Procjena seizmickog rizika od potresa u urbanim sredinama

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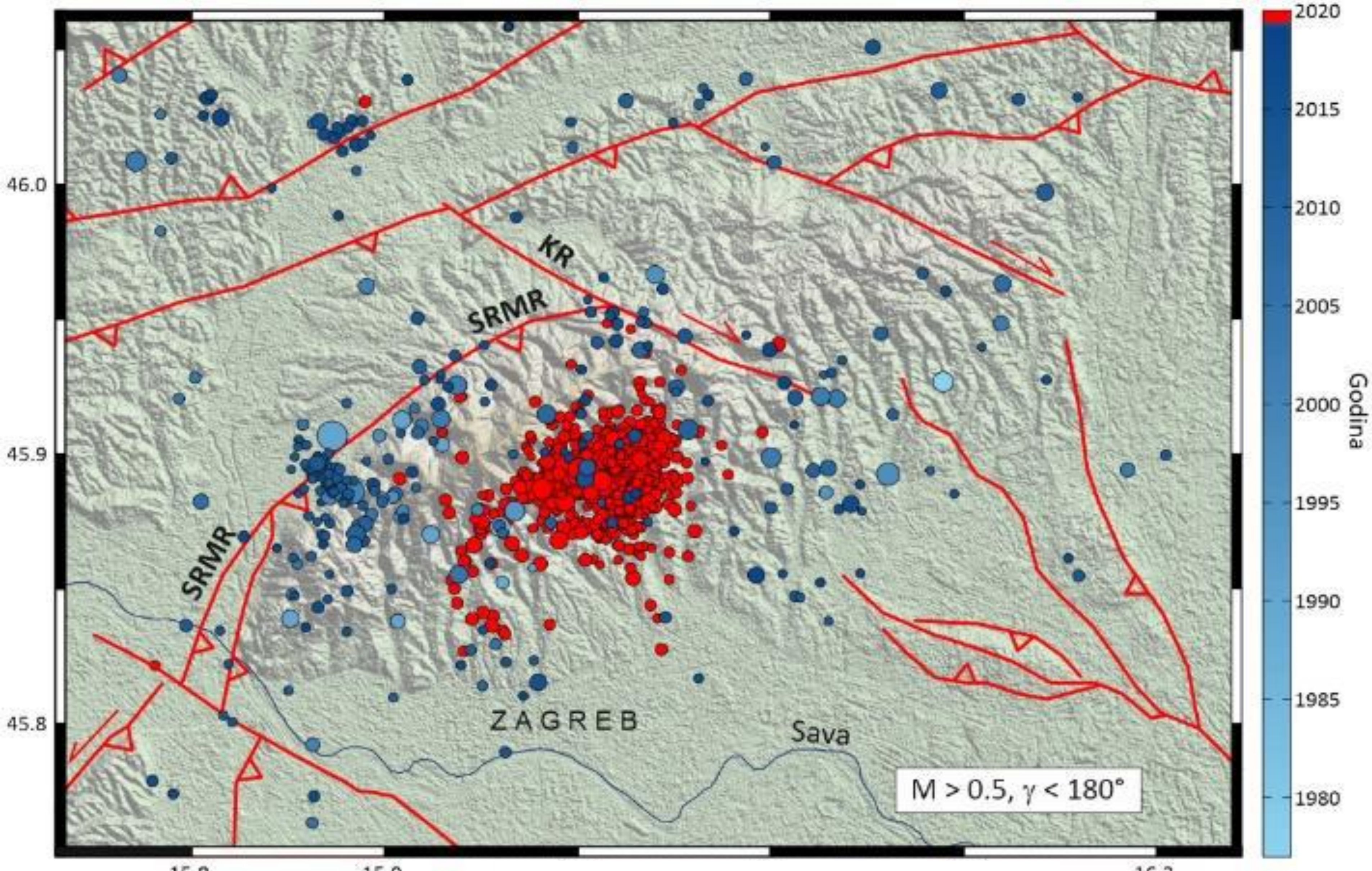
Presentation outline

- **Risk assessment process**
- Seismic hazard
- Exposure (izloženost)
- Vulnerability (oštetljivost)
- Risk communication - ER2 Rapid Risk Evaluator

Potresi



PMF-Geofizicki odsjek (https://www.pmf.unizg.hr/)

Zagrebacki potres

Fotografije: Mario Todorić, hr.n1info.com

Centar civilne zaštite, Ottawa (CND)

Procjena negativnih utjecaja od potresa

a) Dugoročno planiranje ublažavanja rizika

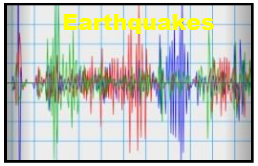
Interactivne simulacije "what-if" scenarios

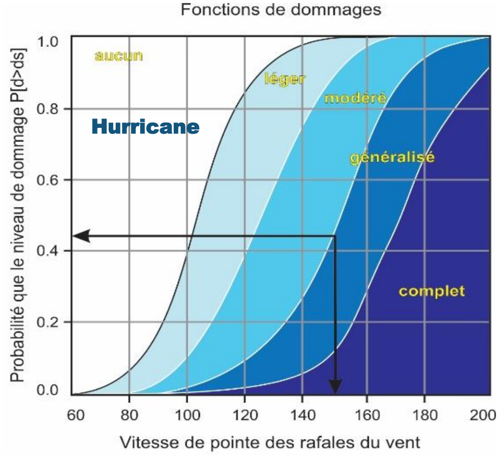
b) Upravljanje u hitnim situacijama

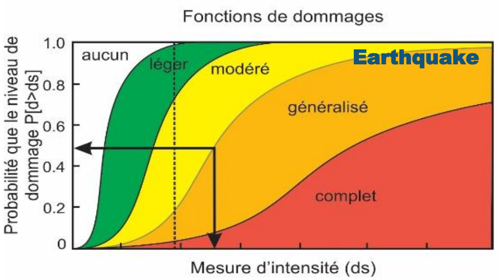
Procjena negativnih utjecaja u "real time"

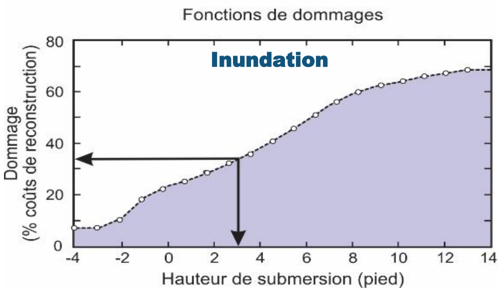
Proces procjene rizika

Hazard * Izloženost * Oštetljivost = Negativne posljedice









Stakeholders and end-users

- Decision makers for disaster pr…ntion and emergency response
- Land use and urban plann…r…
- Stakeholders who sho… kn… …isks
- Authorities w… …imp… …ent costly measures
- Citizens wh… …arent information for choosing wh…

Mota de Sá et al 2013; M.Šavor Novak, J.Atalic, M.Uroš et al. 2020

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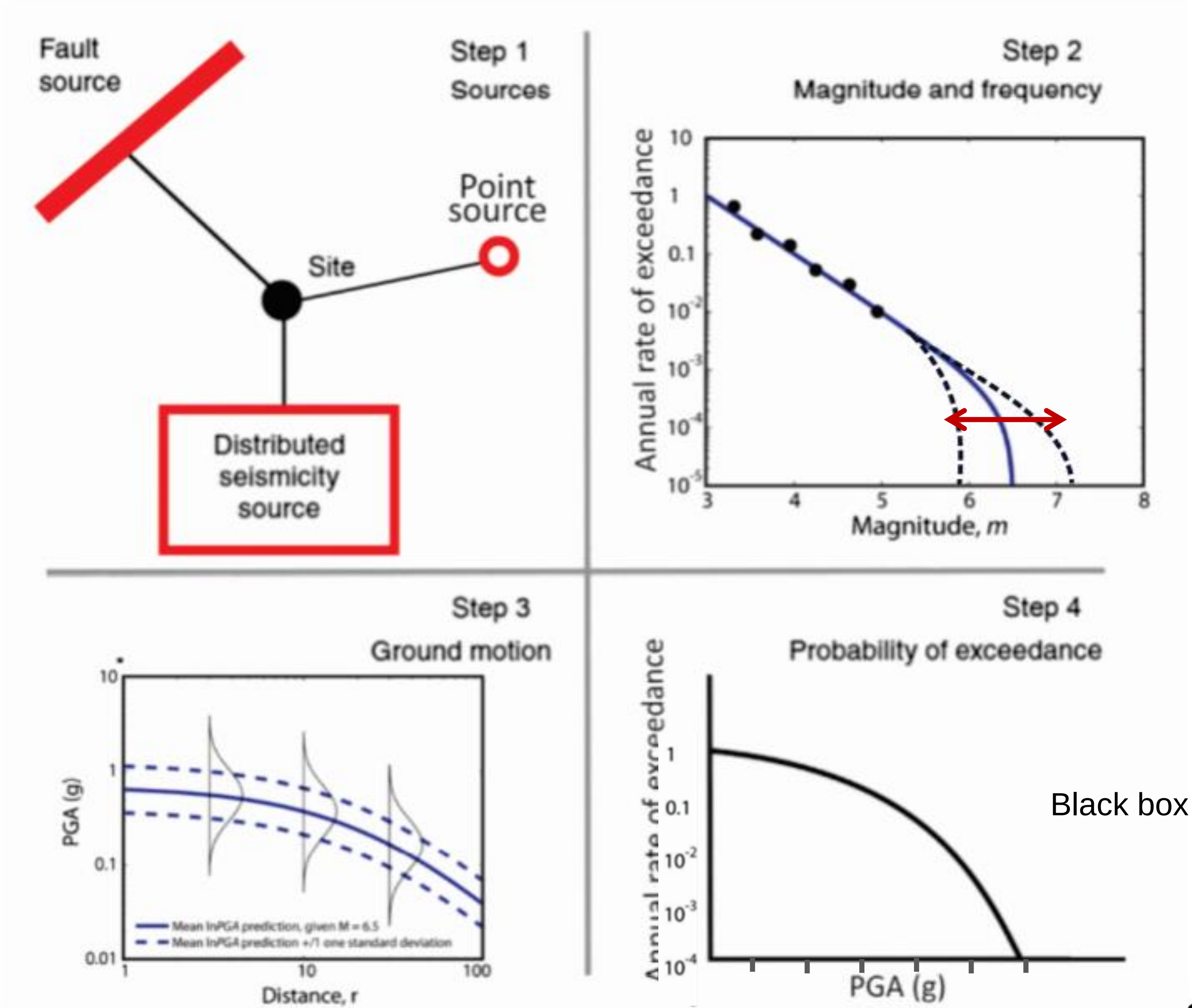
Probabilistic seismic hazard analysis PSHA



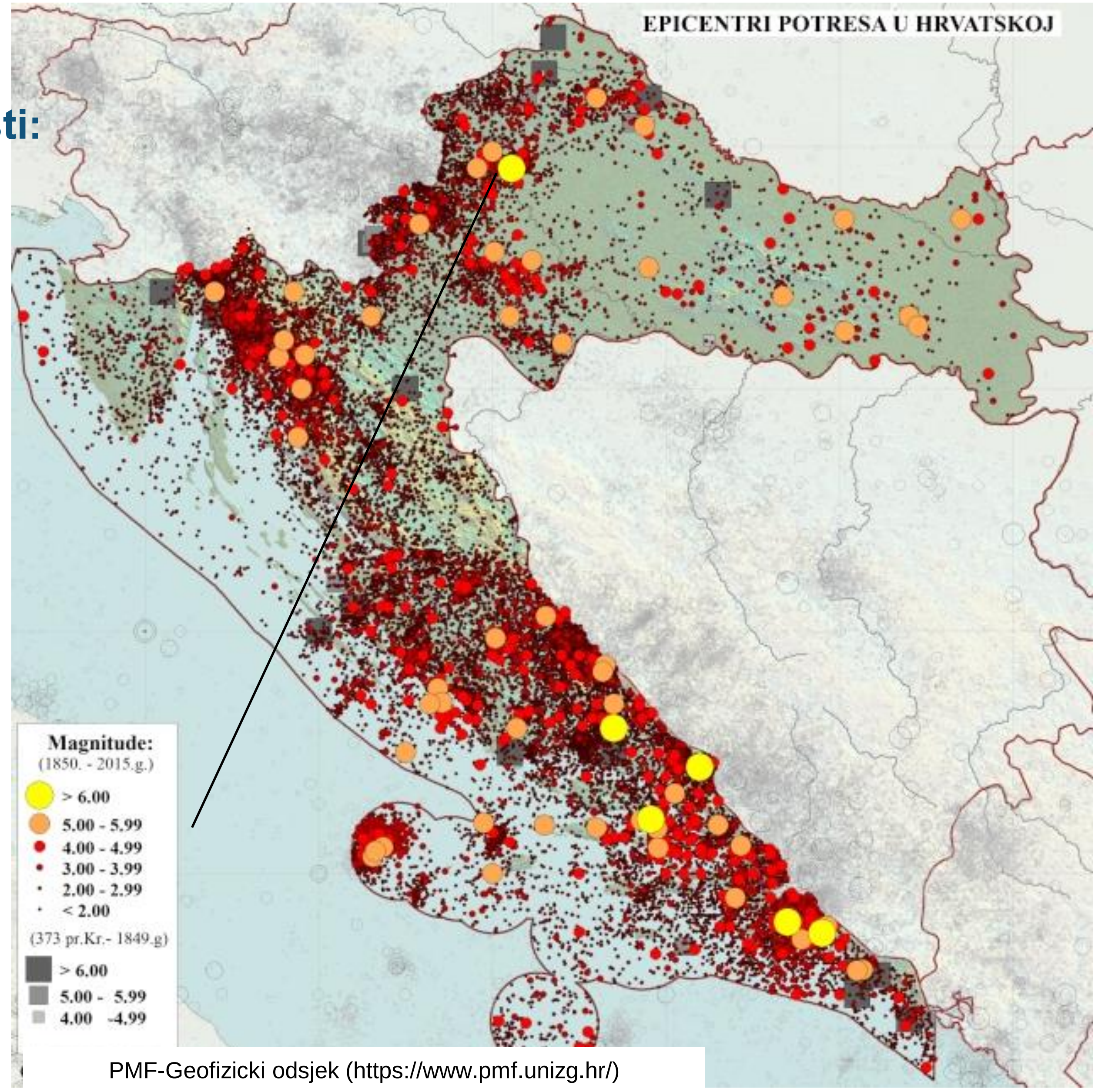
Black box !?

A.Cornell 1968; R.K.McGuire 1976; J.W.Baker 2008; M.W.Stirling 2014

Probabilistic seismic hazard analysis PSHA

Hrvatski katalog seizmičnosti:

- **lokacija,**
- **jacina, i**
- **frekvencija potresa**

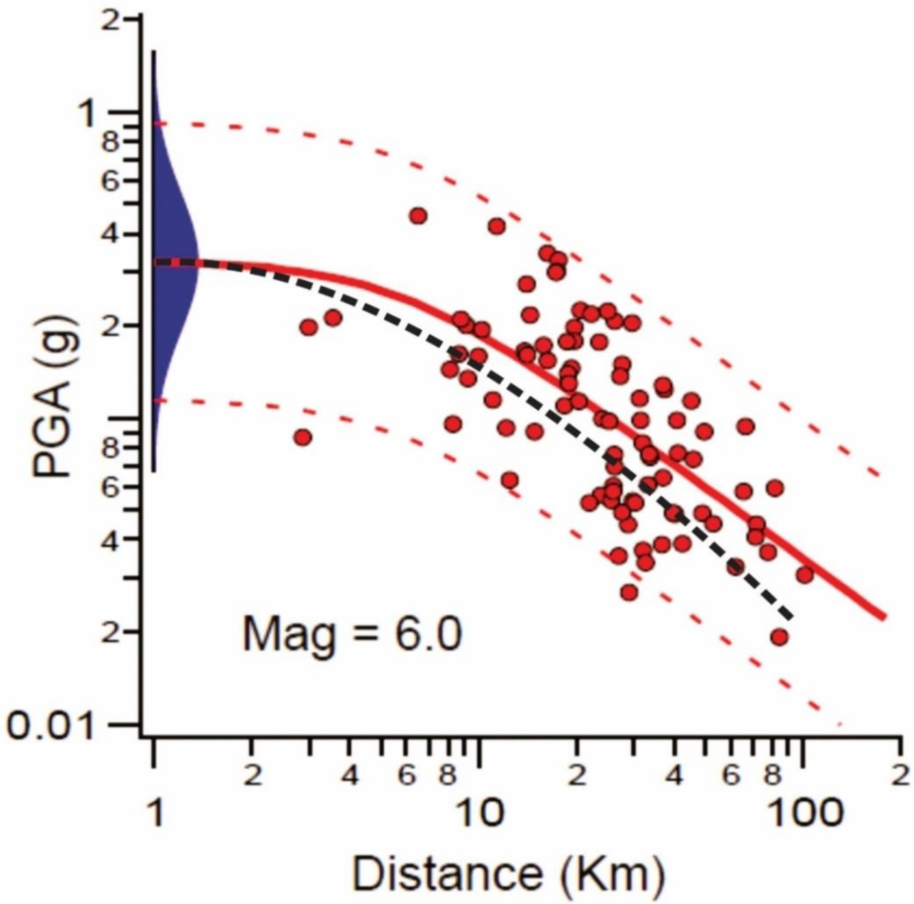


PMF-Geofizicki odsjek (https://www.pmf.unizg.hr/)

Probabilistic seismic hazard analysis PSHA

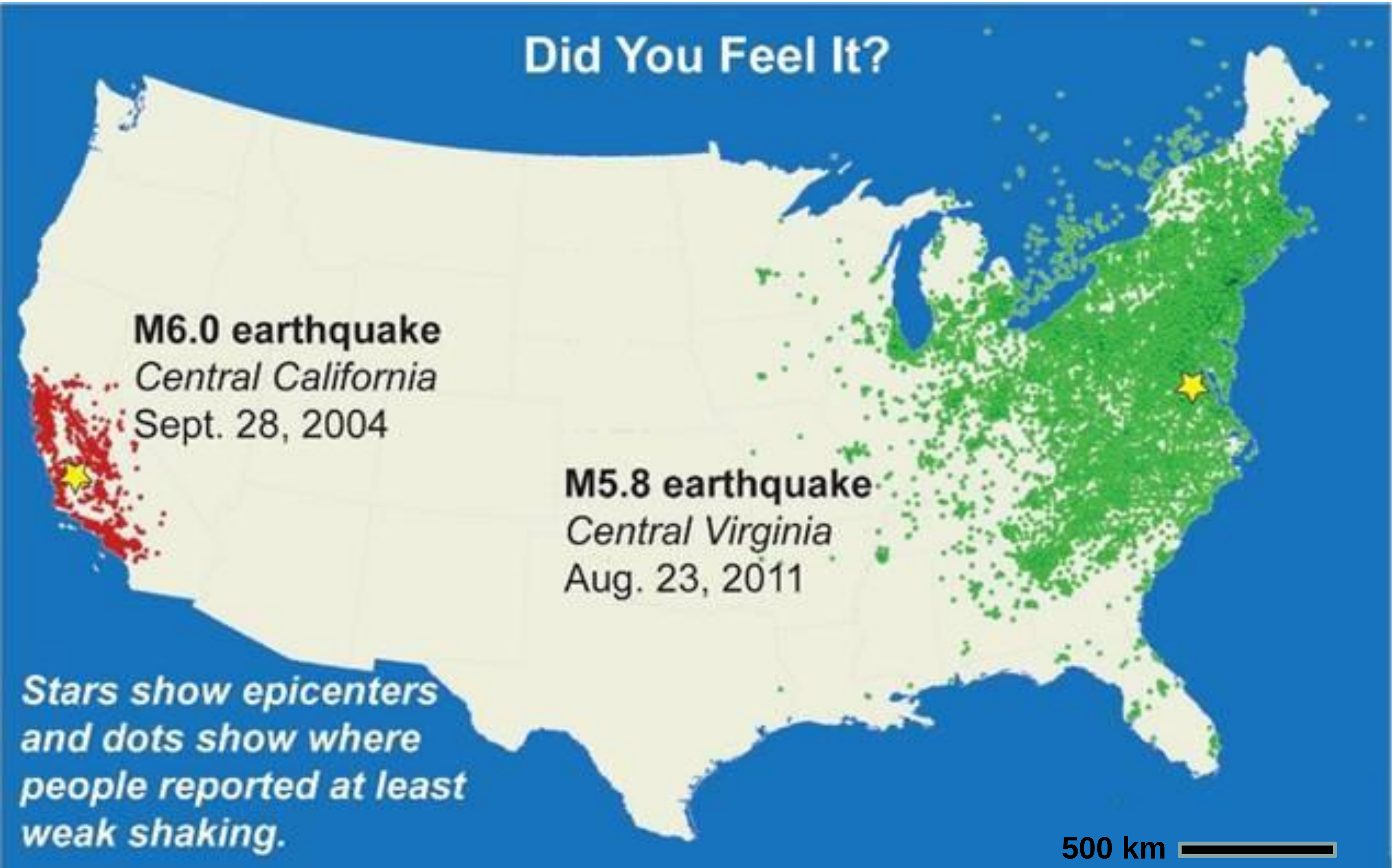
GMPEs are developed from strong motion data sets; describe the change of amplitude of seismic shaking with D for given M magnitude.

- **regression analysis**
- **considers inter-event and intra-event variability**
- **may consider local site conditions**
- **may consider fault type (n, r, ss)**
- **estimates mean and σ of PGA, PGV & Spectral accelerations**



Akkar & Boomer, 2010; Atkinson et al 2012.

Probabilistic seismic hazard analysis PSHA



Source: USGS

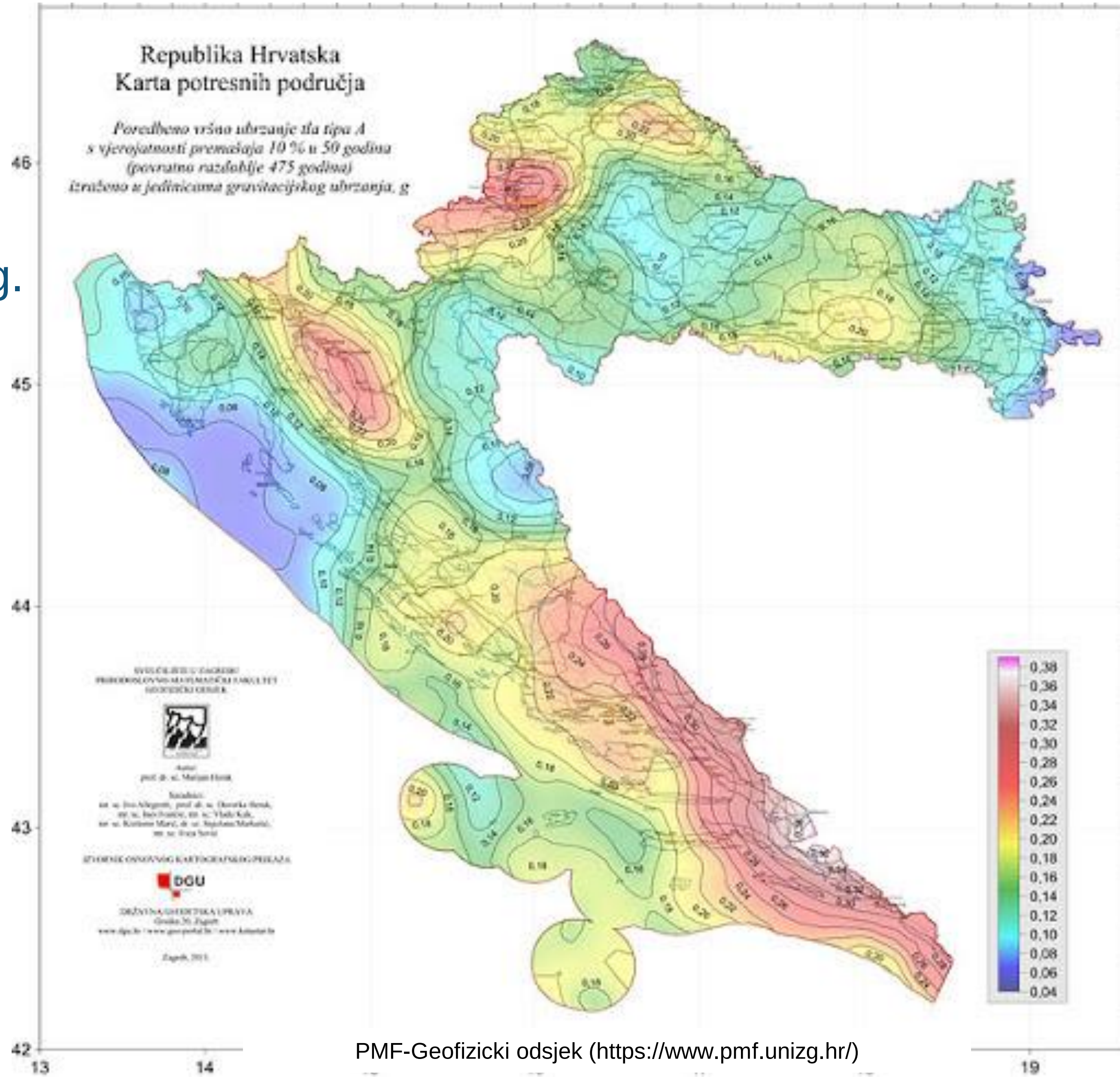
Probabilistic seismic hazard analysis PSHA

<u>Karta horizontalnih vršnih ubrzanja:</u>

- PGA (g)
- Site class A
- Return period of 475g. (10% probability of exceedance in 50yrs vs. 2% in 50 yrs)

<u>Utility of those maps:</u>

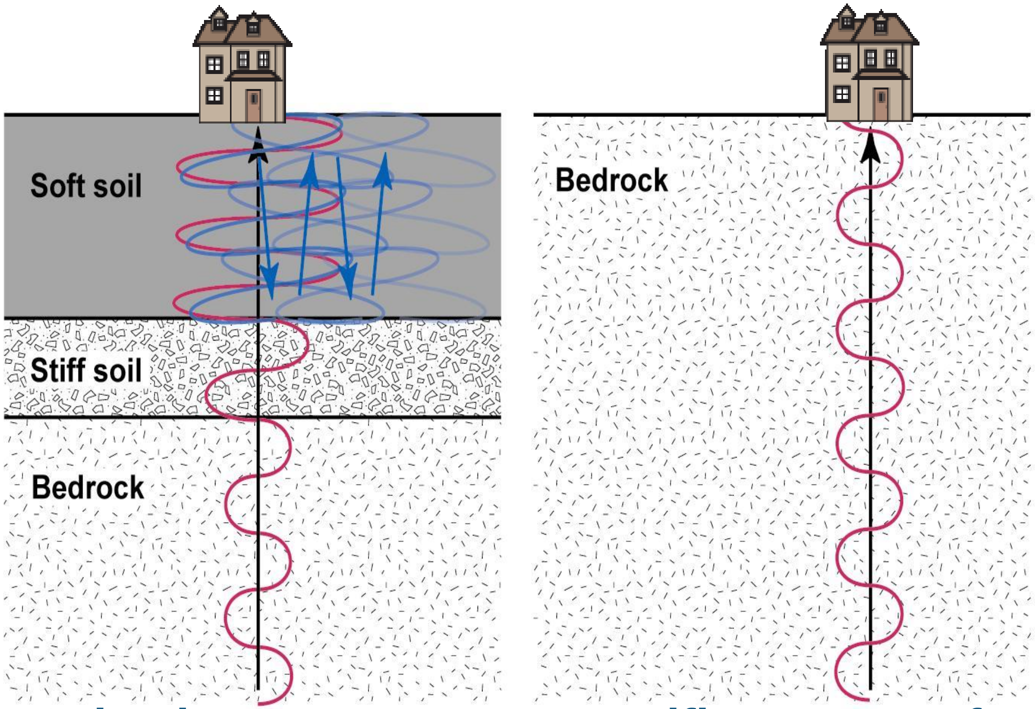
- Engineers
- Insurance industries
- Policymakers & Legislators
- Land-use planners
- Comparisons regions and hazards
- Cost-benefit

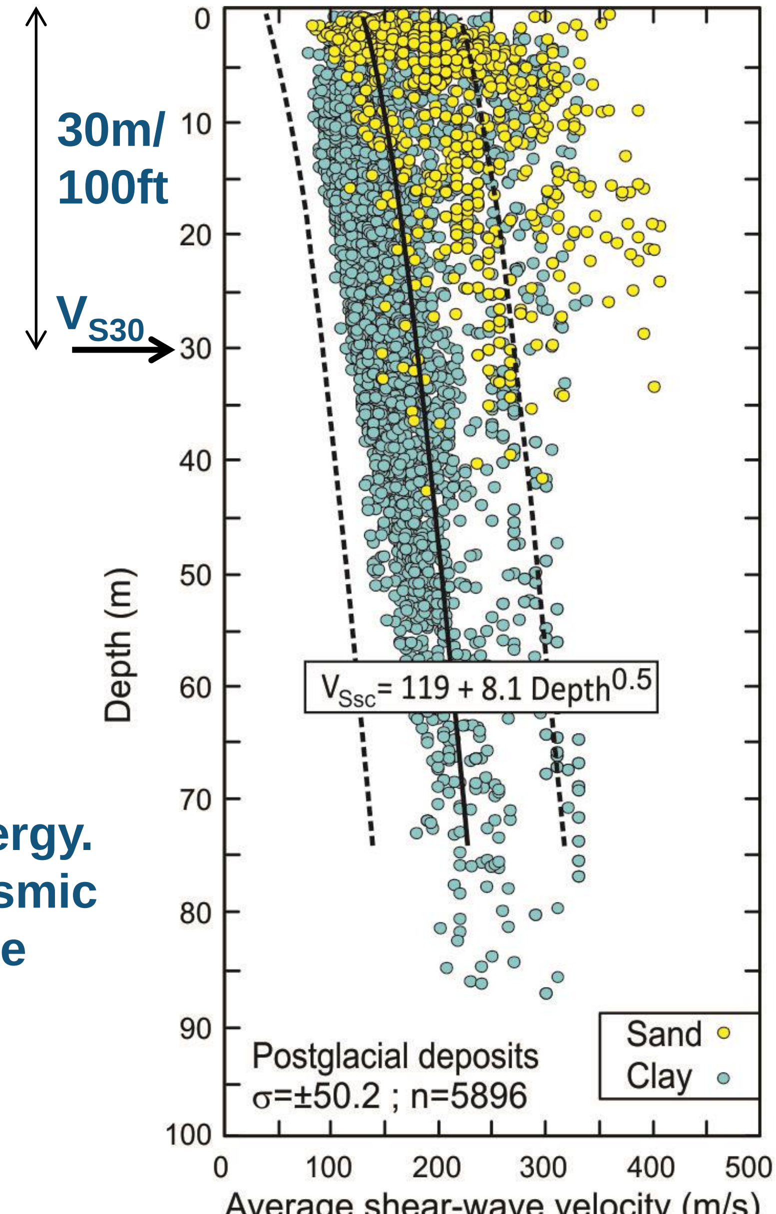


PMF-Geofizicki odsjek (https://www.pmf.unizg.hr/)

Local site effects

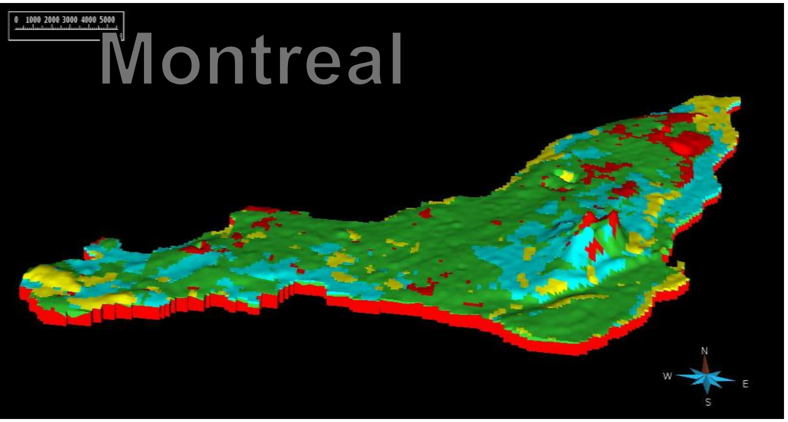
Utjecaj lokalnih uvjeta tla



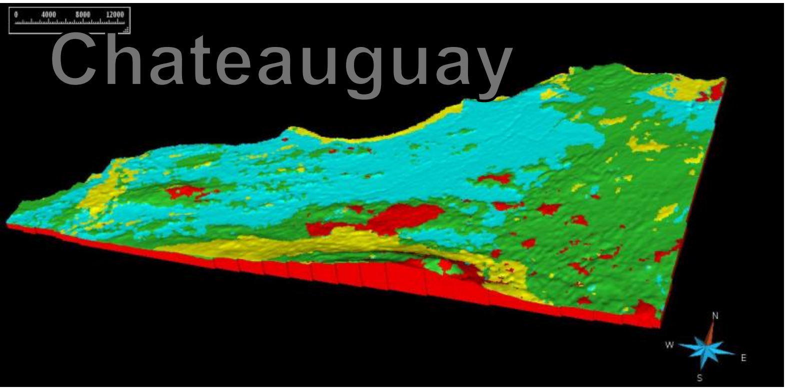


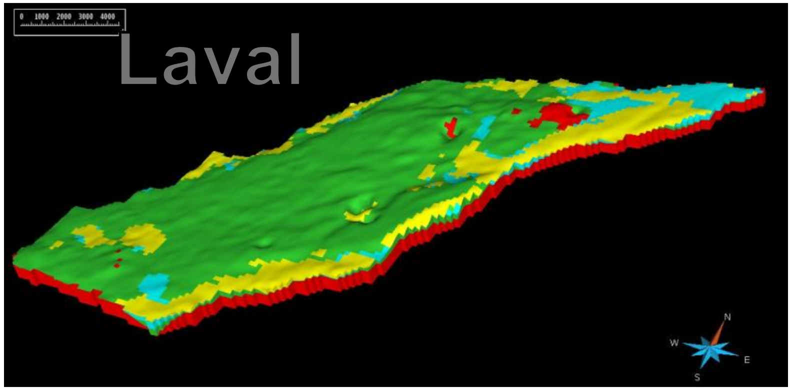
- **Seismic waves carry a specific amount of energy. When a lower V_S medium is encountered, seismic waves slow down. To conserve the energy, the amplitude of the seismic waves increases.**
- **Average vs. Interval Vs**

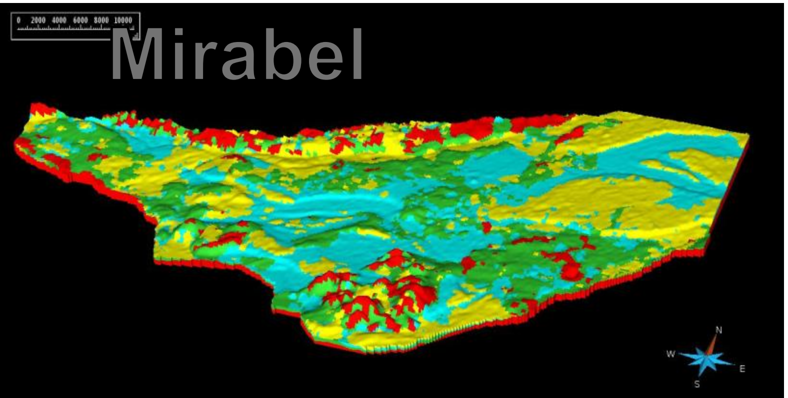
3D Geological models

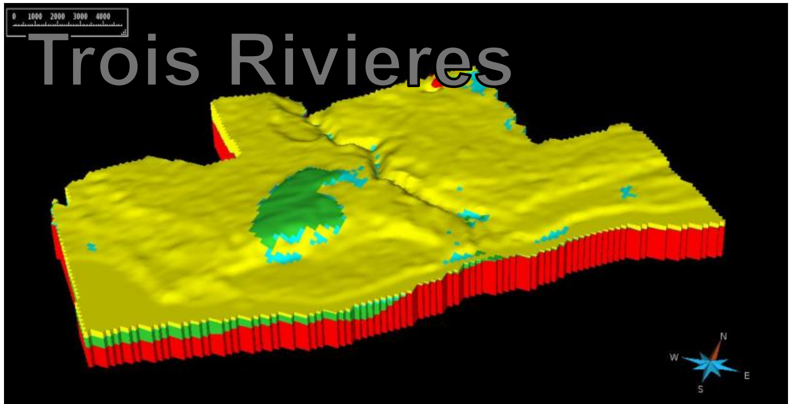


- Sand (alluvion)
- Clay (fine sediments)
- Till (glacial sediments)
- Bedrock









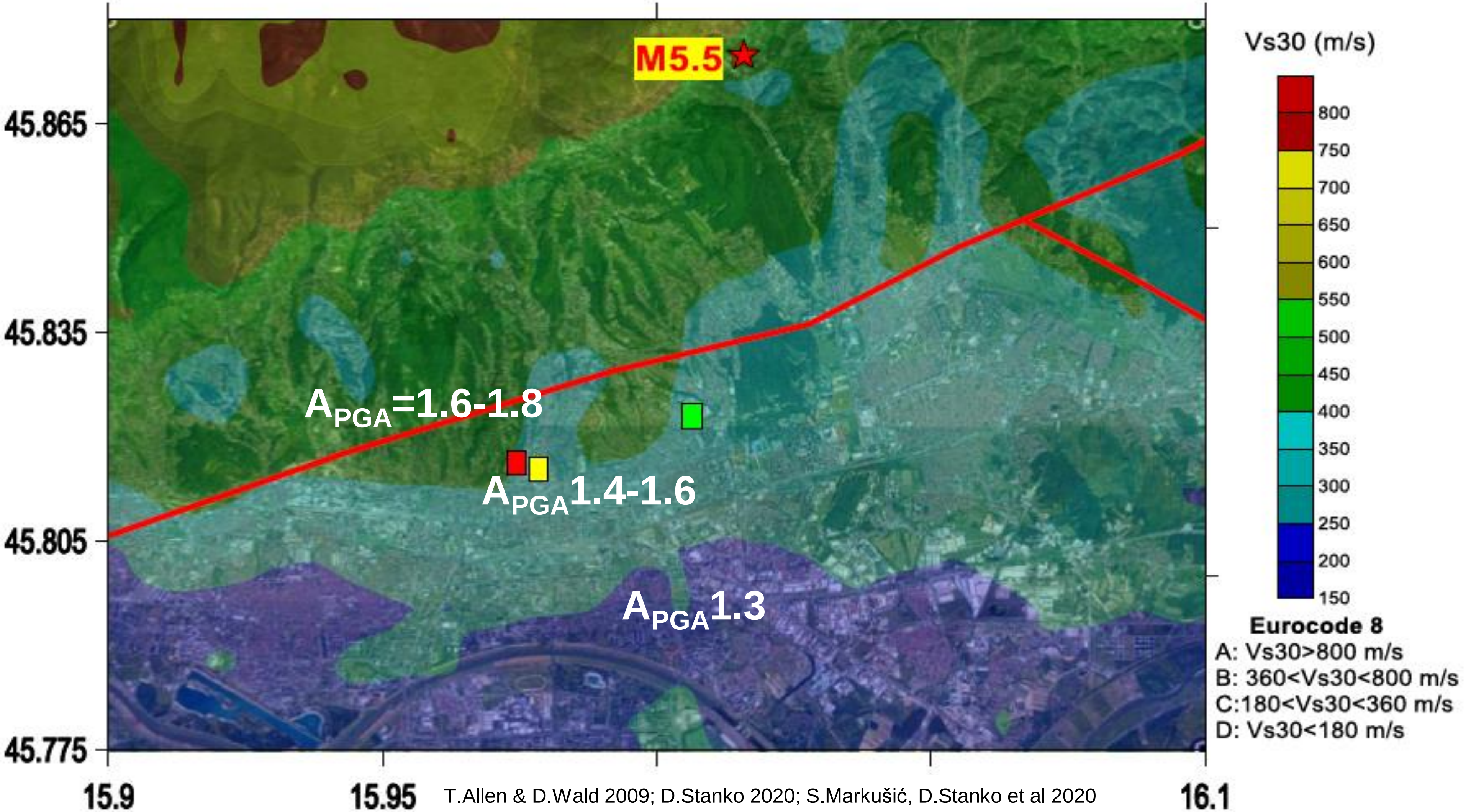
University of Waterloo

M.Ross, 2013

Local site amplification

Utjecaj lokalnih uvjeta tla (V_{S30} - topografija)

Ulazno potresno gibanje PGA=0.185g

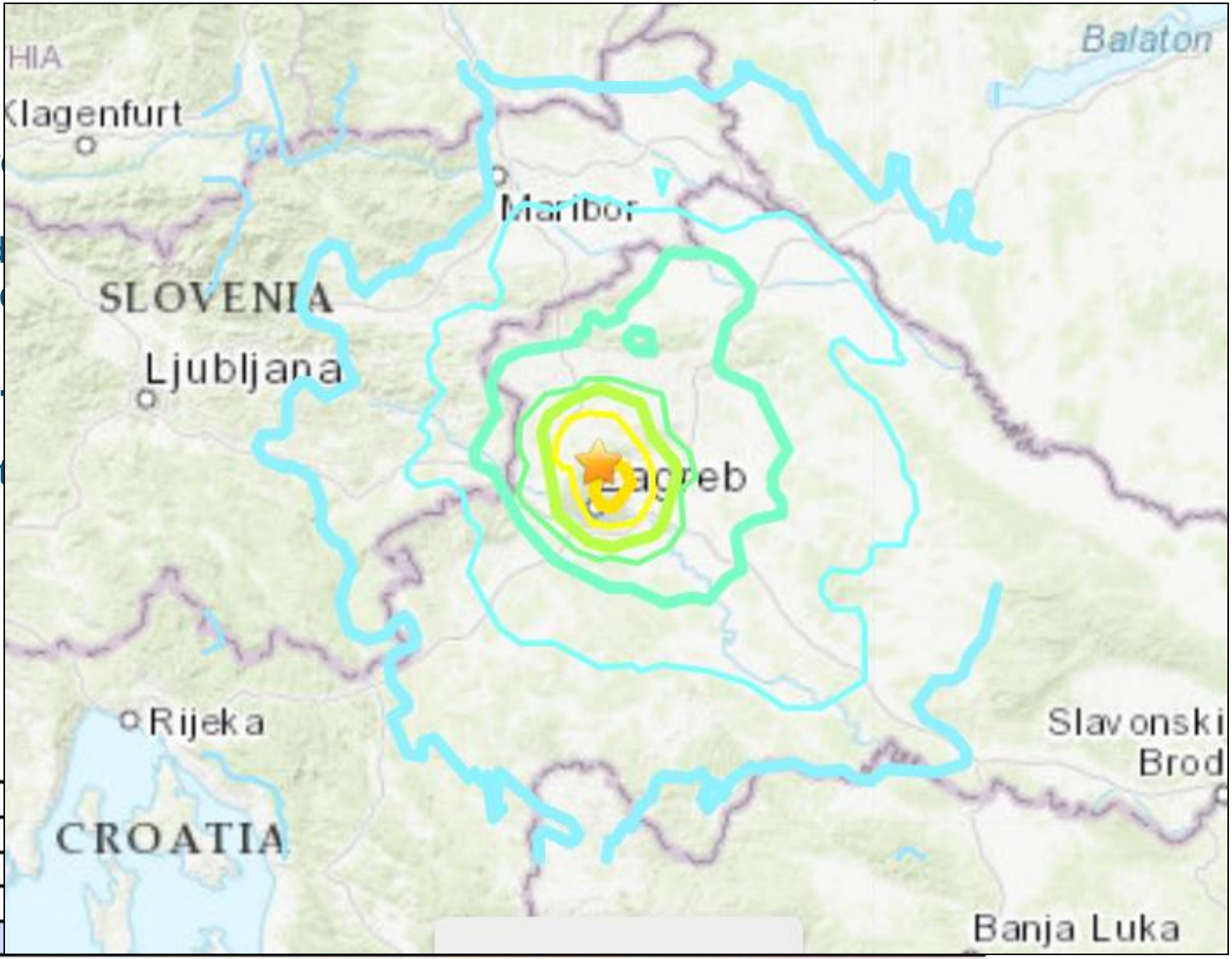


T.Allen & D.Wald 2009; D.Stanko 2020; S.Markušić, D.Stanko et al 2020

USGS shakemap: March 22, 2020 M_L5.5 Zagreb

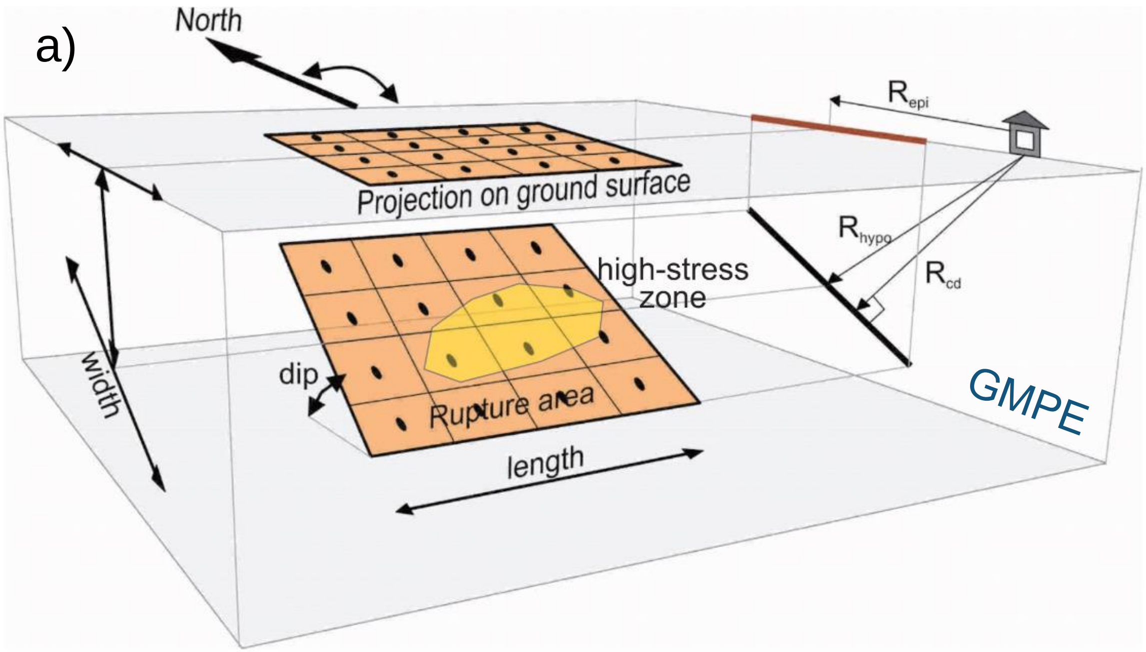
- **Perceived** ... **strong – v**...
- **Potential d**... **light – mo**...
- **PGA (g): 0.**...
- **Instrument**...

SHAKING	Not felt
DAMAGE	None
PGA(%g)	<0.0464
PGV(cm/s)	<0.0215
INTENSITY	I



Event scenario modelling (point source vs. FF)

a)

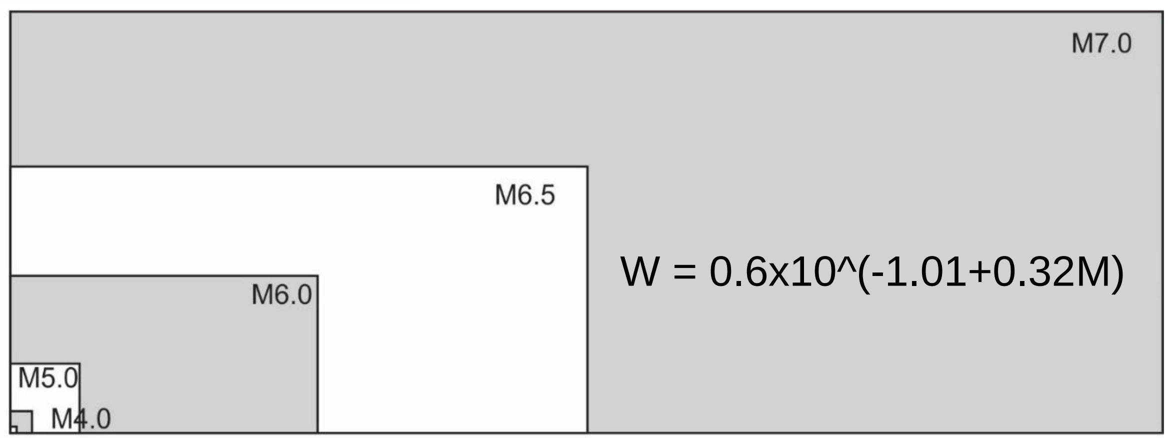


Rupture length:

- 2004 M9.2 Sumatra - 1000 km
- 2011 M9.0 Tohoku - 500 km
- 2010 M7.0 Haiti - 40 km
- 1988 M5.9 Saguenay - 10 km
- 2010 M5.0 Val-des-Bois - 1 km

Top depth = 21-2.5M

c)



W = 0.6x10^(-1.01+0.32M)

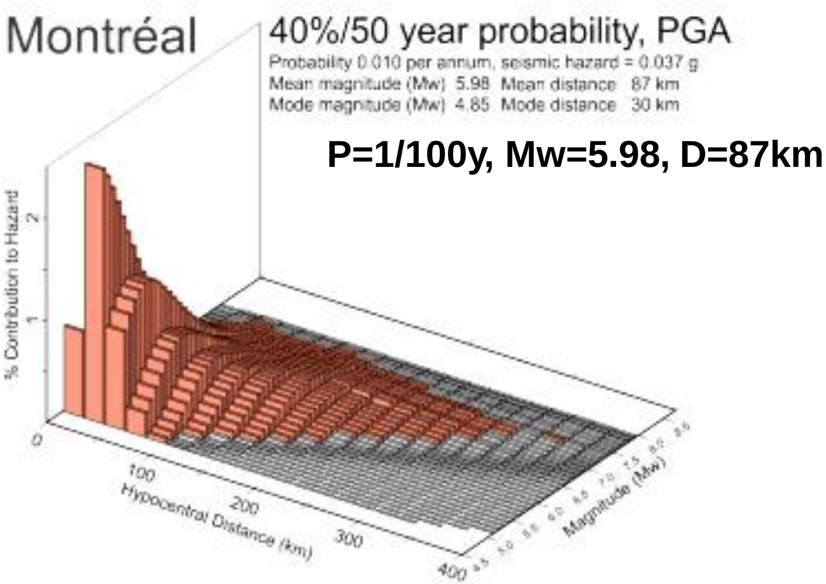
L = 0.6x10^(-2.44+0.59M)

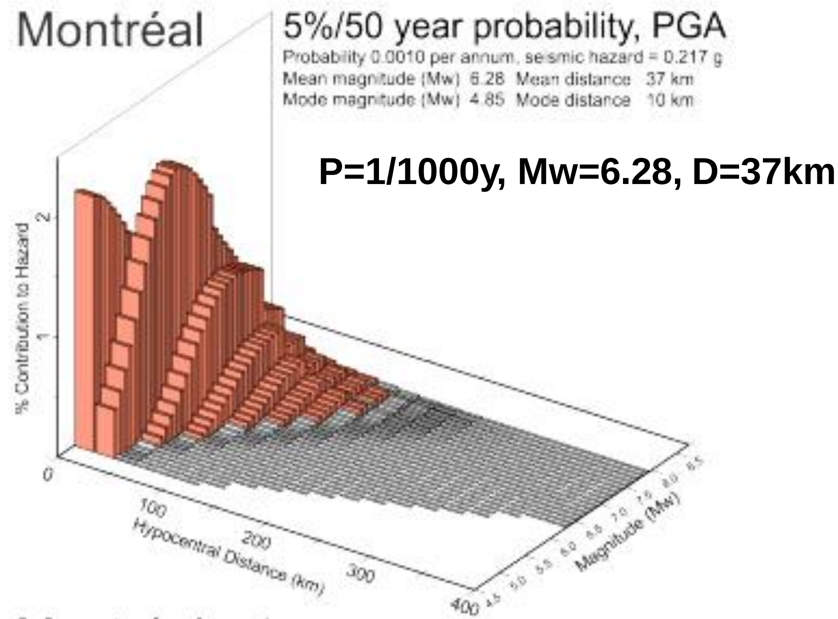
- disaster planning
- preparedness exercises
- emergency response
- post-eq. recovery
- public/sci. info

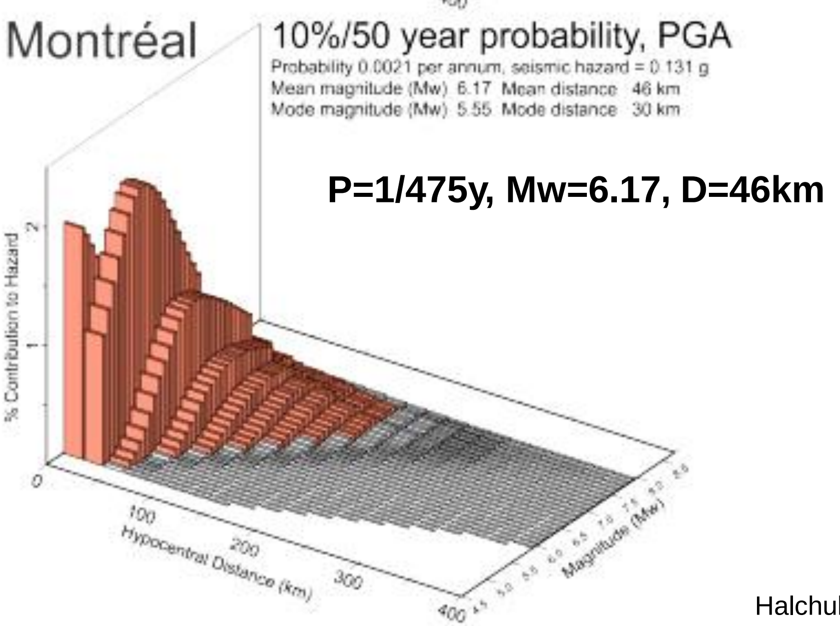
Wells and Coppersmith 1984, Somerville 2005, Atkinson et al 2012

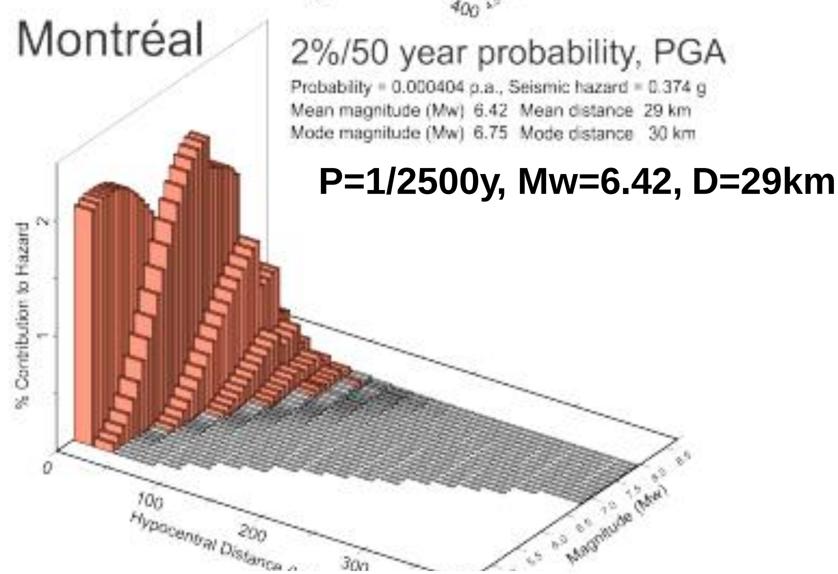
Deaggregation of Seismic Hazard

Identifying predominant sources









Halchuk et al. 2019

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Standardized inventory (buildings)

No.	Label	Description	Height: Range Name	Height: Range Stories	Height: Typical Stories	Height: Typical Feet
1 2	W1 W2	Wood, Light Frame (≤ 5,000 sq. ft.) Wood, Commercial and Industrial (> 5,000 sq. ft.)		1 - 2 All	1 2	14 24
3 4 5	S1L S1M S1H	Steel Moment Frame	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
6 7 8	S2L S2M S2H	Steel Braced Frame	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
9	S3	Steel Light Frame		All	1	15
10 11 12	S4L S4M S4H	Steel Frame with Cast-in-Place Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
13 14 15	S5L S5M S5H	Steel Frame with Unreinforced Masonry Infill Walls	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
16 17 18	C1L C1M C1H	Concrete Moment Frame	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
19 20 21	C2L C2M C2H	Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
22 23 24	C3L C3M C3H	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
25	PC1	Precast Concrete Tilt-Up Walls		All	1	15
26 27 28	PC2L PC2M PC2H	Precast Concrete Frames with Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
29 30	RM1L RM2M	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	Low-Rise Mid-Rise	1-3 4+	2 5	20 50
31 32 33	RM2L RM2M RM2H	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
34 35	URML URMM	Unreinforced Masonry Bearing Walls	Low-Rise Mid-Rise	1 - 2 3+	1 3	15 35
36	MH	Mobile Homes		All	1	10

Design level
- pre-code
- low-code
- med-code
- high code

Occupancy class
- residential
- commercial
- industrial
- agriculture
- religion
- government
- education

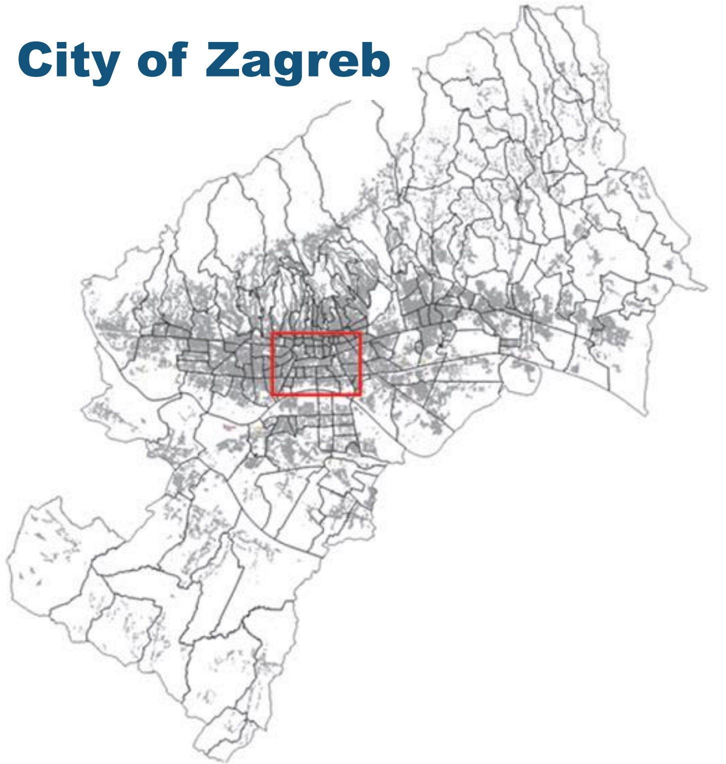
#1: W1
- Wood light frame (< 460 m2)
- Low-Rise: 1-2 Stories
- Residential occupancy

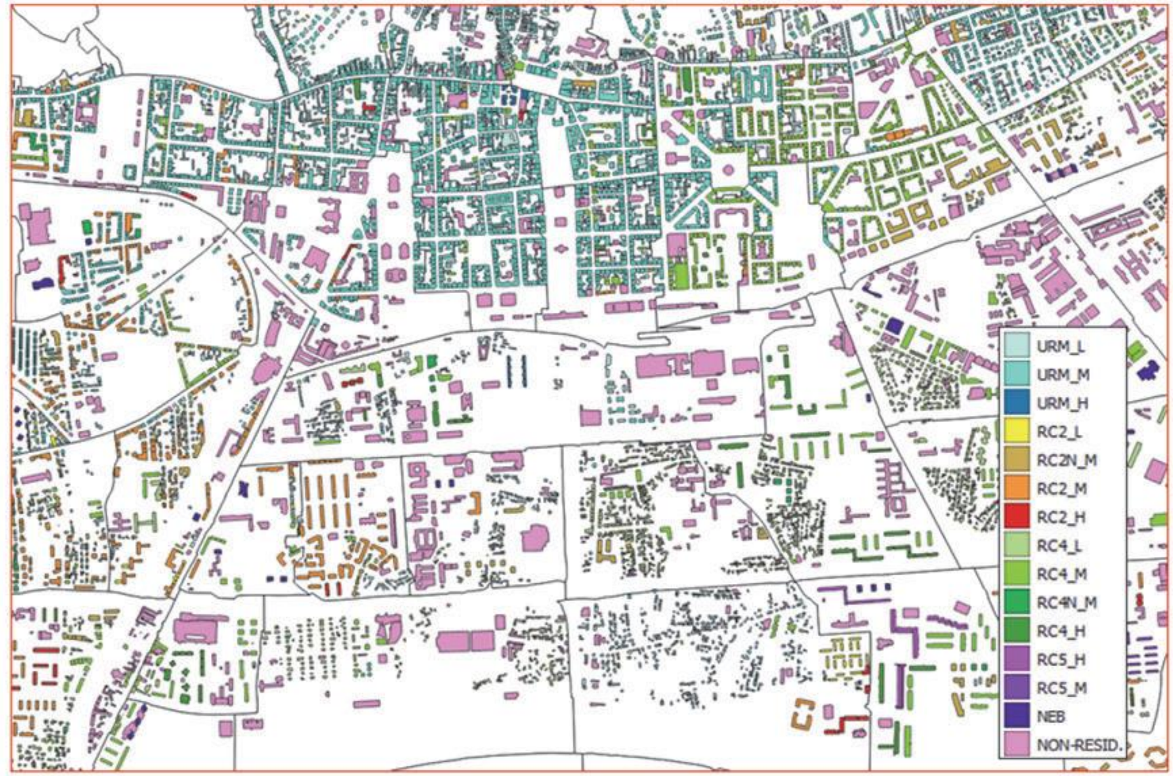
#20: C2M
- Concrete Shear Walls
- Mid-Rise: 4-7 Stories
- Education

FEMA 2012

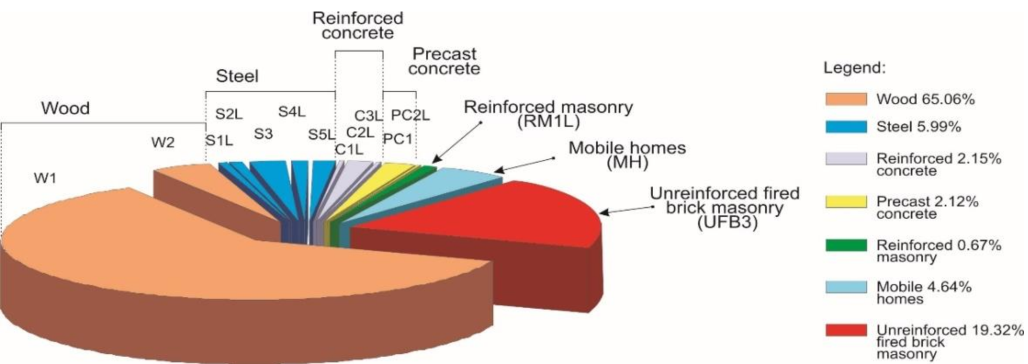
Aggregated vs. Individual Inventory Data

City of Zagreb

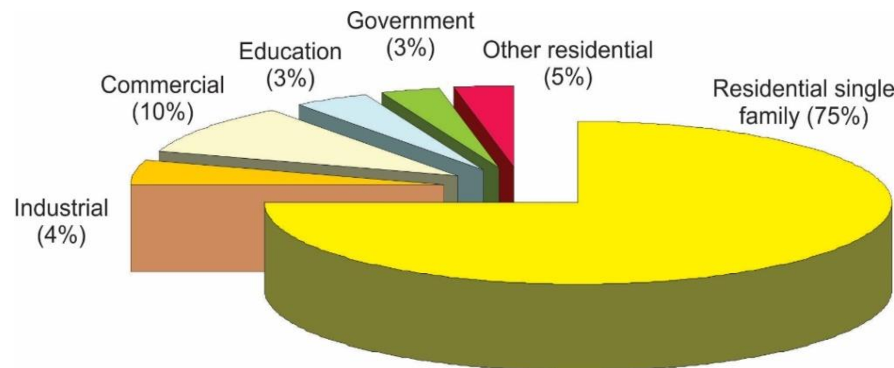




Structural types

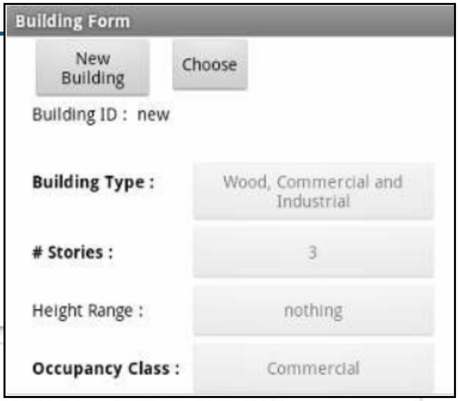


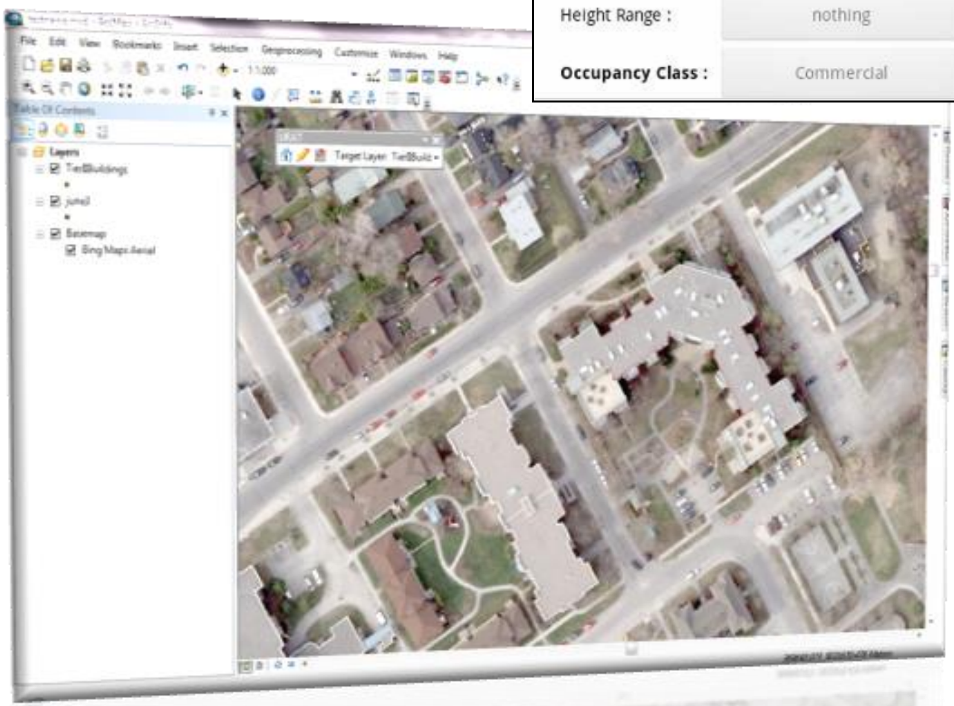
Occupancy types



M.Šavor Novak, J.Atalic, M.Uroš et al. 2020

Exposure: Urban Field RAT app





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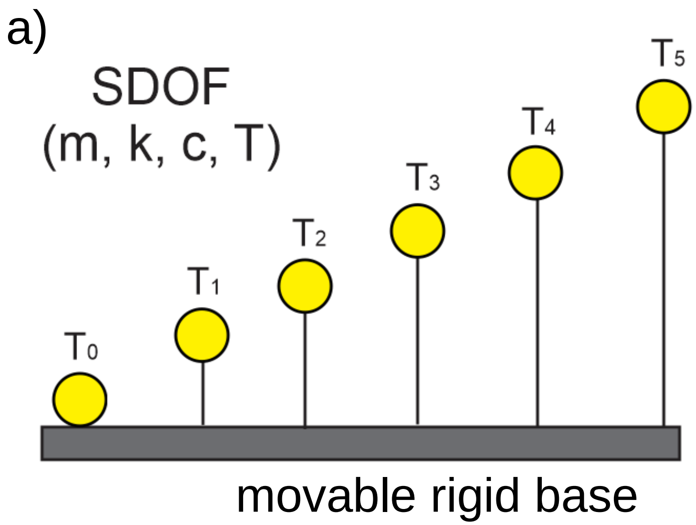
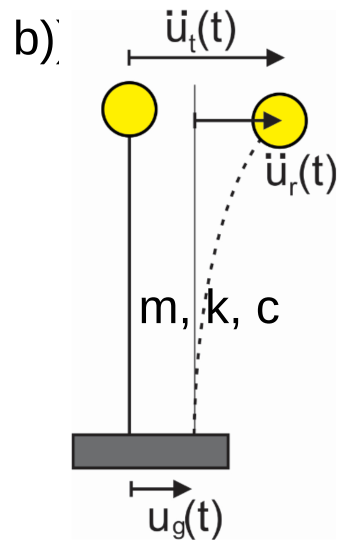
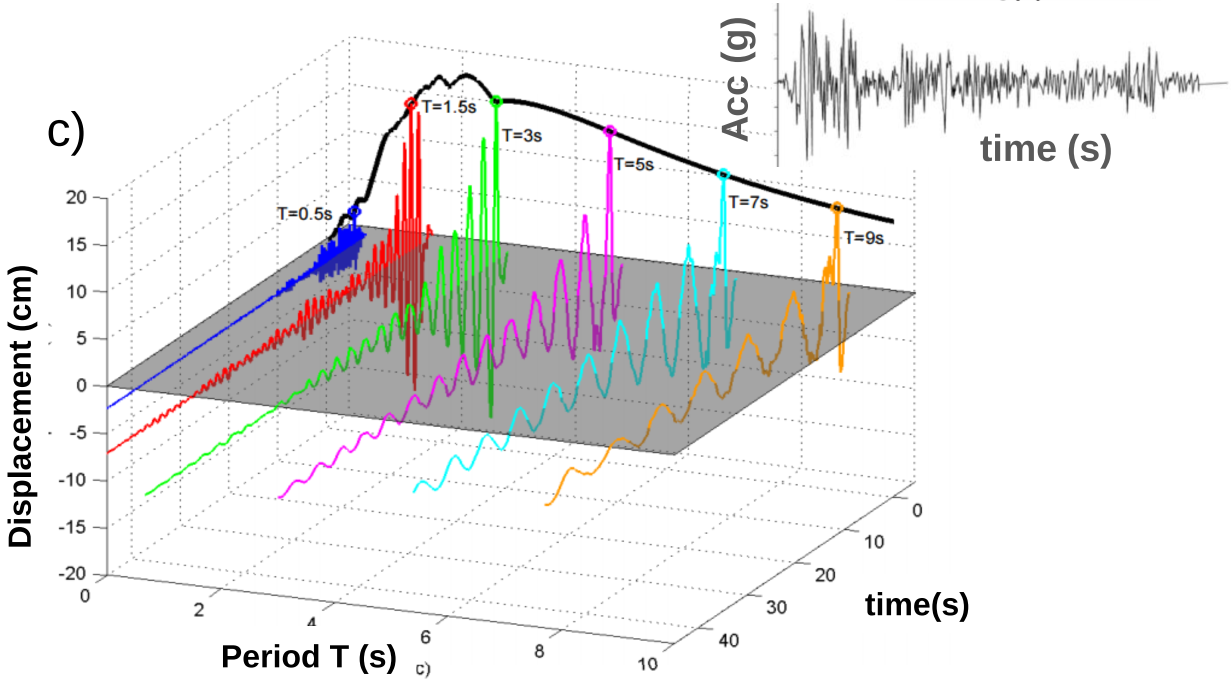
Earthquake Response Spectrum







Equation of motion:

$$F_{inertia} + F_{damping} + F_{elastic} = 0$$

$$m\ddot{u}_g(t) = m\ddot{u}_r(t) + c\dot{u}_r + ku_r$$

$$m\ddot{u}_t(t) = c\dot{u}_r + ku_r$$

c : coeff. viscous damping (% of critical damping)

k : stiffness = $m\omega^2$, $\omega = 2\pi/T$

ω: natural (angular) frequency

Elastic response:

Spectral (pseudo) acceleration:

$$S_a(t) = \omega_i^2 u_r(t)$$

Maximum ground acceleration:

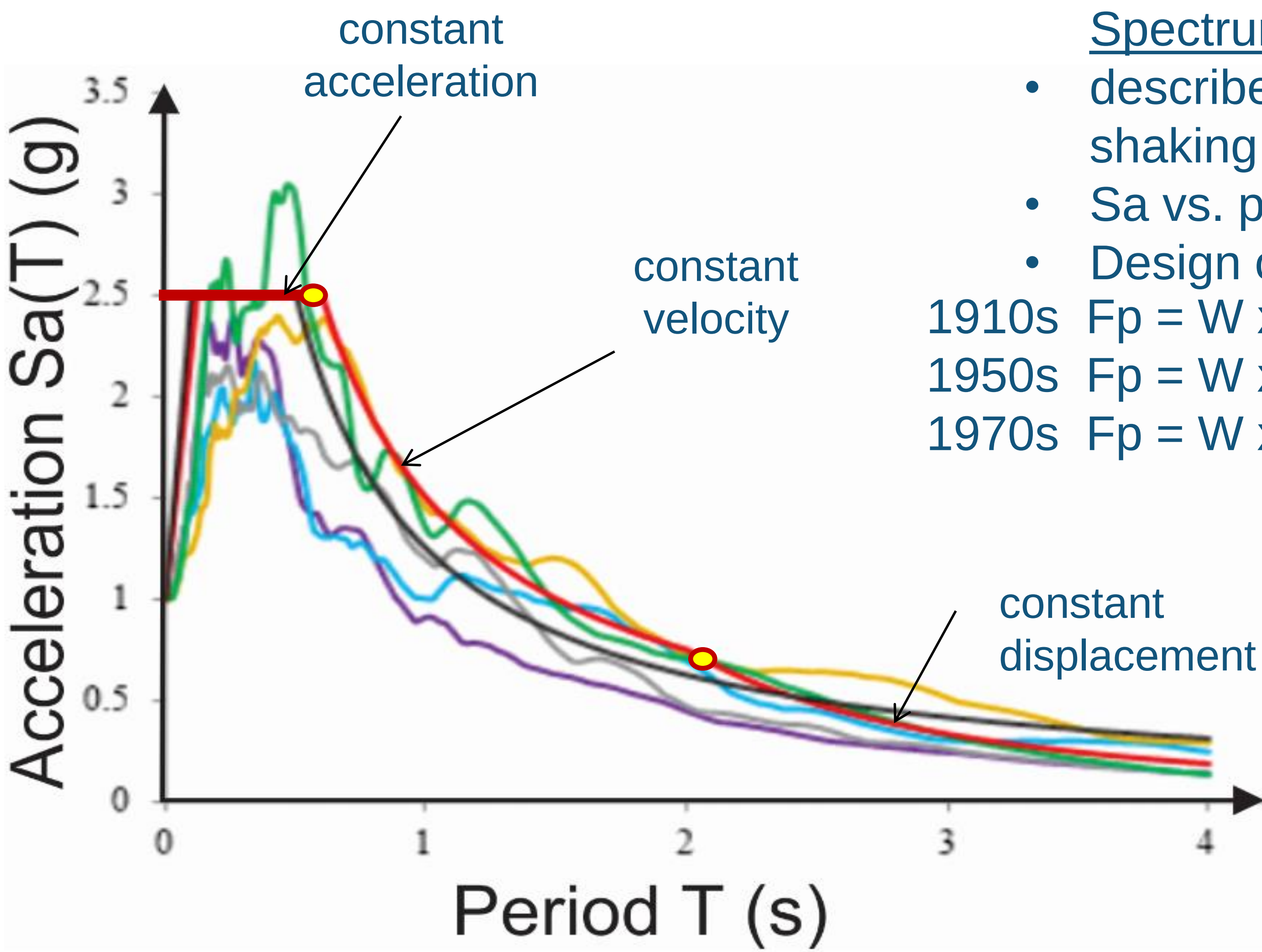
$$PGA = \ddot{u}_g^{max}(t)$$

Maximum ground velocity:

$$PGV = \max \int \ddot{u}_g(t)dt$$

Canada

Response spectrum UHS



- smoothed Elastic Response Spectrum for SDOF
- describes the design ground shaking
- Sa vs. period T domain
- Design codes (base shear)

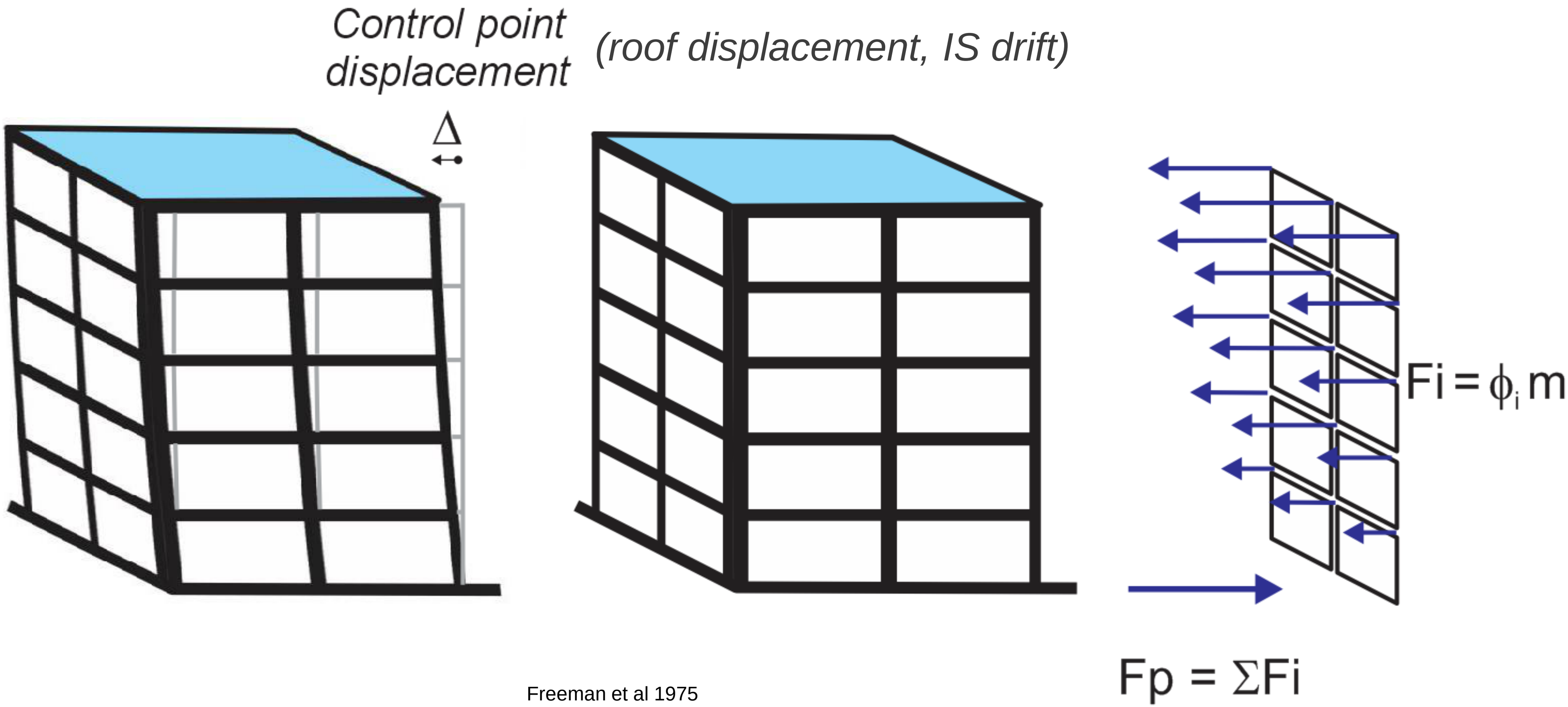
1910s Fp = W x 0.1

1950s Fp = W x Sa(T_o)

1970s Fp = W x Sa(T_o) x Factors

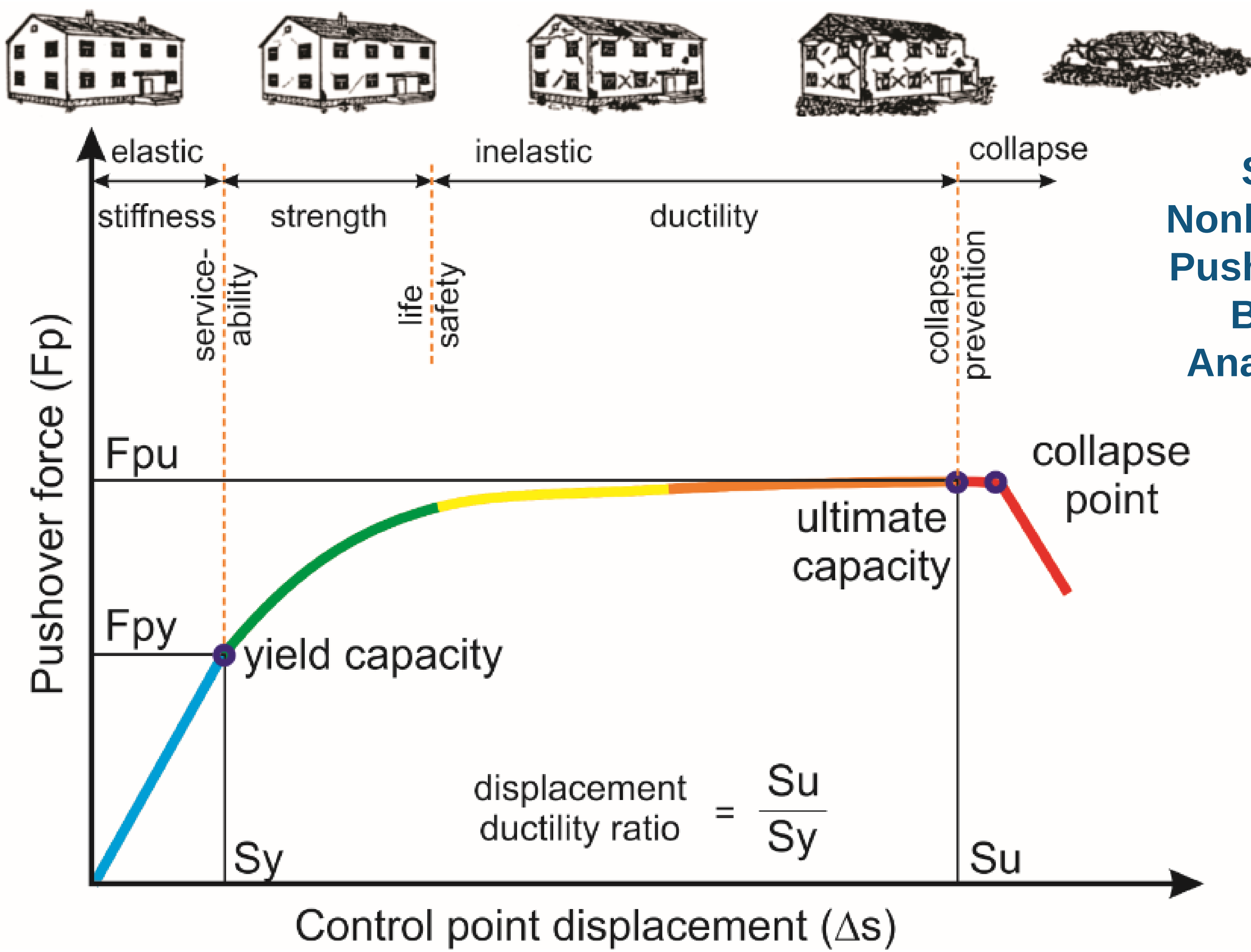
Seismic vulnerability: capacity curve

- Static Nonlinear Pushover Based Analysis vs. NRHA
- Choose height-wise distribution of lateral forces
- Monotonically increase lateral forces
- Develop capacity (pushover) curve as base shear vs. lateral deformation



Freeman et al 1975

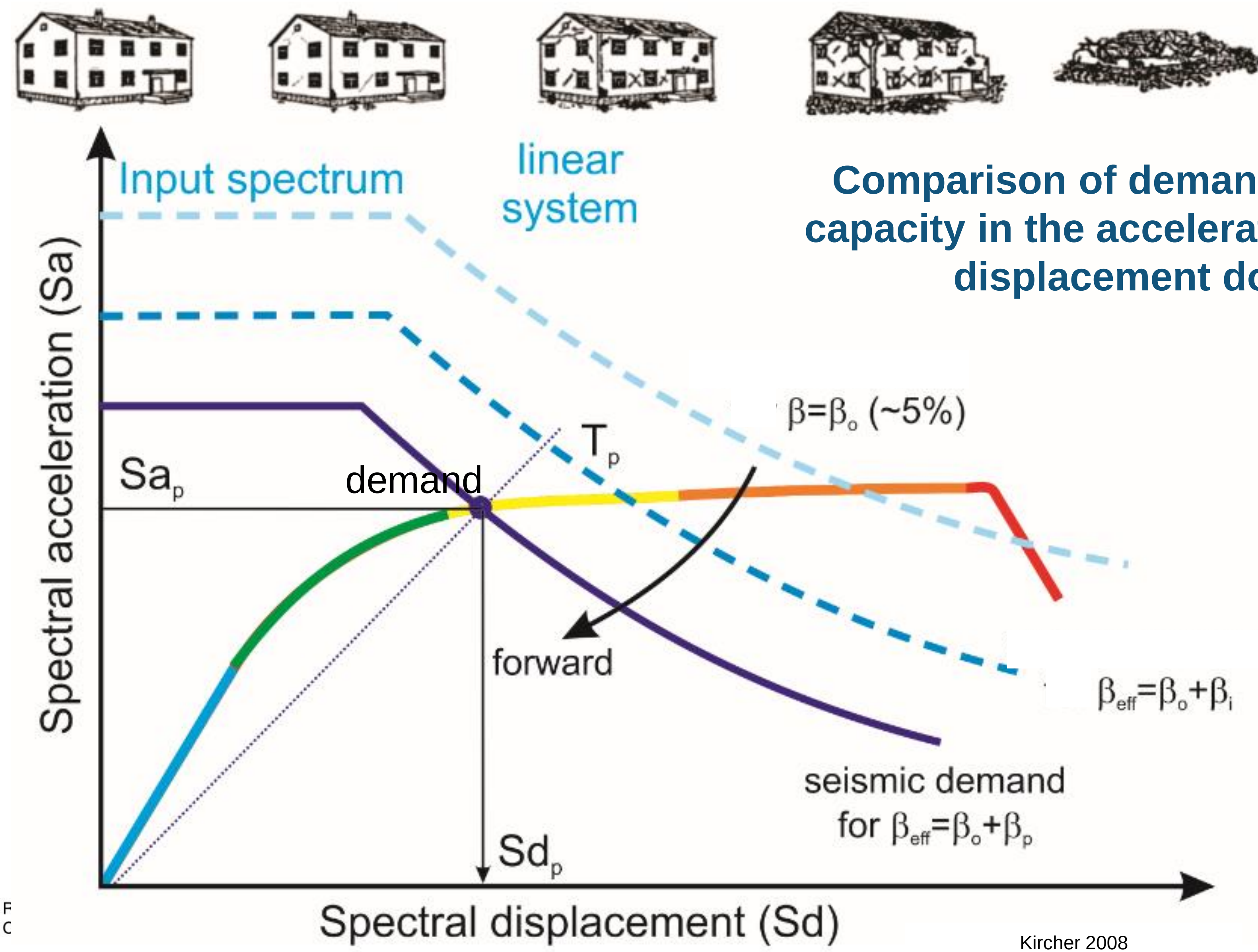
Seismic vulnerability: capacity curve



Static Nonlinear Pushover Based Analysis

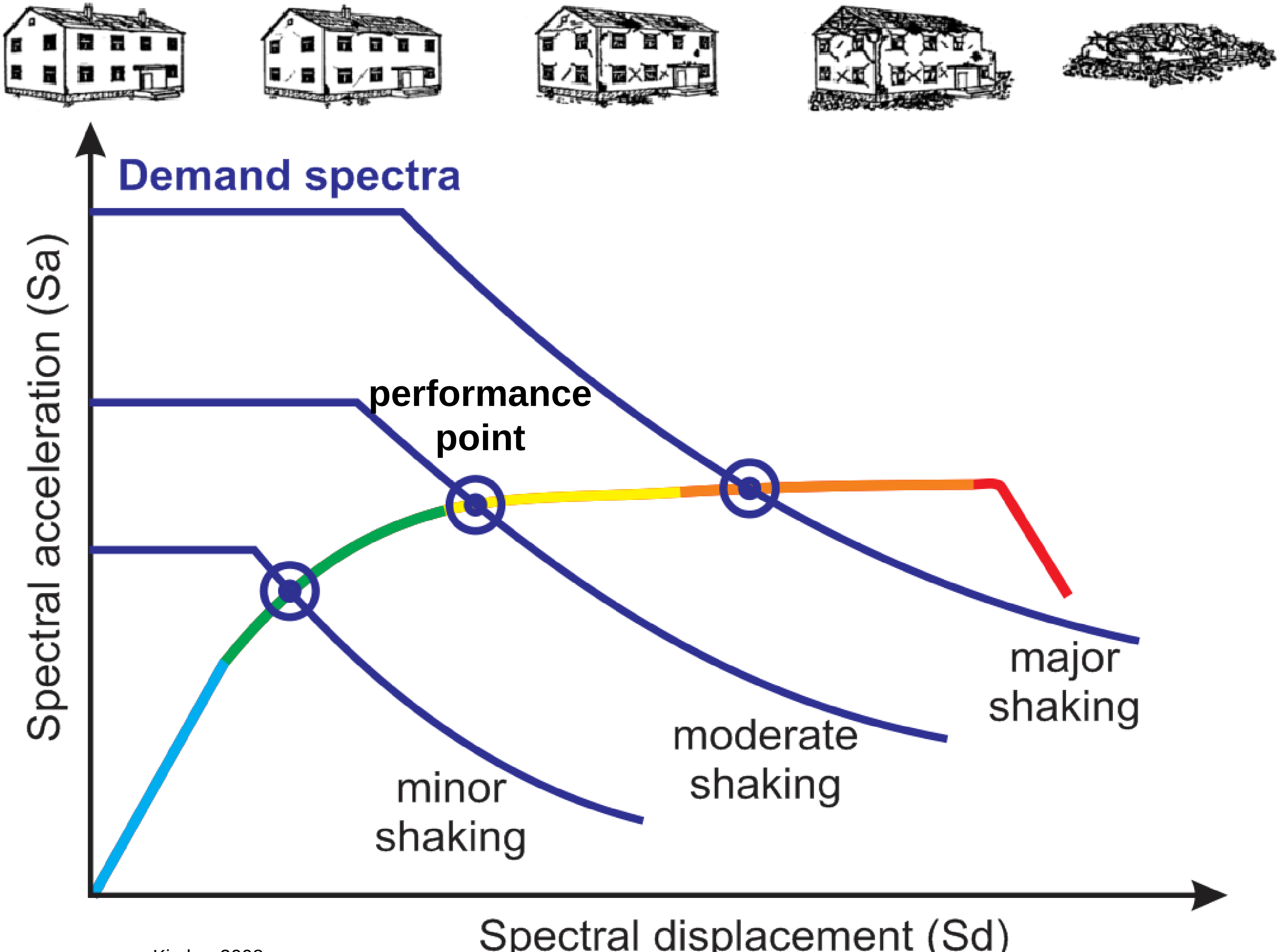
Seismic vulnerability: CSM (Sa vs. Sd domain)

Comparison of demand and capacity in the acceleration – displacement domain



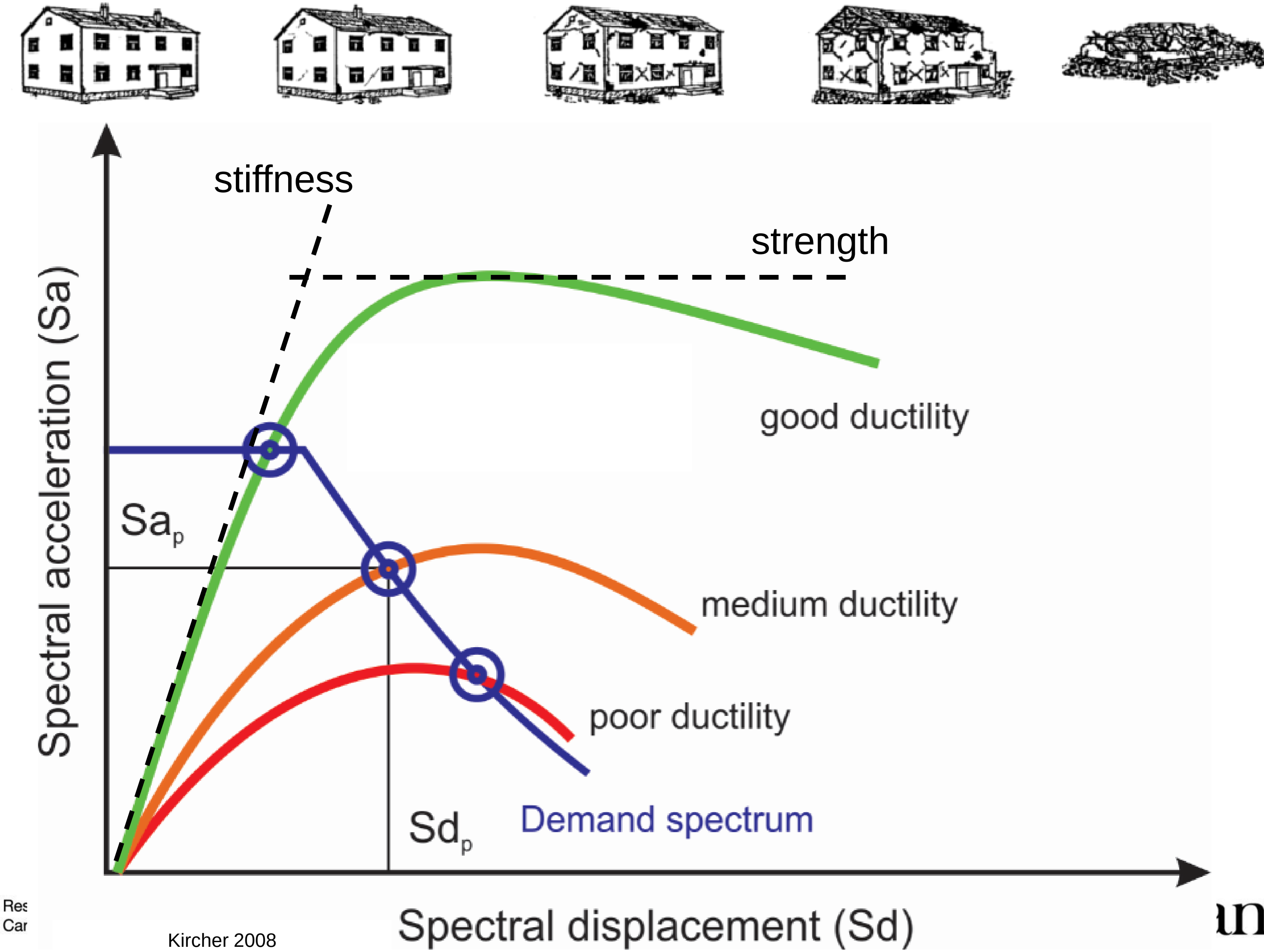
Kircher 2008

Seismic vulnerability: CSM



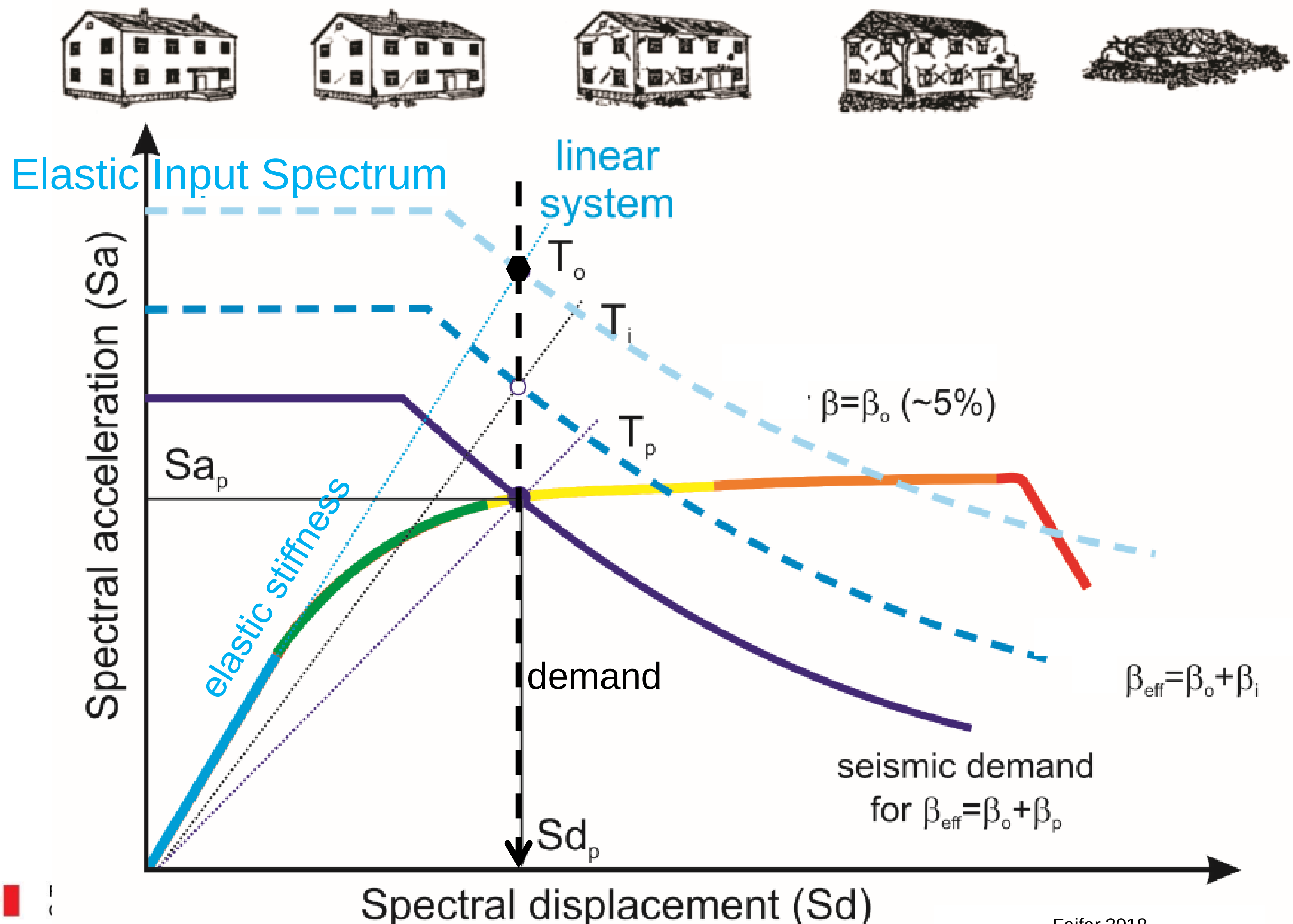
Kircher 2008

Seismic vulnerability: CSM



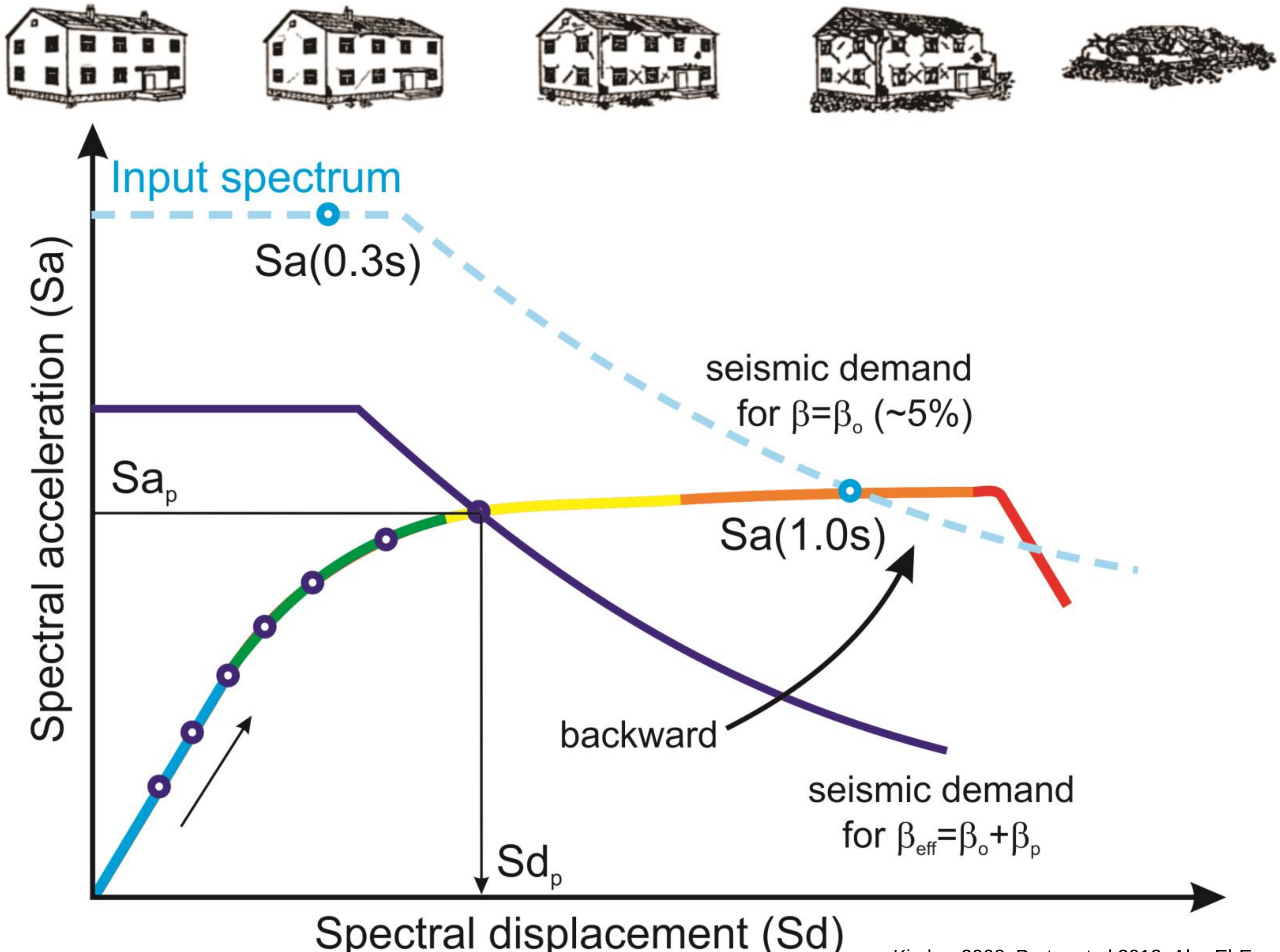
Kircher 2008

Seismic vulnerability: CSM



Fajfar 2018

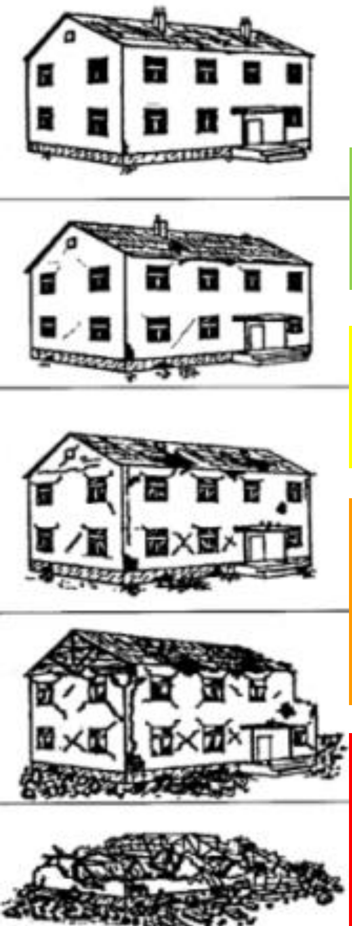
Seismic vulnerability: CSM



Kircher 2008, Porter et al 2012, Abo-El-Ezz et al. 2019

Seismic vulnerability: damage curves

Analytical method



No damage (DS0)

Slight damage (DS1):
First wall Flexural cracking

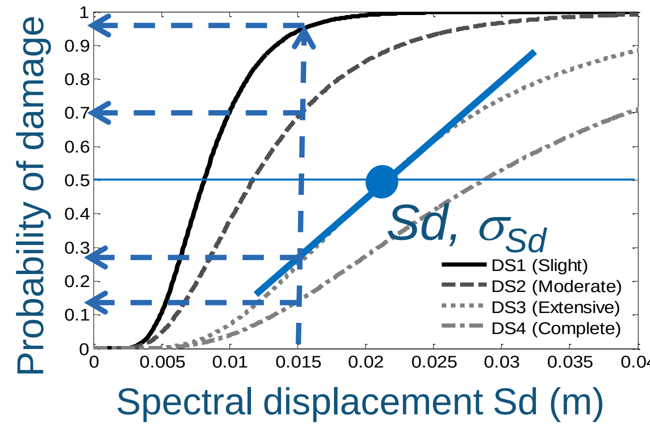
Moderate damage (DS2):
First wall Shear cracking

Extensive damage (DS3):
Maximum base shear capacity of the building

Complete damage (DS4):
20% reduction in base shear capacity

Fragility data:

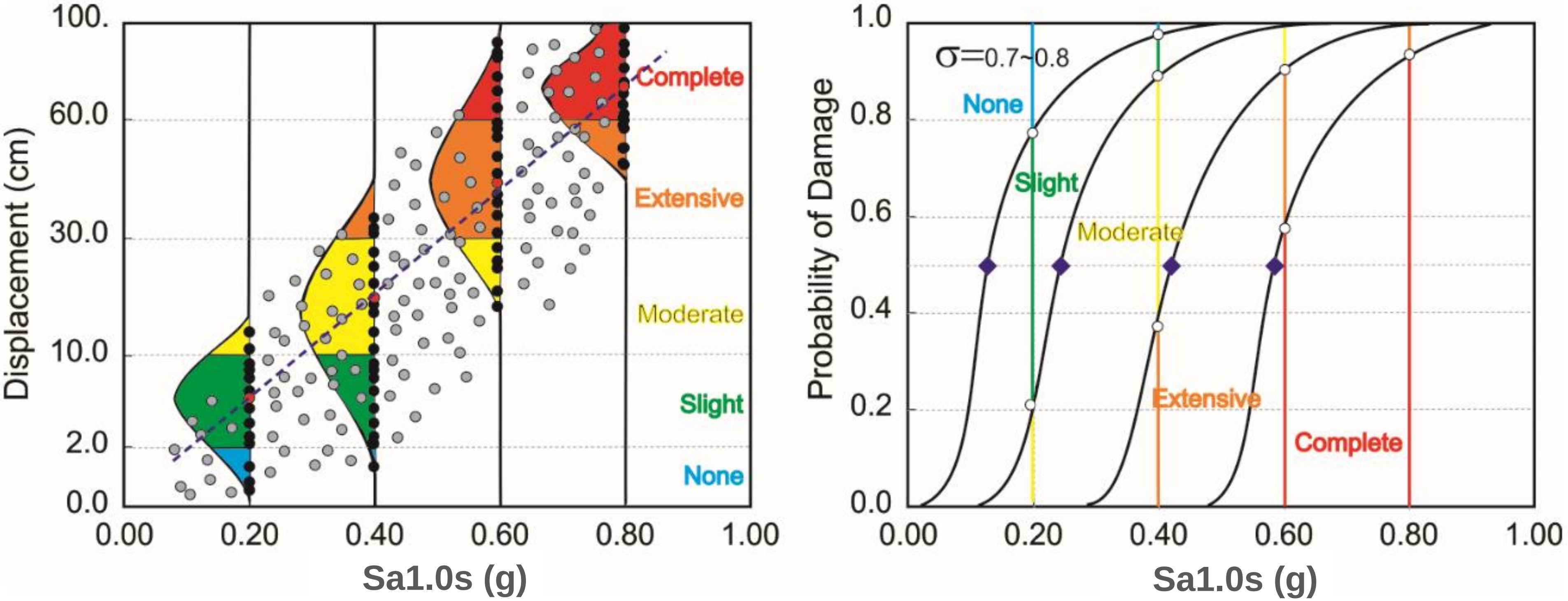
Median values *Sd*
Standard deviations σ_{Sd}



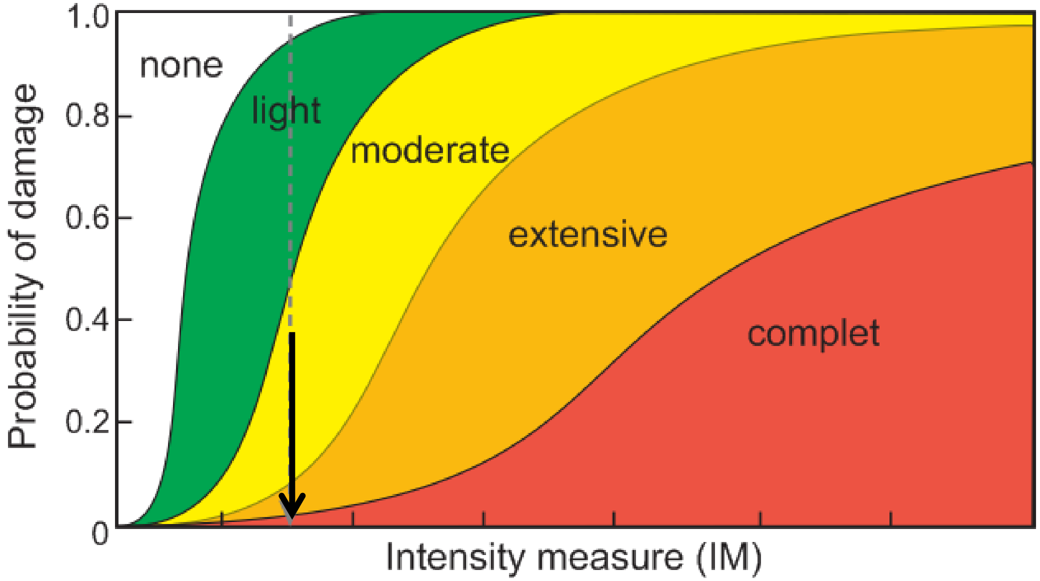
Damage state DS	ISD [%]
Slight	0.05
Moderate	0.8
Extensive	1.15
Complete	2.8

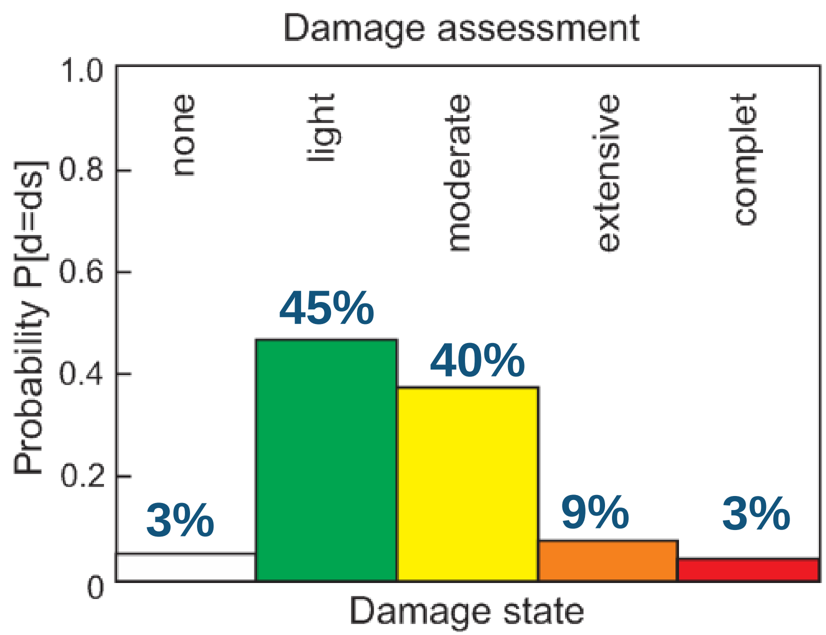
Seismic vulnerability: damage curves

Empirical based on post-earthquake damage observations
Sa(1.0) used as IMs of seismic shaking



Seismic vulnerability: damage curves

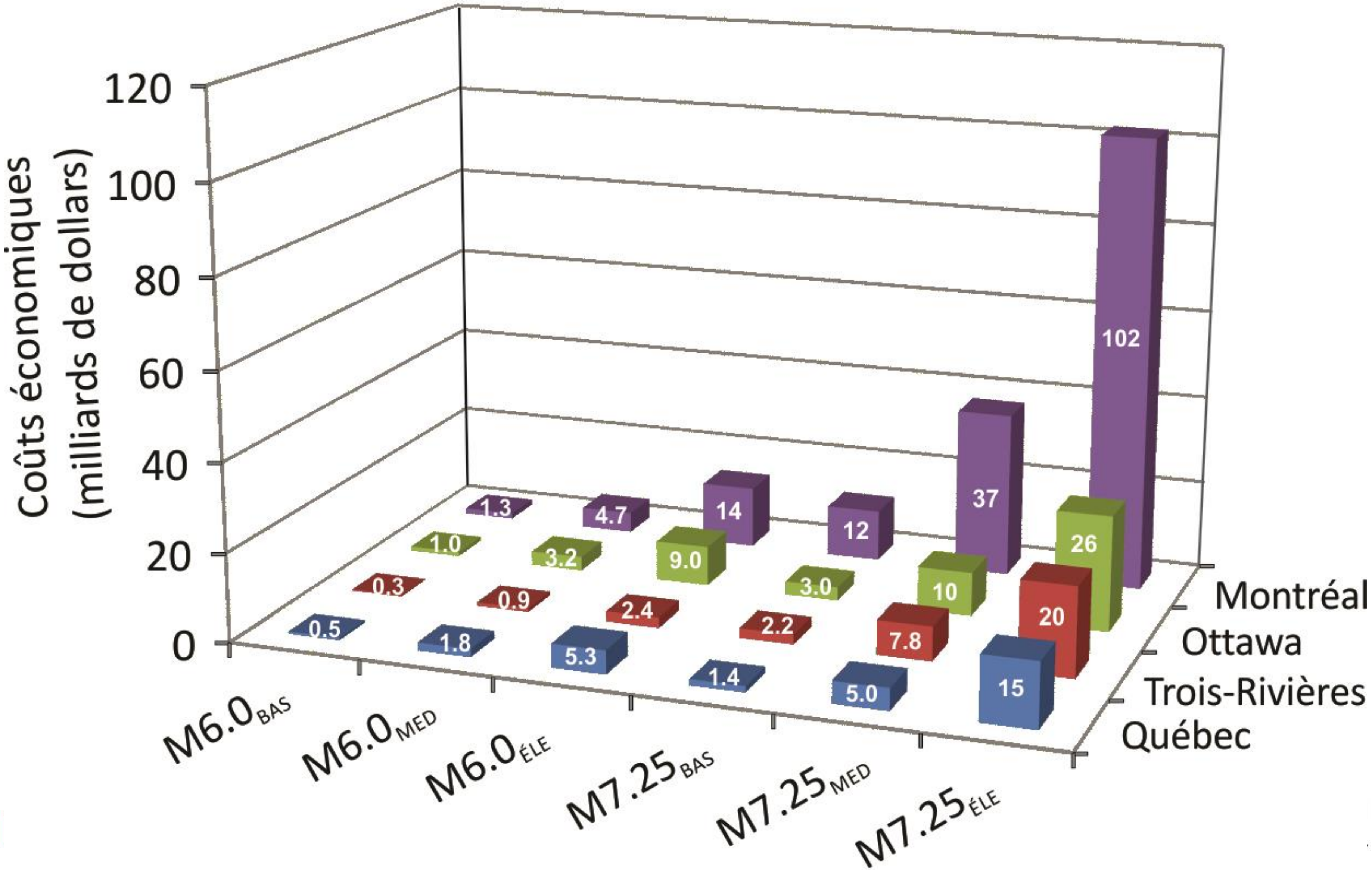




Damage factors: cost of repair - % replacement cost (example 100,000€)

	none	light	mod.	ext.	compl.	23,550€
Turkey :	0%	5%	30%	70%	100%	Σ=0+2,250+12,000+6,300+3,000=
USA :	0%	2%	10%	50%	100%	Σ=0+ 900+ 4,000+4,500+3,000=
						12,400€

Uncertainty analysis



Risk communication - ER2

- Despite numerous research efforts in recent years, seismic risk continues to be difficult to perceive and communicate
  - **Risk assessment**
  - **Risk communication**
  - Risk perception
  - Risk management

- ER2 Rapid Risk Evaluator

  https://er2.geosciences.ca/earthquake

  username: MNastev

  password: NjE8ZePM

  https://www.youtube.com/watch?v=kNZbv0VPsmw&feature=youtu.be&ab_channel=NickGibb

M.Nastev et al 2015; M.Šavor Novak, J.Atalic, M.Uroš et al. 2020