ~100 km
2023/02/06 4:17 am: M 7.8
2023/02/20 20:04 pm: M 6.4
Türkiye
Kırşehir
Nevşehir
Kayseri
Aksaray
Niğde
Ereğli
Karaman
Mersin
Adana
Ceyhan
Osmaniye
Kahramanmaraş
Elbistan
Malatya
Elâzığ
Tunceli
Bingöl
Muş
Tatvan
Diyarbakır
Batman
Siirt
Şırnak
Midyat
Mardin
Cizre
Viranşehir
Nusaybin
Kızıltepe
Gaziantep
Kilis
İskenderun
Aleppo
Antakya
Samandağ
Silifke
Anamur
Al Hasakah
Sinjar
Deir ez-Zur
Nicosia

- 11 major cities centers were affected:
- 161 municipalities & 1,300 villages
- >100,000 km^2 affected (included Syria)
- >14 million people affected
- > 60,000 deaths (include Syria)
- >2.5 million buildings are affected by the earthquakes.




Hatay
Population: 1.6 million

Hatay

Kahramanmaraş:
Population: 1.1 million

Kahramanmaraş


Kahramanmaraş

Adıyaman
Population: 632,148

Adıyaman

Osmaniye
Population: 559,405

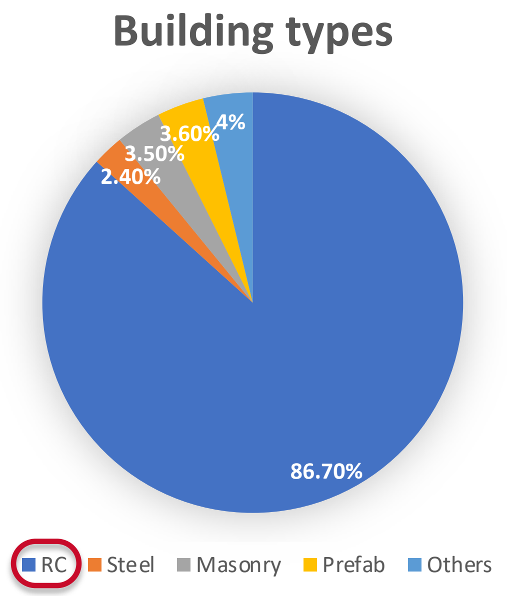
Osmaniye

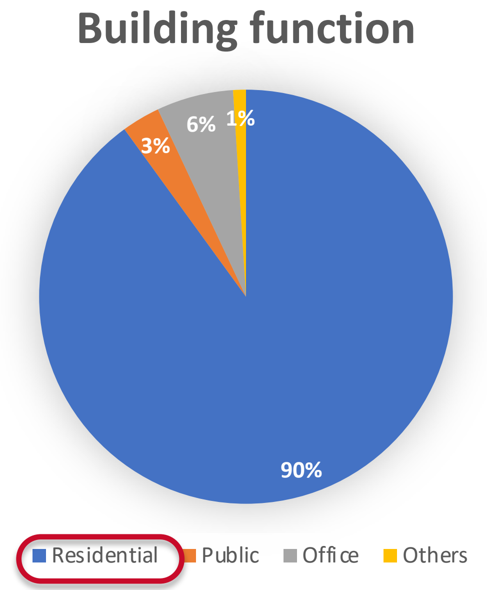
Building information:

Total building inventory: 2.5 million

Province	Building construction year (%)			
	1980 or before	1981-2000	2001 or after	unknown
Adana	13.0	34.8	38.7	13.5
Adıyaman	8.7	23.6	52.3	15.4
Diyarbakır	6.5	26.6	57.1	8.8
Elazığ	10.0	23.6	52.8	13.6
Gaziantep	6.6	25.9	51.6	15.9
Hatay	13.5	32.6	50.0	3.9
Malatya	11.7	26.9	58.1	3.3
Kahramanmaraş	11.2	21.7	52.3	14.9
Kilis	14.0	28.1	48.4	9.5
Osmaniye	10.5	25.7	46.5	17.3
Şanlıurfa	5.5	18.5	61.0	14.9
Total - 11 Cities	10.0	27.6	51.1	11.3
Total Türkiye	12.6	30.9	47.4	9.1

Source: SBB Report





Building damage information:

As of March 6th 2023

	Total Number of Urgent + Severely Damaged + Collapsed Houses	Number of Moderately Damaged Houses	Number of Lightly Damaged Houses
Adana	2,952	11,768	71,072
Adıyaman	56,256	18,715	72,729
Diyarbakır	8,602	11,209	113,223
Elazığ	10,156	15,22	31,151
Gaziantep	29,155	20,251	236,497
Kahramanmaraş	99,326	17,887	161,137
Malatya	71,519	12,801	107,765
Hatay	215,255	25,957	189,317
Kilis	2,514	1,303	27,969
Osmaniye	16,111	4,122	69,466
Şanlıurfa	6,163	6,041	199,401
Total	518,009	131,577	1,279,727

Source: MoEUCC

	billion USD
Damage[1]	
Reconstruction Cost of Unusable Housing	54.7
Reconstruction Cost of Unusable Barns	0.2
Reconstruction Cost of Unusable Businesses	2
Repair Assistance for Lightly Damaged Housing[2]	0.7
Furniture Cost in Unusable Housing	3.1
Total Damage	60.7
Loss	
Debris Removal and Cleaning Cost[3]	1.6
Household Payments for Housing with Severe Damage + Requiring Urgent Demolition + Moderate Damage	0.3
Temporary Accommodation	1.3
Meal and Accommodation	2.1
Total Loss	5.3
Total Damage and Loss	66

In light of this data, 2,273,551 people were directly faced with accommodation problem after the earthquake.

Besides, 14,314 farm barns were determined as severely damaged, demolished, or requiring urgent demolition in the earthquake-affected region. The total damage to farm and businesses 2.2 billion USD.

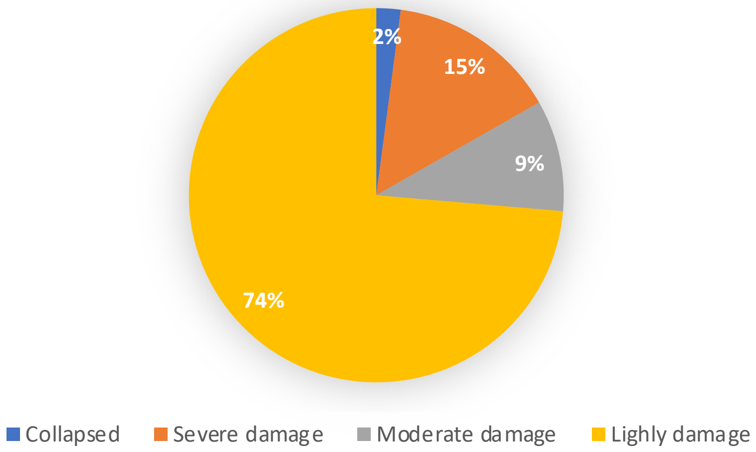
Education system:

11,699 educational institutions (21% of Tu̇rkiye). The institutions have 20,340 independent buildings, including various annexes such as lodging houses, sports halls, and workshops.

Provinces	Kindergarten	Primary School	Secondary School	High School	Teachers' Guest-house	Public Education Centre	Vocational Education Centre	Special Education Practice School + CRC	Total
Adana	157	490	321	220	16	20	5	30	1,259
Adıyaman	78	402	215	88	7	9	4	21	824
Diyarbakır	129	851	419	179	21	17	5	23	1,644
Gaziantep	233	572	352	212	9	11	7	30	1,426
Elazığ	36	185	127	72	8	10	5	8	451
Hatay	165	558	415	160	12	15	5	38	1,368
Kahramanmaraş	69	440	295	145	8	12	4	23	996
Kilis	20	98	42	25	1	5	2	9	202
Malatya	60	272	210	111	7	13	1	12	686
Osmaniye	42	164	113	63	3	7	4	17	413
Şanlıurfa	179	1260	712	219	9	13	5	33	2,430
Total Region	1168	5292	3221	1494	101	132	47	244	11,699

Source: MoNE

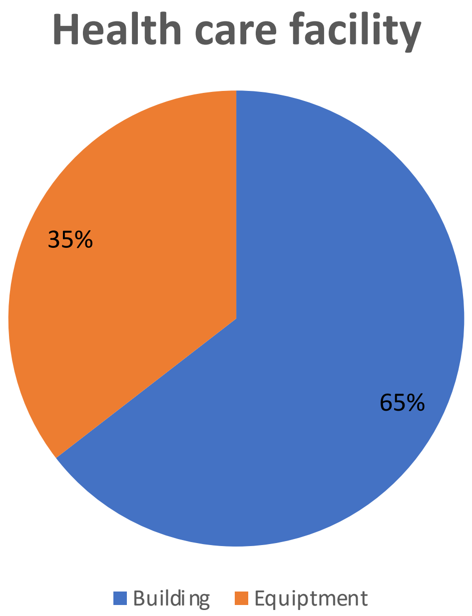
School buildings (8,162 out of 20,340)



Loss for the education system: 2.11 billion USD.

Health care system:

- 116 secondary- and tertiary-level healthcare facilities (12.5% of Türkiye).
- 2503 primary-level healthcare facilities (17.5% of Türkiye).
- Total patient bed capacity 7,806.
- 31.3 beds/ 10,000 people (< average of Türkiye = 32.3 beds / 10,000 people)

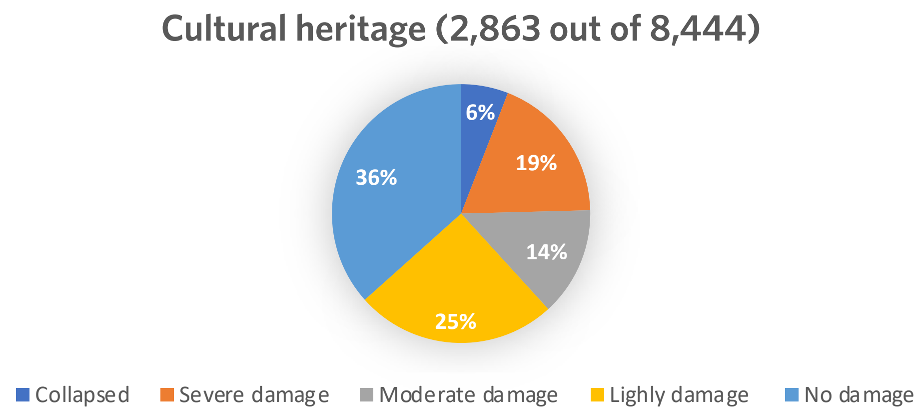


Total loss to the health sector: 4.3 billion USD

Cultural heritage:

Ministry of Culture (MoCT) owns 8,444 inventory of cultural heritage

	Protected streets	Monuments	Administrative building	Culture structure	Military structures	Industry and commercial structures	Religious structures	Cemeteries	Civil architectures	Ruins	Total
Adana	3	1	54	143	39	85	75	61	320	95	876
Adıyaman	-	2	2	46	6	7	54	14	8	25	164
Diyarbakır	-	-	70	261	11	4	153	93	606	22	1220
Elazığ	-	1	36	89	5	-	72	23	80	9	315
Gaziantep	-	4	36	95	6	22	77	36	797	8	1081
Hatay	2	3	50	144	16	53	114	88	576	62	1108
Kahramanmaraş	-	9	5	58	25	41	46	33	327	17	561
Kilis	-	2	5	28	5	13	35	4	356	4	452
Malatya	-	4	23	119	5	14	99	37	454	10	765
Osmaniye	-	1	13	24	8	1	19	28	45	26	165
Şanlıurfa	14	1	26	155	7	13	120	76	1301	24	1737
Total	19	28	320	1162	133	253	864	493	4870	302	8444



Total loss to the culture heritage:
489 million USD

Social and Economical impacts:

- 11 major city centres and 14 million people were affected.
- A total of 50,783 people lost their lives, and 115,353 people were injured.
- The number of collapsed or urgently demolished buildings in the region is reported as 58,039, while the number of severely damaged buildings is 205,534 (May 2, 2023).
- Housing sector: 56.9 billion USD
- Deconstruction sector: 12.9 billion USD
- Private industries (including manufacturing, energy, communications, tourism, healthcare, education sectors): 11.8 billion USD
- Other insurance section
- Total economy loss: 103.6 billion USD (~9% of GDP of Türkiye in 2023)

TIME	TITLE	SPEAKER(s)
1:20 - 1:40	Seismology and Geotechnical Effects	Alemdar Bayraktar, *Visiting Professor, UBC (Remote)* Keshab Sharma, *Geotechnical Engineer, BGC Engineering Inc. (Remote)* Carlos Ventura, *Professor, UBC*
1:40 - 2:00	Building Codes and Construction Practices	Tony Yang, *Professor, UBC*
2:00 - 2:20	Break	
2:20 - 2:40	Performance of Residential Buildings	Svetlana Brzev, *Adjunct Professor, UBC*
2:40 - 3:00	Performance of Schools Buildings	Bishnu Pandey, *Instructor, BCIT* Allison Chen, *Practice Advisor, EGBC*
3:00 - 3:20	Performance of Health Care Facilities	Jeffrey Salmon, *Structural Engineer, Ausenco*
3:20 - 3:40	Break	
3:40 - 4:20	Preparedness, Response, and Recovery	Allison Chen, *Practice Advisor, EGBC* Jeffrey Salmon, *Structural Engineer, Ausenco* Serife Ozata, *Research, teaching assistant, Ahi Evran University (Remote)*
4:20 - 4:50	Panel Discussion	
4:50 - 5:00	Concluding Remarks	Tony Yang, *Professor, UBC*

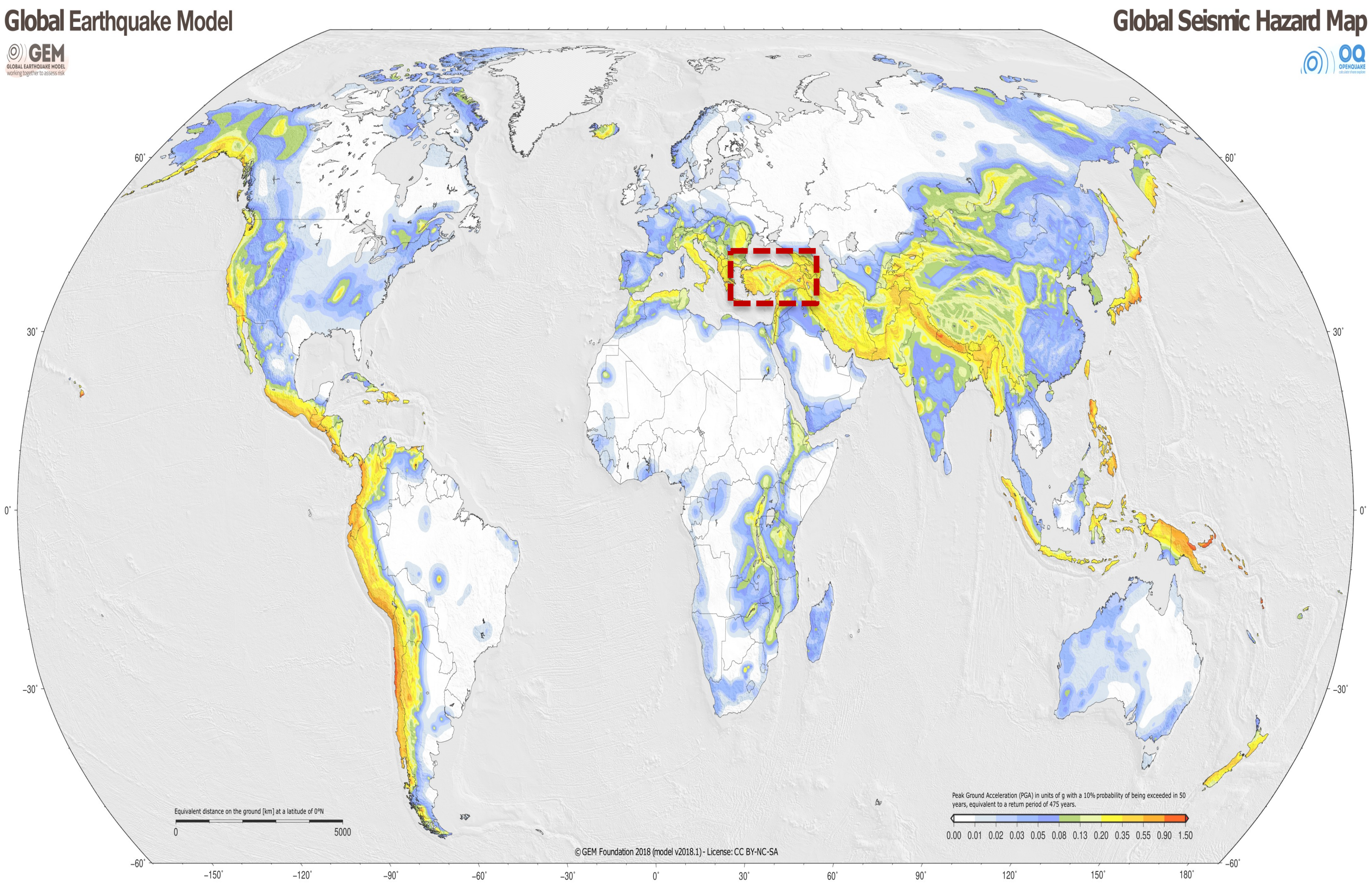
2.
Seismology and Geotechnical Effects

Alemdar Bayraktar, Visiting Professor, UBC Civil Engineering Department
Keshab Sharma, Geotechnical Engineer, BGC Engineering Inc.
Carlos E. Ventura, Professor, UBC Civil Engineering Department

Content

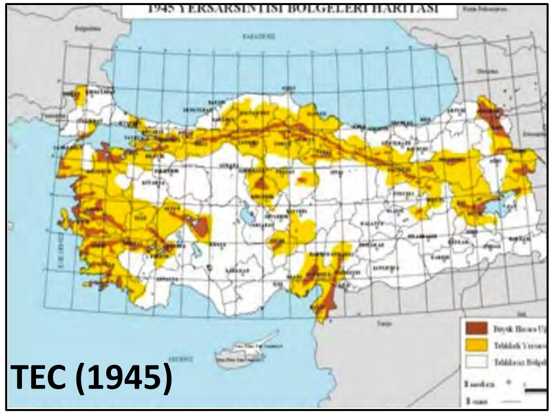
- Global and Local Seismic Hazard Maps of Turkey
- Active Faults of Turkey
- Historical Seismicity of Turkey
- Main and Aftershocks of the February 2023 Kahramanmaraş Earthquakes
- Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes
- Conclusions

Global and Local Seismic Hazard Maps of Turkey

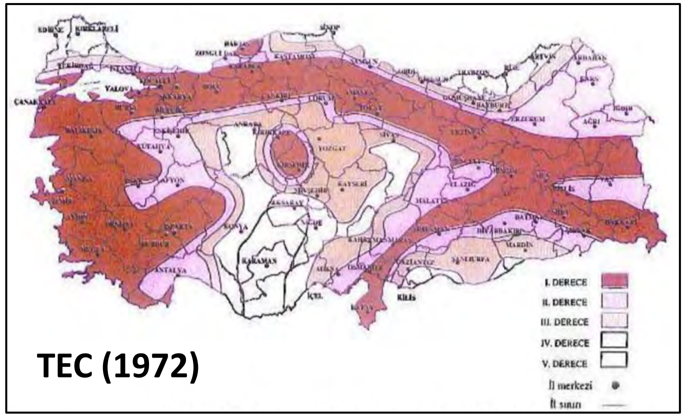


Turkey is located in one of the most seismically active regions in the world.

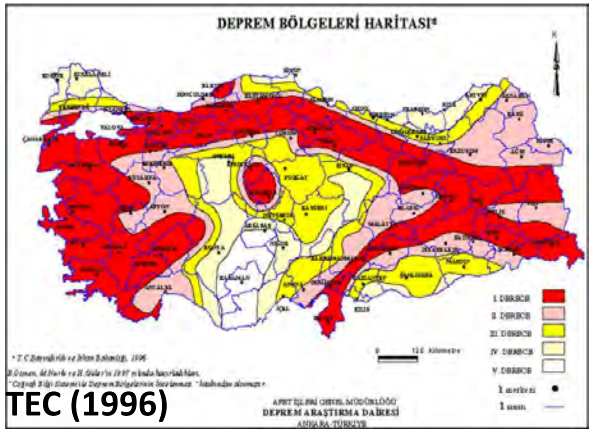
Global and Local Seismic Hazard Maps of Turkey


TEC (1945)


TEC (1963)

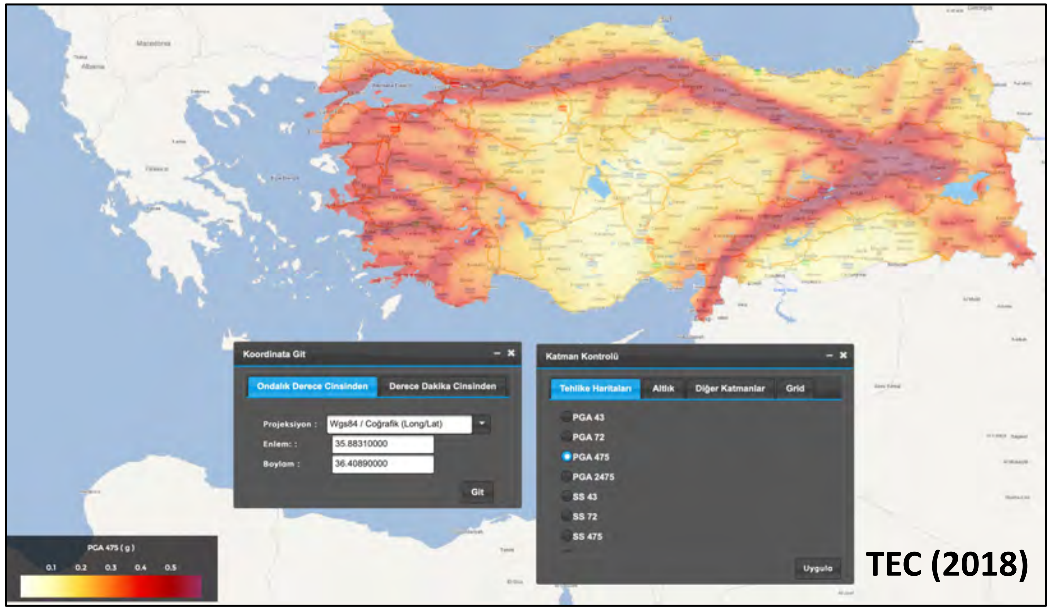


TEC (1972)



TEC (1996)

from AFAD



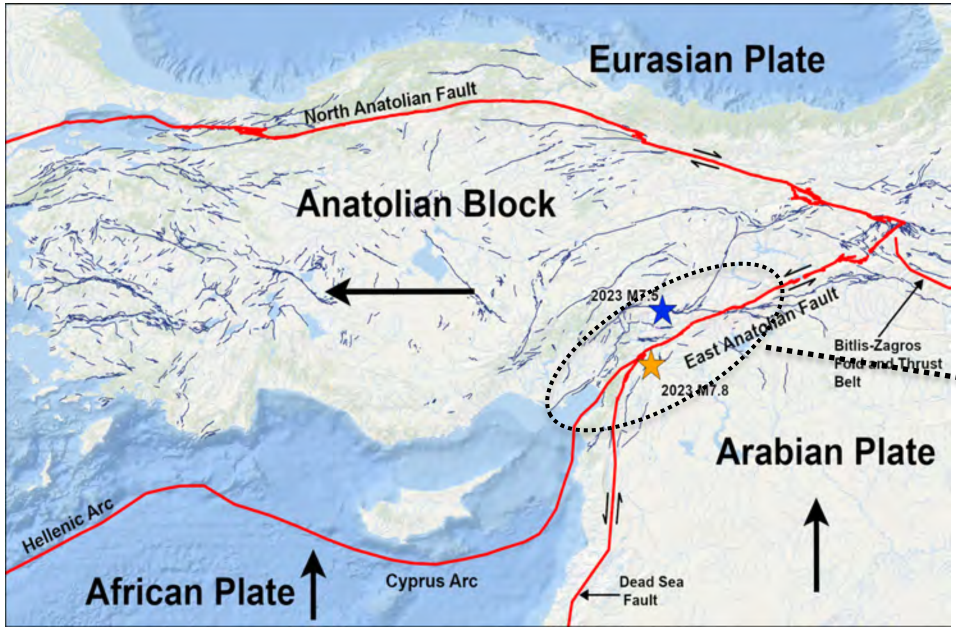
TEC (2018)

from AFAD

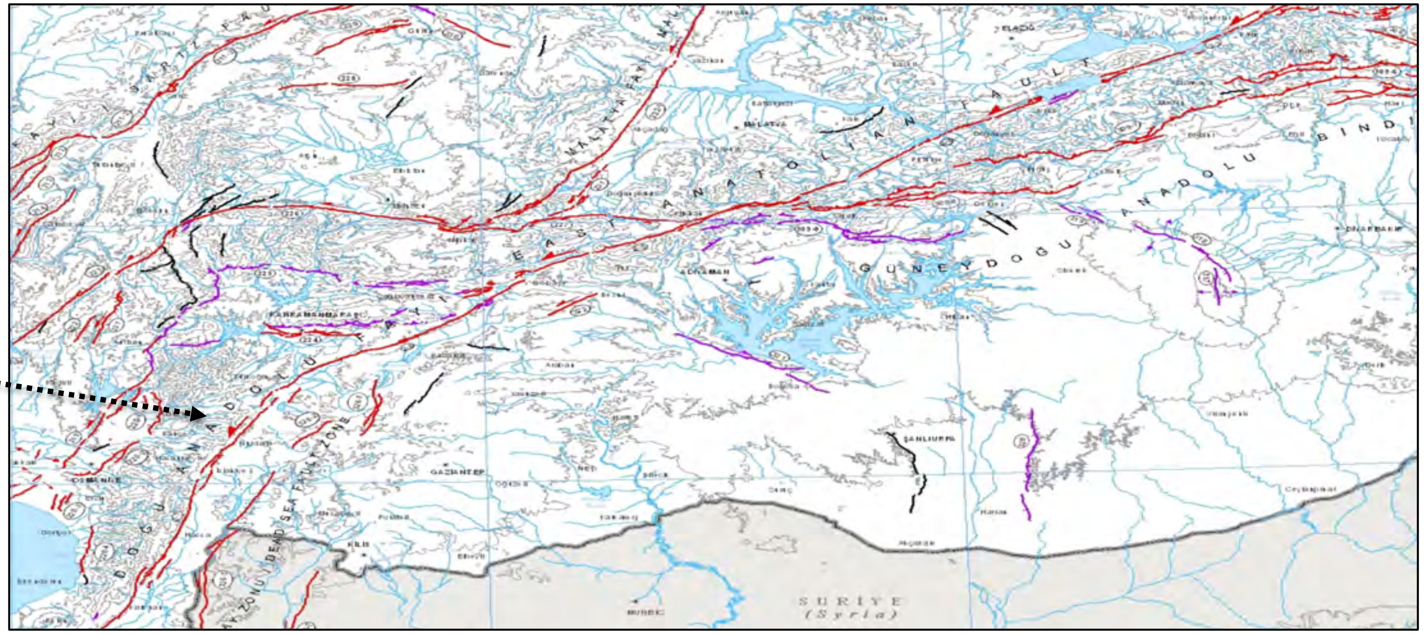
The seismicity parameters are defined depending on the geographic location in TEC (2018) for the four seismic levels as follows:

i) DD-1: 2 percent probability of exceedance within a 50-year period having a return period of 2475 years
ii) DD-2: 10 percent probability of exceedance within a 50-year period having a return period of 475 years
iii) DD-3: A earthquake with 50 percent probability of exceedance within a 50-year period having a return period of 72 years
iv) DD-4: A earthquake with 68 percent probability of exceedance within a 50-year period having a return period of 43 years

Active Faults of Turkey



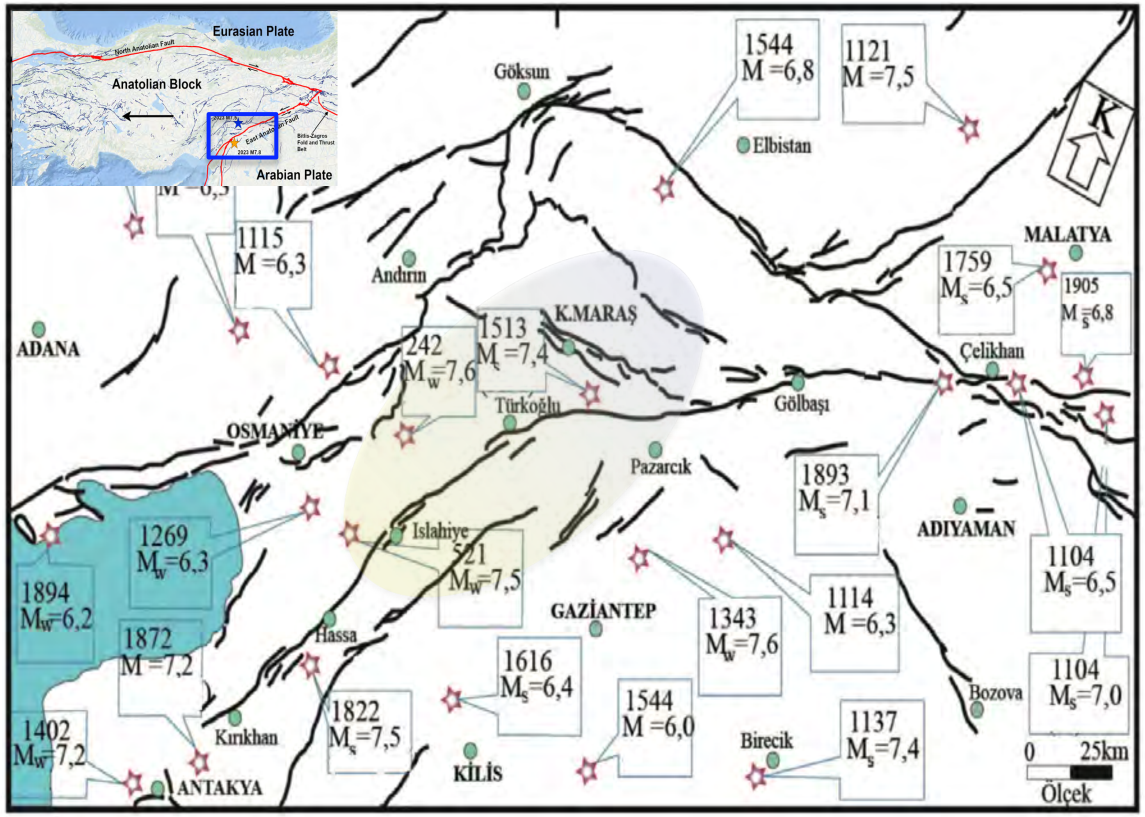
from USGS (2023)



from Emre et al. (2013), MTA (2023)

- Turkey is located between the Eurasian Plate in the north and the African-Arabian Plates in the south.
- The Arabian plate is moving towards the northeast with respect to the Anatolian plate at approximately 10-11 mm/yr.
- Two main major faults of Turkey are North Anatolian Fault (NAF) and East Anatolian Fault (EAF). The 2023 Kahramanmaraş earthquakes occurred on the EAF.
- The north Anatolian fault lies between Karlıova and Istanbul.
- The fault mechanism of the East Anatolian Fault Zone (EAFZ), which is about 450km long, is NE-trending left-lateral strike-slip fault system that lies between Karlıova and Hatay.

Historical Seismicity of Turkey



The last destructive earthquake in the city of Kahramanmaraş and its surroundings occurred approximately 500 years ago. A destructive earthquake has been anticipated in this area for a long time.

- The most damaging prior earthquakes in Turkey since the beginning of the 20th century are the 1939 M7.8 Erzincan and the 1999 M7.6 İzmit (Kocaeli) earthquakes, which occurred on the North Anatolian Fault.

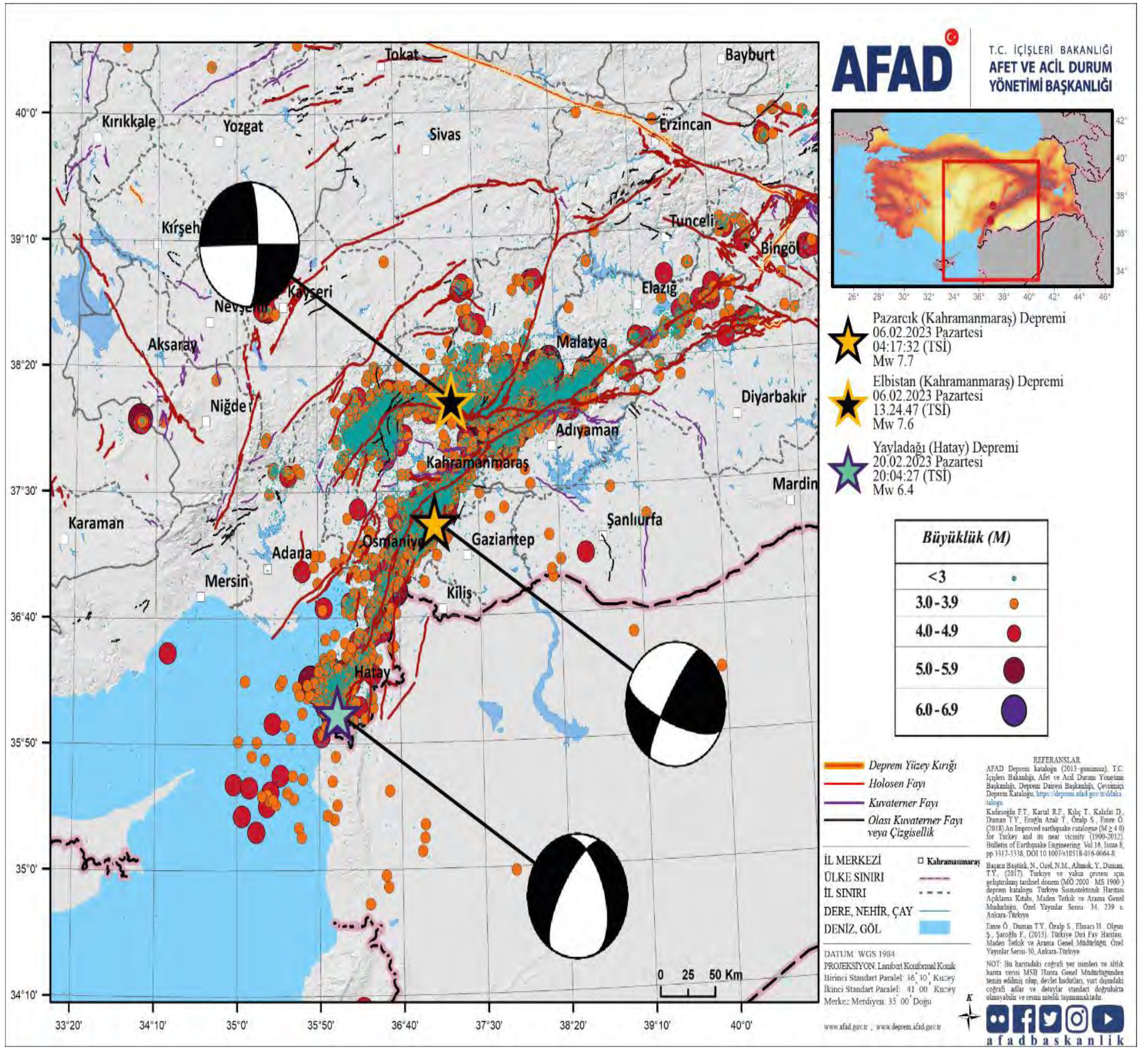
- The 1939 Erzincan earthquake killed more than 32,000 people and injured more than 100,000, whereas the 1999 Izmit (Kocaeli) earthquake killed more than 17,000 and injured more than 50,000.

- From the year 2000 to the February 6, 2023, Kahramanmaraş earthquakes, the following destructive earthquakes occurred on the East Anatolian Fault:
  - On May 1, 2003, in Bingöl with a magnitude of 6.3
  - On March 14, 2005, in Karlıova (Bingöl) (M5.8)
  - On February 21, 2007, in Doğanyol (Malatya) (M5.7)
  - On March 8, 2010, in Kovancılar (Elazığ) (M6.1)
  - On January 24, 2020, in Sivrice (Elazığ) (M6.8)
  - On June 14, 2020, in Karlıova (Bingöl) (M5.7)

Main and Aftershocks of the February 2023 Kahramanmaraş Earthquakes

Earthquake sequences with a back-to-back effect on structures

- On February 6, 2023, at 04:17 a.m. local time (01:17 GMT), Pazarcık-Kahramanmaraş earthquake **(M7.8)** with a depth of 8.6 km.
- **Ten minutes after the first mainshock,** an aftershock with **M6.6 and** a depth of 6.2 km occurred at Nurdağı-Gaziantep.
- **9 hours later**, a **M7.5** earthquake at Elbistan-Kahramanmaraş-Türkiye shook the region again, with a depth of 7.0 km.
- A **M6.4** in Yayladağ-Hatay on the EAF occurred on **February 20**, 2023 at 20:04 p.m. local , with a depth of 21.73km.
- There were **a total of 33,591 aftershocks** in the region between February 6 and May 6.
- Aftershocks had magnitudes ranging from 0.2 to 6.6. 48 had magnitudes between 5.0 and 6.0, and 2 had magnitudes between 6.0 and 7.0.



from AFAD (2023)

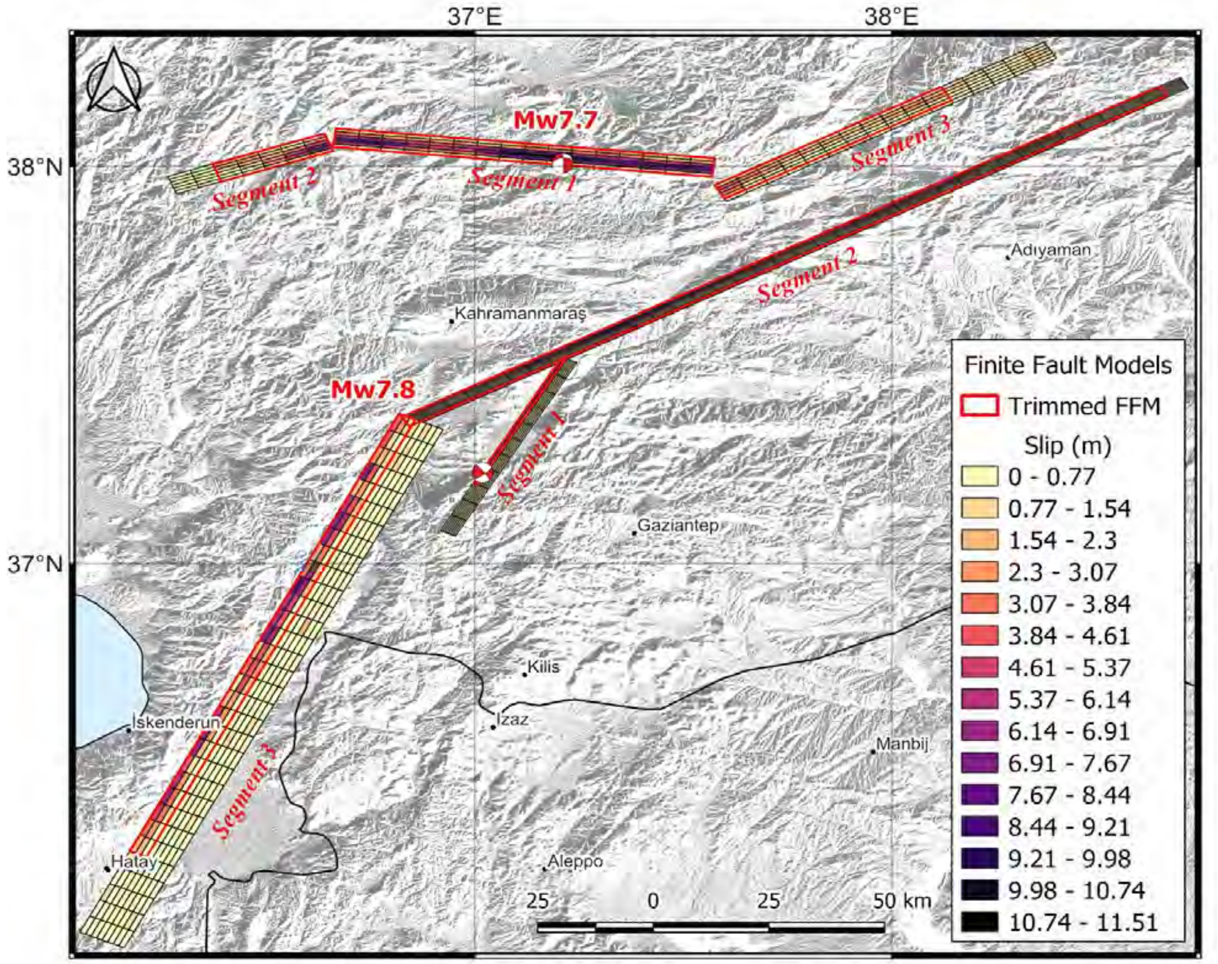
Main and Aftershocks of the February 2023 Kahramanmaraş Earthquakes

Multiple fault ruptures

- In the M7.7 Pazarcık earthquake, multiple fault segments associated with the East Anatolian Fault (**Narlı, Gölbaşı, Erkenek, and Amanos faults) ruptured** in a multi-segmented manner (AFAD, 2023).

- In the M7.6 Elbistan earthquake, it has been evaluated that both the **Çardak and Doğanşehir faults ruptured** simultaneously (AFAD, 2023).

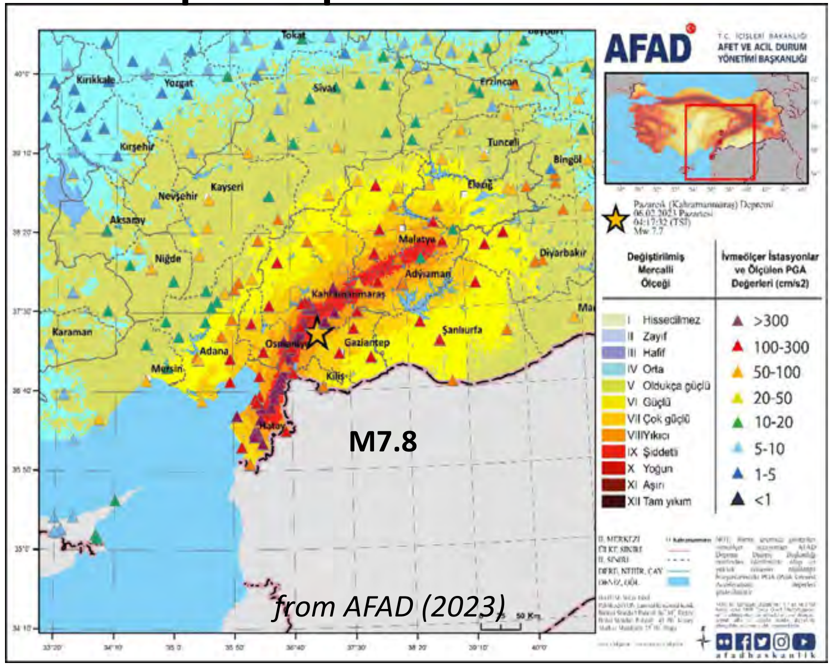
- After both earthquakes, surface deformations ranging from **centimeters to 4 meters** have been detected (AFAD, 2023).

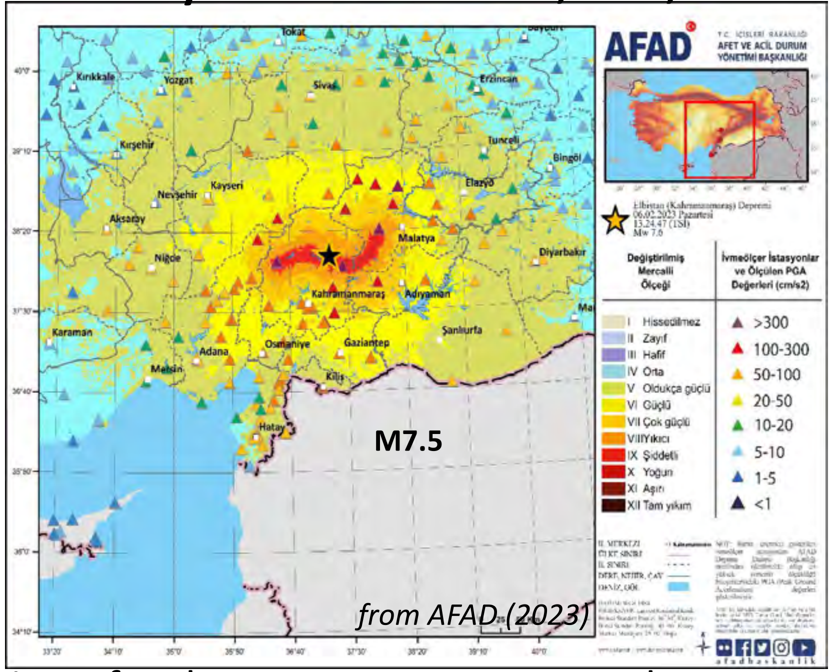


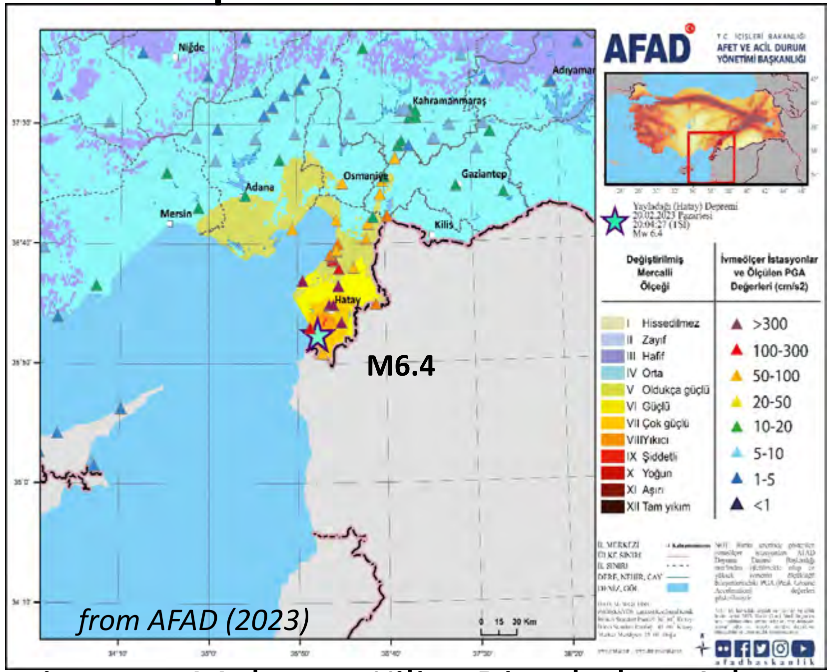
from USGS (2023) and EERI (2023)

Main and Aftershocks of the February 2023 Kahramanmaraş Earthquakes

Earthquake epicenters and fault lines near the city and town centers, and , and shallow earthquakes

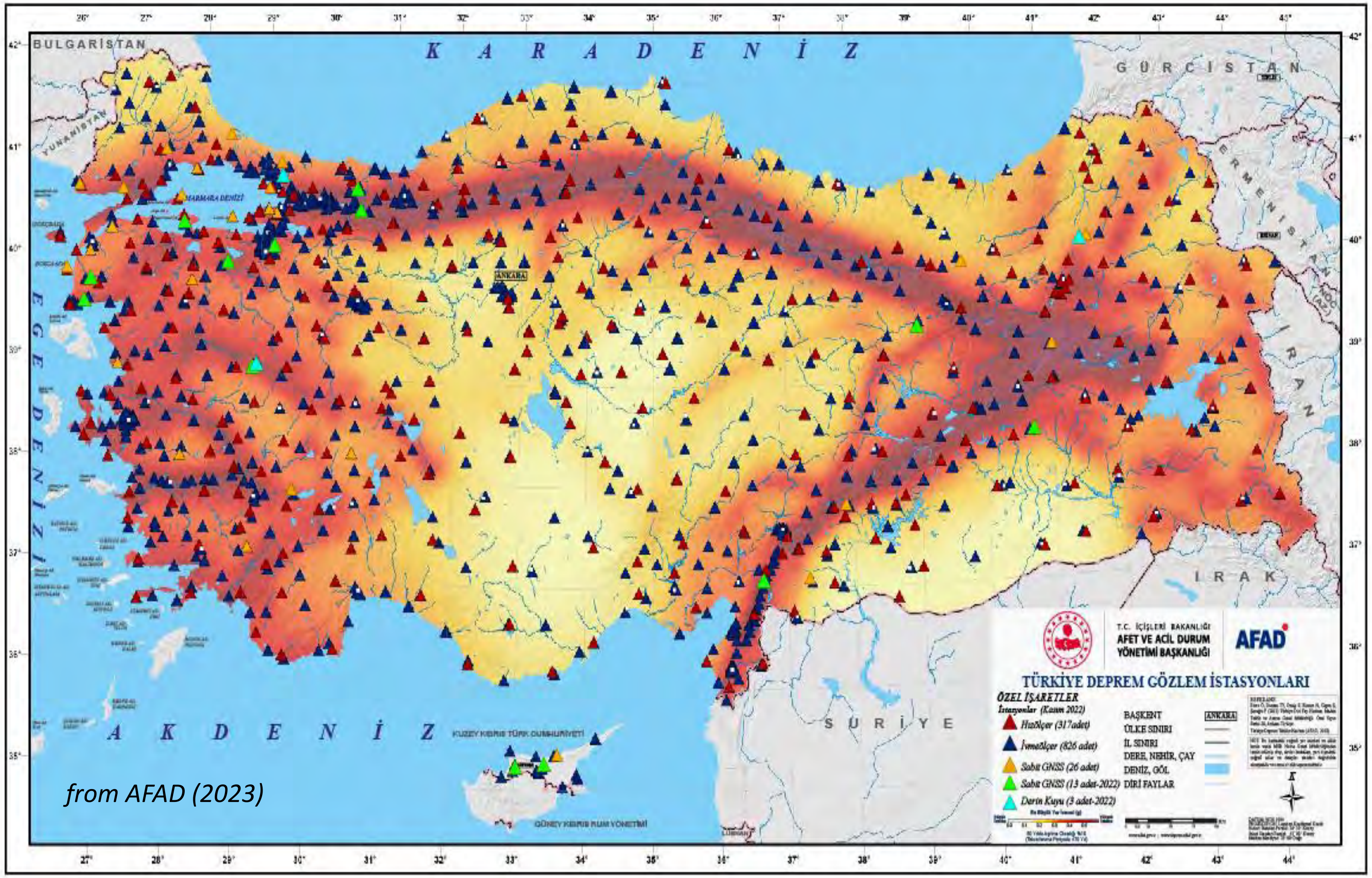






- The earthquakes mostly affected the cities of Kahramanmaraş, Hatay, Adıyaman, Gaziantep, Malatya, Kilis, Diyarbakır, Adana, Osmaniye, Şanlıurfa and Elazığ with residents of over 14 million, and north part of Syria.
- Due to the earthquakes the 2023 Kahramanmaraş earthquakes, a total of 50,783 people lost their lives, and 115,353 people were injured.
- According to the damage assessment dated May 2, 2023, from the Ministry of Environment, Urbanization, and Climate Change, the number of collapsed or urgently demolished buildings in the region is reported as 58,039, while the number of severely damaged buildings is 205,534.
- These figures exceed the losses experienced in the 1939 Erzincan earthquake (M7.9) and the 1999 Kocaeli earthquake (M7.6), which were the largest earthquakes in our country in this century.

Ground Motion Records from the February 2023 Kahramanmaraş Earthquakes

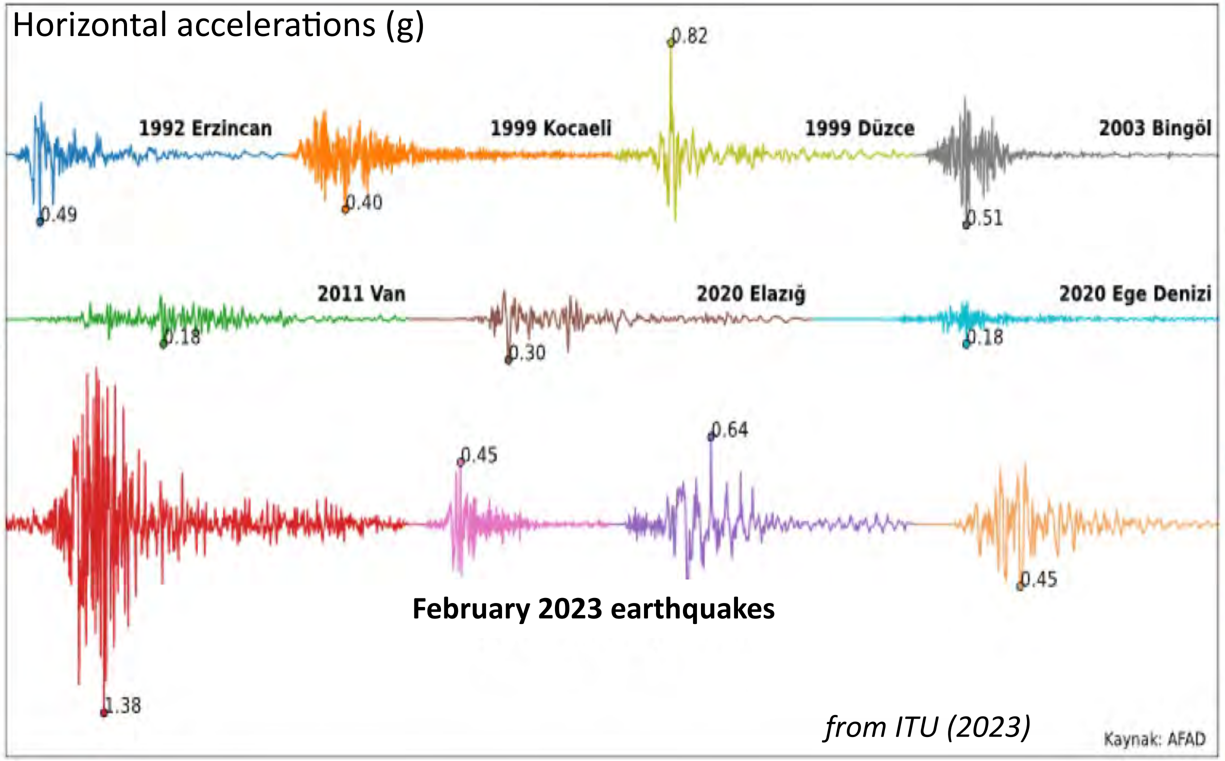


from AFAD (2023)

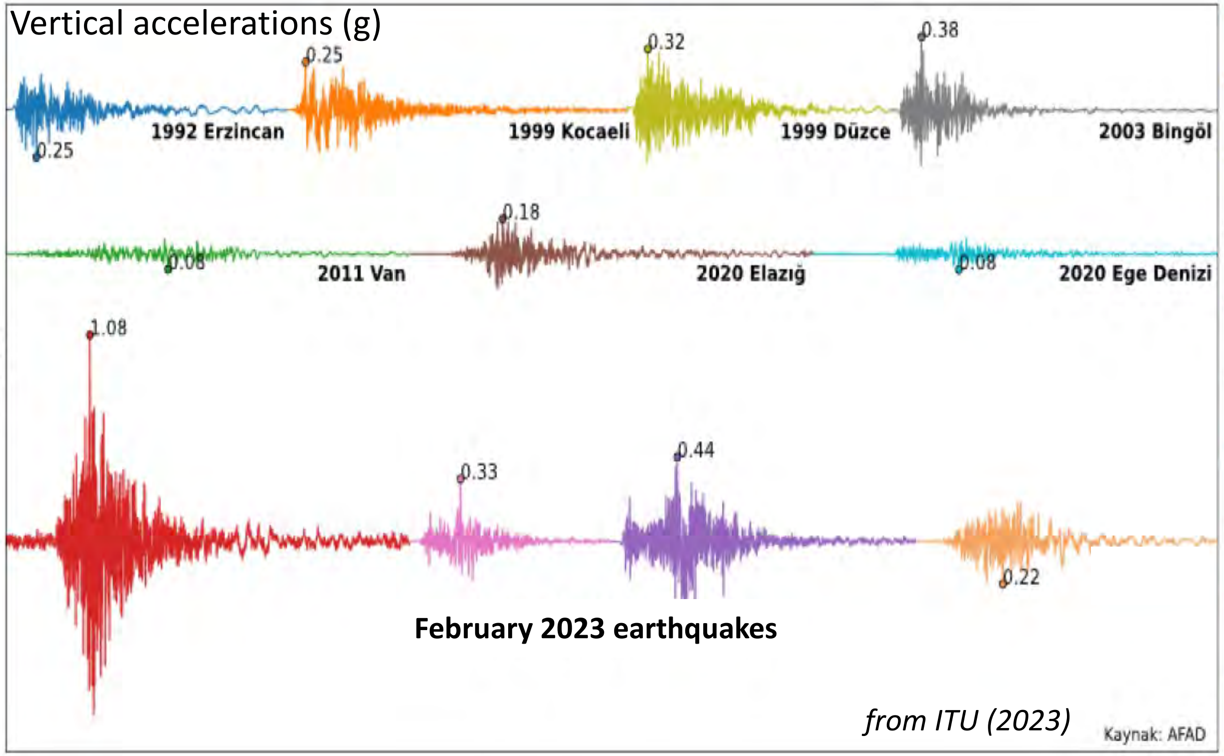
The strong ground motion data of the February 2023 Kahramanmaraş earthquakes recorded by the Turkish Accelerometric Database and Analysis System (TADAS) (https://tadas.afad.gov.tr), which is operated by AFAD (Disaster and Emergency Management Presidency) by using more than 800 strong motion stations in Turkey.

Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

Comparing horizontal and vertical PGAs with the previous earthquakes in Turkey



from ITU (2023)



from ITU (2023)

The peak horizontal and vertical ground acceleration values of the 2023 Kahramanmaraş earthquake are larger than the highest horizontal and vertical ground acceleration values of the 1999 Kocaeli and the other earthquakes in Turkey, respectively.

Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

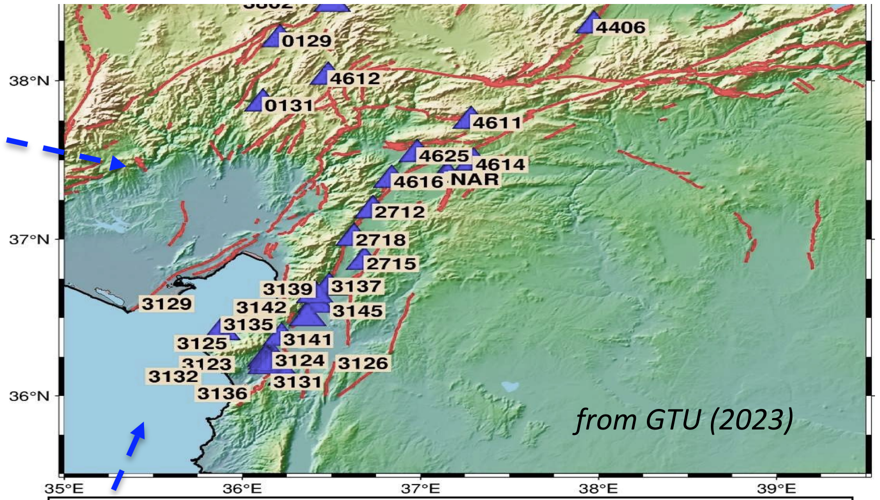
Recorded PGAs at selected stations during the M7.8 earthquake

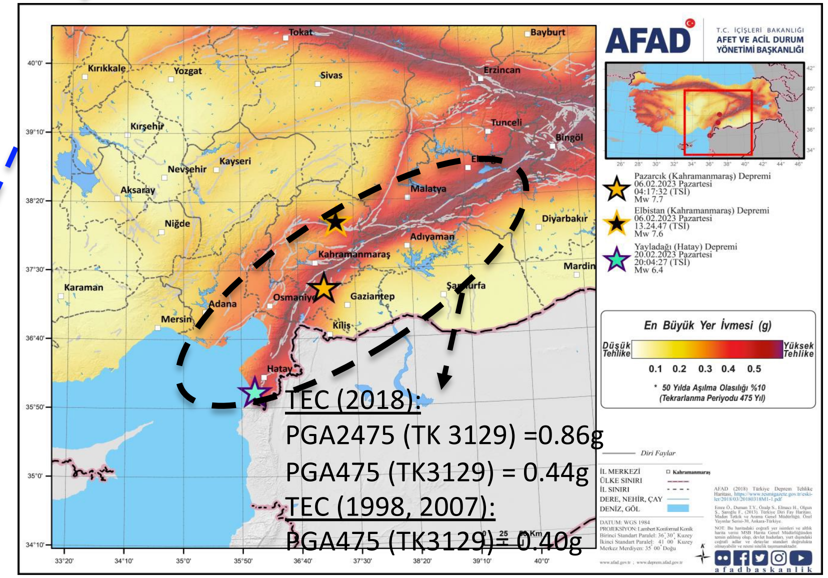
İstasyon Kodu	Boylam	Enlem	İl	İlçe	R_{jb} (km)	R_{rup} (km)	R_{epi} (km)	R_{hyp} (km)	$V_{s,30}$ (m/s)	Zemin Sınıfı	PGA_NS (cm/s²)	PGA_EW (cm/s2)	PGA_UD (cm/s²)
3129	36.1343	36.1912	Hatay	Defne	214.65	214.65	146.39	146.64	447.0	ZC	1350.49	1207.62	707.55
3126	36.1375	36.2202	Hatay	Antakya	211.96	211.96	143.54	143.80	350.0	ZD	1211.04	1030.18	1071.45
3141	36.2197	36.3726	Hatay	Antakya	194.26	194.26	125.42	125.71	338.0	ZD	961.12	868.82	722.66
3125	36.1326	36.2381	Hatay	Antakya	210.71	210.71	142.15	142.41	448.0	ZC	822.62	1121.95	1151.56
3135	35.8831	36.4089	Hatay	Arsuz	212.40	212.40	142.15	142.41	460.0	ZC	740.97	1372.07	588.97
2718	36.6266	37.0078	Gaziantep	İslahiye	22.76	22.76	48.30	49.06	-	-	702.42	644.97	585.79
3123	36.1597	36.2142	Hatay	Antakya	211.22	211.22	143.00	143.26	470.0	ZC	655.57	593.94	867.58
4616	36.8384	37.3755	Kahramanmaraş	Türkoğlu	81.78	81.78	20.54	22.27	390.0	ZC	652.76	502.87	397.27
3142	36.3661	36.4980	Hatay	Kırıkhan	175.15	175.15	106.49	106.84	539.0	ZC	646.63	749.51	505.89
NAR	37.1574	37.3919	Kahramanmaraş	Pazarcık	55.60	55.60	15.35	17.60	-	-	646.50	578.80	398.66
3145	36.4064	36.6454	Hatay	Kırıkhan	160.58	160.58	91.13	91.54	533.0	ZC	600.04	696.39	663.18
4615	37.1380	37.3868	Kahramanmaraş	Pazarcık	57.36	57.36	13.83	16.28	484.0	ZC	587.74	556.46	664.58
3139	36.4144	36.5838	Hatay	Kırıkhan	165.13	165.13	96.19	96.57	272.0	ZD	577.13	504.82	378.62
3124	36.1722	36.2387	Hatay	Antakya	208.40	208.40	140.11	140.37	283.0	ZD	572.63	638.32	578.08
2712	36.7328	37.1840	Gaziantep	Nurdağı	99.71	99.71	29.79	31.01	-	-	554.85	602.66	346.12
3136	36.2472	36.1159	Hatay	Altınözü	215.21	215.21	148.38	148.63	344.0	ZD	534.22	401.97	220.46
3132	36.1716	36.2067	Hatay	Antakya	211.21	211.21	143.12	143.38	377.0	ZC	515.31	514.63	354.18
2715	36.6856	36.8554	Gaziantep	İslahiye	27.39	27.39	57.62	58.25	-	-	456.12	340.76	263.92
3137	36.4885	36.6929	Hatay	Hassa	151.71	151.71	82.48	82.93	688.0	ZC	453.09	848.01	501.98
4625	36.9819	37.5387	Kahramanmaraş	Dulkadiroğlu	64.43	64.43	28.40	29.67	346.0	ZD	448.15	483.65	367.37
3131	36.1633	36.1912	Hatay	Antakya	213.03	213.03	144.98	145.23	567.0	ZC	363.03	366.05	153.96

Recorded PGAs Recorded PGAs during the M7.5 earthquake

İstasyon Kodu	Boylam	Enlem	İl	İlçe	R_{jb} (km)	R_{rup} (km)	R_{epi} (km)	R_{hyp} (km)	$V_{s,30}$ (m/s)	Zemin Sınıfı	PGA_NS (cm/s²)	PGA_EW (cm/s2)	PGA_UD (cm/s²)
4612	36.4819	38.0240	Kahramanmaraş	Göksun	94.52	94.52	66.68	67.05	246.0	ZD	635.45	523.21	494.91
4406	37.9738	38.3439	Malatya	Akçadağ	109.15	109.15	70.17	70.52	815.0	ZB	467.20	409.31	318.75
0131	36.1153	37.8566	Adana	Saimbeyli	130.83	130.83	101.83	102.07	-	-	402.32	331.69	85.29
4409	37.4908	38.5606	Malatya	Darende	114.09	114.09	56.86	57.28	-	-	287.04	218.04	124.28
3802	36.5036	38.4781	Kayseri	Sarız	66.94	66.94	77.41	77.73	305.0	ZD	195.79	220.88	122.81
4611	37.2843	37.7472	Kahramanmaraş	Çağlayancerit	97.41	97.41	38.21	38.85	731.0	ZC	194.40	139.04	72.57
4614	37.2978	37.4851	Kahramanmaraş	Pazarcık	126.57	126.57	67.35	67.71	671.0	ZC	160.82	206.05	89.21
4412	38.1839	38.5969	Malatya	Yazıhan	142.61	142.61	99.89	100.14	-	-	159.03	126.38	79.90
4405	37.9396	38.8107	Malatya	Hekimhan	152.67	152.67	100.81	101.05	579.0	ZC	155.41	158.05	121.88
0129	36.2109	38.2592	Adana	Tufanbeyli	99.27	99.27	91.84	92.11	965.0	ZB	154.46	172.18	83.75

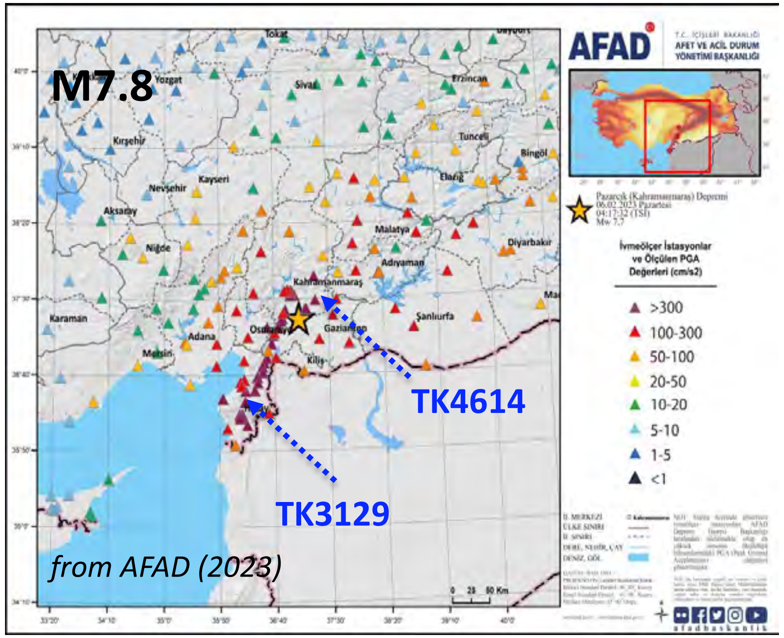
from GTU (2023)

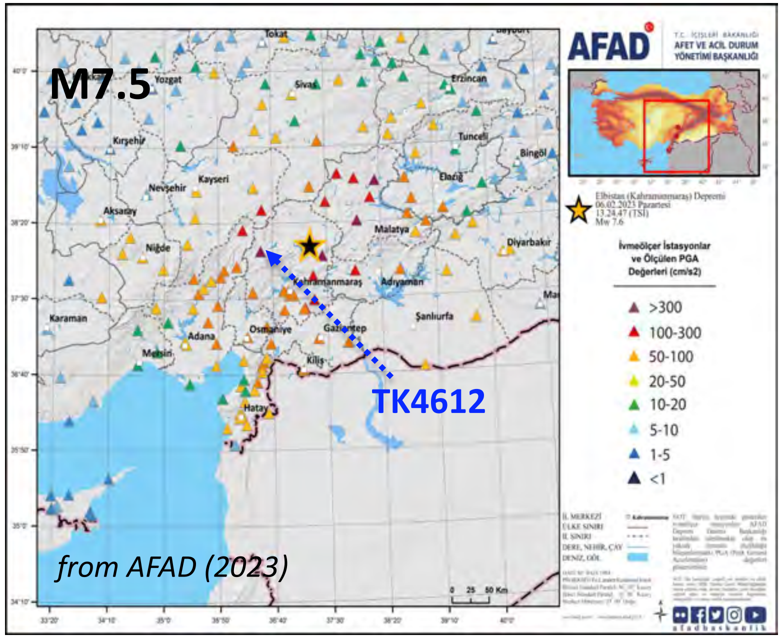


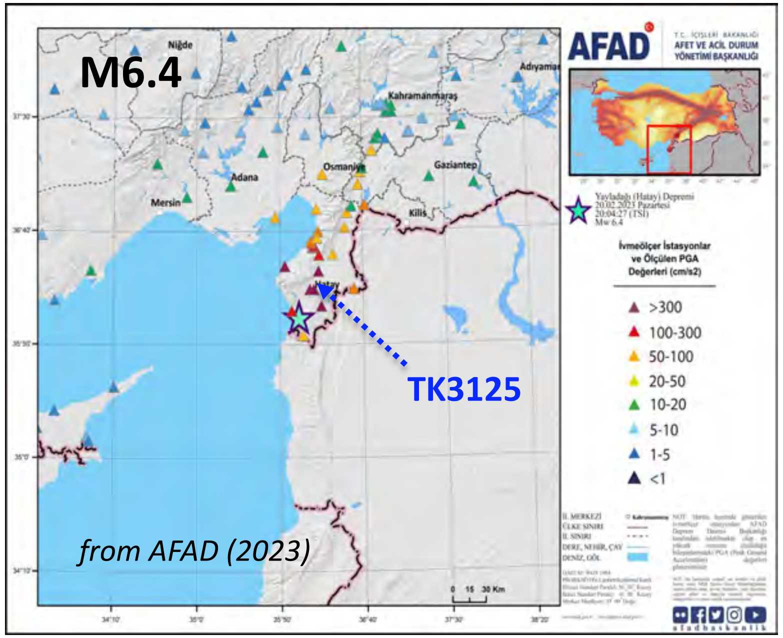


Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

High PGAs



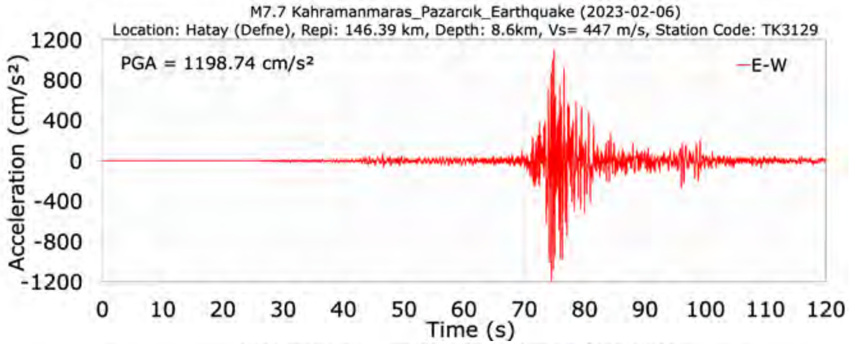


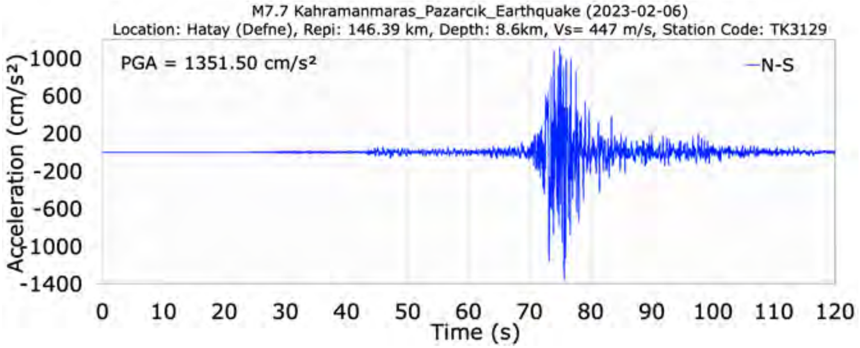


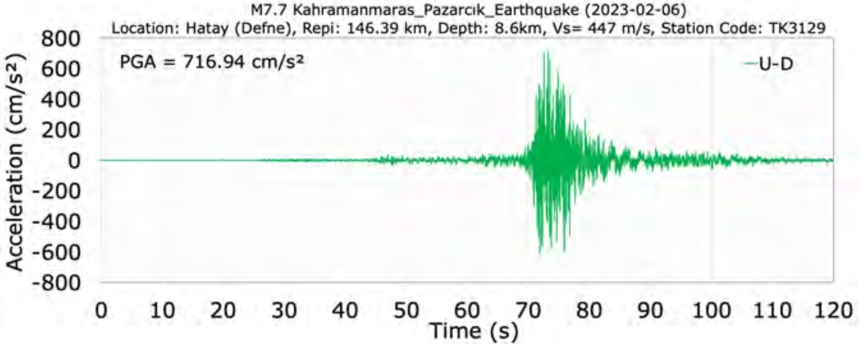
- During the **M7.8** earthquake,
  - the first PGA at Pazarcık station TK4614 (Vs=541 m/s) was measured in the east-west direction as **2039.20 cm/s²** (Repi=31.42km)
  - the second PGA was recorded at Hatay station TK3129 (Vs=447 m/s, ZC) was recorded in the north-south direction as **1351.50 cm/s²** (Repi=146.39 km).
- During the **M7.5** earthquake, the PGA at Göksun station TK4612 (Vs=246 m/s, ZD) was measured in the north-south direction as **635.45 cm/s²** (Repi=66.68 km).
- During the **M6.4** earthquake, the PGA at Hatay station TK 3125 (Vs=448 m/s, ZC) was recorded in the north-south direction as **775.40 cm/s²** (Repi=24.50 km).

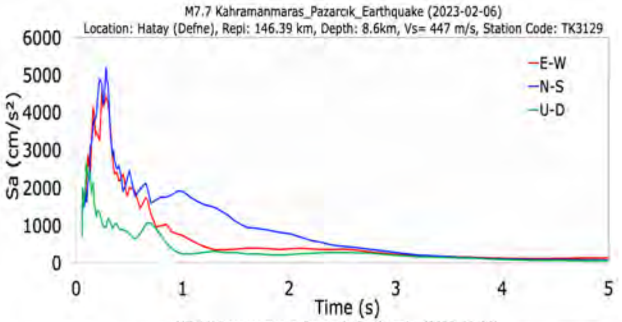
Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

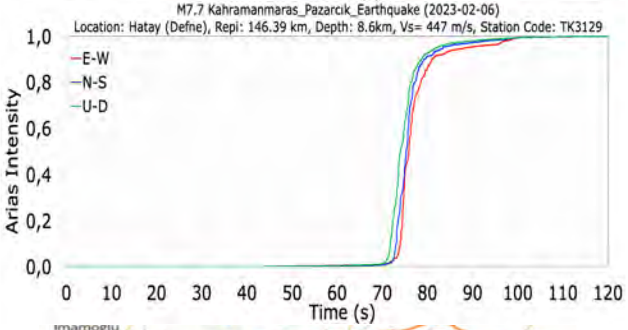
Characteristics of maximum accelerations recorded at TK3129 Hatay (Defne) station during the M7.8 earthquake





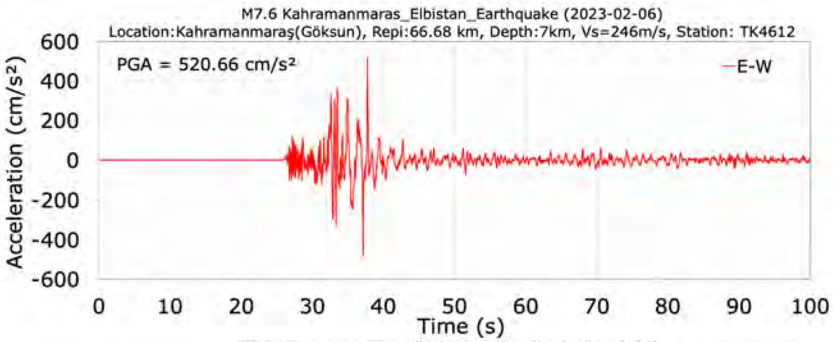


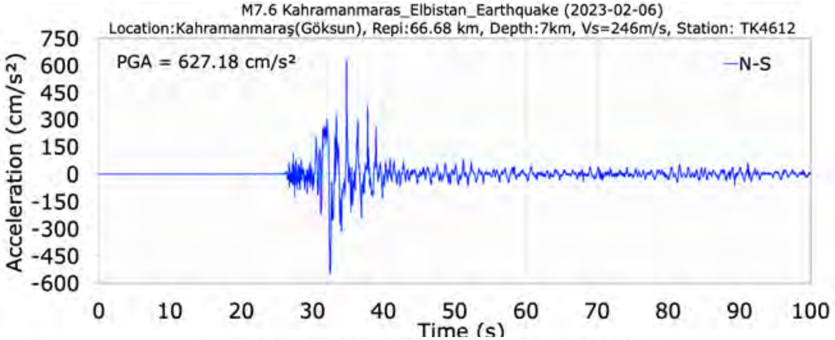


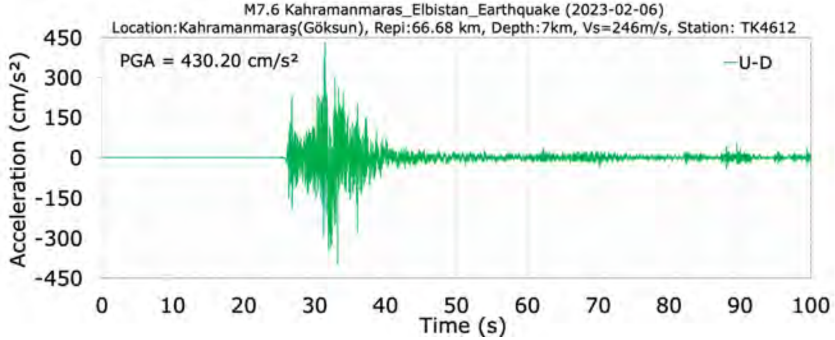


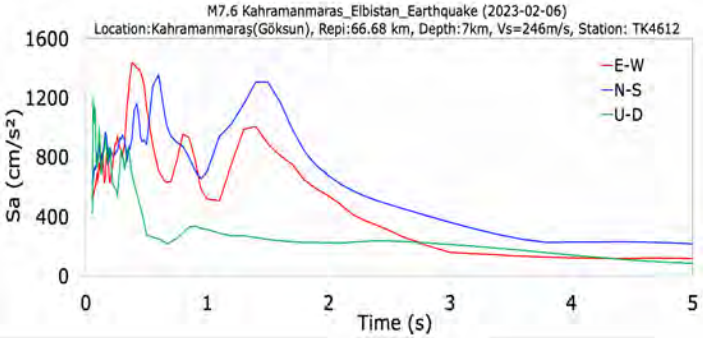
Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

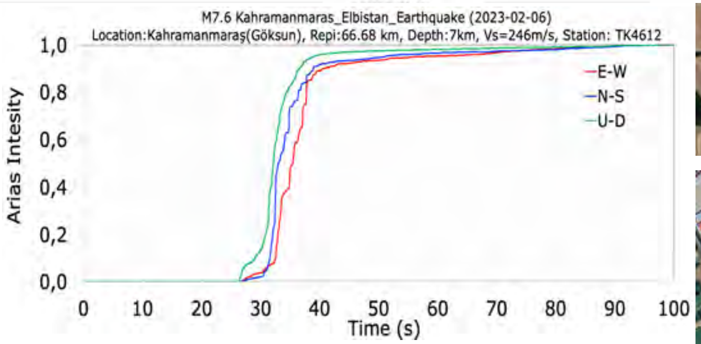
Characteristics of maximum accelerations recorded at TK4612 Kahramanmaraş (Göksun) station during the M7.5 earthquake

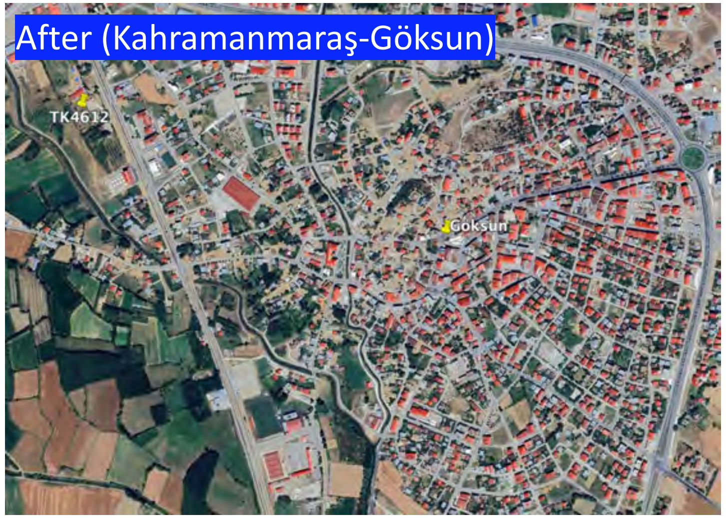




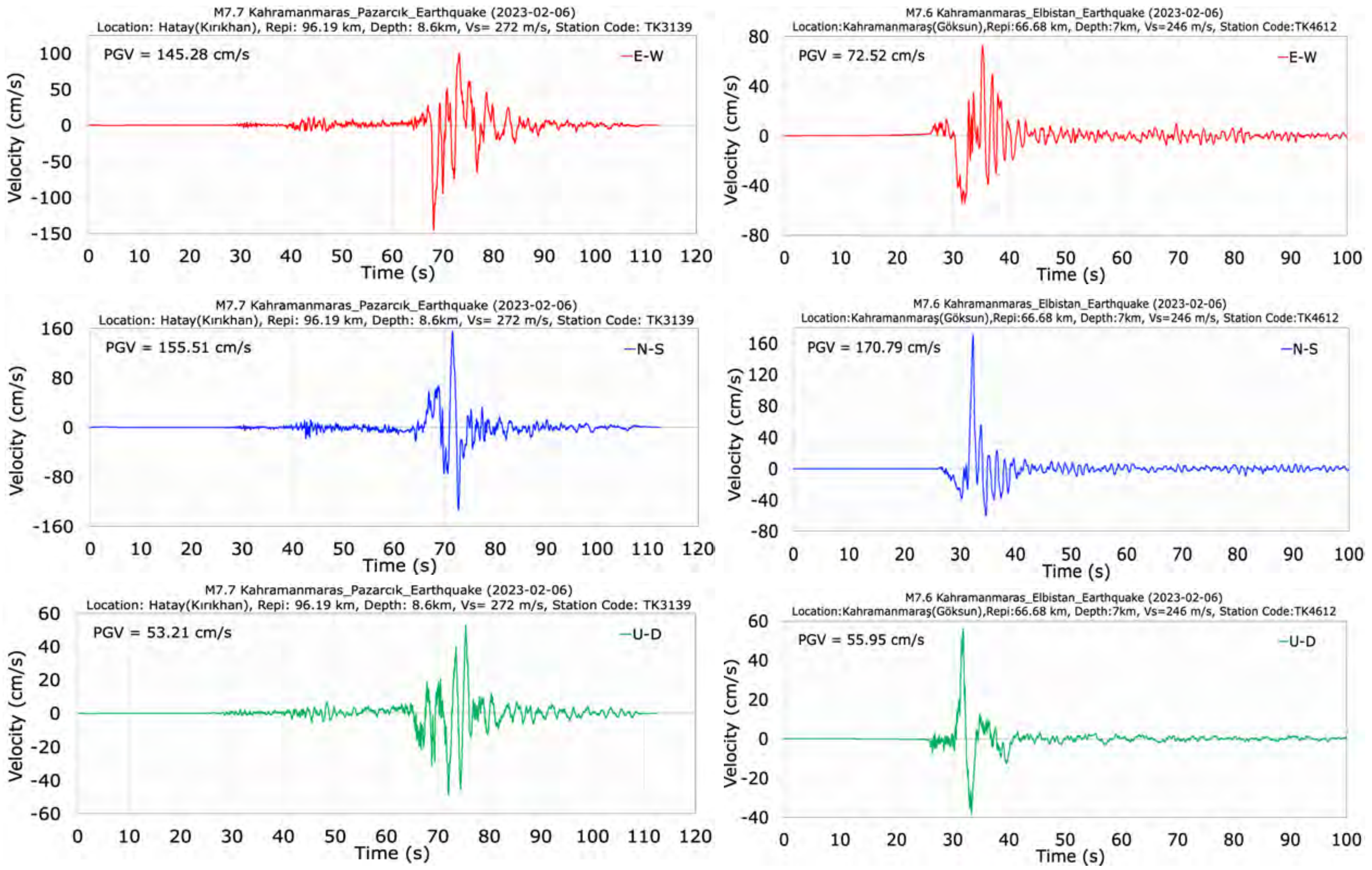


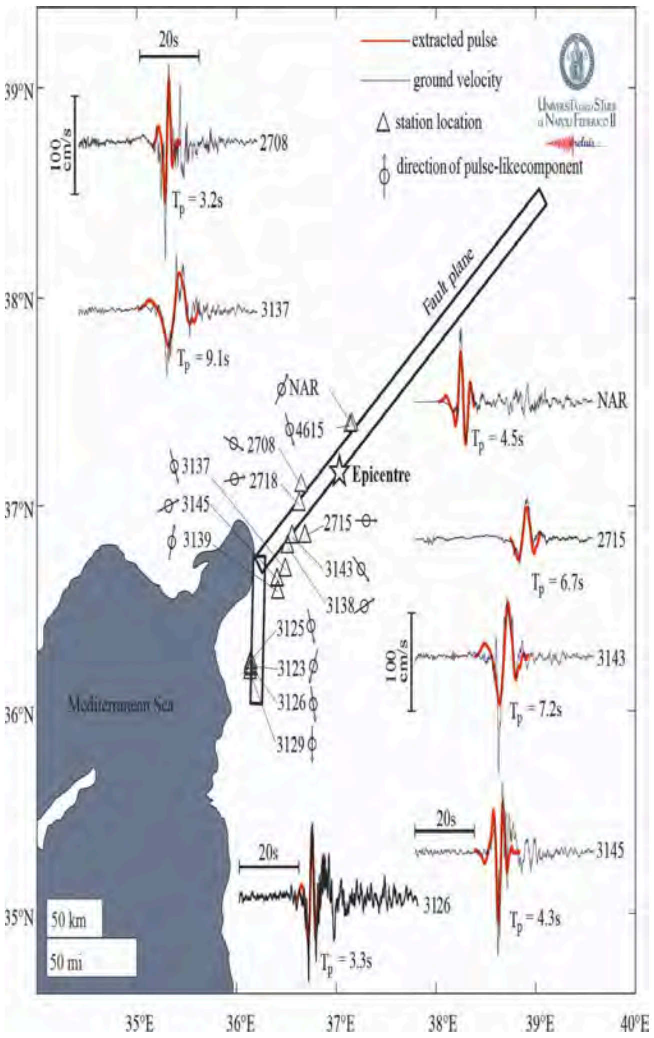






Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

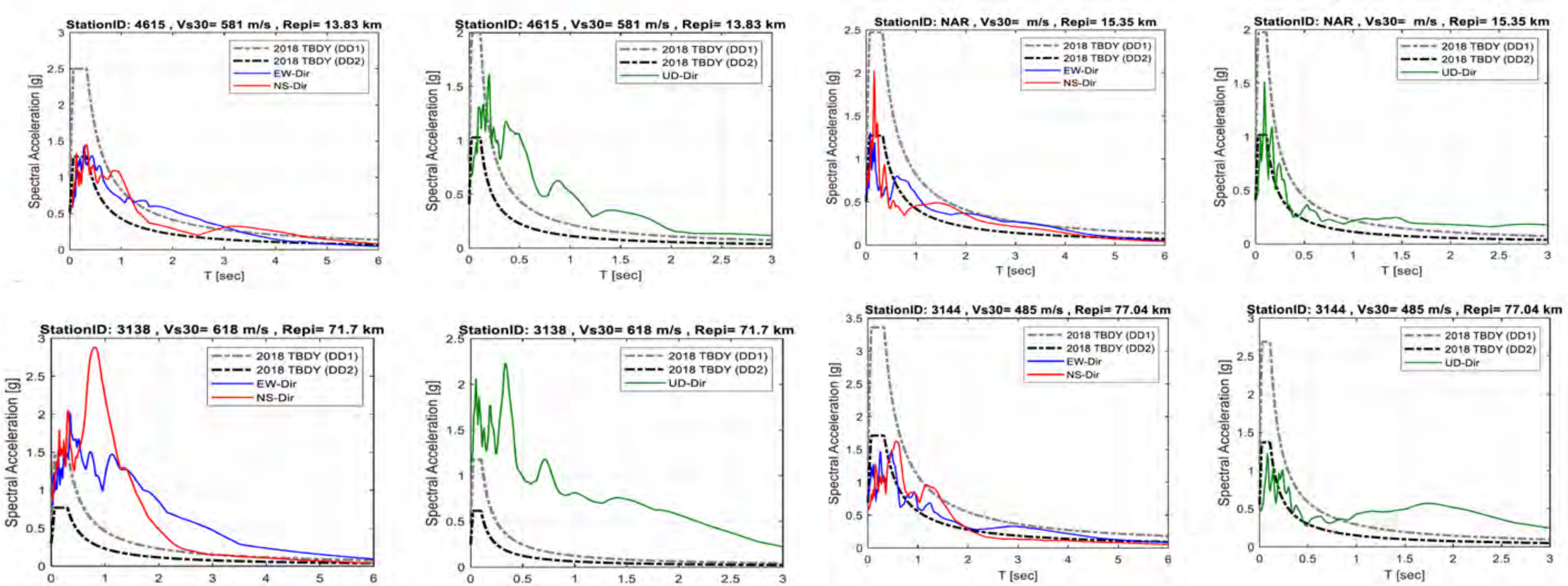




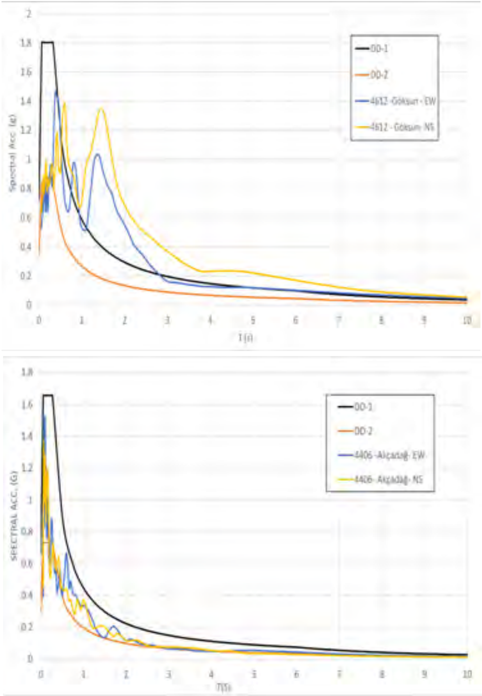
Pulse-like ground velocity and high PGV were recorded during the the 2023 earthquakes.

From Dr. Iunio Iervolino

Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes



from BU (2023)



from EERI (2023)

- The design response spectra for residential buildings (i.e. maximum design earthquake with a return period of 475 years) are exceeded for a wide period range, whereas the maximum credible earthquake level (return period of 2475 years) response spectra is generally exceeded for long periods especially in soft soils, in certain regions.
- Buildings having periods around of 0.5-2s completely collased or heavily damaged.
- This implies that the buildings in Gaziantep (İslahiye and Nurdağı districts), Hatay, Kahramanmaraş, and Adıyaman were subjected to seismic actions larger than Turkish Earthquake Code design levels.

Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

Comparison of damages and PGAs, PGVs, and PGDs recorded at stations in Hatay (Antakya), located approximately 150km from the epicenter, during the 2023 earthquakes

TK3126 (Vs= 350 m/s), TK3123 (Vs= 470m/s), TK3132 (Vs= 377 m/s), TK3129 (Vs= 447 m/s)

Ground Motion Characteristics of the February 2023 Kahramanmaraş Earthquakes

https://www.linkedin.com/feed/update/urn:li:activity:7034080118608125952/

Content

In addition to design and construction phases mistakes, there are some reasons due to the seismic characteristics of the 2023 earthquakes for the extensive damages and collapses of a large number of buildings:

- High seismic intensity ((large PGA, PGV, PGD and spectral values),
- Earthquake sequence (back-to-back events),
- Near-fault effects, basin effects, soil amplification
- Shallow earthquakes (less than 10km deep),
- Long duration of the ground shaking,
- Epicenters proximity to many of the cities severely affected,
- Proximity of several cities to the faults that caused the events,
- Very long ruptured fault systems,
- Different ruptured fault segments,
- Underestimation of the seismic demands during the design process

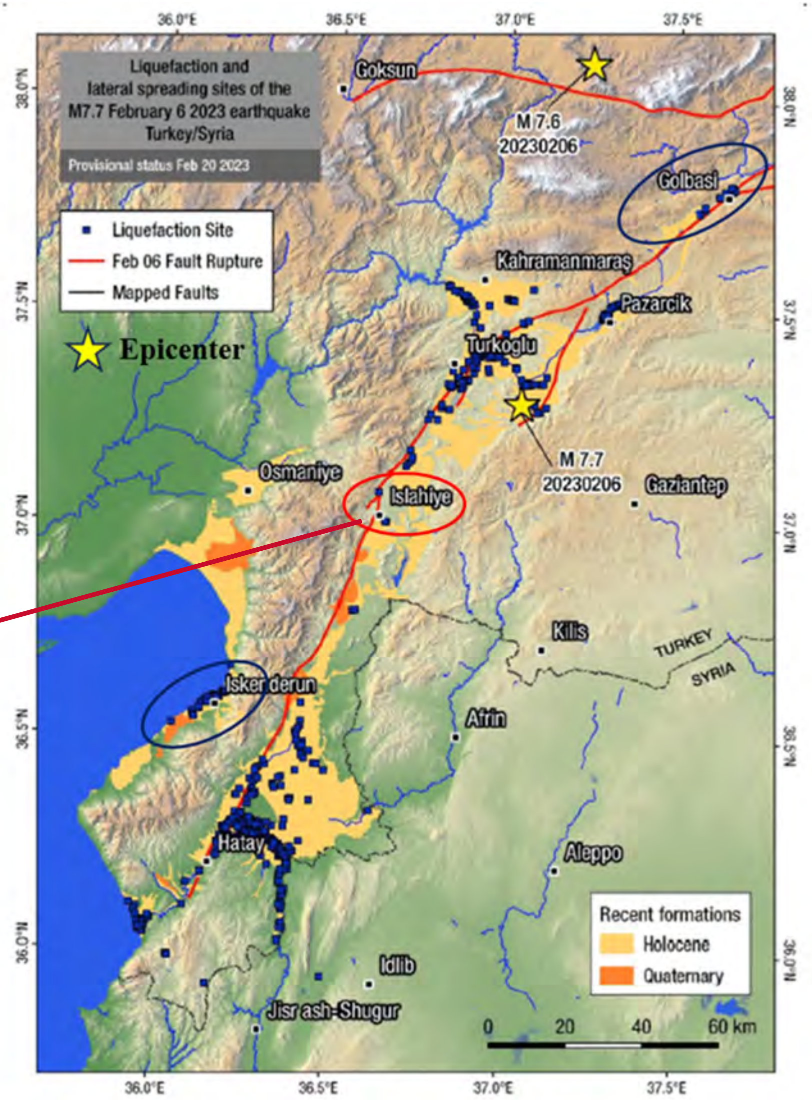
Geotechnical observations

- Surface Rupture
- Liquefaction and Subsidence
- Performance of Dam

Surface Rupture

Fault rupture on multiple segment of the faults that crosses infrastructures (i.e., highway, pipelines, buildings)

Islahiye



Taftsoglou et al. 2023

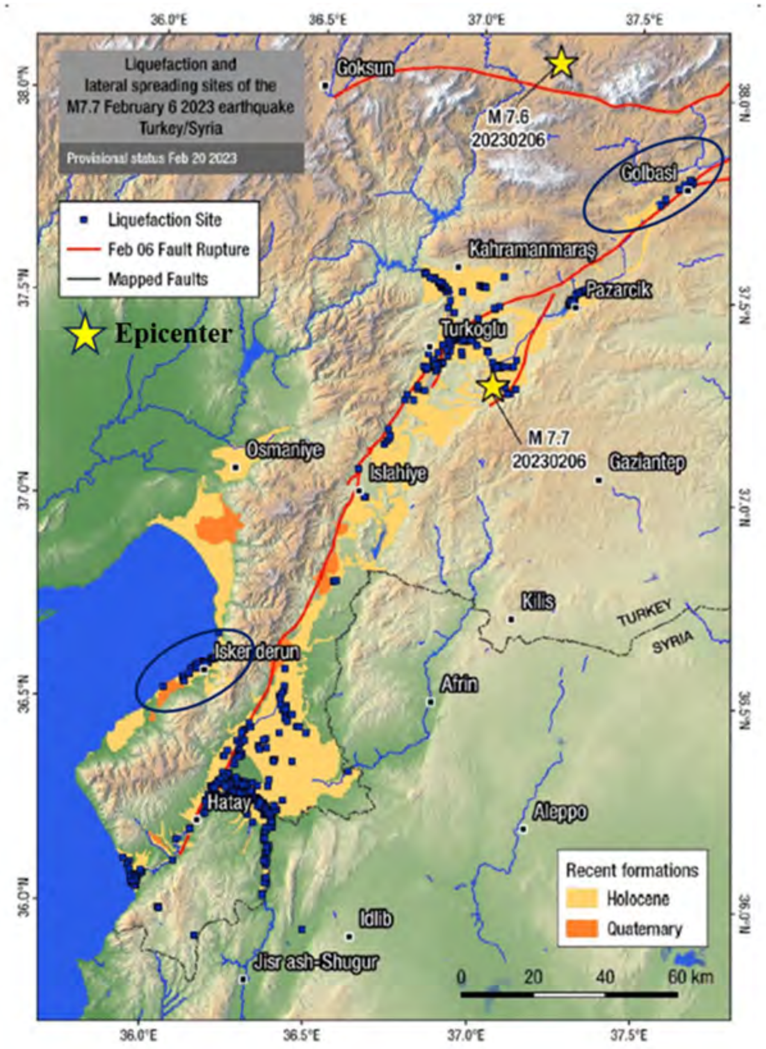
Surface Rupture in Islahiye

The fault zone becomes 10-50 m in width in a N30°E direction

Liquefaction and Subsidence

Liquefaction is the process by which the soil below the water table temporarily lose Its strength during earthquake and behave as a viscous liquid rather than soil.

- **Liquefied sites were along the faults line at several locations**
- **Widespread liquefaction on wetlands and along the costal line**
- **Liquefaction induced ground and structural failures were widespread in some cities**

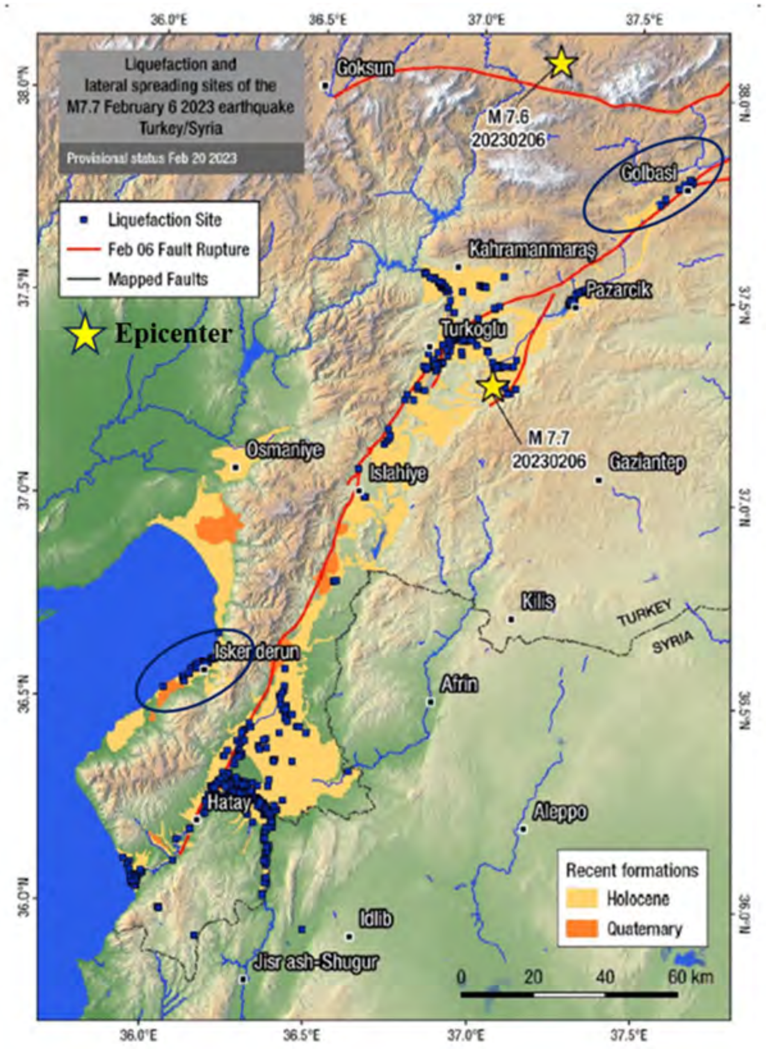


Taftsoglou et al. 2023

Liquefaction and Subsidence

Golbasi

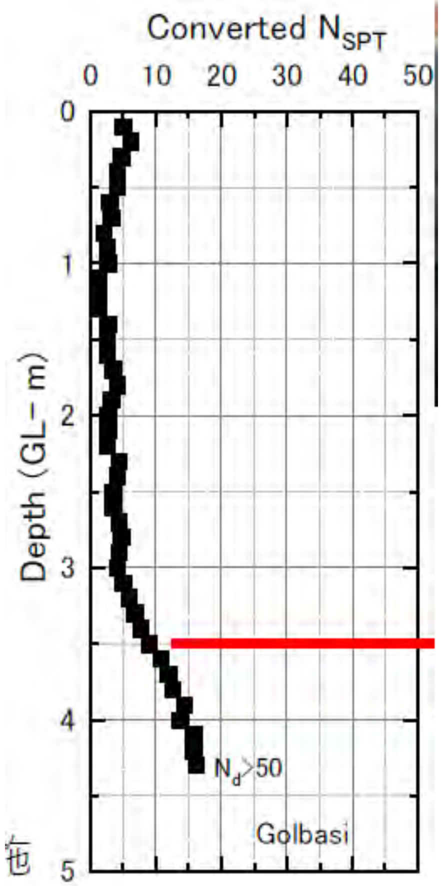
- City built up after the 1950s on a former wetland
- Compressible wetland sediments up to 21 m thick
- Liquefaction induced ground failures were widespread in several cities



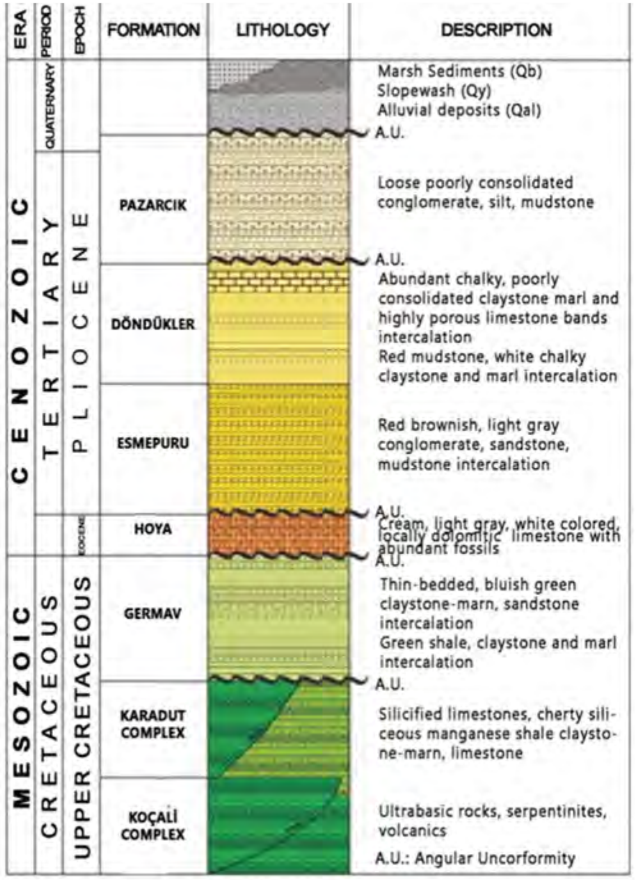
Taftsoglou et al. 2023

Liquefaction and Subsidence

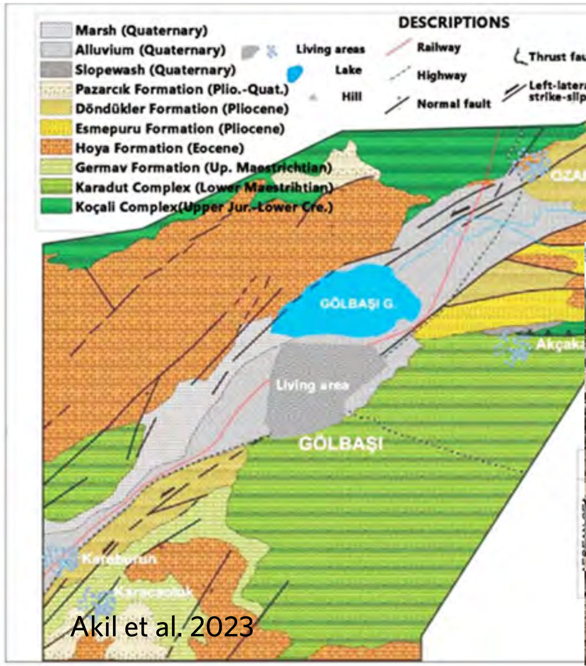
Golbasi



Source: GDM lab, u of Tokyo



Akil et al. 2023



Liquefaction and Subsidence

Golbasi

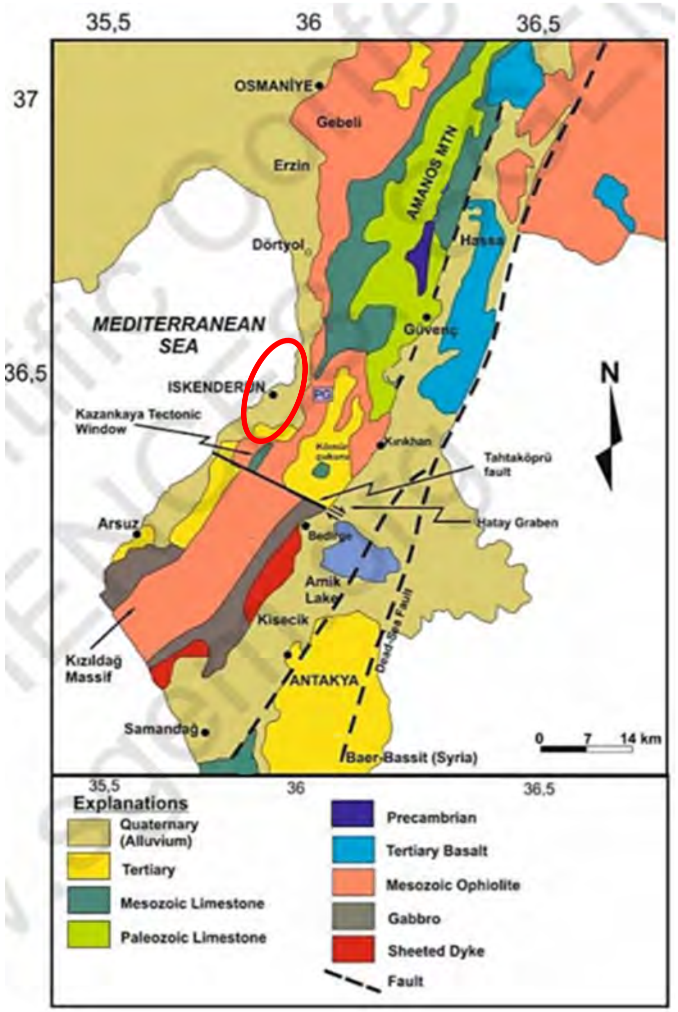
Liquefaction and Subsidence

Golbasi Lake

Liquefaction and Subsidence

Iskenderun

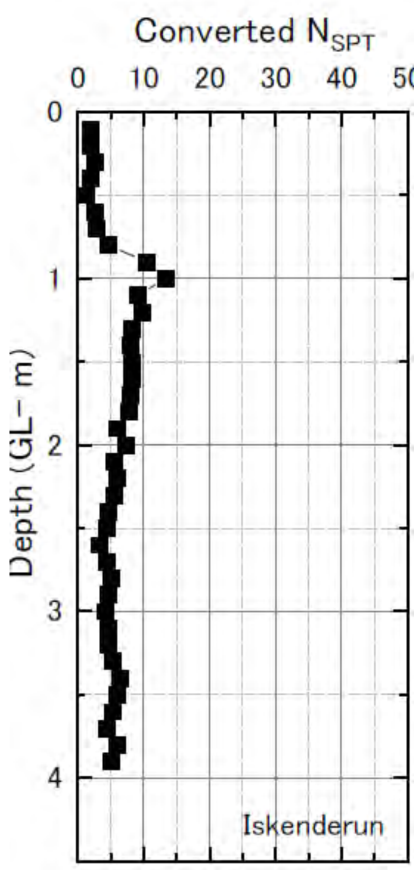
- Young marine deposits and fills dominate the coastal plains.
- Soils along the coastal area include loose to medium dense sands and silty sands.
- Soil conditions are highly variable because of the marine and alluvial depositional environment, as well as the reclamation fill.
- Severely damaged due to widespread lateral spreading and liquefaction along its coastal front.



Özdemir and Şahinoğlu, 2018

Liquefaction and Subsidence

Iskenderun



Source: GDM lab, u of Tokyo

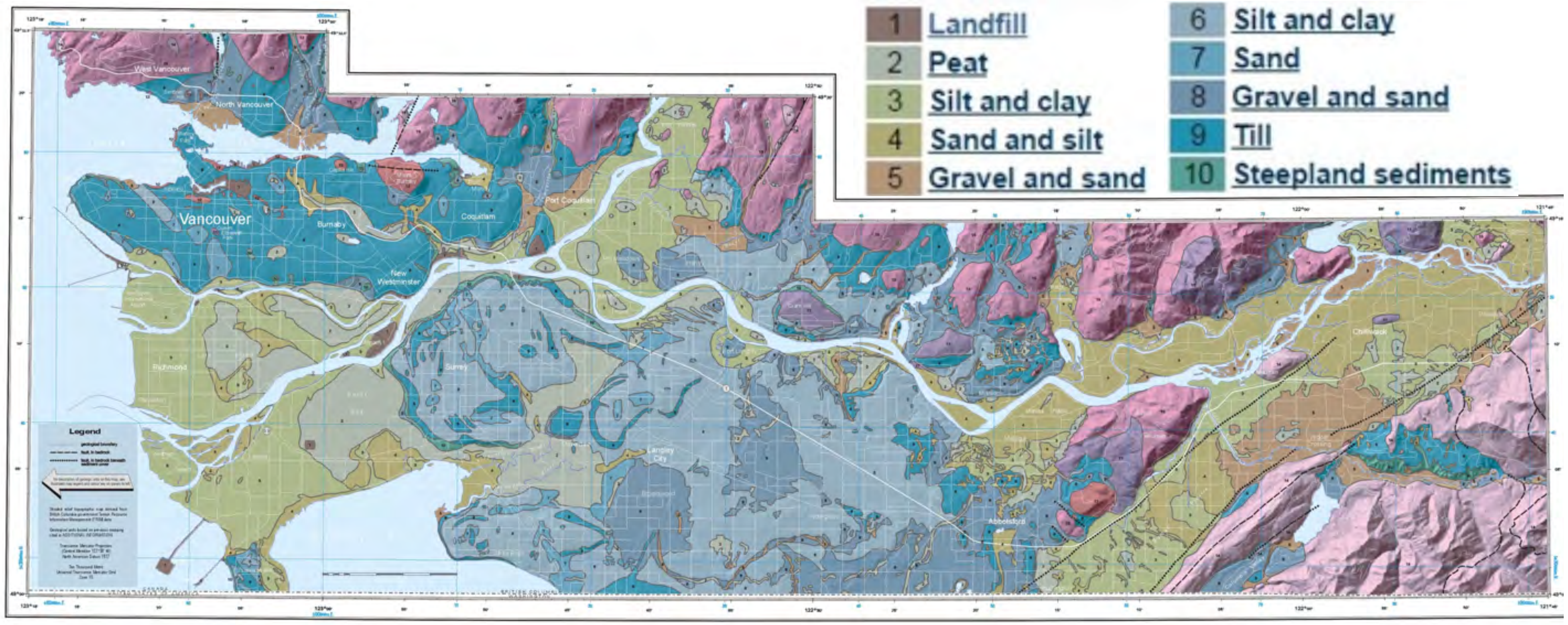
Land reclamation using liquefiable material is problematic.

Performance of Dam

Kartalkaya dam

- A clay core earthfill dam constructed in 1972 in Kahramanmaraș
- Crest height from the stream level is 56 meters and store 1.45 million m^3 water.
- Dam is 3 km away from the epicenter of the first event.
- Moderate damage with crack widths varying in between 15-35 cm was observed along the crest of the dam

Liquefaction in Canada



Several locations in Western Canada including Vancouver has all the parameters that trigger liquefaction i.e., shallow ground water; loose, sandy soil; nearby faults and the Cascadia Subduction Zone, with the capacity to produce large earthquakes.

Conclusions

- Fault rupture on multiple segment of the faults that crossed and damaged the infrastructures.
- Widespread liquefaction on wetlands and along the costal line
- Liquefaction induced severe damage was observed in Golbasi and Iskenderun.
- Embankment dams exhibited varied performance based on several factors.
- Land reclamation using liquefiable material is problematic. Seismic microzonation and land use planning are key factors.
- Several locations in Western Canada including Vancouver (along the costal line and river) are highly vulnerable to liquefaction and can cause several damage to infrastructures.

Key Message

- Seismic microzonation and land use planning are key factors.
- Land reclamation using liquefiable material is problematic.
- Geotechnical consideration is equally important as structural design.

3.
Building codes in Turkey

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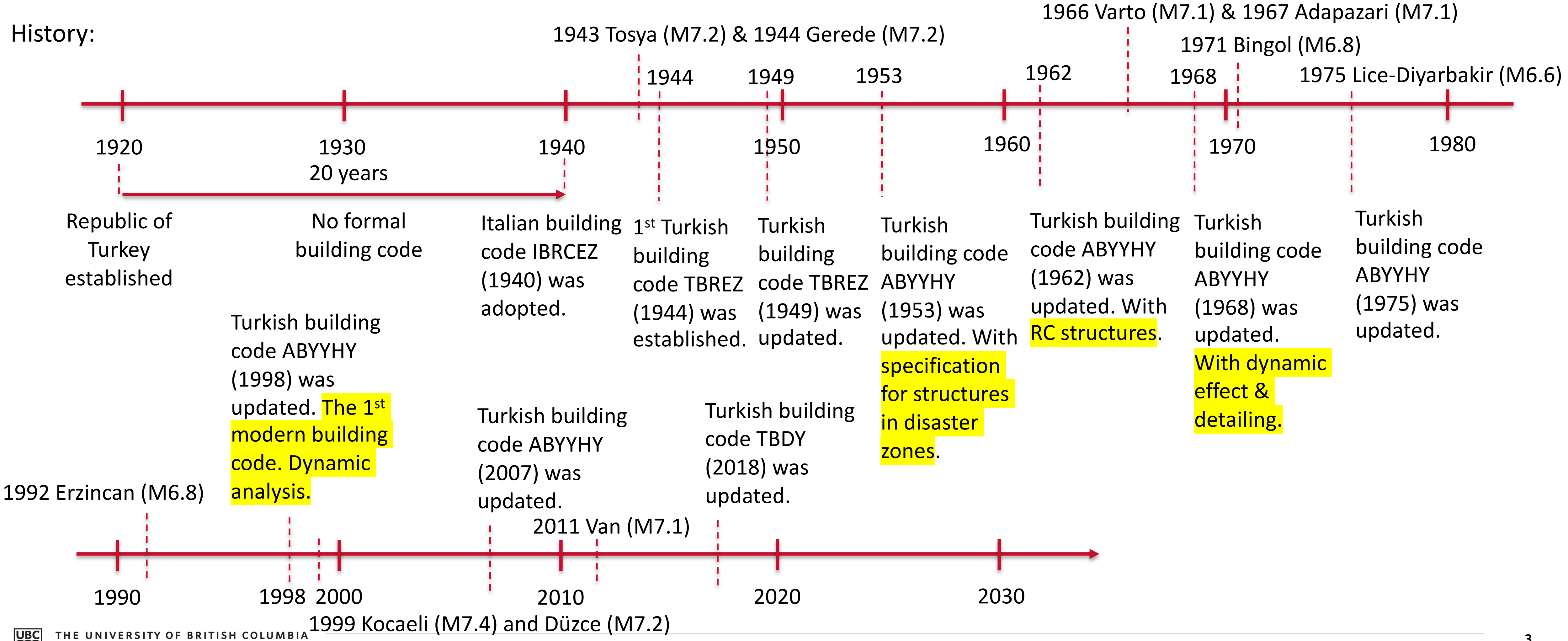
Alemdar Bayraktar, Visiting Professor, UBC
Svetlana Brzev, Ph.D., P.Eng., FEC, Adjunct Professor, UBC

Introduction:

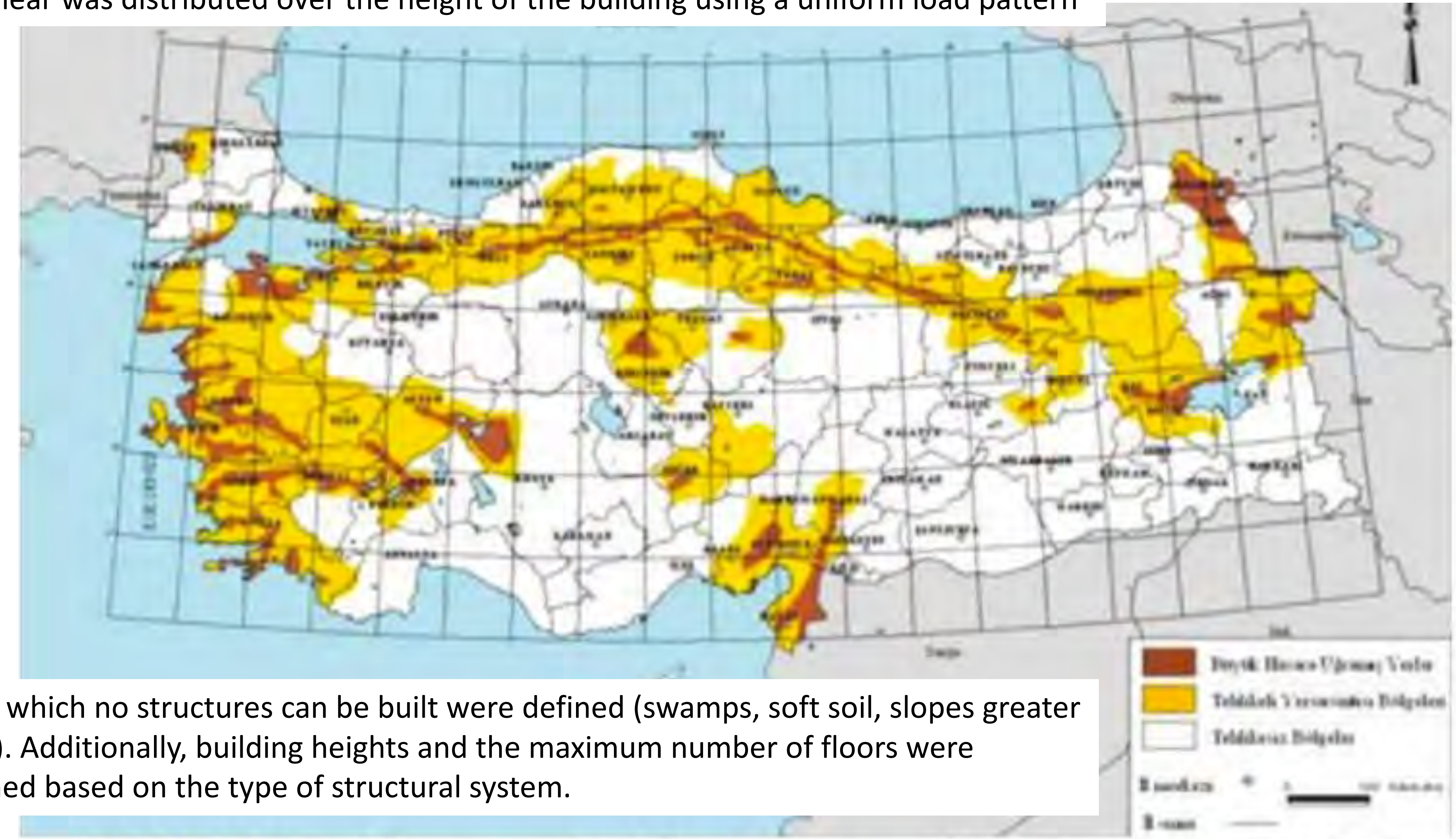
➢ Many large earthquakes occurred in 1940s to early 2000s have resulted in more than 100,000 deaths, 200,000 injuries, and the destruction of 750,000 buildings before the February 6, 2023 Kahramanmaraş earthquakes. These earthquakes have shaped the fundamental of the seismic design codes in Turkey.

History:



1944 Turkish building code:

- First seismic hazard map in Turkey
- 3 zones: Red (0.1 W), Yellow (0.05 W), White (0 W)
- Base shear was distributed over the height of the building using a uniform load pattern



- Lands on which no structures can be built were defined (swamps, soft soil, slopes greater than 1/3). Additionally, building heights and the maximum number of floors were determined based on the type of structural system.

1949 Turkish building code:

- Live load was included in the calculation of the weight of the building:

$W = \Sigma w_i$ $w_i = g_i + n\, p_i$

where w_i is the weight of the ith floor, g_i is the dead load of the ith floor, n is a live load coefficient (equal to 0.33 for houses, 0.5 for commercial buildings, and 1.0 for high-occupancy buildings), and p_i is the live load of the ith floor.

- 3 zones:
  Red (0.1 W ➔ 0.04 to 0.02 W, base on building height)
  Yellow (0.05 W ➔ 0.03 to 0.01 W, based on building height)
  White (0 W)

- 1953 Turkish building code remains similar to the 1949 Turkish building code.

1962 Turkish building code:

- A new seismic hazard map in Turkey
- 4 zones

- Base shear coefficient:

$C = C_0 \, n_1 \, n_2$

where $C_0 = 0.10$ to 0.06 (depends on building height),

n_1 and n_2 depends on building material (steel or reinforced concrete), soil classifications, and earthquake zone.

- For heights greater than 40 m, C_0 was increased by 0.01 for every 3.0 m above 40 m.

1968 Turkish building code:

- Made significant changes to the seismic design:
  - Introducing the requirement for detailing of RC structure
  - Use spectra shape & dynamic effect to quantify the earthquake load
  - Introduce important factor

- Base shear:

$C = C_0\, \alpha\, \beta\, \gamma$

where C_0 is a seismic zone coefficient:

Zone 1: 0.06; Zone 2: 0.04; Zone 3: 0.02; Zone 4: 0

α is a soil coefficient:

Rock: 0.80; Sand, gravel, and hard clay : 1.00; other loose soil containing water or poor soils: 1.20;

β is the importance factor:

critical, high-occupancy, or historically important buildings: 1.50

otherwise: 1.00;

γ was a dynamic coefficient:

max (0.5/T, 0.3) for T > 0.50 sec $\quad T = 0.09\,\frac{H}{\sqrt{D}}$, H = height and D = width of the building

1.00 for T ≤ 0.5 sec

- $F_i = V\,\frac{w_i\,h_i}{\sum_i w_i h_i}$, where h_i is the height of the floor above the foundation.

1975 Turkish building code:

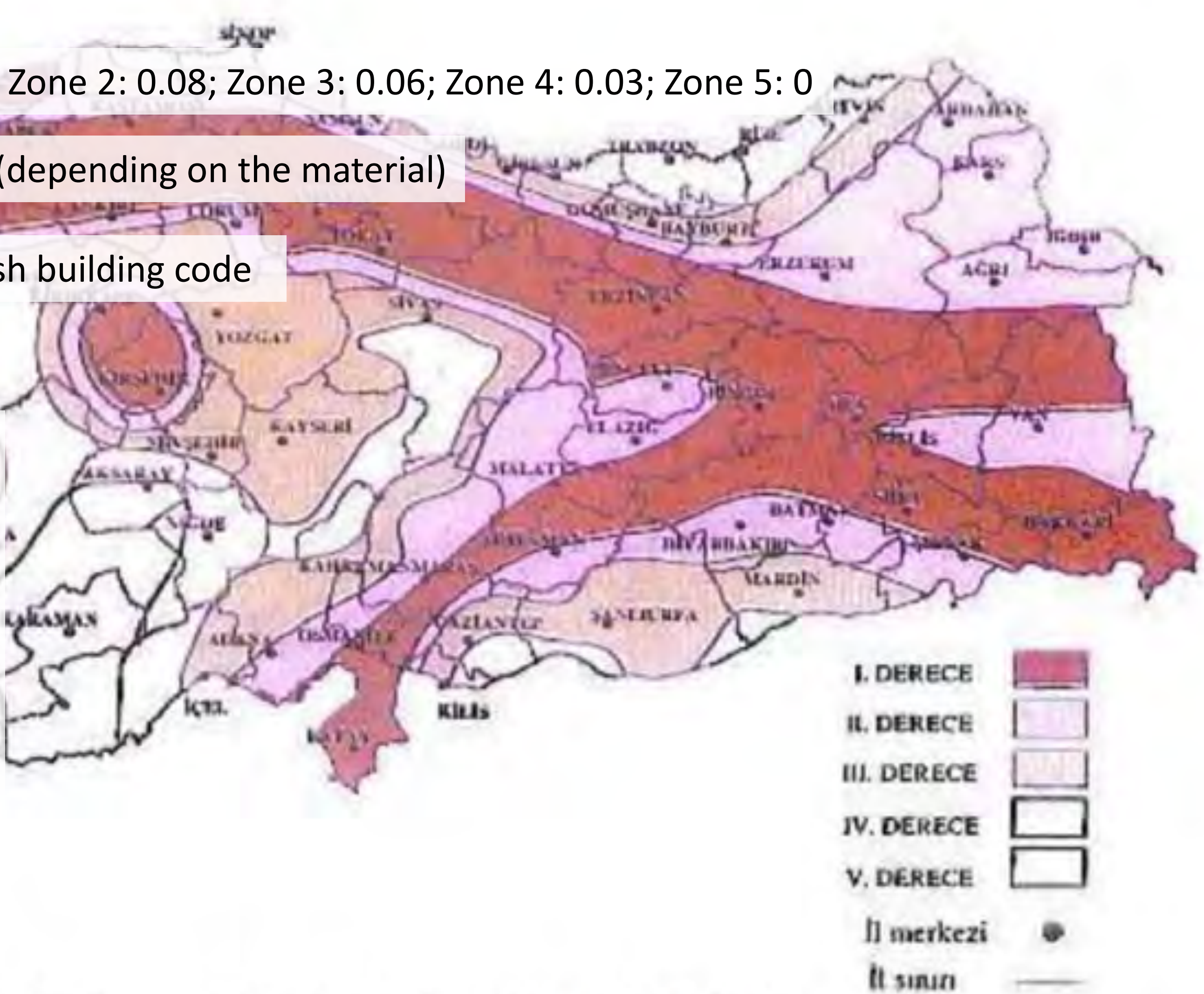
- A new seismic hazard map in Turkey
- 5 zones
- $C = C_0 K I S$

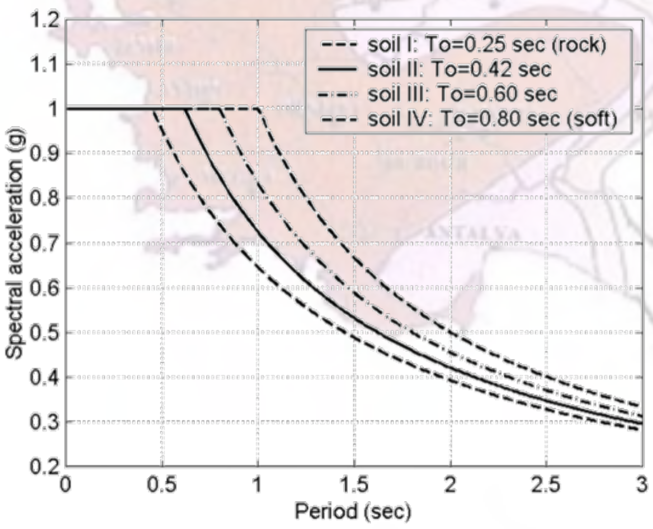
C_0 is a seismic zone coefficient: Zone 1: 0.1; 1; Zone 2: 0.08; Zone 3: 0.06; Zone 4: 0.03; Zone 5: 0

K is ductility coefficient: between 0.6 and 1.5 (depending on the material)

I is importance factor: Same as the 1968 Turkish building code

S is spectra coefficient:

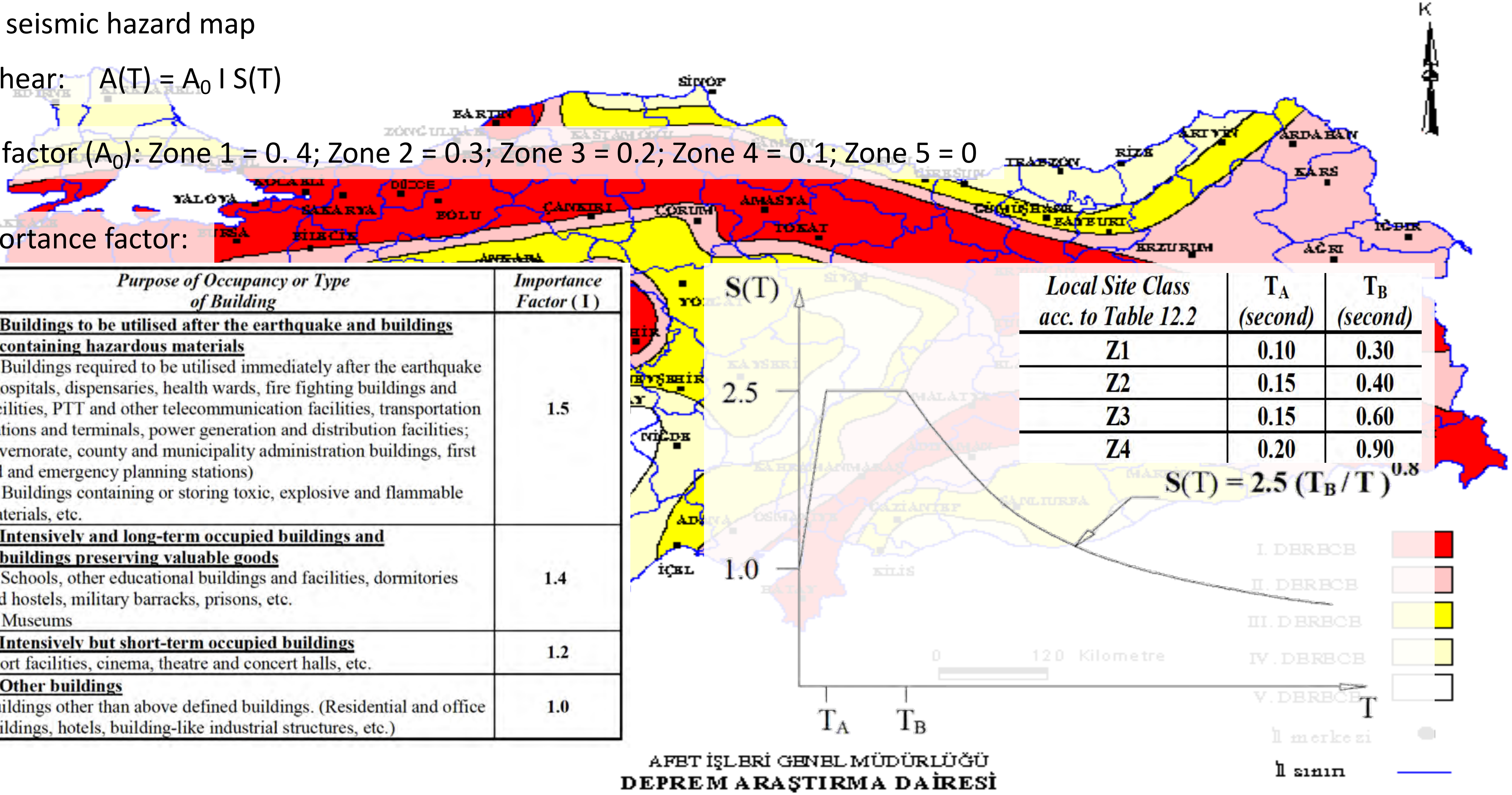




1998 Turkish building code:

- Consider as the 1st modern building code in Turkey.
- A new seismic hazard map
- Base shear: $A(T) = A_0 \, I \, S(T)$

Zone factor (A_0): Zone 1 = 0. 4; Zone 2 = 0.3; Zone 3 = 0.2; Zone 4 = 0.1; Zone 5 = 0



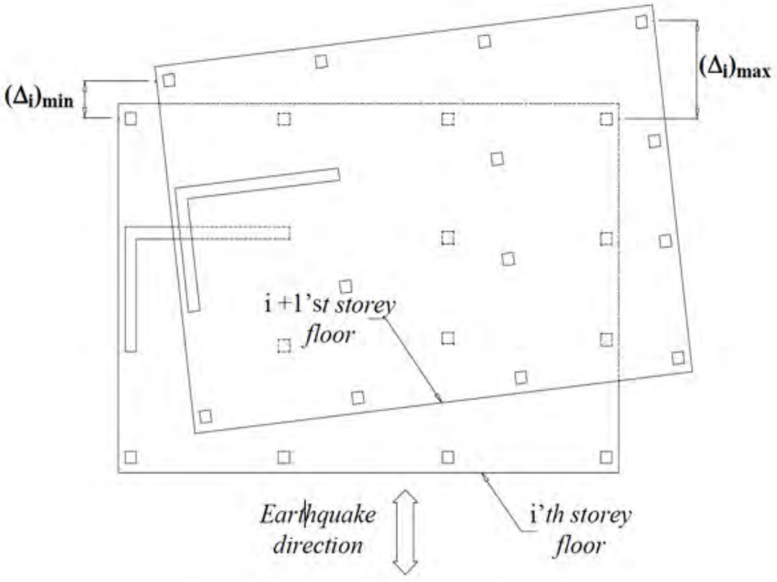
I is importance factor:

Purpose of Occupancy or Type of Building	*Importance Factor (I)*
1. Buildings to be utilised after the earthquake and buildings containing hazardous materials **a)** Buildings required to be utilised immediately after the earthquake (Hospitals, dispensaries, health wards, fire fighting buildings and facilities, PTT and other telecommunication facilities, transportation stations and terminals, power generation and distribution facilities; governorate, county and municipality administration buildings, first aid and emergency planning stations) **b)** Buildings containing or storing toxic, explosive and flammable materials, etc.	1.5
2. Intensively and long-term occupied buildings and buildings preserving valuable goods **a)** Schools, other educational buildings and facilities, dormitories and hostels, military barracks, prisons, etc. **b)** Museums	1.4
3. Intensively but short-term occupied buildings Sport facilities, cinema, theatre and concert halls, etc.	1.2
4. Other buildings Buildings other than above defined buildings. (Residential and office buildings, hotels, building-like industrial structures, etc.)	1.0

Local Site Class acc. to Table 12.2	T_A *(second)*	T_B *(second)*
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

1998 Turkish building code:

- Deals with irregularities



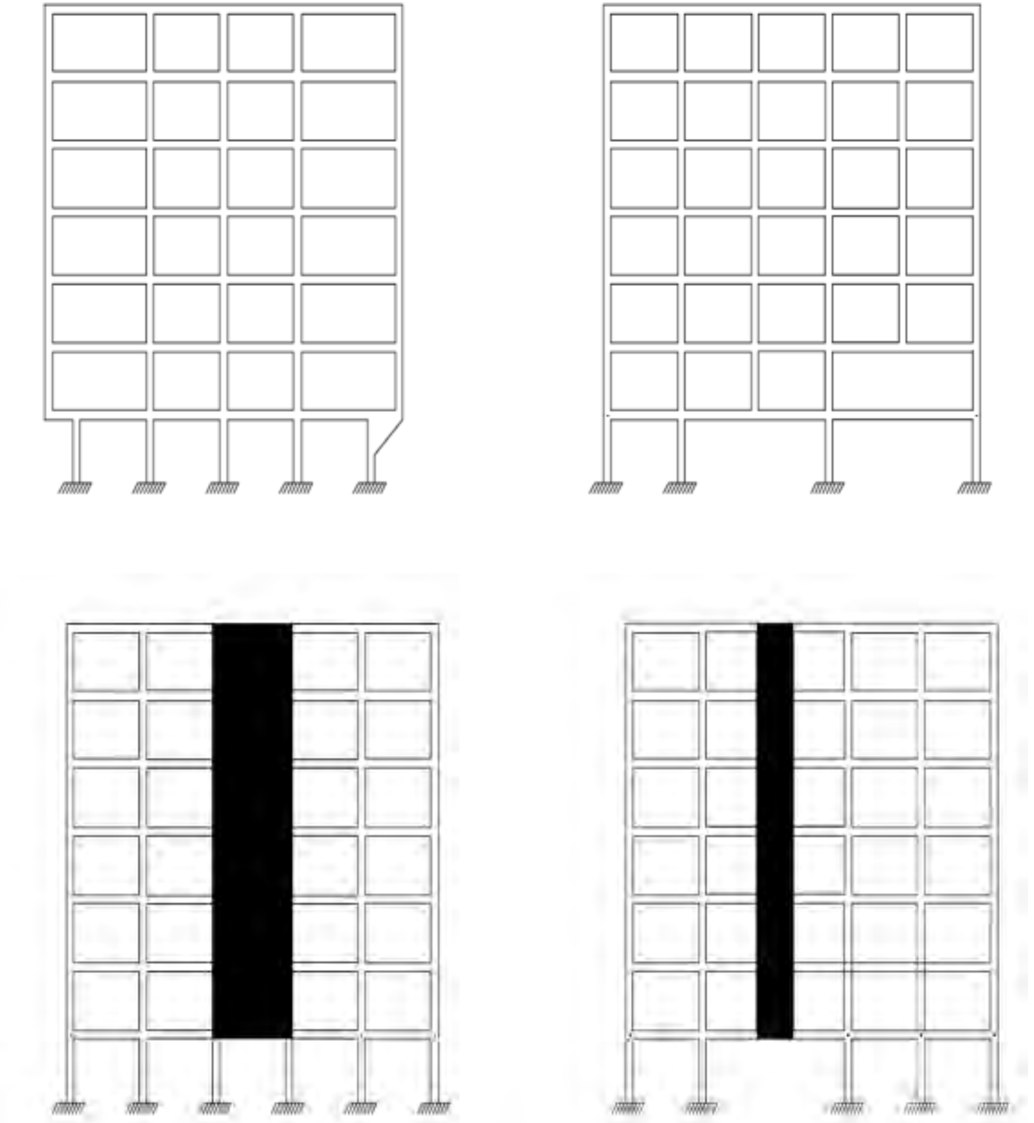
In the case where floors behave as rigid diaphragms in their own planes:

$$(\Delta_i)_{ort} = 1/2\,[(\Delta_i)_{max} + (\Delta_i)_{min}]$$

Torsional irregularity factor :

$$\eta_{bi} = (\Delta_i)_{max} / (\Delta_i)_{ort}$$

Torsional irregularity : $\eta_{bi} > 1.2$



1998 Turkish building code:

- Reduction factor

BUILDING STRUCTURAL SYSTEM	Systems of Nominal Ductility Level	Systems of High Ductility Level
(1) CAST-IN-SITU REINFORCED CONCRETE BUILDINGS		
(1.1) Buildings in which seismic loads are fully resisted by frames	4	8
(1.2) Buildings in which seismic loads are fully resisted by coupled structural walls	4	7
(1.3) Buildings in which seismic loads are fully resisted by solid structural walls	4	6
(1.4) Buildings in which seismic loads are jointly resisted by frames and solid and/or coupled structural walls	4	7
(2) PREFABRICATED REINFORCED CONCRETE BUILDINGS		
(2.1) Buildings in which seismic loads are fully resisted by frames with connections capable of cyclic moment transfer	3	6
(2.2) Buildings in which seismic loads are fully resisted by single-storey hinged frames with fixed-in bases	—	5
(2.3) Buildings in which seismic loads are fully resisted by prefabricated solid structural walls	—	4
(2.4) Buildings in which seismic loads are jointly resisted by frames with connections capable of cyclic moment transfer and cast-in-situ solid and/or coupled structural walls	3	5
(3) STRUCTURAL STEEL BUILDINGS		
(3.1) Buildings in which seismic loads are fully resisted by frames	5	8
(3.2) Buildings in which seismic loads are fully resisted by single-storey hinged frames with fixed-in bases	4	6
(3.3) Buildings in which seismic loads are fully resisted by braced frames or cast-in-situ reinforced concrete structural walls		
(a) *Concentrically braced frames*	3	—
(b) *Eccentrically braced frames*	—	7
(c) *Reinforced concrete structural walls*	4	6
(3.4) Buildings in which seismic loads are jointly resisted by frames and braced frames or cast-in-situ reinforced concrete structural walls		
(a) *Concentrically braced frames*	4	—
(b) *Eccentrically braced frames*	—	8
(c) *Reinforced concrete structural walls*	4	7

$R_a(T) = 1.5 + (R - 1.5)\, T / T_A \qquad (0 \le T \le T_A)$

$R_a(T) = R$

1998 Turkish building code:

- Dynamic analysis methods
  Methods such as mode superposition and Time history analysis

- Requirement to check drift limits

  $(\Delta i)_{max} / h_i \leq 0.0035$

  $(\Delta i)_{max} / h_i \leq 0.02 / R$, where h_i is ith the story height.

- Minimum strength requirements

  In all buildings to be built in seismic zones, concrete strength less than that of C16 (BS 16) shall not be used. However, it is mandatory to use C20 (BS 20) quality or higher strength concrete in buildings to be built in the first and second seismic zones. Reinforcing steel with strength exceeding that of S420 shall not be used reinforced concrete structural elements. The rupture strain of reinforcement to be used shall not be less than 10%.

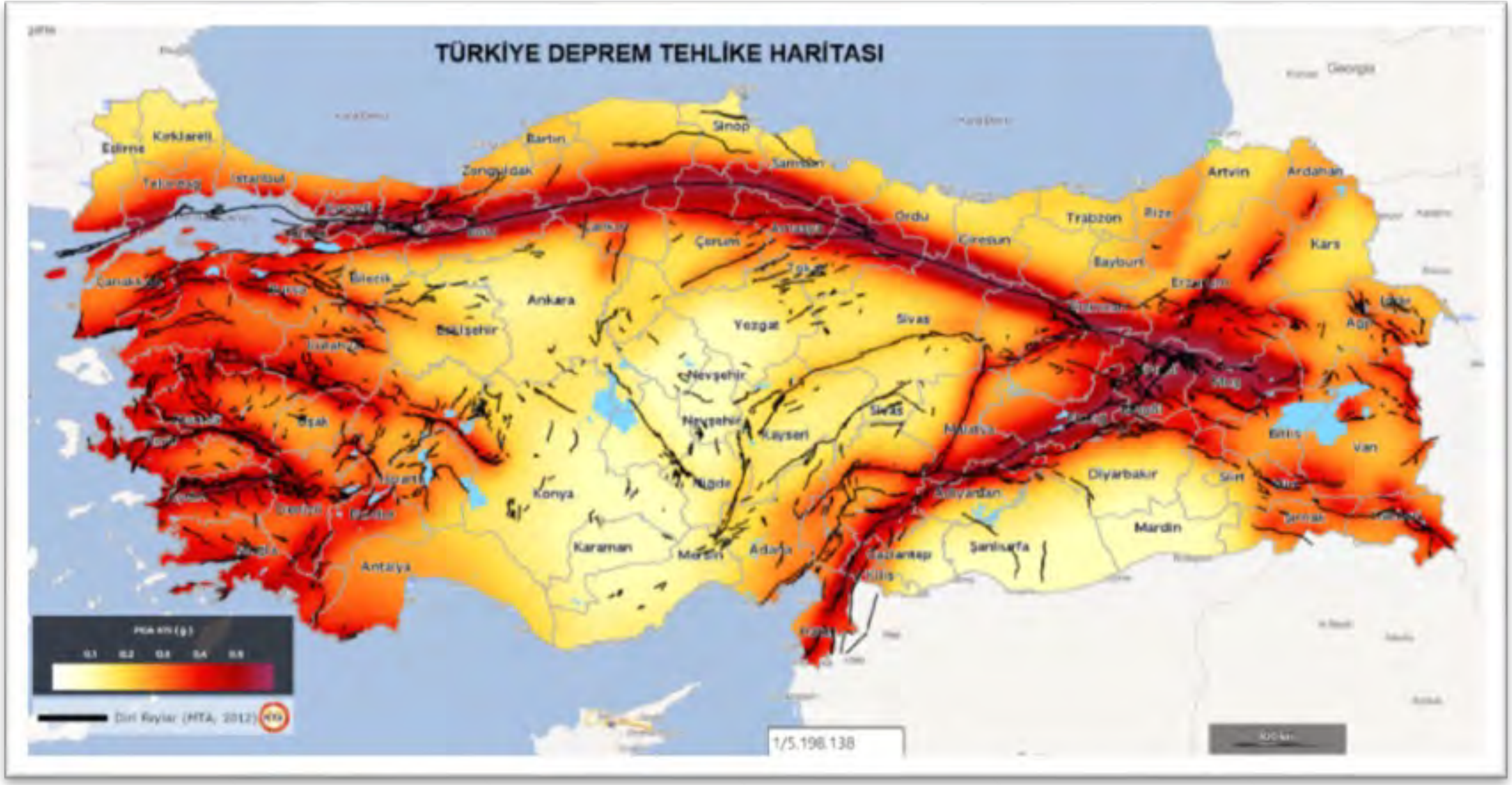
- More detailing requirements

2007 Turkish building code:

- Minor change from the 1998 Turkish building code.
- Significant change include:
  - Chapter for assessment and retrofit for existing buildings
  - Different design earthquake levels and performance levels
  - Can use push over analysis and nonlinear dynamic analysis for building assessment.

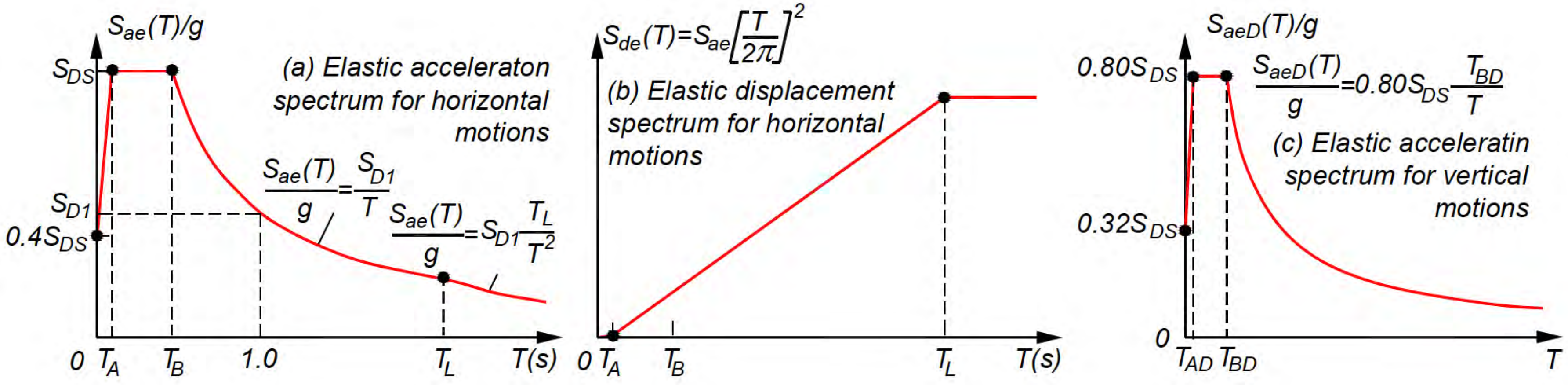
2018 Turkish building code:

- Latest building code.
- New hazard map. More refined (by coordinate not by zone)



2018 Turkish building code:

- Latest building code.
- New hazard map. More refined (by coordinate not by zone)
- Covers RC buildings, RC prefabricated buildings, steel buildings, masonry buildings, timber buildings, cold form steel buildings, high rise buildings, base-isolated buildings, evaluation and retrofitting existing buildings.
- It does not cover other type of structures, such as, historical structures, lifeline structures, coastal and port structures.
- Account for the vertical spectra



2018 Turkish building code:

- Multiple design earthquake shaking intensities
  - DD-1: 2/50 hazard level. RT = 2475 years.
  - DD-2: 10/50 hazard level. RT = 475 years.
  - DD-3: 50/50 hazard level. RT = 72 years.
  - DD-4: 68/50 hazard level. RT = 43 years.
- Account for multiple soil conditions:
  - ZA, ZB, ZC, ZD, ZE and ZF
- Account for soil amplification factors:

$S_{DS} = S_S F_s$ & $S_{D1} = S_1 F_1$

Local soil class	Local soil impact factor F_s for the short-period zone					
	$S_s \leq 0.25$	$S_s = 0.25$	$S_s = 0.75$	$S_s = 1.00$	$S_s = 1.25$	$S_s \geq 1.50$
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.3	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.2	1.1	1.0	1.0
ZE	2.4	1.7	1.3	1.1	0.9	0.8
ZF	A site-specific soil behavior analysis will be conducted.					

Local soil class	Local soil impact factor F_1 for the 1s-period zone					
	$S_1 \leq 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 = 0.50$	$S_1 \geq 0.60$
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.8	0.8	0.8	0.8	0.8	0.8
ZC	1.5	1.5	1.5	1.5	1.5	1.4
ZD	2.4	2.2	2.0	1.9	1.8	1.7
ZE	4.2	3.3	2.8	2.4	2.2	2.0
ZF	A site-specific soil behavior analysis will be conducted.					

2018 Turkish building code:

- Building use classes and important factors

Building Usage Class	Purpose of Building Usage	Building Importance Coefficient
BKS=1	a) Hospitals, dispensaries, health center, fire buildings, communication buildings and facilities, transportation stations and terminals, energy production and distribution facilities, first aid and disaster relief facilities, and provincial, district governorship and municipality administration buildings b) Schools, other educational buildings and facilities, dormitories, military barracks, prisons, etc. c) Museums d) Buildings stored toxic, explosive, flammable, etc..	1.5
BKS=2	Shopping malls, sport facilities, cinemas, theatres, concert halls, places of worship, etc.	1.2
BKS=3	Other buildings that do not fall within the definitions given for BKS=1 and BKS=2 (Residential and commercial buildings, hotels, building type industrial structures, etc.)	1.0

- Seismic design class (DTS)

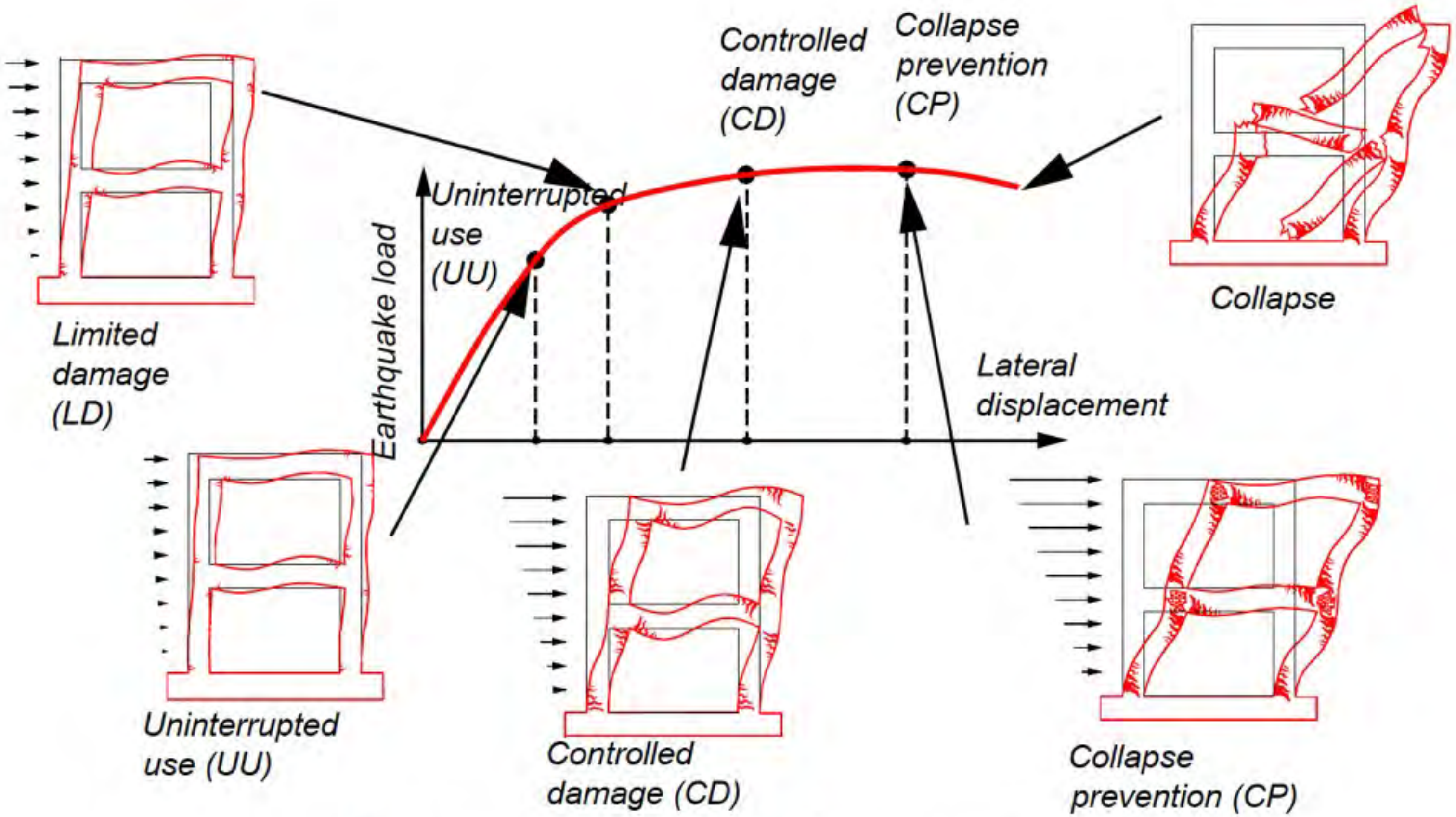
Short Period Design Spectral Acceleration Coefficient (S_{DS}) at Earthquake Ground Motion Level DD-2	Building Usage Class	
	BKS=1	BKS=2,3
$S_{DS} < 0.33$	DTS=4a	DTS=4
$0.33 \le S_{DS} \le 0.50$	DTS=3a	DTS=3
$0.50 \le S_{DS} \le 0.75$	DTS=2a	DTS=2
$0.75 \le S_{DS}$	DTS=1a	DTS=1

- Building height classes

Building High Class	Building Height Intervals Defined According to Building Height Categories and Earthquake Design Classes [m]		
	DTS = 1, 1a, 2, 2a	DTS = 3, 3a	DTS =4, 4a
BYS=1	$H_N > 70$	$H_N > 91$	$H_N > 105$
BYS=2	$56 < H_N < 70$	$70 < H_N \le 91$	$91 < H_N \le 105$
BYS=3	$42 < H_N < 56$	$56 < H_N \le 70$	$56 < H_N \le 91$
BYS=4	$28 < H_N \le 42$	$42 < H_N \le 56$	
BYS=5	$17.5 < H_N \le 28$	$28 < H_N \le 42$	
BYS=6	$10.5 < H_N \le 17.5$	$17.5 < H_N \le 28$	
BYS=7	$7 < H_N \le 10.5$	$10.5 < H_N \le 17.5$	
BYS=8	$H_N \le 7$	$H_N \le 10.5$	

2018 Turkish building code:

- Multiple Performance levels:



Structural performance level (Celep and Güler, 2020)

2018 Turkish building code:

- Defined performance objectives:

a) New RC Buildings, Precast and Steel Buildings
(Except High Rise Buildings – BYS ≥ 2)

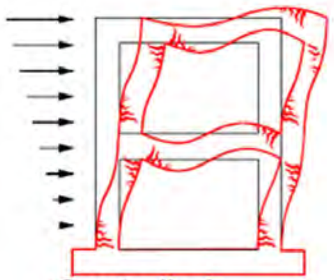
Earthquake Level	DTS = 1, 1a[(1)], 2, 2a[(1)], 3, 3a, 4, 4a		DTS = 1a[(2)], 2a[(2)]	
	Normal Performance Target	Evaluation/Design Approach	Advanced Performance Target	Evaluation/Design Approach
DD-3 (72 yrs)	-	-	LD	SGDT
DD-2 (475 yrs)	CD	DGT	CD	DGT[(3,4)]
DD-1 (2475 yrs)	-	-	CD	SGDT

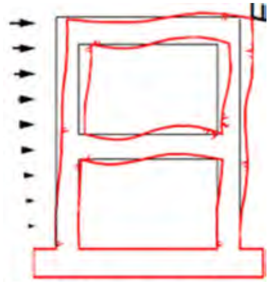
b) New or Existing High Rise Buildings - BYS = 1

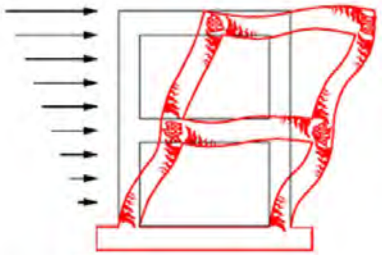
Earthquake Level	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performance Target	Evaluation/Design Approach	Advanced Performance Target	Evaluation/Design Approach
DD-4 (43 yrs)	UU	DGT	-	-
DD-3 (72 yrs)	-	-	LD	SGDT
DD-2 (475 yrs)	CD	DGT[(3)]	CD	DGT[(3,4)]
DD-1 (2475 yrs)	CP	ŞGDT	CD	SGDT

c) Existing RC Buildings, Precast and Steel Buildings
(Except High Rise Buildings – BYS ≥ 2)

Earthquake Level	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performance Target	Evaluation/Design Approach	Advanced Performance Target	Evaluation/Design Approach
DD-3 (72 yrs)	-	-	LD	SGDT
DD-2 (475 yrs)	CD	SDGT	-	-
DD-1 (2475 yrs)	-	-	CD	SGDT


Controlled damage (CD)


Uninterrupted use (UU)


Collapse prevention (CP)

2018 Turkish building code:

- Defined performance objectives:

a) New base-isolated buildings- Superstructure

Earthquake Level	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performance Target	Evaluation/Design Approach	Advanced Performance Target	Evaluation/Design Approach
DD-2 (475 yrs)	LD	DGT	UU	DGT
DD-1 (2475 yrs)	-	-	-	-

b) Existing buildings to be retrofitting by base isolation- Superstructure

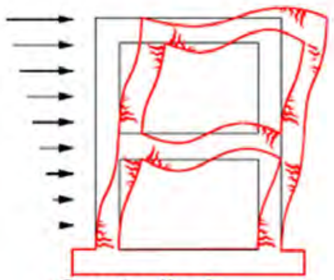
Earthquake Level	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performance Target	Evaluation/Design Approach	Advanced Performance Target	Evaluation/Design Approach
DD-2 (475 yrs)	CD	DGT	LD	DGT
DD-1 (2475 yrs)	-	-	-	-

c) New base-isolated buildings and Existing buildings to be retrofitting by base isolation - Base isolation system and substructure

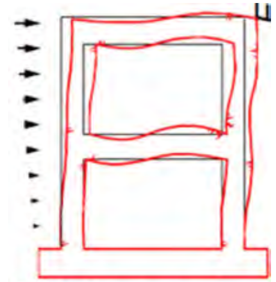
Earthquake Level	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performance Target	Evaluation/Design Approach	Advanced Performance Target	Evaluation/Design Approach
DD-2 (475 yrs)	-	-	-	-
DD-1 (2475 yrs)	UU	ŞGDT [1] – DGT[2]	UU	ŞGDT [1] – DGT[2]

[1] It will be applied for the isolation system

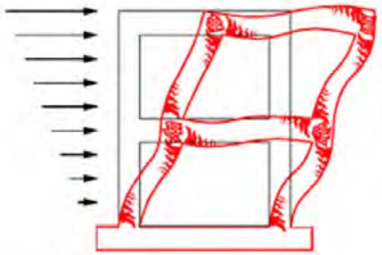
[2] It will be applied for substructure



Controlled damage (CD)



Uninterrupted use (UU)



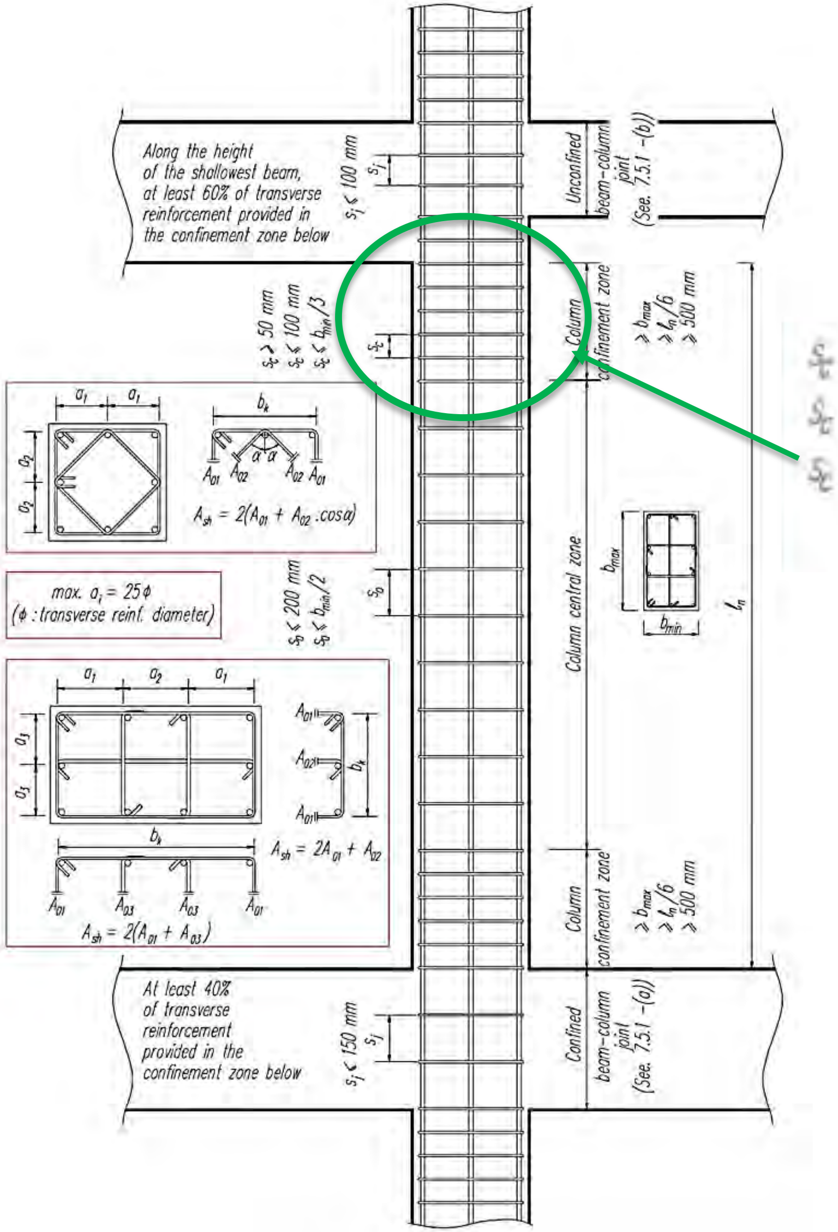
Collapse prevention (CP)

- Turkish Ministry of Health issue a law in 2013
  - Hospital Buildings, located in seismic zones 1 and 2 with number of bed capacity over 100 should be constructed with base-isolation.
  - As of 2017, there were 72 base-isolated structures (e.g., hospitals, schools, airport terminals) in Türkiye.

Reference:
Erdik, Mustafa, et al. "Seismic isolation code developments and significant applications in Turkey." *Soil Dynamics and Earthquake Engineering* 115 (2018): 413-437.

1998&2007 Turkish seismic design codes: **High-Ductility columns**

2018 Turkish seismic design code: **High-Ductility columns**

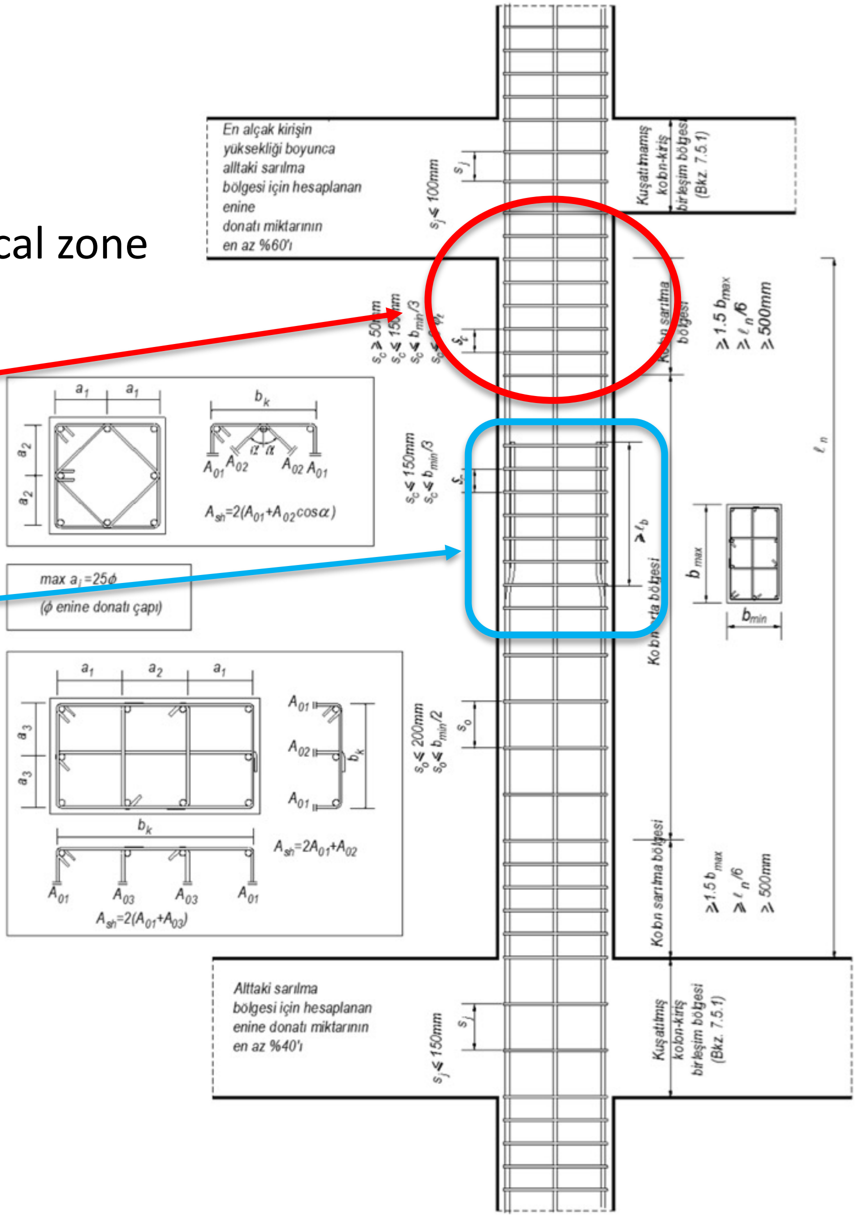


Tie spacing within the critical zone

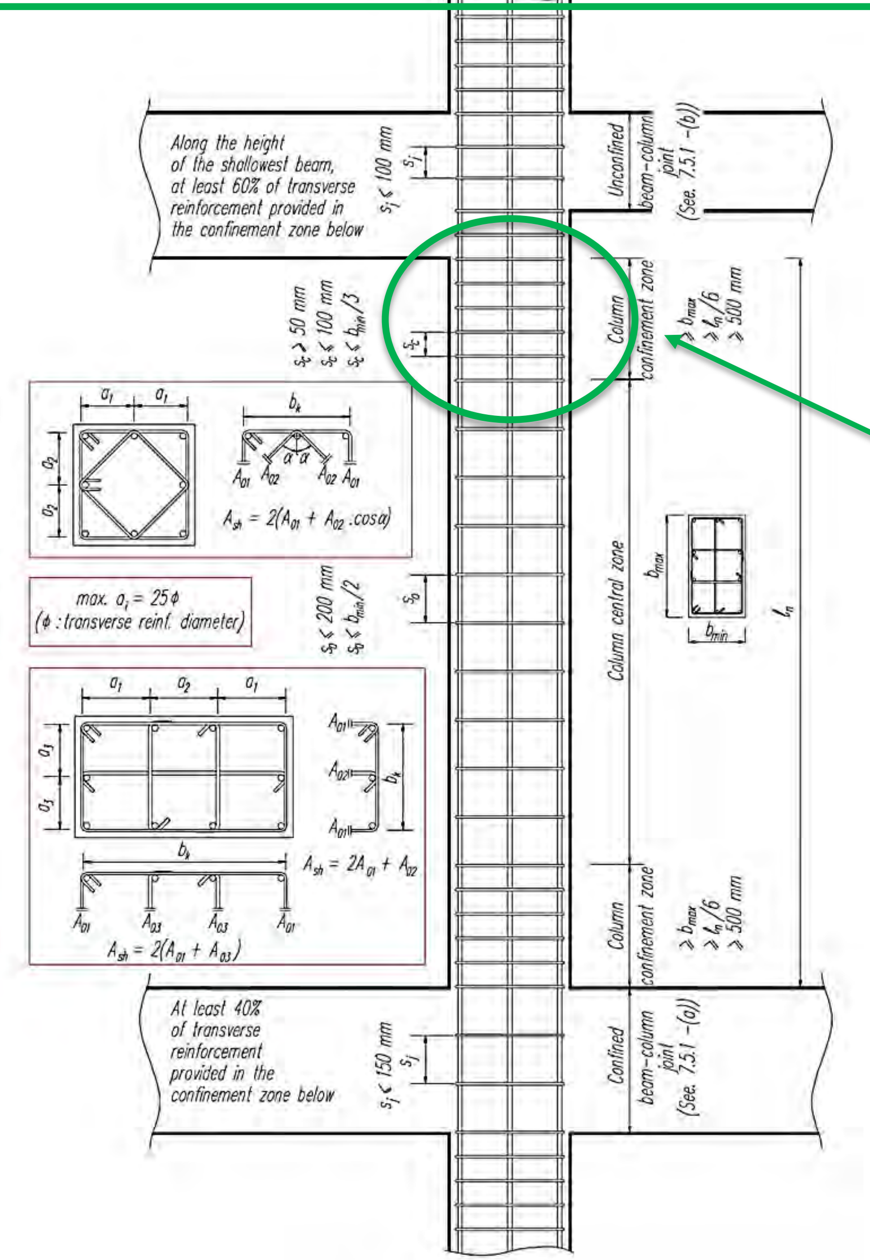
$s_c \geq 50$ mm
$s_c \leq 100$ mm
$s_c \leq b_{min}/3$

$s_c \geq 50$mm
$s_c \leq 150$mm
$s_c \leq b_{min}/3$
$s_c \leq 6\ \phi_\ell$

Lap splice requirements

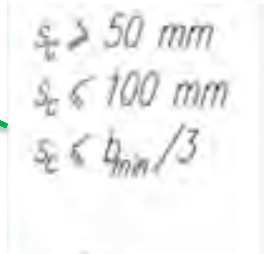


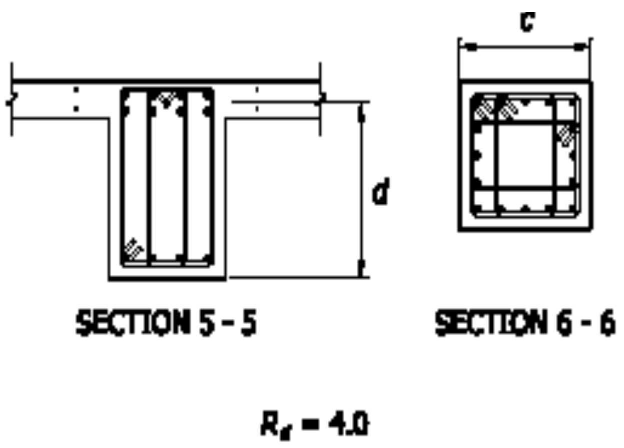
1998&2007 Turkish seismic design codes:
High-Ductility columns

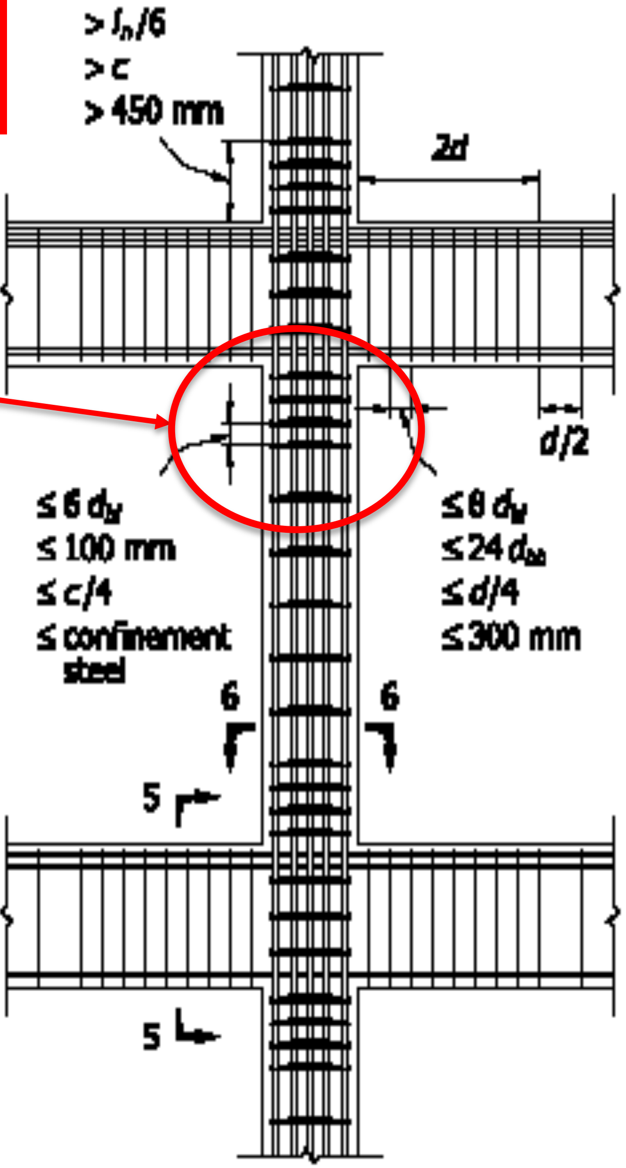


CSA A23.3-14 CSA A23.3-14 design standard
Ductile moment-resisting frames (Rd=4.0)

Tie spacing within the critical zone

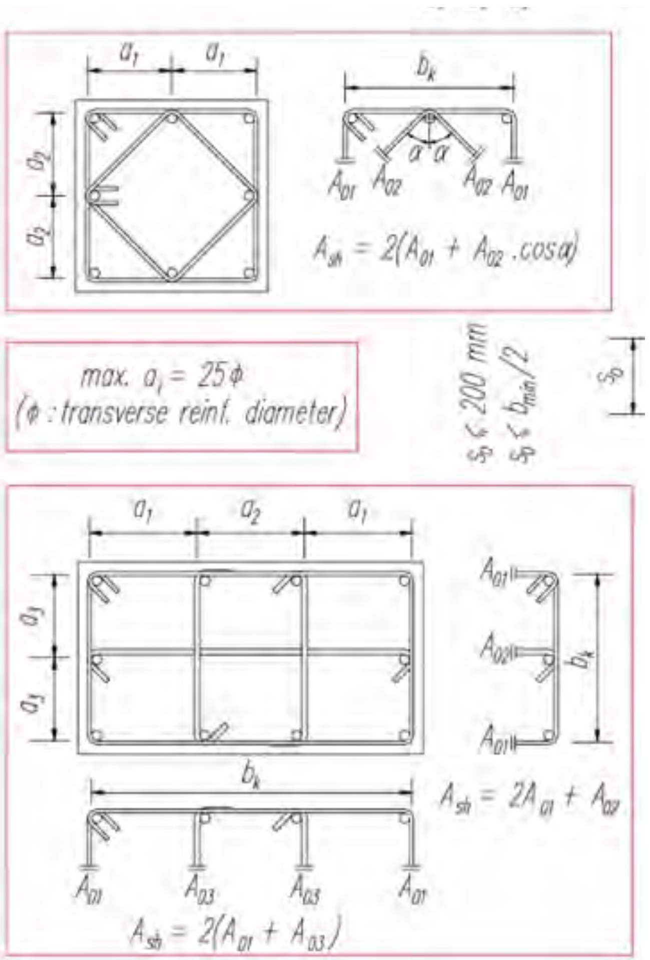




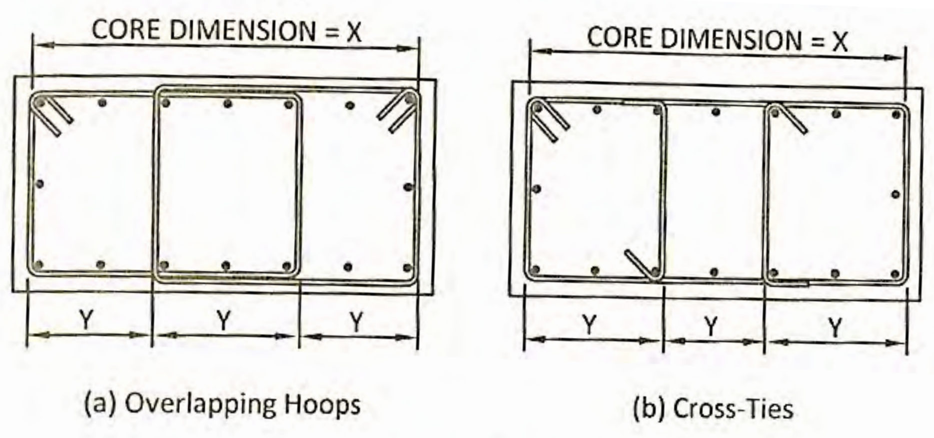


1998&2007 Turkish seismic design codes:
High-Ductility columns

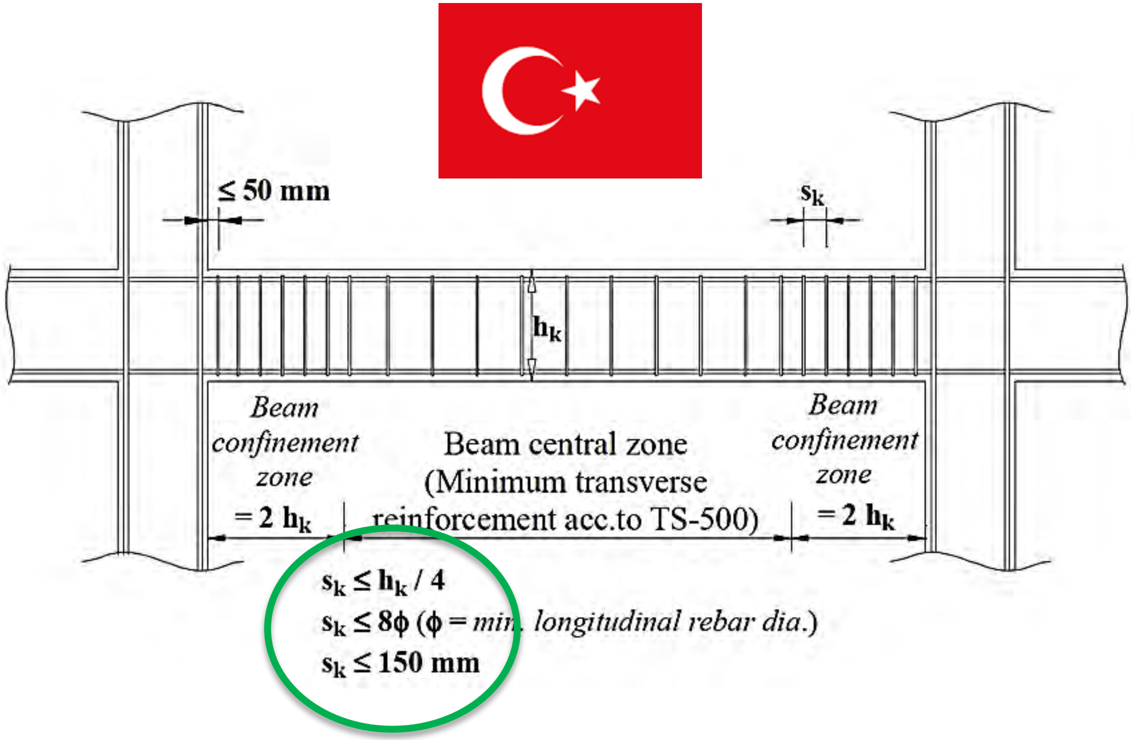
CSA A23.3-14 design standard
Ductile moment-resisting frames (Rd=4.0)



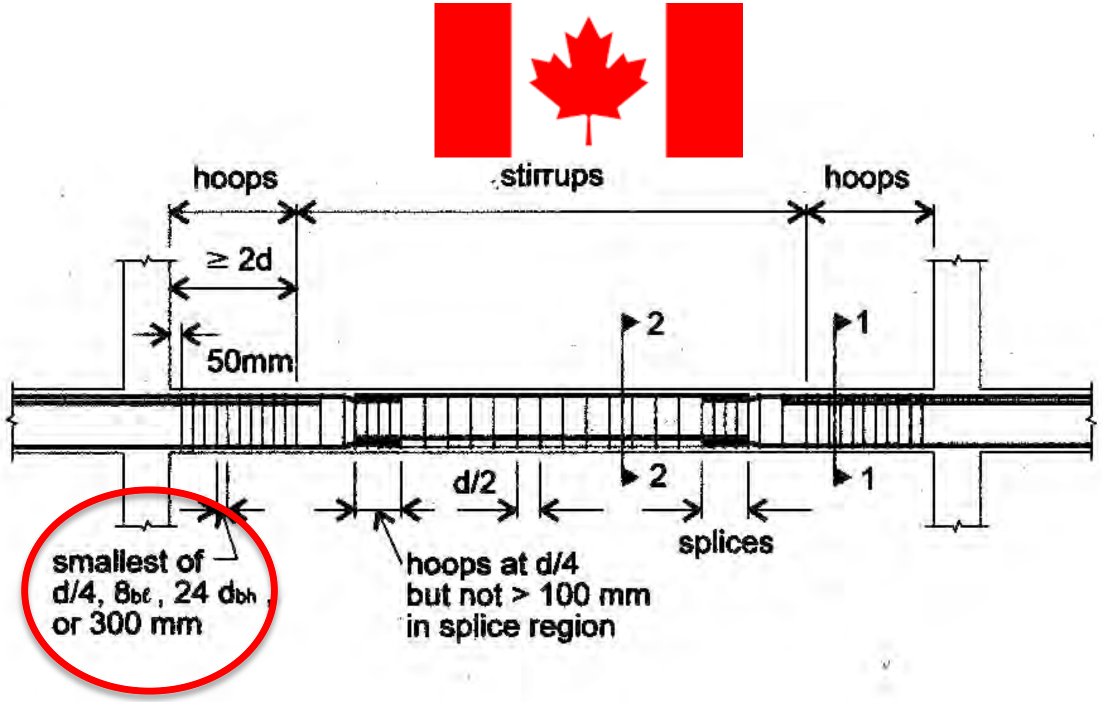
Detailing of column ties



1998&2007 Turkish seismic design codes:
High-Ductility beams



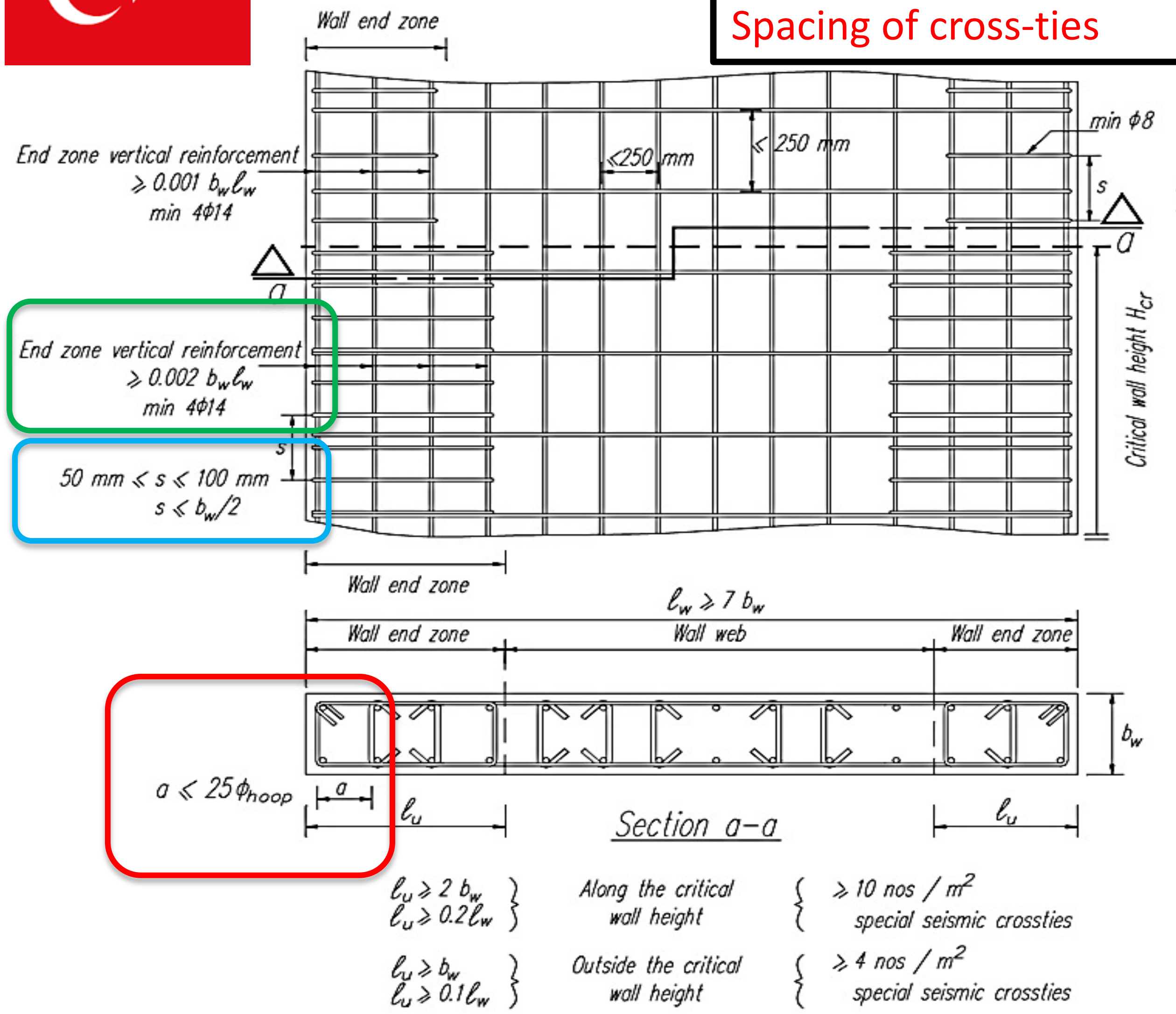
2014 Canadian standard CSA A23.3-14
Ductile moment-resisting frames (Rd=4.0)

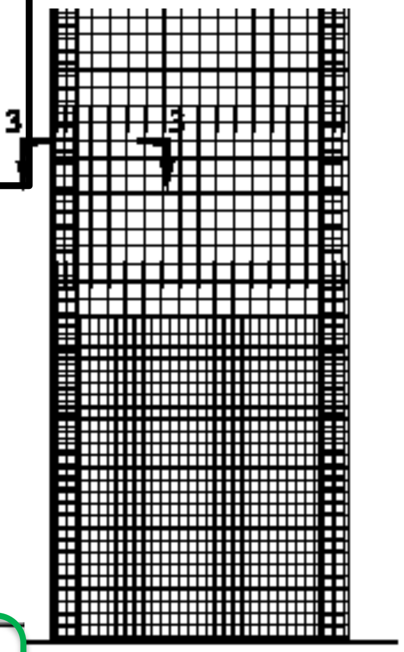


1998&2007 Turkish seismic design codes:
High-Ductility Walls

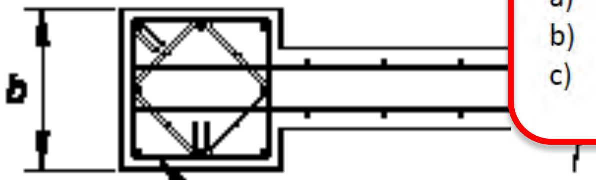
CSA A23.3-14 design standard
Ductile shear walls (Rd=4.0)

Longitudinal steel area – boundary elements
Spacing of ties – plastic hinge zone
Spacing of cross-ties





$A_s \geq 0.0015\ b_w \ell_w$
$A_s \leq 0.06$ x area of concentrated reinforcement region



Cross-ties (buckling prevention ties) – spacing:

a) six longitudinal bar diameters;
b) 24 tie diameters;
c) one-half of the least dimension of the member.

Hoops @ s ≤ 6 d_b
≤ 24 d_{bb}
≤ b/2

4. Performance of Residential Buildings

Svetlana Brzev, PhD, PEng, FEC, Adjunct Professor, Department of Civil Engineering, University of British Columbia

OUTLINE

- Construction practice
- Design codes – implications on the seismic performance of RC buildings
- Causes of damage and failure: typical examples
- Conclusions

RESIDENTIAL BUILDINGS: CONSTRUCTION PRACTICE (1/2)

Reinforced concrete (RC) construction prevalent in urban settlements.

- Major construction boom of high-rise RC buildings started after 2000

Common building typologies:

- Mid-rise buildings (up to 6 storeys)
- High-rise buildings (usually 10 – 15 storeys)

RESIDENTIAL BUILDINGS: CONSTRUCTION PRACTICE (2/2)

Masonry construction found in historic areas of urban settlements, and in rural areas.

- **Usually low-rise buildings for single-family housing**
- **Mostly unreinforced masonry buildings, vulnerable to seismic effects**
- **Stone and adobe (mud) masonry buildings experienced damage.**

Focus of this presentation is on urban reinforced concrete residential buildings.



Credit: Şerife Ozata

SEISMIC DESIGN CODES – IMPLICATIONS ON THE DESIGN OF RC BUILDINGS

Turkish seismic design codes - published in 1998, 2007, and 2018

The corresponding standard for reinforced concrete design TS500 – published in 1981 and 2000 (R2003)

1998 Code – based on the 1996 seismic hazard map

- Prescribes nominal and high-ductility RC structures; the Capacity Design requirements introduced for the first time;
- Minimum column/beam dimension 25 cm (commonly used in practice);
- Shear walls – min thickness 20 cm; boundary elements required for high-ductility structures.

2007 Code – based on the 1996 seismic hazard map

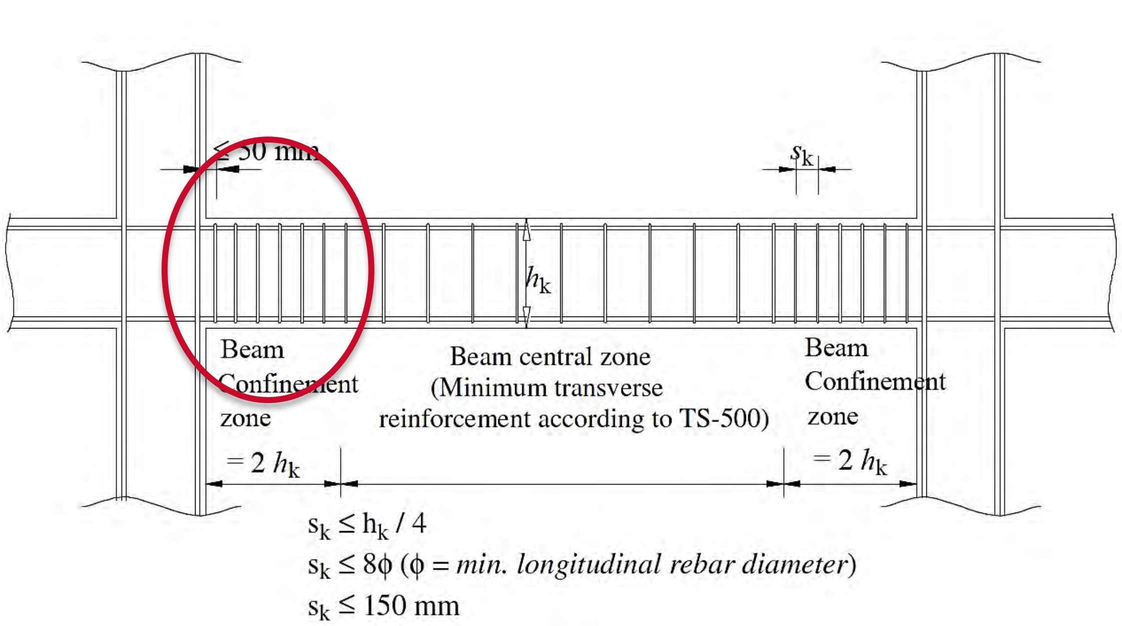
- No significant changes in terms of the design and detailing of RC structures compared to the 1998 code;

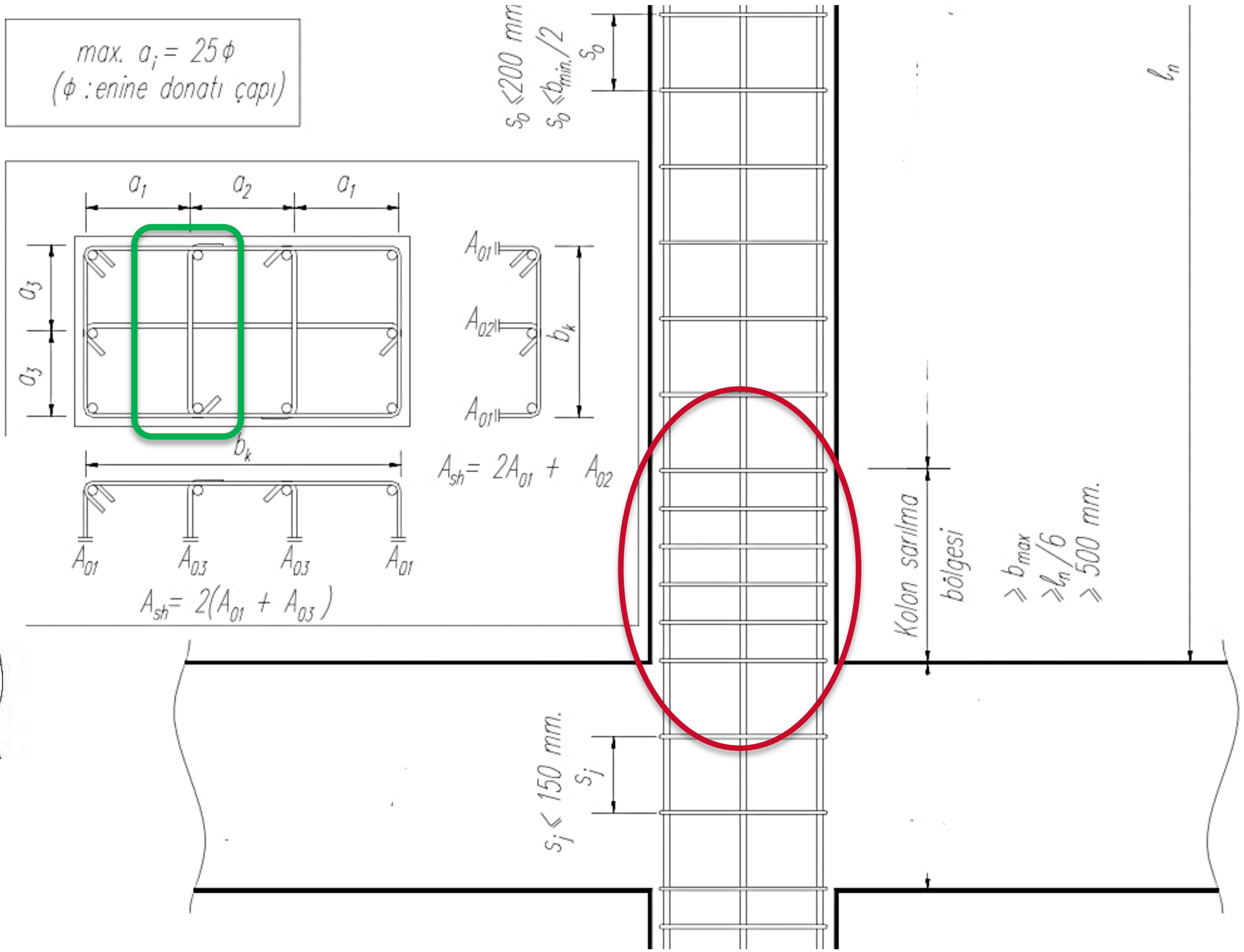
2018 Code – new seismic hazard map

- More advanced, modern code (major changes);

DETAILING REQUIREMENTS FOR HIGH-DUCTILITY RC COLUMNS (1998 AND 2007 CODES)

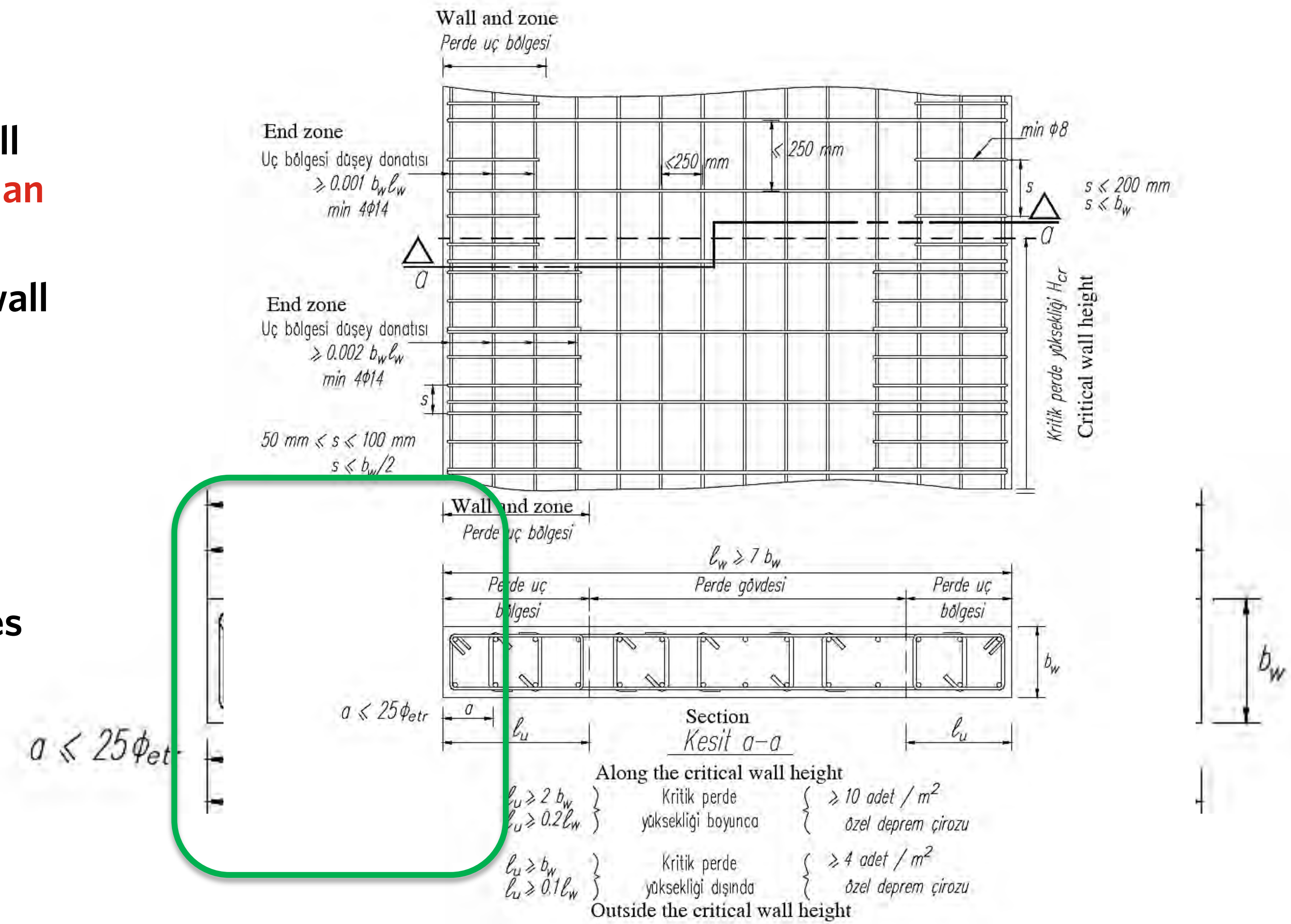
- 135-degree hooks for ties, except for cross-ties (90-degree + 135-degree hooks);
- Closer tie spacing within the end zones
- Lap splice length near beam-column joints increased by 25-50% relative to the basic development length.





DETAILING REQUIREMENTS FOR HIGH-DUCTILITY RC WALLS (1998 AND 2007 CODES)

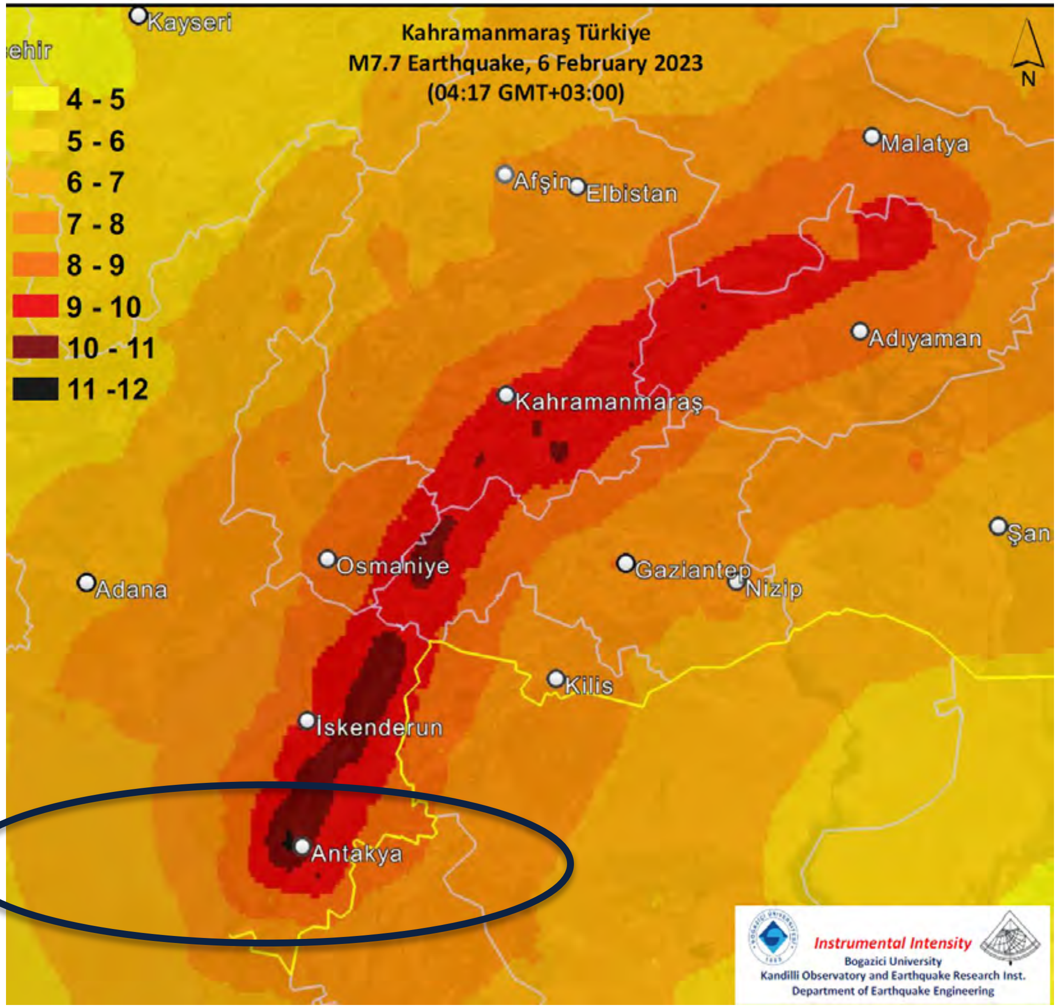
- Confined boundary elements: 0.2% reinforcement ratio (based on the total wall length) – for the plastic hinge zone (less than CSA A23.3)
- Min length of boundary elements = 0.2 x wall length (plastic hinge zone)
- Cross-ties prescribed to connect the reinforcement curtains
- 135-degree hooks for the ties in boundary elements;
- 90- and 135-degree hooks for the cross-ties (same as columns);



CAUSES OF DAMAGE - REINFORCED CONCRETE (RC) RESIDENTIAL BUILDINGS

Credit: SUZI-SAEE

1. Extremely high intensity of earthquake shaking (e.g. Antakya)
2. Deficiencies of the Seismic Force Resisting System (SFRS) for buildings with RC frames and shear walls
3. Configuration irregularities
4. Inadequate detailing of reinforcement in RC walls, columns, beams
5. Substandard quality of materials and construction



2. DEFICIENCY OF THE SEISMIC FORCE RESISTING SYSTEM (SFRS): EXCESSIVE FLEXIBILITY

Three types of SFRS for RC structures permitted by the 2007 Turkish code (3.2.1.1):

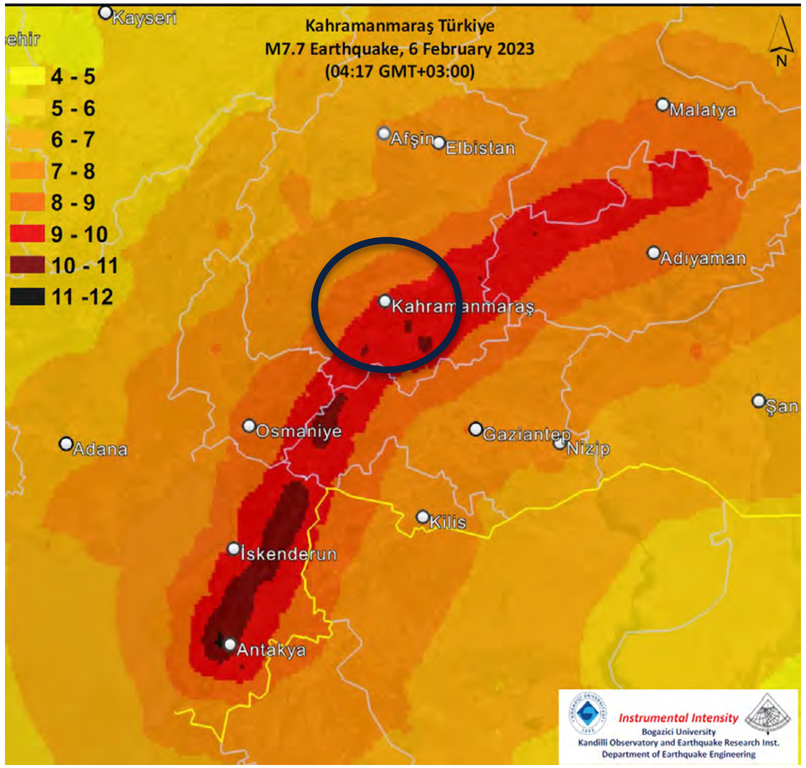
1) Moment frame system
2) Wall system
3) Dual frame-wall system

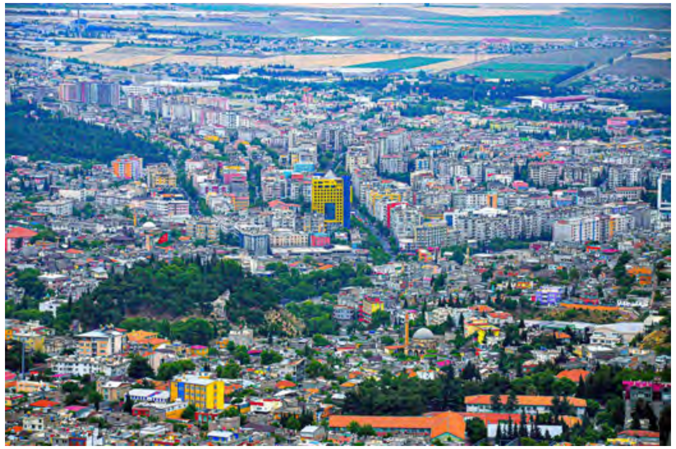
Wall system has been clearly defined by the code: the walls must contribute more than 75 % to the seismic base shear force – the remaining contribution (up to 25%) by the frame.

However, the minimum required contribution of the walls in a Dual frame-wall system has not been well defined – this is a code deficiency…

Excessive flexibility of the SFRS in taller RC buildings is mostly due to inadequate amount of shear walls!

EXCESSIVE MOMENT FRAME FLEXIBILITY – AN EXAMPLE OF A BUILDING COMPLEX IN KAHRAMANMARAŞ

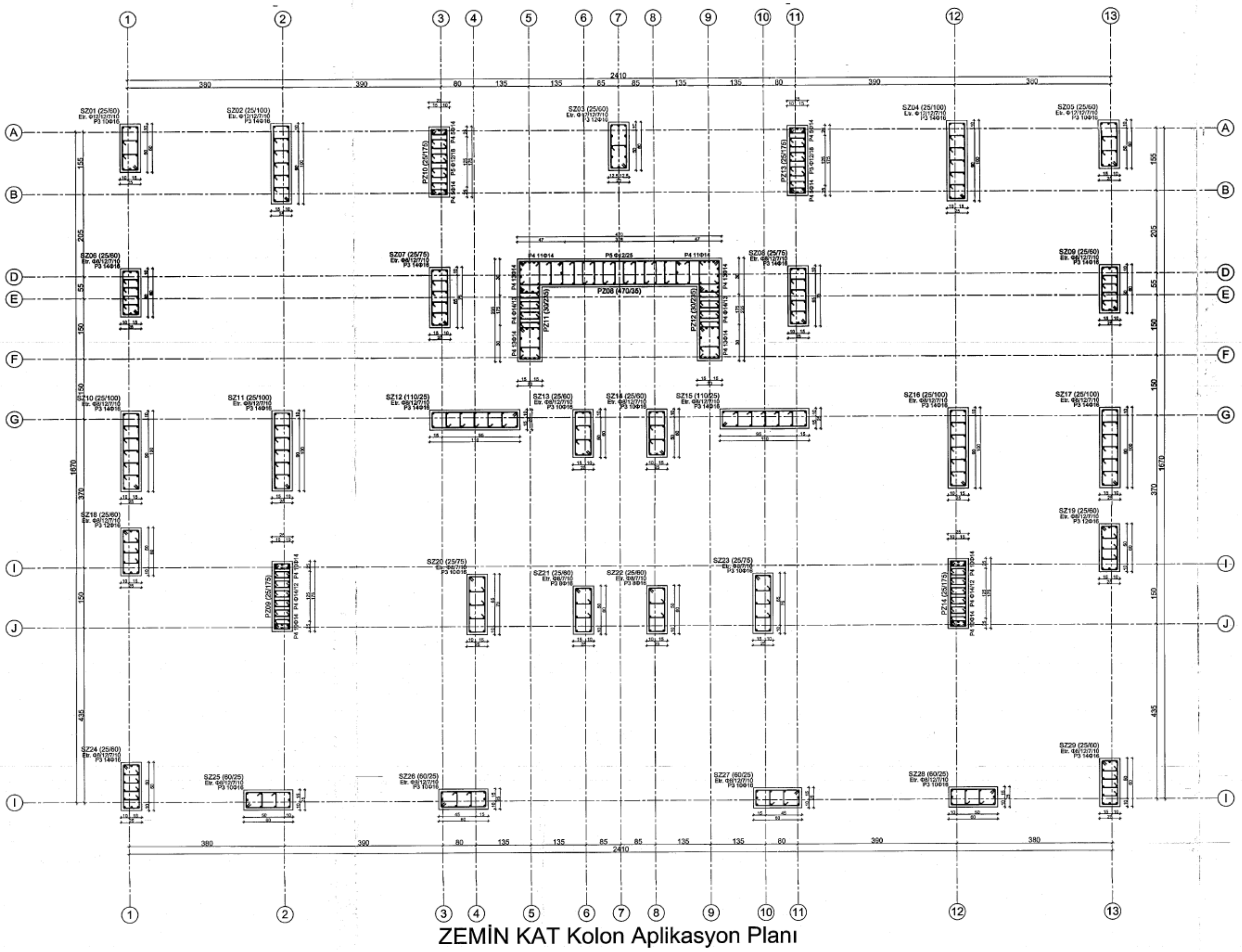




EXCESSIVE MOMENT FRAME FLEXIBILITY – COLUMN LAYOUT

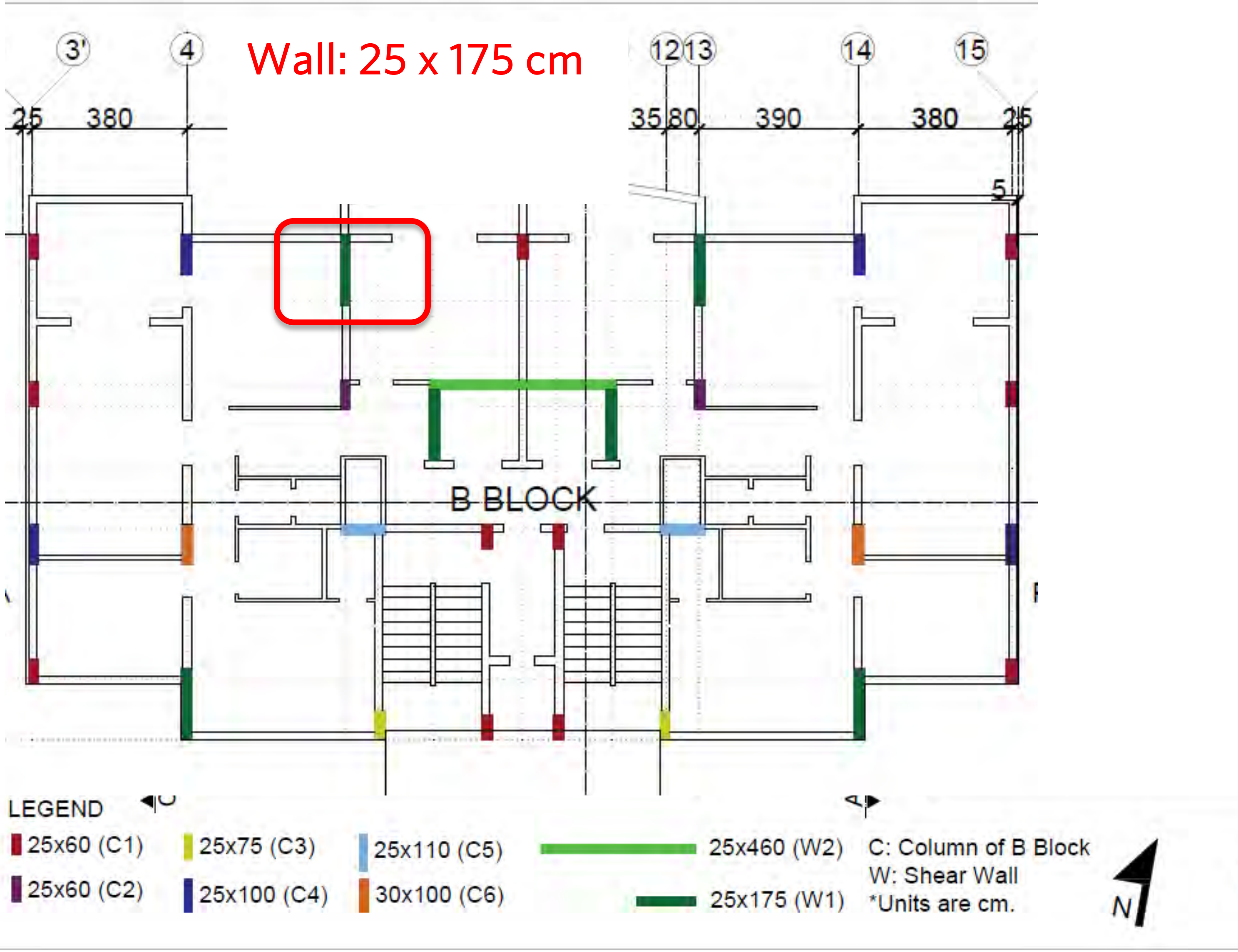
North

- Majority of the columns were aligned in the N-S direction
- Very few columns aligned in E-W direction
- Column layout inadequate for resisting lateral seismic forces in both directions



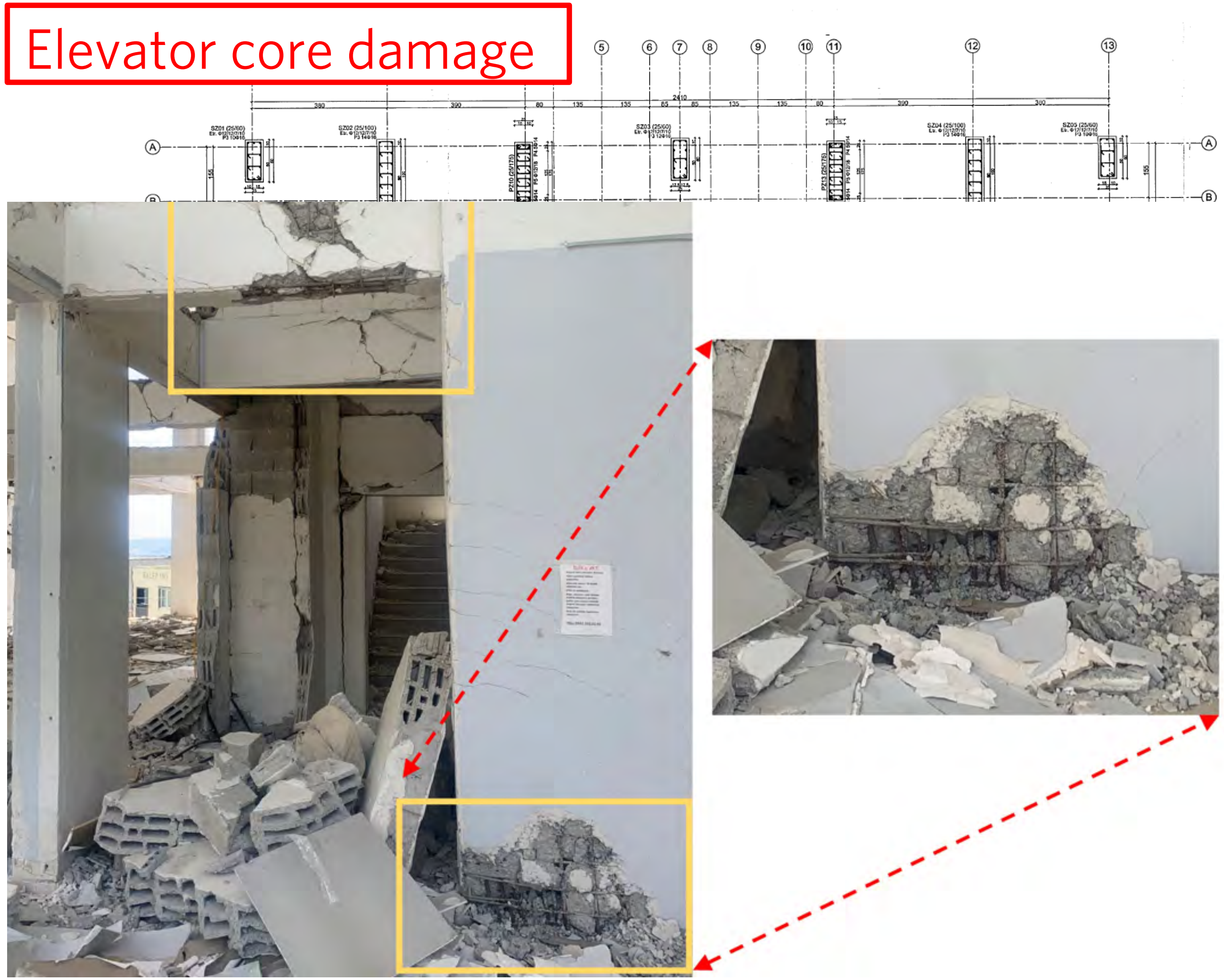
EXCESSIVE MOMENT FRAME FLEXIBILITY - INADEQUATE SHEAR WALLS

- Many tall RC buildings with moment frames have only a few shear walls.
- In some buildings, an elevator core is the only vertical element that acts like a shear wall.
- Typical columns have an oblique (rectangular) shape, with 25 cm width and depth ranging from 60-100 cm.
- When present, shear walls are relatively short (length less than 2 meters).
- Min required length/thickness ratio for RC shear walls = 7.0 (2007 code).



STRUCTURAL DAMAGE (1/2)

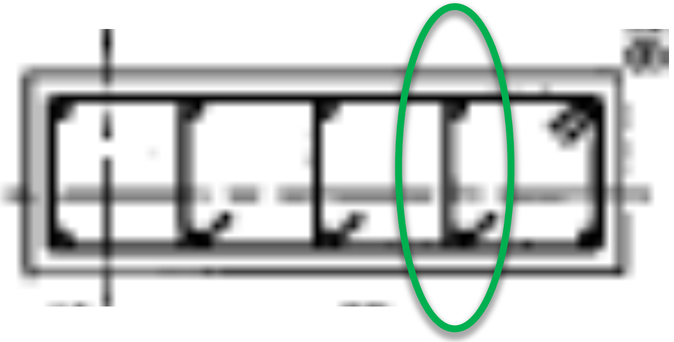
- Some of these buildings experienced structural damage due to inadequate lateral load-resisting capacity (as expected due to inadequate amount of walls)
- In many cases the extent of structural damage was minor to moderate
- Main structural elements: columns, beams, walls (e.g. elevator core)



STRUCTURAL DAMAGE (2/2)

- It is true that columns and beams were subjected to high seismic demand, but in many cases detailing of reinforcement was deficient

- Cross-ties missing from the constructed columns (although prescribed by the designers)!



Column damage

NON-STRUCTURAL DAMAGE (1/2)

Interior partition walls – higher floor levels

- **Extensive non-structural damage observed – particularly in masonry infills and partitions**
- **Damage observed both in exterior and interior infills/partitions**
- **Non-structural damage can be attributed to significant lateral displacements (drift) – due to excessive flexibility**

Exterior infills (interior view)

NON-STRUCTURAL DAMAGE (2/2)

- Another cause of damage for nonstructural elements – poor quality of masonry materials used for infill construction

- Hollow concrete blocks – made of low-strength material, known as bimsblock or briket in Turkish – similar to AAC blocks in North America (Aerated Autoclaved Blocks)

- Wall thickness ranges from 100 to 190mm

Compressive strength – only 1.7 MPa!

BlokBims® Entegre Tesisleri

BUILDING IRREGULARITIES

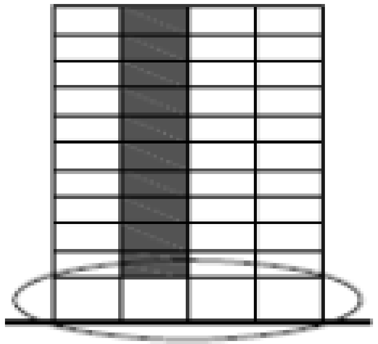
- Several surveyed buildings had an irregular configuration

- Common irregularities:

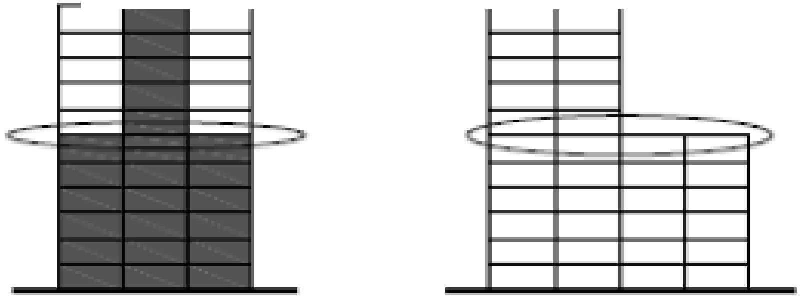
  - 1) Weak storey

  - 2) Vertical geometric irregularity
  - - Buildings with podiums
  - - Buildings with overhangs

Irregularity types according to the National Building Code of Canada



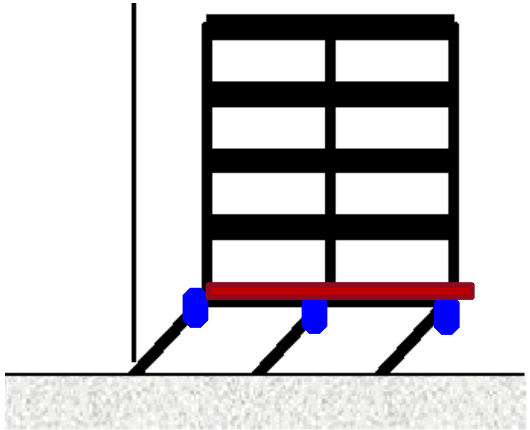
Type 6: Discontinuity in Capacity - Weak Storey



Type 3: Vertical Geometric Irregularity

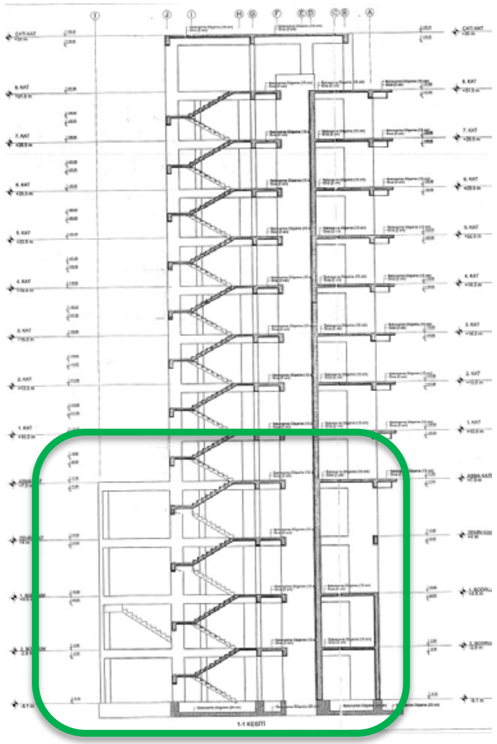
WEAK STOREY (AKA “SOFT STOREY”)

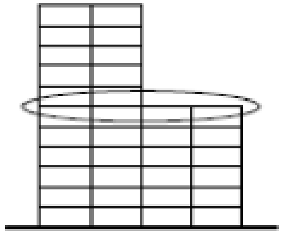
Many buildings in urban areas have mixed function, with the bottom floor intended for commercial use – leading to a “Soft storey” collapse mechanism



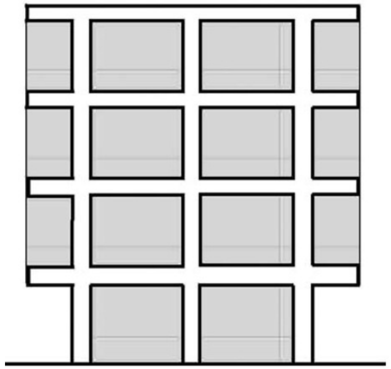
Credit: SUZI-SAEE

VERTICAL IRREGULARITY: PODIUM





VERTICAL IRREGULARITY: OVERHANGS



5.
Performance of schools and Impact of earthquakes on education sector

Bishnu Pandey, PhD. P.Eng. Faculty, BCIT
Allison Chen, P.Eng., P.E, Practice Advisor , Engineers and Geoscientists BC

Turkey Earthquake

Impact on the education sector

Nearly three in every 10 earthquake-affected households assessed across Türkiye reported having no access to education

(*Source : save the children report*)

Key facts

- 1842 facilities completely damaged
- 637 partially damaged
- 17951 with minor damage

(source : World Bank)

As of September 2023, 27% of affected households missing education of their children

Turkey Earthquake

Observations

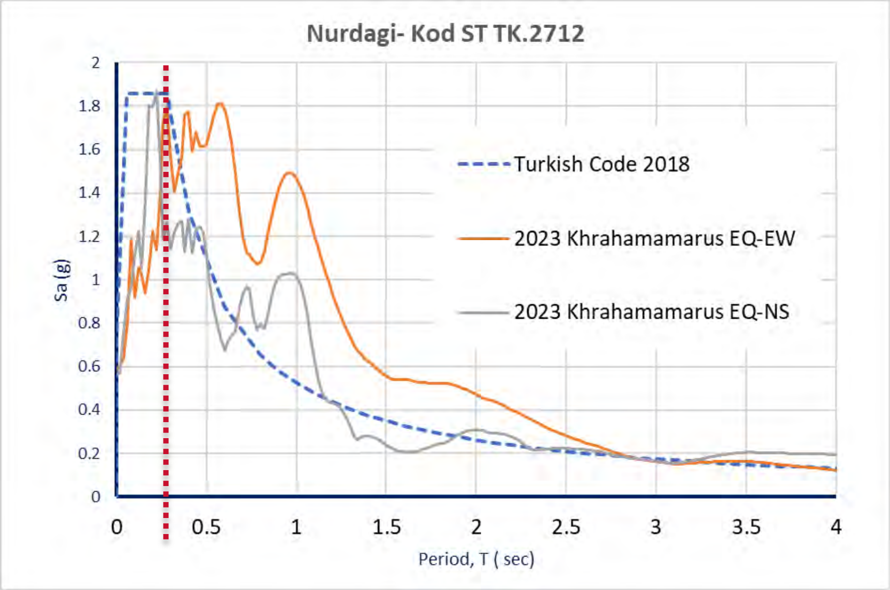
- Schools buildings fair better than residential buildings with minor or no damage (code enforcement)
- Most are frame structures with some shear walls incorporated
- Damages are mostly limited to non-structures and roof
- Some schools use gym for immediate shelter purpose to community
- Return rate of students was still low (by the time we visited)

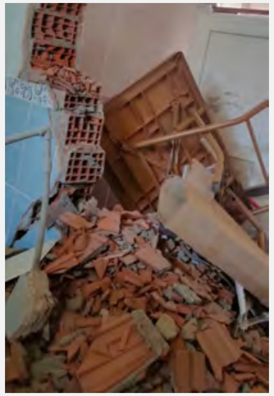
Performance of Schools – Case Study

1. Nurdagi

Before

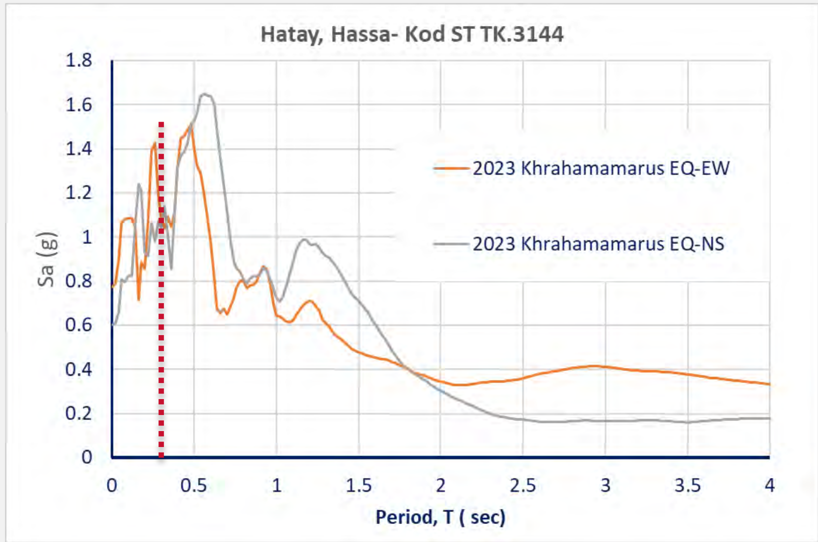
After





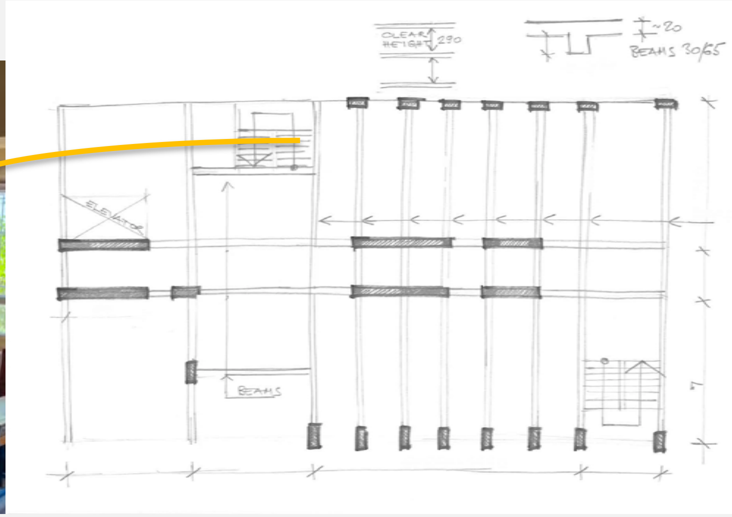
Performance of Schools – Case Study

2. Hatay (Hassa)



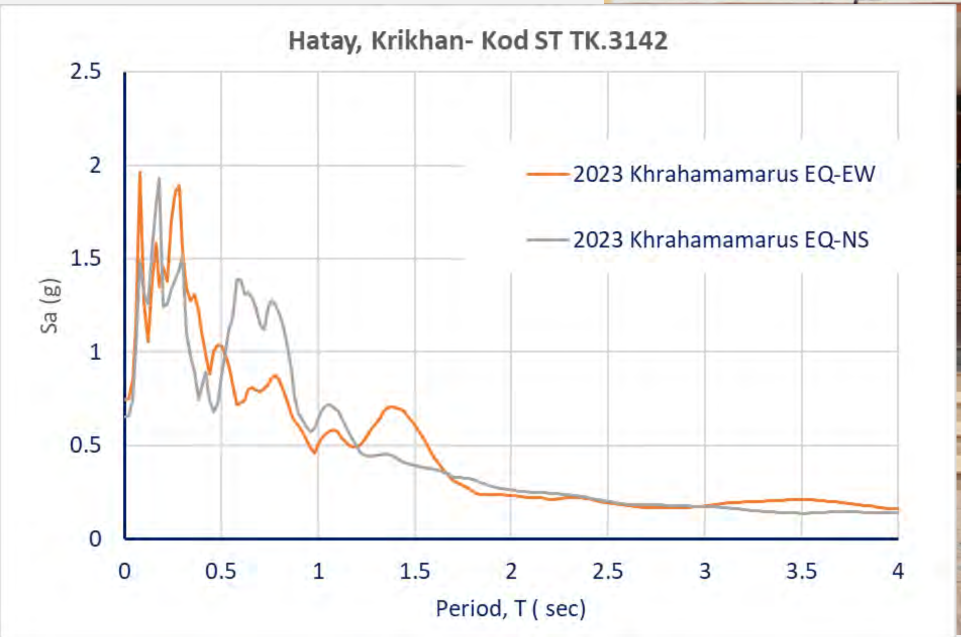
Residential homes in village

Community school



Performance of Schools – Case Study

3. Kirikhan (Kindergarten)



Fall of ceiling in the main lobby of kindergarten

Performance of Schools – Case Study

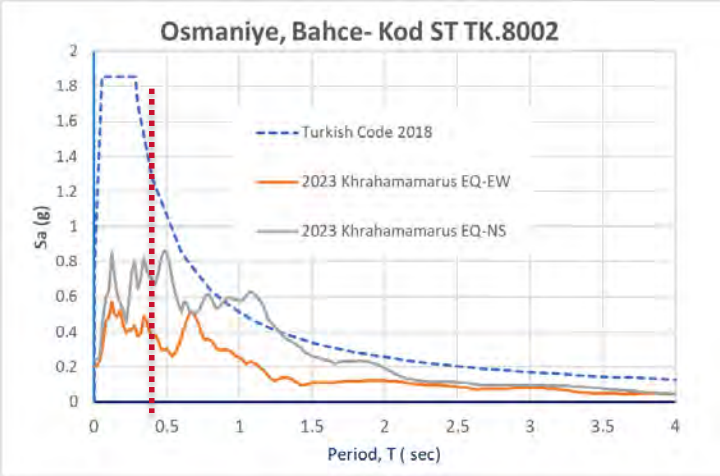
4. Hatay Kirikhan (Technical Institute)

Damage to Roof truss

Significant non-structural damage in lab

Performance of Schools – Case Study

5. Bache (Osmaniye)



No significant damage

Gym used for temporary shelter

Lessons on

Performance of schools and impact on education sector

- Robust design and construction of school buildings pay off
    - Provision of shear walls
- Non-structural damages render the school unusable
- Use of Gym block as a temporary shelter (post-EQ use)
- Even minor damage in school put children off the school
- Provision of cross school admission in the disaster plan

Drawing Parallels

Prioritizing performance of school buildings in Türkiye and BC

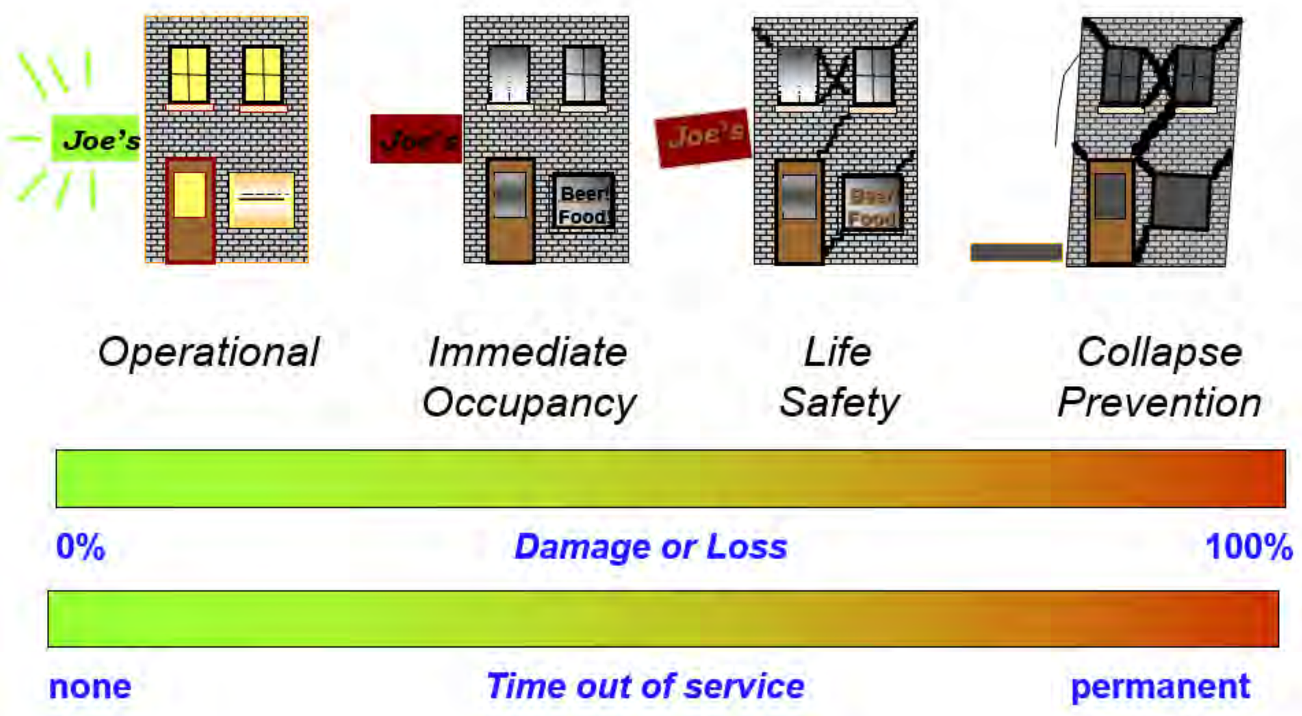
Turkiye	British Columbia
School buildings are "Building Use Class 1" (1.5 factor)	School buildings are "high importance" in BC Building Code (1.15 – 1.3 factor)
Policy to do pre-earthquake inspections of critical infrastructure and prioritization for strengthening (after 1999 Izmit EQ)	Ministry of Education's Seismic Mitigation Program (started in 2004)
Guidelines for Seismic Retrofitting of School and Hospital Facilities in Istanbul	Seismic Retrofit Guidelines for Low-Rise School Buildings
One of first priorities for post disaster building assessments – closed for 2 weeks	

What are the Seismic Retrofit Guidelines?

- Guidelines for the assessment and retrofit of existing low-rise school buildings in BC
- Starting in 2004, developed for the Ministry of Education by Engineers and Geoscientists BC and the University of British Columbia Civil Engineering Department
- 14 volumes with over 2000 pages
- Seismic Performance Analyzer (Analyzer I Version 4.0)

Two Underlying Goals for the Seismic Retrofit Guidelines

1. Implement seismic retrofits that achieve a life safety objective in a cost-effective manner
2. To adopt a common engineering approach to the seismic retrofit of school buildings



Underlying goal of the Ministry of Education to mitigate the risk of seismically deficient buildings in their inventory.

Liquefaction

Operational & Functional Components

Post-Earthquake Evaluation Guidelines

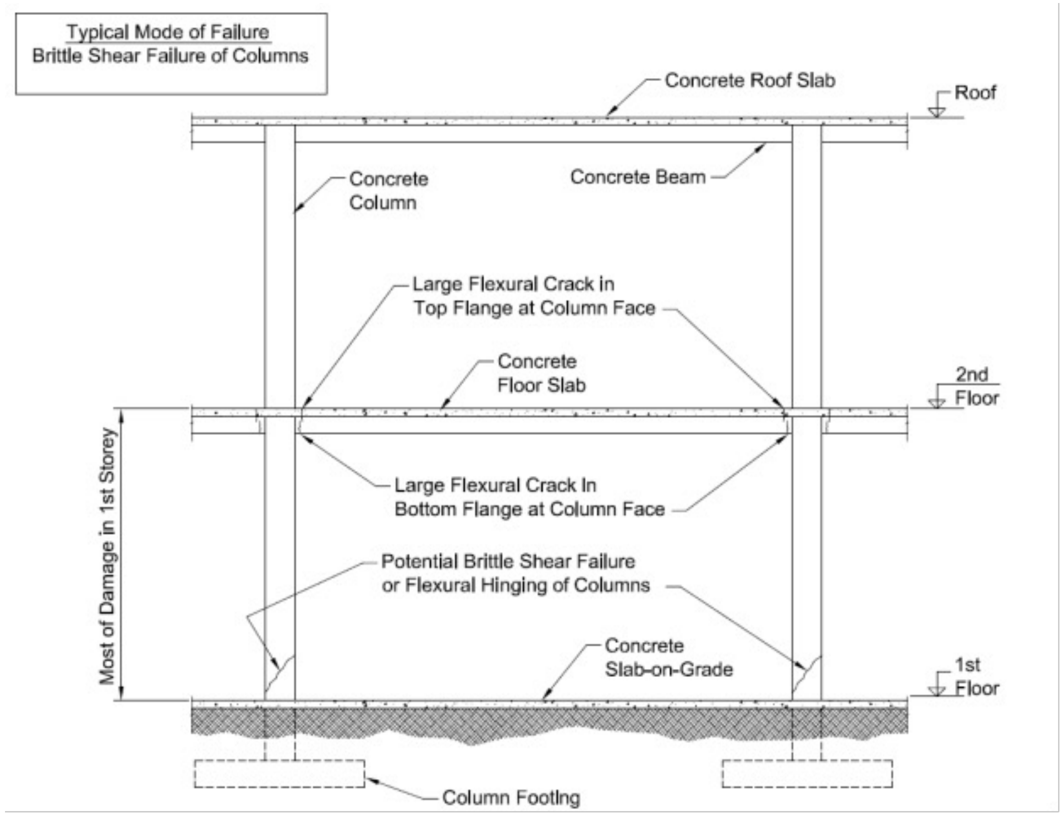
Key Components in the SRG that Address Issues Experienced in Turkiye

Table 2.1: Description of Four PSR Categories for Rating H1 High Risk Blocks for Moderate Level of Shaking

PSR Category	PSR Rating	PSR Category Description
P1	#1	(a) Total damage (b) Highest life safety consequences (c) Demolition post-event outcome
P2	#2	(a) High probability of total damage (b) High life safety consequences (c) Demolition probable post-event outcome
P3	#3	(a) Moderate probability of total damage (b) Moderate life safety consequences (c) High post-event repair costs
P4	#4	(a) Low probability of total damage (b) Low life safety consequences (c) Readily repairable post-event

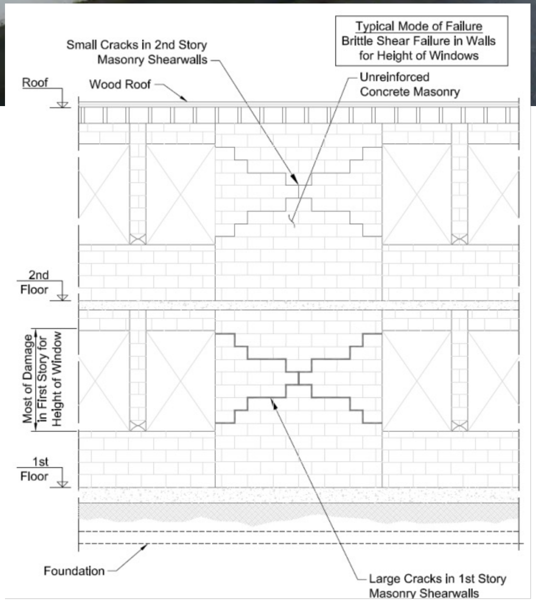
Seismic Mitigation Program Summary (September 2023)	
219	Schools Completed
12	Under Construction
5	Proceeding to Construction
17	Business Case Development
244	Future Priorities
497	**TOTAL PROJECTS**

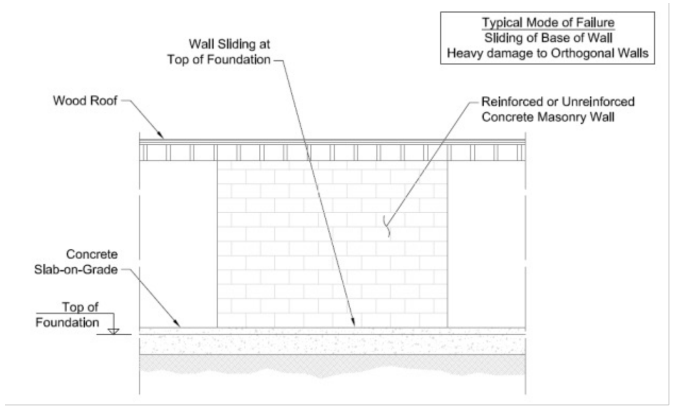
Non-ductile Concrete Frame



URM with Ineffective Roof

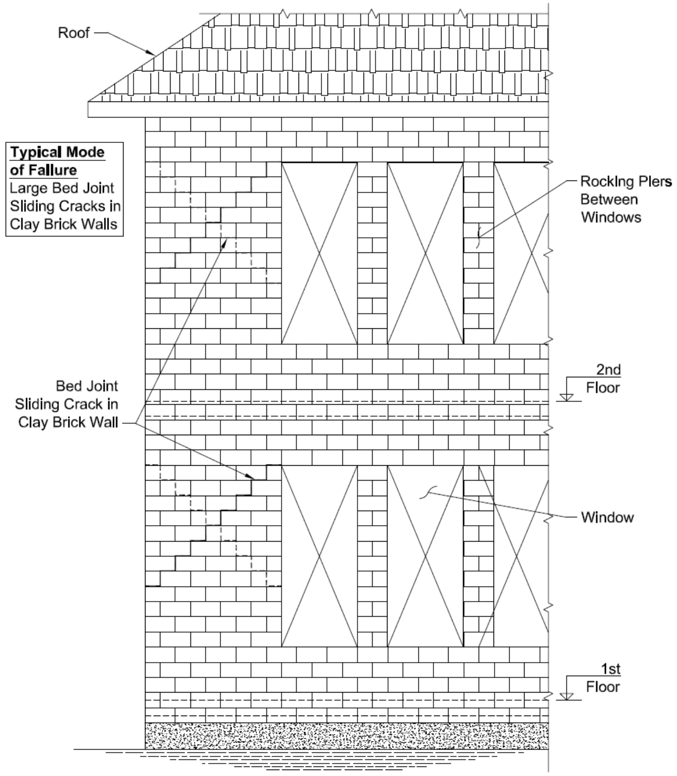
URM with Effective Roof





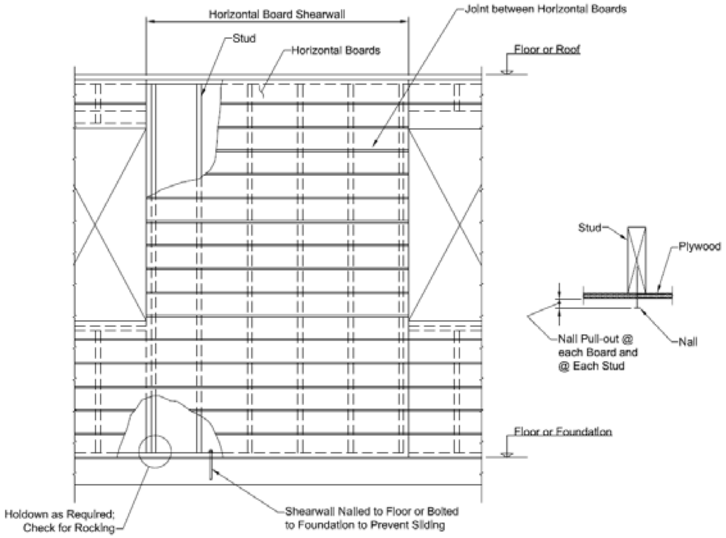
Clay Brick with Concrete Diaphragms

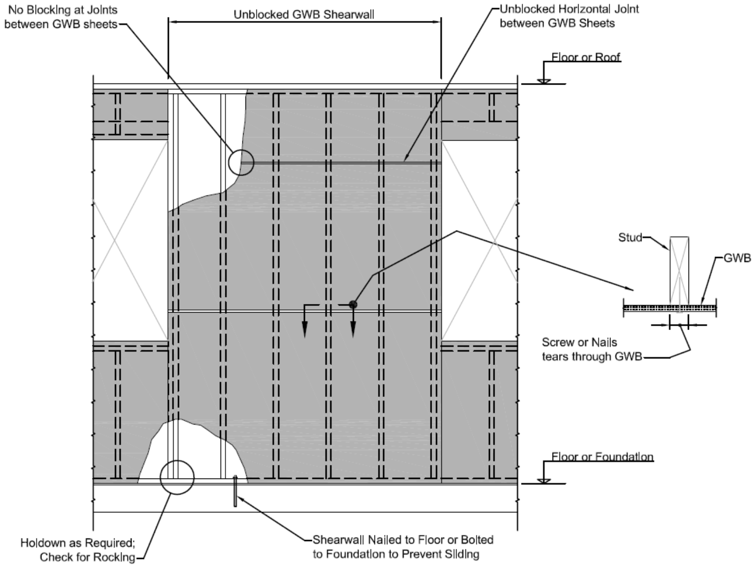
Clay Brick with Ineffective Roof



One Storey 1950s Wood Frame

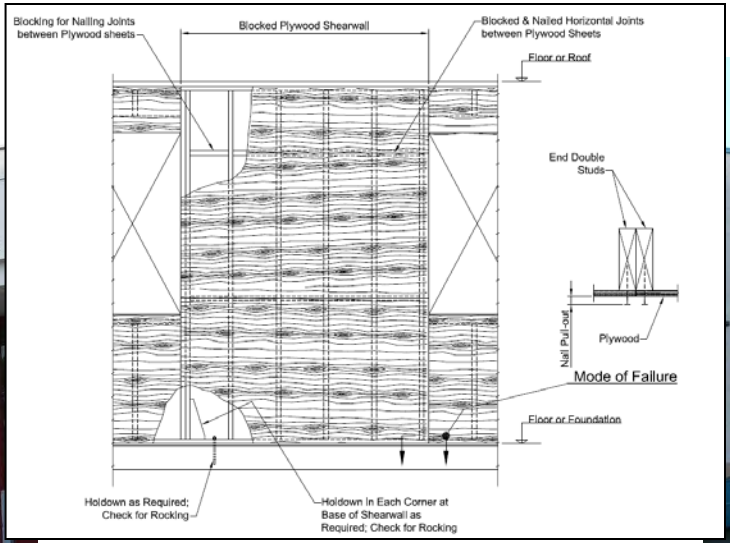
Two Storey 1950s Wood Frame





Wood Frame with Basement Pony Walls

Gym – Wood Frame



Final Words – Application to Low-Rise Buildings

SRG 2020 Training Workshop, May 5, 2023:

For seismic retrofits of existing buildings from "voluntary upgrades" through to "major renovations" the SRG is one methodology, that has been internationally peer reviewed, for achieving the acceptable alternative solutions identified in the Design Upgrade Level Tables provided in the revised Vancouver Building Bylaw

6. Performance of Health Care Facilities

Jeffrey Salmon, Ph.D., Structural EIT, Ausenco Engineering Canada Ltd.

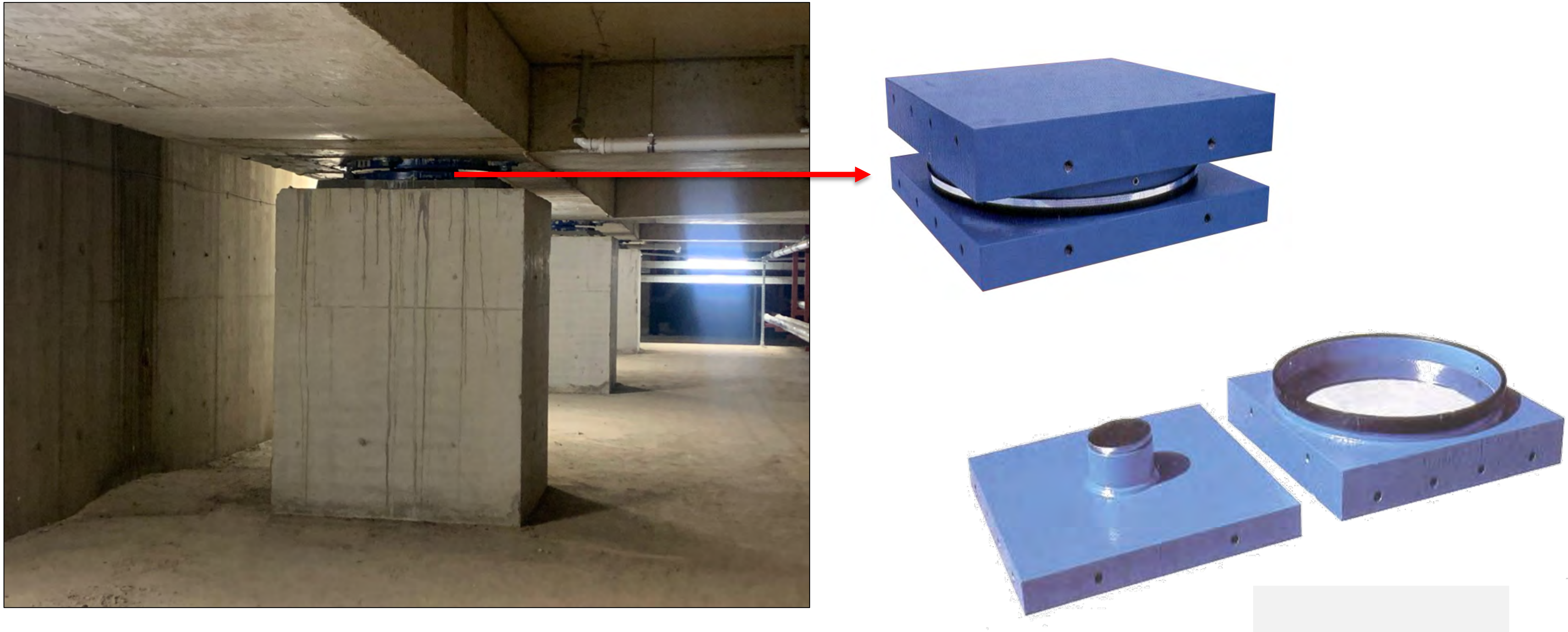
Base Isolation Legislation for Health Care Facilities in Türkiye

- Turkish Ministry of Health issue a law in 2013:
  - “Hospital Buildings, located in seismic zones 1 and 2 with number of bed capacity over 100 should be constructed with base-isolation.”
  - In 2017, a code on Seismic Isolation Design for Building Structures was prepared and enforced in January of 2019
- As of 2017, there were 72 base-isolated structures (e.g., hospitals, schools, airport terminals) in Türkiye

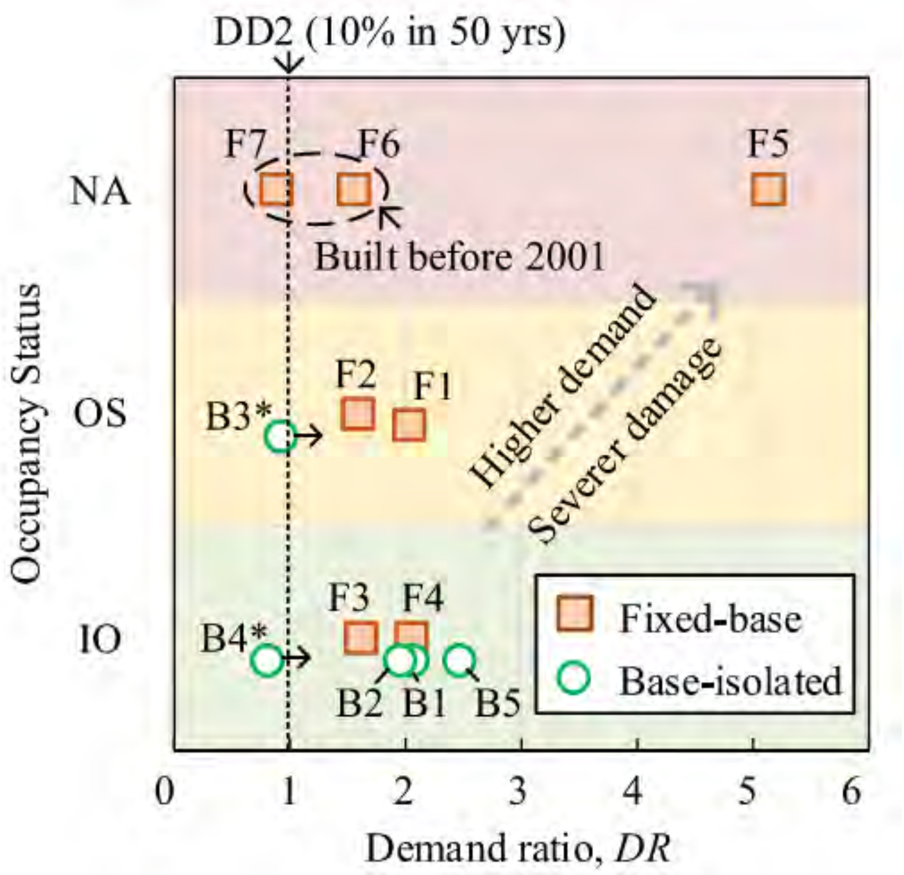
Reference:
Erdik, Mustafa, et al. "Seismic isolation code developments and significant applications in Turkey." *Soil Dynamics and Earthquake Engineering* 115 (2018): 413-437.

Base Isolated and Conventional Structure

Friction Pendulum Isolators



12 Hospitals Visited in the Earthquake Affected Areas

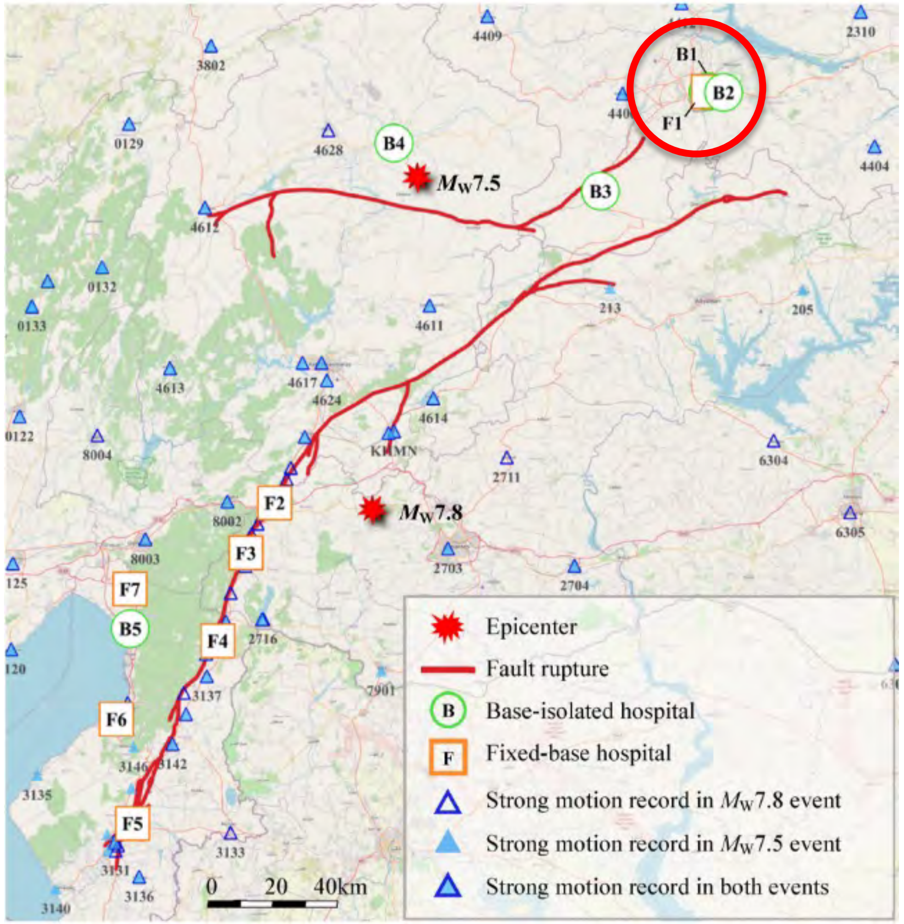


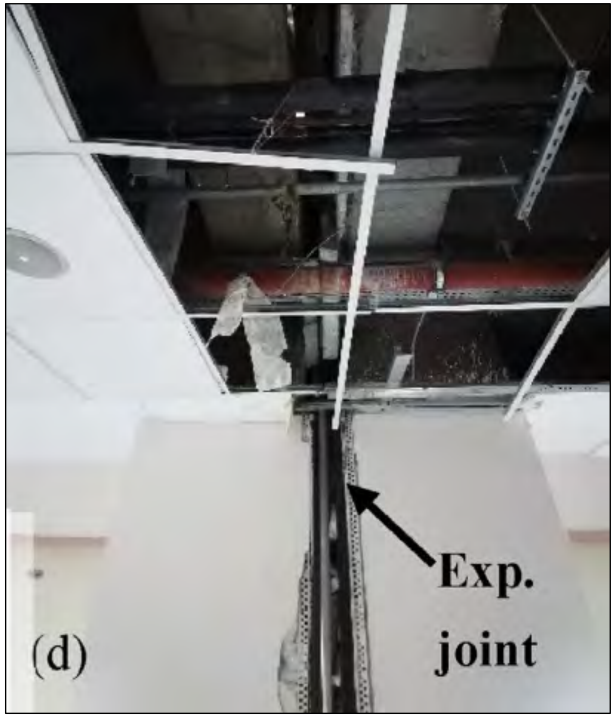
Reference:
Qu, Zhe, et al. "Rapid report of seismic damage to hospitals in the 2023 Turkey earthquake sequences." Earthquake Research Advances (2023)

Base-Isolated Hospital: Malatya

Reference:
Qu, Zhe, et al. "Rapid report of seismic damage to hospitals in the 2023 Turkey earthquake sequences." Earthquake Research Advances (2023)

Fixed-Base Hospital: Malatya





Reference:
Qu, Zhe, et al. "Rapid report of seismic damage to hospitals in the 2023 Turkey earthquake sequences." Earthquake Research Advances (2023)

Fixed-Base Hospital: Nurdagi

- Nurdagi population of 41,000
- Built in 2003, upgraded in 2015
- Hospital was out of service; significant non-structural damage.

Google Maps – May 2021

June 5, 2023

Fixed-Base Hospital: Nurdagi

Fixed-Base Hospital: Nurdagi

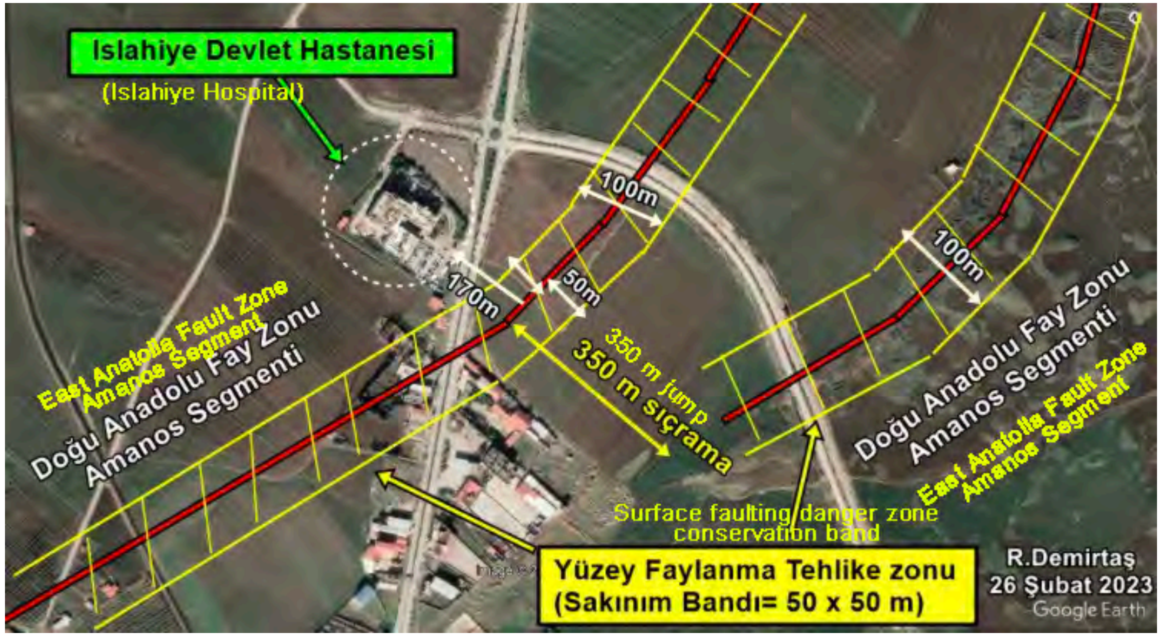
Fixed-Base Hospital: Islahiye

- Islahiye population of 67,650
- Hospital is located roughly 100 m from the fault line
- Hospital remained operational after the earthquake

Google Maps – November 2022

June 5, 2023

Fixed-Base Hospital: Islahiye



Reference:

Dr. Ramazan Demirtas [@Paleosismolog]. Images of Islahiye hospital. X. February 26, 2023. https://twitter.com/Paleosismolog/status/1633621597977210880

Base-Isolated Hospital: Malatya

- Malatya population of 797,000
- 200-bed hospital
- Hospital was operational during and after the EQ

Base Isolated Hospital

Hospital built in the 1930s.

Base-Isolated Hospital: Malatya

Base-Isolated Hospital: Malatya

Hospital has 5 back-up generators and additional purifying systems

Base-Isolated Hospital: Malatya

Pumice-like material was used in the moat (crushable material)

Base-Isolated Hospital: Osmaniye

- Osmaniye population of 534,000
- Base-Isolated hospital
- 600-bed hospital
- Hospital under construction during the earthquakes; started operation after the EQ

Base-Isolated Hospital: Osmaniye

Base-Isolated Hospital: Osmaniye

Base-Isolated Hospital: Osmaniye

Flexible connections between at the interface between the isolated and superstructure and fixed substructure

General Observations

- The hospitals were subjected to significant ground shaking during the earthquakes

- Base isolated hospitals performed well and continued operation during and after the earthquakes
  - One base-isolated hospital suffered nonstructural damages and was closed – this was a result of filling the moat, which hindered the performance of the isolators

- Nonstructural damage in fixed-base hospitals resulted in their closure
  - Structural damage resulted in the closure of hospitals built before 2001

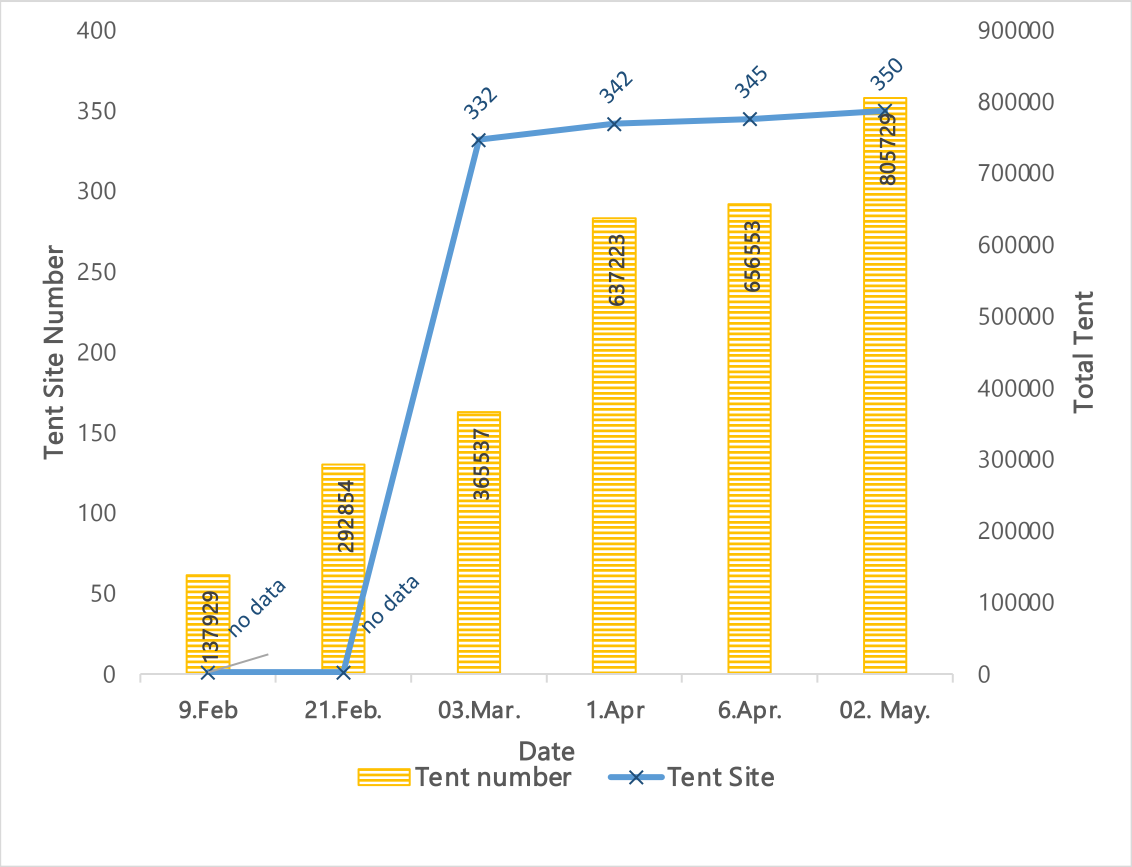
7.
Preparedness, Response, and Recovery

Allison Chen, P.Eng., P.E., Practice Advisor, Engineers and Geoscientists BC
Șerife ÖZATA, Ph.D., Architect, Research Assistant, Kirsehir Ahi Evran University
Jeffrey Salmon, Ph.D., Structural EIT, Ausenco Engineering Canada Ltd.

Response and Recovery Timeline (First 2 Months)

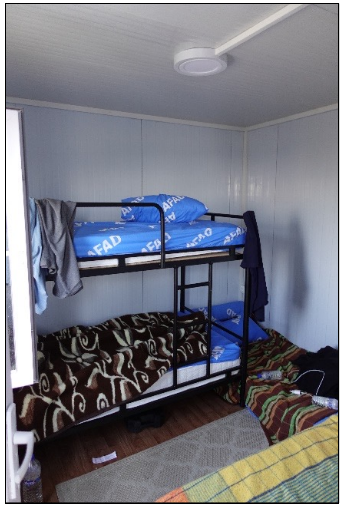
Response and Recovery

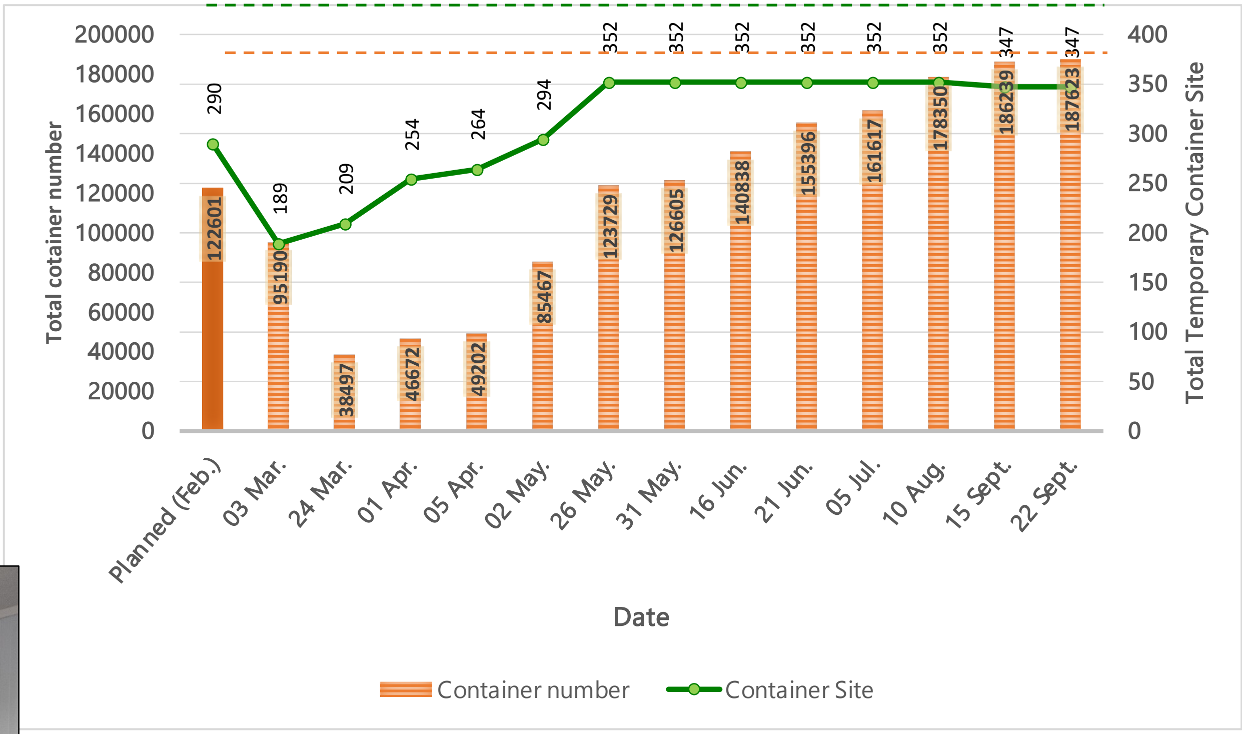
Tents and Shelter Areas



Response and Recovery

Containers and Shelter Areas





Response and Recovery - Containers and Earthquake Housing

Hatay Qatar Funded Container City

Earthquake Housing Const., Sept.'23

Karacay Container City

Hatay

Earthquake Housing Const., Sept.'23

Osmaniye

Container City

Sanliurfa

Earthquake Housing Const., June'23

Gaziantep

Container Area

Earthquake Housing Const., Sept.'23

Kilis

Container City

Earthquake Housing Const., June.'23

Response and Recovery

Containers and Earthquake Housing

Kahramanmaras

Eq. Housing Const., July. '23

Earthquake Housing Const., July. '23

Adiyaman K-2B Container City

Earthquake Housing Const., Aug. '23

Adiyaman

Malatya

Kahramanmaras Elbistan Container City

Malatya Dogansehir Container City, April '23

Diyarbakir

Diyarbakir Kayapinar Container City

Earthquake Housing Const., Sept '23

Adana

Eq. Housing Const., Aug. '23

Adana Şambayadı Temporary Shelter Area

Response and Recovery

Debris clean-up started on a large-scale February 23, 2023

– Material separated to be recycled

Reported Issues of the Response and Recovery

- Damaged airport runway in Hatay delayed rescue efforts; airport was reopened 6 days after the earthquakes.

- Rescue and aid delayed in some regions due to inaccessibility

- Mismanaged distribution of goods reported in some areas

- In some areas, water, sanitation and hygiene conditions need improvement

Damage Assessment

Response and Recovery

Damage Assessment

Post-earthquake damage assessment
is the process of observationally evaluating and classifying the damage caused
by the earthquake to the building by a technical team.

The assessment
- does not consider the potential damage that a larger earthquake in the region could cause
- is not the determination of whether the building is earthquake resistant or not.

The assessment methodology → rapidly applicable and straight forward
number of buildings requiring inspection and the shortage of qualified inspectors

The Damage Assessment Methodology has been developed by Prof. Dr. Alper İlki and his team (2021).
It has been used in many earthquakes to evaluate the damages in reinforced concrete (RC) and masonry structures.
+several adjustments and improvements to enhance its applicability.

It is accepted by Ministry of Environment, Urbanization and Climate Change (MoEUCC) as a general damage assessment method in crisis situations.

[1] Ilki, A., O. F. Halici, M. Comert, and C. Demir. 2021. The modified post-earthquake damage assessment methodology for TCIP (TCIP-DAM-2020). In Advances in assessment and modeling of earthquake loss, ed. S. Akkar, A. Ilki, M. Erdik, and C. Goksu, 85–107. Cham: Springer.

Damage Assessment System

Building Damage Categories

Undamaged Building

No earthquake damage

Dulkadiroğulları, Kahramanmaraş

Slightly Damaged Building

Minor damages

Bahçe, Osmaniye

Moderately Damaged Building

Certain decrease in the capacity

Nurdağı, Gaziantep

Heavily Damaged Building

Significant lost of pre-earthquake performance

Nurdağı, Gaziantep

Building to be Urgently Demolished

partial collapse, residual displacements

Kırıkhan, Hatay

Collapsed Building

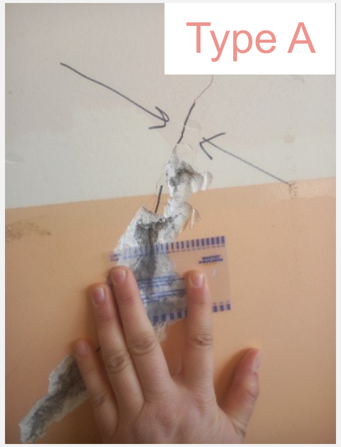
Complete collapse

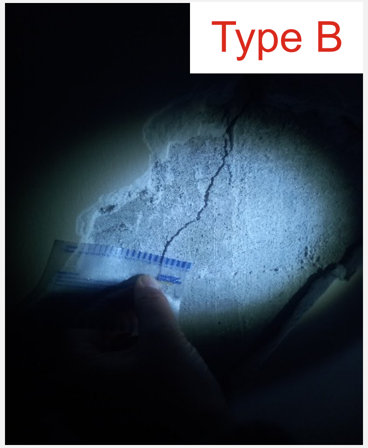
Kömürler, Gaziantep

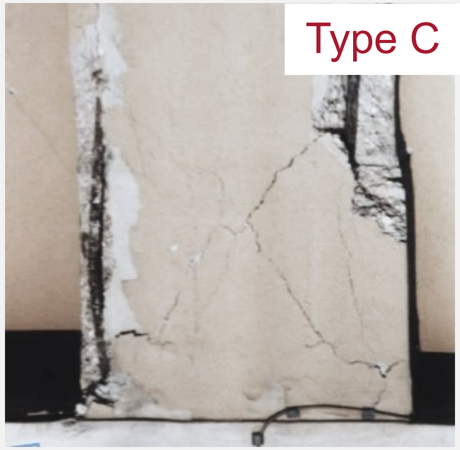
Damage Assessment System

Damage Categories for RC Members

Damage Category	Residual crack width (w)	Compression damage
Type 0	-	-
Type A	w≤ 0.5 mm	-
Type B	0.5≤ w≤ 3 mm	Cover crushing
Type C	> 3mm	Cover spalling
Type D	-	Buckling of reinforcement, core crushing residual displacement



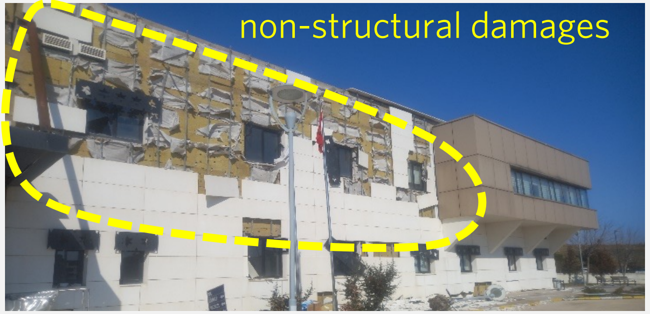


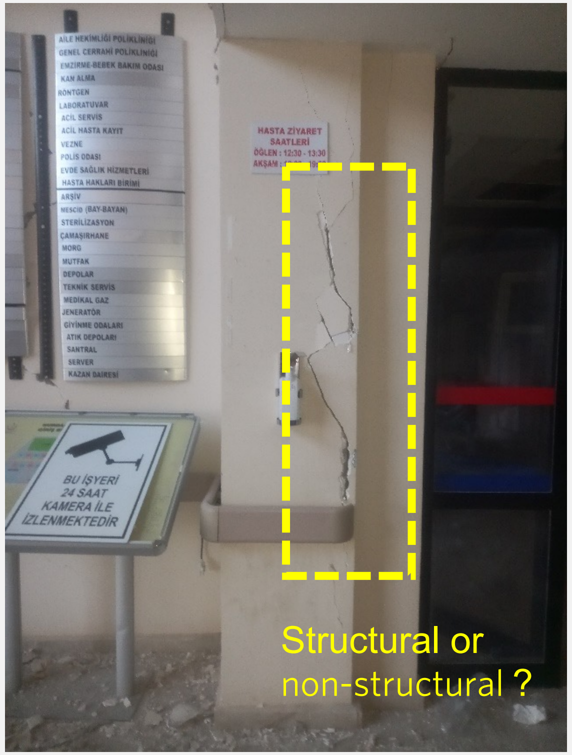


Damage Assessment System

Damage Assessment Algorithm

This algorithm consists of a two-stage procedure;
Exterior assessment and **Interior assessment**.





Damage Assessment System

Exterior Assessment

1. Is there total collapse?

Yes → Collapsed Building

No ↓

2. Is there partial collapse?

Yes → Building to be Urgently Demolished

No ↓

Continue…

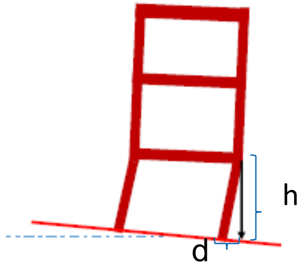
Damage Assessment System

Exterior Assessment

3. Is there any permanent horizontal residual displacement measured at any story in the building is greater than 1% of the corresponding story height?

Yes → >1% → Heavily Damaged Building

Yes → >3% → Building to be Urgently Demolished



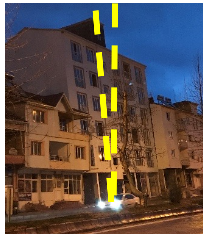
d/h >0.01

No ↓

4. Does the structure experience a rigid rotation exceeding 2° due to earthquake-induced settlements?

Yes → >2° → Heavily Damaged Building

Yes → >4° → Building to be Urgently Demolished



No ↓

Interior assessment

Damage Assessment System

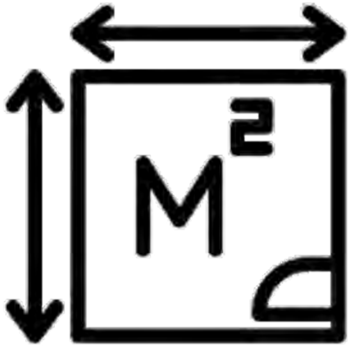
Interior Assessment

Three levels of interior inspection are possible depending on the *urgency of the inspection*, *extent of damage* in the city and *size of the building*:

- Detailed Assessment,
- Rapid Assessment,
- Assessment in Crisis Situations.

It is applicable for ;

- Low and mid-rise buildings ≤ 10 stories
- Plan area ≤ 800 m^2



*Initiate the assessment from the most damaged floor of the building.

Damage Assessment System

Interior Assessment

1. Is the number of columns or shear walls that have **Type D** damage equal to or bigger than 1?

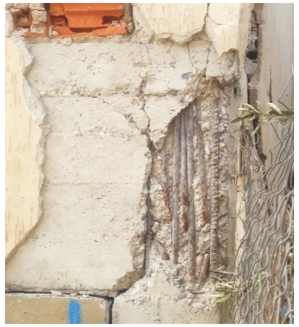
Yes, ≥ 1 → Heavily Damaged Building

No ↓

2. Are there any **Type C** damaged columns or shear walls in the structure, and if so, how many?

Yes, ≥ 2 → Heavily Damaged Building

No ↓ Continue…



Damage Category	Residual crack width (w)	Compression damage
Type 0	-	-
Type A	w≤ 0.5 mm	-
Type B	0.5≤ w≤ 3 mm	Cover crushing
Type C	> 3mm	Cover spalling
Type D	-	Buckling of reinforcement, core crushing residual displacement

Damage Assessment System

Interior Assessment

3. Is the number of **damaged elements of Type B <3** if no damaged elements of Type C or D are observed?

Yes, <3 → Slightly Damaged Building

No, ≥ 3 → Moderately Damaged Building

Damage Category	Residual crack width (w)	Compression damage
Type 0	-	-
Type A	w≤ 0.5 mm	-
Type B	0.5≤ w≤ 3 mm	Cover crushing
Type C	> 3mm	Cover spalling
Type D	-	Buckling of reinforcement, core crushing residual displacement

4. Are all damages **Type A**, regardless of the number?

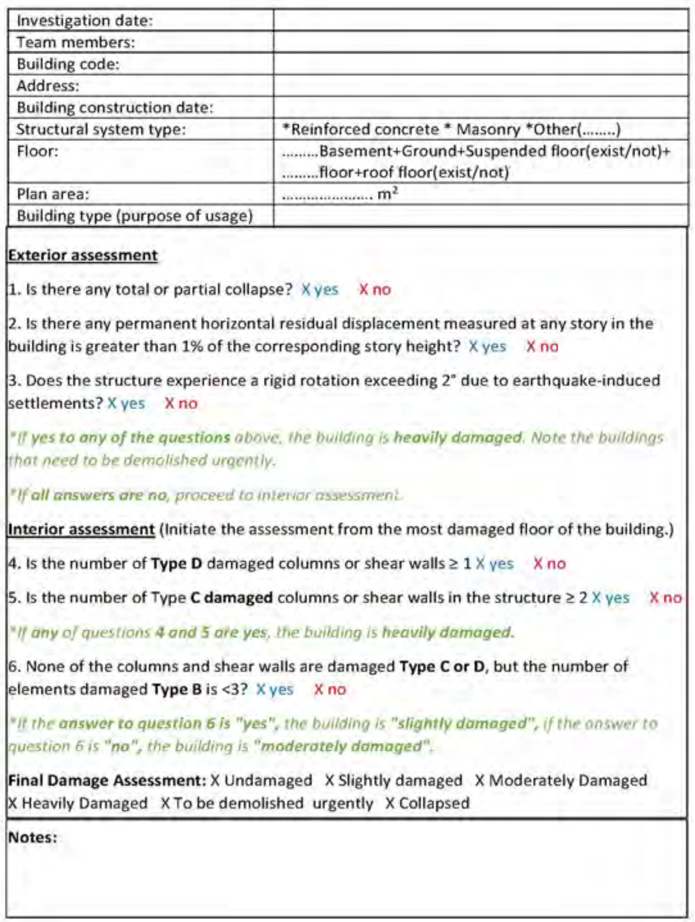
Yes → Slightly Damaged Building

If there is not any earthquake-induced damage

Yes → Undamaged Building

Damage Assessment System

- quickly implementable
- easy to follow
- **easy to understand**



Investigation date:	
Team members:	
Building code:	
Address:	
Building construction date:	
Structural system type:	*Reinforced concrete * Masonry *Other(........)
Floor:	........Basement+Ground+Suspended floor(exist/not)+ ....floor+roof floor(exist/not)
Plan area:	.... m²
Building type (purpose of usage)	

Exterior assessment

1. Is there any total or partial collapse? X yes X no

2. Is there any permanent horizontal residual displacement measured at any story in the building is greater than 1% of the corresponding story height? X yes X no

3. Does the structure experience a rigid rotation exceeding 2° due to earthquake-induced settlements? X yes X no

If yes to any of the questions* above, the building is ***heavily damaged*. Note the buildings that need to be demolished urgently.*

**If all answers are no*, proceed to interior assessment.*

Interior assessment (Initiate the assessment from the most damaged floor of the building.)

4. Is the number of **Type D** damaged columns or shear walls ≥ 1 X yes X no

5. Is the number of Type **C damaged** columns or shear walls in the structure ≥ 2 X yes X no

If any of questions 4 and 5 are yes*, the building is ***heavily damaged.**

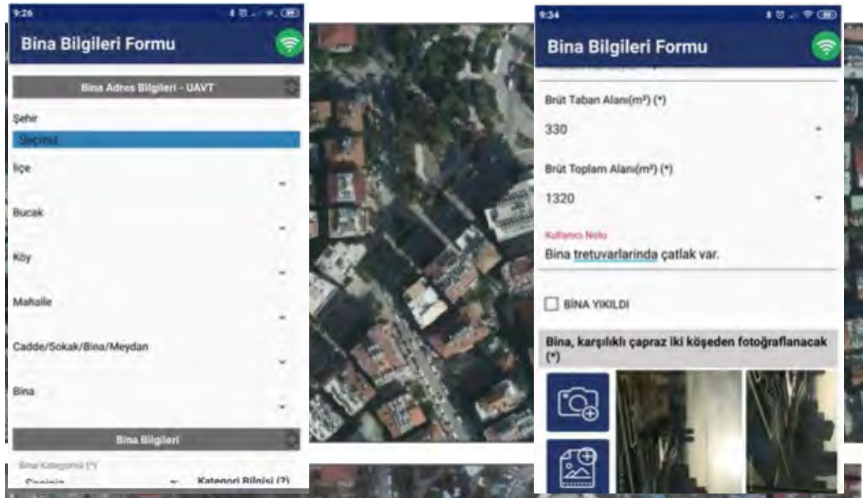
6. None of the columns and shear walls are damaged **Type C or D**, but the number of elements damaged **Type B** is <3? X yes X no

If the answer to question 6 is "yes"*, the building is *"slightly damaged"***, if the answer to question 6 is "no", the building is ***"moderately damaged"***.*

Final Damage Assessment: X Undamaged X Slightly damaged X Moderately Damaged X Heavily Damaged X To be demolished urgently X Collapsed

Notes:

Printed damage assessment sheet



Number of Buildings Included in Damage Assessment (6 March 2023)

Status	Number of Buildings	Number of Detached Units
Undamaged	860,006	2,387,163
Lightly Damaged	431,421	1,615,817
Moderately Damaged	40,228	166,132
Severely Damaged	179,786	494,588
Collapsed	35,355	96,100
Requiring Urgent Demolition	17,491	60,728
Not Assessed	147,895	296,508
Total	1,712,182	5,117,036

Source: MoEUCC

https://www.sbb.gov.tr/wp-content/uploads/2023/03/2023-Kahramanmaras-and-Hatay-Earthquakes-Report.pdf

Ongoing Recovery and Societal Impact

- Community
- Home Life
- School life
- Work Life

Community

Municipalities and NGOs providing ongoing social services

- Meals
- Psychosocial support
- Free public transportation

Continuing redevelopment

- Prefabricated single family dwellings
- Tunnel form multi-storey, multi-unit buildings

Home Life

- Tent cities continue to be replaced with container cities
- Residents returning to lightly damaged buildings

Long term recovery is long term.

- First rebuilt residences expected to be completed in January 2024
- Full recovery expected to be 3-5 years for worst-hit areas

School Life

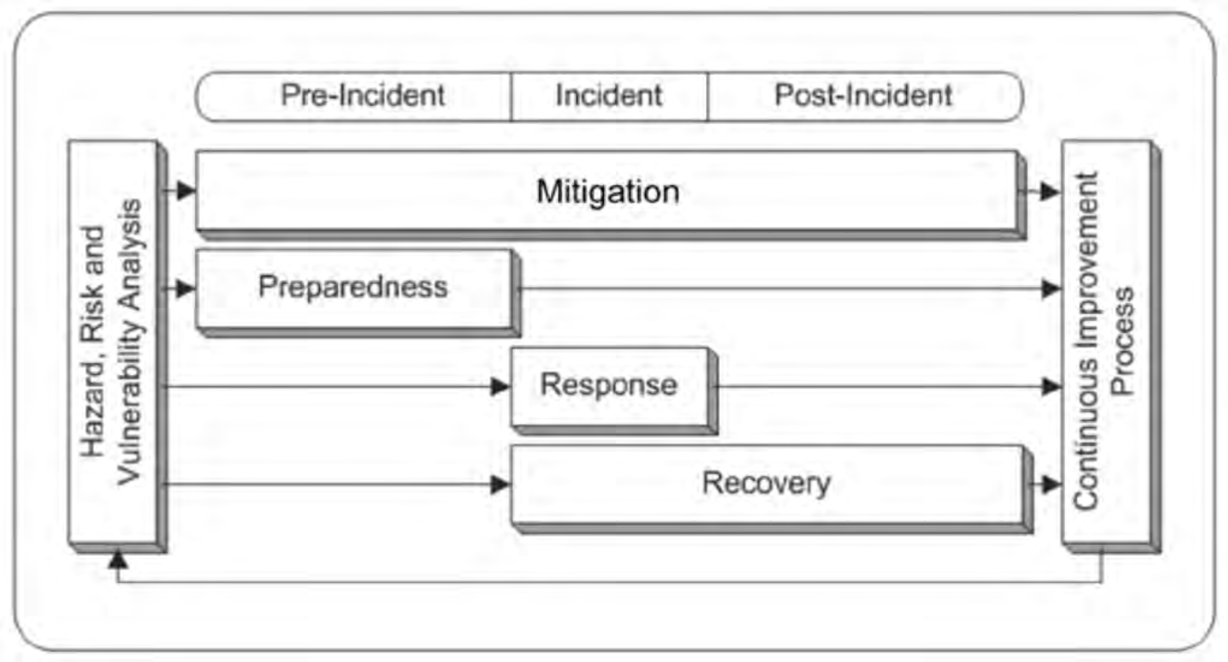
- Priority to get children back to school as quickly as possible
- Schools with light damage were used as shelters
- Schools continue to be used to store food and donated goods
- Tents and temporary buildings

Work Life

- Business as usual as best as possible
- Container and temporary structures allocated for bazaars and markets - lottery system for tenancy
- Prefabricated commercial buildings under construction

Earthquake Preparedness

- Overview
- Institutional Setup & Responsibilities
- Turkiye Disaster Response Plan (TARP)
- Turkiye Disaster Risk Reduction Plan (TARAP)
- Examples of Earthquake Preparedness
- BC Resources



References:
Kahramanmaras and Hatay Earthquakes Report (Gov. Turkiye, 2023)
British Columbia Emergency Management System Guide (Gov. BC, 2016)
An Emergency Management Framework for Canada (Gov. Can., 2016

Institutional Setup & Responsibilities

Disaster and Emergency Management Agency (AFAD)

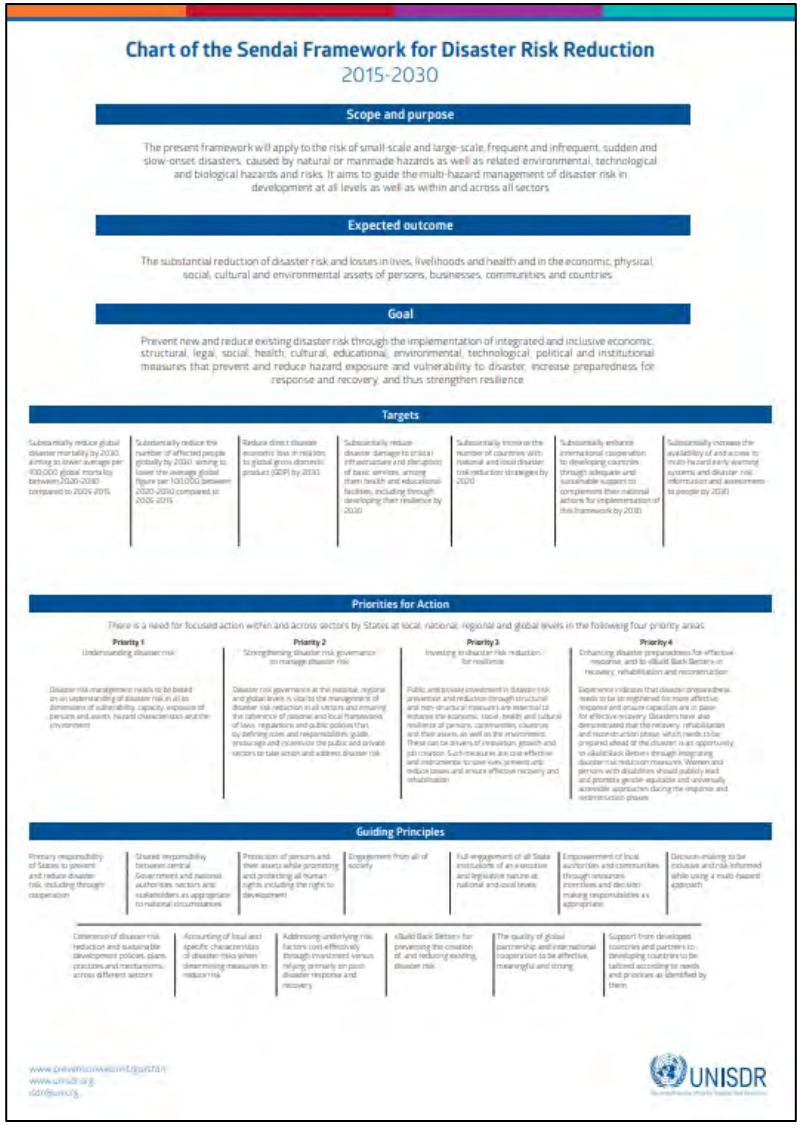
- Develop Turkiye Disaster Risk Reduction Plan (TARAP)
- Develop Turkiye Disaster Response Plan (TAMP)
- Execution of disaster response process

Ministry of Environment, Urbanization and Climate Change (MoEUCC)

- Activities related to spatial planning, geological surveys and geographic information systems
- Damage assessment studies
- Demolition of damaged buildings
- Debris removal

Türkiye Disaster Risk Reduction Plan (TARAP)

- Follows the Sendai Framework (2015–2030)
- Identifies objectives, goals, and actions for disaster risk reduction
- For earthquakes it includes:
  - 7 objectives (out of 66)
  - 29 actions (out of 227)
- Key actions include:
  - Determining Türkiye's crustal structure and model
  - Monitoring crustal deformations in active fault zones,
  - Preparing liquefaction potential maps and local scale soil amplification potential maps



Develop Türkiye Disaster Response Plan (TAMP)

Prepared in 2004, updated in 2022 to:

- Ensure effective response to disasters (11 kinds)
- Minimize operational risks during disasters

Does this by:

- Determining the basic principles of response planning before, during, and after disasters
- Identifying the roles and responsibilities of the working groups and coordination units (28 total)

Requirements for success:

- All responsible groups own it
- Organizations coordinate with each other
- Actions are performed on time and in accordance with the general principles of the plan

Mitigation

- Codes – updated based on research and past earthquakes
- Hospitals – require base isolation
- Schools & Hospitals – designed as high importance, seismic upgrades

Preparedness

- Development of Turkiye Disaster Response Plan
- Development of Turkiye Disaster Risk Reduction Plan
- Training on post disaster building assessments
- Earthquake drills for students (4/year)

Response

- Humanitarian aid – Turkish Red Crescent, Ministry of National Defense
- Execution and coordination of response efforts
    - Post disaster building assessments, demolition, debris removal, etc.

Recovery

- Determine which buildings will be retrofitted or demolished and rebuilt
- Determine how and where to rebuild
- Project management for housing developments

(a few) Key Takeaways for Türkiye and British Columbia

Make good development and land use planning decisions	Prioritize social support for communities	Educate engineers, contractors, and municipalities about seismic design and construction	Increase quality control of materials and processes
Ensure infrastructure can withstand and perform after the earthquake so people and resources can move in and out	Train locals to respond and participate in search and rescue, first aid, post disaster building assessments, etc.	Designate sister province(s) for each, considering geographical distance, population size, and disaster risks	Conduct risk analyses and post-earthquake predictions to inform response and/or retrofit priorities

8.
Concluding remarks

Tony T.Y. Yang, Ph.D., P.Eng., F.CAE, Professor, UBC

Acknowledgement:

UBC APSC

SEABC program

certificate

CAE

THE UNIVERSITY OF BRITISH COLUMBIA
Engineering
Faculty of Applied Science

Certificate in Structural Engineering Program

All local contacts (in alphabetical) in Türkiye:

Ali Gemci, Director of Urban Planning of Onikişubat Municipality; Ali Gül, Headman of Hacilar Village; Ali Osman Coşkun, Hüseyin Sünnetçioğlu, Abdulmutalip Barubay, Sedat Humartekin in BRY and GNR Altyapı Inc.; Alpay Atmaca, Engineer in Osmaniye State Hospital; Bülent Haksal, Director of Disaster Coordination of Gaziantep Municipality in Nurdağ; Eflahun Yıkıcı, Guard in Kartalkaya Dam in Pazarcık; Engin Özer, The deputy mayor of Antakya Municipality; Enver Kaya, Controller in the Kartalkaya Dam; Erdoğan Emrah Hatunoğlu, Director of Foreign Relations of Kahramanmaraş Municipality; Halil Satıcı, Manager of Social Affairs of Gaziantep Municipality in Nurdağ; Hasan Ay, District Director of National Education in Kırıkhan; H. Abdullah Dinç, Head of Industrial Vocational High School in Kırıkhan; İbrahim Hızyolu, Director of Disaster Coordination of Gaziantep Municipality in Islahiye; Kemal Topçu, Head of 75. Yıl Kindergarten in Kırıkhan; M. Fatih Tosyalı, Mayor of İskenderun Municipality; Metin Çiftçi, Site Manager of the Tunnel and Bridge in Gölbaşı; Muharrem S. Bilgiç, Project Coordinator in Intek Inc. in Islahiye; Mürsel Koçer, Head of Osmaniye State Hospital; Rüstem Keleş, General Secretary of Kahramanmaraş Municipality; Sait Bayraktar, District Director of National Education in Hassa; Osman Tuğrul Adıgüzel, Head of Bahçe High School in Bahçe; Özgür İspir, Representative of Chamber of Civil Engineering in Elbistan; Uğur Pekmez, Pekmez Inc. in Kahramanmaraş; Uğur Yücel, Architect in Gölbaşı; Yusuf Dedeoğlu, Head of Hacılar Middle School in Hassa

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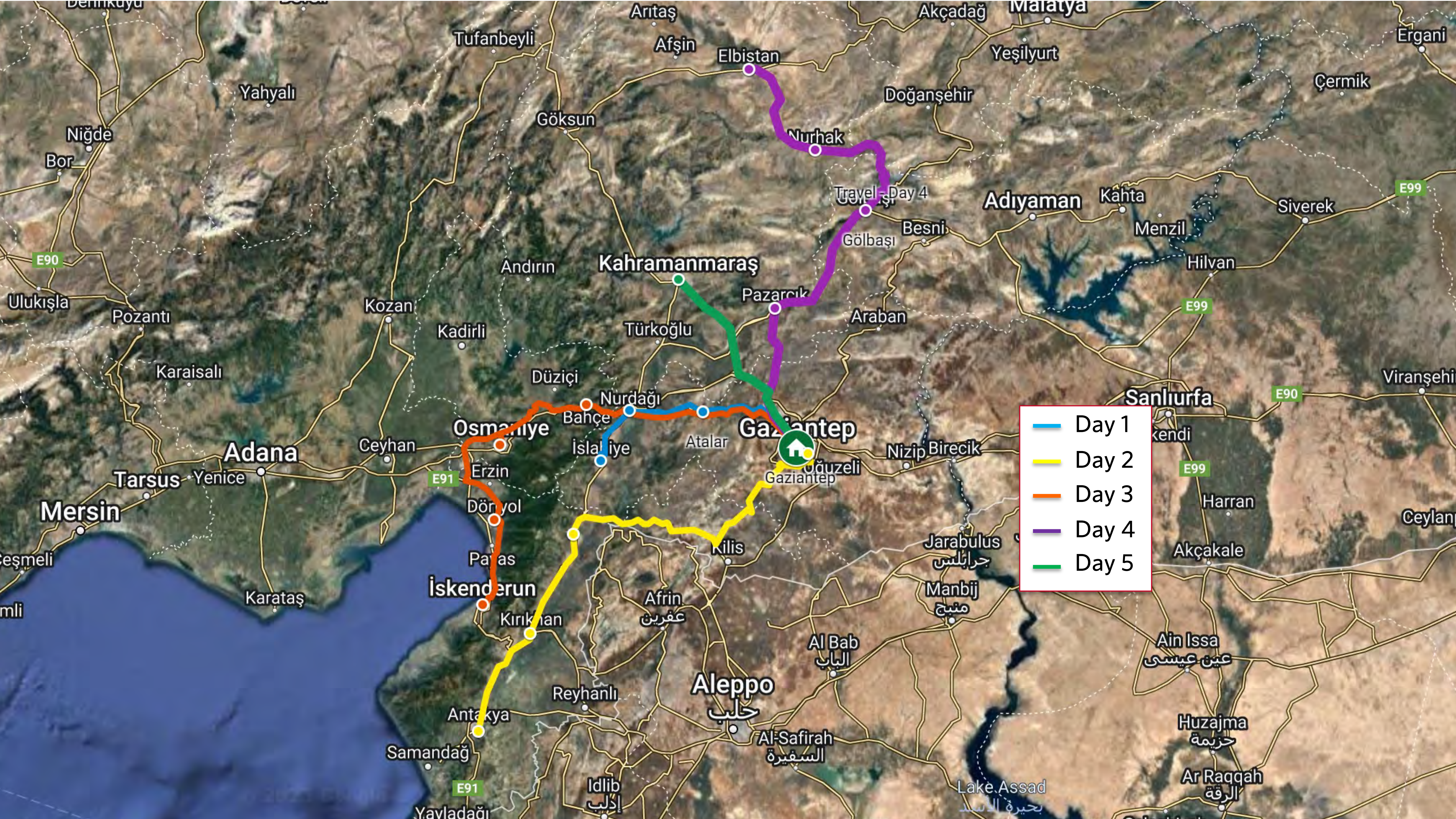
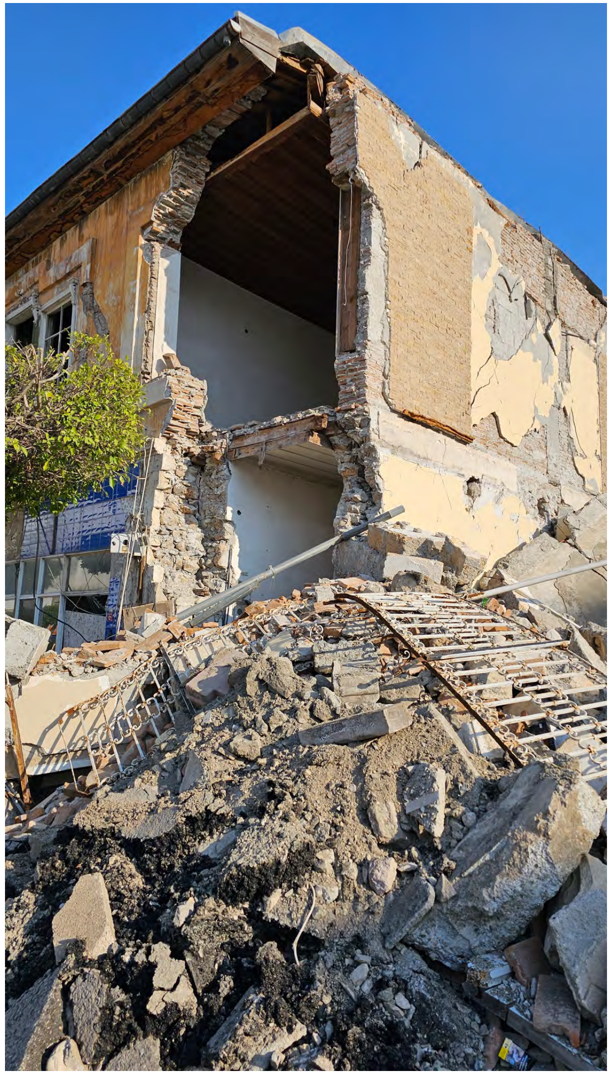


Day 1
Day 2
Day 3
Day 4
Day 5
Travel - Day 4
Elbistan
Arıtaş
Afşin
Akçadağ
Malatya
Tufanbeyli
Yahyalı
Göksun
Niğde
Bor
Doğanşehir
Yeşilyurt
Ergani
Çermik
Nurhak
Adıyaman
Kahta
Siverek
Menzil
Besni
Gölbaşı
Hilvan
Kahramanmaraş
Andırın
Pazarcık
Araban
Kozan
Kadirli
Türkoğlu
Düziçi
Nurdağı
Bahçe
Osmaniye
İslahiye
Atalar
Gaziantep
Oğuzeli
Nizip
Birecik
Şanlıurfa
Viranşehir
Harran
Ceylanpınar
Akçakale
Adana
Ceyhan
Erzin
Dörtyol
Payas
İskenderun
Kırıkhan
Kilis
Afrin
عفرين
Jarabulus
جرابلس
Manbij
منبج
Al Bab
الباب
Ain Issa
عين عيسى
Aleppo
حلب
Al-Safirah
السفيرة
Huzajma
حزيمة
Ar Raqqah
الرقة
Lake Assad
Reyhanlı
Antakya
Samandağ
Idlib
إدلب
Yayladağı
Mersin
Tarsus
Yenice
Karataş
Karaisalı
Pozantı
Ulukışla
E90
E91
E99

Visited the disaster sites:



Structural examination:

Examine the foundation failure sites:






Reconstruction sites:

- The newly constructed village. 400 units, each 1280 sf (3 rooms, 1 living room and a kitchen).
- Cost of one house is ~100,000 USD, and each family will pay 40,000 USD (24 years mortgage) with the remaining amount covered by the government.
- Cold-formed steel fabricated.
- Each house is completed in 20 days with 50 workers.
- Began on March 10, 2023, and it is planned to be completed in 9 months.

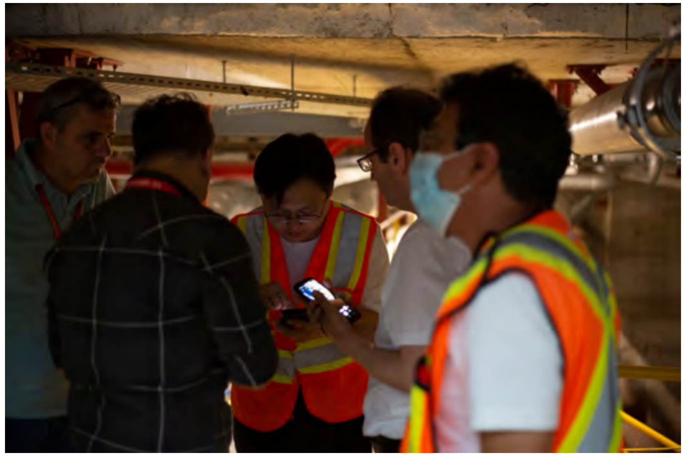
Visited the dam:






On-site measurement:

Visited to health care facilities:



Interacted with government officials:



Interacted with government officials:

Interviewed by the local media:

Turkish Press News

https://www.habertime.com.tr/kanadali-bilim-insanlari-deprem-bolgesini-inceledi

https://www.iha.com.tr/kahramanmaras-haberleri/-4380511

https://www.turkiyegazetesi.com.tr/teknoloji/kanadali-bilim-insanlari-felaketin-boyutunu-ve-izlerini-inceledi-970598

https://kinikgazetesi.com/kanada-british-columbia-universitesi-heyetinden-osmaniye-ziyareti/

https://www.elbistaninsesi.com/haber/15303610/kanadali-bilim-insanlari-felaketin-boyutunu-ve-izlerini-inceledi

https://www.egegundem.com.tr/video/15340034/felaketin-boyutlarina-inanamadilar

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https://beyazgazete.com/haber/2023/6/12/kanadali-bilim-insanlari-felaketin-boyutunu-ve-izlerini-inceledi-6815912.html

https://www.tucsa.org/tr/haber_detay.aspx?haber=4391

https://kahramanmaras.bel.tr/haber/2023/06/09/uluslararasi-akademisyenlerle-afet-yonetimi-toplantisi-yapildi

Connected with the locals:

Having great time:

Time	Title of Presentations	Speaker(s)	Affiliation
1:00 – 1:05 pm	Opening Remarks from Consul General of Türkiye	Mr. Hüseyin Emrah Kurt	Consul General of Türkiye
1:05 – 1:20 pm	Introduction	Tony Yang	Professor, UBC
1:20 – 1:40 pm	Seismology and Geotechnical Effects	Alemdar Bayraktar Keshab Sharma Carlos E. Ventura	Visiting Professor, UBC (Remote) Geotechnical Engineer, BGC Engineering Inc. (Remote) Professor, UBC
1:40 – 2:00 pm	Building Codes and Construction Practices	Tony Yang	Professor, UBC
2:00 – 2:20 pm	Break		
2:20 – 2:40 pm	Performance of Residential Buildings	Svetlana Brzev	Adjunct Professor, UBC
2:40 – 3:00 pm	Performance of Schools Buildings	Bishnu Pandey Allison Chen	Instructor, BCIT Practice Advisor, EGBC
3:00 – 3:20 pm	Performance of Health Care Facilities	Jeffrey Salmon	Structural Engineer, Ausenco
3:20 – 3:40 pm	Break		
3:40 – 4:20 pm	Preparedness, Response, and Recovery	Allison Chen Jeffrey Salmon Serife Ozata	Practice Advisor, EGBC Structural Engineer, Ausenco Research, teaching assistant, Ahi Evran University (Remote)
4:20 – 4:50 pm	Panel Discussion	All	
4:50 – 5:00 pm	Concluding Remarks	Tony Yang	Professor, UBC

Some of the takeaways

Social and economic effects:

- 11 major city centres and 14 million people were affected, and north part of Syria.
- A total of 50,783 people lost their lives, and 115,353 people were injured.
- The number of collapsed or urgently demolished buildings in the region is reported as 58,039, while the number of severely damaged buildings is 205,534 (May 2, 2023).
- Housing sector: 56.9 billion USD
- Deconstruction sector: 12.9 billion USD
- Private industries (including manufacturing, energy, communications, tourism, healthcare, education sectors): 11.8 billion USD
- Other insurance section
- Total economy loss: 103.6 billion USD (~9% of GDP of Türkiye in 2023)

Some of the takeaways

Seismology and geotechnical effects:

- Recorded PGA, PGV, PGD and spectral values significantly exceeded the design values in many locations.
- Back-to-back effects of the earthquake sequencies on structures.
- Effects of near-fault, basin and soil amplification.
- Effects of shallow earthquake (less than 10km deep).
- Effects of long duration of the ground shaking.
- Proximity of epicenters and fault lines to urban centers.
- Effects of long ruptured fault system.
- Widespread liquefaction on wetlands and along the costal line

Some of the takeaways

Turkish Building codes:

- Turkey has a long history of earthquakes
- Turkish building code has been significant modified over the years to account for the earthquake effects
- The most current Turkish building code has accounted for many of the state of the art practice and research
- Turkey is proactive in using seismic protective technology, such as base isolation. Over 72 major Turkish infrastructures has been protected using base isolation system.

Some of the takeaways

Performance of Residential Buildings:

- **Predominantly constructed using cast-in-situ reinforced concrete (RC) technology.**
- **Older mid-rise RC buildings constructed before 2000 did not perform well due to absence of ductile design and detailing; soft storey collapse was common in the buildings with an open ground floor.**
- **Majority of post-2000 RC buildings (designed according to modern seismic codes) did not collapse, except for the buildings with major design and/or construction deficiencies.**
- **Majority of the buildings (including those with only minor structural damage) experienced extensive non-structural damage and/or collapse of masonry infills and partitions.**
- **Many buildings had to be vacated due to extensive non-structural damage and are likely going to be replaced – even though the structural system may be repairable.**

Some of the takeaways

Performance of School Buildings:

- Robust design and construction of school buildings pay off
- Non-structural damages render the school unusable and hence need special attention
- Use of Gym block as a temporary shelter (post-EQ use) helps towards effective immediate response.
- Need to start school for higher importance
- Need special guidelines targeting schools
- Need to ensure the school can have higher performance where it can functional after the earthquake

Some of the takeaways

Performance of health care facilities:

- Base isolated hospitals performed well and continued to be operation during and after the earthquakes

- One base-isolated hospital suffered nonstructural damages and was closed – this was a result of filling the moat, which hindered the performance of the isolators

- Nonstructural damage in fixed-base hospitals resulted in their closure

  Structural damage resulted in the closure of hospitals built before 2001

Some of the takeaways

Preparedness, Response, and Recovery:

- Turkey has done well in the preparedness, response and recovery.
- They have made good development and land use planning decision
- Prioritizes social support for communities
- Educate engineers, contractors, and municipalities about seismic design and construction
- We need to start planning to ensure infrastructure can withstand and perform after the earthquake so people and resources can move in and out
- We shall start designing our neighboring, cities, province(s) to work together to withstand the earthquake impact
- Conduct risk analyses and post-earthquake predictions to inform response and/or retrofit priorities.

Thank you