Technical University of
Civil Engineering Bucharest

Seismic performance of new and existing buildings in Romania

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FCP VCE ÖIAV Symposium
Modern Earthquake Engineering – Present & Future
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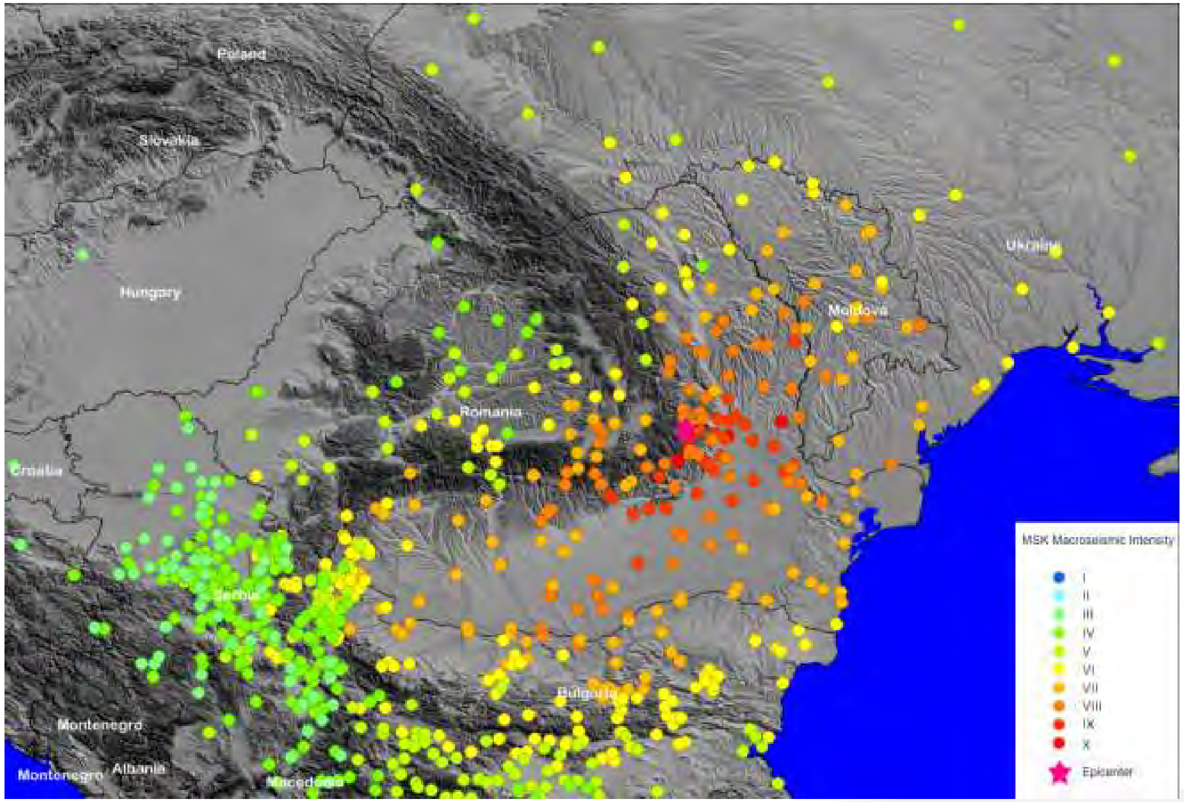
Content

- Major earthquakes in Romania in the 20th century
- Seismic design regulations
- Challenges of seismic design in Bucharest
- Seismic hazard & risk assessments for Romania
- Conclusions
    - Acknowledgements

Major earthquakes in Romania in the 20th century

Major earthquakes in Romania

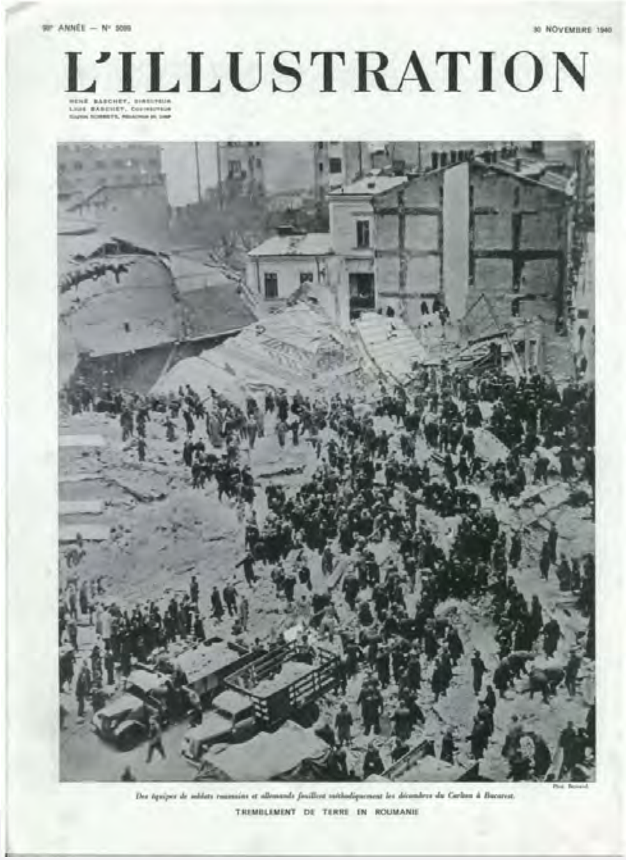
November 10, 1940, Mw=7.7, h=150 km



MSK macroseismic intensities

Major earthquakes in Romania

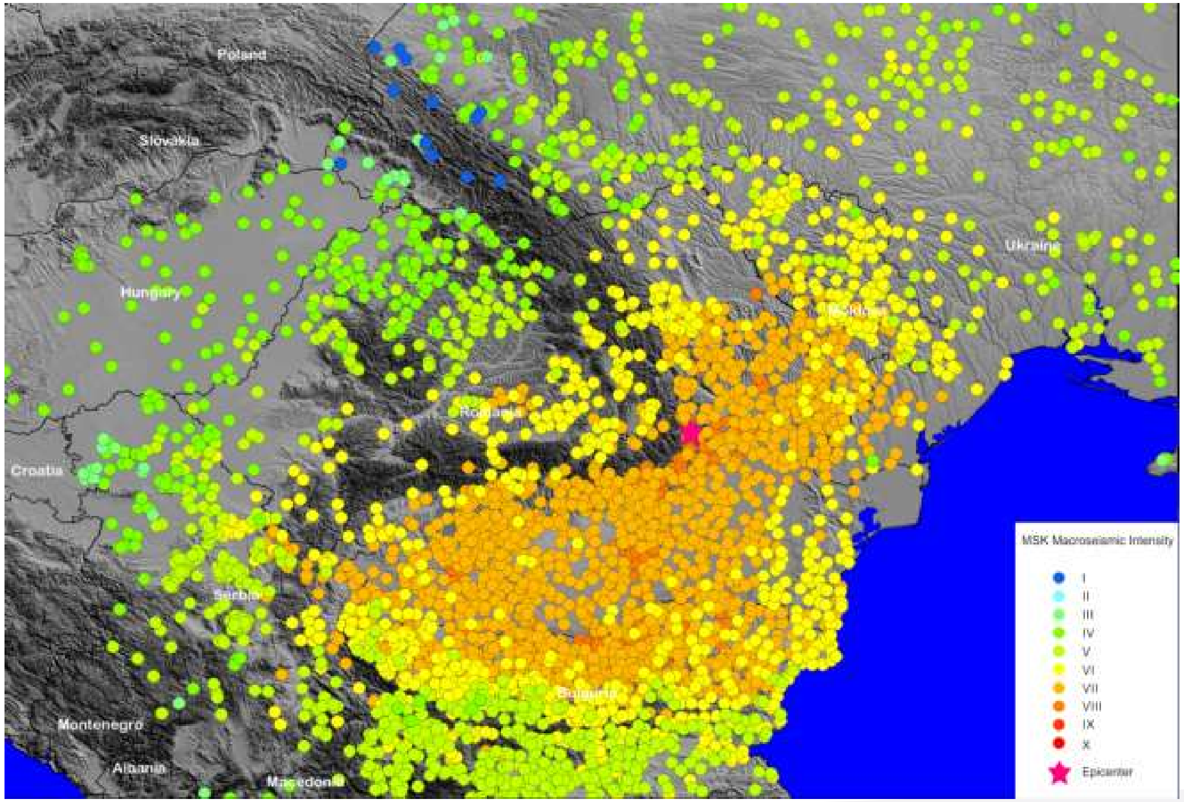
November 10, 1940, Mw=7.7, h=150 km



Carlton Building (l'Illustration, 1940)

Major earthquakes in Romania

March 4, 1977, Mw=7.4, h=94 km



MSK macroseismic intensities

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Major earthquakes in Romania

March 4, 1977, Mw=7.4, h=94 km

- 1578 deaths (1424 in Bucharest)
- 11221 injured (7598 in Bucharest)
- 32 collapsed buildings in Bucharest
- 33000 housing units destroyed or severely damaged
- Total losses: 2.05 bn USD (in excess of 6% of GDP)

(Source: World Bank Report)

Major earthquakes in Romania

March 4, 1977, Mw=7.4, h=94 km

Major earthquakes in Romania

March 4, 1977, Mw=7.4, h=94 km


建築研究資料

Kenchiku Kenkyu Shiryo

No.20 January 1978

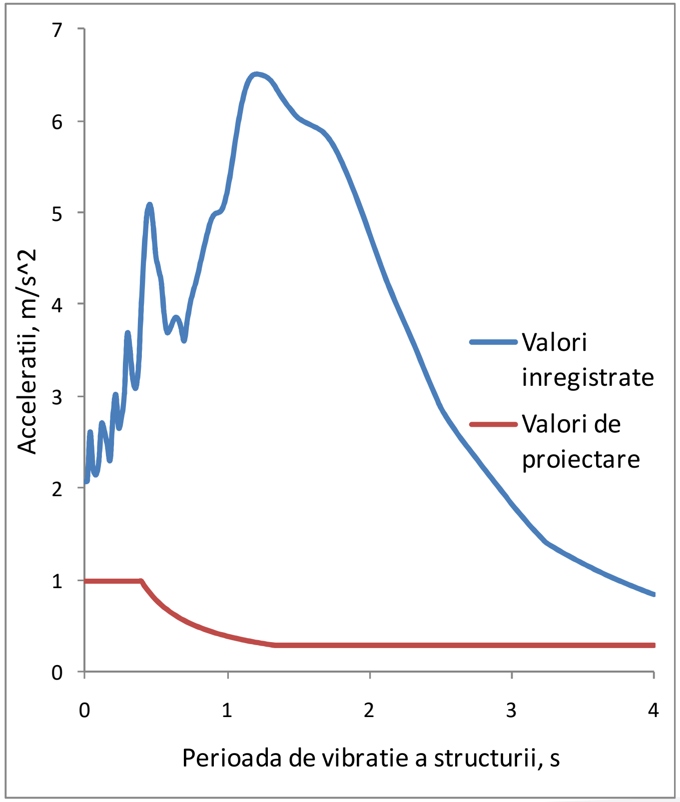
ルーマニア地震ディジタル記録

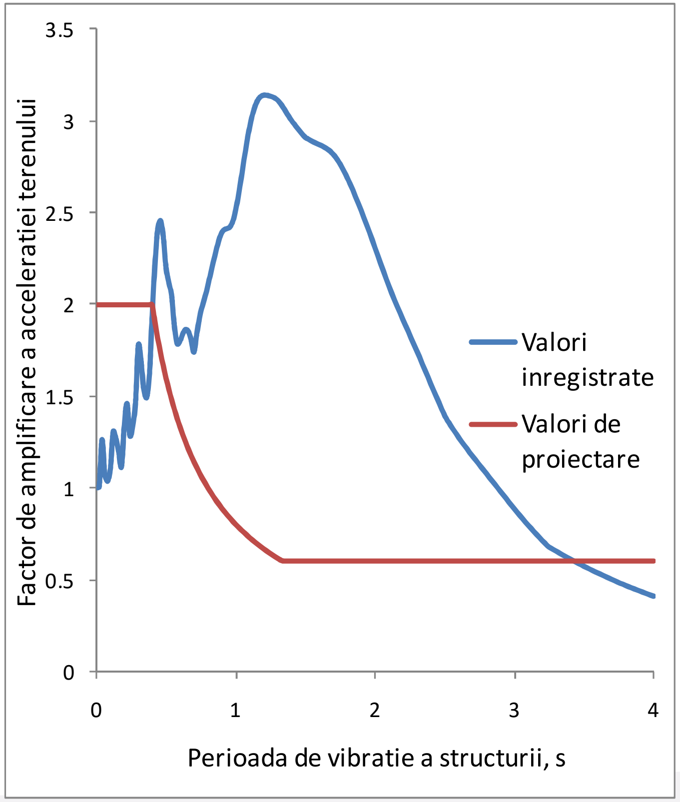
Digitized Data of Strong-Motion
Earthquake Accelerograms in Romania
(March 4, 1977)

強震観測委員会
by
Observational Committee of Strong
Motion Earthquake

建設省建築研究所

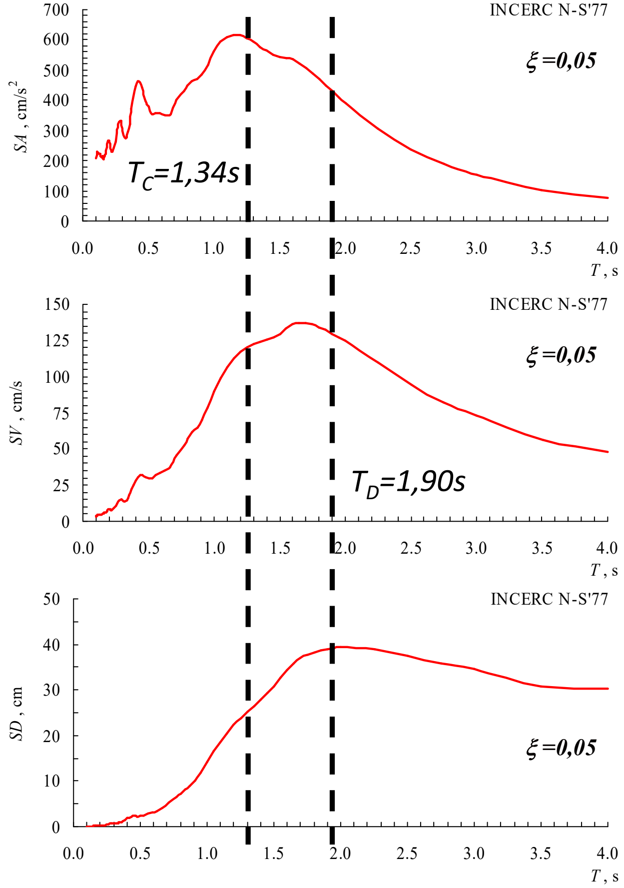
Building Research Institute, Ministry of Construction



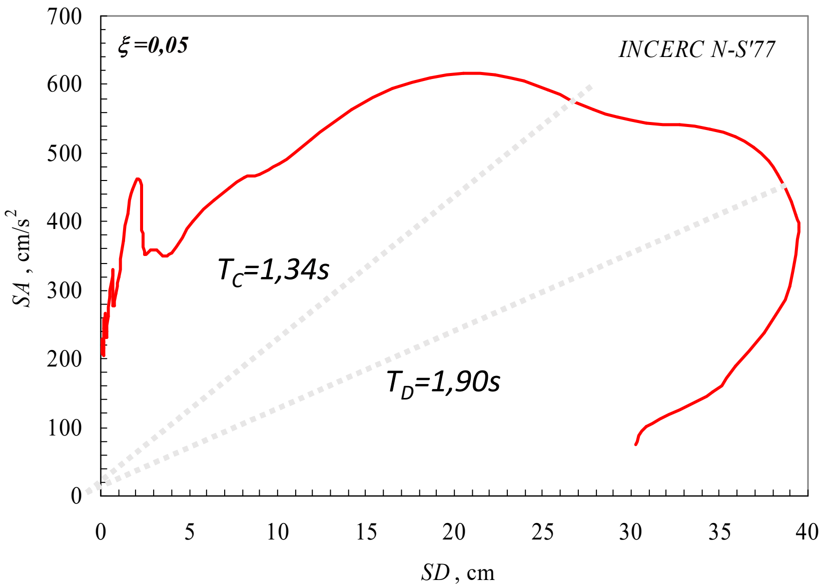


Digitized recorded ground motion (left), acceleration response spectra (centre) and normalized acceleration response spectra (right) – blue – recorded values; red – design values

Major earthquakes in Romania



March 4, 1977, Mw=7.4, h=94 km



Digitized recorded ground motion (left), acceleration response spectra (centre) and normalized acceleration response spectra (right) – blue – recorded values; red – design values

Major earthquakes in Romania

March 4, 1977, Mw=7.4, h=94 km

"Nowhere else in the world is a center of population so exposed to earthquakes originating repeatedly from the same source"

Charles Richter
15 March 1977, Letter to the Government of Romania

“The unusual nature of the ground motion and the extent and distribution of the structural damage have important bearing on earthquake engineering efforts in the United States.”

Jennings & Blume

NRC & EERI Report

Major earthquakes in Romania

March 4, 1977, Mw=7.4, h=94 km

1

"A systematic evaluation should be made of all buildings in Bucharest erected prior to the adoption of earthquake design requirements and a hazard abatement plan should be developed."

From:

"Observation on the behaviour of buildings in the Romanian earthquake of March 4, 1977" by G. Fattal, E. Simiu and Ch. Cluver. Edited as the NBS Special Publication 490, US Dept of Commerce, National Bureau of Standards, Sept 1977.

2

"Tentative provisions for consolidation solutions would preferably be developed urgently".

From:

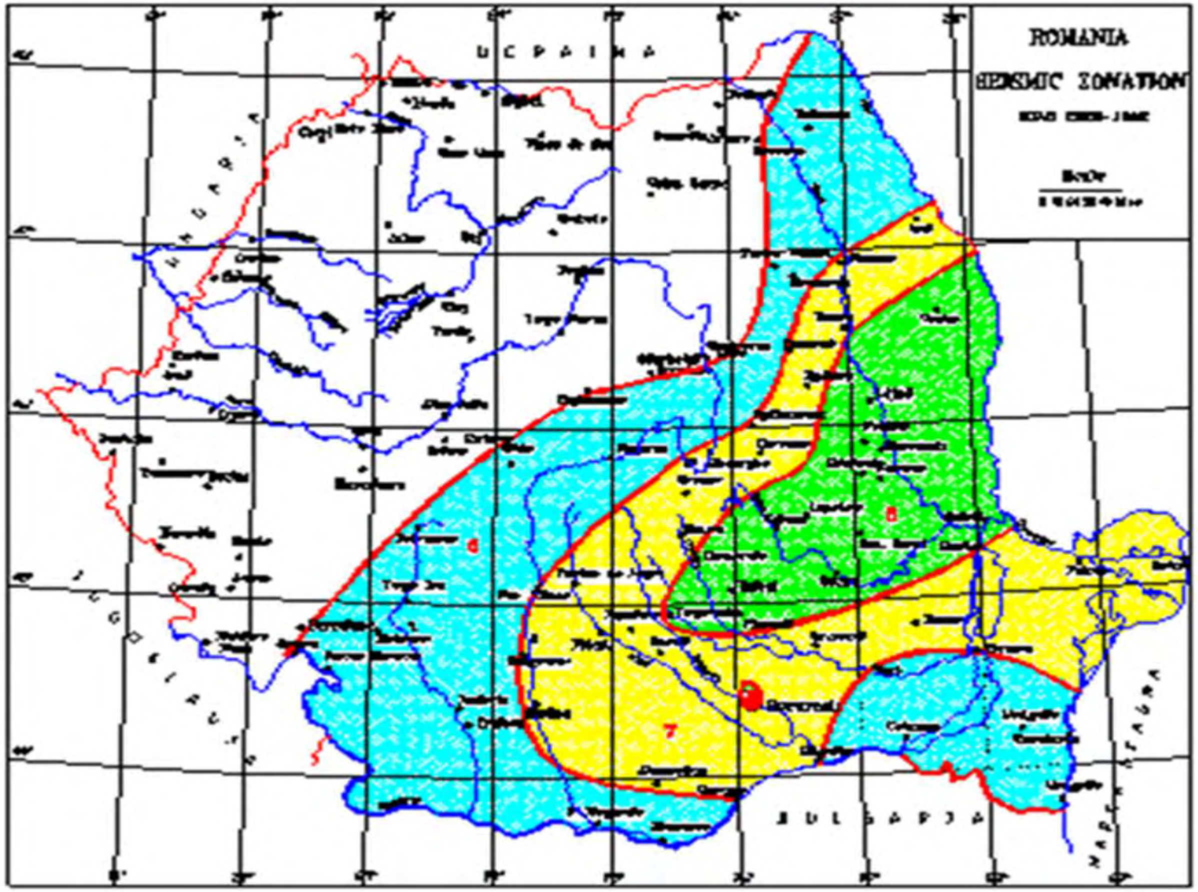
"The Romanian earthquake. Survey report by Survey group of experts and specialists dispatched by the Government of Japan (K. Nakano). Edited by JICA, Japan International Cooperation Agency, June 1977.

Seismic design regulations in Romania

Seismic design regulations in Romania

- Enforced and compulsory for all Romanian territory since 1963
- Two categories:
  1. before 1977 Vrancea earthquake – P13/63 and P13/70 (brittle behaviour) – considered low codes
  2. after 1977 Vrancea earthquake – P100/78, P100/81 (limited ductile behaviour), P100/92, P100-1/2006, P100-1/2013 (ductile behaviour) – considered moderate and high codes

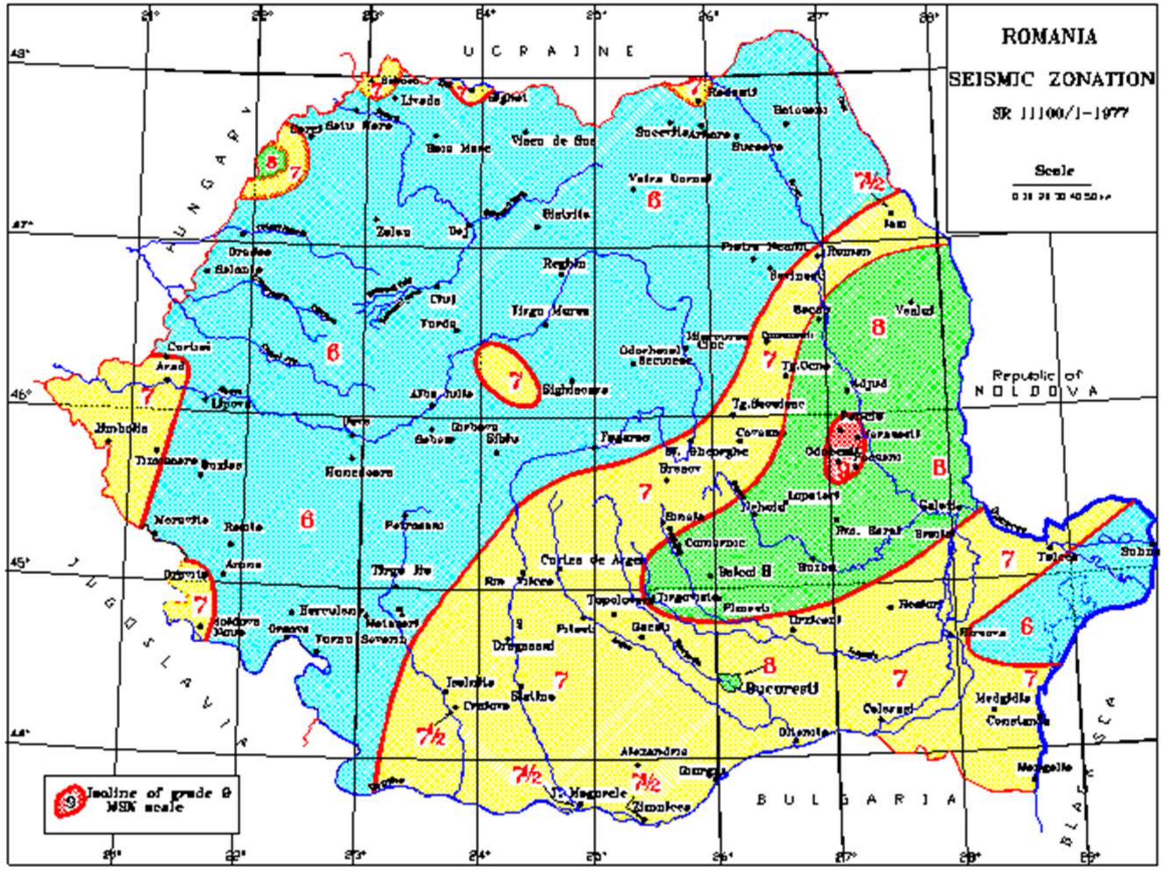
Seismic zonation of Romania – P13/63



Macroseismic intensity (MSK)	*PGA* (‘g)
7	0.025
8	0.050
9	0.100

Macroseismic intensity (MSK) values

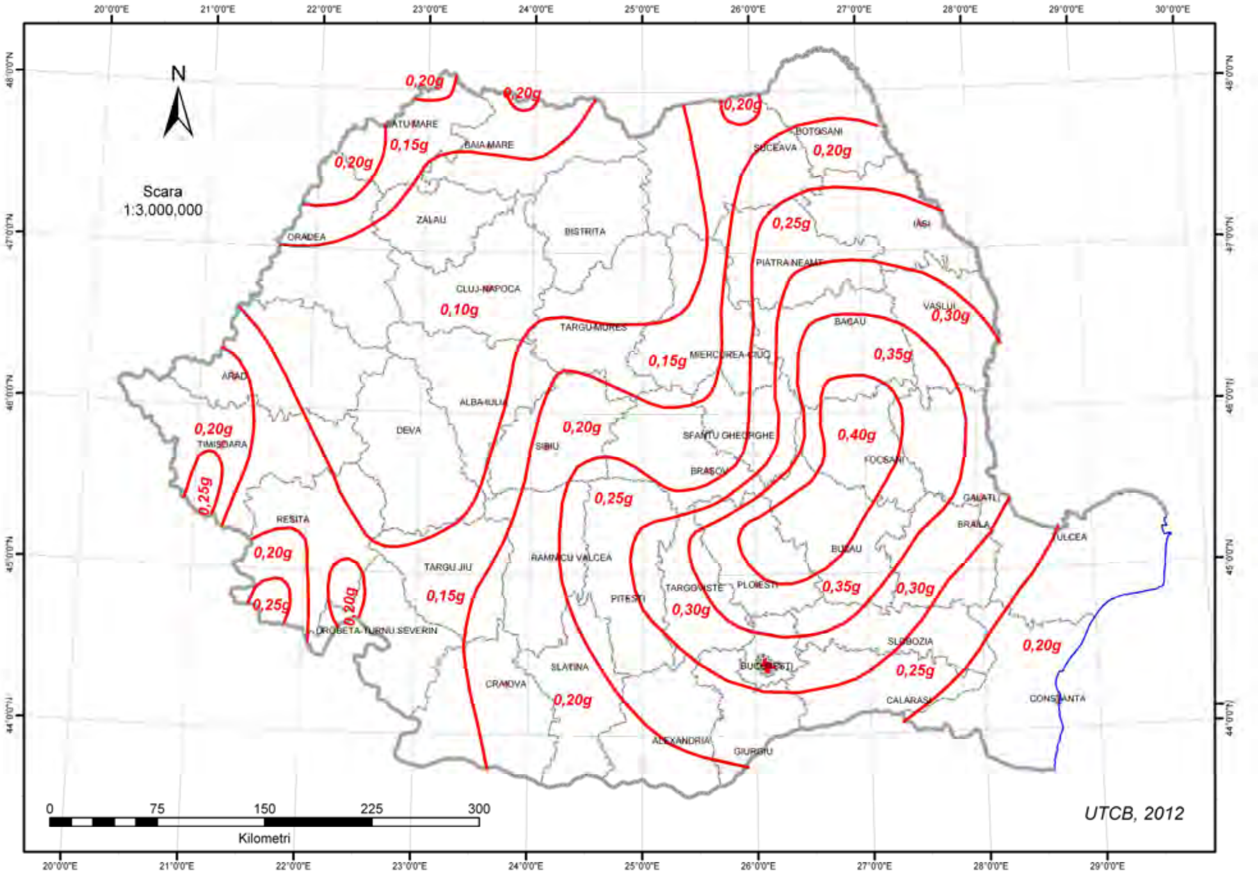
Seismic zonation of Romania – P100/78/81



Macroseismic intensity (MSK)	*PGA* ('g)
6	0.07
6 ½	0.09
7	0.12
7 ½	0.16
8	0.20
8 ½	0.26
9	0.32

Macroseismic intensity (MSK) values

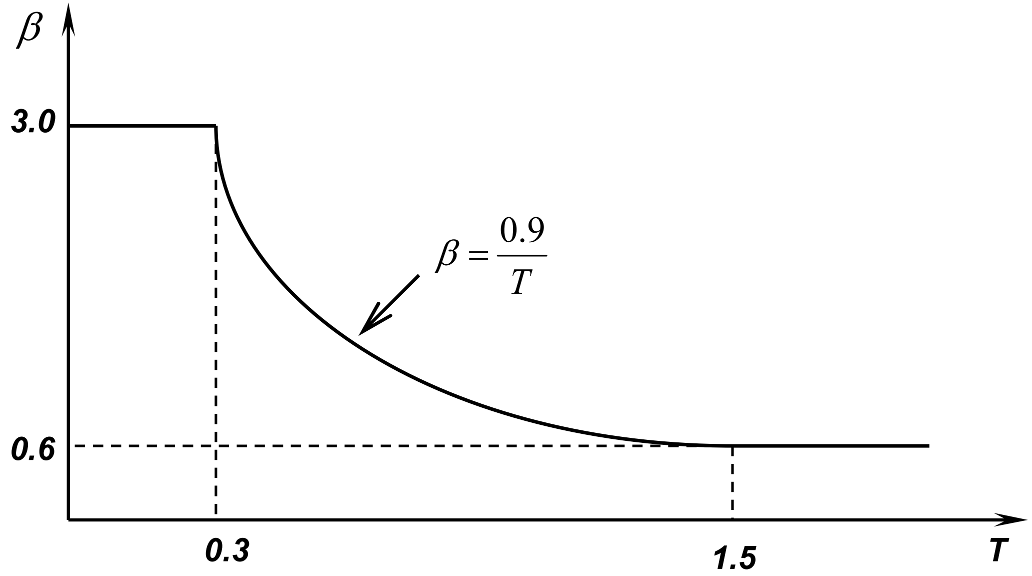
Seismic zonation of Romania – P100-1/2013

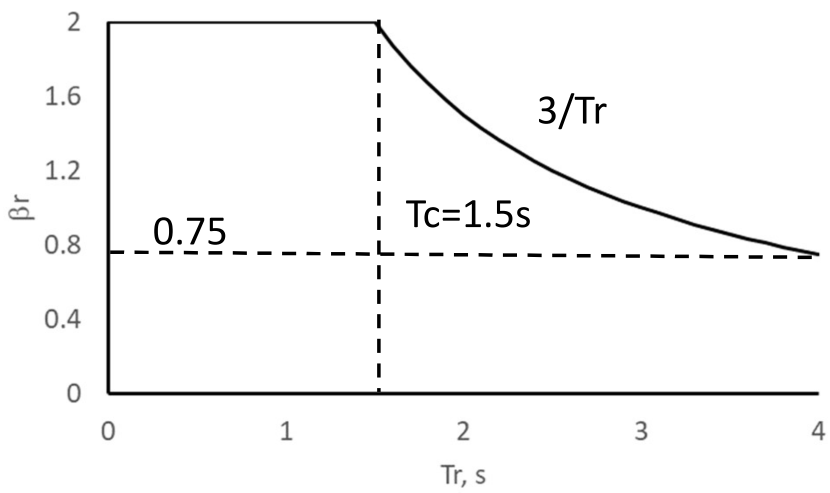


Seismic zone	PGA ('g)
A	0.40
B	0.35
C	0.30
D	0.25
E	0.20
F	0.15
G	0.10

Peak ground acceleration design values with 20% exc. prob. in 50 years

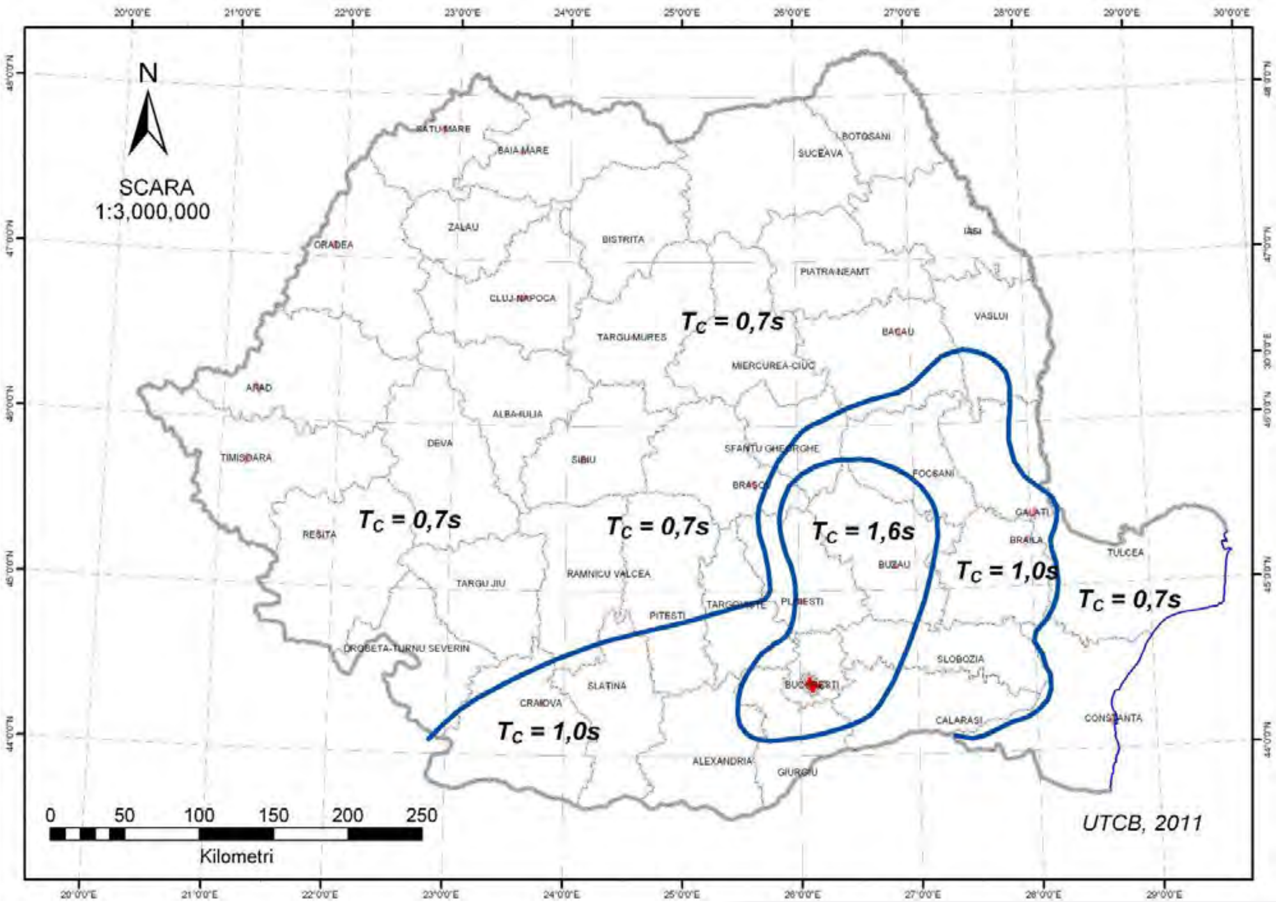
Soil conditions in seismic design regulations

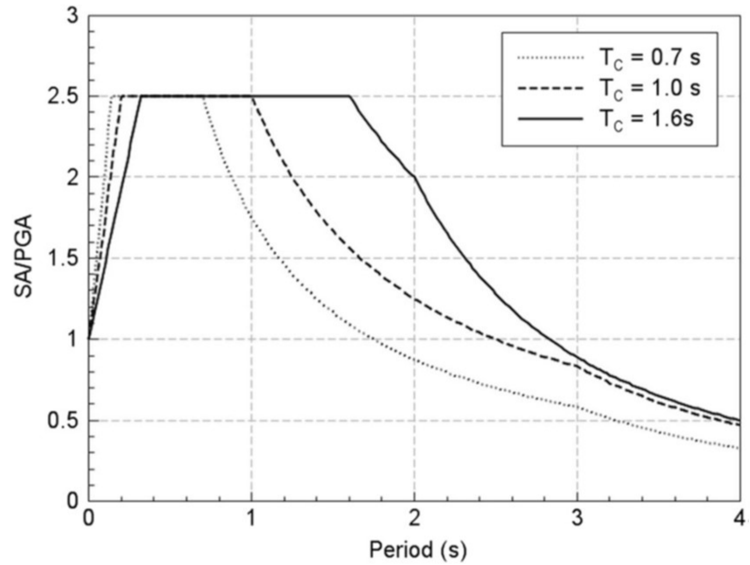




Normalised acceleration response spectra in P13/63 (left) and P100/78-81 (right) – spectral shape valid for all Romanian territory

Soil conditions – P100-1/2013

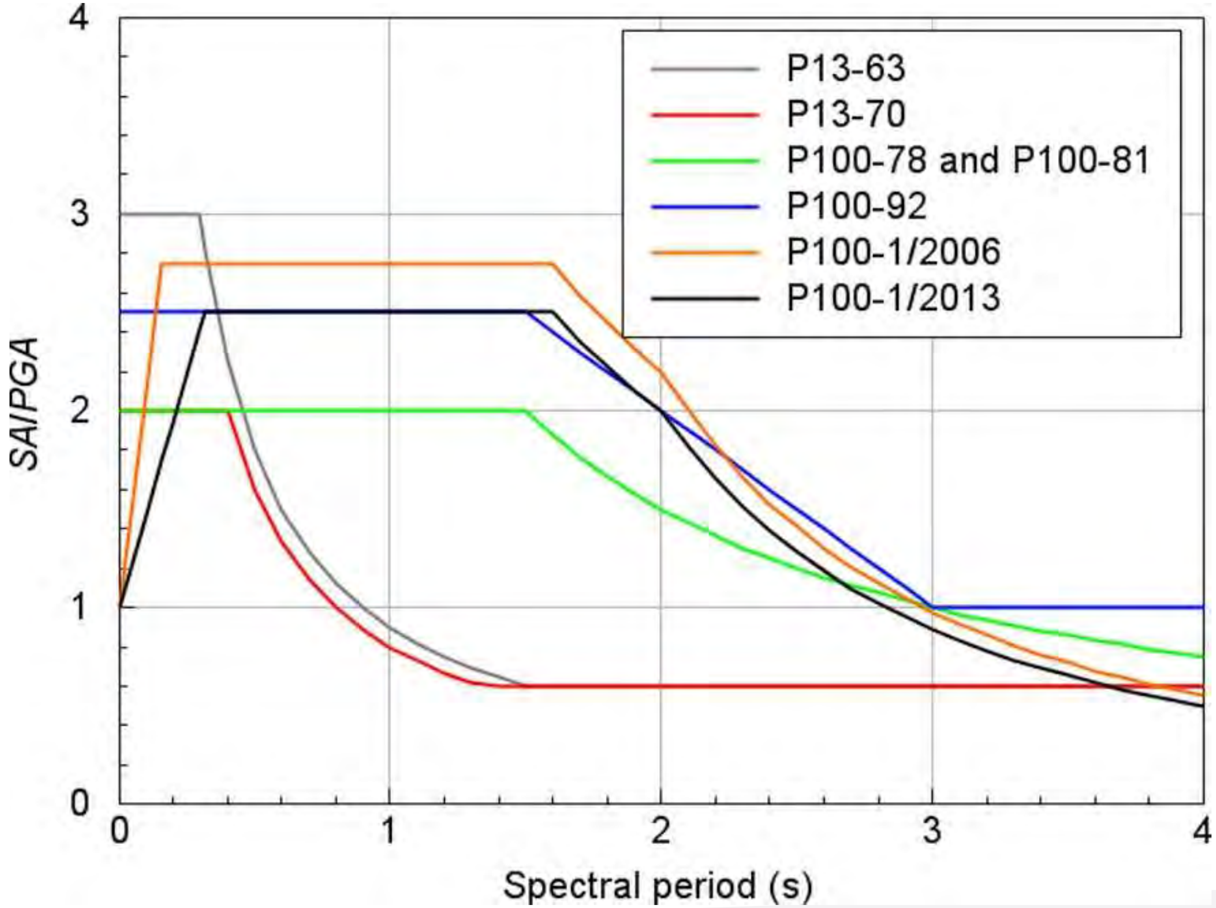




T_C (s)	T_D (s)
0.7	3.0
1.0	3.0
1.6	2.0

Zonation of control period Tc and normalized acceleration elastic response spectra from P100-1/2013

Soil conditions in Bucharest



Evolution of normalised acceleration response spectra for Bucharest (1963 – 2013)

Challenges of seismic design in Bucharest

Seismic design code in force

P100-1/2013

- Compulsory for entire RO territory, enforced by RO Government
- Similar to EN1998-1 (procedures, format, symbols) with specific recommendations for Romania (seismic action, capacity design, detailing rules)
- Performance based approach – 2 performance objectives
- Capacity design method

Importance classes

- P100-1 classifies the structures into IV importance classes
- Seismic demands dependent on consequences of failure
- Classification similar to ASCE 07

- Classification of buildings based on height
  - $\geq$ 28m – importance class II, 20% increase of design spectral values
  - $\geq$ 45m – importance class I, 40% increase of design spectral values

Fundamental seismic demands

	Damage control	Life Safety	
Mean return period = 40 years (22% probability of exceedance in 10 years)	Check stiffness (drift limitation 0,5%; 0,75%; 1,0%)		Normal importance buildings
Mean return period = 225 years (20% probability of exceedance in 50 years)		Check strength, drift (2,5%); ductility measures	

Courtesy to Viorel Popa – UTCB

Ductility classes

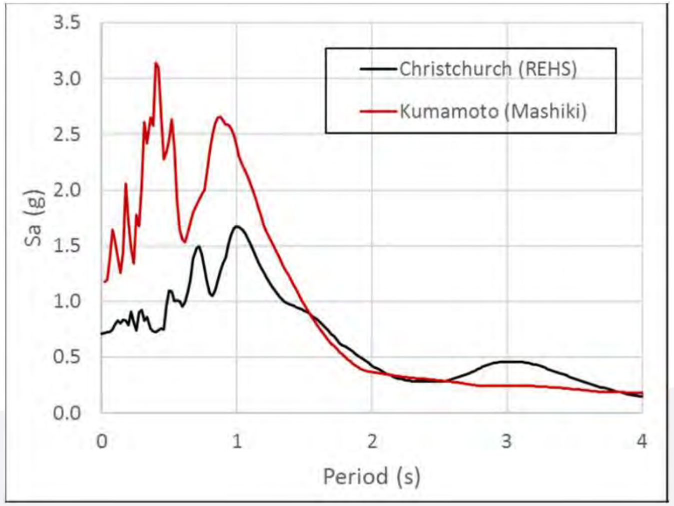
DC High – large reduction factors (q=2 .. 6.75), capacity design with severe local ductility conditions

DC Medium – medium reduction factors (q=1.50 .. 4.75) capacity design with average local ductility conditions

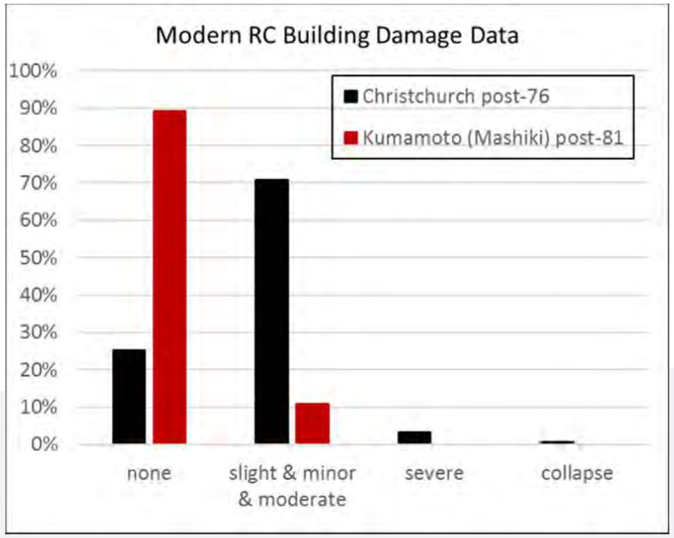
DC Low – low reduction factors (q=1.50 .. 2) no capacity design, no special detailing conditions (valid for a_g<0,1g)

Challenges of seismic design in Bucharest

- Japan – focus on strength and stiffness



- New Zealand – focus on ductility



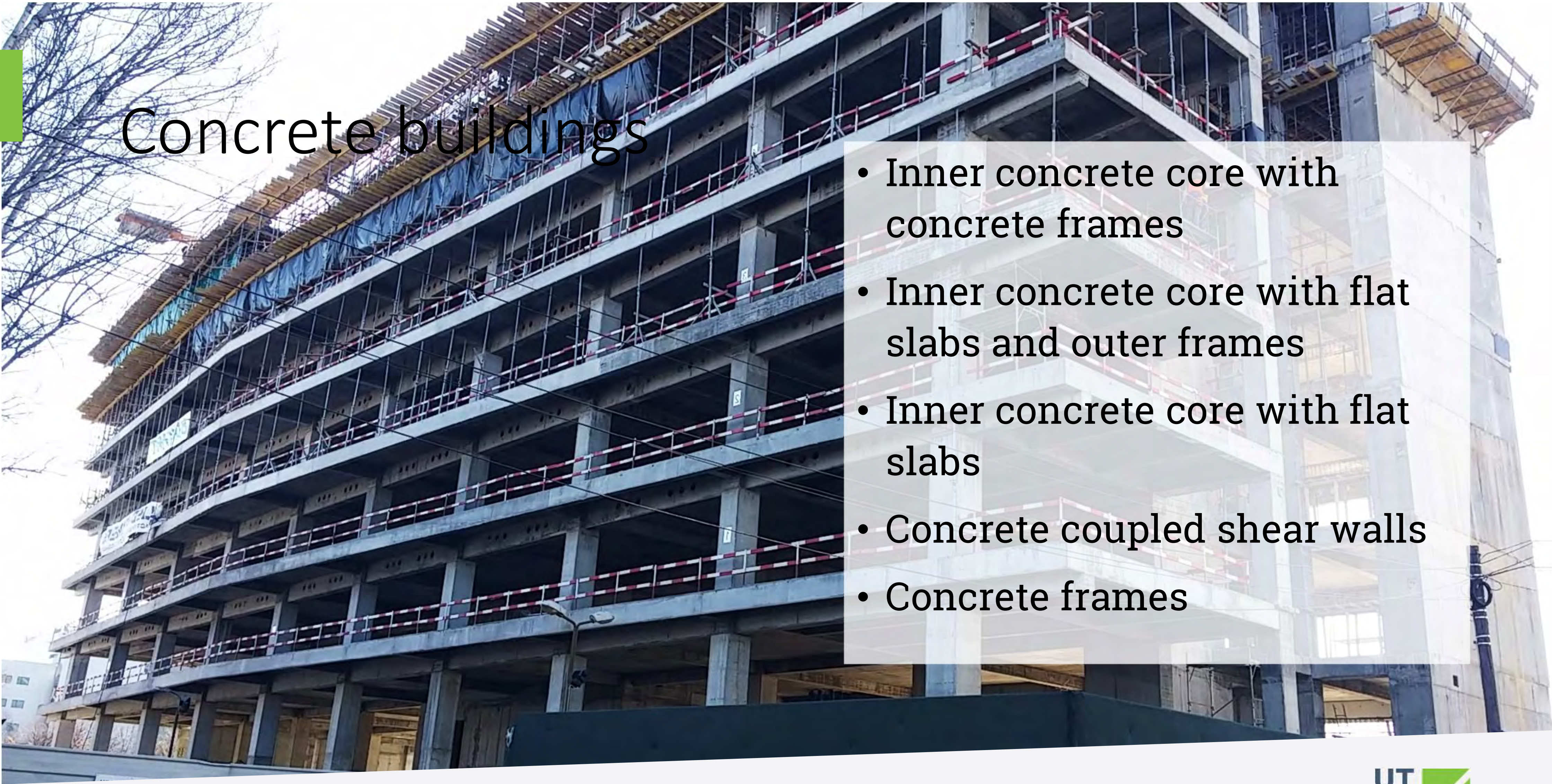
Concrete buildings

Key objectives (DCH):

- Ductility
- Lateral stiffness for damage limitation
- Lateral strength and ductility to control displacement demand

Courtesy of Viorel Popa – UTCB

Concrete buildings



- Inner concrete core with concrete frames
- Inner concrete core with flat slabs and outer frames
- Inner concrete core with flat slabs
- Concrete coupled shear walls
- Concrete frames

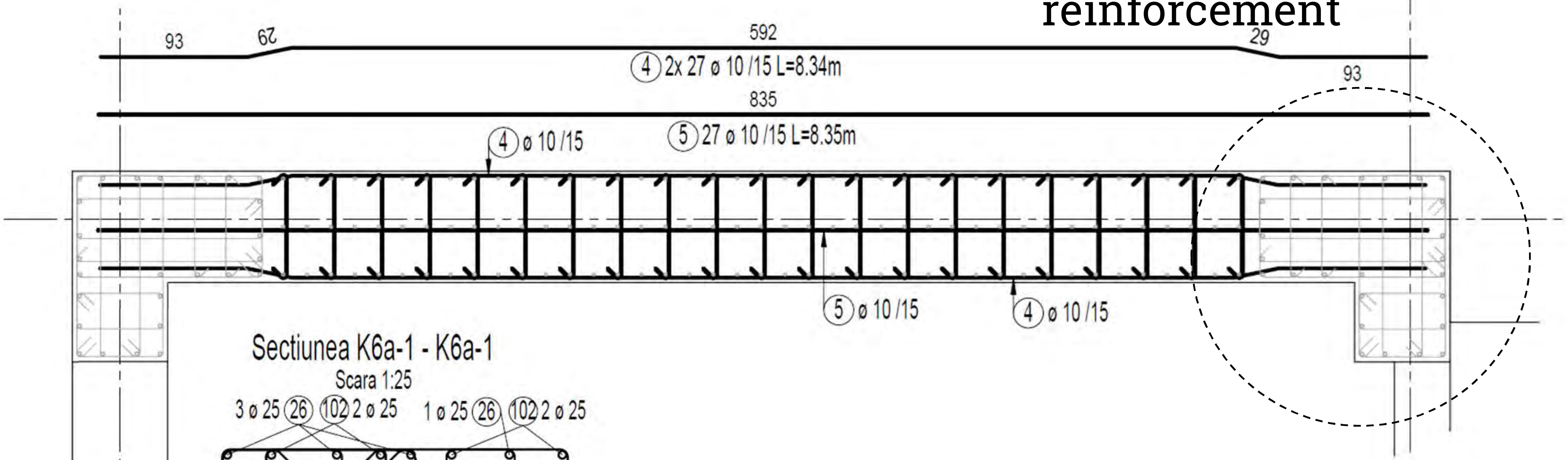
Courtesy of Viorel Popa – UTCB

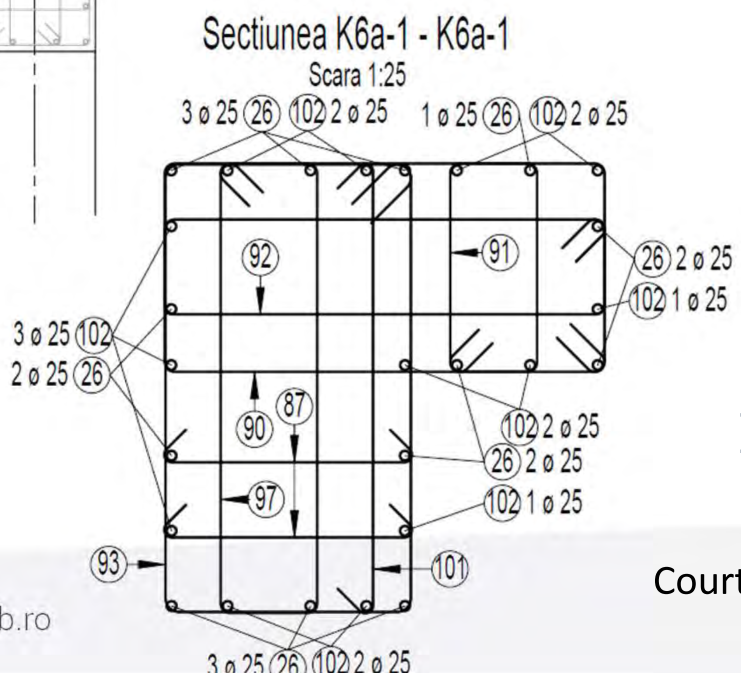
Concrete buildings

- Concrete 32-48 MPa
- Steel 435 MPa
- Monolithic structures
- Columns: rectangular, square sections – 500 mm to 1000 mm width, longitudinal reinforcement ratio 1-2%
- Shear walls: 300-600 (800) mm thickness, with diagonally reinforced coupling beams
- Spacing of transversal reinforcement in plastic region - 100 mm (for columns, beams, shear walls boundary elements)

Detailing for ductility

Min. 0.3% vertical reinforcement





Min. 0,3% horizontal web reinforcement
Min. 0,25% vertical web reinforcement
Min. 0.5% vertical reinf. in boundary elements

Courtesy of Viorel Popa – UTCB

Detailing for ductility

Courtesy of Viorel Popa – UTCB

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Large lateral displacement

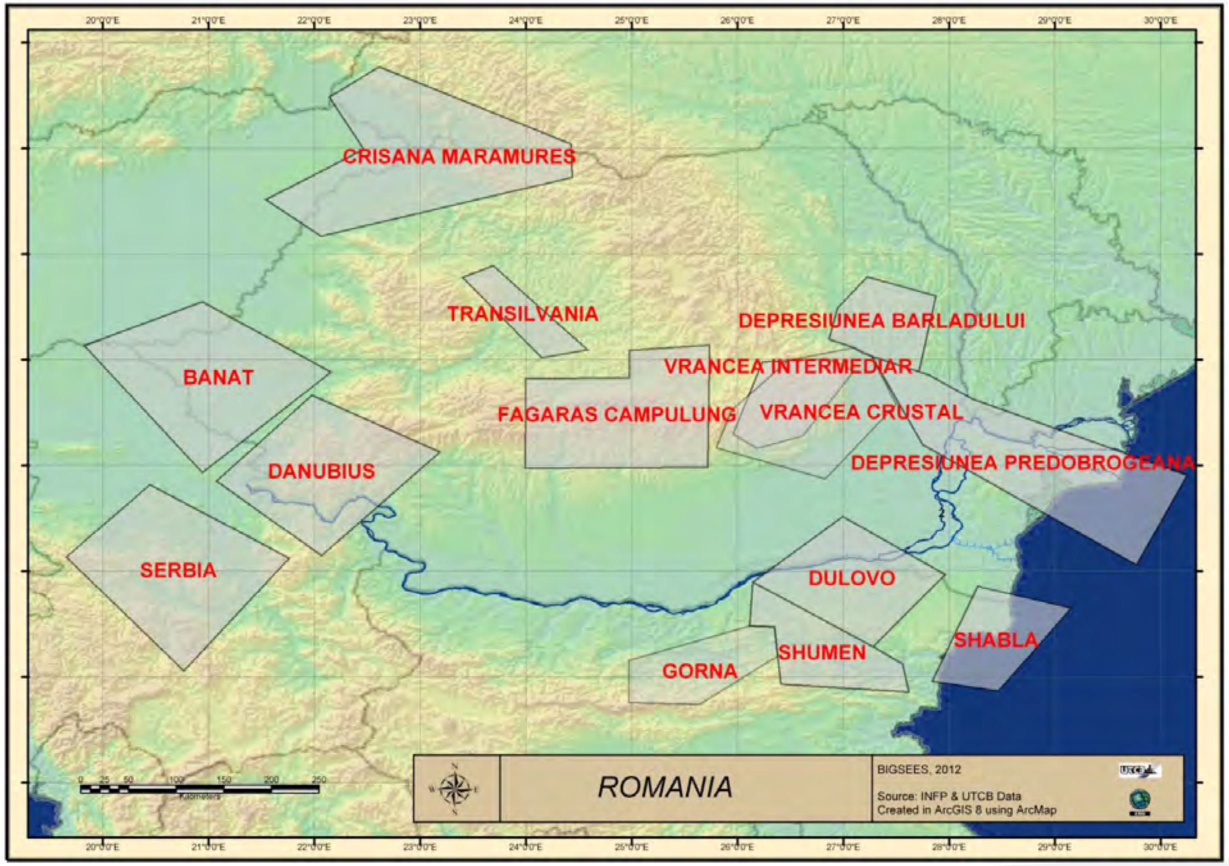
- Design for large lateral displacement demand: > 60 cm under design earthquake (> 80 cm for buildings over 45 m in height)
  - Limited international experience
  - High rotational ductility demand (beams (θ>0.03) and coupling beams (θ>0.06))
  - Increase damping – vibration control
  - Limited option for base isolation
  - Design for ductility, protection of non-structural elements

Courtesy of Viorel Popa – UTCB

Seismic hazard assessment

Seismic hazard of Romania

Seismic source	Maximum credible M_W
Banat	6.4
Bârlad Basin	5.8
Crișana	6.6
Danubius	6
Făgăraș - Câmpulung	6.8
Pre-Dobrogea Basin	5.7
Serbia	6.6
Transilvania	6.2
Vrancea crustal	6.2
Vrancea intermediate depth	8.1
Dulovo	7.1
Shabla	7.8
Gorna	7.4
Shumen	6.7



Seismic sources

(BIGSEES & RO-RISK Projects)

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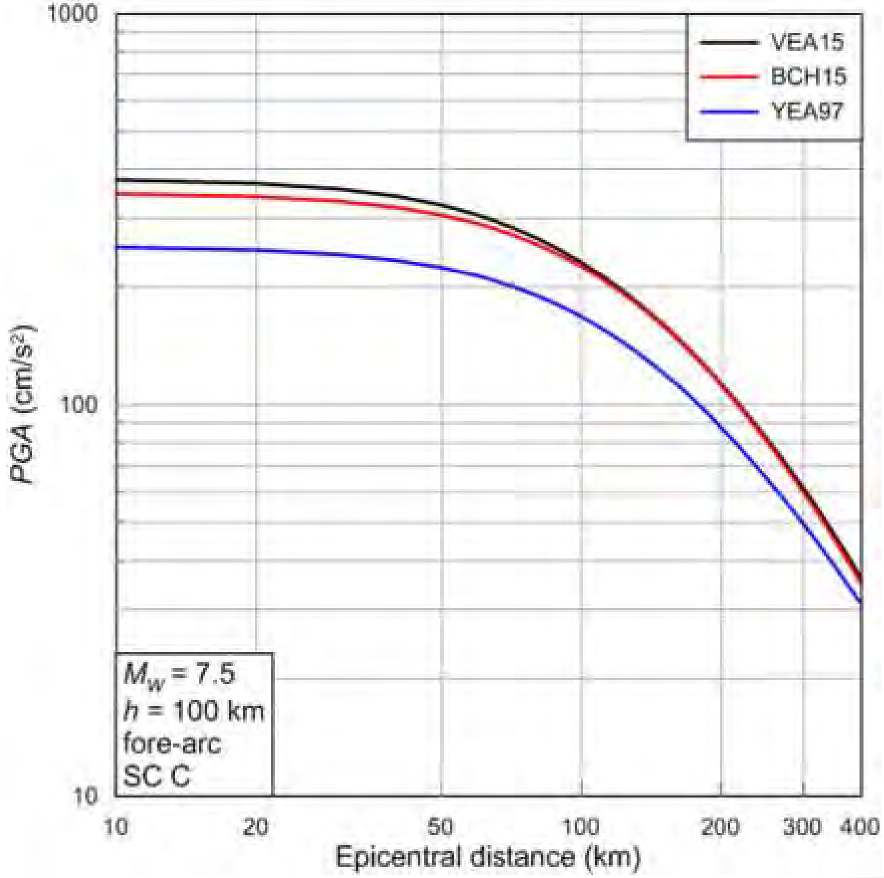
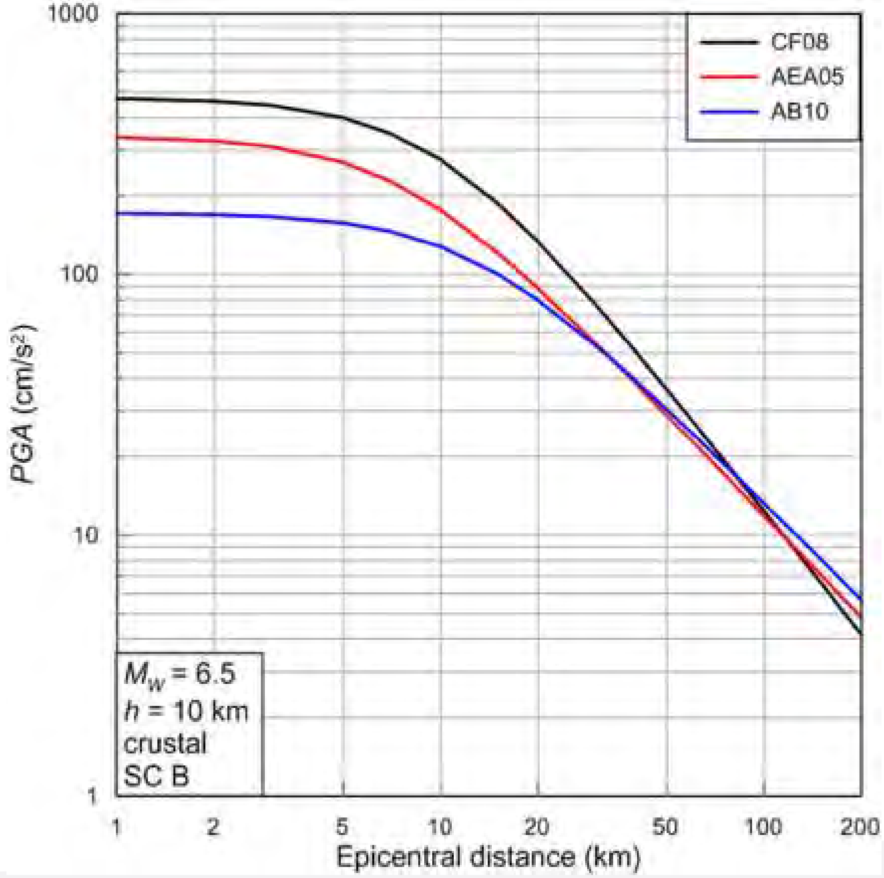
Seismic hazard of Romania

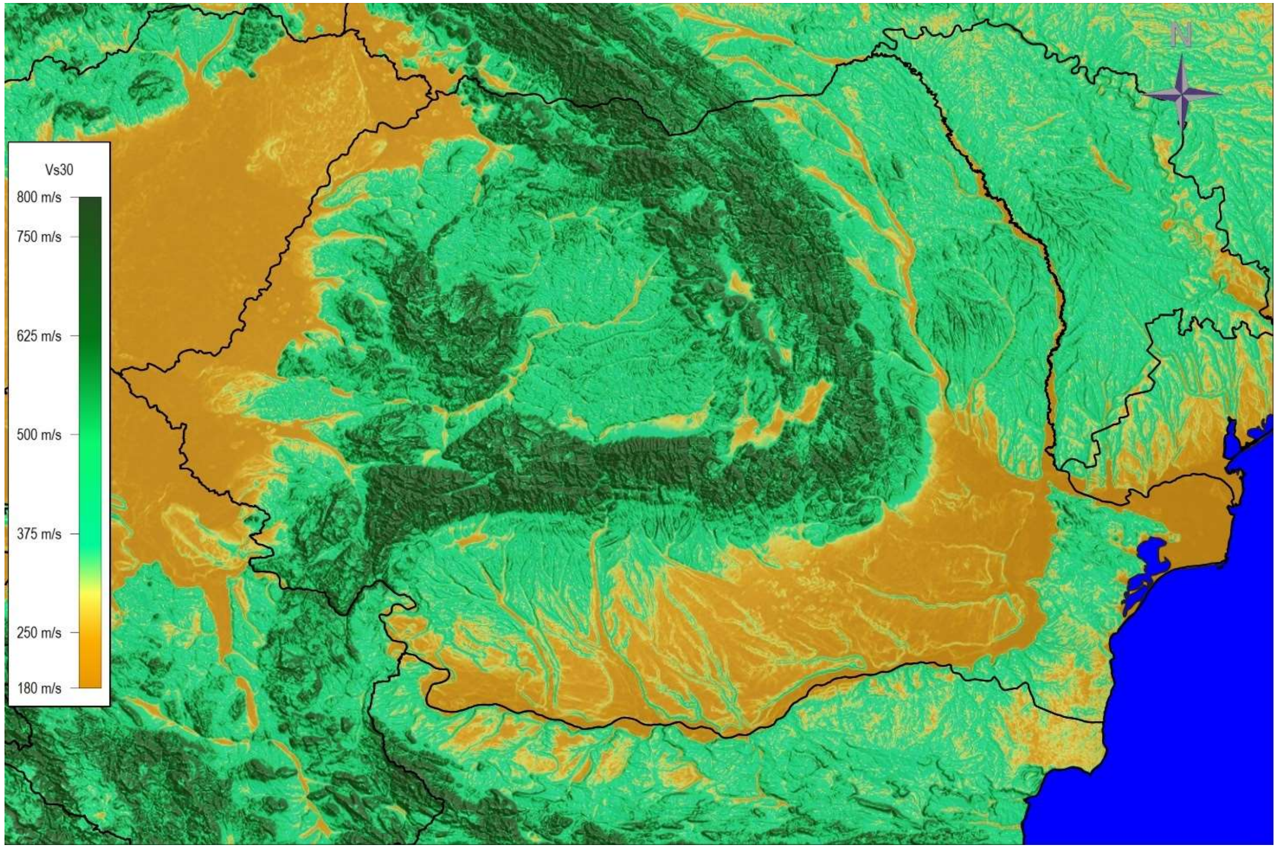
- Ground motion prediction equations used in RO-RISK Project for PSHA – VEA15a (Văcăreanu et al. 2015a), BCH15 (Abrahamson et al. 2015), YEA97 (Youngs et al. 1997), AB03 (Atkinson și Boore, 2003), CF08 (Cauzzi și Faccioli, 2008), AEA05 (Ambraseys et al. 2005) and AB10 (Akkar și Bommer, 2010)

Seismic hazard of Romania





Seismic hazard of Romania



$V_{s,30}$ (m/s) (USGS and domestic boreholes data)

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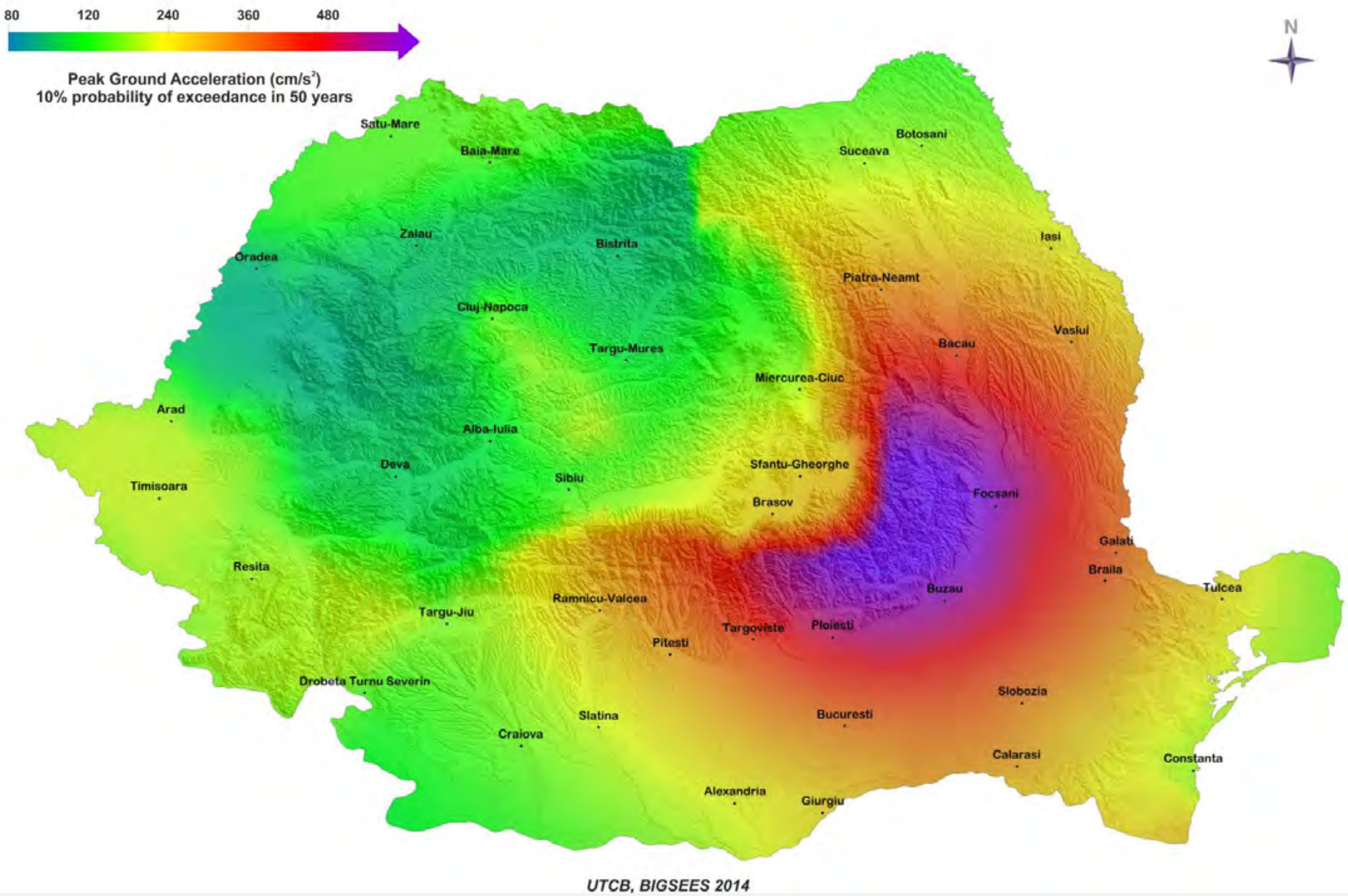
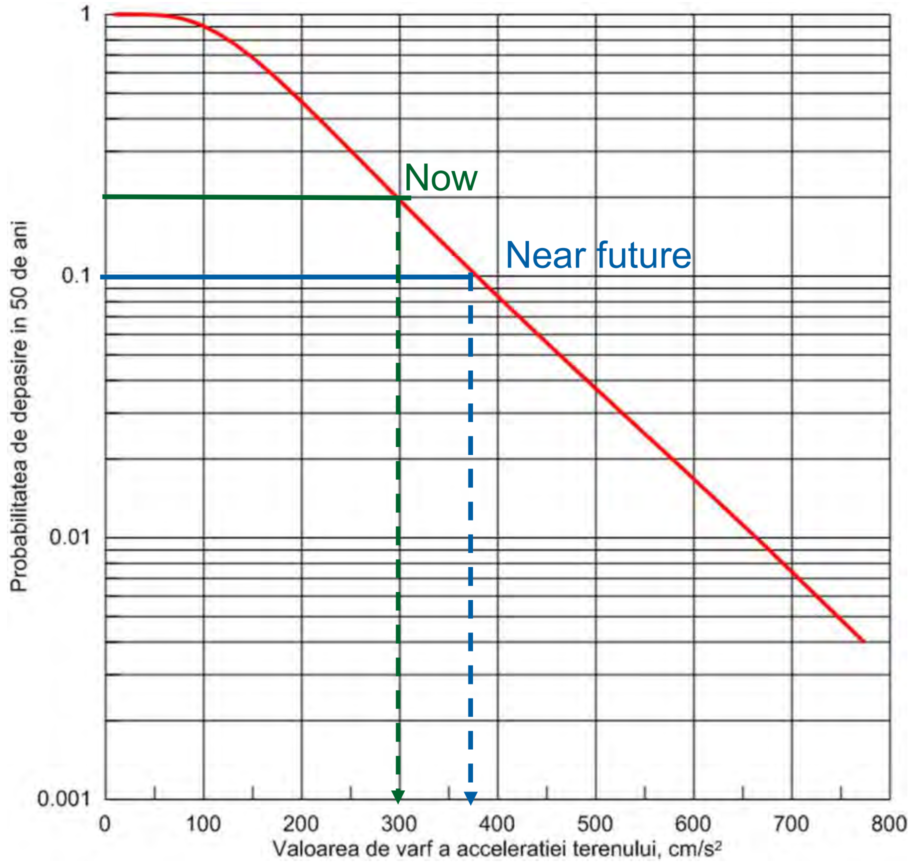
Seismic hazard of Romania



Peak ground acceleration values with 10% exc. prob. in 50 years
BIGSEES Proiect

Seismic hazard of Romania



Seismic hazard curve for Bucharest
Prob. of exc. in 50 years, *PGA* (cm/s^2)

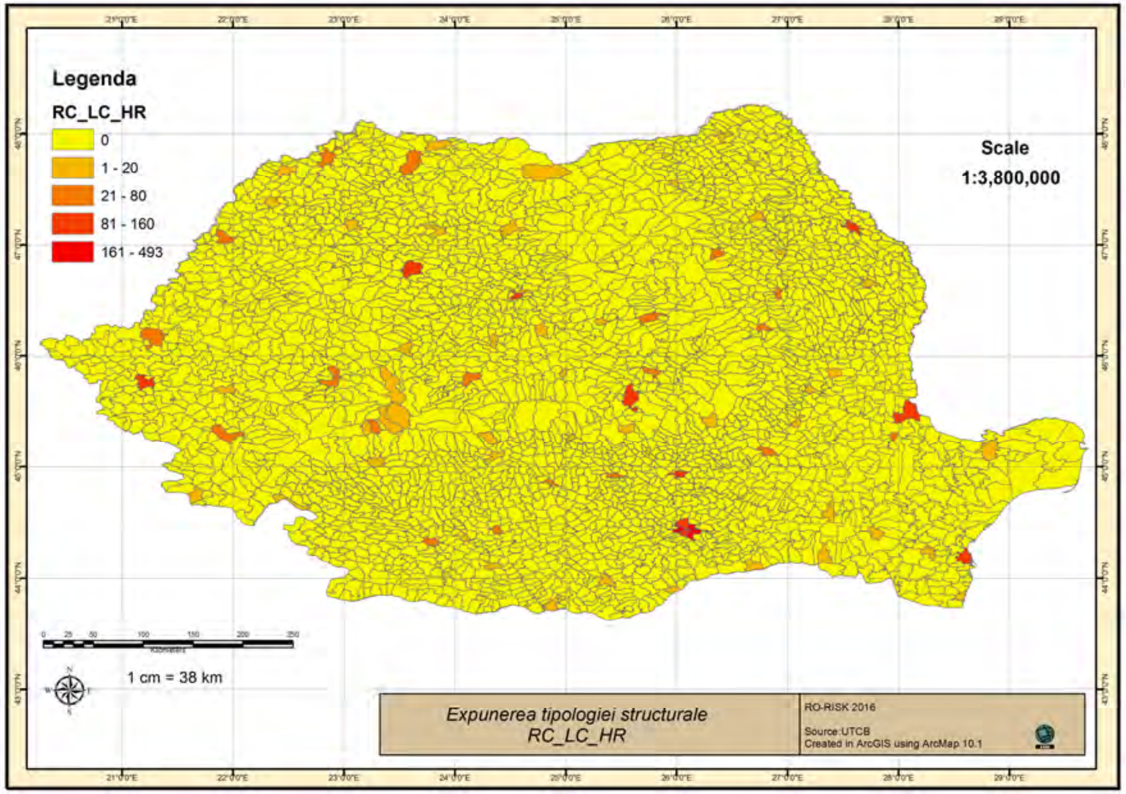
Seismic risk assessment

Exposure - Romania

Exposure data - available from the latest census of 2011
(RO-RISK Project)

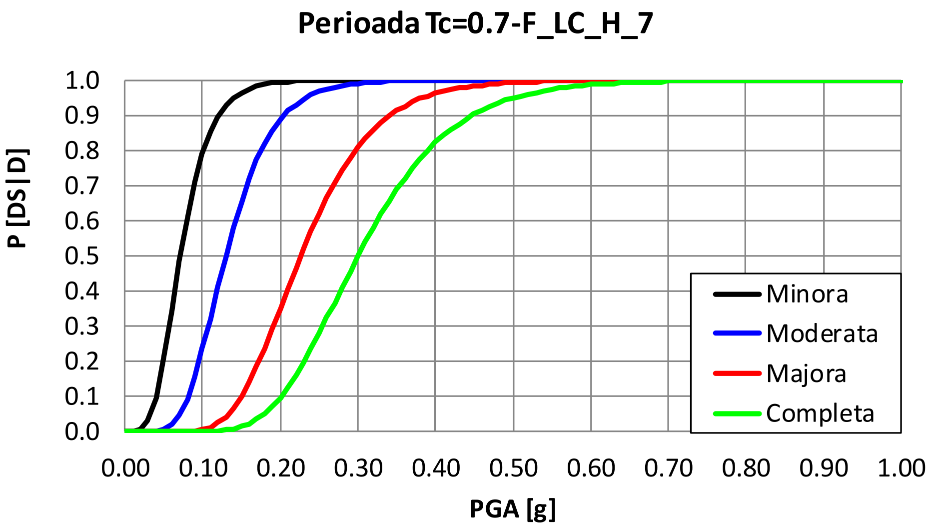
	1992 Census	2002 Census	2011 Census
Population	23.286.794	22.628.665	20.121.641
No. of buildings	4.482.119	4.837.215	5.341.908
Housing units	7.666.181	8.111.391	8.723.699
GDP (current US$ Billions)	25,12	46,18	185,36

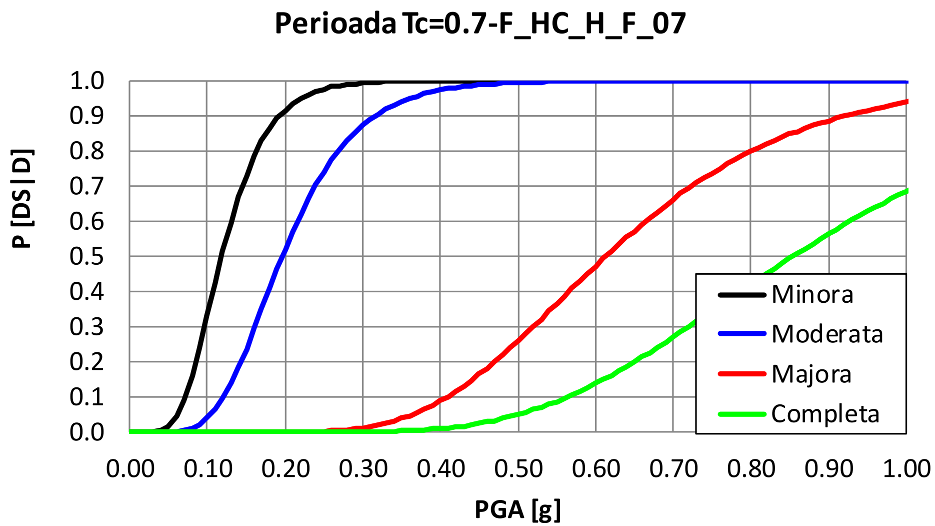
RC Building exposure - Romania



Distribution of number of reinforced concrete high-rise buildings designed according to low seismic code by census unit (RO-RISK Project)

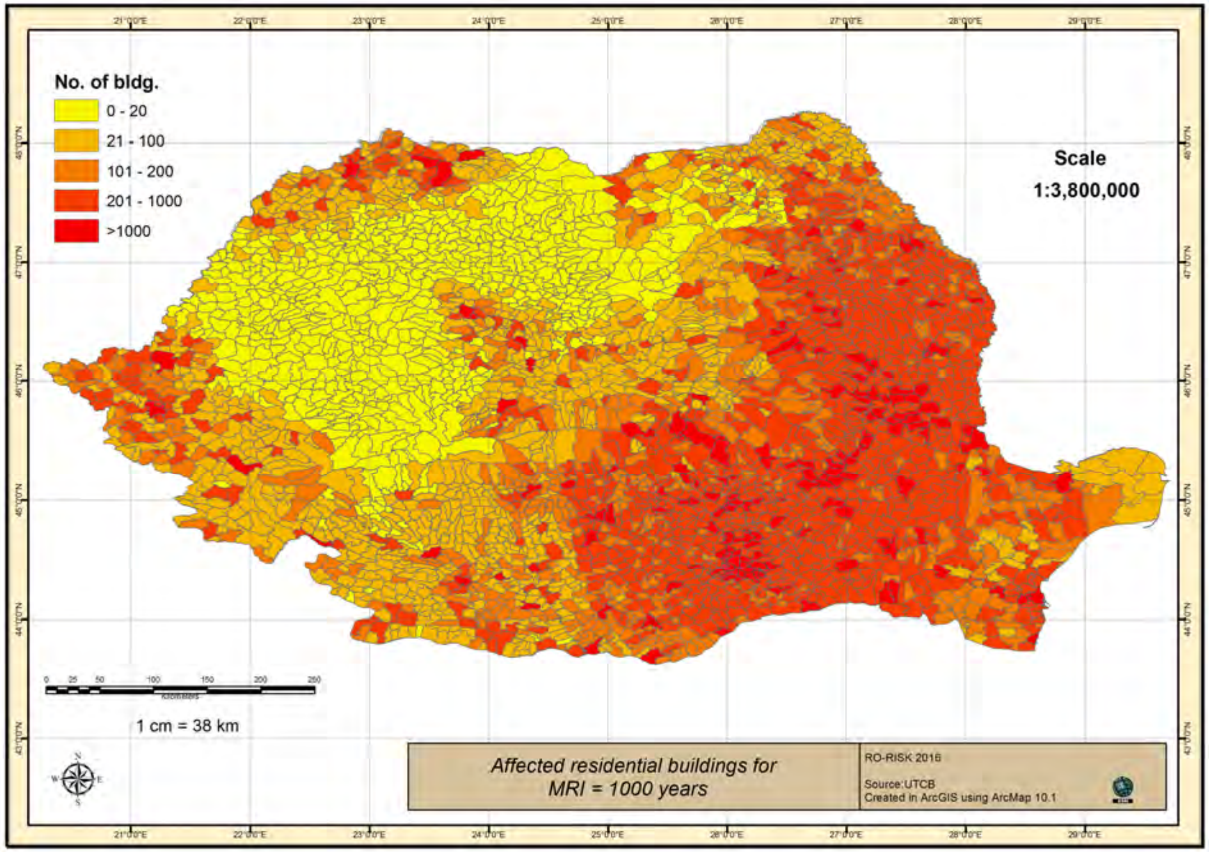
Seismic fragility





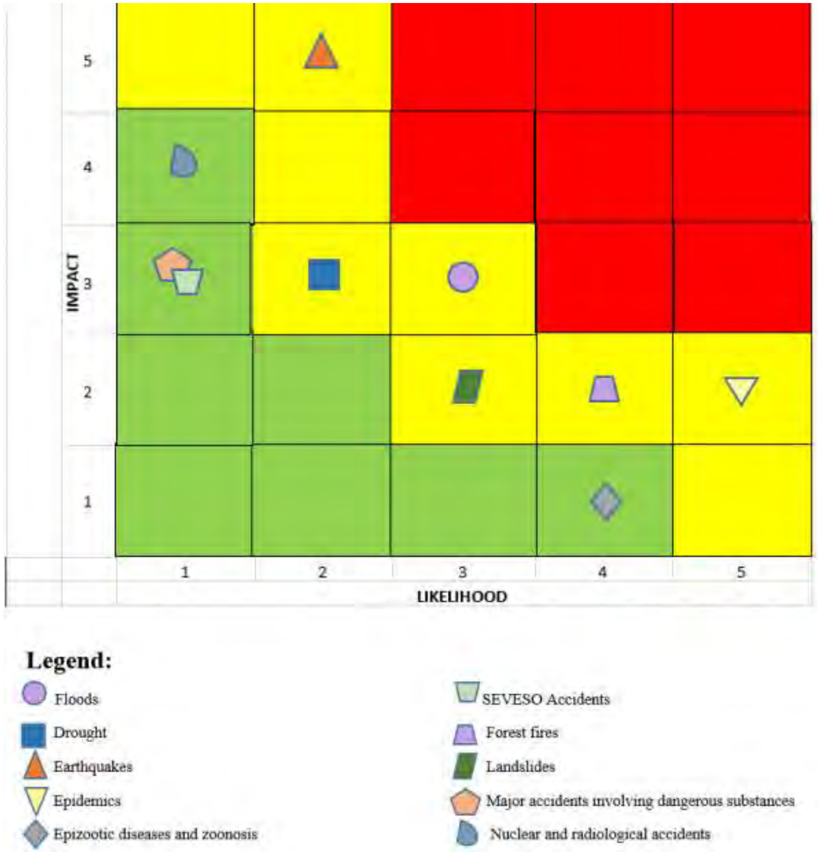
Fragility curves for RC frames low-code (left) and high-code (right) high-rise buildings (RO-RISK Project)

Seismic risk in Romania



Distribution of number of damaged residential buildings for an earthquake scenario with 1000 years MRP (RO-RISK Project)

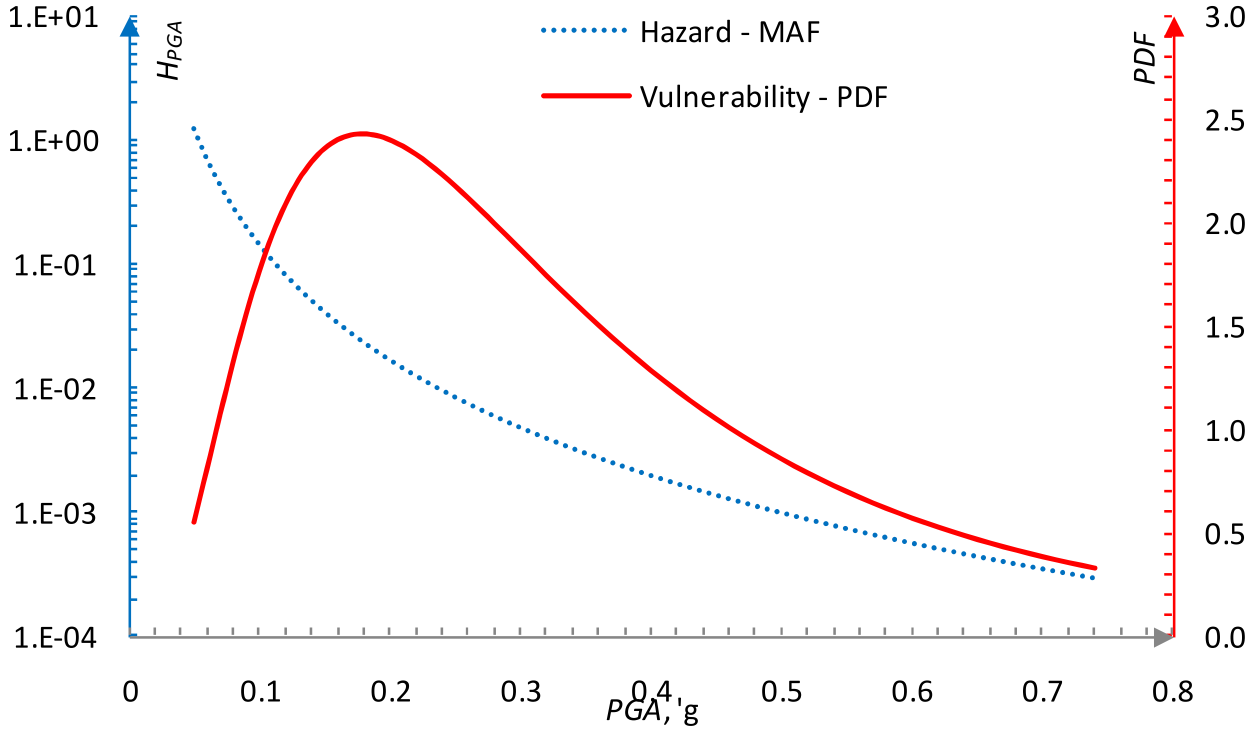
Seismic risk in Romania



Risk matrix for Romania (RO-RISK Project)
(https://www.igsu.ro/index.php?pagina=analiza_riscuri)

Seismic risk – probabilistic approach

$$P_F \cong \int_0^{\infty} H_A(a) \cdot \frac{dP_{F|a}}{da} da$$

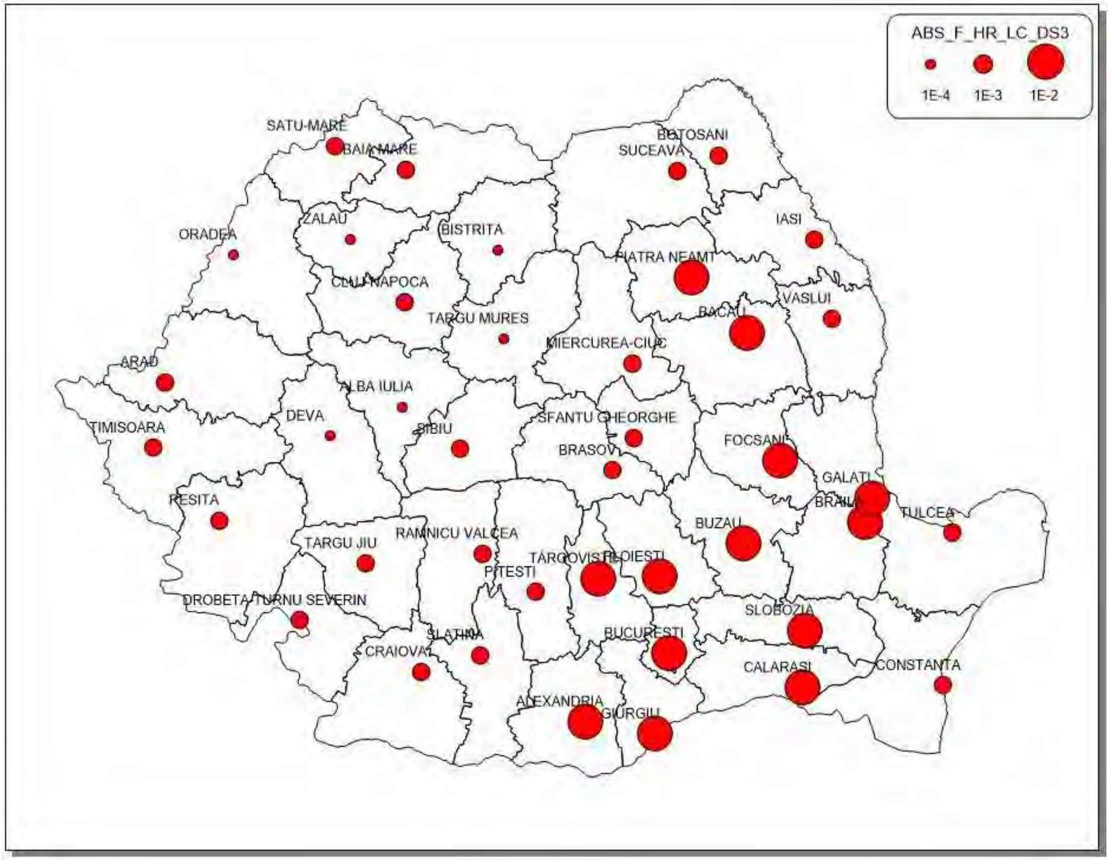


Convolution integral of seismic risk

Seismic risk in Romania - probabilistic

Failure means exceeding of extensive structural damage state (DS3)

Annual probability of exceedance	Probability of exceedance in 50 years
1.0E-02	3.9E-01
1.0E-03	4.9E-02
1.0E-04	5.0E-03



Annual probability of failure for high rise RC frames designed according to low codes (P13-63, P13-70)

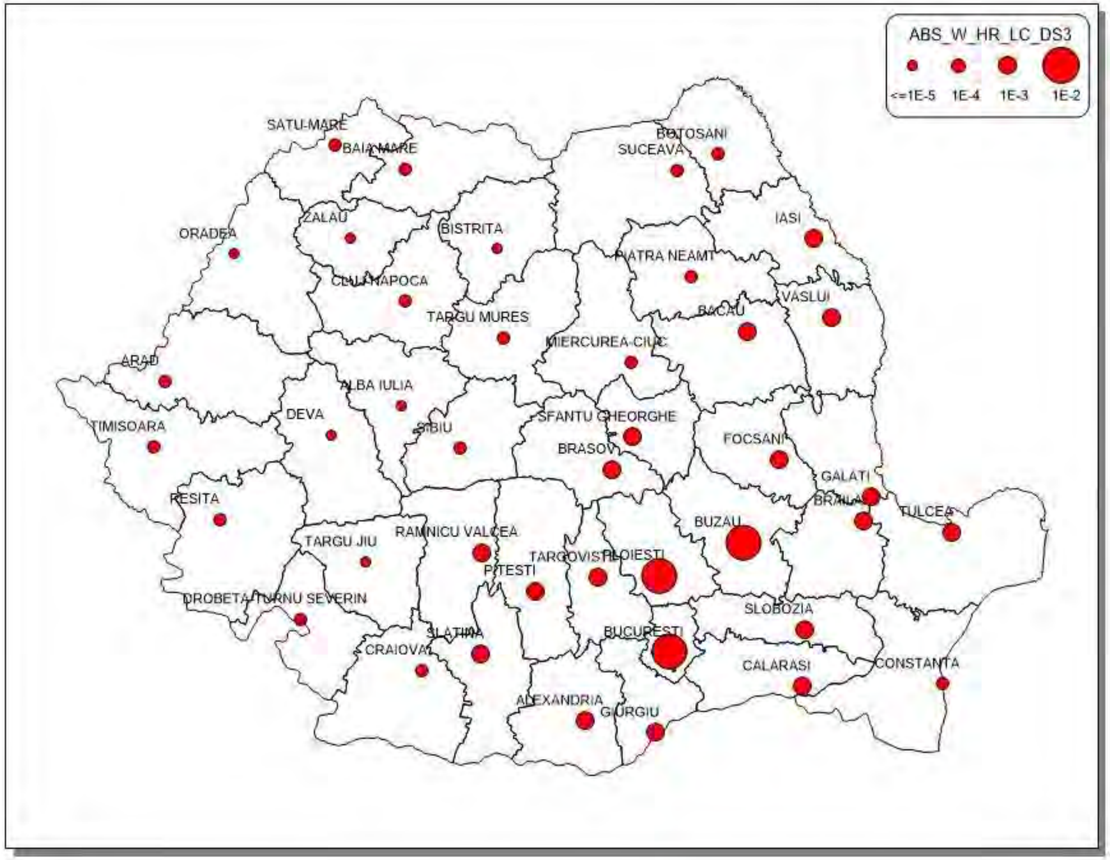
Extensive Structural Damage

Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement; nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns which may result in partial collapse (HAZUS MR4 Technical Manual, 2003)

Seismic risk in Romania - probabilistic

Failure means exceeding of extensive structural damage state (DS3)

Annual probability of exceedance	Probability of exceedance in 50 years
1.0E-02	3.9E-01
1.0E-03	4.9E-02
1.0E-04	5.0E-03
1.0E-05	5.0E-04

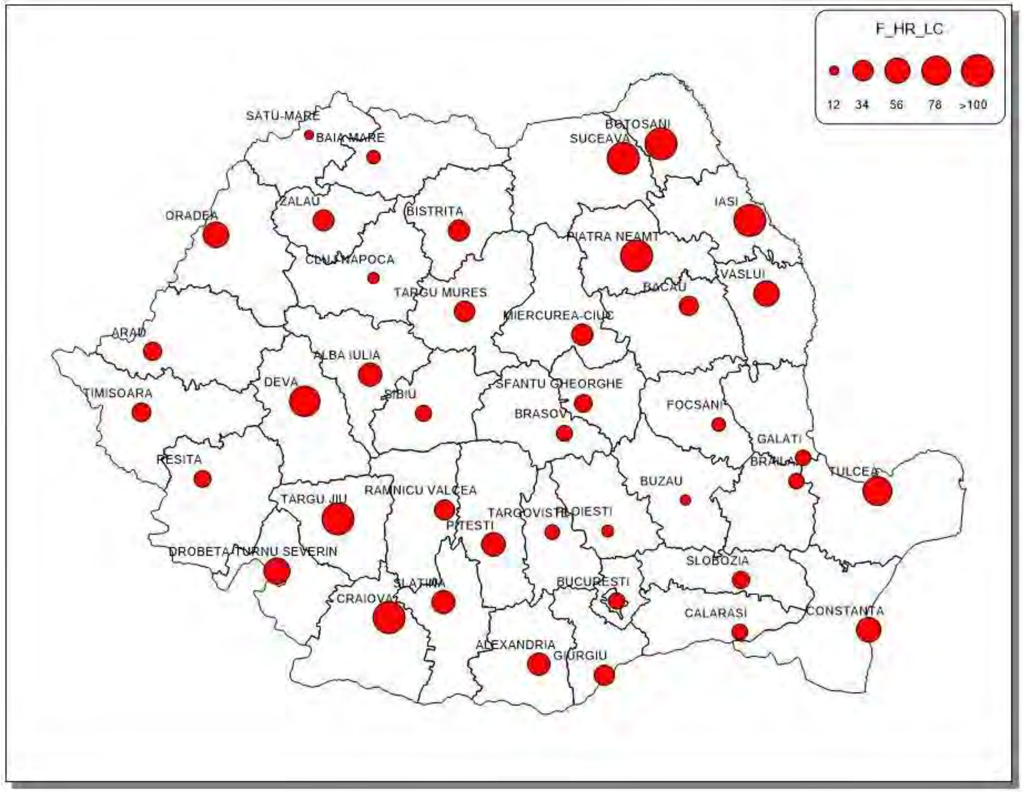


Annual probability of failure for high rise shear walls designed according to low codes (P13-63, P13-70)

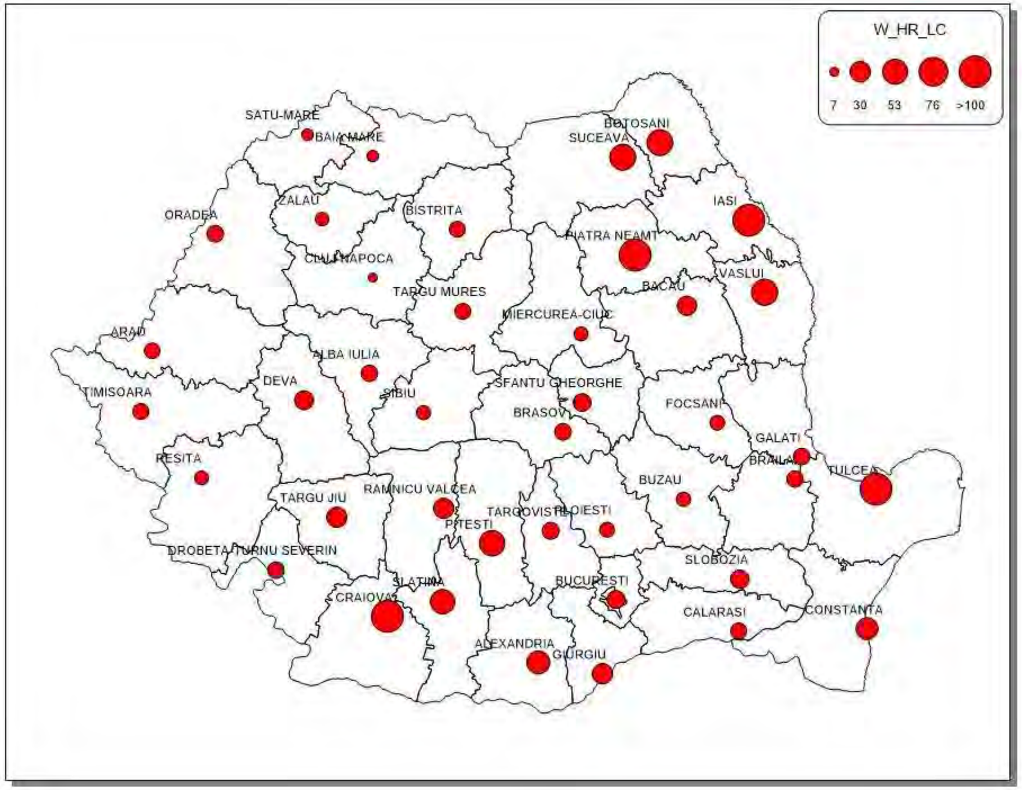
Extensive Structural Damage

Most concrete shear walls have exceeded their yield capacities; some walls have exceeded their ultimate capacities indicated by large, through-the-wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement or rotation of narrow walls with inadequate foundations. Partial collapse may occur due to failure of nonductile columns not designed to resist lateral loads (HAZUS MR4 Technical Manual, 2003)

Seismic risk in Romania - probabilistic

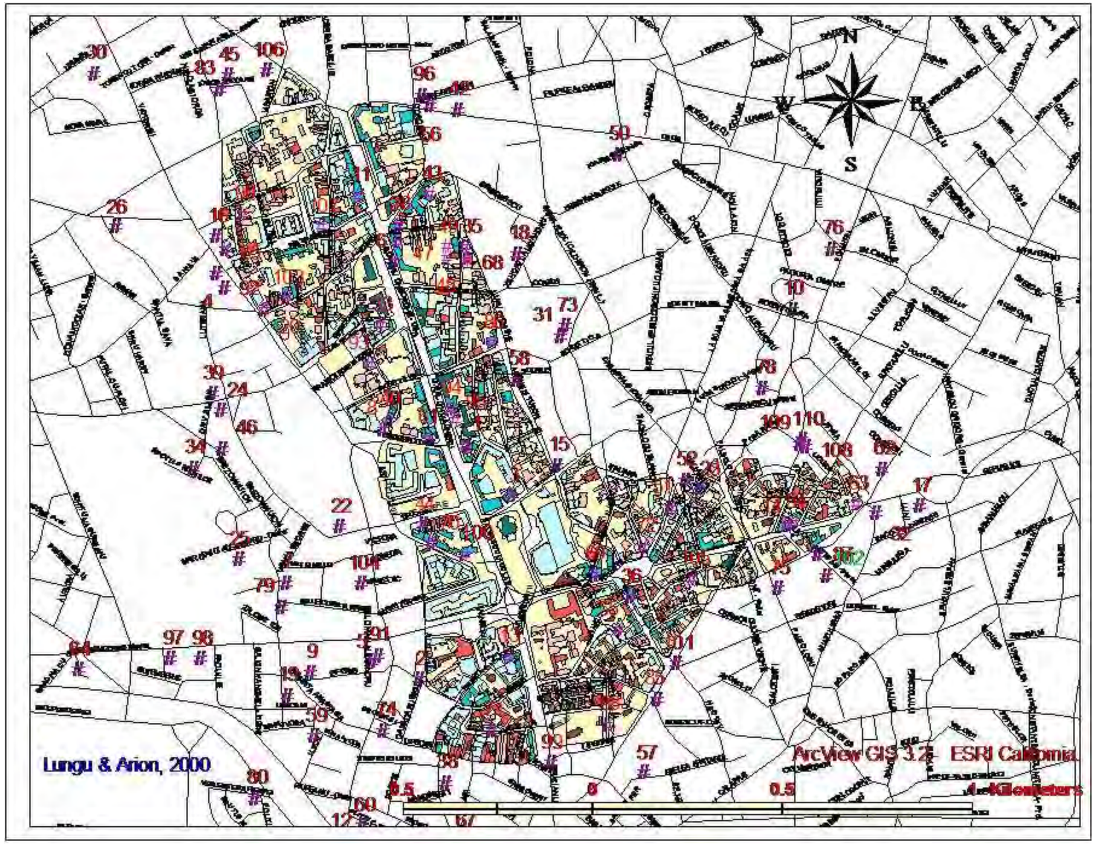


Ratio of probability of failure for high rise RC frames designed according to low codes (P13-63, P13-70) to the ones designed according to high codes (> P100-92)



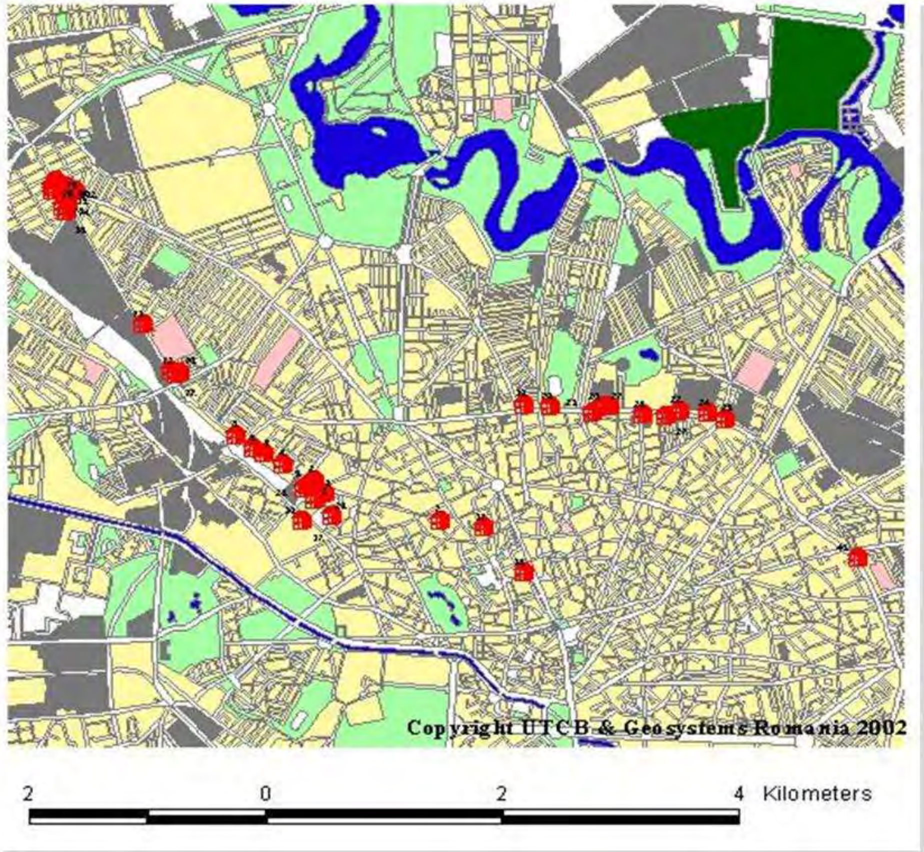
Ratio of probability of failure for high rise RC shear walls designed according to low codes (P13-63, P13-70) to the ones designed according to high codes (> P100-92)

Seismic risk in Bucharest



Identified seismic risk class I residential buildings in Bucharest

Seismic risk in Bucharest



Soft and weak groundfloor residential buildings in Bucharest

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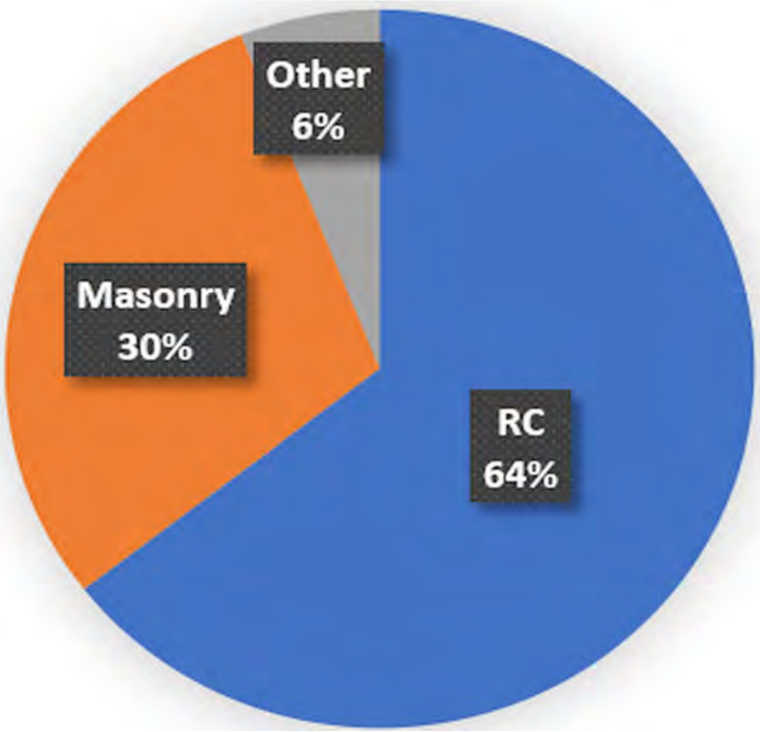
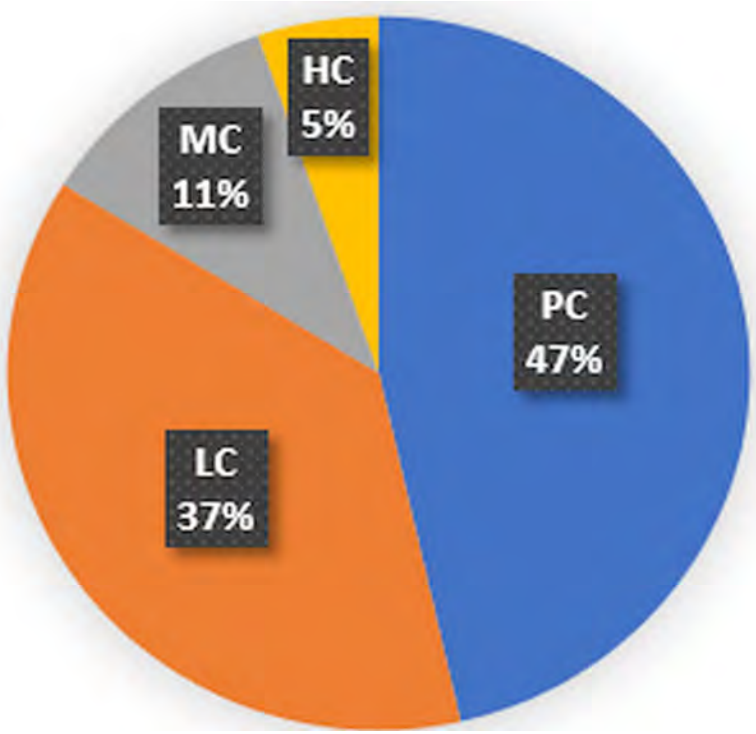
Seismic risk in Bucharest



Seismic losses as a function of building material (64% of losses attributable to RC buildings)
Scenario earthquake with moment magnitude of 7.5 originating from Vrancea at a depth of 100 km



Seismic losses as a function of the level of seismic design code (85% of losses occur in PC + LC buildings)
Scenario earthquake with moment magnitude of 7.5 originating from Vrancea at a depth of 100 km

Conclusions

Conclusions

- Bucharest faces a unique combination (at least in Europe) of Vrancea seismic source effects and site effects, which generate very large displacement demands
- Seismic risk of Bucharest – very high; social and economic impact – very high; mitigation, possible
- Bucharest accounts for more than a quarter of GDP of Romania
- Seismic risk in Romania – very high; there are premises for reduction

Conclusions

- Program for seismic retrofitting of private residential buildings – hard to implement
- Program for seismic retrofitting of public buildings – more focus and visibility
- The Italian experience of Civil Protection in tackling seismic risk – must be accounted for
- An approach similar to *National Earthquake Hazards Reduction Program (NEHRP) - A research and implementation partnership* – is definitely needed

Conclusions

- International scientific and technical cooperation in the field of seismic risk reduction – must be continued
- Major challenges in front of us:
  - Seismic evaluation and retrofitting of a large building stock
  - Weak public awareness; increase public awareness – daunting task
  - Shallow crustal sources dormant
  - Quest for seismic resilience
  - Seismic resilience – a paradigm shift absolutely needed

3rd European Conference on Earthquake Engineering and Seismology (3ECEES)


3rd EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY (3ECEES)
June 19th - 24th 2022 – BUCHAREST, ROMANIA

CONFERENCE VENUE

PALACE OF PARLIAMENT - BUCHAREST INTERNATIONAL CONFERENCE CENTRE (BICC)

June 19th - 24th 2022

Palace of Parliament - second largest administrative building in the world (365,000 sqm.)

BICC:

- part of Palace of Parliament
- it hosted in past years outstanding international events, such as NATO Summit in 2008 & Economic and Trade Forum – Central and Eastern European Countries in 2013.

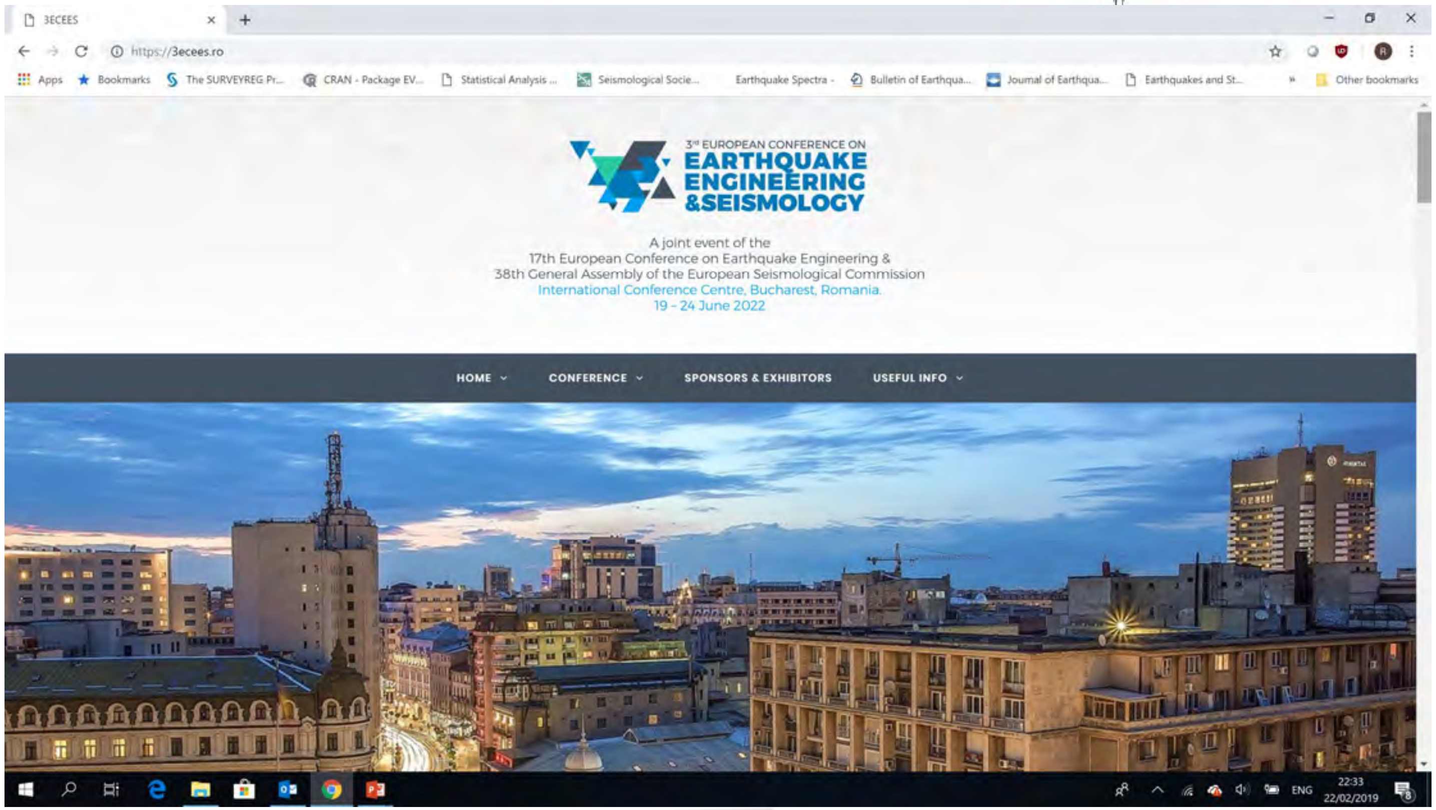
UTCB ARIS INFP 2022 - 3ECEES

CONFERENCE FEES

Participation	– 310 Euro, until March 1st, 2022
	- 390 Euro, until May 1st, 2022
	- 490 Euro, on site registration
Participation with papers submitted	– 400 Euro, until March 1st, 2022
	- 480 Euro, until May 1st, 2022
Students	– 150 Euro, until March 1st, 2022
	- 150 Euro, until May 1st, 2022
	- 180 Euro, on site registration

Note: Travel and participation grants will be awarded to fifty PhD students.

CONFERENCE WEBSITE



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Thank you!

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