Structural Engineering Lessons from the 2023 Kahramanmaras EQs

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Caglar Goksu
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İTÜ

İSTANBUL TEKNİK ÜNİVERSİTESİ 1773

BOĞAZİÇİ ÜNİVERSİTESİ 1863

İZMİR YÜKSEK TEKNOLOJİ ENSTİTÜSÜ 1992

MİMAR SİNAN GÜZEL SANATLAR ÜNİVERSİTESİ

İSTANBUL AU

HARRAN ÜNİVERSİTESİ 1992

TÜRKİYE CUMHURİYETİ ÇEVRE, ŞEHİRCİLİK VE İKLİM DEĞİŞİKLİĞİ BAKANLIĞI

dask DOĞAL AFET SİGORTALARI KURUMU

東京大学
THE UNIVERSITY OF TOKYO

İSTANBUL BÜYÜKŞEHİR BELEDİYESİ

TÜRKİYE DEPREM VAKFI

HASAN KALYONCU ÜNİVERSİTESİ

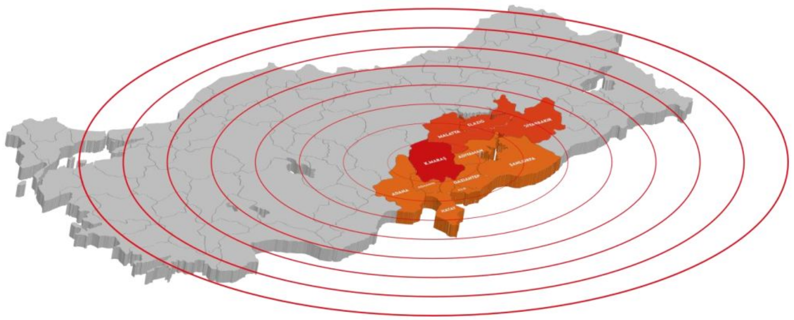
ARUP

KORDSA

HILTI

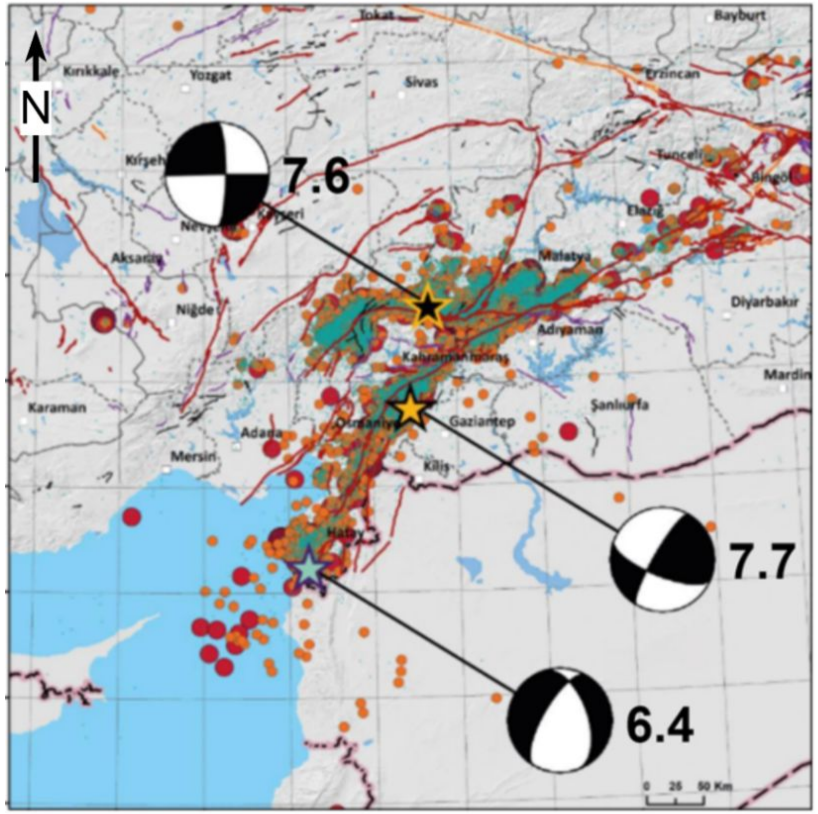
Content

- February 2023 Türkiye EQs
- Building Damage Inventory
- Damage Assessment Methodology
- Field Observations
- Evolution of Local Normative Specifications/Regulations
- Istanbul
- Conclusions



February 2023 Türkiye earthquakes

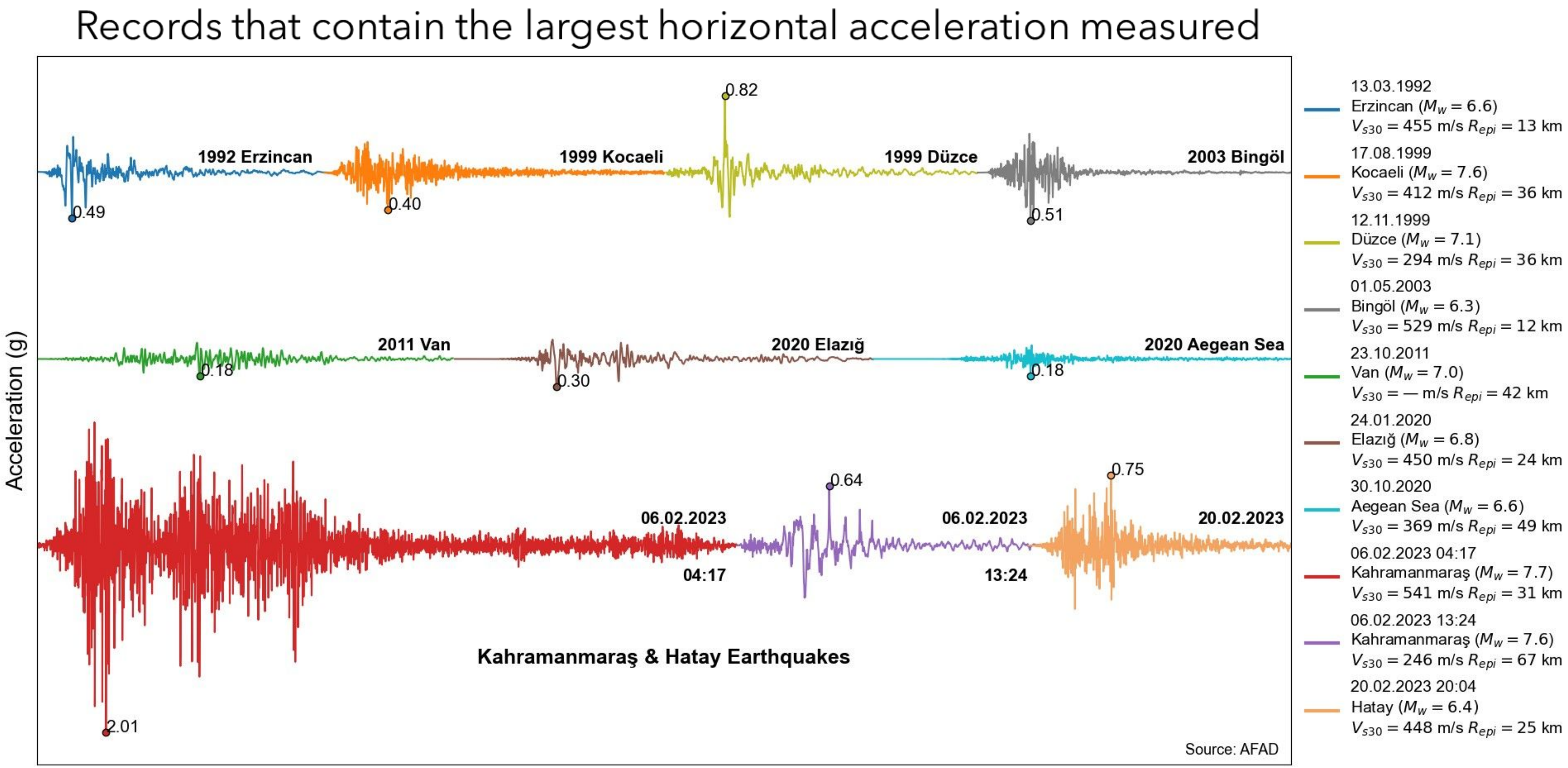
Loss of Life 50k+ **Injured 100k+** **Cost US$100b+**



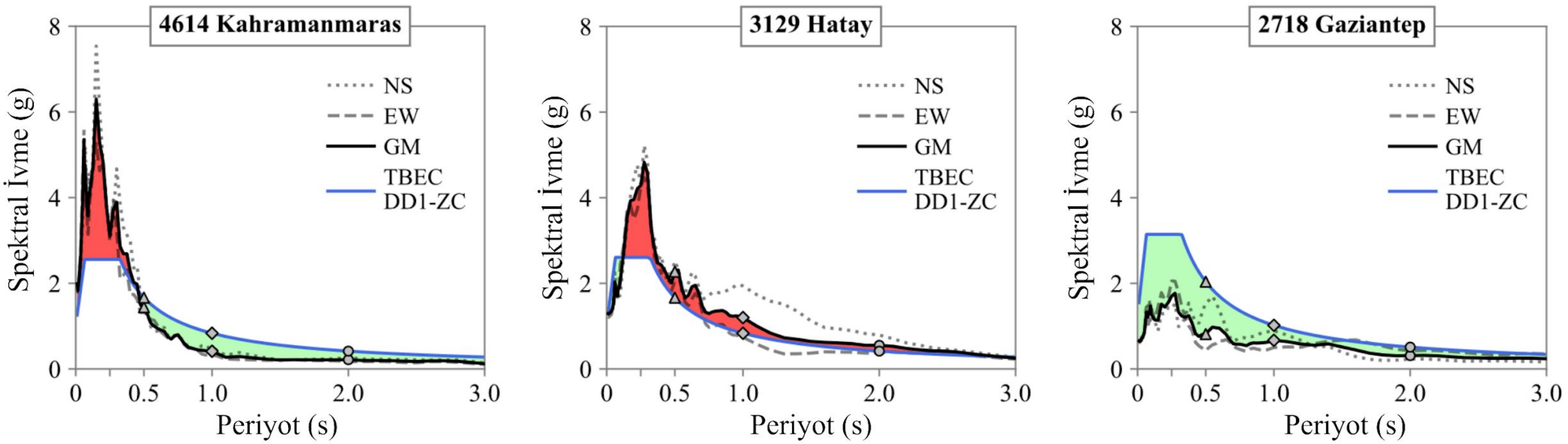
AFAD (2023)

- Surface ruptures of ~300 km (Pazarcik) and ~130 km (Elbistan) in length
- Lateral surface displacements of over 6.5 m

Previous earthquakes in Türkiye (1990-2023)

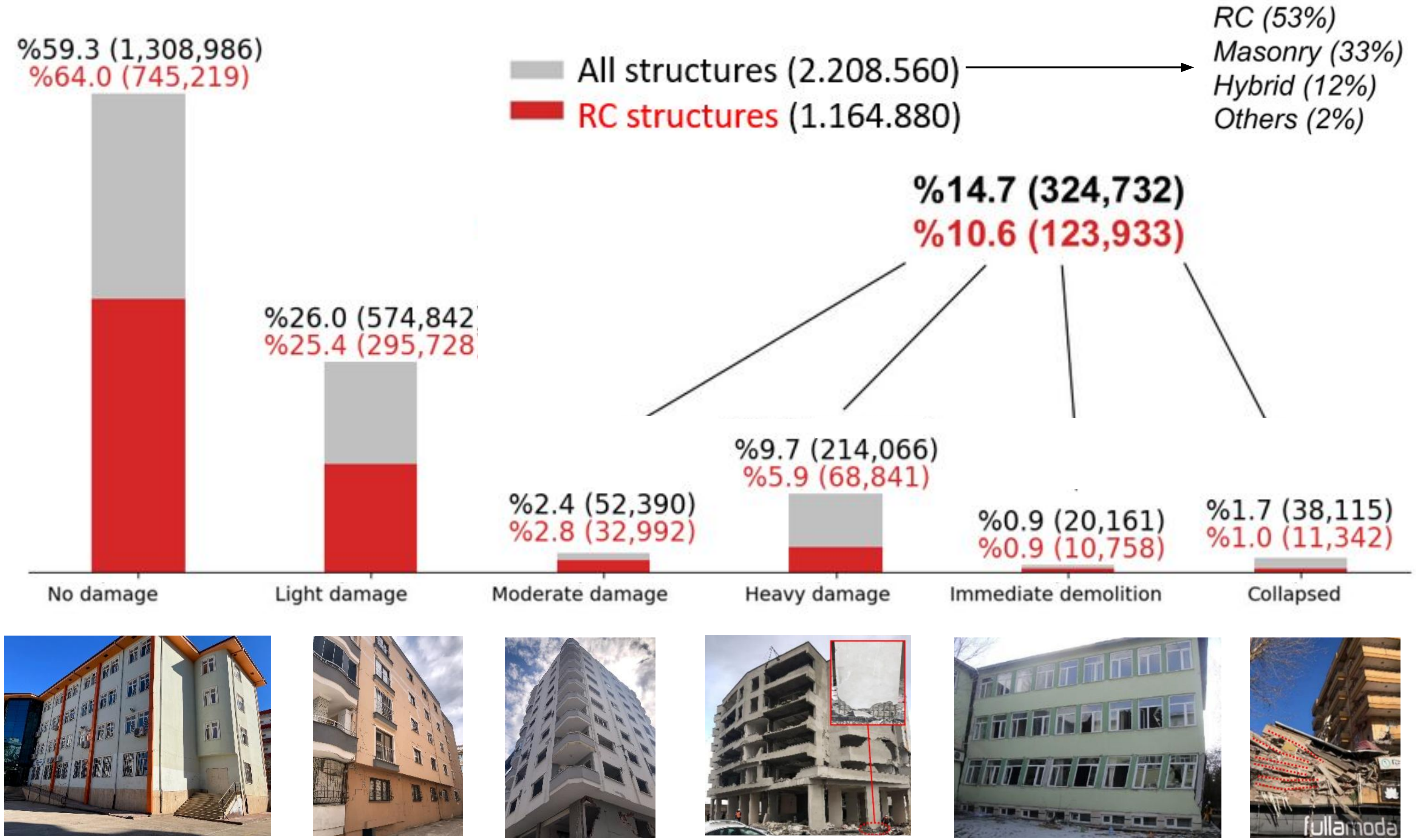


Spectral accelerations

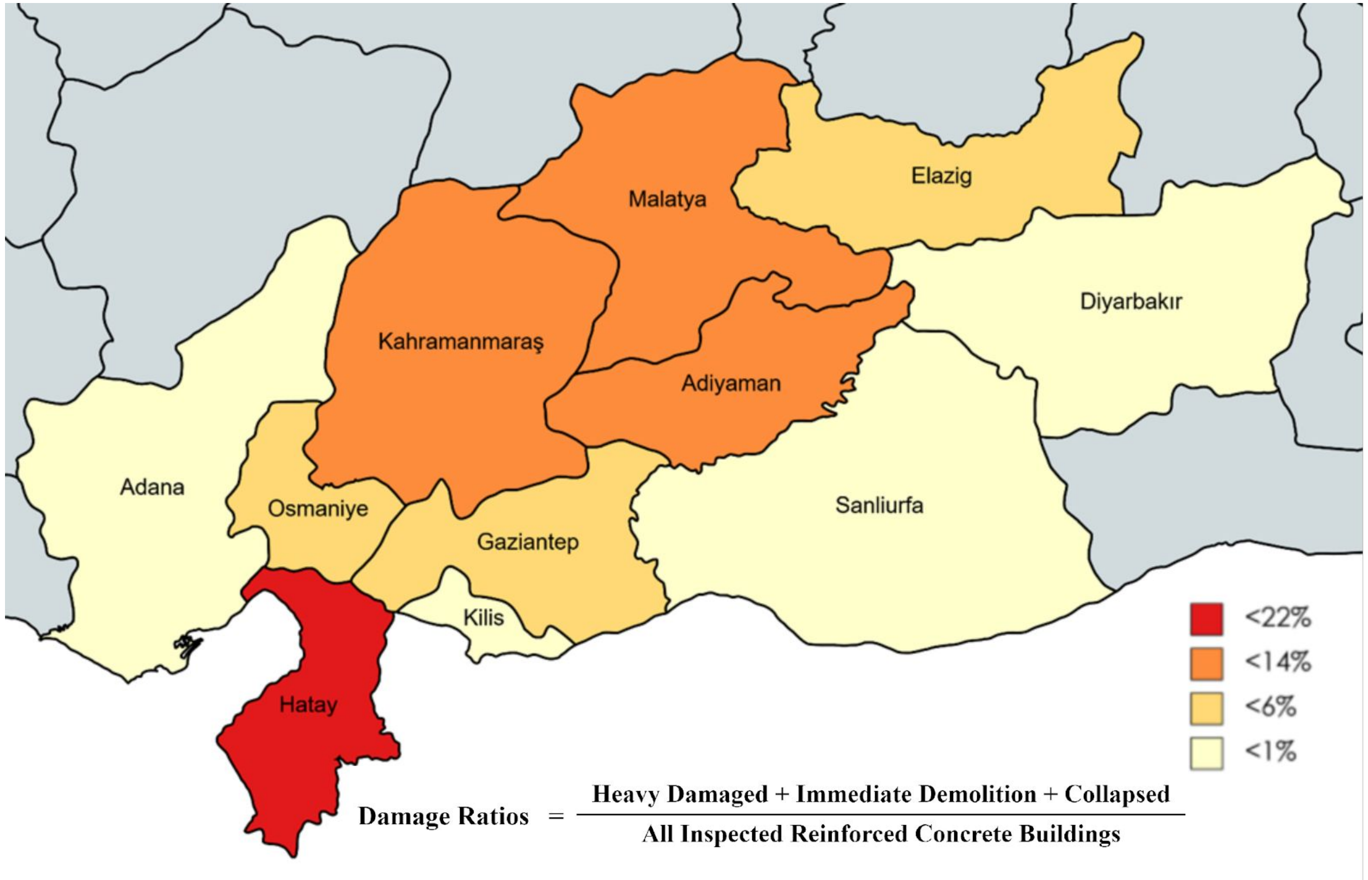


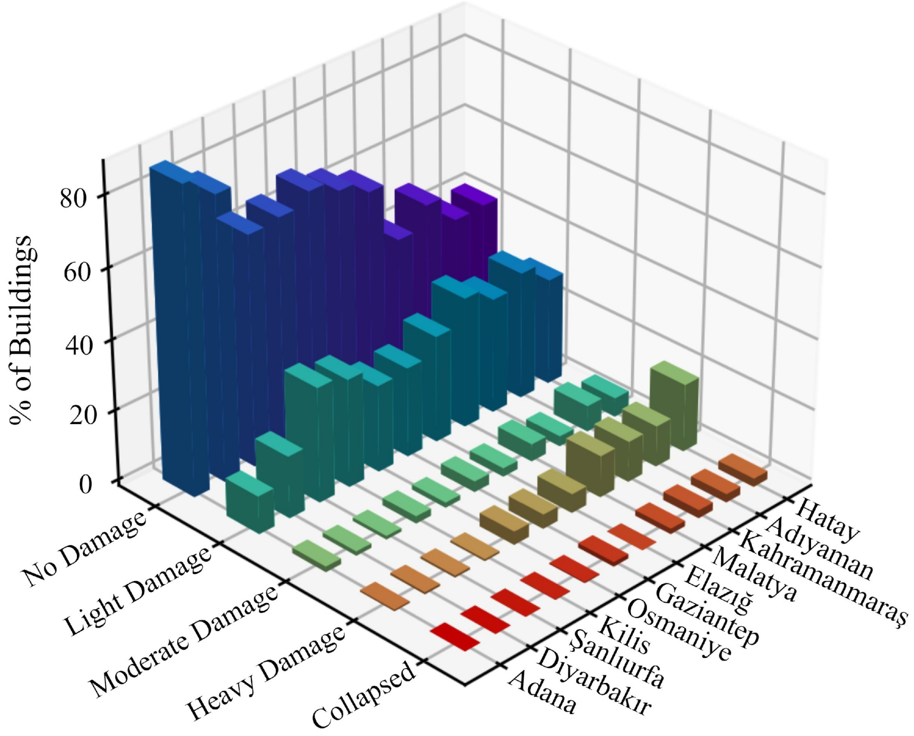
İstasyon Kodu	Şehir	İlçe	Boylam	Latitude	V_{s30} (m/s)	TBDY Zemin Sınıfı	PGA (g)
4614	Kahramanmaras	Pazarcik	37.29775	37.48513	541	ZC	2.08
3129	Hatay	Defne	36.1343	36.19117	447	ZC	1.38
2718	Gaziantep	Islahiye	36.6266	37.00777	-	ZC*	0.67

Building damage inventory

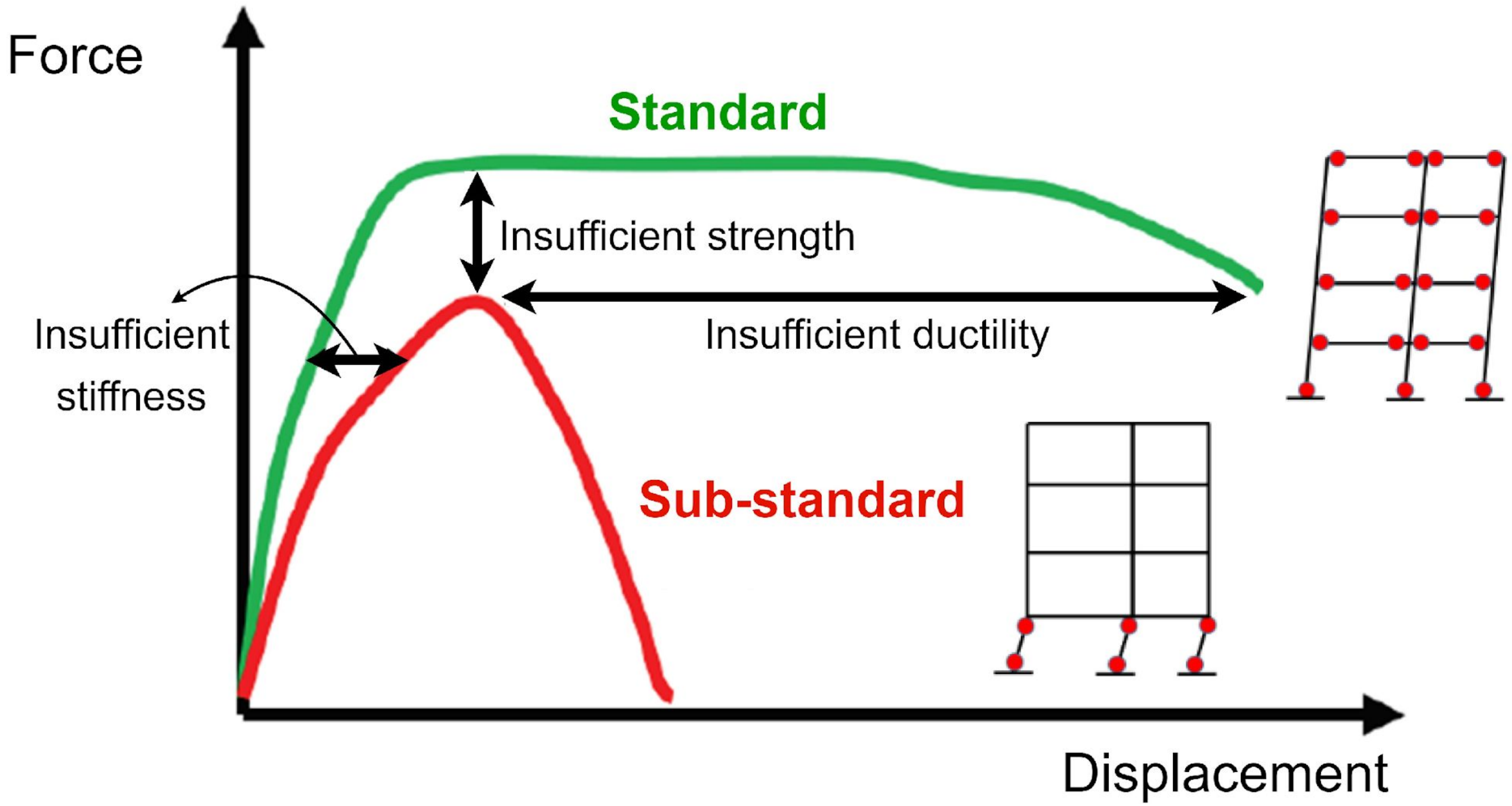


Building damage inventory





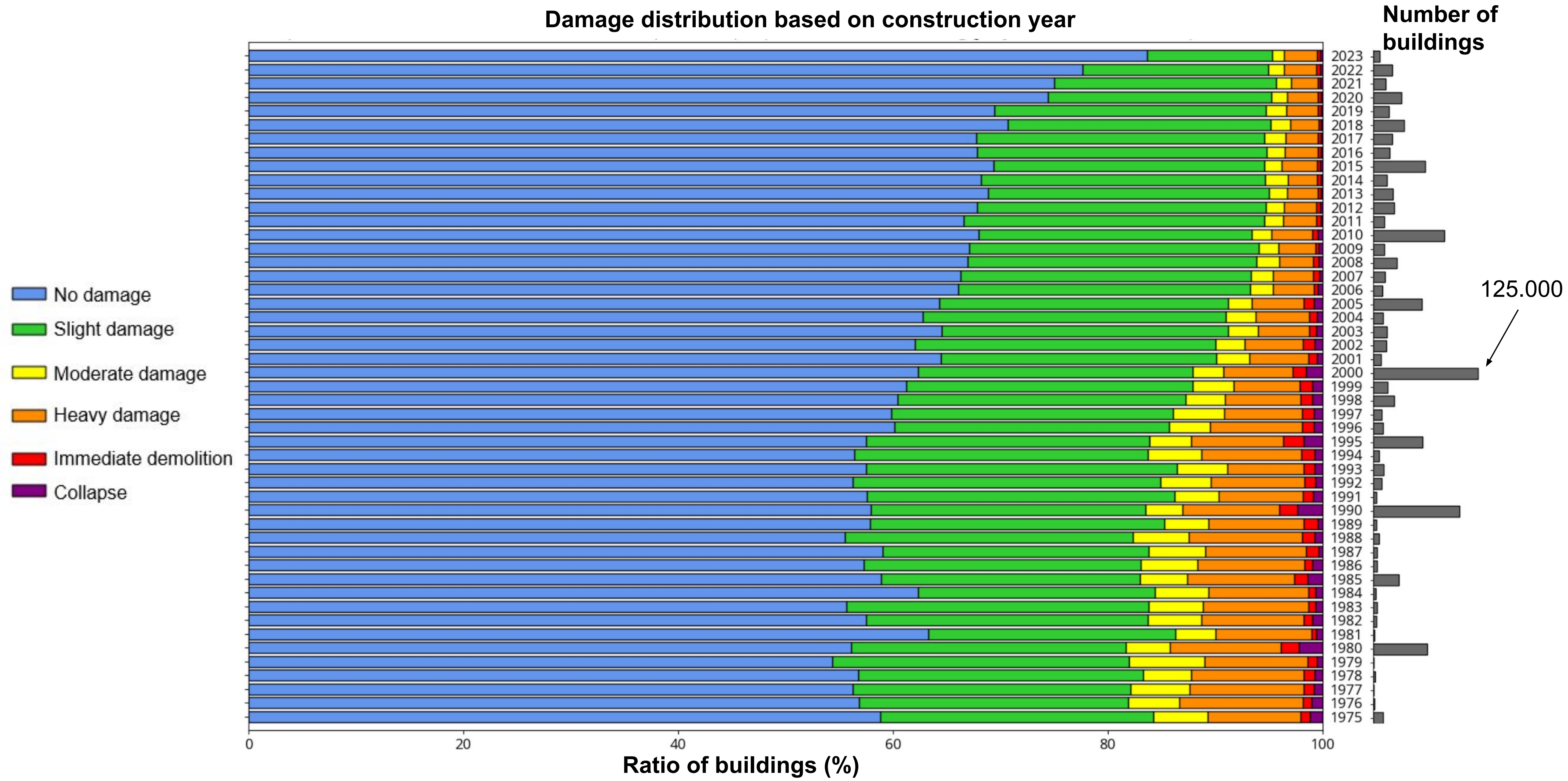
Turkish Building Seismic Code



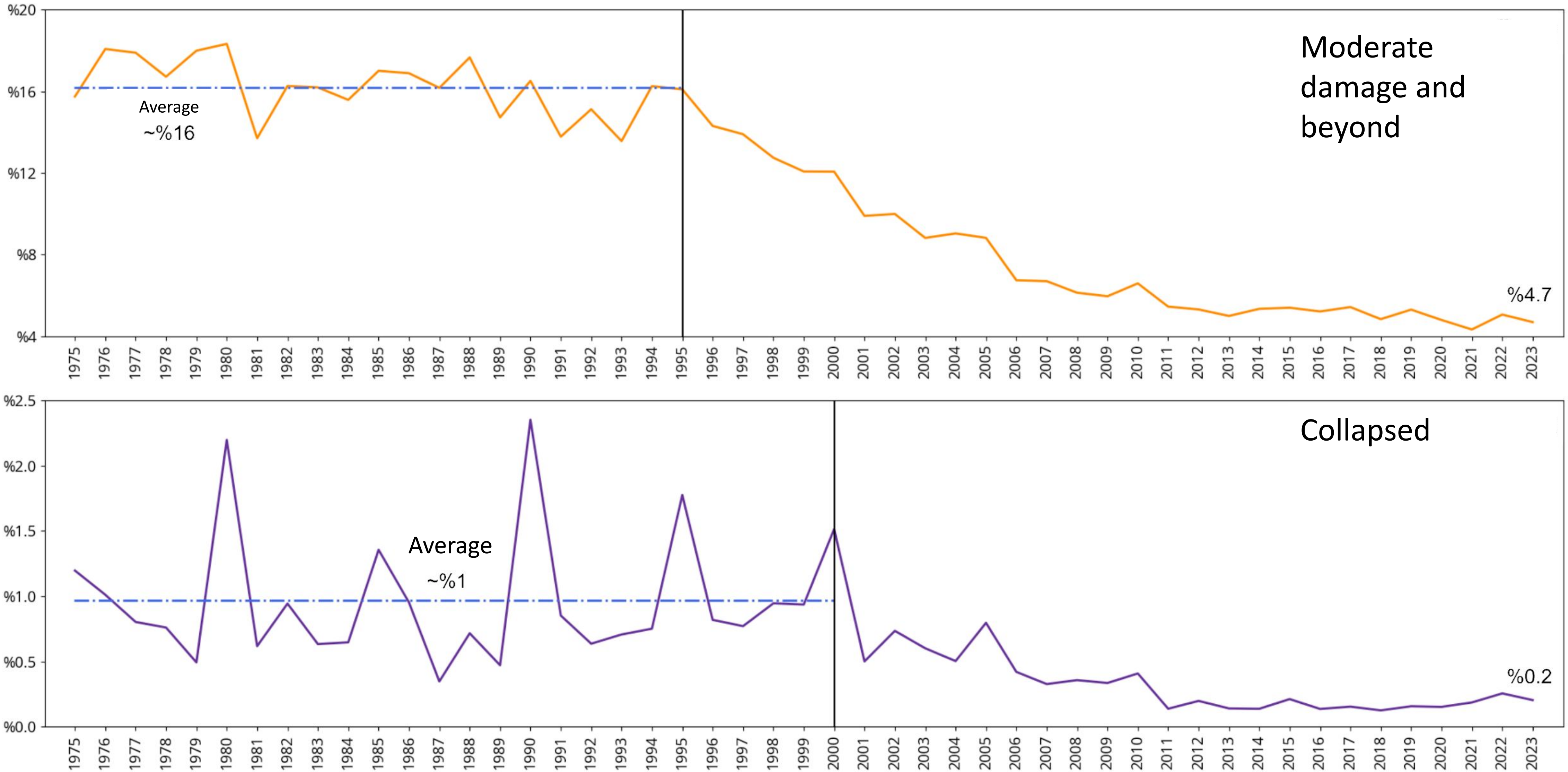
Is year 2000 a milestone?

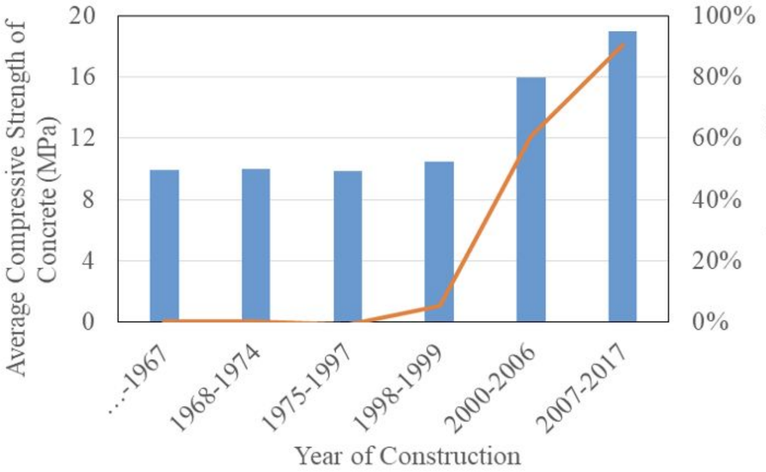
- Earthquake code was updated in 1998,
- Two destructive earthquakes occurred on August 17, and November 12, 1999, in Kocaeli and Düzce awakening awareness for seismic resistance,
- Reinforced concrete design guideline (TS-500) revised in 2000,
- Ready mix concrete and deformed bars,
- Building Inspection Law enacted on July 13, 2001, for 19 pilot cities (including Gaziantep and Hatay),
  - The law was extended to the whole country in 2011.
  - The option to determine the preferred building inspection companies by contractors was eliminated in the year 2019.

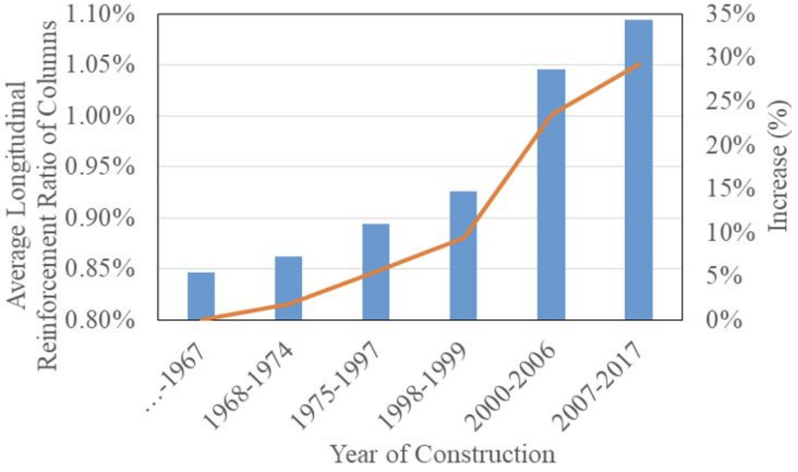
Building damage inventory

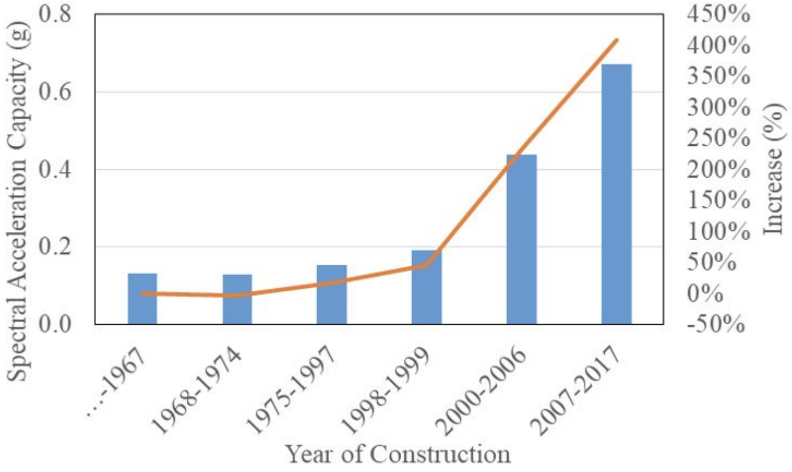


Damage distribution for RC structures

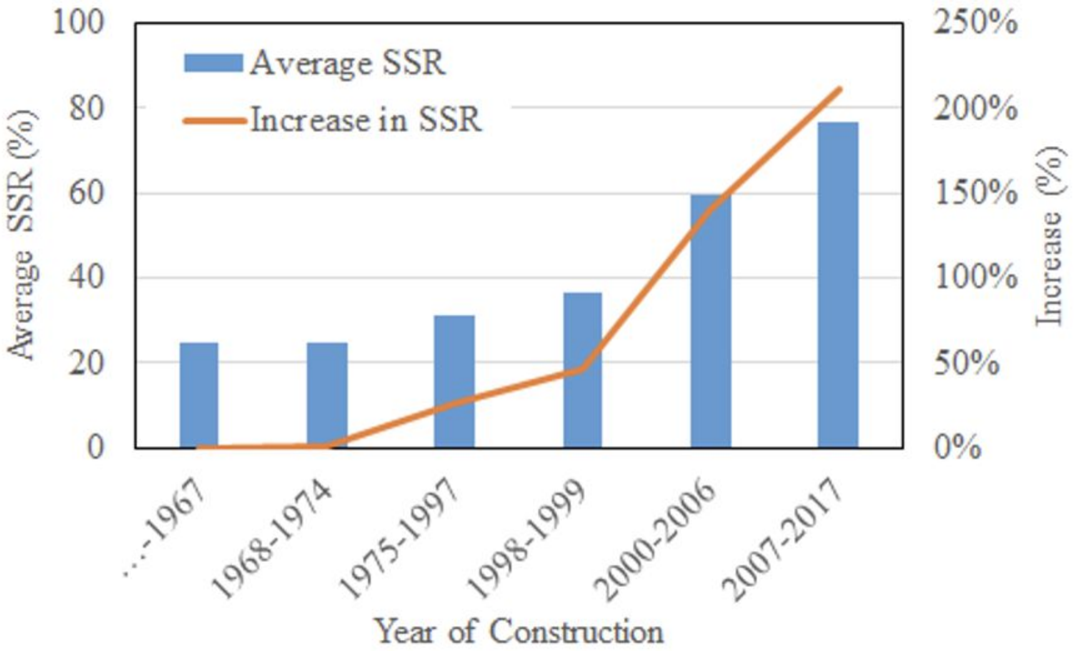


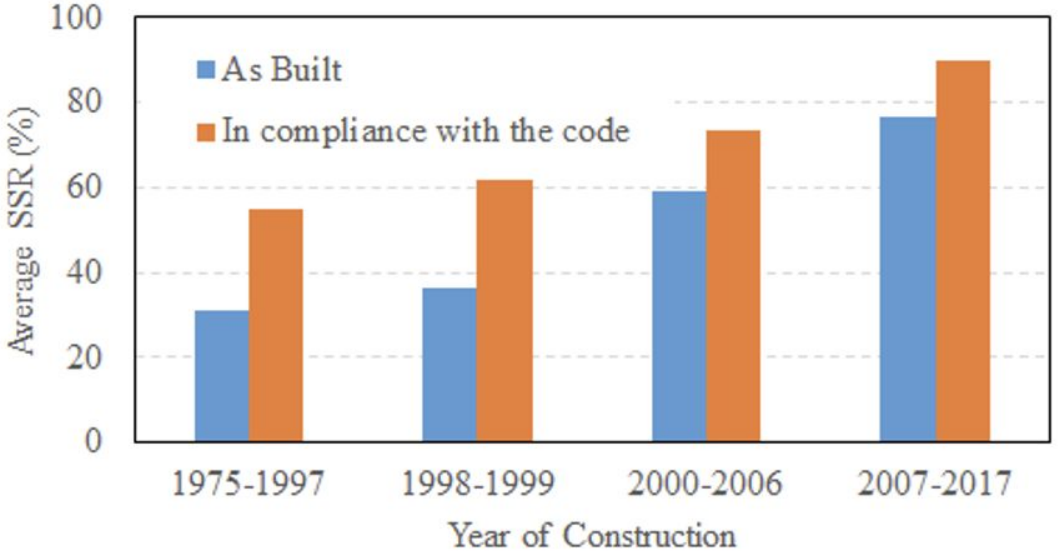






Hasan Hüseyin Aydoğdu, PhD thesis, Feb 2024

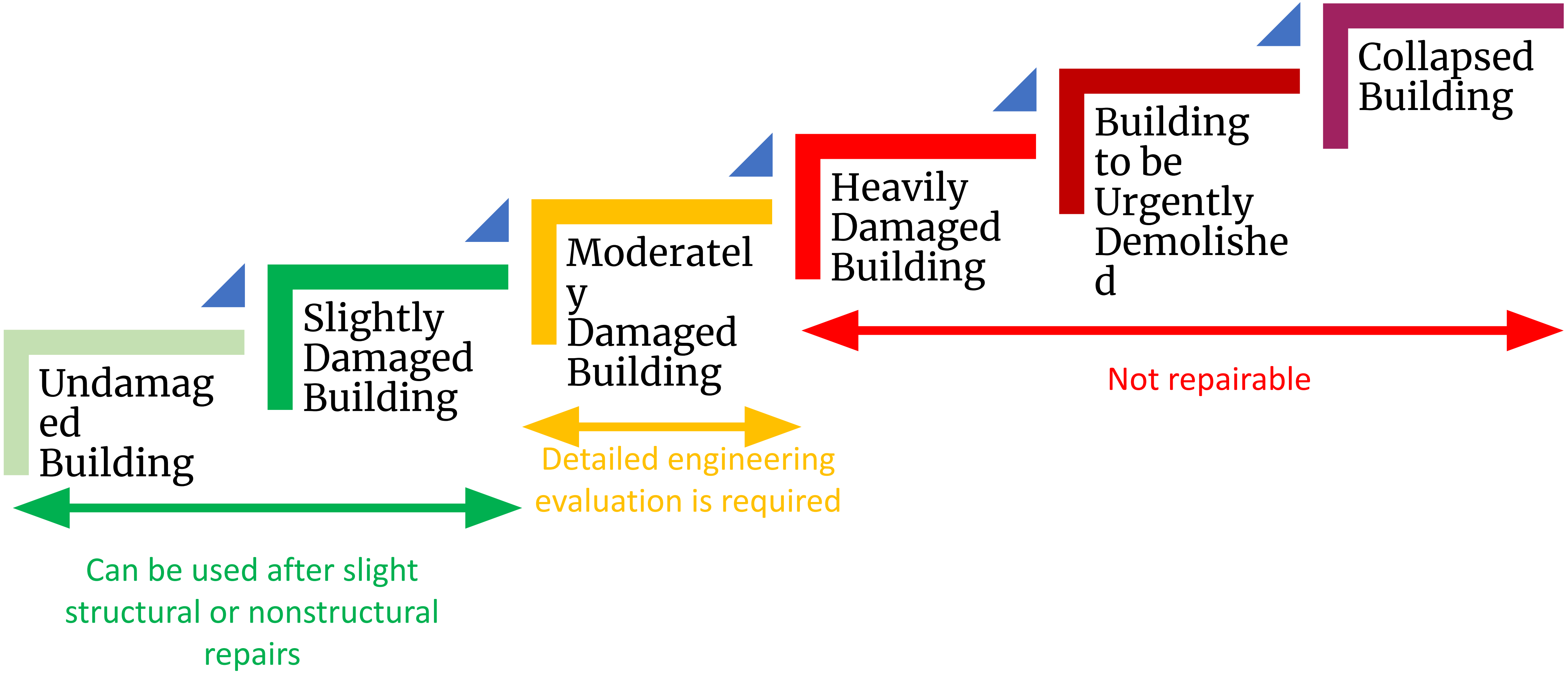




Hasan Hüseyin Aydoğdu, PhD thesis, Feb 2024

Turkish national damage assessment system

Building Damage Categories



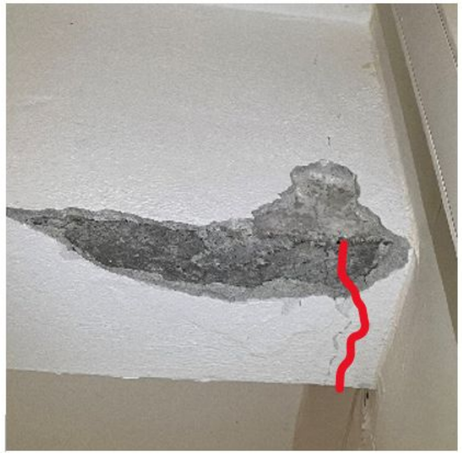
Turkish national damage assessment system

Building Category	Reinforced Concrete	Masonry
Building Category I	Plan area is less than 600 m^2 and the number of stories above ground is not greater than 10	The number of stories above ground is not greater than 5
Building Category II	Plan area is greater than 600 m^2 or the number of stories above ground is greater than 10 but not greater than 15	
Building Category III	The number of stories above ground is greater than 15 or special structural elements exist (e.g. isolators, dampers, etc.)	The number of stories above ground is greater than 5

Out of Scope

Turkish national damage assessment system

Damage Categories for RC Members



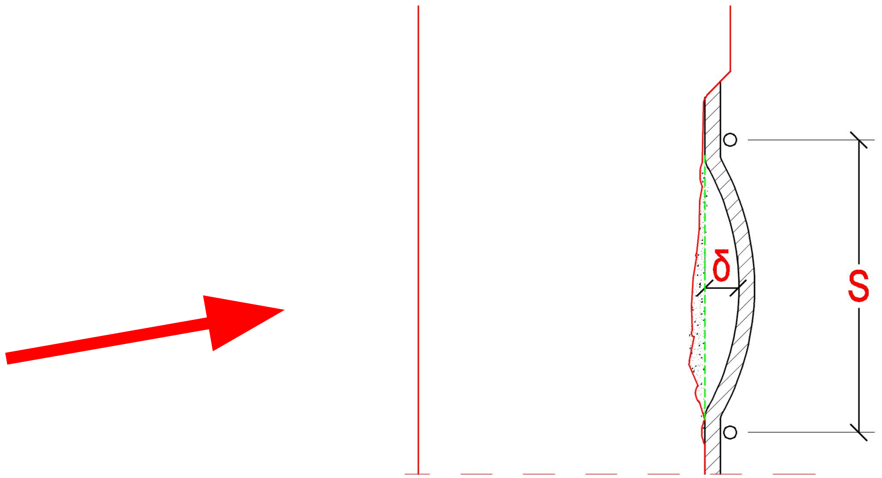
Type A

Type B

Type C

Type D

Damage Category	Residual Crack Width	Compression Damage
Type O	-	-
Type A	≤0.5 mm	-
Type B	0.5 mm< w ≤3 mm	Cover crushing, cover spalling
Type C	>3 mm	Slight buckling of reinforcement (buckling (δ) ≤ stirrup spacing (s) /20 and 1.5 cm)
Type D	-	Core crushing, rupture of reinforcement, buckling of reinforcement (buckling (δ) > stirrup spacing (s) /20 or 1.5 cm)



Turkish national damage assessment system

Exterior Assessment

Interior Assessment for Building Category I

PA< 600 m^2
Number of Stories above the ground ≤ 10

Interior Assessment for Building Category II

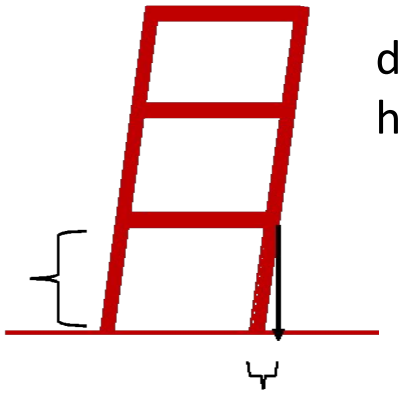
PA> 600 m^2
10 < Number of Stories above the ground ≤ 15

Turkish national damage assessment system

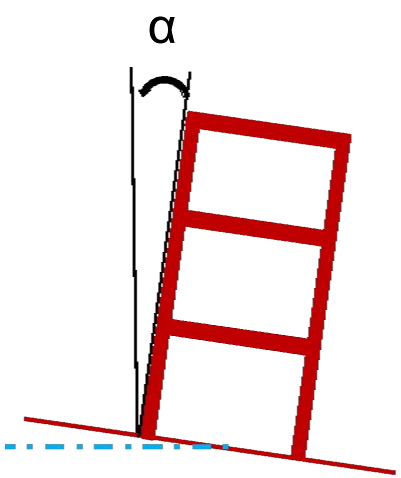
Exterior Assessment

(a) If the building is totally collapsed → Collapsed Building

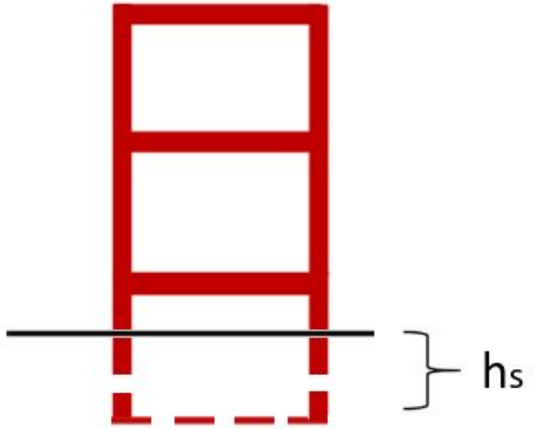
(b) If the building is partially collapsed → Building to be Urgently Demolished



d: Residual displacement
h: Story height



α: rigid rotation



$d/h>0.01$ → Heavily Damaged

$d/h>0.03$ → Building to be Urgently Demolished

$\alpha>1°$ → Heavily Damaged

$\alpha>3°$ → Building to be Urgently Demolished

$h_s > h/3$ → Heavily Damaged

Turkish national damage assessment system

Exterior Assessment

Interior Assessment for Building Category I

PA< 600 m^2
Number of Stories above the ground ≤ 10

Interior Assessment for Building Category II

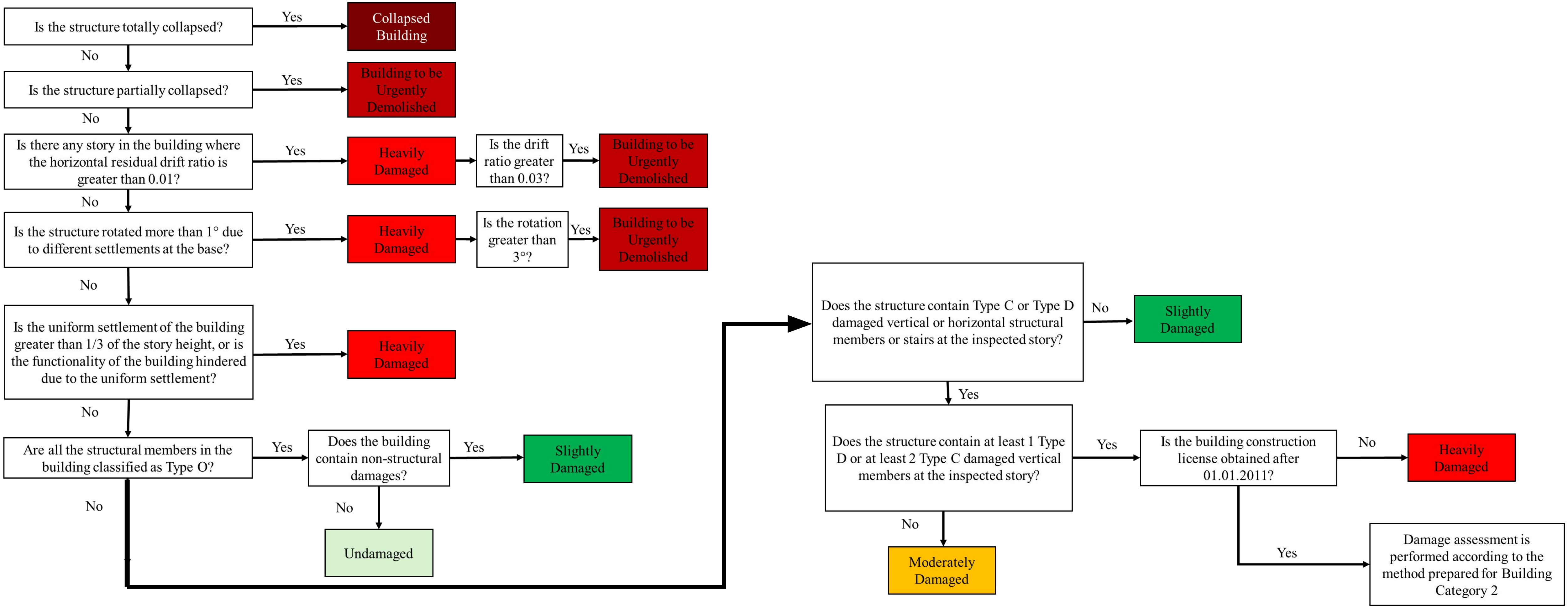
PA> 600 m^2
10 < Number of Stories above the ground ≤ 15

Turkish national damage assessment system

Interior Assessment for Building Category I

Plan Area< 600 m^2
Number of Stories above the ground ≤ 10

Reinforced Concrete Buildings



Turkish national damage assessment system

Exterior Assessment

Interior Assessment for Building Category I

PA< 600 m^2
Number of Stories above the ground ≤ 10

Interior Assessment for Building Category II

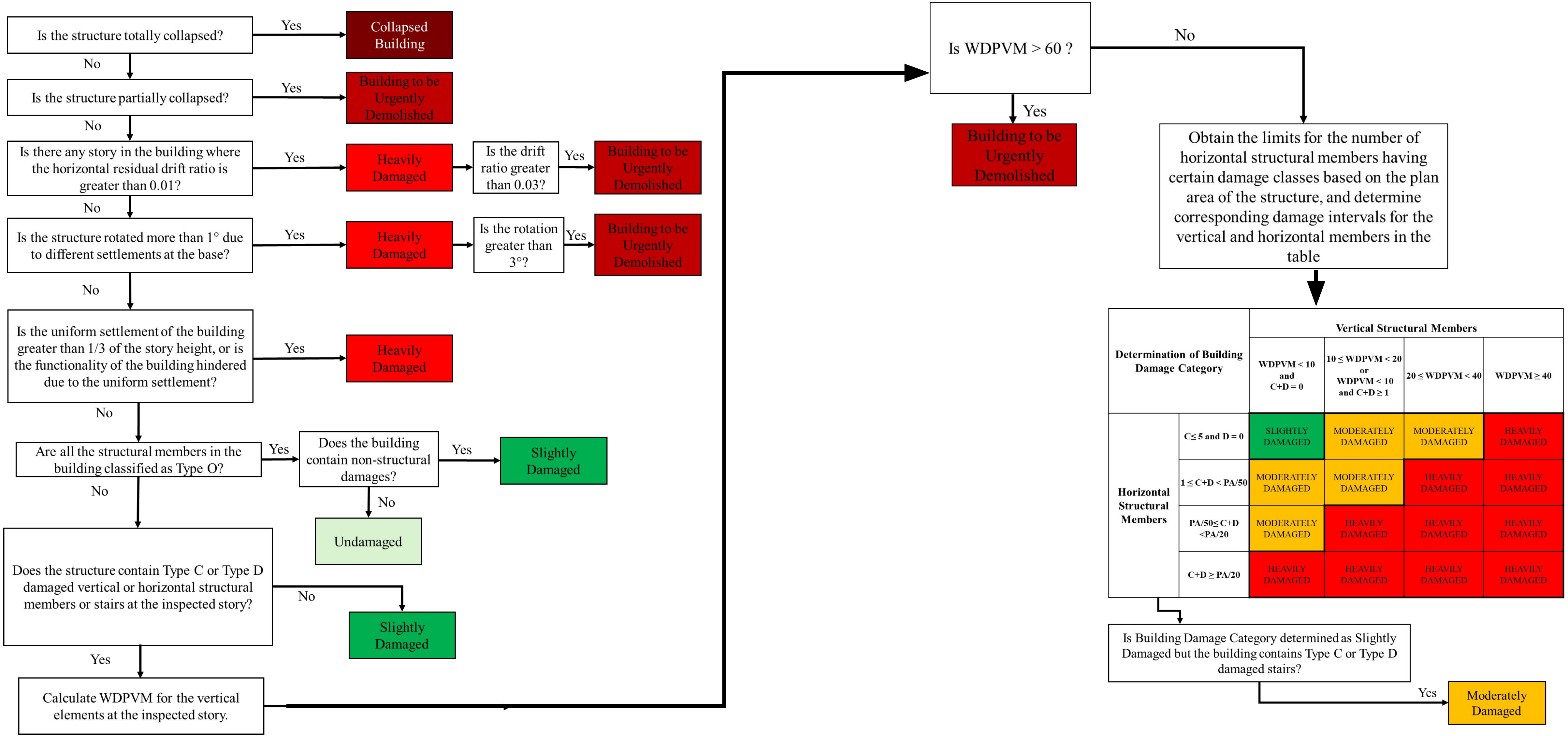
PA> 600 m^2
10 < Number of Stories above the ground ≤ 15

Turkish national damage assessment system

Interior Assessment for Building Category II
Reinforced Concrete Buildings

Plan Area> 600 m^2

10 < Number of Stories above the ground ≤ 15



Determination of Building Damage Category		Vertical Structural Members			
		WDPVM < 10 and C+D = 0	10 ≤ WDPVM < 20 or WDPVM < 10 and C+D ≥ 1	20 ≤ WDPVM < 40	WDPVM ≥ 40
Horizontal Structural Members	C≤ 5 and D = 0	SLIGHTLY DAMAGED	MODERATELY DAMAGED	MODERATELY DAMAGED	HEAVILY DAMAGED
	1 ≤ C+D < PA/50	MODERATELY DAMAGED	MODERATELY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED
	PA/50≤ C+D <PA/20	MODERATELY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED
	C+D ≥ PA/20	HEAVILY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED

Turkish national damage assessment system

Interior Assessment for Building Category II

Plan Area> 600 m^2
10 < Number of Stories above the ground ≤ 15

Determination of Building Damage Category		Vertical Structural Members			
		WDPVM < 10 and C+D = 0	10 ≤ WDPVM < 20 or WDPVM < 10 and C+D ≥ 1	20 ≤ WDPVM < 40	WDPVM ≥ 40
Horizontal Structural Members	C≤ 5 and D = 0	SLIGHTLY DAMAGED	MODERATELY DAMAGED	MODERATELY DAMAGED	HEAVILY DAMAGED
	1 ≤ C+D < PA/50	MODERATELY DAMAGED	MODERATELY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED
	PA/50≤ C+D <PA/20	MODERATELY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED
	C+D ≥ PA/20	HEAVILY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED	HEAVILY DAMAGED

$$WDPVM = \frac{A \times 0.20 + B \times 0.40 + C \times 0.70 + D \times 1.00}{O + A + B + C + D} \times 100$$

Performance of RC structures

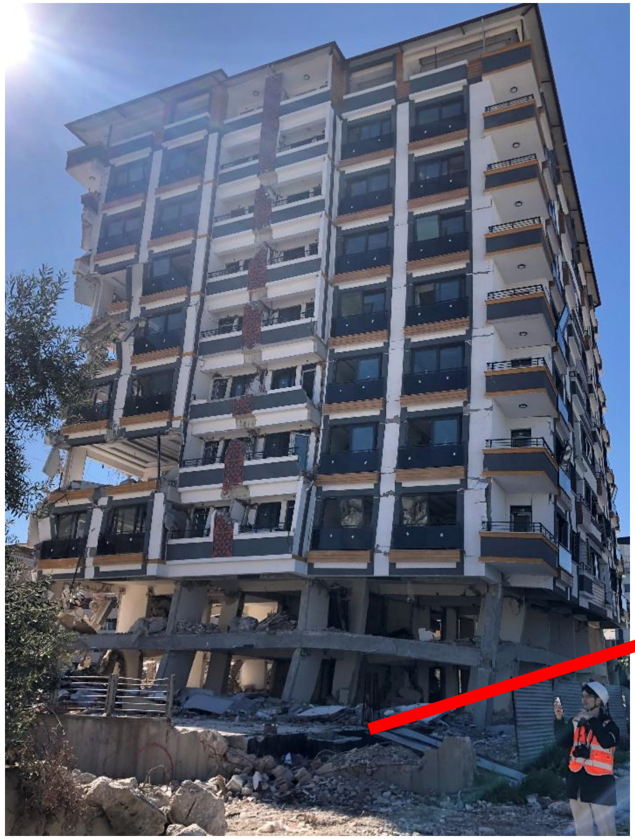
Design deficiencies in structural systems

(insufficient/unbalanced stiffness, weak column-strong beams, insufficient beam-column connections, diaphragm problems)

Performance of RC structures

Design deficiencies in structural systems

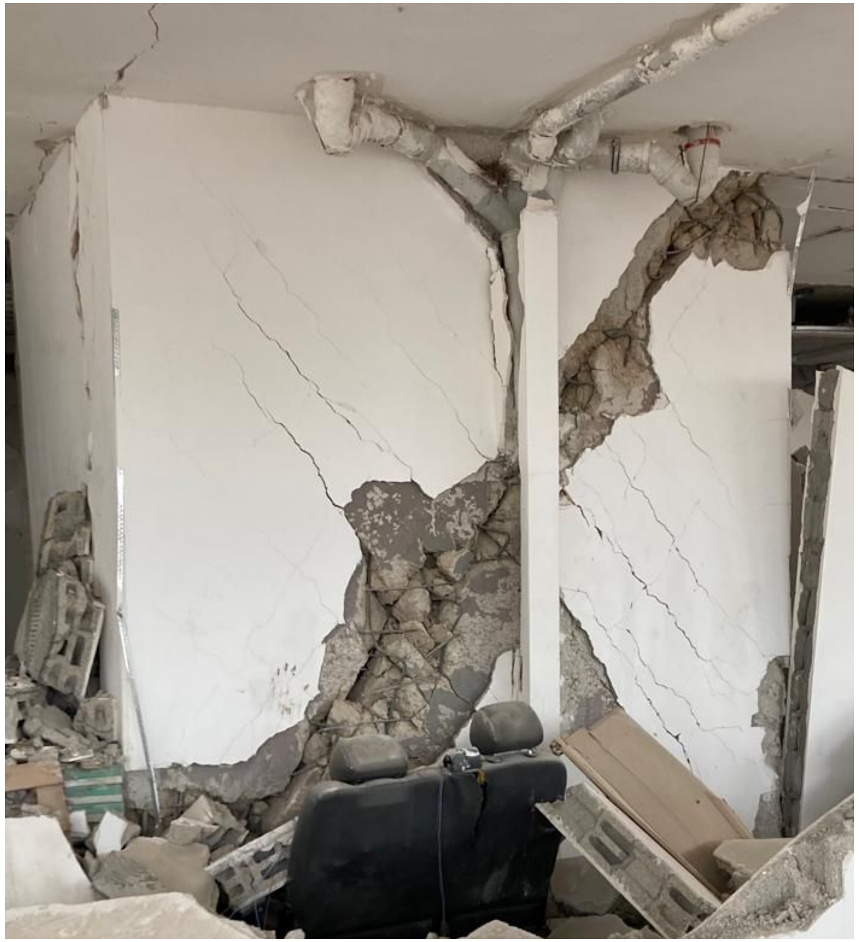
First floors of the many buildings either completely or partially collapsed, soft story, irregular structural systems, flat/thin columns



Performance of RC structures

- Design deficiencies in structural systems

(strength hierarchy)



Performance of RC structures

- Poor detailing of reinforcement

Insufficient confinement

- Excessive spacing
- 90-degree hooks
- Lack of crossties

Performance of RC structures

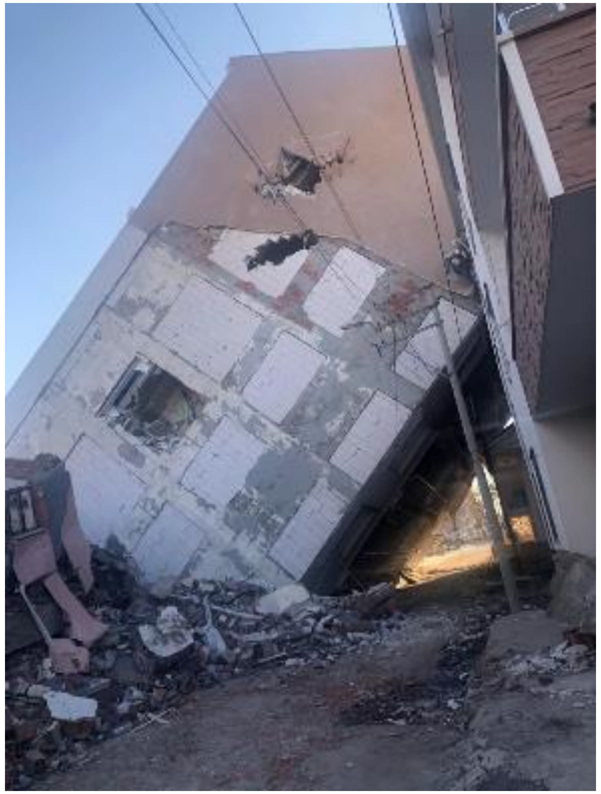
- Poor detailing of reinforcement

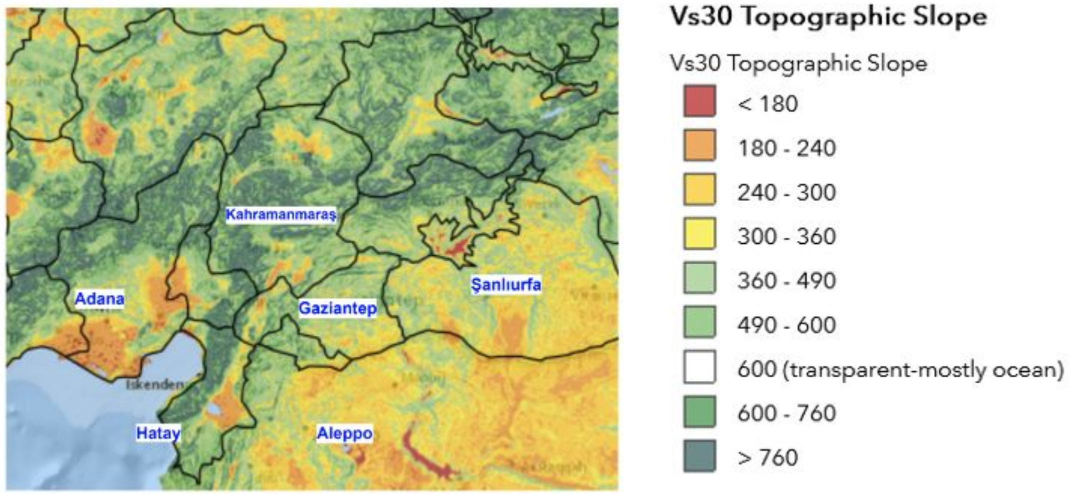
Performance of RC structures

- Low quality construction materials (particularly in older structures)

Performance of RC structures

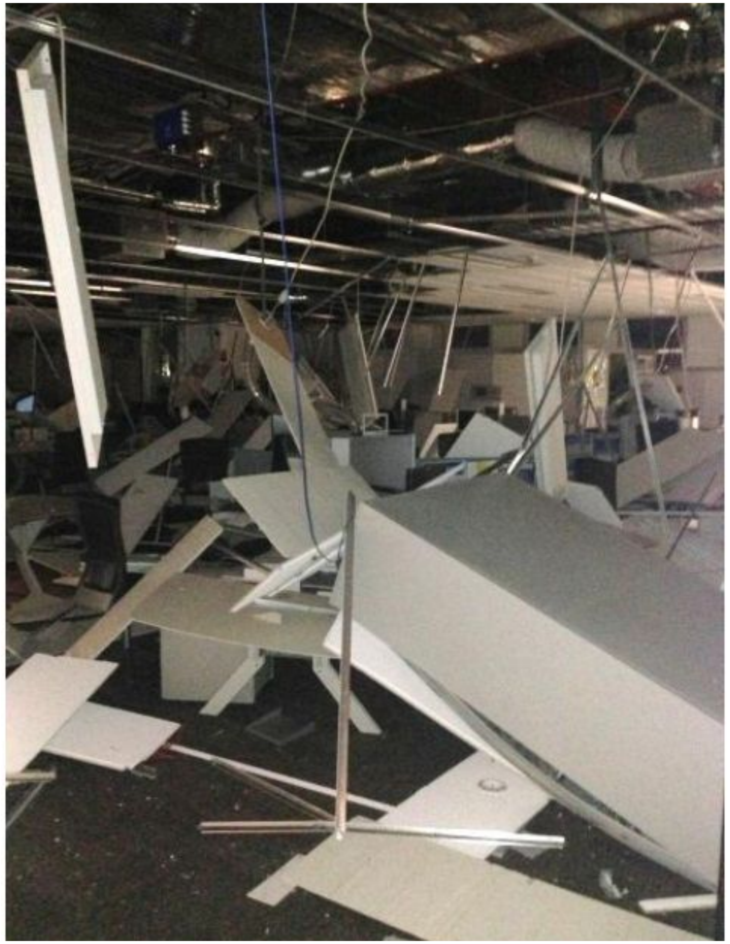
- Soil-related damages





Performance of RC structures

- Non-structural damages



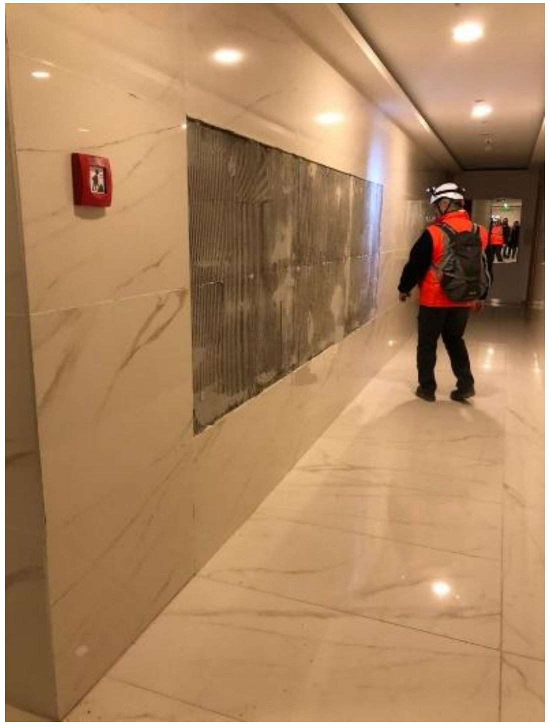
Performance of prefabricated/industrial buildings

- A portion of 8.6% of the total country exports (USD 254.2 billion)
- A portion of 11.5% of the total country's GDP (manufacturing industry)
- 38 Organized Industrial Zones, 116 Small Industrial Sites
- 5000 companies
- Employment of 550,000 people
- Total estimated cost of earthquakes: USD 104 billion (9% of GDP ratio)

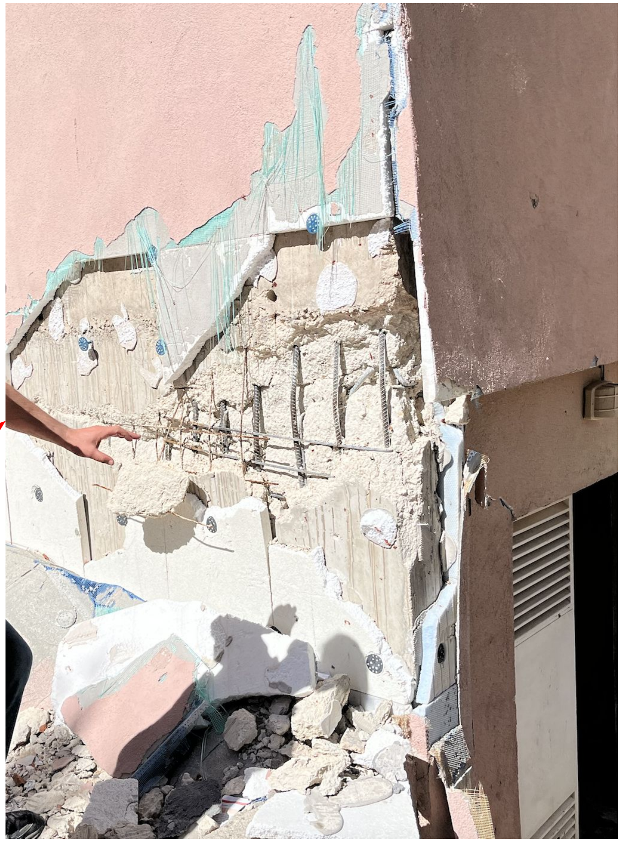
Strategy and Budget Office of Presidency of Türkiye (2023)

Performance of RC Structures

- Tall Buildings
- Non-structural damages



Performance of Tunnel-form Buildings



- Generally performed well
- Avoided life loss
- Repairable damage

! Detailing problems (transverse bars and connections)

! Out-of-plane weakness

Irregular placement of bars (cover)

Performance of historical structures

February 2023 Earthquakes

The rich repertoire of historic buildings from different ages in the affected area

8444 cultural heritages (Religious structures, foundation buildings, etc…)
28 museums and 22 archeological sites

Experts from Directorate of Surveying and Monuments, Turkiye completed damage survey by 25th February 2023 (Kahramanmaraş and Hatay Earthquakes Report, Strategy and Budged Department, 2023):

2863 cultural heritage buildings (11 cities in total)

- 1048 buildings have no damage
- 721 buildings were slightly damaged
- 390 buildings were moderately damaged
- 535 buildings were severely damaged
- 169 buildings collapsed

Performance of historical structures

February 2023 Earthquakes

Collapse of Habibi Neccar Mosque, First mosque built in Turkiye (7th century)

https://arkeofili.com/antakyadaki-depremde-habib-i-neccar-camisi-yikildi/

Numerous minaret collapses

Şirvani Camii (17th century), Gaziantep

Çarşı Atik Camisi 15th century

Failure at the boot and overturning of the minaret

Retrofitted Buildings in Hatay 2008/2023

Seismic Assessment and Rehabilitation of Existing Buildings (NATO SfP9977231)
Project Director: Prof.Dr. Güney Özcebe

Retrofitted Buildings in Hatay 2008/2023

A1 BLOK

FRP Wrapping

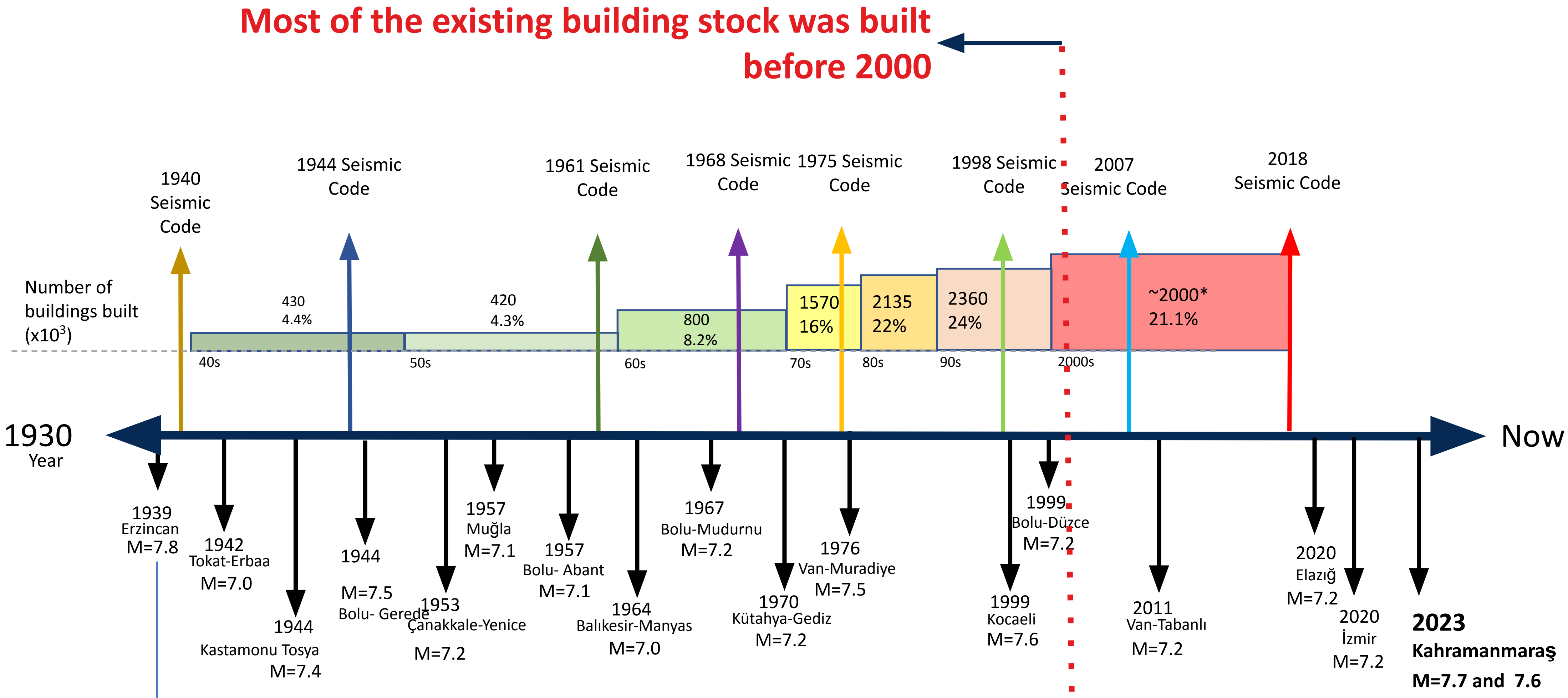
A2 BLOK

FRP Wrapping + Addition of Shear Wall

A3 BLOK

Not Retrofitted

Seismic design codes in Türkiye

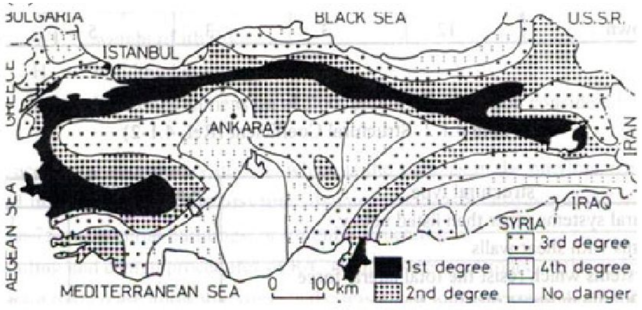


- The first major catastrophic natural disaster experienced by Republic of Türkiye was the Erzincan EQ in 1939, causing a loss of more than 33,000 lives and destruction of 140,000 homes.

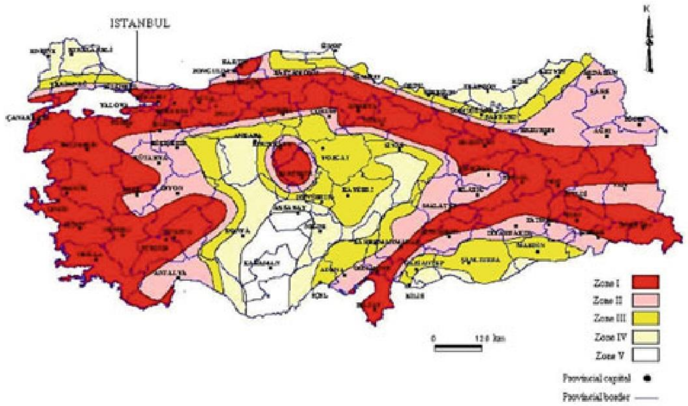
Seismic design codes in Türkiye

2019 Seismic Regulation

Seismic zone map-1972

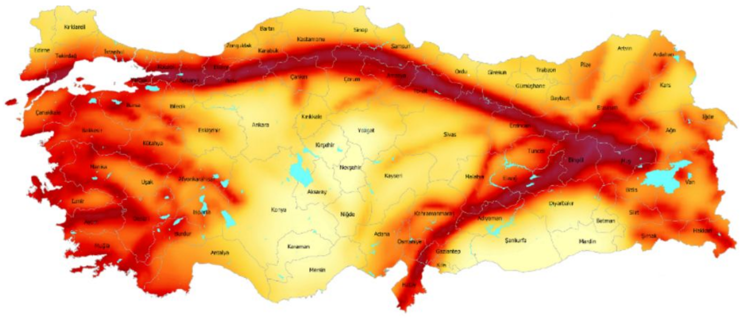


Seismic zone map-1996



Seismic zones on the 1996 map consist of extensive geographical bands (widths exceeding 100 km). Describing the earthquake hazard in these broad bands with a single PGA was insufficient.

Seismic hazard map-2019



A contour map based on geographic coordinates is established, and defined not in terms of PGAs but in terms of spectral acc.

Site-specific spectral acc. are derived using probabilistic seismic hazard analysis method for T=0.2 s and T=1 s periods, on stiff ground, and for return periods of 2475, 475, 72, 43 years.

Seismic design codes in Türkiye

1940 Seismic Regulation

- first seismic regulation
- fundamental base shear coefficient of **0.10** for calculation of the lateral seismic load

$$H = 0.10\left(G + \frac{P}{2}\right) + \frac{W}{2}$$

W: Wind load
H : Design lateral load
P : Live load
G : Dead load

1942 Seismic Regulation annexed with a seismic zone map

Seismic design codes in Türkiye

1975 Seismic Regulation

$$C = C_o K S I \geq \frac{C_o}{2}$$

C : Fundamental base shear coefficient
C_o : Seismic zone coefficient (0.10, 0.08, 0.06 and 0.04, for Zones I, II, III and IV, respectively)
K : Structure type coefficient
S : Dynamic coefficient
I : Building importance factor

$$S = \frac{1}{|0.8 + T - T_o|} \leq 1.0$$

$$T = (0.07 - 0.10)N$$

S : Dynamic coefficient (spectrum coefficient) (1.0 for one and two-story structures and all masonry buildings)
T_o : Effective period of the ground (s)
N : Number of stories

$$F_i = (F - F_t)\frac{W_i h_i}{\sum W_i h_i}$$

Distribution of the base shear force along the height of the building
(inverse triangular distribution

$$F_t = 0.004F\left(\frac{H}{D}\right)^2 \leq 0.15F$$

F_t : An additional singular force to be applied to the top
story

Seismic design codes in Türkiye

1998 Seismic Regulation

- Capacity design principles were introduced.
- Explicit definition of the design earthquake in terms of occurrence probability.
- Explicit definition of the acceptable structural performance under the design earthquake.
- Definition of the elastic design spectrum.
- Definition of the seismic load reduction factor depending on the structural characteristics, including dynamic properties and ductility of the structural system and the over-strength factor.
- Inclusion of detailed requirements on confinement and explicit rules for reinforcement detailing.
- Quantitative definition of irregularities.

Seismic design codes in Türkiye

2007 Seismic Regulation

- Inclusion of a new extensive chapter on seismic safety assessment and retrofitting of existing buildings.
- Inclusion of a linear elastic method for seismic safety assessment considering the inelastic behavior in terms of approximate allowable demand/capacity ratios given depending on the damage level.
- Inclusion of different levels of design EQs (service/design/maximum earthquakes) and performance levels (IO/LS/CP).
- Inclusion of analysis (single-mode/push-over/nonlinear time history) for seismic safety assessment and retrofitting.

Damage levels are determined depending on the concrete compressive strain at the extreme compression fiber and tensile reinforcement strain.

Seismic design codes in Türkiye

2018 Seismic Regulation

Performance Matrix for New Buildings (except H>70m)

Earthquake Ground Motion Level	Immediate Occupation	Limited Damage	Controlled Damage	Collapse Prevention
DD-4 Frequent 43 years				
DD-3 Occasional 72 years		SBD		
DD-2 Rare 475 years			FBD	
DD-1 Very Rare 2475 years			SBD	

Performance Level

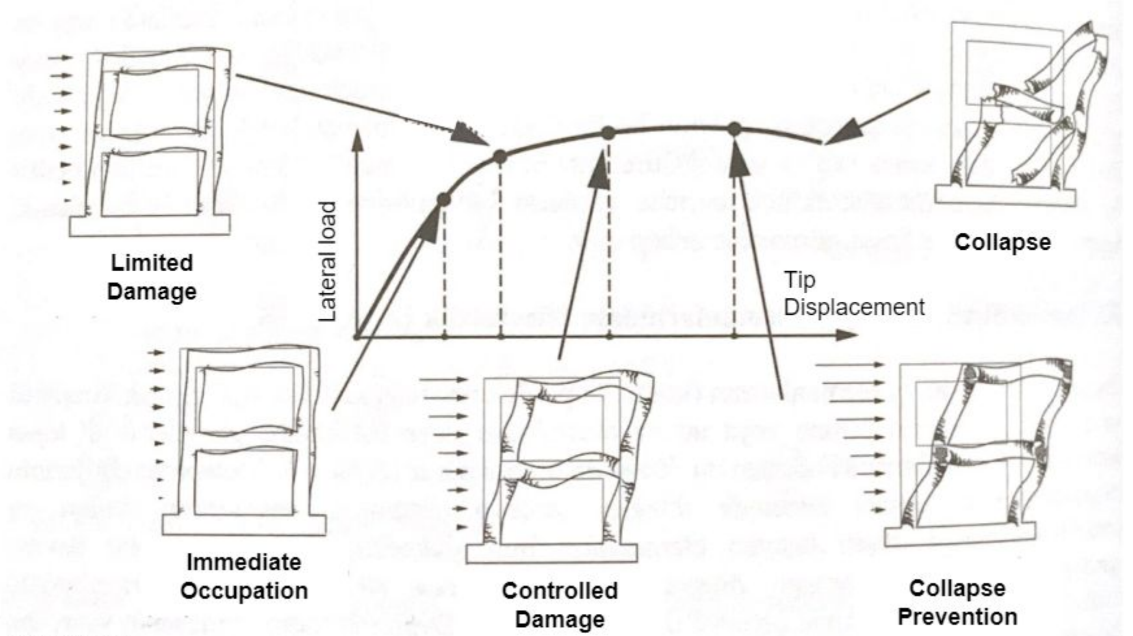
Repairable → **Irrepairable**

Main design approach

Important & relatively tall buildings

FBD Force-based design

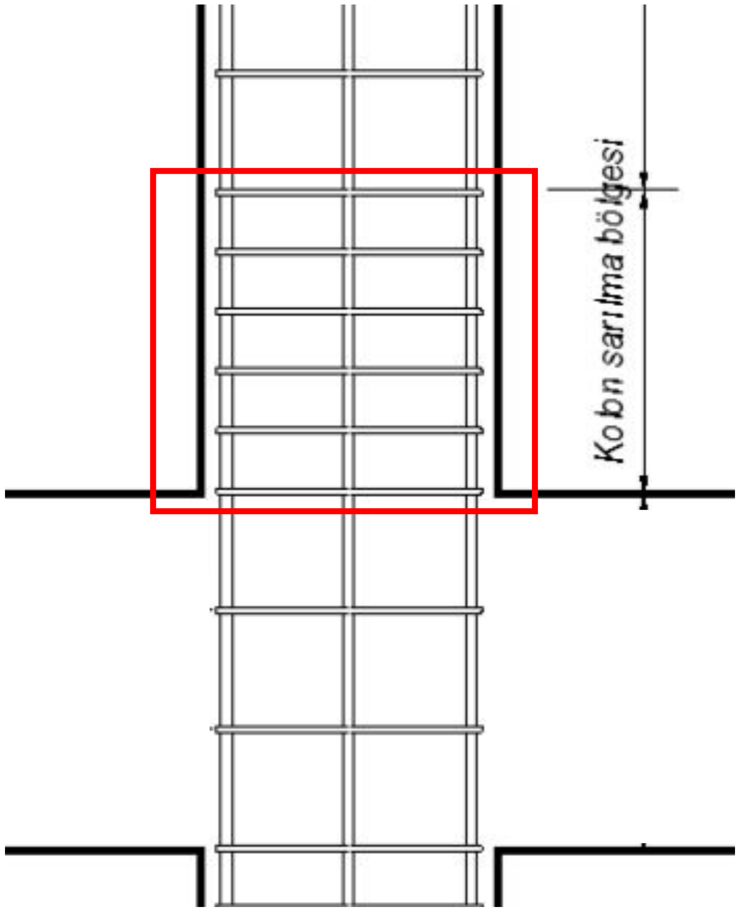
SBD Strain-based design



Zekai Celep

Columns

- Length of the column confinement zone will be equal to
  - Largest section dimension
- Maximum spacing of transverse reinforcement in the column confinement zone
  - 100 mm (reduced from 150 mm)



Ongoing study!!!

Draft for Revisions in TBEC (2018) aftermath of February 2023 EQs

Shear Walls

- The level of axial load upper limit coefficient for shear walls has been reduced from 0.35 to 0.30.

- Minimum thickness conditions for shear walls have been simplified. Instead of 1/30 of the unsupported length in the lateral direction of the wall in the plan, now it is 1/25. The 1/30 condition remains for tunnel form buildings.

- No lap splicing will be performed in the vertical reinforcement of the shear wall end zone for at least one story height above the building base. In cases where the story height is greater than 3.5 m, lap splicing will be performed at least 3.5 m above the building base.

Ongoing study!!!

Shear Walls

- The maximum spacing of stirrups in the end zones of the critical shear wall height has been reduced from 150 mm to 100 mm.
- In buildings with a rigid basement, the design shear force to be considered for the first two basement levels below the shear wall base, down to the height of those two basement levels, shall not be less than the design shear force calculated at the shear wall base.
- In addition to the ties, around the perimeter of the coupling beam, the ratio of $A_{sw}/(s_{bw})$ shall not be less than 0.002, and the ties shall be spaced no more than 300 mm apart. Moreover, the total longitudinal reinforcement ratio shall not be less than 0.002, and horizontal (longitudinal) reinforcement shall be uniformly distributed with a vertical spacing not exceeding 300 mm between reinforcing bars.

Ongoing study!!!

Strict rules to be applied until the next TBEC is issued

1. Use of shear walls is mandatory in both directions

for RC buildings

- Seismic Design Class DTS=1,1a, 2, 2a
- Building Height Class BYS≤6
- Seismic Design Class DTS=3,3a, 4, 4a
- Building Height Class BYS≤5

In these buildings:

(a) The shear walls will satisfy the condition $A_{pi} \geq N_{dm}/0.25 f_{ck}$

(b) At least two closed ties will be placed in the end zones of the shear walls.

(c) The total shear wall area on any i_{th} floor will satisfy the condition as:

$$\frac{\sum A_{pi}}{A_{ki}} \geq 0.002\, n\, S_{DS}:\ n \leq 10$$

$$\frac{\sum A_{pi}}{A_{ki}} \geq 0.02\, S_{DS}:\ n > 10$$

(d) The total column and shear wall area on any i_{th} floor will satisfy the condition as:

$$\frac{\sum A_{ci}}{A_{ki}} + \frac{\sum A_{pi}}{A_{ki}} \geq 0.004\, n\, S_{DS}:\ n \leq 10$$

$$\frac{\sum A_{ci}}{A_{ki}} + \frac{\sum A_{pi}}{A_{ki}} \geq 0.04\, S_{DS}:\ n > 10$$

Ongoing study!!!

Strict rules to be applied until the next TBEC is issued

2. Total column area on each floor will satisfy the condition as:

$$\frac{\sum A_{ci}}{A_{ki}} \geq 0.003\, n\, S_{DS}$$

for RC buildings

- Seismic Design Class DTS=1,1a, 2, 2a
- Building Height Class BYS>6
- Seismic Design Class DTS=3,3a, 4, 4a
- Building Height Class BYS>5

3. For the columns of high ductile RC frames with Seismic Performance Level BKS=3:

(a) The ratio of the long side to the short side of all columns will not exceed 1.5.

(b) The condition $A_{ci} \geq N_{dm}/0.35 f_{ck}$ will be satisfied.

(c) At least two closed ties will be placed in the confinement zones.

Ongoing study!!!

Strict rules to be applied until the next TBEC is issued

4. In all buildings, columns will be located on a linear axis system excluding exterior axes.
    - All columns will be connected to each other with beams designed according to Section 7.4.
    - Eccentricity from the column center to the beam center will not exceed half of the width of the column interface where the beam intersects.
    - Torsional irregularity coefficient η_{bi} in these buildings will not exceed **2**.
5. In buildings constructed with brittle material infill walls, under the seismic effect of DD-2 for R/I=1, the maximum relative story drift ratio calculated at any floor in each seismic direction will not exceed **0.01**.
6. In buildings constructed with brittle material infill walls and connections between infill walls and frame that prevent the infill wall from being damaged and have sufficient out-of-plane resistance, this drift limit can be increased by a maximum of **50%**.
7. It is necessary for the reverse cyclic behavior of these connections under in-plane and out-of-plane seismic effects to be experimentally documented, and the test results should be provided in the Project appendices.

Ongoing study!!!

Guideline for historical structures in Türkiye

In addition to international charters (i.e. Venice Charter):

- ISO 13822: Basis for design of structures, an annex for historical structures is provided
- ISCARSAH Principles for the analysis, conservation and structural restoration of architectural heritage (2003)
- Seismic design and assessment documents (i.e. EN 1998-3 Eurocode 8, ASCE 41-13, TSDC 2007, NTC 08, etc)
- Specific guidelines for historic structures (i.e. Italian, Turkish guidelines)

GUIDELINE FOR EARTHQUAKE RISK MANAGEMENT
OF HISTORICAL STRUCTURES IN TURKEY (2017)

CDW from Earthquake-hit site

February 2023 Türkiye EQs

90,000 RC buildings were heavily damaged

450 - 920 million tonnes of debris!

(Xiao et al., 2023)

Previous Experimental Studies

- Structural behavior of RAC slabs (Goksu et al. 2019)
- Flexural behavior of RAC columns (Saribas et al. 2019)
  - *effects of different axial load levels*
  - *effects of different amount of transverse reinforcements*
- Shear-flexure interaction in RAC columns (Saribas et al. 2021)
- Post-fire seismic behavior of RAC columns (Demir et al. 2020)

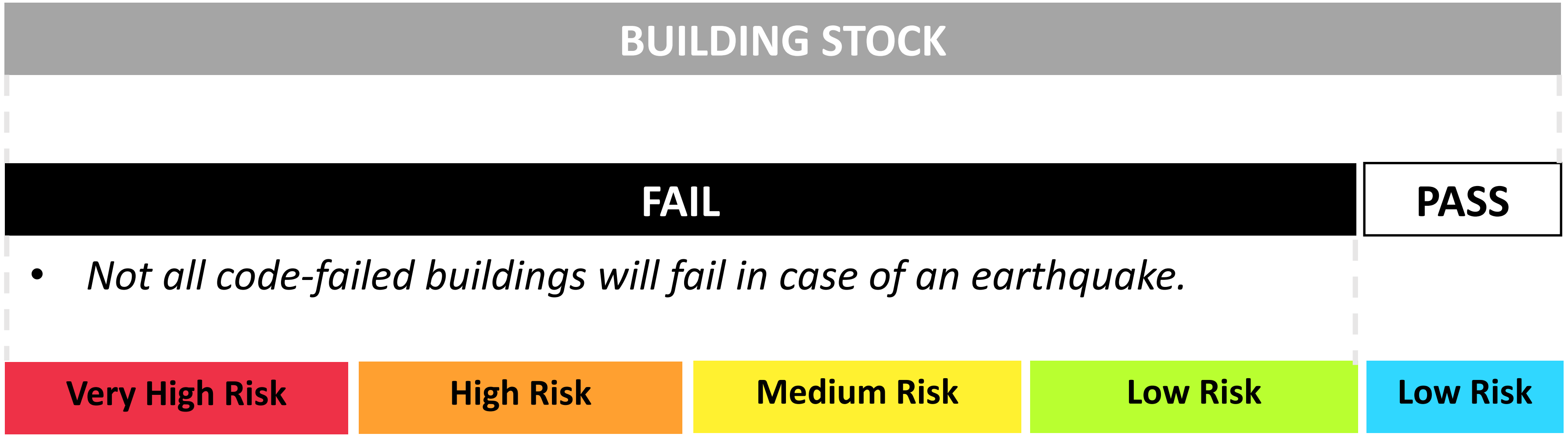
RCA, sourced from concrete structural members, which has low concrete compressive strength.

NAC : Natural Aggregate Concrete
RAC : Recycled Aggregate Concrete

Seismic Risk Assessment of Building Stock

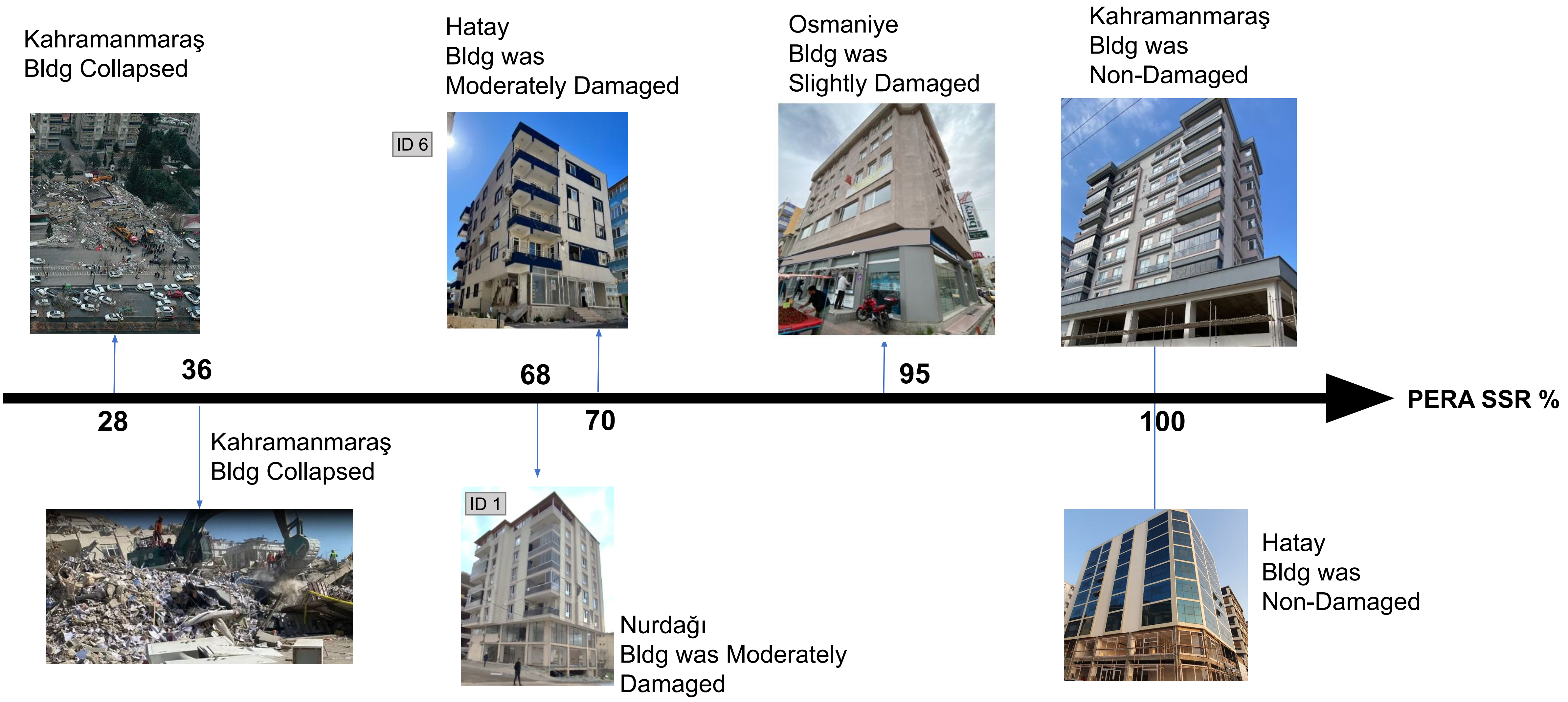
There are two legal documents in Türkiye for seismic safety assessment:

1. Turkish Building Earthquake Code (2018)
2. Provisions for the Seismic Risk Evaluation of Existing Buildings (2019)



- *Not all code-failed buildings will fail in case of an earthquake.*
- *Ranking of the buildings with respect to relative seismic risk.*

PERA methodology - February 2023 Eq. damage comparison

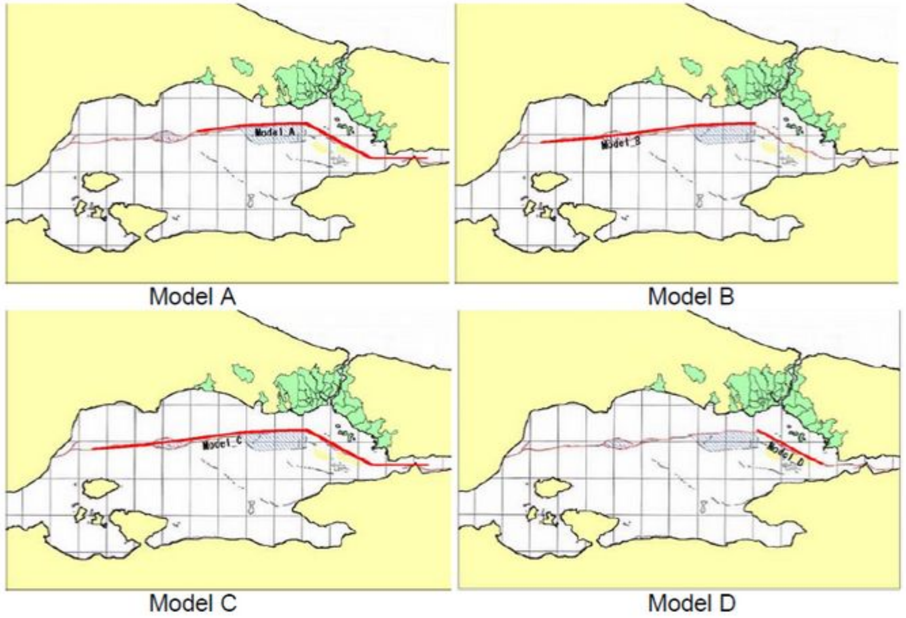


Suggested Approach : The Recent Campaign of IMM

Scenario Earthquake

A potential earthquake of magnitude M_w=7.5

Fay	Model A	Model B	Model C	Model D
Uzunluk (km)	119	108	174	37
Moment Büyüklüğü (Mw)	7.5	7.4	7.7	6.9
Eğim açısı (degree)	90	90	90	90
Türü	Doğrultu atımlı	Doğrultu atımlı	Doğrultu atımlı	Doğrultu atımlı

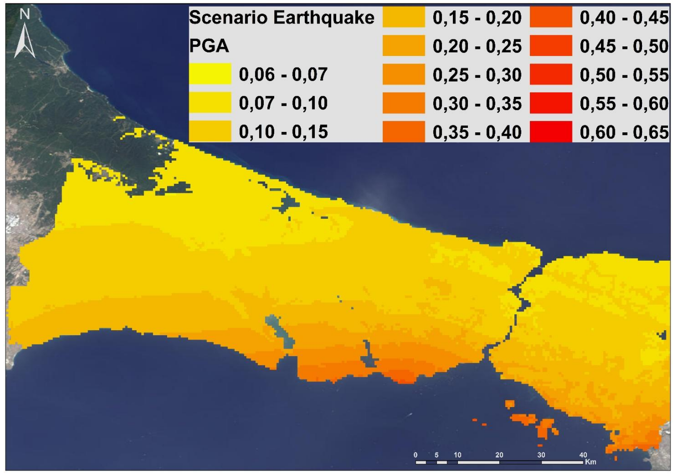


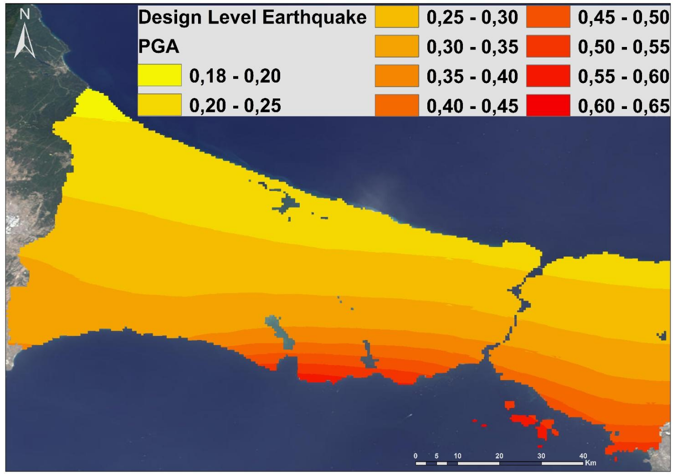
JICA (2002)

Seismicity

Istanbul Earthquake Risk Reduction Project

- Application of **PERA** on **25000 buildings** constructed before 2000 in Istanbul.

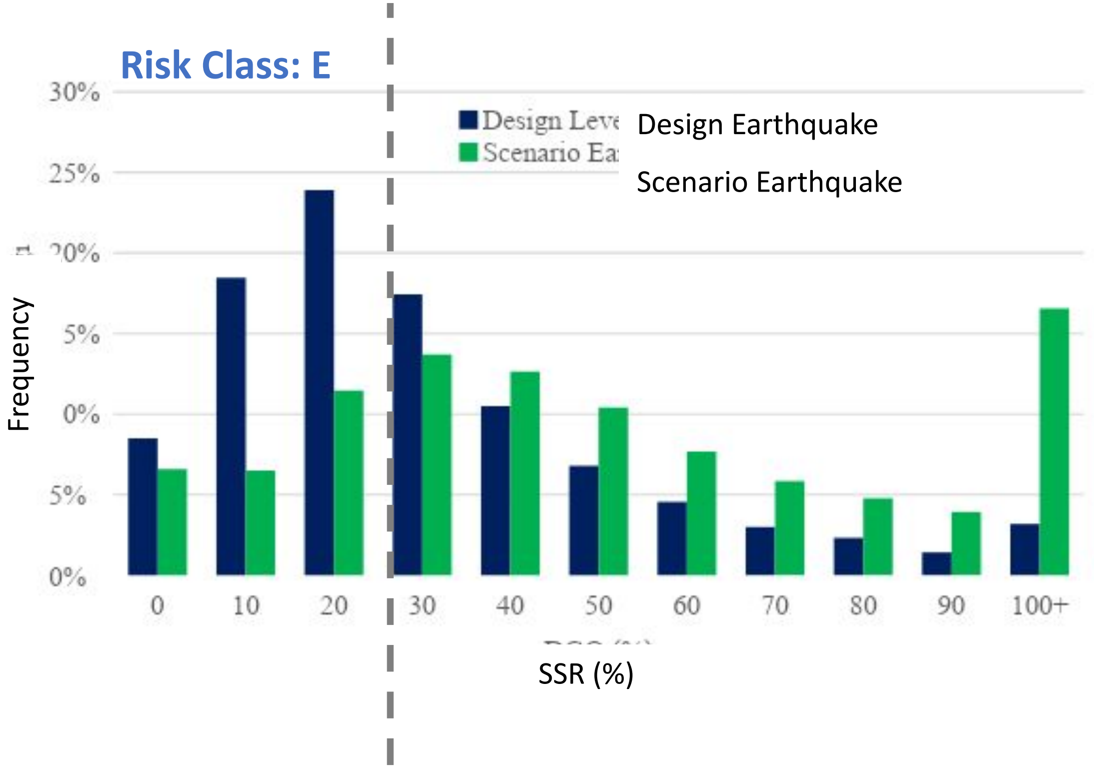




KOERI (2019)

Suggested Approach : The Recent Campaign of IMM

Risk Class	E	D	C	B	A
Risk Level	Very High	High	Medium	Low	Low
SSR	≤25	25-49	50-74	75-99	≥100



SSR (%)	Design EQ Cumulative (%)	Scenario EQ Cumulative (%)
<5	9	7
<15	27	13
<25	**51**	**25**
<35	68	38
<45	79	51
<55	86	61
<65	90	69
<75	93	75
<85	95	80
<95	97	84
≥95	100	100

Suggested Approach : The Recent Campaign of IMM

Distribution of building classes for extrapolated SSR values

25000 bldgs.

↓

580000 bldgs. (RC building stock of Istanbul constructed before 2000)

Risk Class	E	D	C	B	A
Risk Level	Very High	High	Medium	Low	Low
SSR	≤25	25-49	50-74	75-99	≥100
Design Earthquake	40% (231000)	31% (178000)	15% (85000)	7% (40000)	7% (40000)
Scenario Earthquake	19% (110000)	22% (130000)	18% (102000)	12% (72000)	29% (165000)

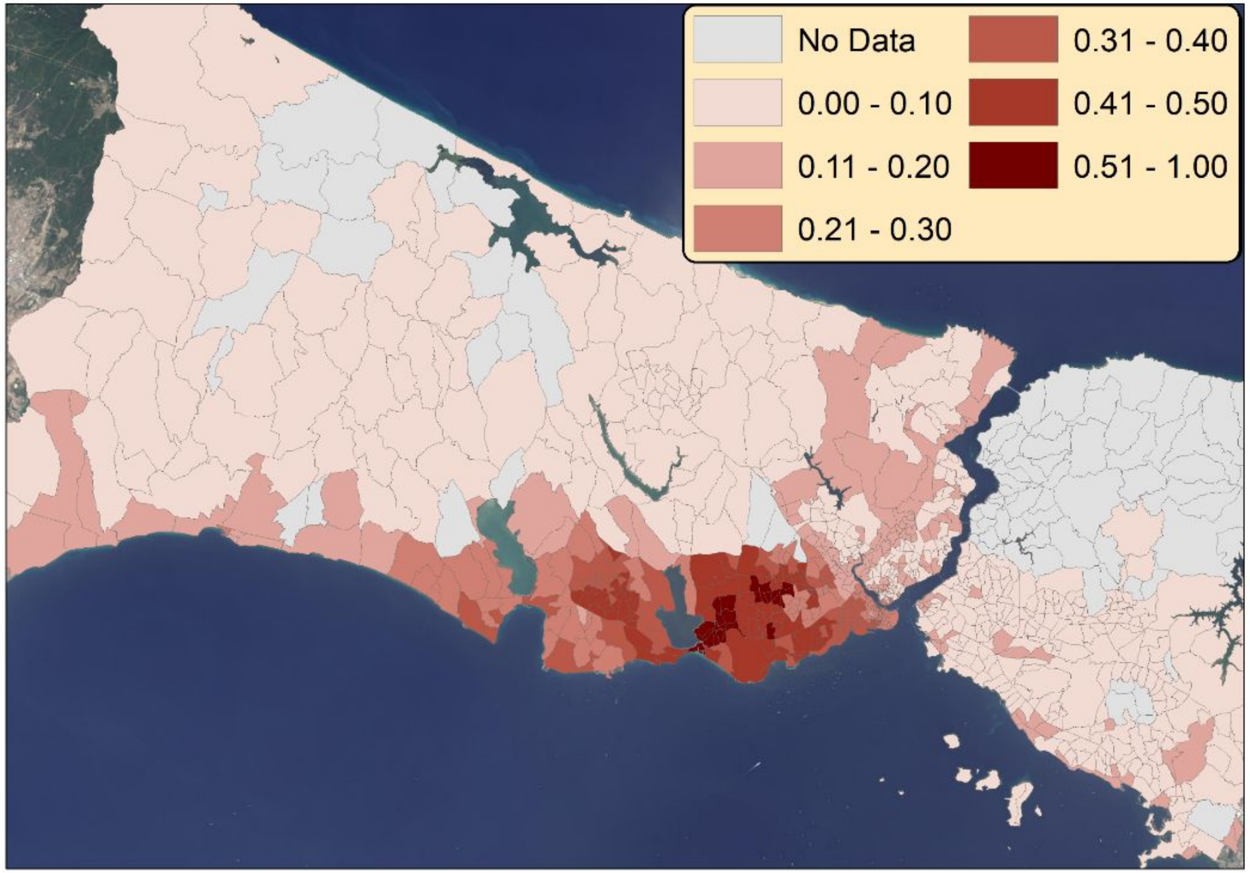
Residential buildings with high seismic risk!

409000 buildings (71% of all) for Design EQ

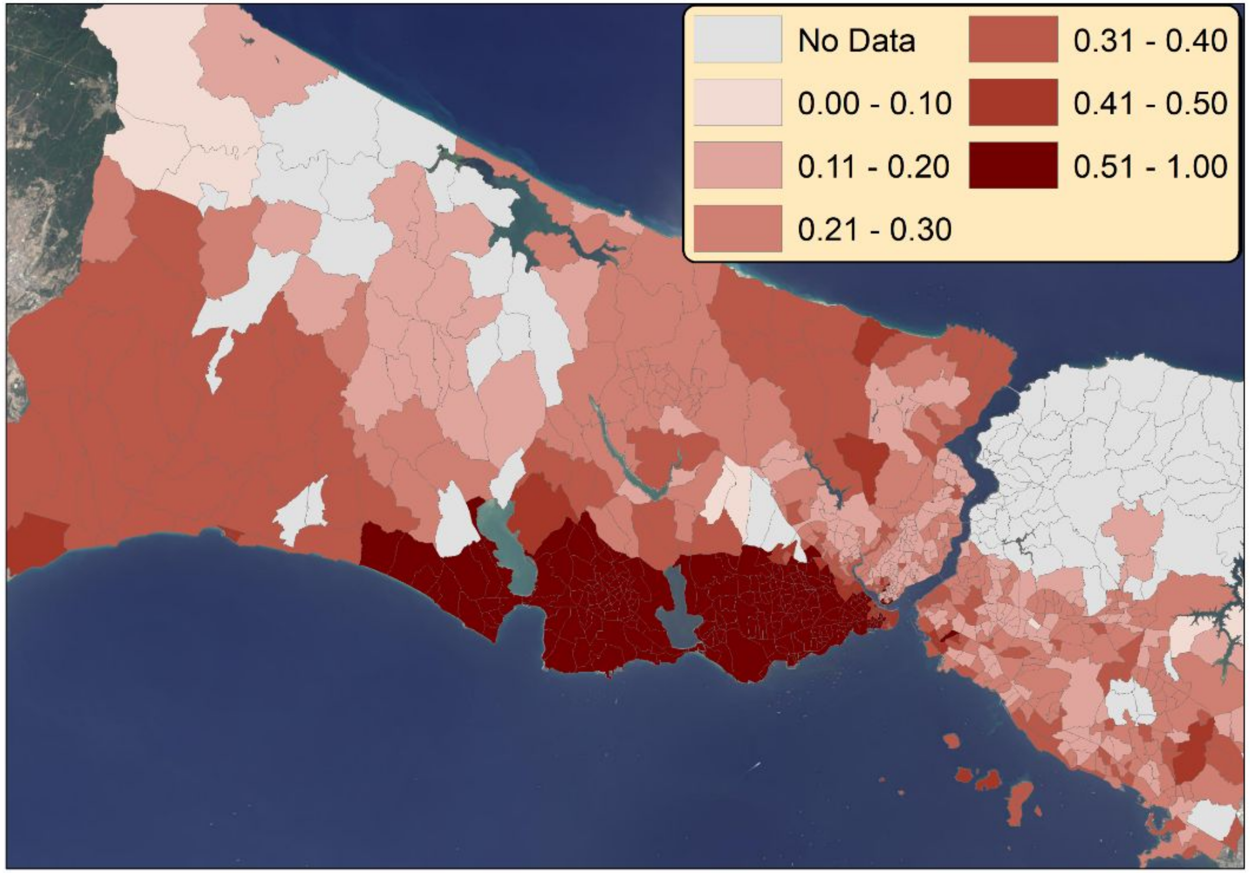
240000 buildings (41% of all) for Scenario EQ

Suggested Approach : The Recent Campaign of IMM

E Class Buildings (SSR≤25)



Scenario Earthquake



Design Earthquake

What could be done for Existing Building Stock?

- **Cost-Benefit Analysis**

Intervention Strategy	Pre-earthquake costs (million x Unit Cost)		Post-earthquake costs (million x Unit Cost)		Total cost (million x Unit Cost)	
	Design EQ	Scenario EQ	Design EQ	Scenario EQ	**Design EQ**	**Scenario EQ**
No intervention	0.0	0.0	983.5	552.6	**983.5**	**552.6**
Intervening in all SSR<25% buildings	126.2	65.5	129.7	95.2	**255.9**	**160.7**

The SSR<25% buildings were assumed to be reconstructed if the retrofitting cost exceeded 40% of the reconstruction costs.

Conclusions / Suggestions

- Many buildings, especially those constructed before the year 2000 and some newer buildings, have not been built according to earthquake-resistant design principles/technical documents (lack of proper inspection).
- Code-complying buildings, designed/constructed with a little of engineering did not collapse (heavy damage is expected and accepted under such an huge earthquake).
- All the collapsed buildings are observed to exhibit severe structural problems either related to design or construction, and sometimes both.

Conclusions / Suggestions

- Due to limited financial resources and time, priority should be given to the highest-risk buildings. The most vulnerable buildings need to be identified using rapid and reliable methods and strengthened to become earthquake-resistant.
- A huge effort is required for recovery, to improve seismic capacity of existing buildings in other cities and to build new buildings sufficiently safe.
- Non-structural components!

THANK YOU

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