Site classification and definition of seismic actions in the revision of EC8

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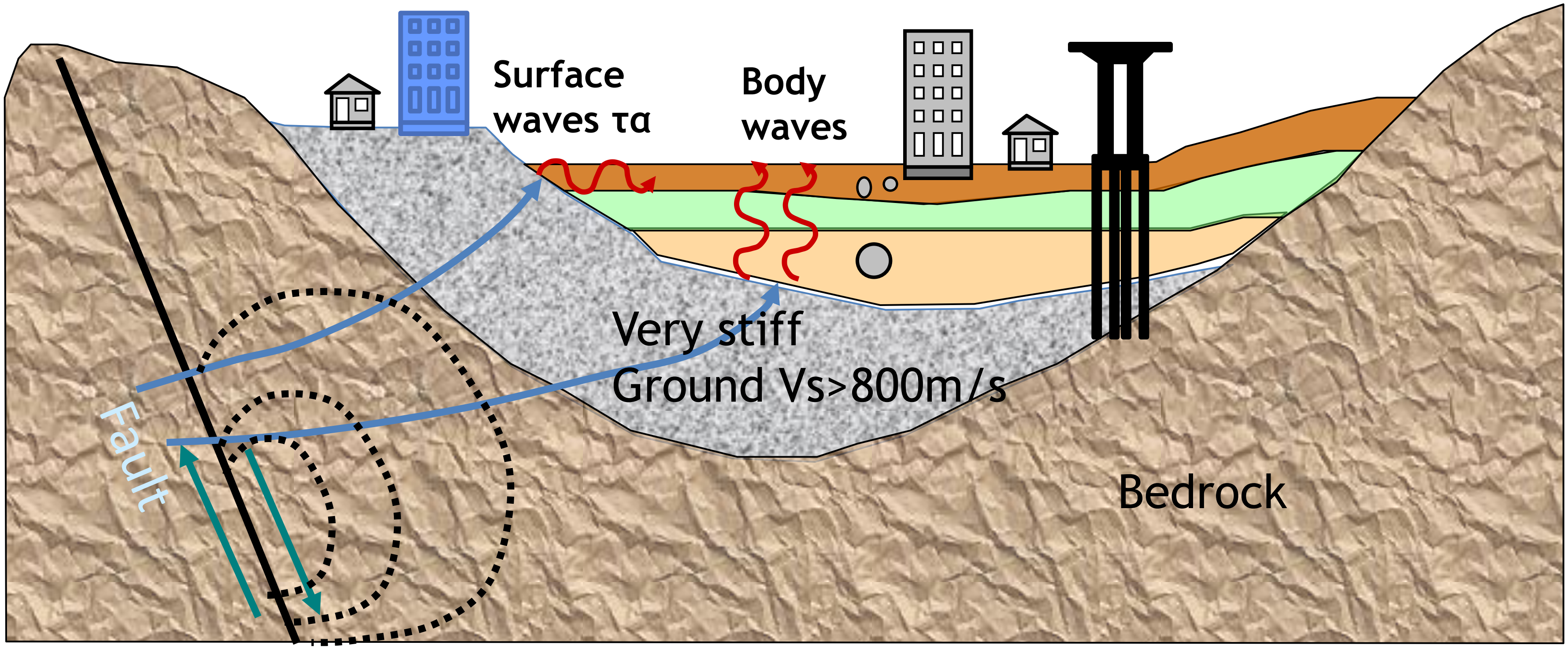
Contents

- Present situation of EC8 Part1
- Improved site classification and design response spectra in the present EC8
- New AUTH proposal for site classification, amplification factors and design response spectra
- Aggravation factors to account for basin and valley effects
- Comments on the application of EC8 Part 1 in Romania

Related publications

- **Riga E., Makra K., Pitilakis K., 2016**, "Aggravation factors for seismic response of sedimentary basins: A code-oriented parametric study", Soil Dynamics and Earthquake Engineering, Special Issue of Invited Papers at the 6th International Conference on Earthquake Geotechnical Engineering (6ICEGE), Christchurch, New Zealand, 2-4 November 2015, vol. 91, pp. 116-132, DOI: 10.1016/j.soildyn.2016.09.048.
- **Pitilakis K., Riga E., Anastasiadis A., 2013**, "New code site classification, amplification factors and normalized response spectra based on a worldwide ground-motion database", Bulletin of Earthquake Engineering, 11, 4, 925-966, DOI: 10.1007/s10518-013-9440-9.
- **Pitilakis K., Riga E., Anastasiadis A., 2012**, "Design spectra and amplification factors for Eurocode 8", Bulletin of Earthquake Engineering, 10, 5, 1377-1400, DOI: 10.1007/s10518-012-9367-6.

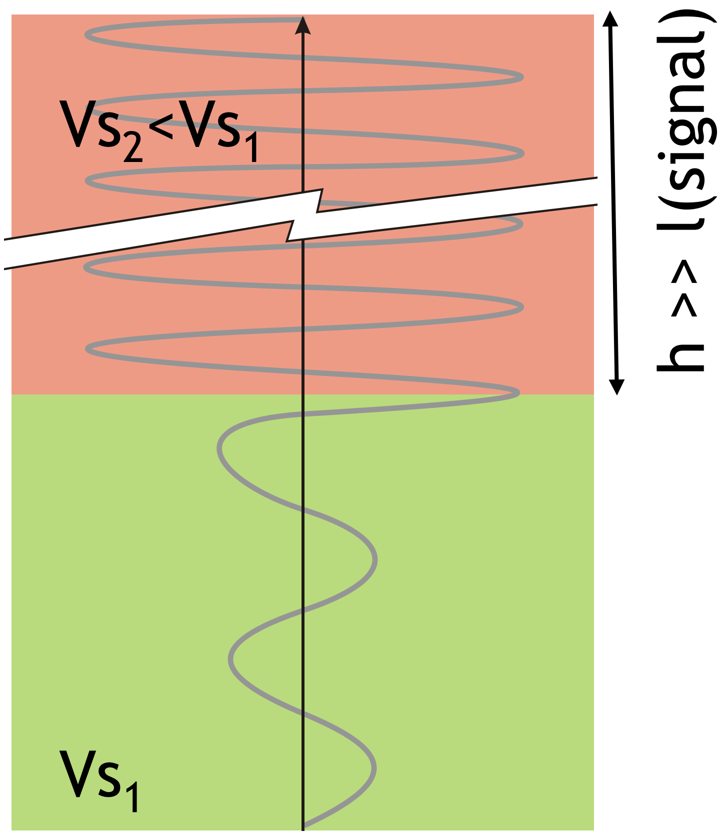
Wave propagation   Seismic actions



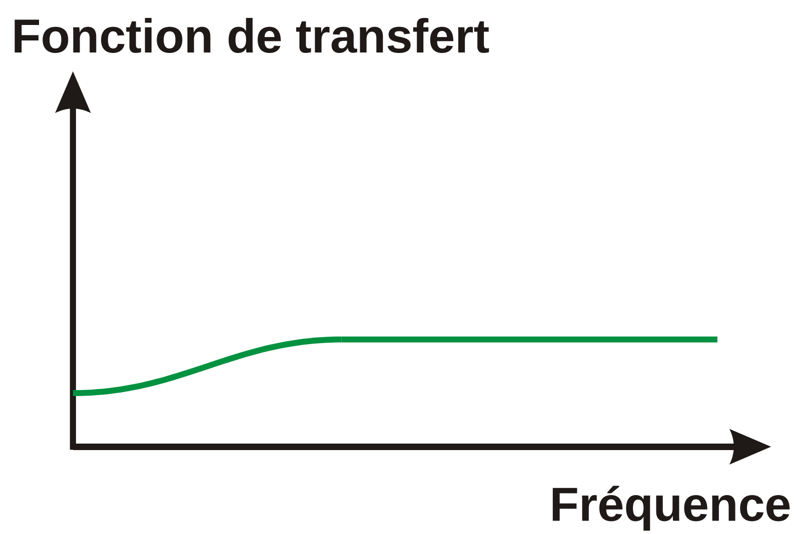
H = Source * Path * Site effects

Site effects 1

Amplification of the amplitude of ground motion due to impedance effects on the surface layer

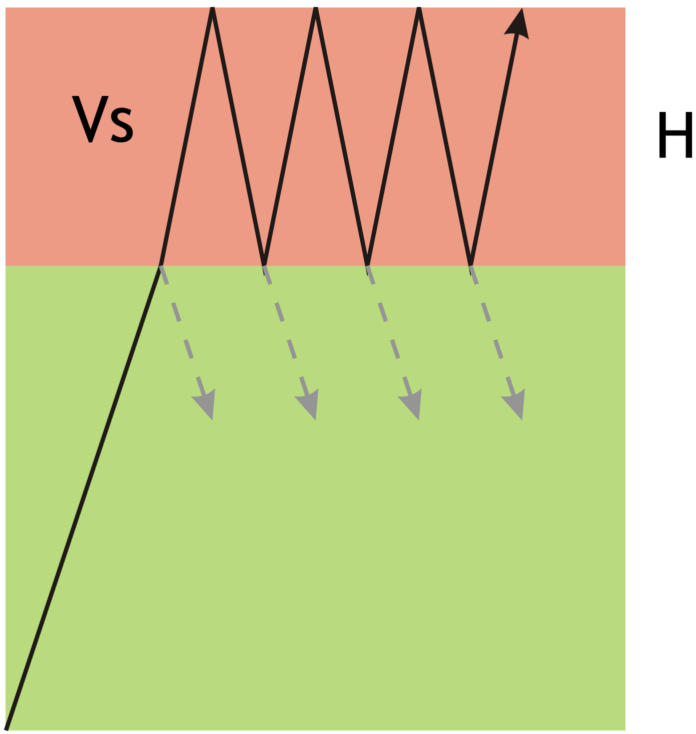


$$\frac{2\rho_1 V_1}{\rho_1 V_1 + \rho_2 V_2}$$

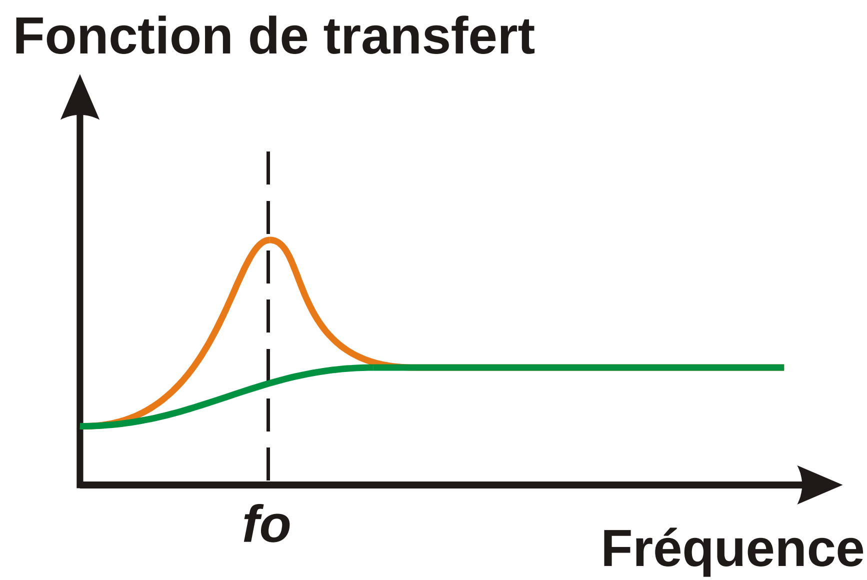


Site effects 2

Multiple reflections and refractions of seismic waves at the shallow soil strata of lower velocity: Amplification of the amplitude at the fundamental mode of soil profile

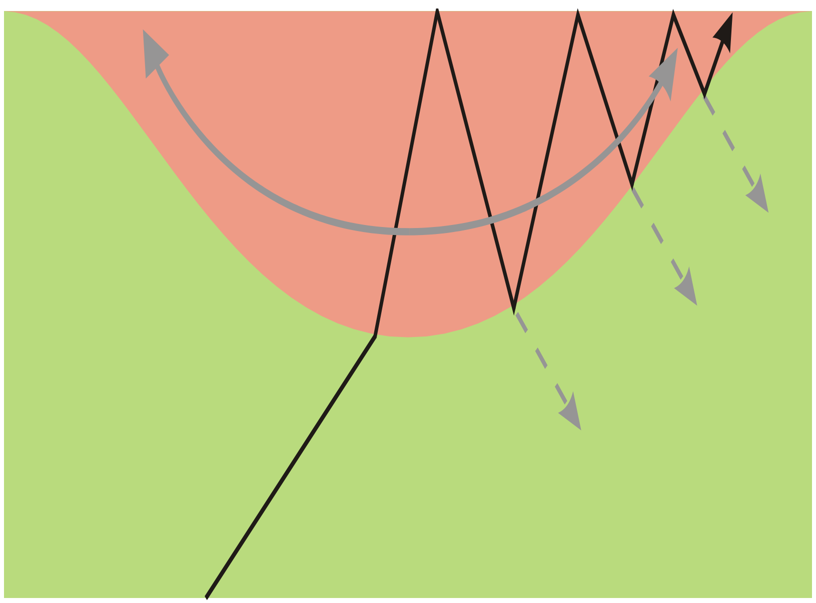


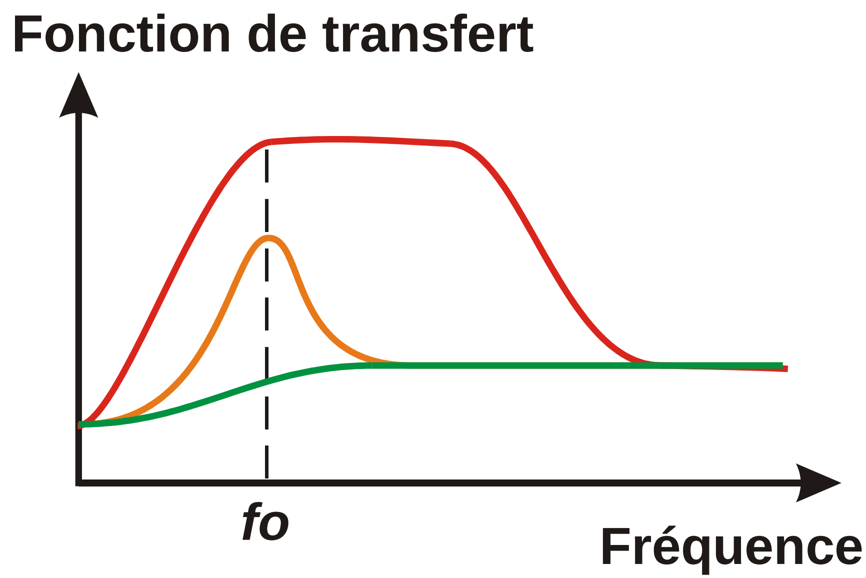
$$fo = Vs/4H$$



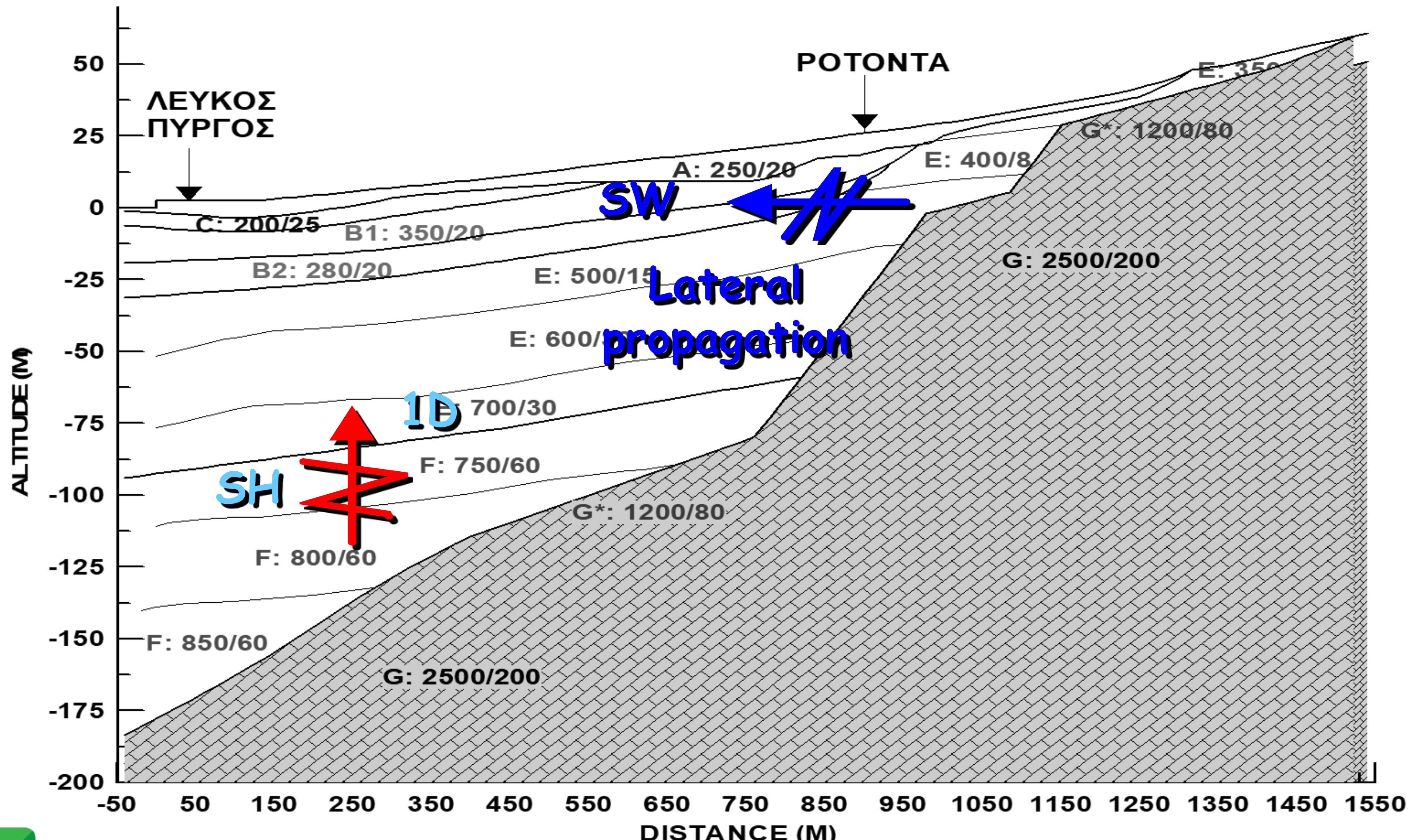
Site effects 3

Creations of multiple refracted and reflected waves propagating with different frequencies: Further amplification in a large spectrum of frequencies





Thessaloniki
1D propagation of SH waves and lateral propagation of diffracted surface waves SW



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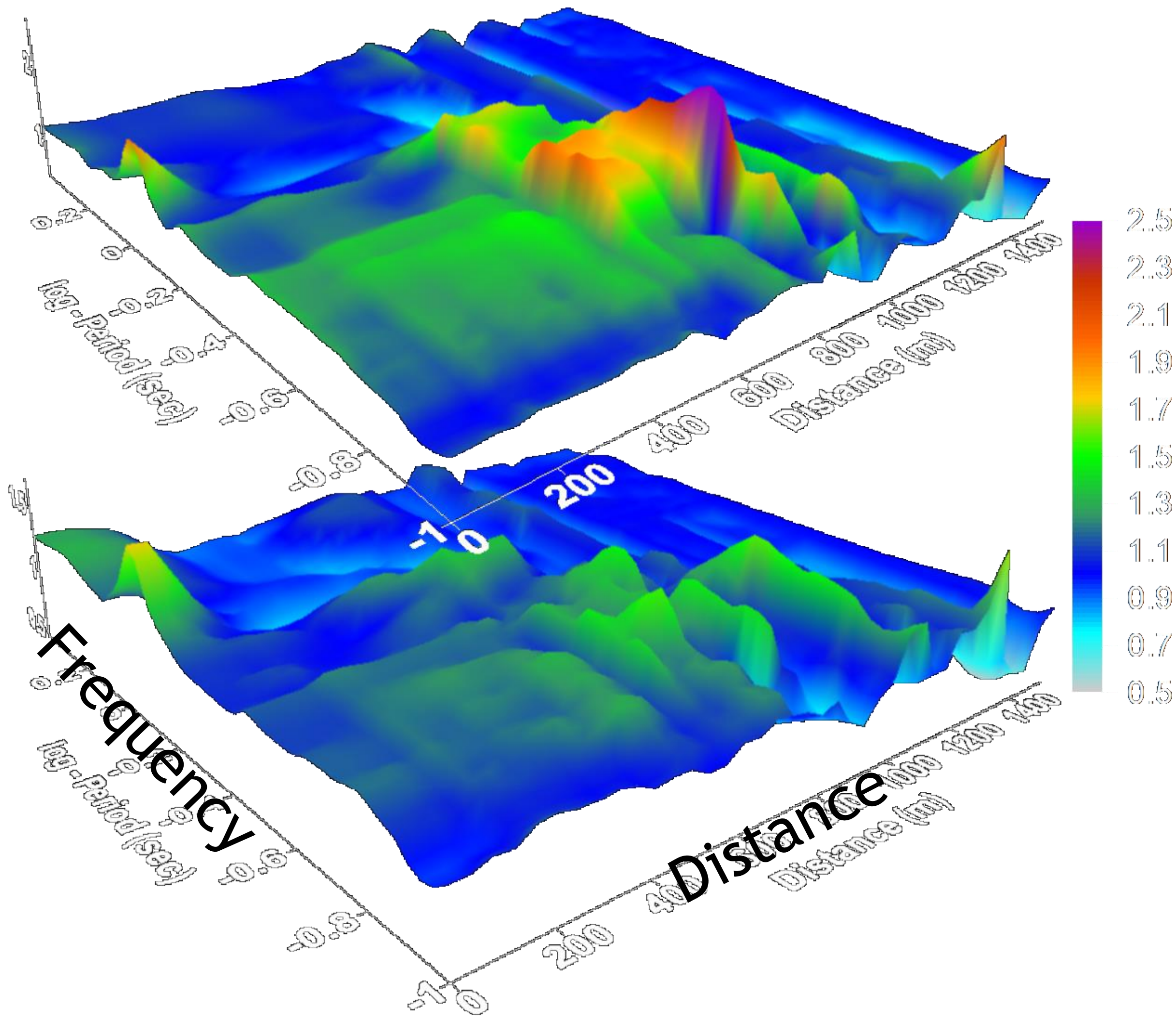
Site amplification

PGA$_{input}$=0.3g

PGA$_{input}$=0.10g



SHARE

- Harmonization of methodologies used for seismic hazard assessment in Europe

- **Probabilistic seismic hazard assessment (PSHA)** for rock-site conditions, for different return periods (72 – 5000 years) and for a grid of 10km size (120,000 points) covering the whole Europe.

- Intensity measures: PGA, spectral acceleration Sa (0.1-10sec)

- Uncertainties are accounted for through a “logic tree” approach.

- The ultimate goal is to contribute to an update of the current EC8.

Project information: www.share-eu.org
Data access: www.efehr.org

SHARE Partners

- 18 universities and research centers from 12 European countries

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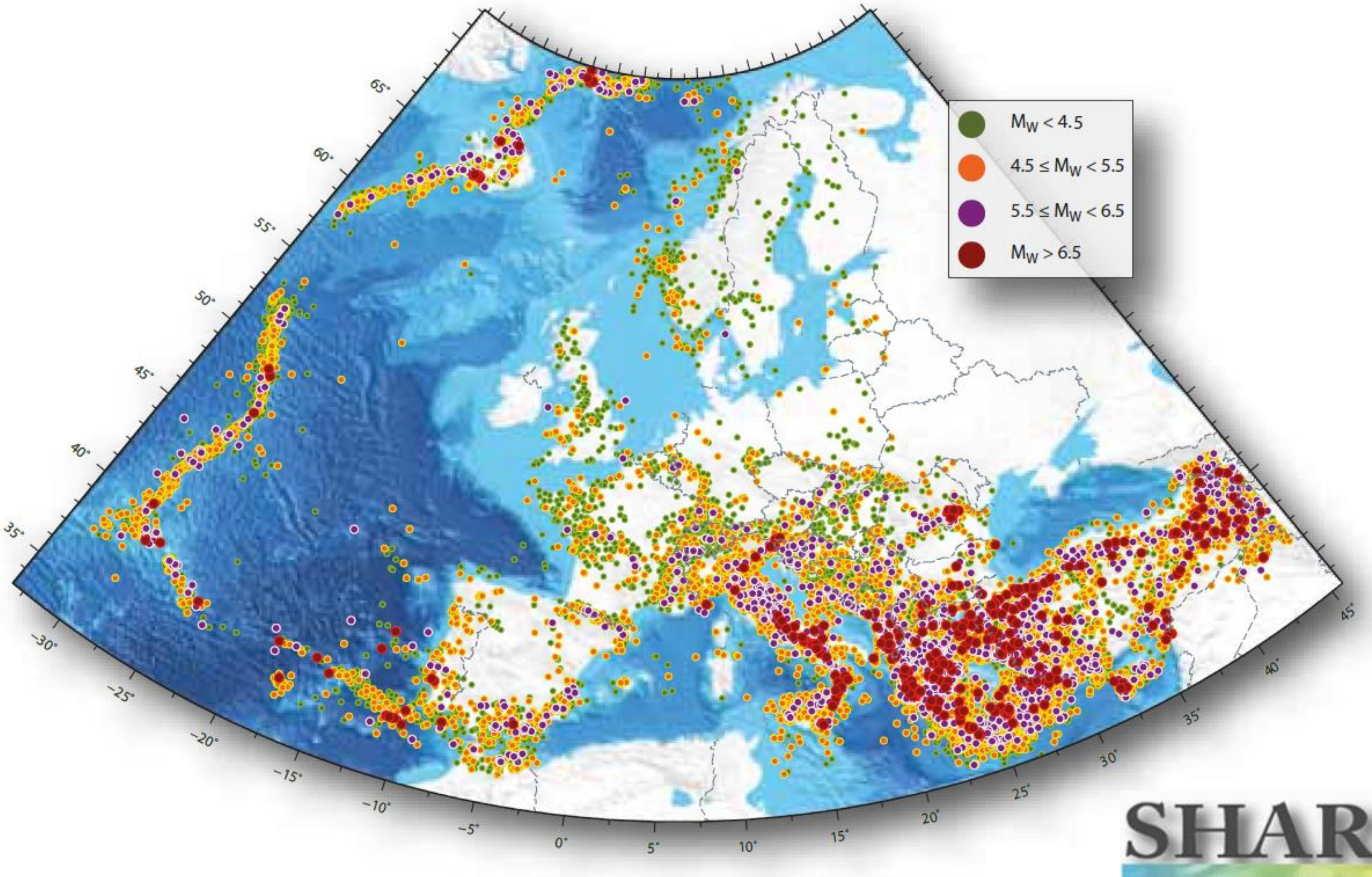
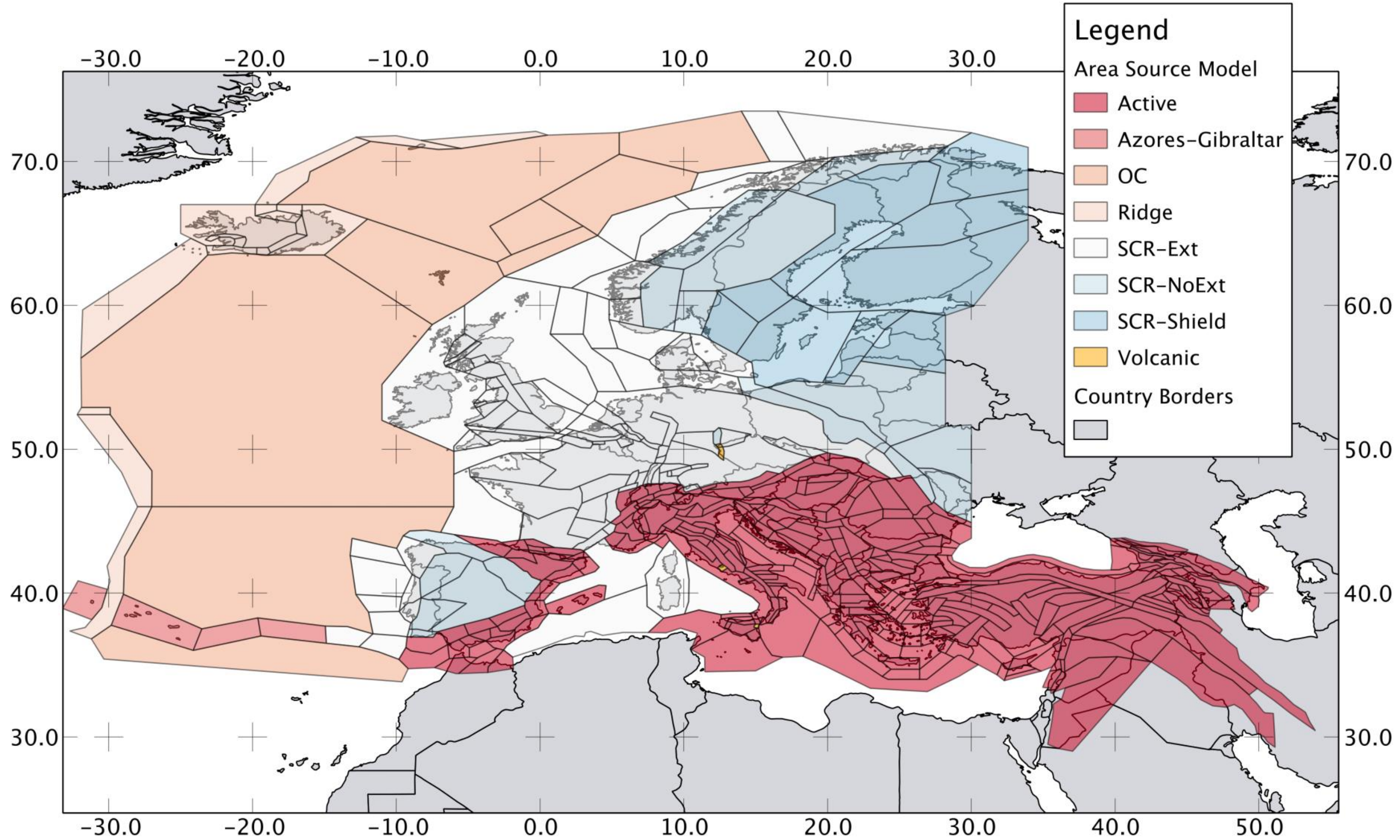
Seismicity in Europe



SHARE

Earthquakes in Europe compiled for the SHARE European Earthquake Catalog (SHEEC) covering the period 1000 - 2007 with moment magnitudes Mw≥3.5

Seismic zones in Europe



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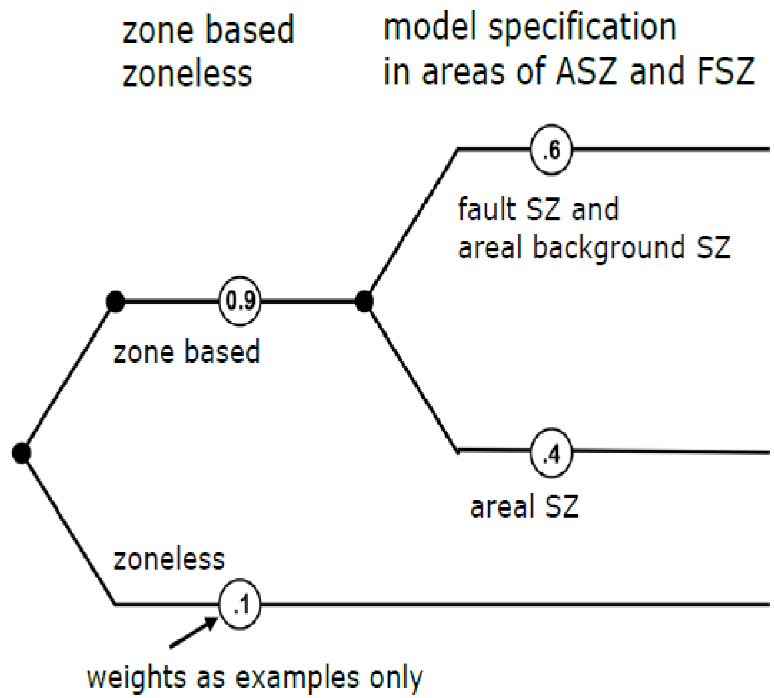
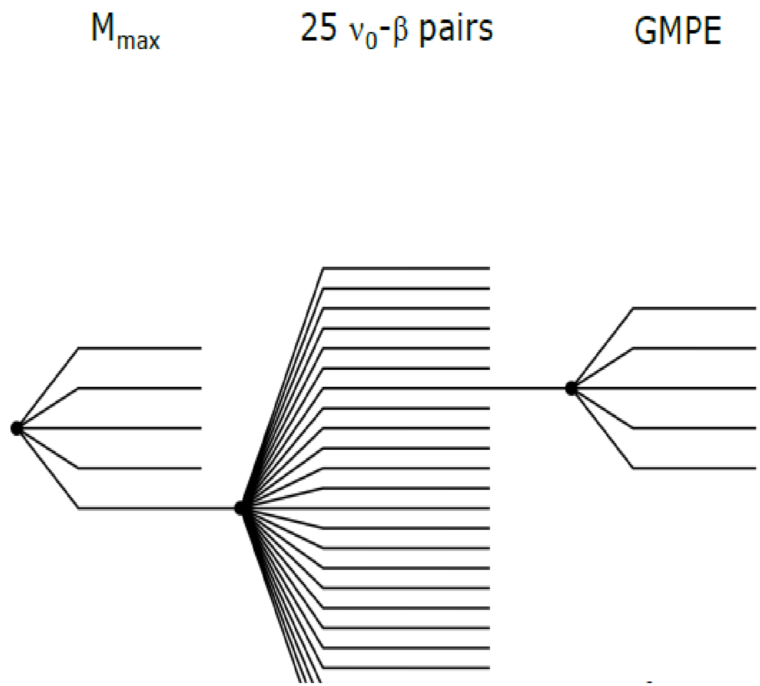
Uncertainties - Logic tree

Types of seismic sources



Logic tree structure for each seismic source zone



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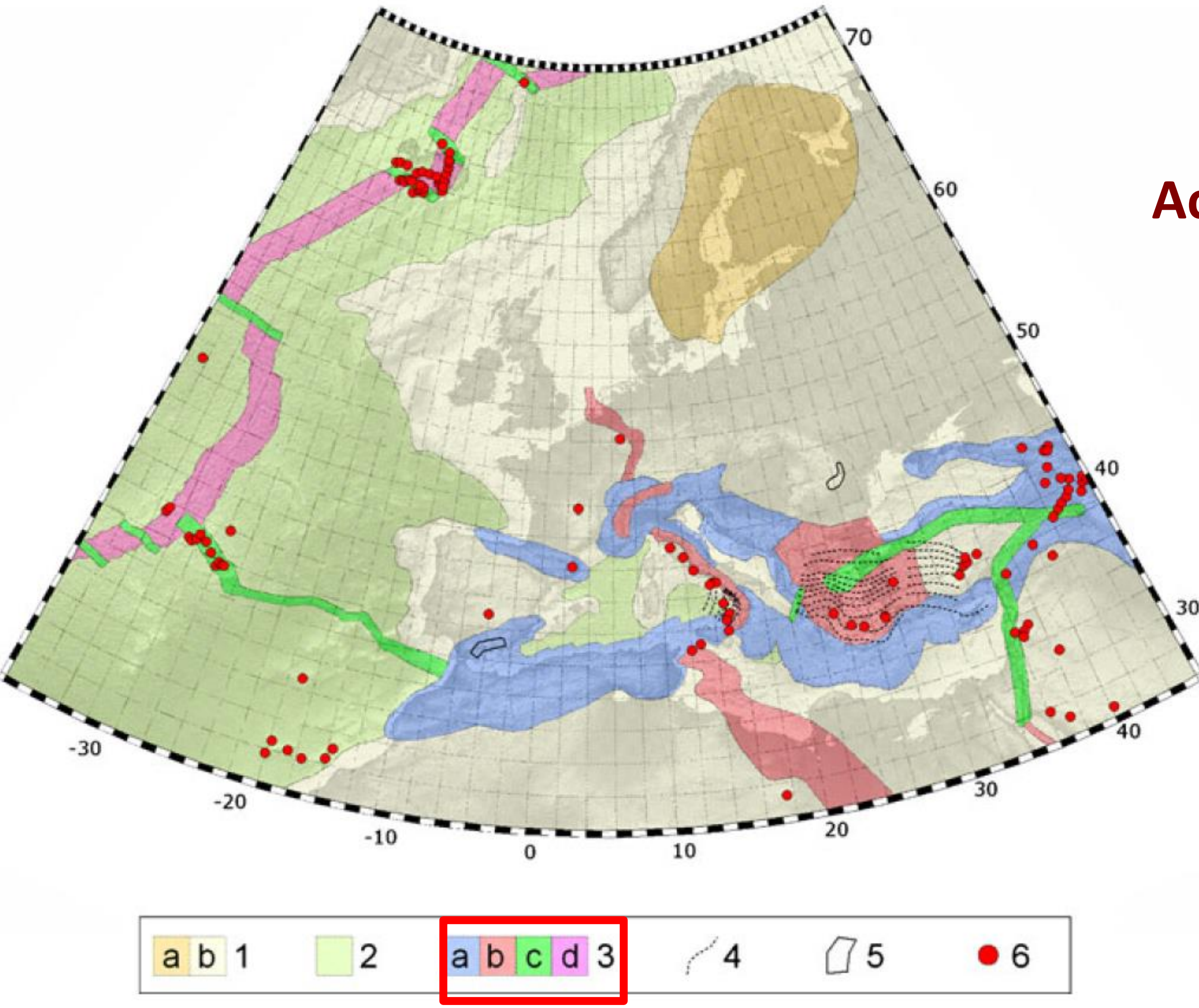
Ground Motion Prediction Equations



Active Shallow Crustal Regions

GMPE	Weight
Akkar & Bommer (2010)	0.35
Cauzzi & Faccioli (2008)	0.35
Zhao et al. (2006)	0.10
Chiou & Youngs (2008)	0.20

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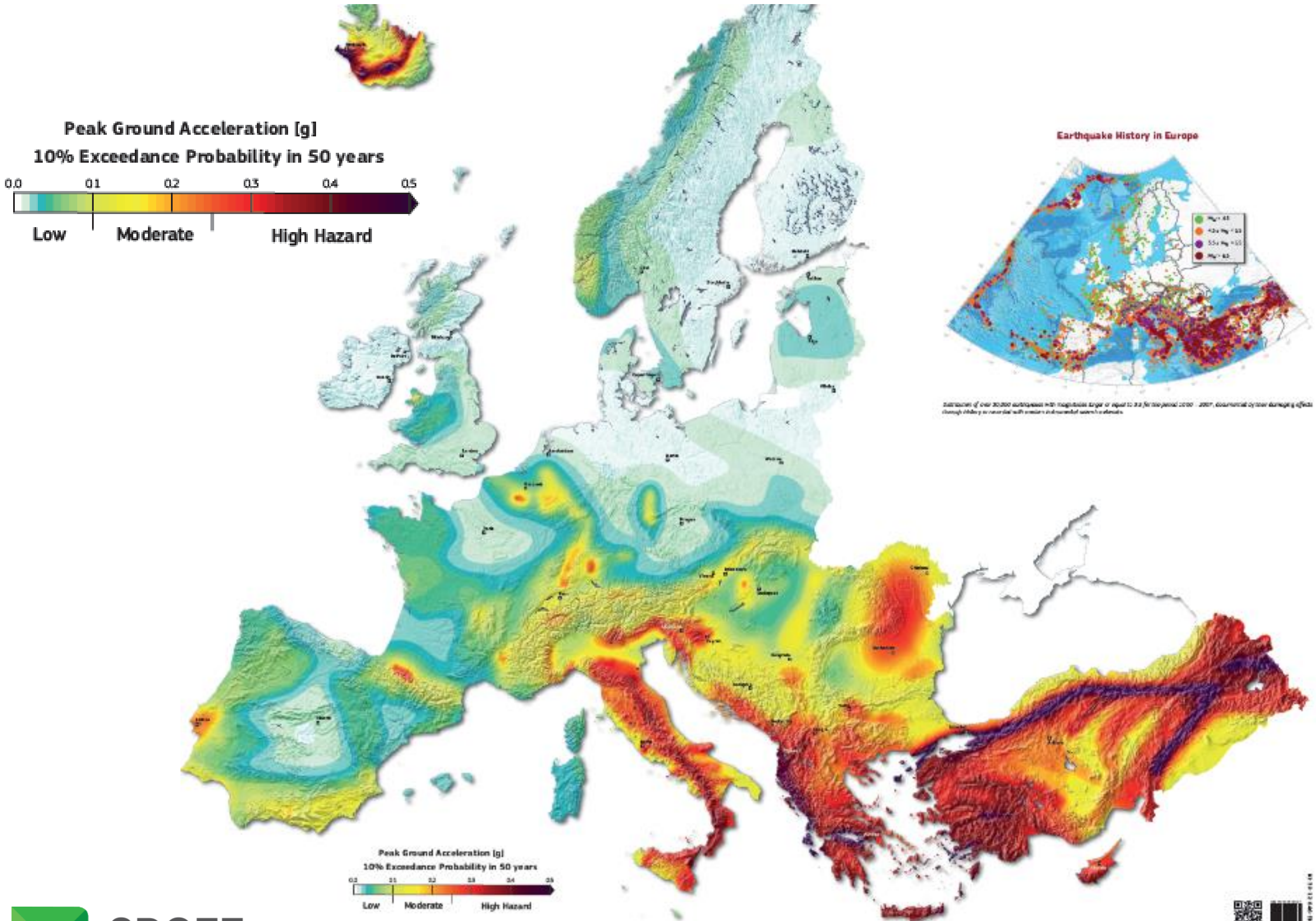
New Seismic Hazard Map (PGA) : Bedrock Vs>800m/s

Return Period = 475 years



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www.share-eu.org

http://www.efehr.org

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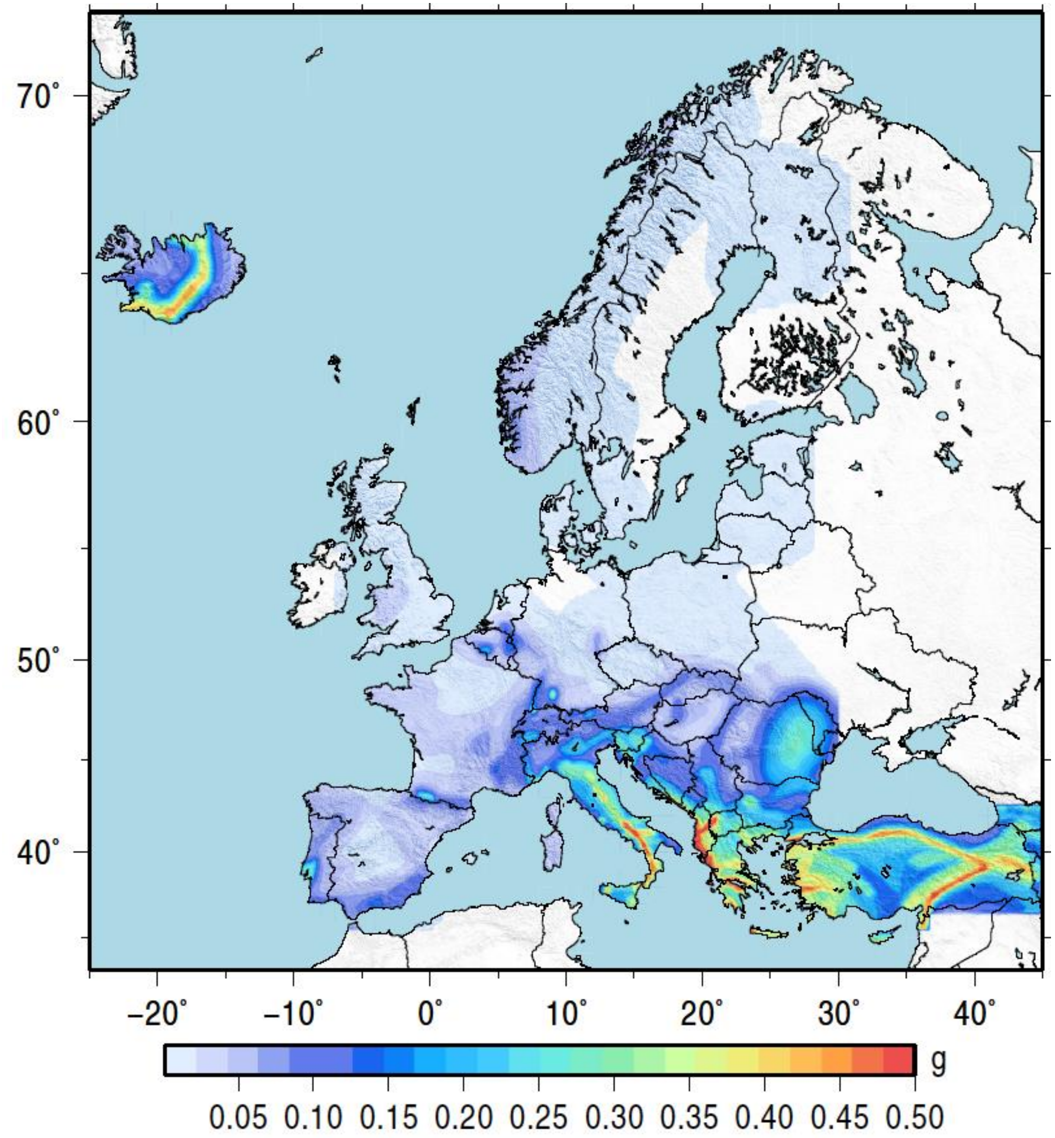
Area Source Branch

Return Period = 475 years

Period = **PGA**



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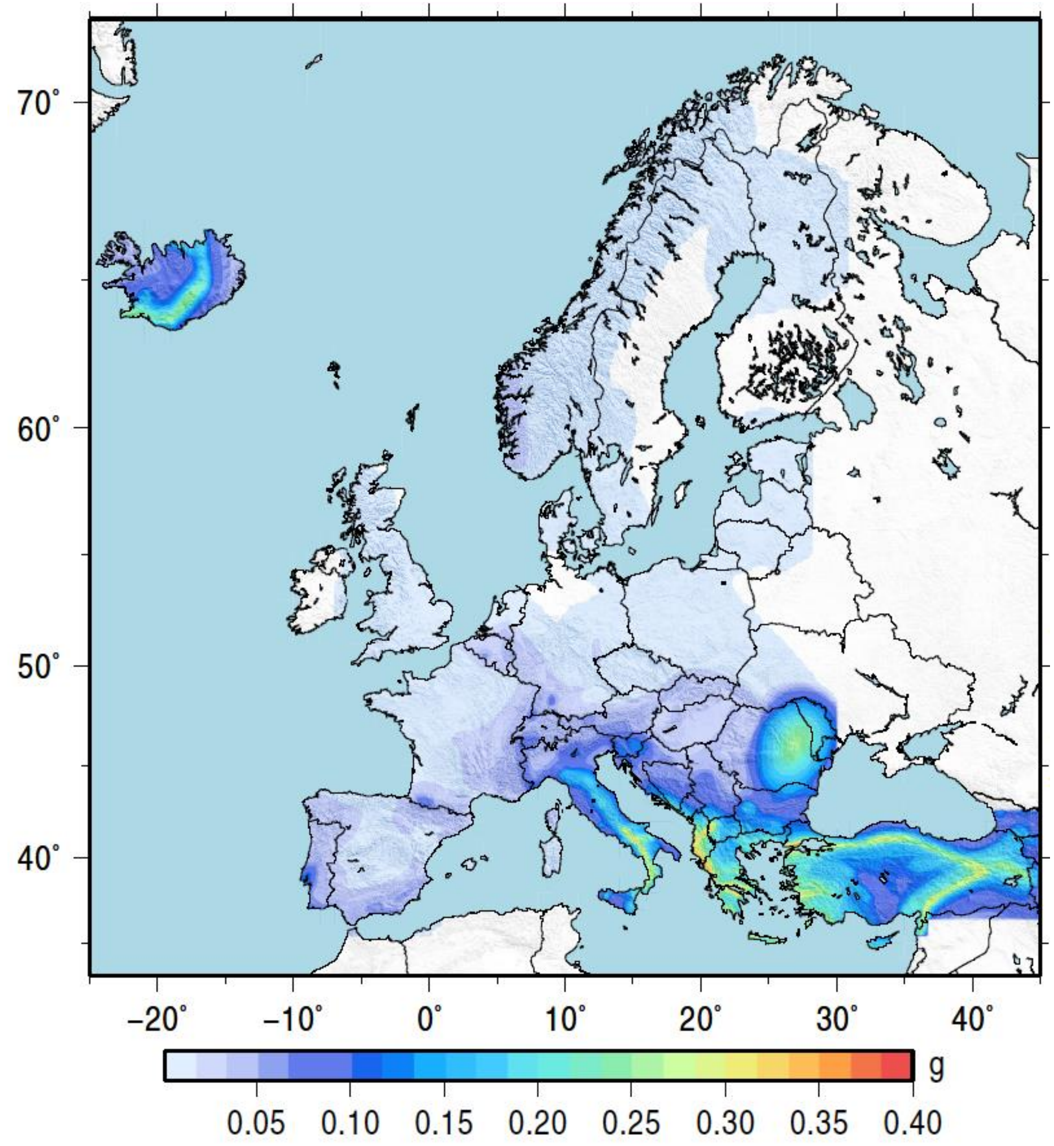
Area Source Branch

Return Period = 475 years

Period = **Sa (1.0)**



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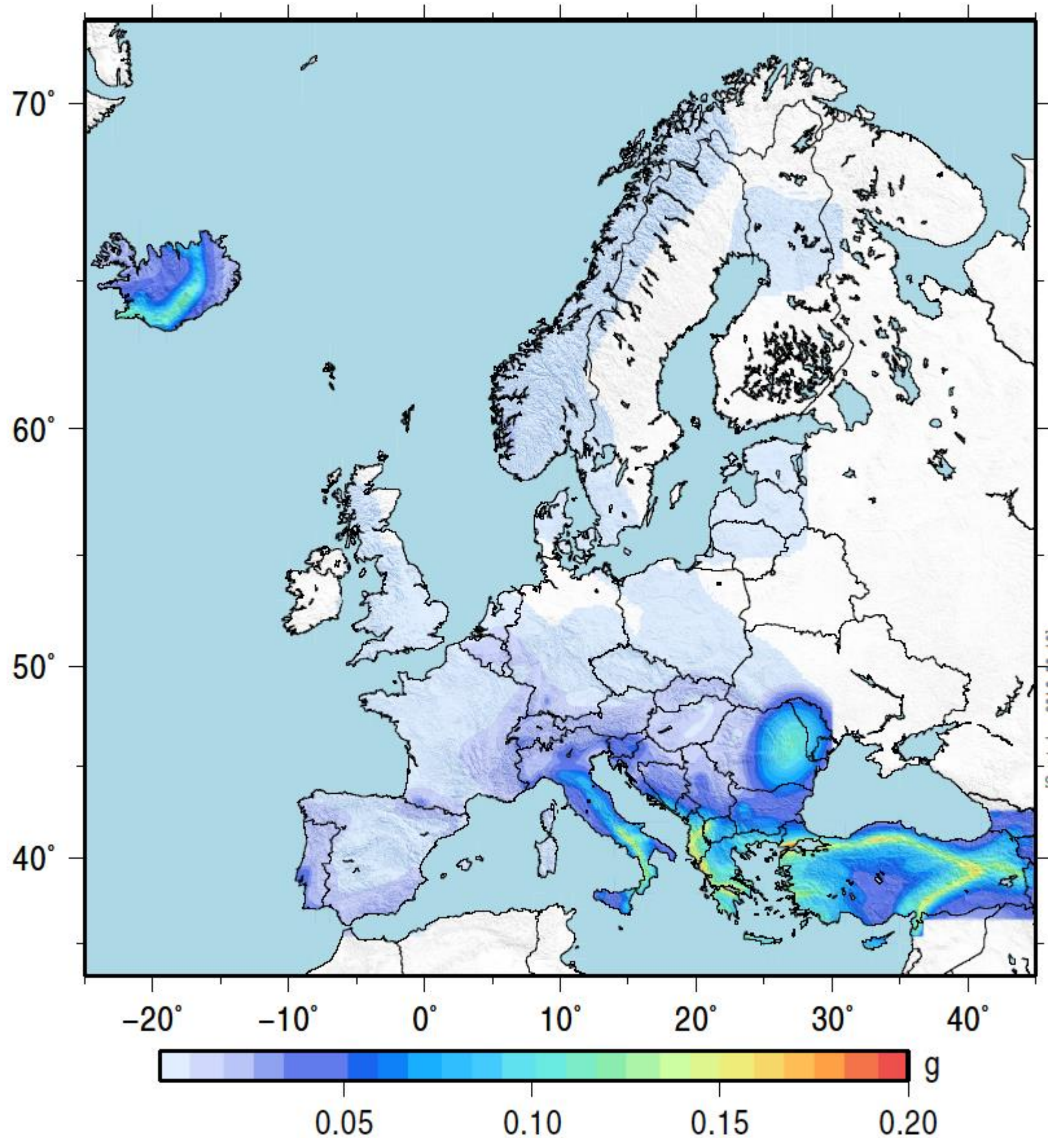

Area Source Branch

Return Period = 475 years

Period = **Sa (2.0)**

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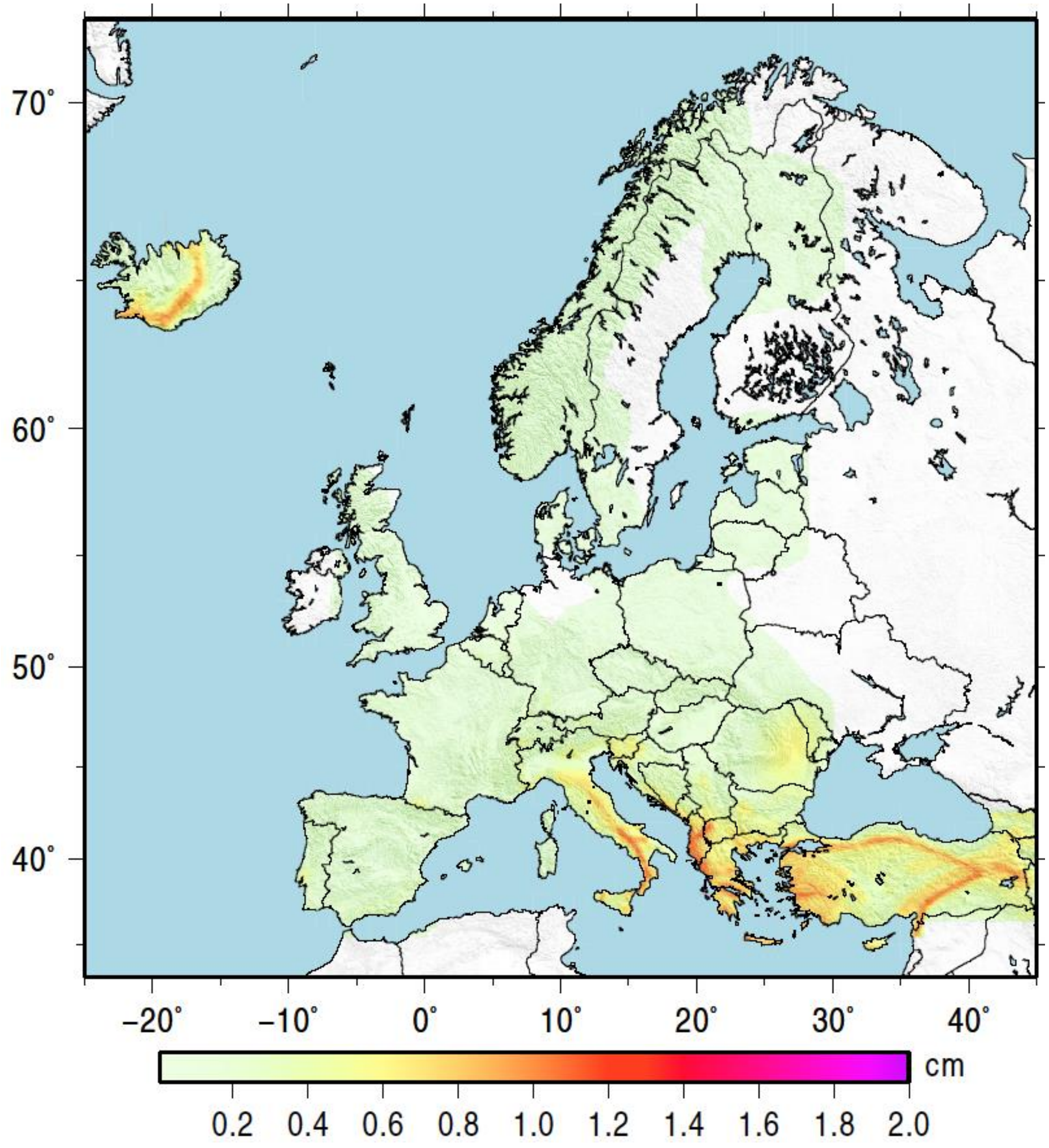
Area Source Branch

Return Period = 475 years

Period = **Sd (0.2)**



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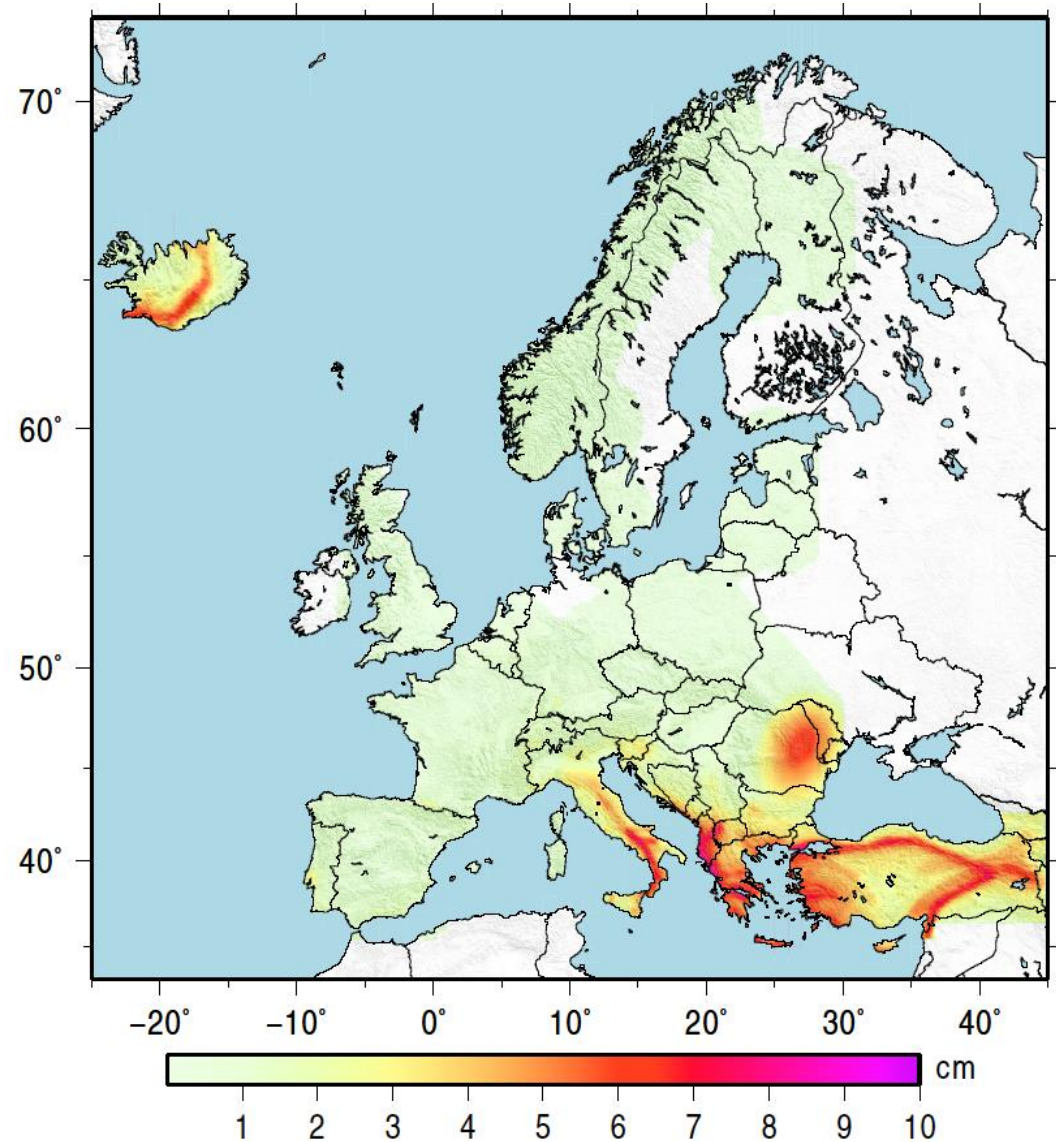

Area Source Branch

Return Period = 475 years

Period = **Sd (1.0)**

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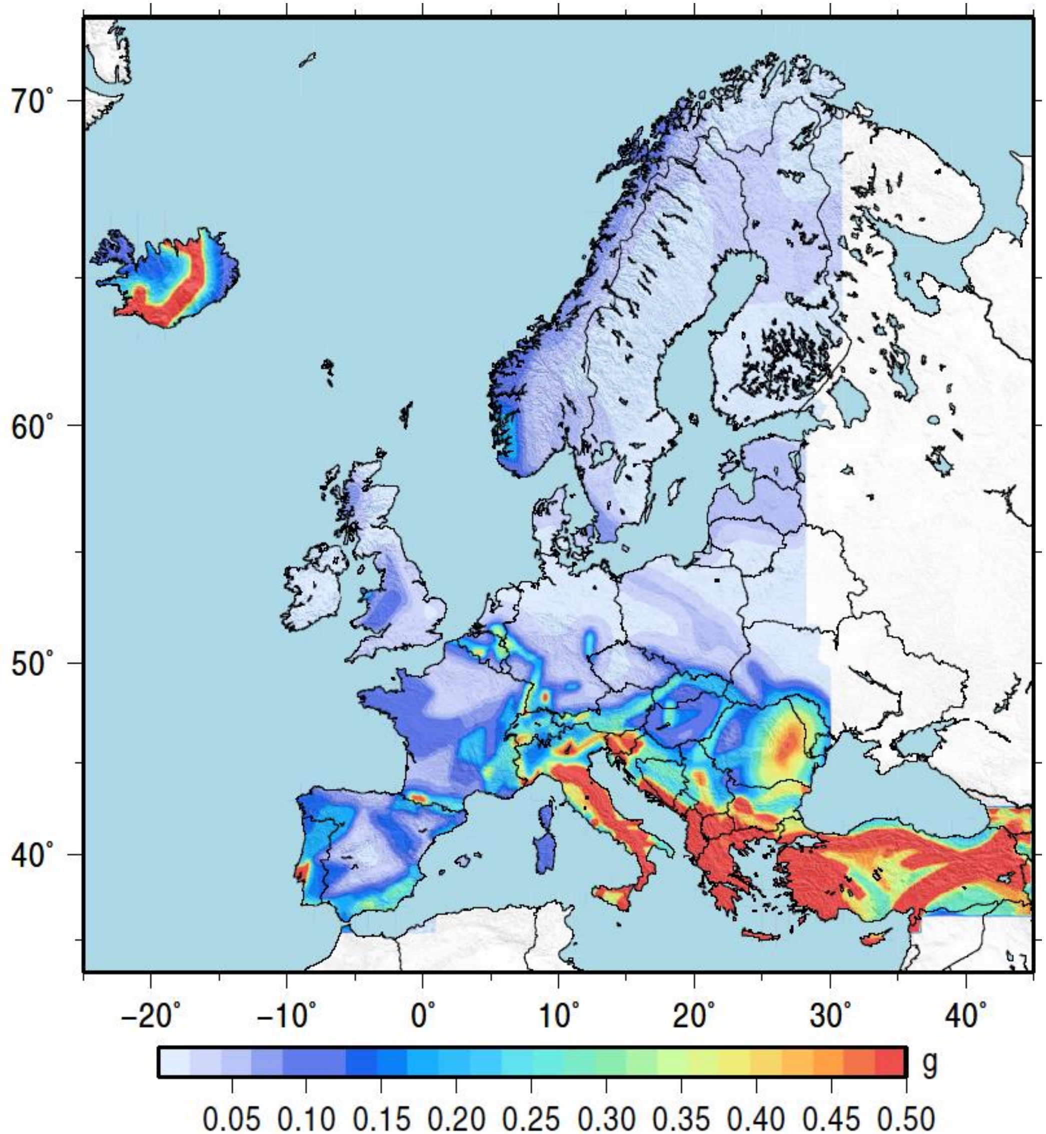
SHARE

Area Source Branch

Return Period = 2475 years

Period = **PGA**



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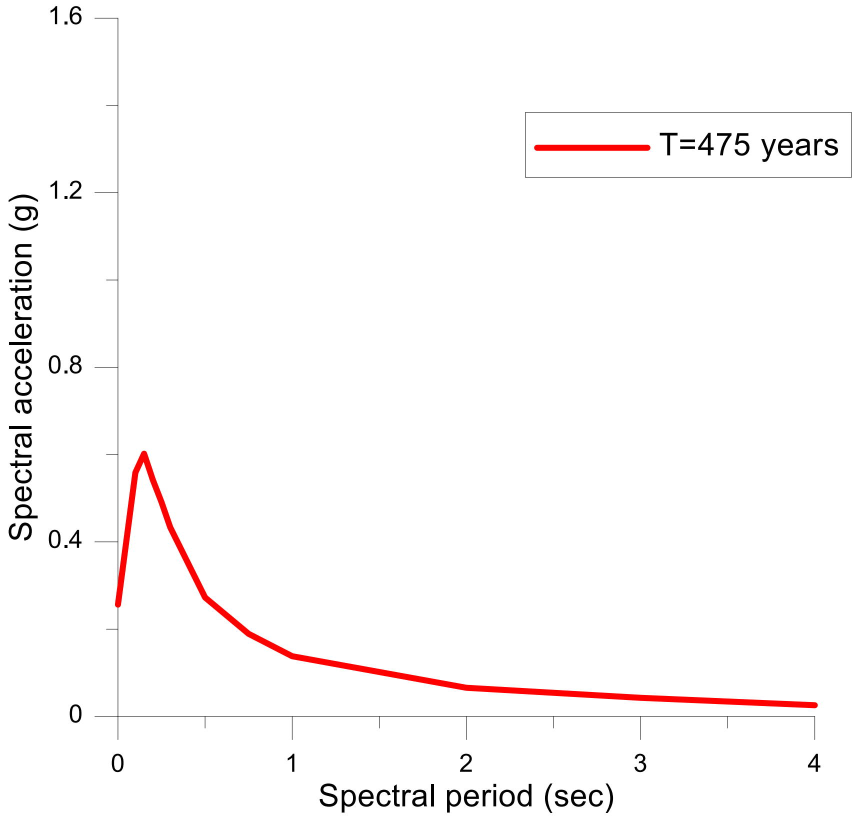
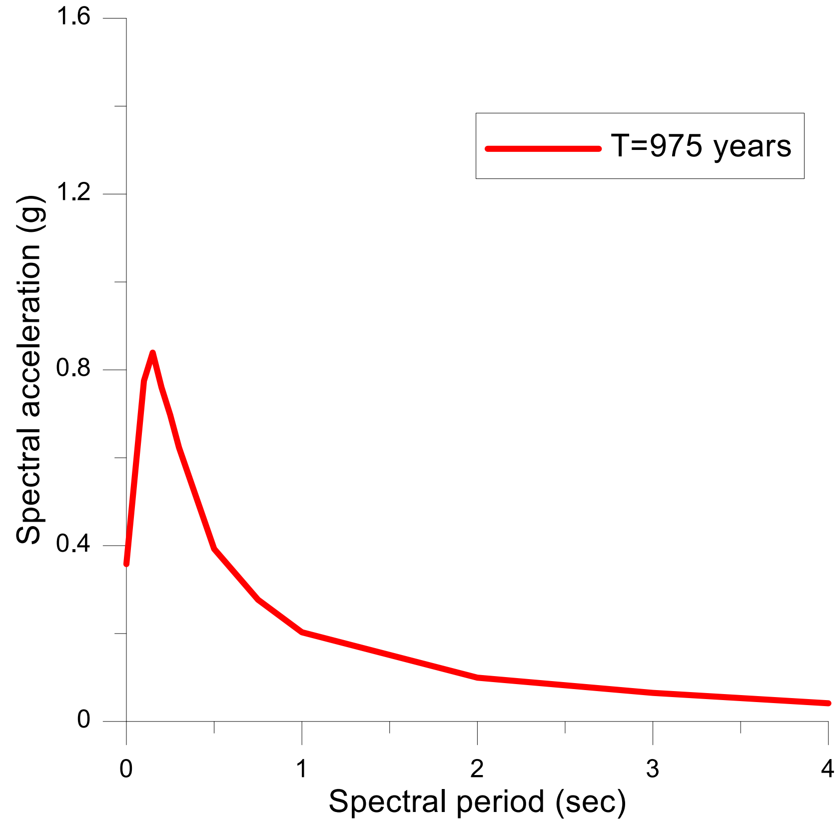
Uniform Hazard Spectra for Thessaloniki, Greece

Bedrock Vs>800m/s





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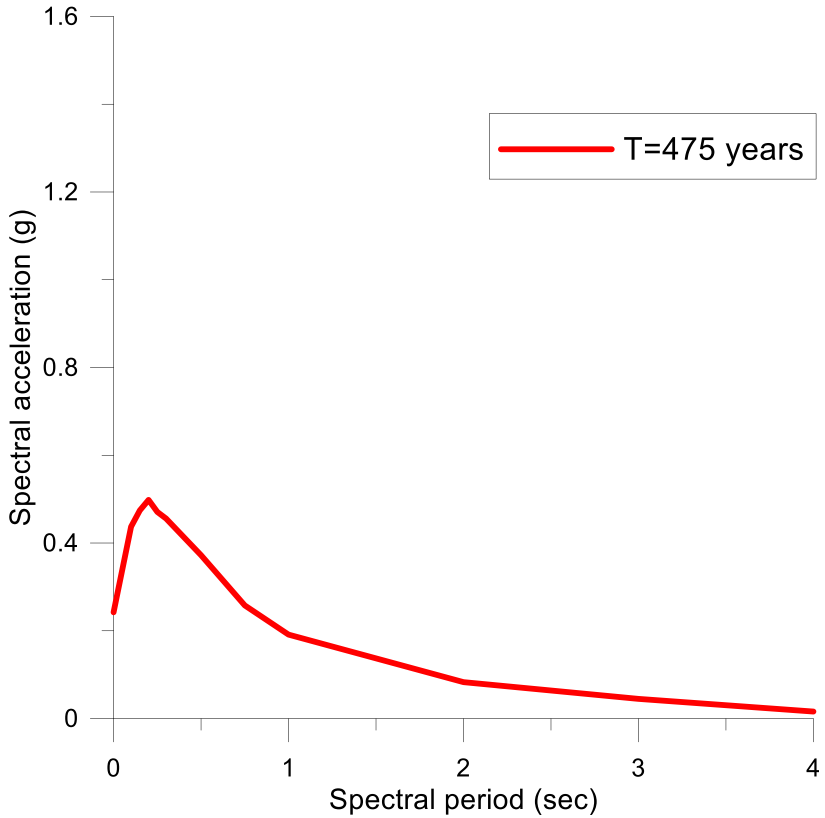
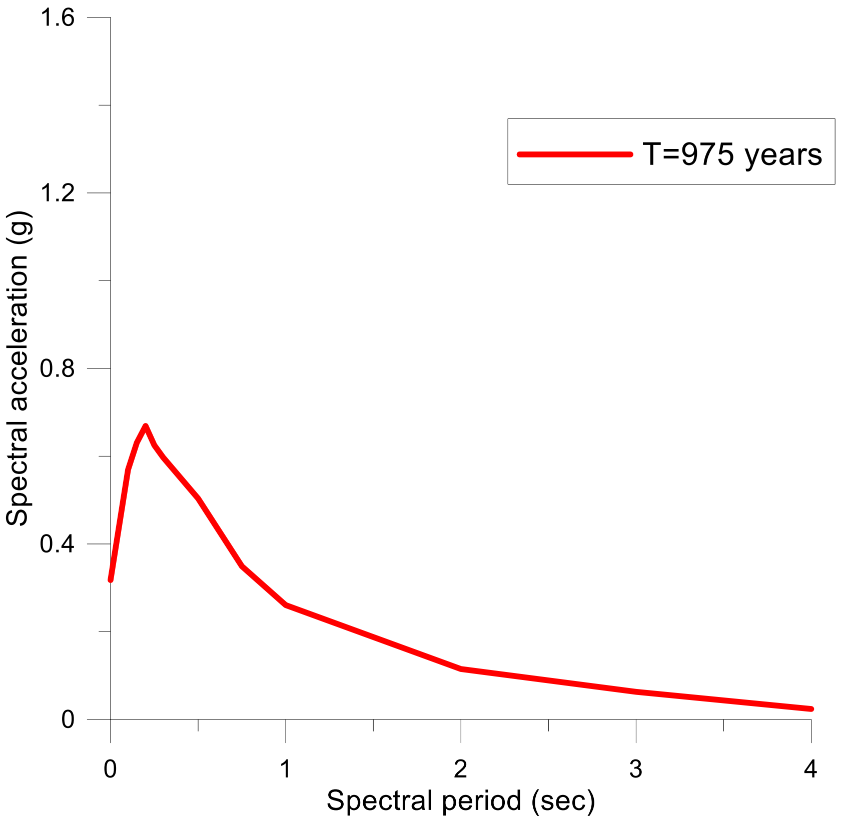
Uniform Hazard Spectra for Bucharest

Bedrock Vs>800m/s





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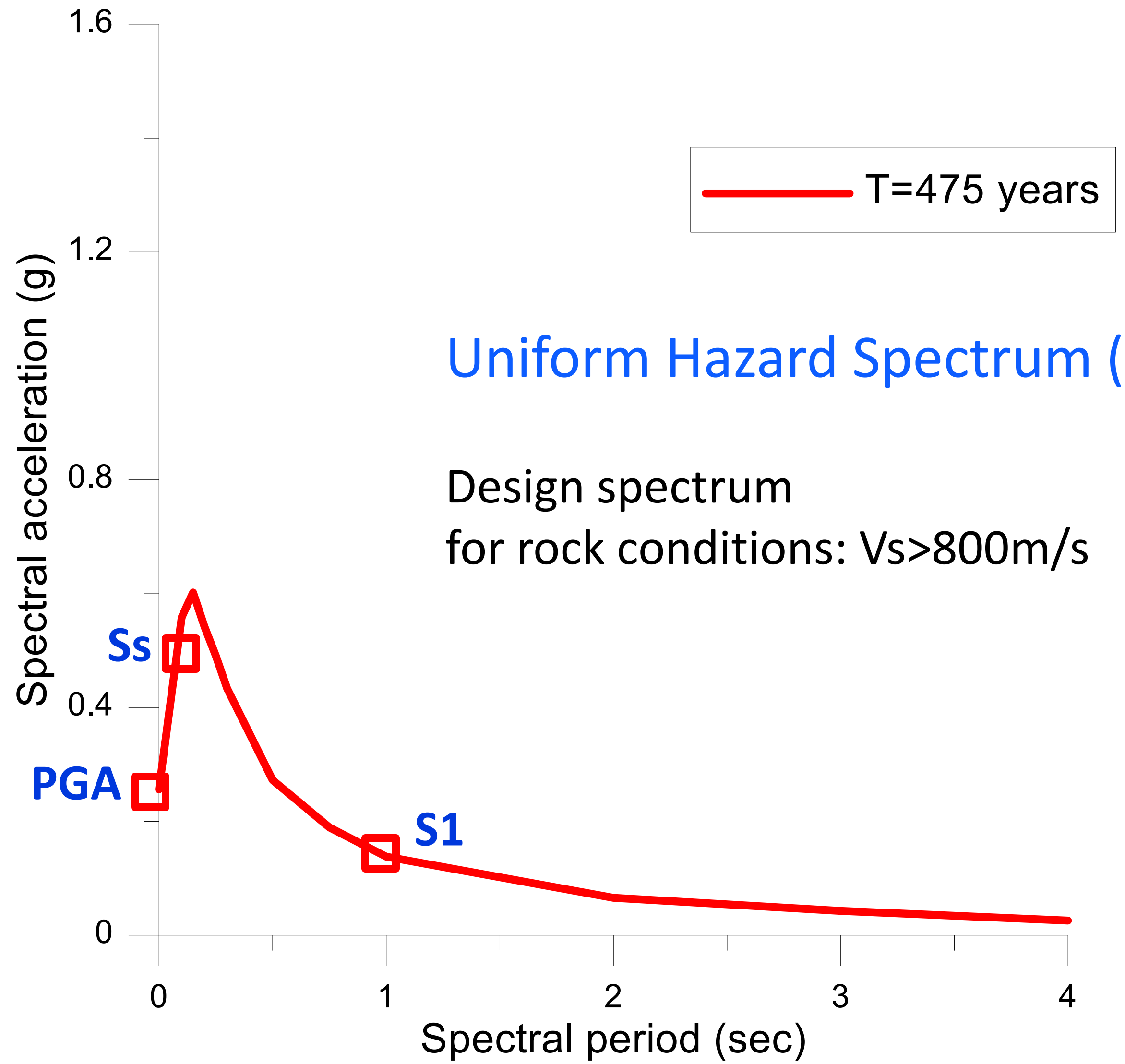


Uniform Hazard Spectrum (UHS)

Design spectrum
for rock conditions: Vs>800m/s

EC8-Part1
Seismic actions
Present situation and needs

Soil and site classification in EC8

Ground type	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ (m/s)	N_{SPT}	*Su* (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	>800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	360-800	>50	>250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.	180-360	15-50	70-250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	<180	<15	<70
E	A soil profile consisting of a surface alluvium layer with Vs values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with Vs>800 m/s.			
S1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI>40) and high water content.	<100 (indicative)	-	10-20
S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S1.			

Is $V_{s,30}$ appropriate for site classification?

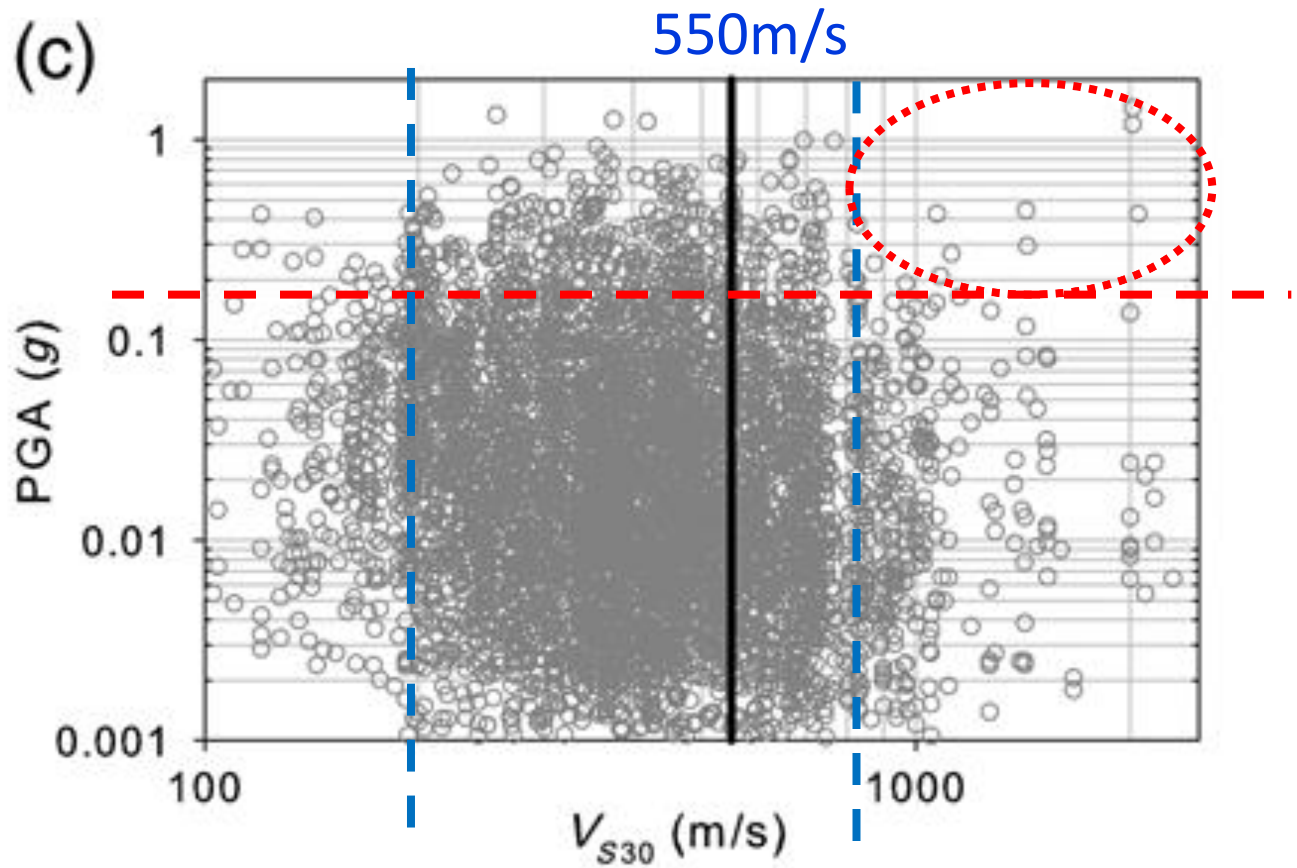
- Advantages of $V_{s,30}$:
  - Simple and effective in practice
  - Requires few data: a simple N-SPT of 30m long or less is maybe enough!

- Disadvantages of $V_{s,30}$:
  - It is not a fundamental (neither a geotechnical) parameter
  - Could mislead grossly in different cases like: deep low stiffness deposits lying on much harder rock; sites with a shallow velocity inversion; sites with velocity profiles which are not monotonically increasing with depth etc

$$V_{s,30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{V_i}}$$

Vs Measurements – Methods and Data

A Sandıkkaya,*S.Akkar, & P-Y Bard, 2013, "A Nonlinear Site-Amplification Model for the Next Pan-European Ground-Motion Prediction Equations"



Poor and loose data distribution for hard-rock conditions and PGA>0.20g

The bulk of the data are within 200 m/s $\leq V_{S30} \leq$ 700 m/s and PGA<0.20g

Is $V_{s,30}$ appropriate for site – soil classification?

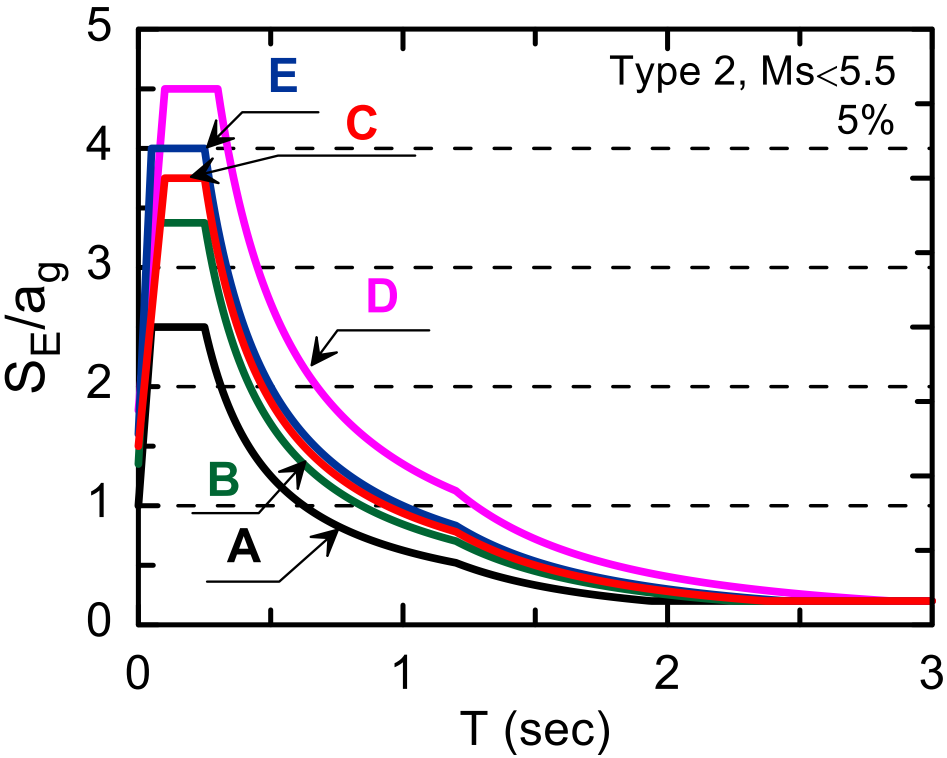
The answer is yes but only under certain conditions. For example very shallow and very deep, rather soft soil profiles should be excluded of the use of V_{s30}

Should be certainly complemented with a detailed geotechnical – geological description including the depth to the seismic bedrock (Vs>800m/s) and with several geotechnical parameters like SPT, CPT, Su, PI.

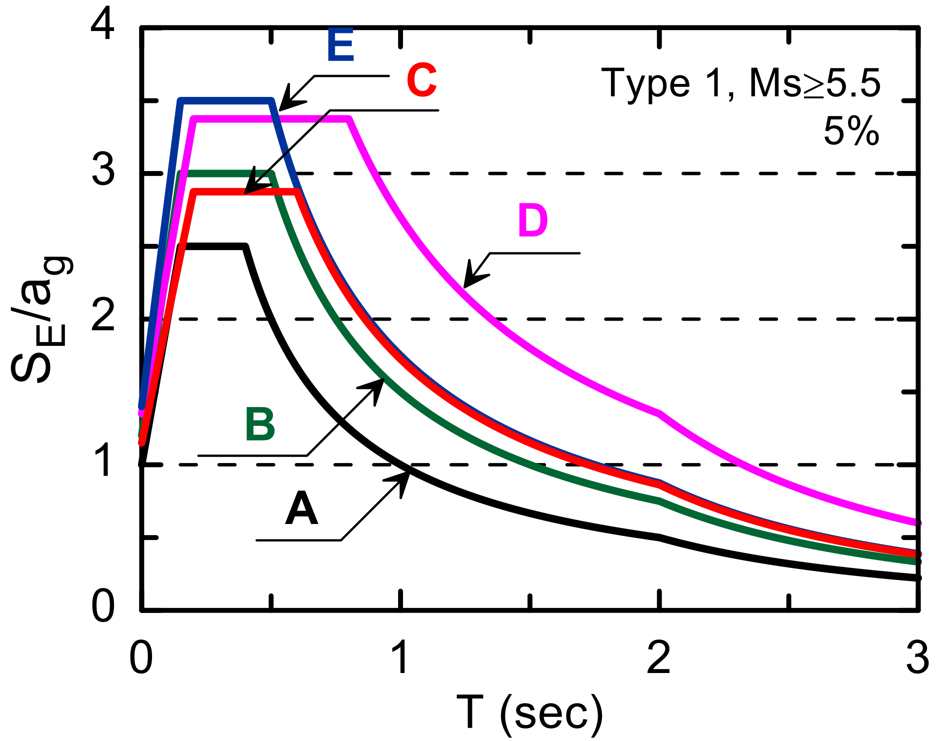
In any case a very useful parameter to describe the site amplification particularly in low intensities (linear elastic range of ground response) is the fundamental period of the site To

Normalized elastic response spectra (EC8)

M≤ 5.5



M> 5.5



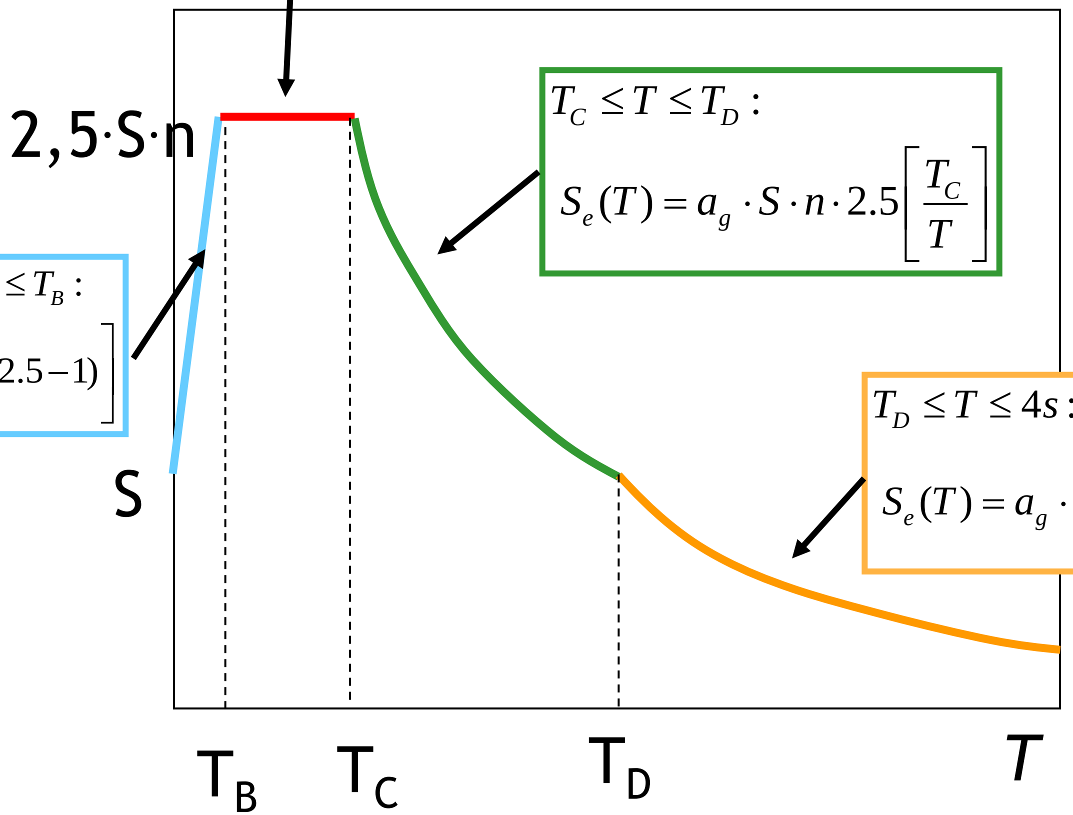
Horizontal elastic response spectrum (EC8)

$$T_B \leq T \leq T_C :$$
$$S_e(T) = a_g \cdot S \cdot n \cdot 2.5$$

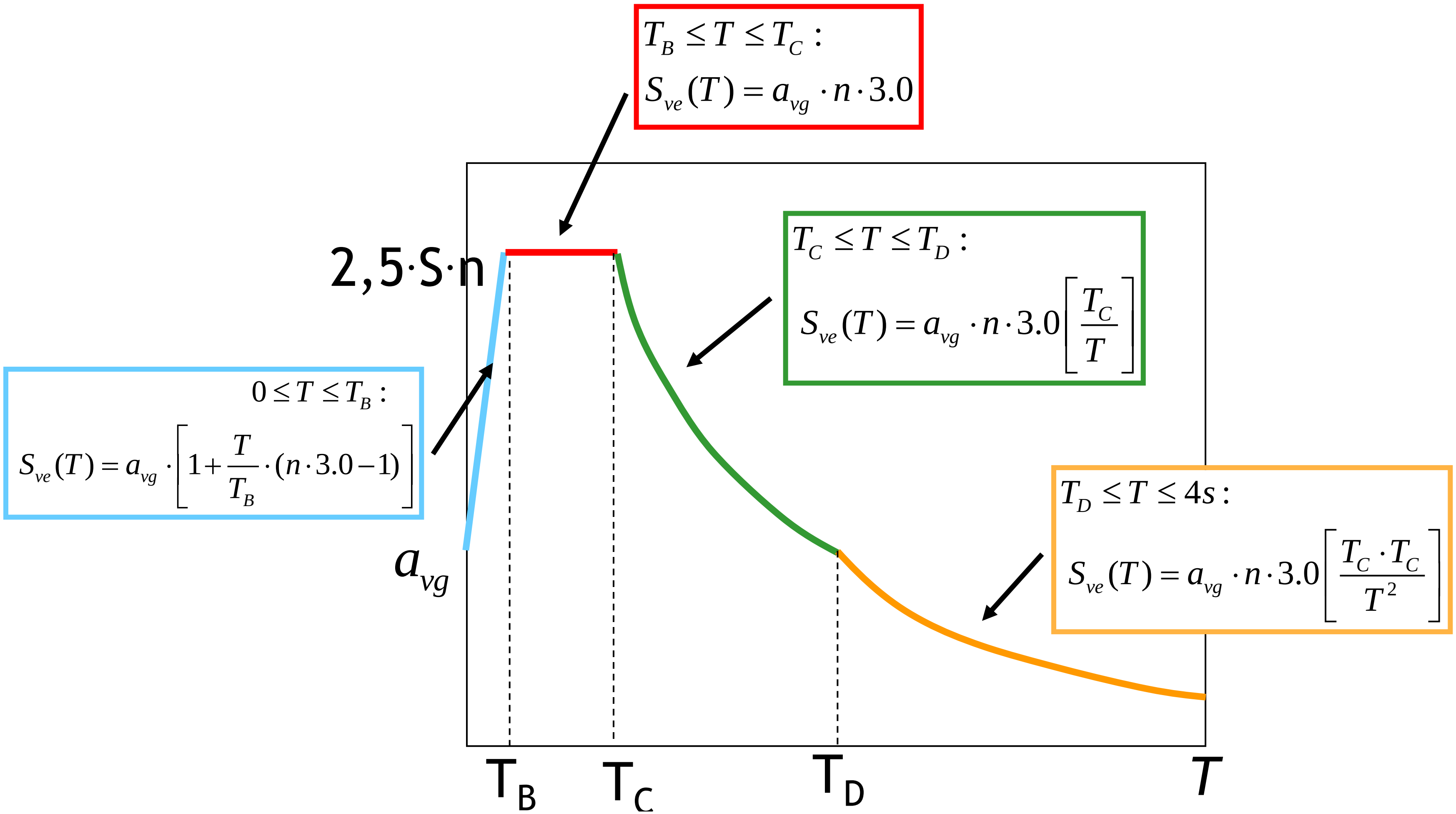
$$T_C \leq T \leq T_D :$$
$$S_e(T) = a_g \cdot S \cdot n \cdot 2.5 \left[\frac{T_C}{T}\right]$$

$$0 \leq T \leq T_B :$$
$$S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (n \cdot 2.5 - 1)\right]$$

$$T_D \leq T \leq 4s :$$
$$S_e(T) = a_g \cdot S \cdot n \cdot 2.5 \left[\frac{T_C \cdot T_D}{T^2}\right]$$



Vertical elastic response spectrum (EC8)



Spectrum	a_{vg}/a_g	T_B (s)	T_C (s)	T_D (s)
Type 1	0,90	0,05	0,15	1,0
Type 2	0,45	0,05	0,15	1,0

Amplification factors and elastic response spectra in EC8

Type 1 Spectrum - M_S>5.5				
Ground Type	S	T_B (s)	T_C (s)	T_D (s)
A	1.00	0.15	0.40	2.00
B	1.20	0.15	0.50	2.00
C	1.15	0.20	0.60	2.00
D	1.35	0.20	0.80	2.00
E	1.40	0.15	0.50	2.00
Type 2 Spectrum - M_S≤5.5				
Ground Type	S	T_B (s)	T_C (s)	T_D (s)
A	1.00	0.05	0.25	1.20
B	1.35	0.05	0.25	1.20
C	1.50	0.10	0.25	1.20
D	1.80	0.10	0.30	1.20
E	1.60	0.05	0.25	1.20

Needs for revision

- Site classification and amplification factors are based on very few data (available almost 20-25 years ago!) and should be at least upgraded and adapted to the acquired numerous new data, rich scientific knowledge and the exponential increase of available strong motion records in Europe and worldwide.

- Instead of having two seismicity regions i.e. Mw<5.5 and M>5.5 is probably better to propose amplification factors for increasing ground motion intensity for example PGA steps of 0.1g as in NEHERP

- Instead of anchoring the design response spectra to PGA (T=0sec) should be better to anchor to two spectral parameters Ss at 0.1-0.2sec and S1 at 1.0sec

Validation of the present amplification factors in EC8

&

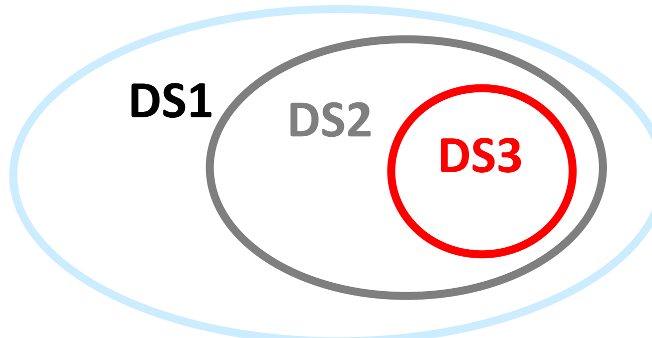
New site-soil classification scheme, amplification factors and design response spectra

keeping the present seismicity categorization

Data selection

- Validation of the present EC8 elastic response spectra:
    - SHARE database (www.share-eu.org)
    - soil/site documentation: $V_{s,30}$ and EC8 soil class
    - only records with $M_s \geq 4$ and $T_{usable} \geq 2.5$ sec were used
    - compilation of three subsets with different PGA levels
        - DS1: all PGA values
        - DS2: PGA ≥ 20 cm/s^2
        - DS3: PGA ≥ 150 cm/s^2

- **SHARE database (Giardini et al., 2013, www.share-eu.org)**
- **Soil/site documentation: $V_{s,30}$ and EC8 soil class**
- Only records with $M_s \geq 4$ and $T_{usable} \geq 2.5$ sec were used → DS1 dataset with 7161 3-component accelerograms
- DS1: all *PGA* values (N=7161)
- DS2: *PGA* ≥20 cm/s^2 (N=3500)
- DS3: *PGA* ≥150 cm/s^2 (N=559)



Soil class	DS1		DS2		DS3	
	Type 2	Type 1	Type 2	Type 1	Type 2	Type 1
A	402	264	105	125	9	23
B	1508	1896	419	1151	38	214
C	1133	1775	353	1261	44	219
D	10	4	3	1	-	-
E	73	96	33	49	5	7
Total	3126	4035	913	2587	96	463
	7161		3500		559	

Data selection

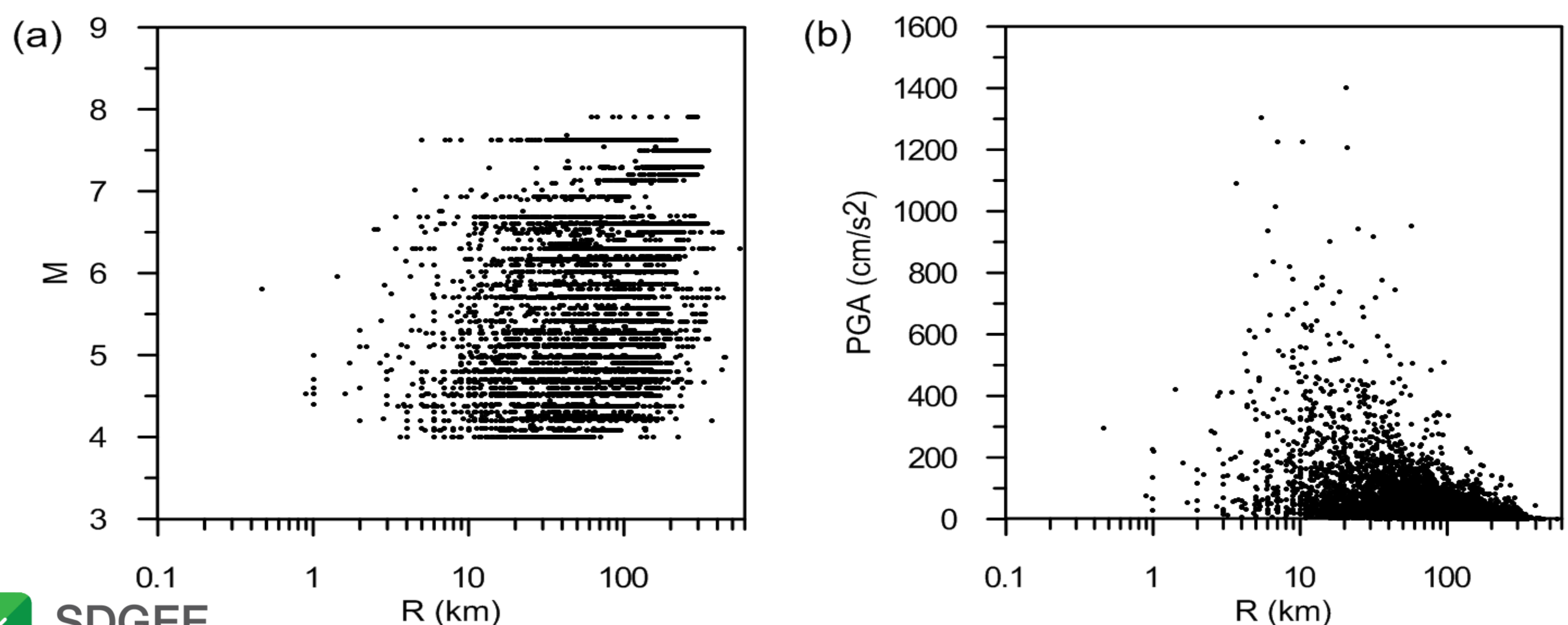
- Proposal of a new soil-site classification scheme, amplification factors and design spectra:

  - SHARE-AUTH database (Pitilakis et al., 2013)
  - 3,666 records from 536 stations from Greece, Italy, Turkey, Japan and USA with a **well-documented soil profile** up to the 'seismic' bedrock (V_s>800m/s)
  - For all sites: $H_{bedrock}$, $V_{s,average}$, $V_{s,30}$, T_0
  - Dataset DS4: $M_s \geq 4$, $T_{usable} \geq 2.5$ sec and PGA ≥ 20 cm/s^2

Data selection

Dataset	Database of origin	Number of records	M_S range	PGA range (cm/s^2)
DS1	SHARE	7,161	4–7.9	≤1,400
DS2	SHARE	3,500	4–7.9	20<PGA≤1,400
DS3	SHARE	559	4–7.9	150<PGA≤1,400
DS4	SHARE-AUTH	715	4–7.5	20<PGA≤1,302

DS1 dataset



Validation of EC8 normalized spectra

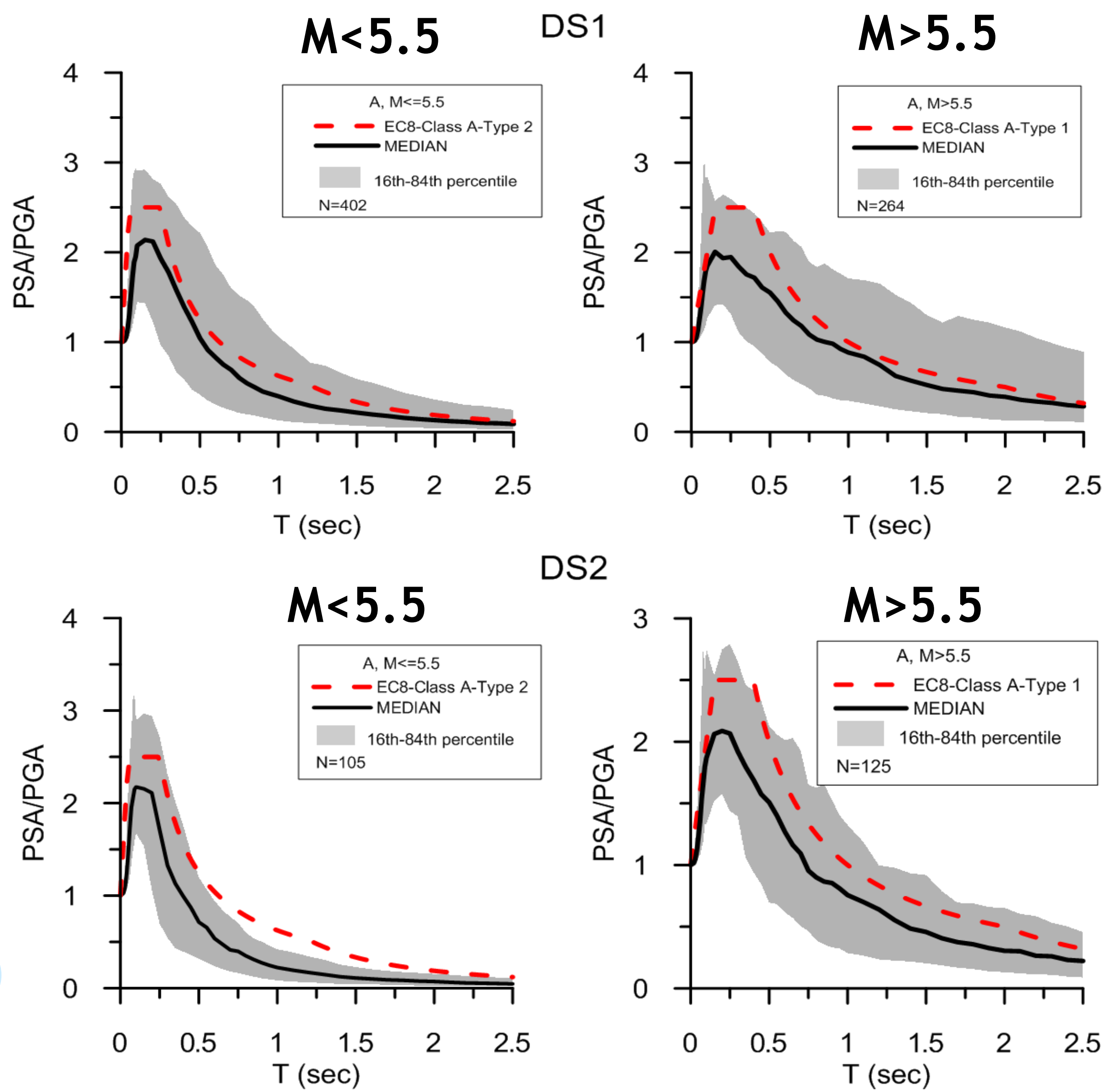
- DS1 and DS2 for Type 2 ($M_s \leq 5.5$) and Type 1 ($M_s > 5.5$) spectra
- DS3 only for Type 1 spectra
- Calculation of geometric mean (GM) of the response spectra for the two orthogonal horizontal components of each record
- Normalization to GM PGA
- Grouping of records based on soil class and spectrum type (1 or 2)
- Calculation of median, 16^{th} and 84^{th} percentiles (average $\pm$ 1 standard deviation) and comparison

Validation of EC8 normalized spectra

Soil Class A

- EC8 spectra match the empirical data to a satisfactory extent (between median and 84th pctl)
- EC8 spectra become more conservative for datasets with higher mean *PGA* values

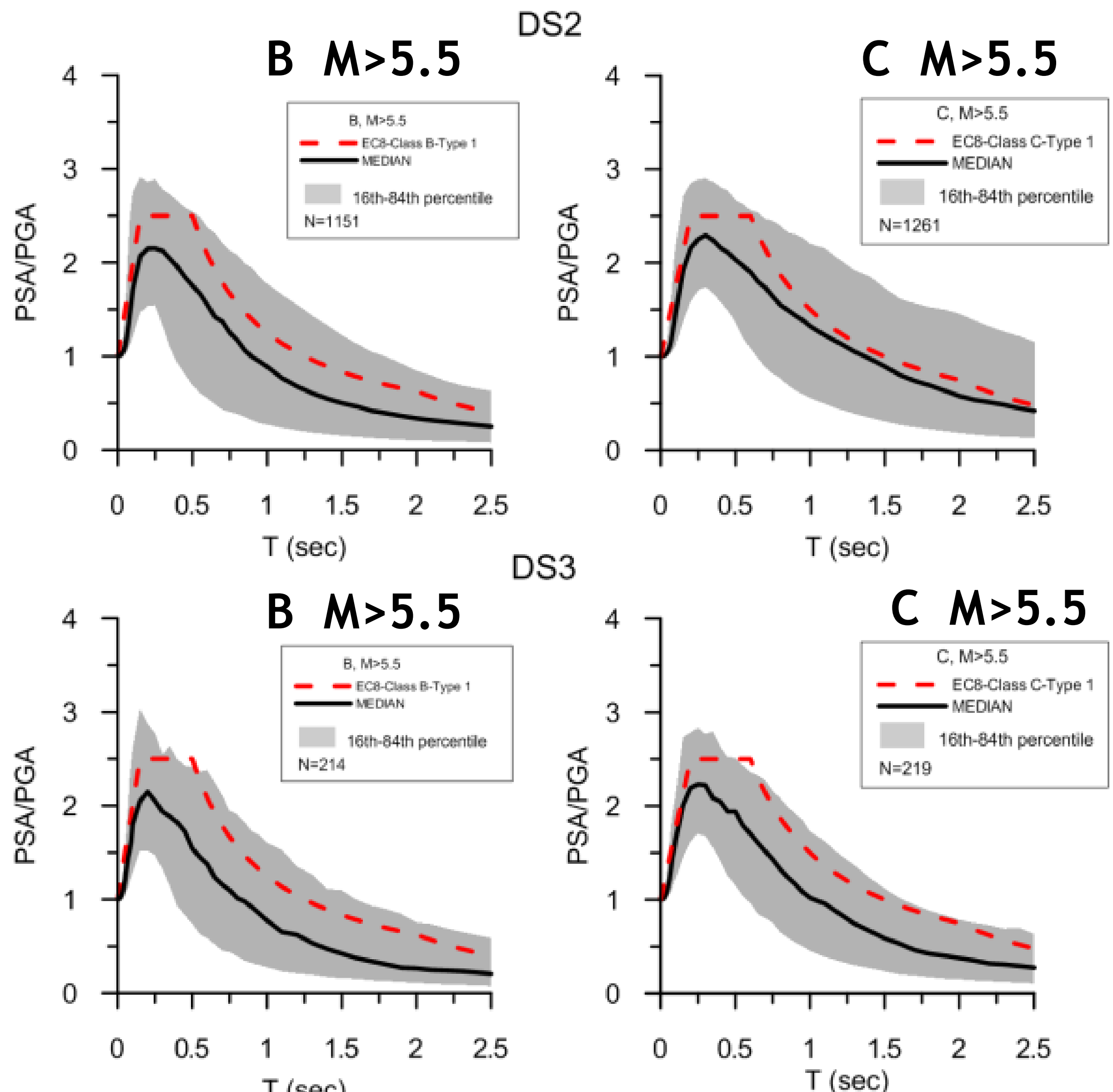
Pitilakis et al. (2012)



Validation of EC8 normalized spectra TYPE1

Soil Classes B-C

- Good agreement between EC8 and empirical data
- Wide range of normalized values, which becomes more constrained for datasets with higher mean *PGA* values



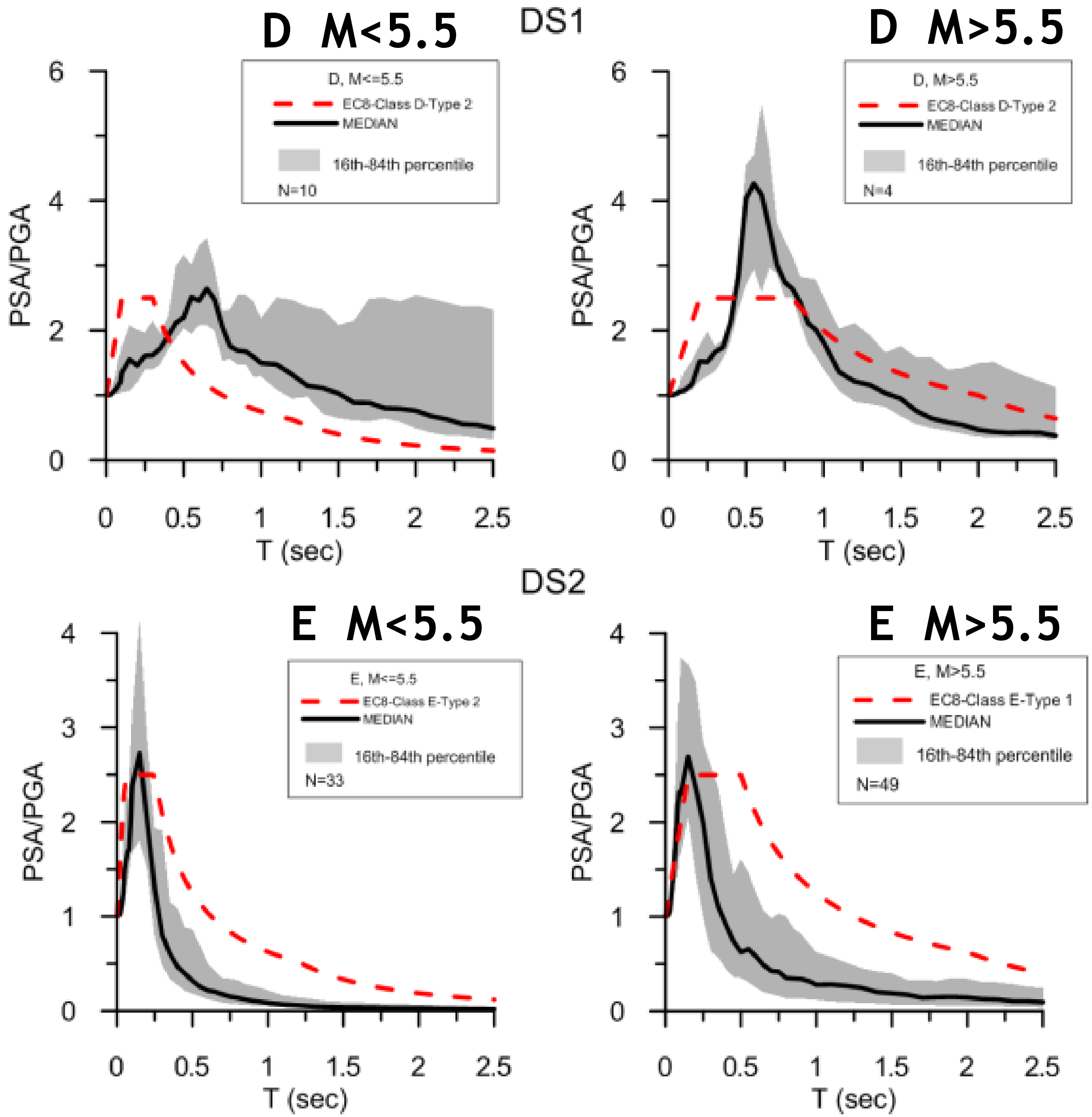
Pitilakis et al. (2012)

Validation of EC8 normalized spectra

Soil Classes D-E

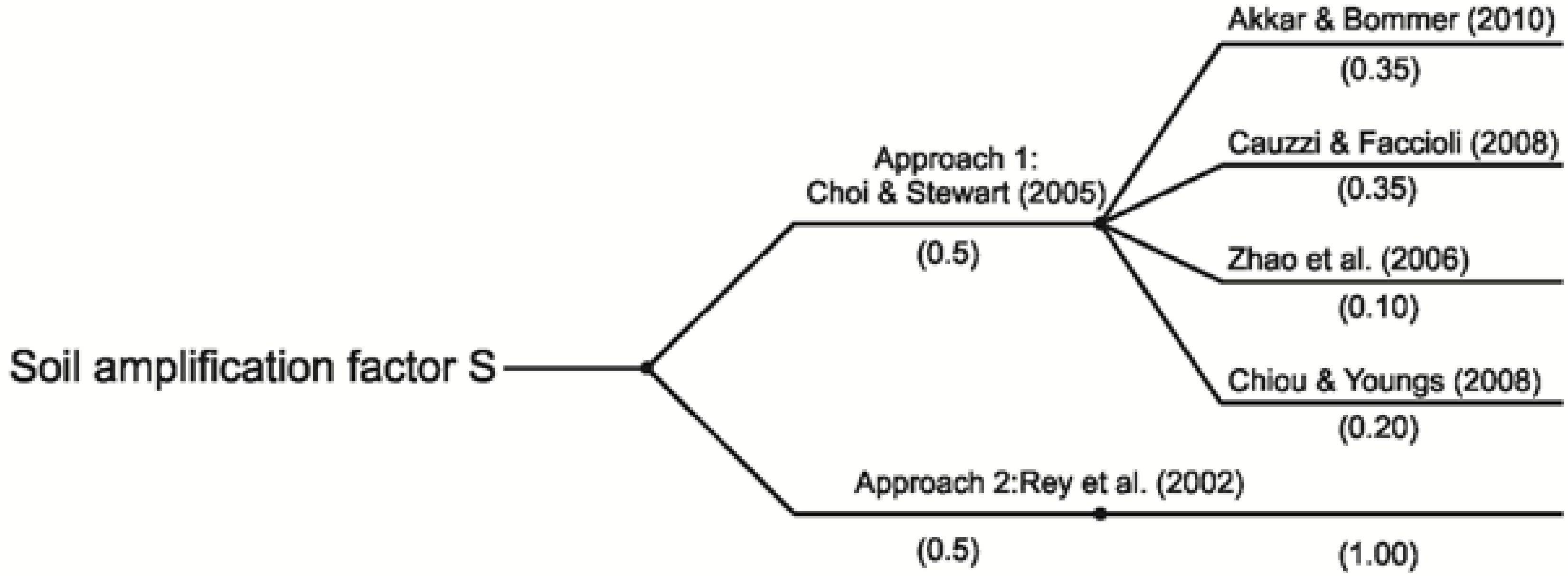
- Soil class D: the ordinates of EC8 spectra do not provide a satisfactory fit to the median empirical spectra.
- Soil class E: EC8 spectra are conservative for periods greater than 0.3s. Potential need to increase the plateau

Pitilakis et al. (2012)



Improved Soil Amplification Factors for EC8 soil classification

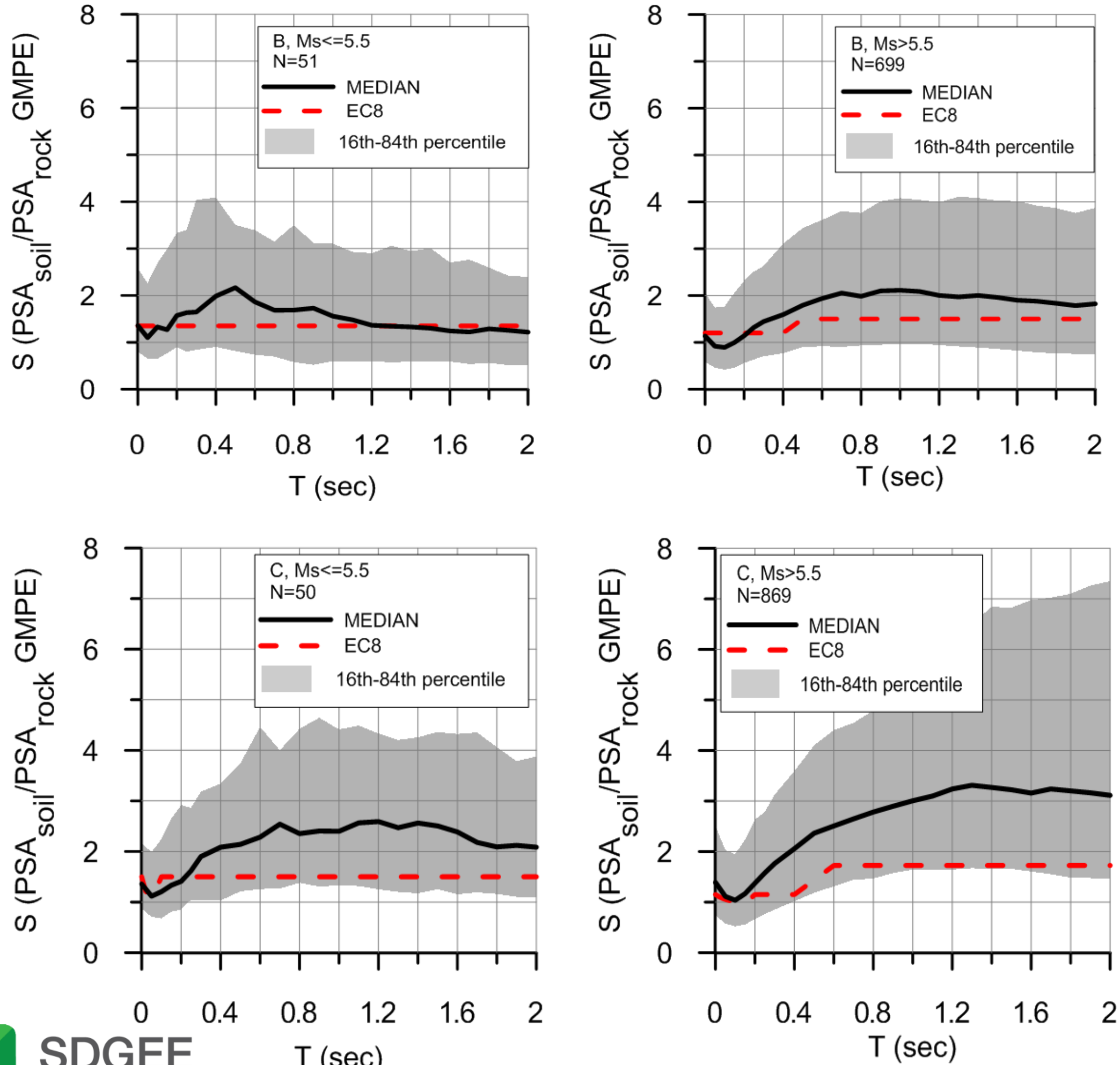
Logic tree approach



Pitilakis et al. (2012)
GMPE selection and weights from Delavaud et al. (2012)

Improved Soil Factors for EC8 soil classification

Approach 1 (Choi & Stewart, 2005)



$$S_{ij}(T) = GM_{ij} / (GM_r)_{ij}$$

$$\begin{aligned}(GM_r)_{ij}(T) = {} & 0.35 \cdot (GM_r)_{ij,AB} \\ & + 0.35 \cdot (GM_r)_{ij,CF} \\ & + 0.10 \cdot (GM_r)_{ij,Zh} \\ & + 0.20 \cdot (GM_r)_{ij,CY}\end{aligned}$$

Main problem:
Results depend on the reliability of **the GMPEs for rock**

Pitilakis et al. (2012)

Improved Soil Factors for EC8 soil classification

Type 2 ($M_s \le 5.5$)											
Soil Class	SHARE-DS1			SHARE-DS2			SHARE-DS3			EC8	Proposed
	Ap.1	Ap.2	W.A.	Ap.1	Ap.2	W.A.	Ap.1	Ap.2	W.A.		
B	0.90	1.55	1.23	1.51	1.37	1.44	-	-	-	1.35	1.40
C	1.93	2.54	2.23	2.19	2.12	2.16	-	-	-	1.50	2.10
D	3.36	3.07	3.22	2.92	2.00	2.46	-	-	-	1.80	1.80[a]
E	0.98	1.79	1.39	1.30	1.96	1.63	-	-	-	1.60	1.60[a]

Type 1 ($M_s > 5.5$)											
Soil Class	SHARE-DS1			SHARE-DS2			SHARE-DS3			EC8	Proposed
	Ap.1	Ap.2	W.A.	Ap.1	Ap.2	W.A.	Ap.1	Ap.2	W.A.		
B	1.47	1.34	1.41	1.53	1.08	1.31	1.49	0.94	1.22	1.20	1.30
C	2.09	2.24	2.16	2.06	1.46	1.76	1.82	1.15	1.48	1.15	1.70
D	1.74	1.42	1.58	1.56	0.92	1.24	-	-		1.35	1.35[a]
E	0.91	1.07	0.99	0.97	0.83	0.90	0.93	0.78	0.85	1.40	1.40[a]

(a) site specific ground response analysis required

Pitilakis et al. (2012)

New site – soil classification scheme

- Soil classes initially proposed based on theoretical 1D numerical analyses of representative models of realistic soil conditions (Pitilakis et al., 2004, 2006)

- Further developed based exclusively on experimental data from the SHARE – AUTH database (Pitilakis et al., 2013)

- Main parameters:
  - **Fundamental period of soil deposit T_0**
  - Average shear wave velocity of the entire soil deposit $V_{s,av}$
  - Thickness of soil deposit H to the “seismic” bedrock
  - N-SPT, PI, S_u
  - More detailed geotechnical soil description and categorization

Soil classification scheme by Pitilakis et al. (2013)

	Description	T_0	Remarks
A	Rock formations		$V_s \geq 1500$ m/s
A2	Slightly weathered / segmented rock formations (thickness of weathered layer <5.0m)	≤ 0.2s	Surface weathered layer: $V_{s,av} \geq 200$ m/s Rock Formations: $V_s \geq 800$ m/s
	Geologic formations resembling rock formations in their mechanical properties and their composition (e.g. conglomerates)		$V_s \geq 800$ m/s
B1	Highly weathered rock formations whose weathered layer has a considerable thickness (> 5.0m - 30.0m)	≤ 0.5s	Weathered layer, $V_{s,av} \geq 300$ m/s
	Soft rock formations of great thickness or formations which resemble these in their mechanical properties (e.g. stiff marls)		Vs: 400-800 m/s N-SPT > 50 Su> 200 KPa
	Soil formations of very dense sand – sand gravel and/or very stiff/ to hard clay, of homogenous nature and small thickness (up to 30.0m)		$V_{s,av}$: 400-800 m/s N-SPT > 50 Su > 200 KPa
B2	Soil formations of very dense sand – sand gravel and/or very stiff/ to hard clay, of homogenous nature and medium thickness (30.0 - 60.0m), whose mechanical properties increase with depth	≤ 0.8s	$V_{s,av}$: 400-800 m/s N-SPT > 50 Su > 200 KPa

Soil classification scheme by Pitilakis et al. (2013)

	Description	T_0	Remarks
C1	Soil formations of dense to very dense sand – sand gravel and/or stiff to very stiff clay, of great thickness (> 60.0m), whose mechanical properties and strength are constant and/or increase with depth	≤ 1.5s	$V_{s,av}$: 400-800 m/s N -SPT> 50 Su > 200 KPa
C2	Soil formations of medium dense sand – sand gravel and/or medium stiffness clay (PI > 15, fines percentage > 30%) of medium thickness (20.0 – 60.0m)	≤ 1.5s	$V_{s,av}$: 200-450 m/s N -SPT> 20 Su > 70 KPa
C3	Category C2 soil formations of great thickness (>60.0 m), homogenous or stratified that are not interrupted by any other soil formation with a thickness of more than 5.0m and of lower strength and Vs velocity	≤ 1.8s	$V_{s,av}$:200-450 m/s N-SPT > 20 Su > 70 Kpa

Soil classification scheme by Pitilakis et al. (2013)

	Description	T_0	Remarks
D1	Recent soil deposits of substantial thickness (up to 60m), with the prevailing formations being soft clays of high plasticity index (PI>40), high water content and low values of strength parameters	≤ 2.0s	$V_{s,av} \leq 300$ m/s N-SPT < 25 Su < 70KPa
D2	Recent soil deposits of substantial thickness (up to 60m), with prevailing fairly loose sandy to sandy-silty formations with a substantial fines percentage (not to be considered susceptible to liquefaction)	≤ 2.0s	$V_{s,av} \leq 300$ m/s N-SPT < 25
D3	Soil formations of great overall thickness (> 60.0m), interrupted by layers of category D1 or D2 soils of a small thickness (5 – 15m), up to the depth of ~40m, within soils (sandy and/or clayey, category C) of evidently greater strength, with Vs≥ 300 m/sec	≤ 3.0s	$V_{s,av}$: 150-600 m/s

Soil classification scheme by Pitilakis et al. (2013)

	Description	T_0	Remarks
E	Surface soil formations of small thickness (5 - 20m), small strength and stiffness, likely to be classified as category C and D according to its geotechnical properties, which overlie category A formations (Vs ≥ 800 m/sec)	≤ 0.7s	Surface soil layers, $V_{s,av} \leq 400$ m/s
X	Loose fine sandy-silty soils beneath the water table, susceptible to liquefaction (unless a special study proves no such danger, or if the soil's mechanical properties are improved) Soils near obvious tectonic faults Steep slopes covered with loose lateral deposits Loose granular or soft silty-clayey soils, provided they have been proven to be hazardous in terms of dynamic compaction or loss of strength. Recent loose landfills Soils with a very high percentage in organic material Soils requiring site-specific evaluations		

Methods to estimate T_0

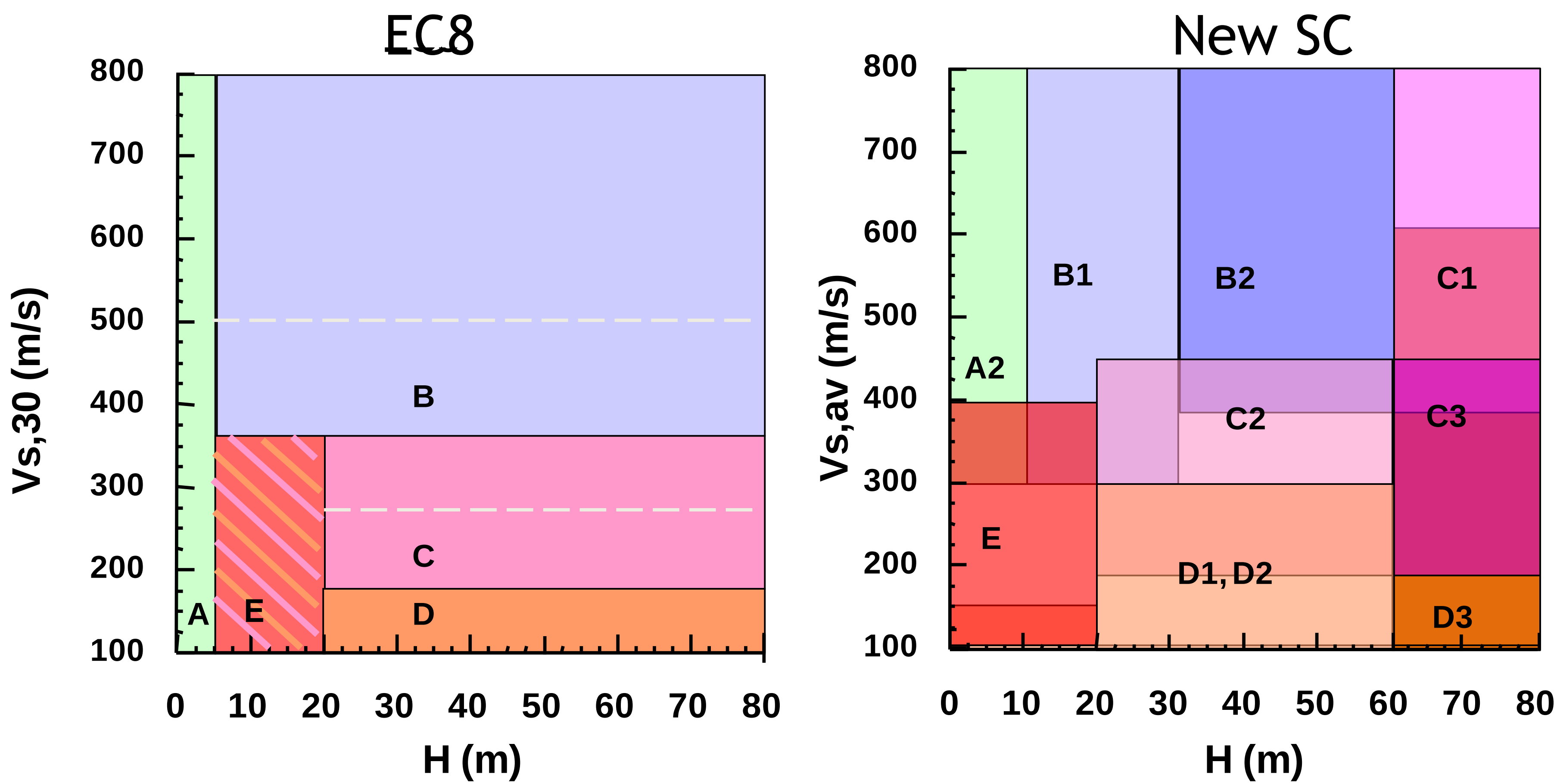
- Geotechnical and geophysical data (boreholes, lab tests, SPT, CPT, Cross-hole, Down-hole tests, SASW, Array measurements of mictrotremors etc)

$$T_0 = 4H/Vs$$

- Geophysical-seismic methods

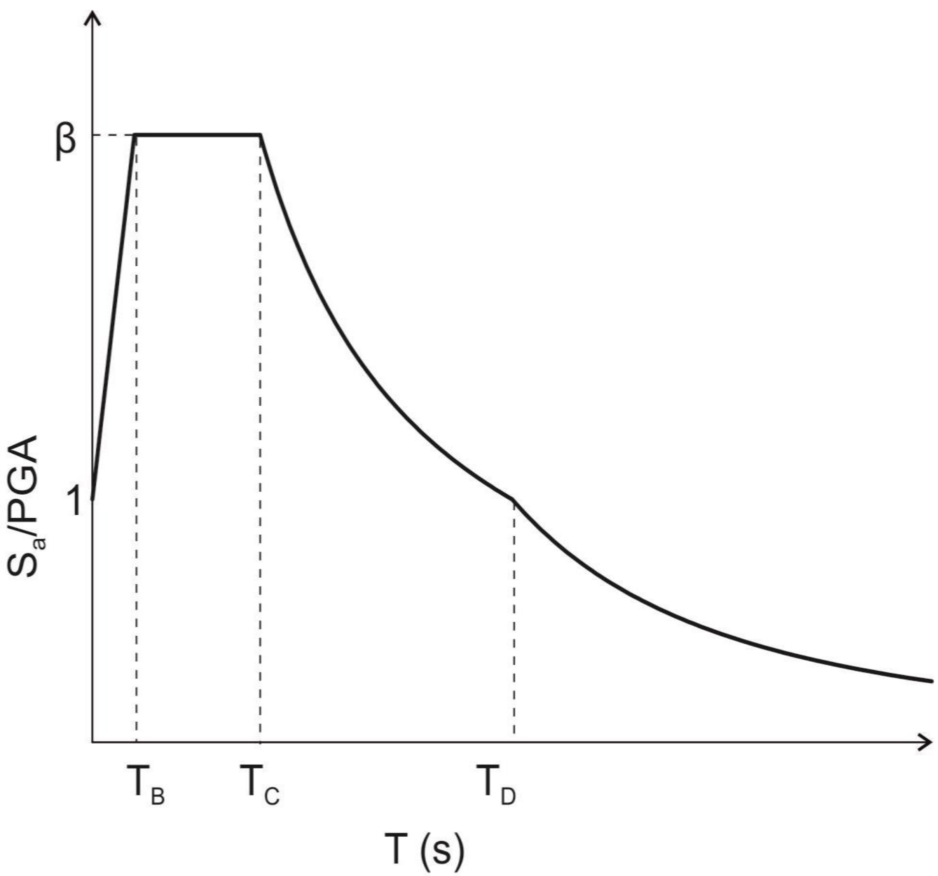
  - Ambient noise measurements
  - SSR : Two stations, one on the nearby reference outcrop
  - HVSR (Nakamura method) : Single station method

New site – soil classification scheme



New site – soil classification scheme

Normalized spectra



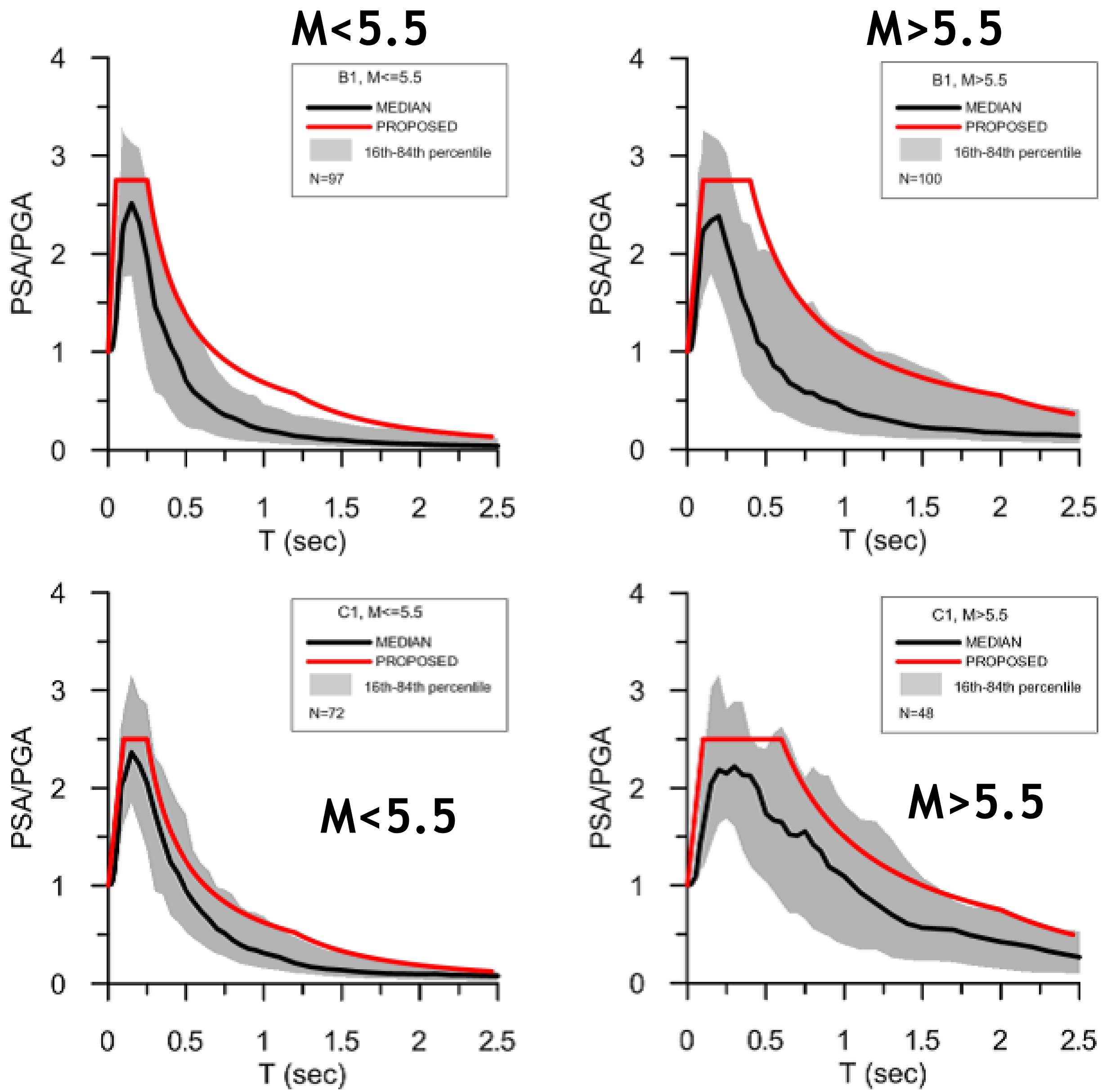
- SHARE-AUTH database
- 2 spectrum Types (same as EC8)
  - Type 1: Ms > 5.5
  - Type 2: Ms ≤ 5.5
- Same equation forms as in EC8 but with varying spectral amplification parameter β.
- For each soil class and spectrum type: median, 16^{th} and 84^{th} pctls
- Parameters T_B, T_C, T_D and β → fit to 84^{th} pctl

New site – soil classification scheme

Soil class B1

Normalized spectra

Soil class C1



Pitilakis et al. (2013)

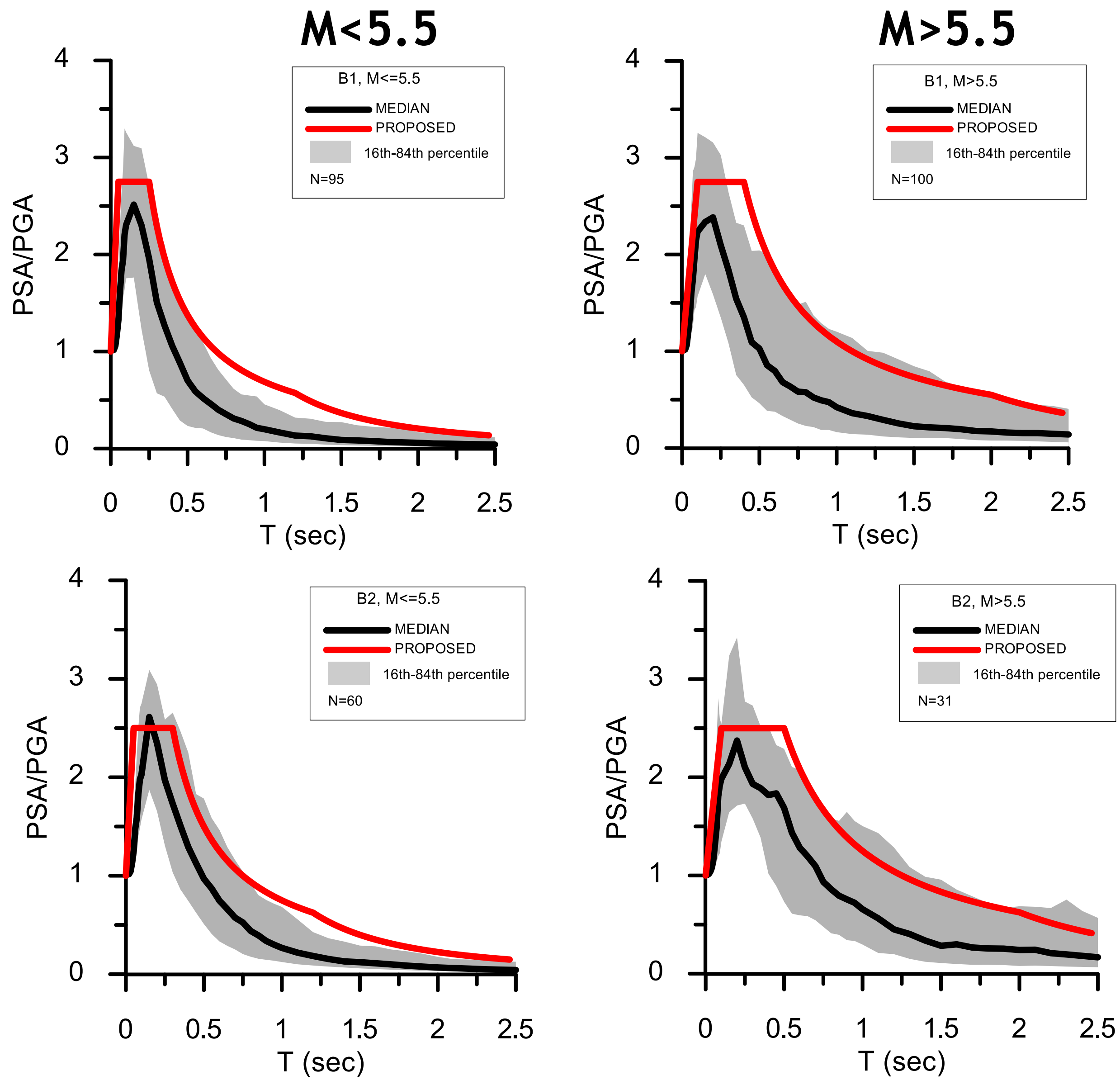
New site – soil classification scheme

Soil class B1

Normalized spectra

Soil class B2

Pitilakis et al. (2013)



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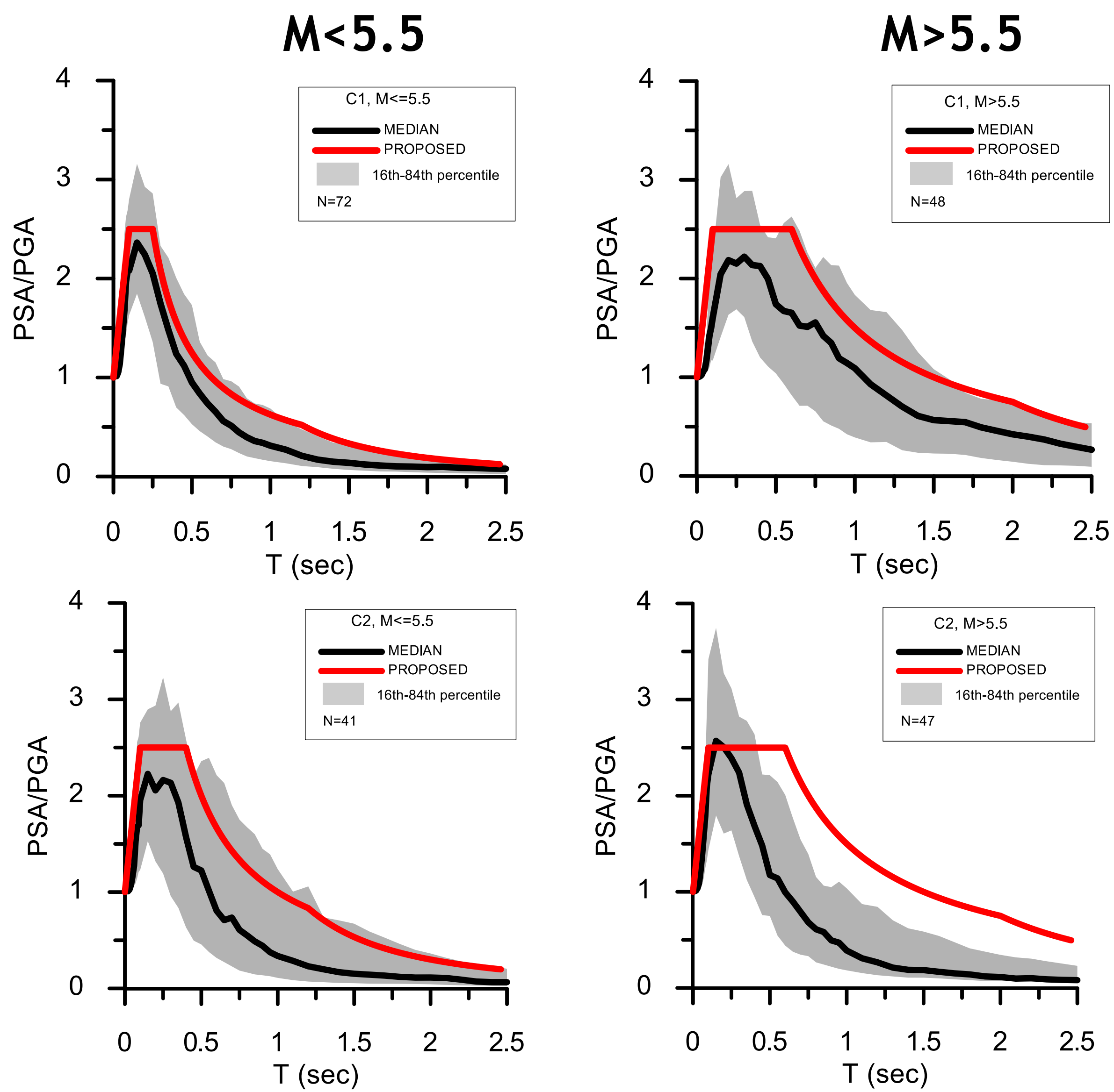
New site – soil classification scheme

Soil class C1

Normalized spectra

Soil class C2



Pitilakis et al. (2013)

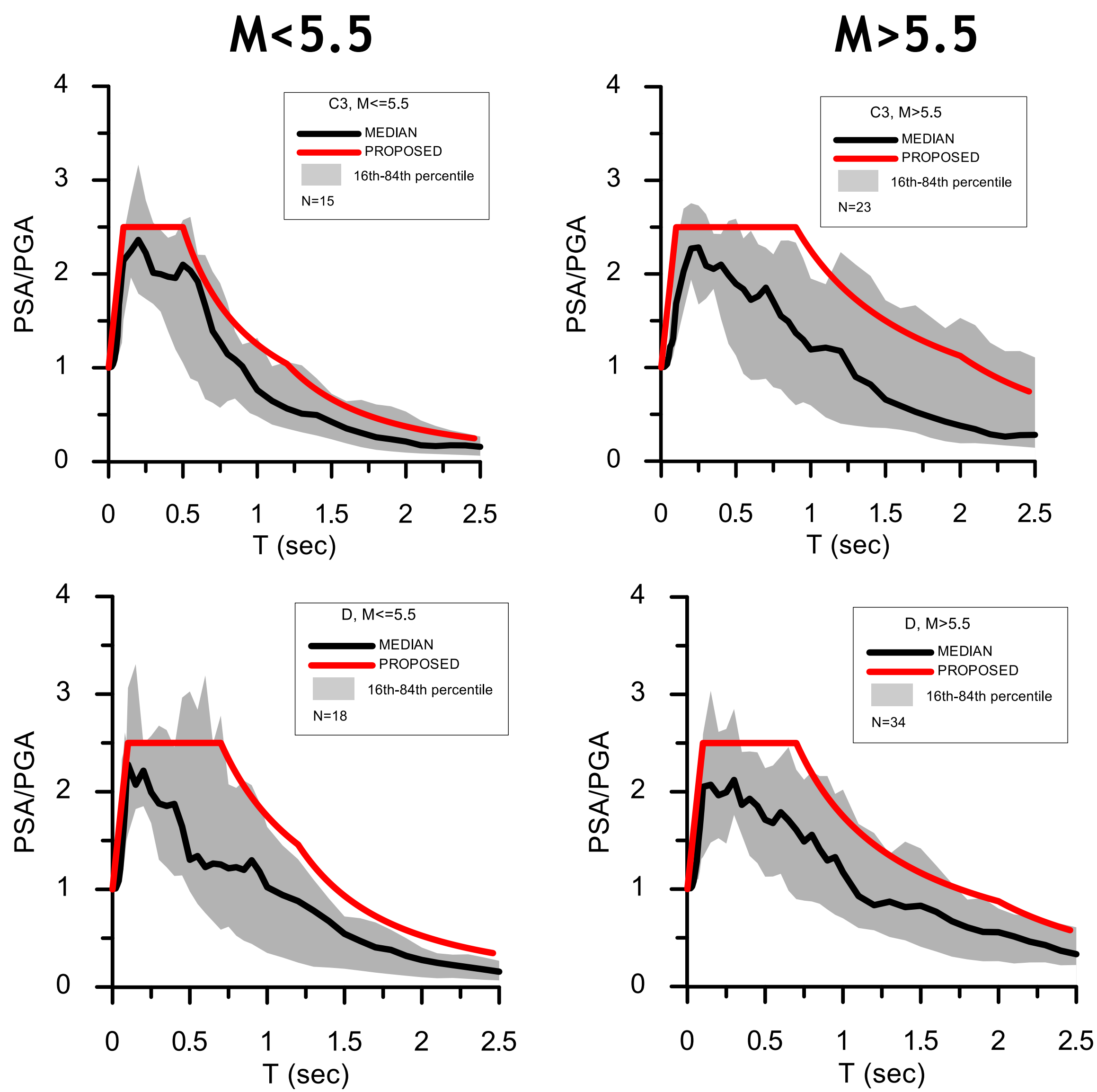
New site – soil classification scheme

Soil class C3

Normalized spectra

Soil class D

Pitilakis et al. (2013)

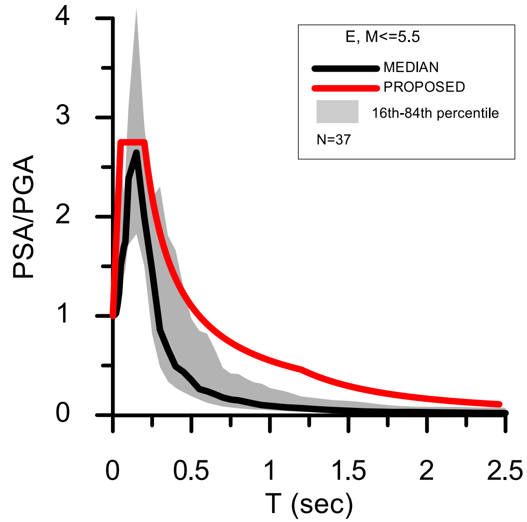


New site – soil classification scheme

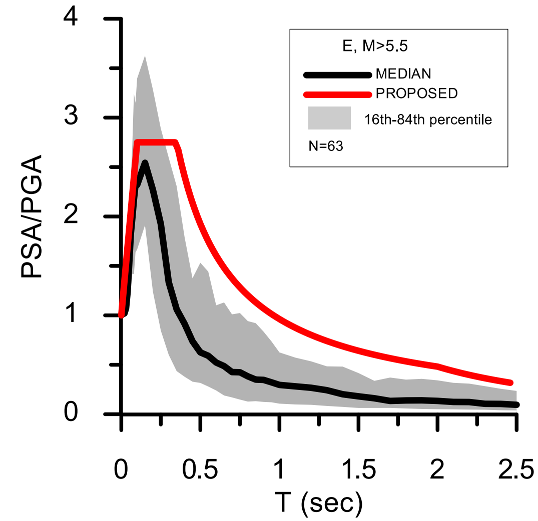
Soil class E

Normalized spectra

M<5.5



M>5.5



Pitilakis et al. (2013)

New site – soil classification scheme and amplification factors

- Same logic tree approach as for EC8
- Dataset DS4 from SHARE-AUTH database : $M_s \geq 4$, $T_{usable} \geq 2.5$ sec and PGA ≥ 20 cm/s^2

Soil Class	Type 2 ($M_s \leq 5.5$)					Type 1 ($M_s > 5.5$)				
	Ap. 1	Ap. 2	Weighted Average	Proposed	EC8	Ap. 1	Ap. 2	Weighted Average	Proposed	EC8
B1	1.28	0.99	1.13	**1.20**	**1.35 (B)**	1.03	1.03	1.03	**1.10**	**1.20 (B)**
B2	1.89	1.17	1.53	**1.50**		1.36	1.28	1.32	**1.30**	
C1	2.02	1.46	1.74	**1.80**	**1.50 (C)**	2.19	1.27	1.73	**1.70**	**1.15 (C)**
C2	2.08	1.39	1.74	**1.70**		1.35	1.15	1.25	**1.30**	
C3	2.59	1.61	2.10	**2.10**		1.57	1.07	1.32	**1.30**	
D	2.19	2.26	2.23	**2.00**[a]	**1.80**	2.03	1.79	1.91	**1.80** [a]	**1.35**
E	1.54	1.30	1.42	**1.60**[a]	**1.60**	1.10	0.94	1.02	**1.40** [a]	**1.40**

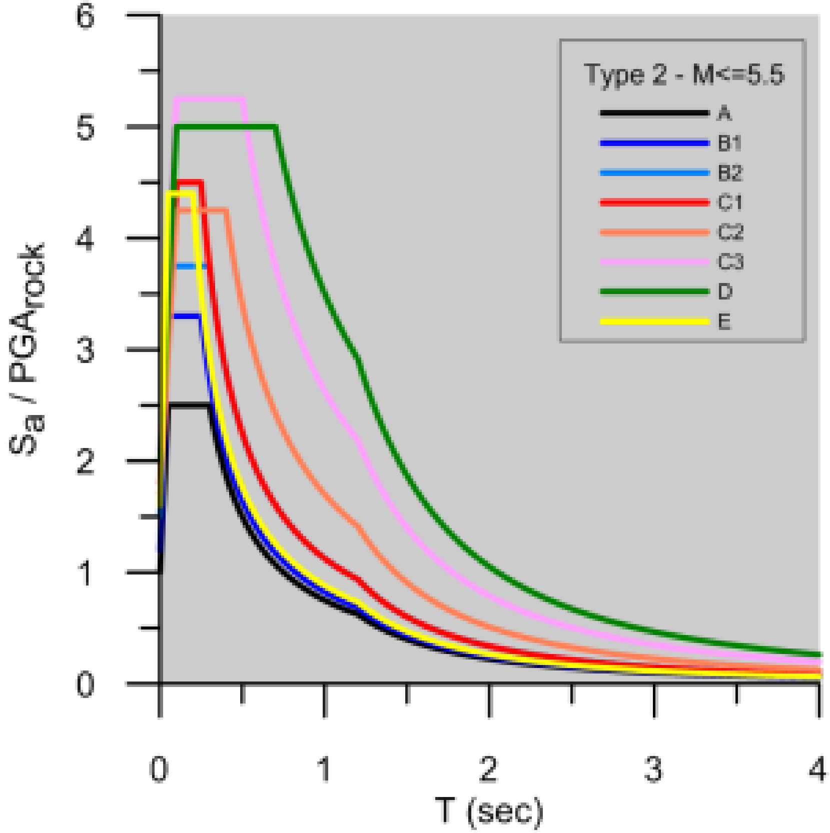
[a] Site specific ground response analysis required

Pitilakis et al. (2013)

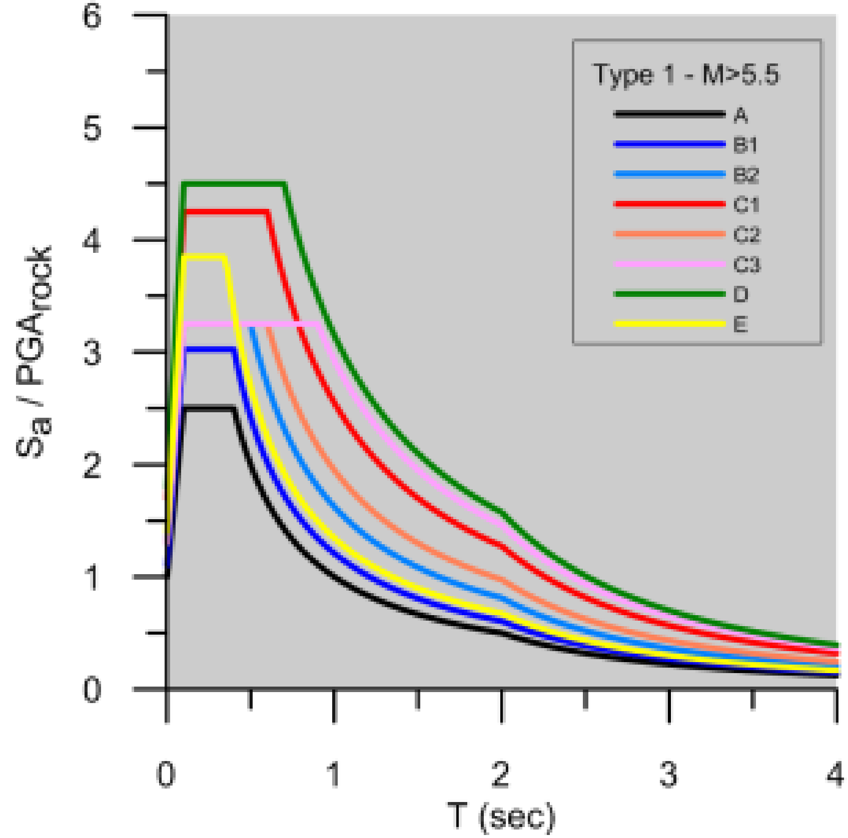
New site – soil classification scheme

Elastic acceleration response spectra (5%)

Type 2 (M<5.5)



Type 1 (M>5.5)



Pitilakis et al. (2013)

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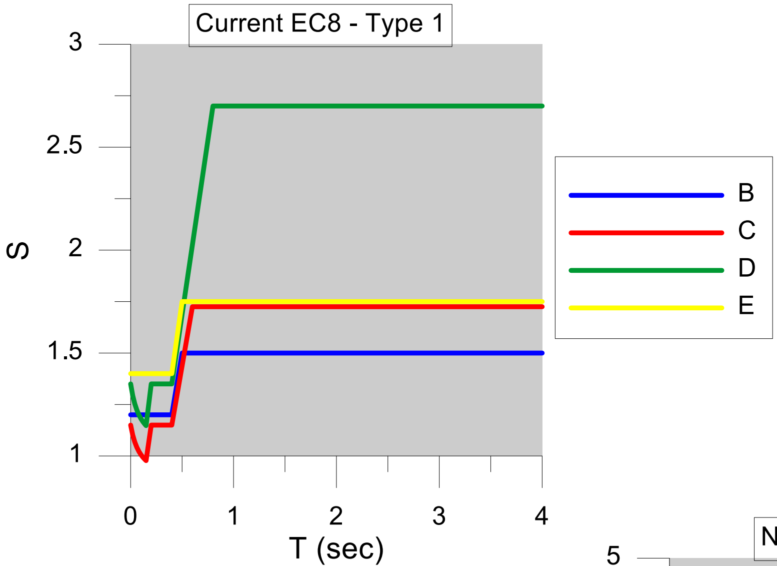
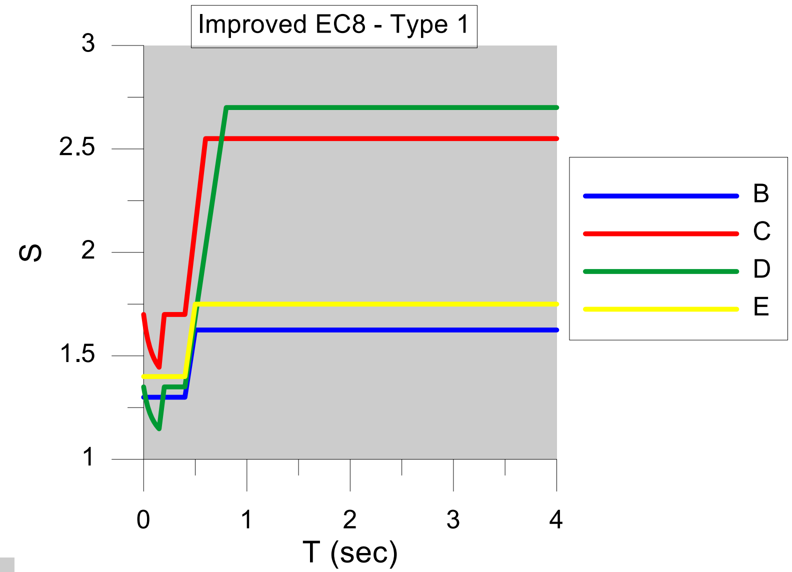
Period – dependent amplification factors TYPE1

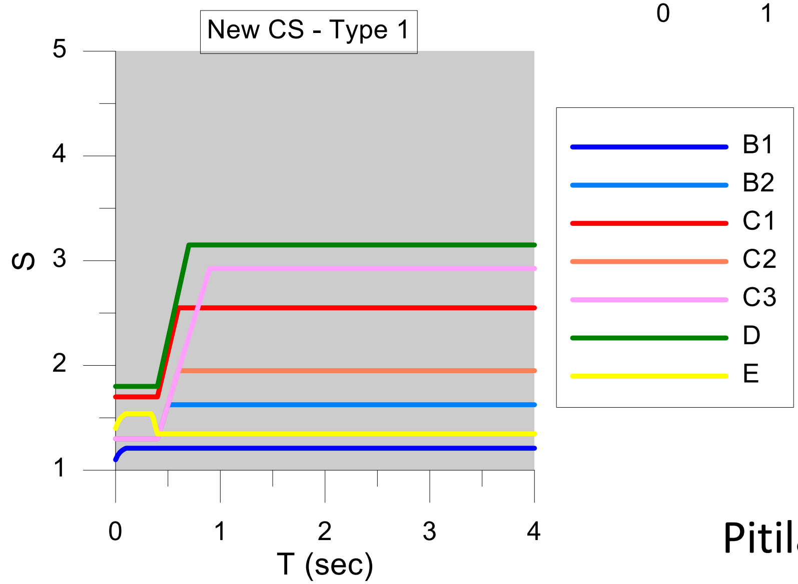
EC8



Improved EC8



New CS



Pitilakis et al. (2012, 2013)

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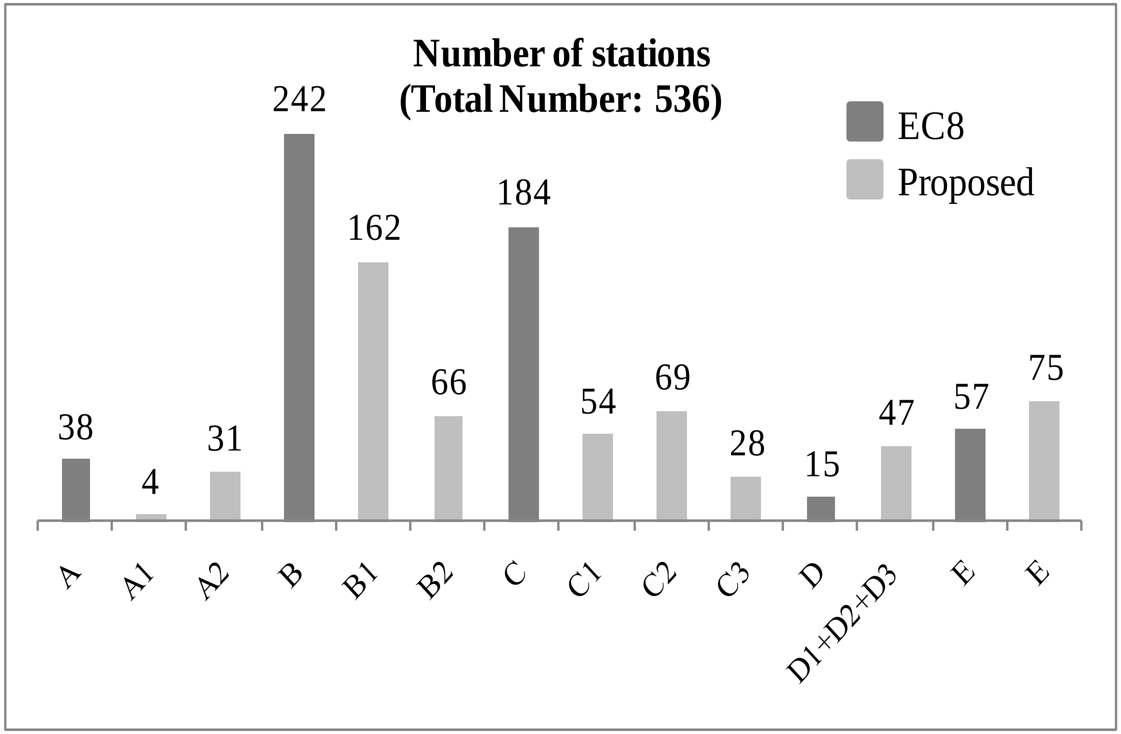
New
site classification, amplification factors and design response spectra

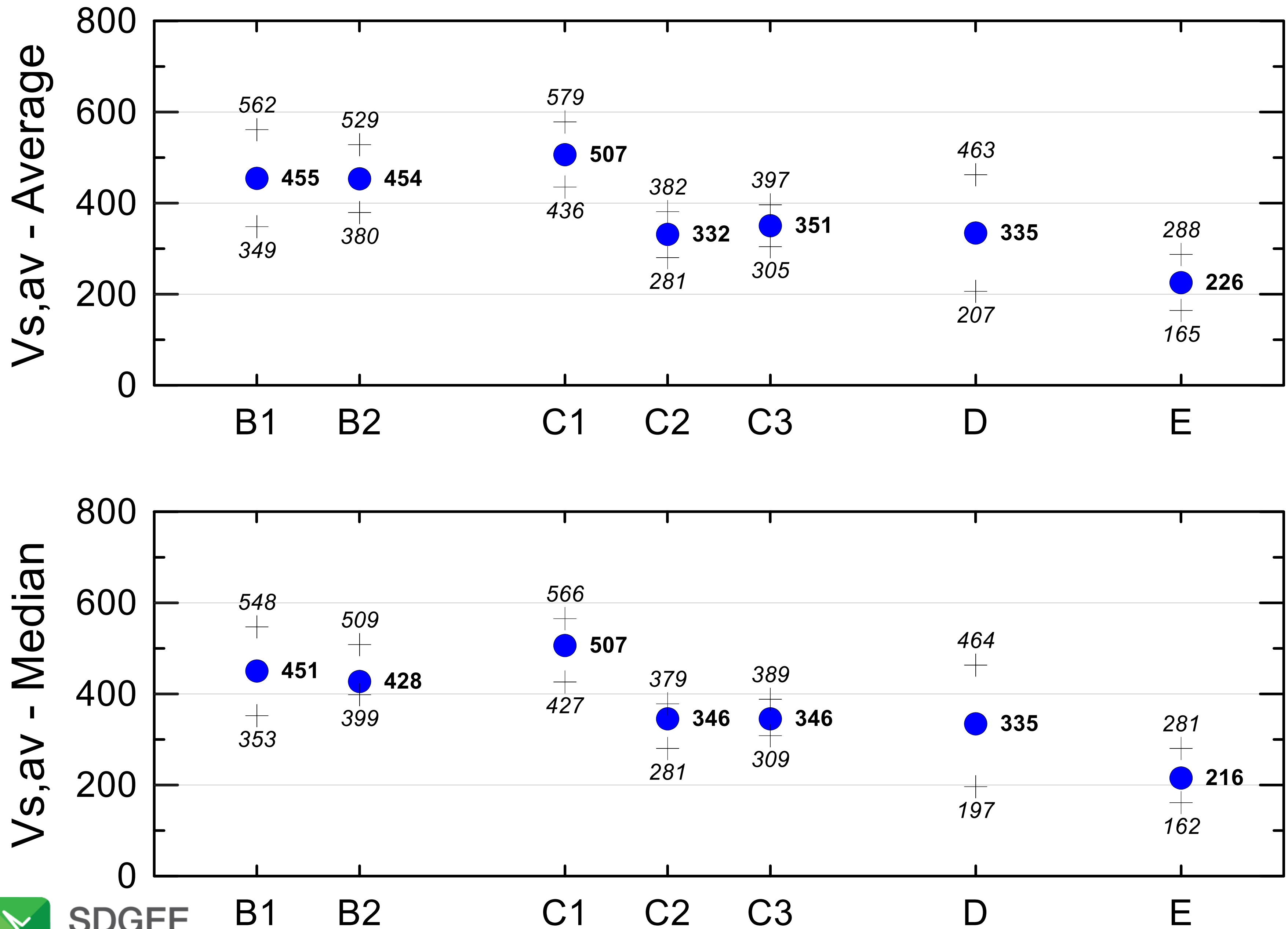
Considering
Two anchoring spectral parameters
Ss and S1
&
Scalar increase of seismic intensity

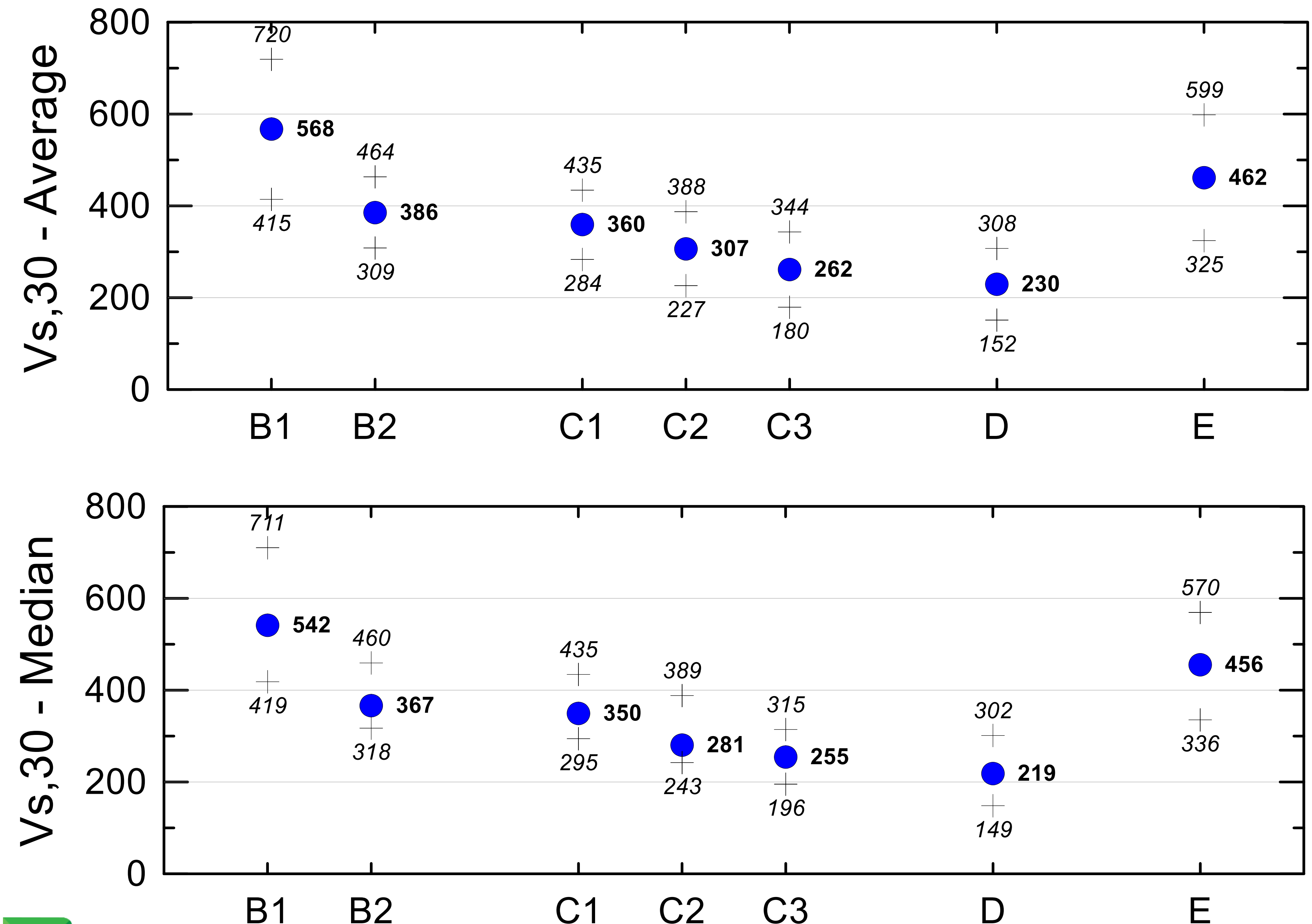
SHARE-AUTH database

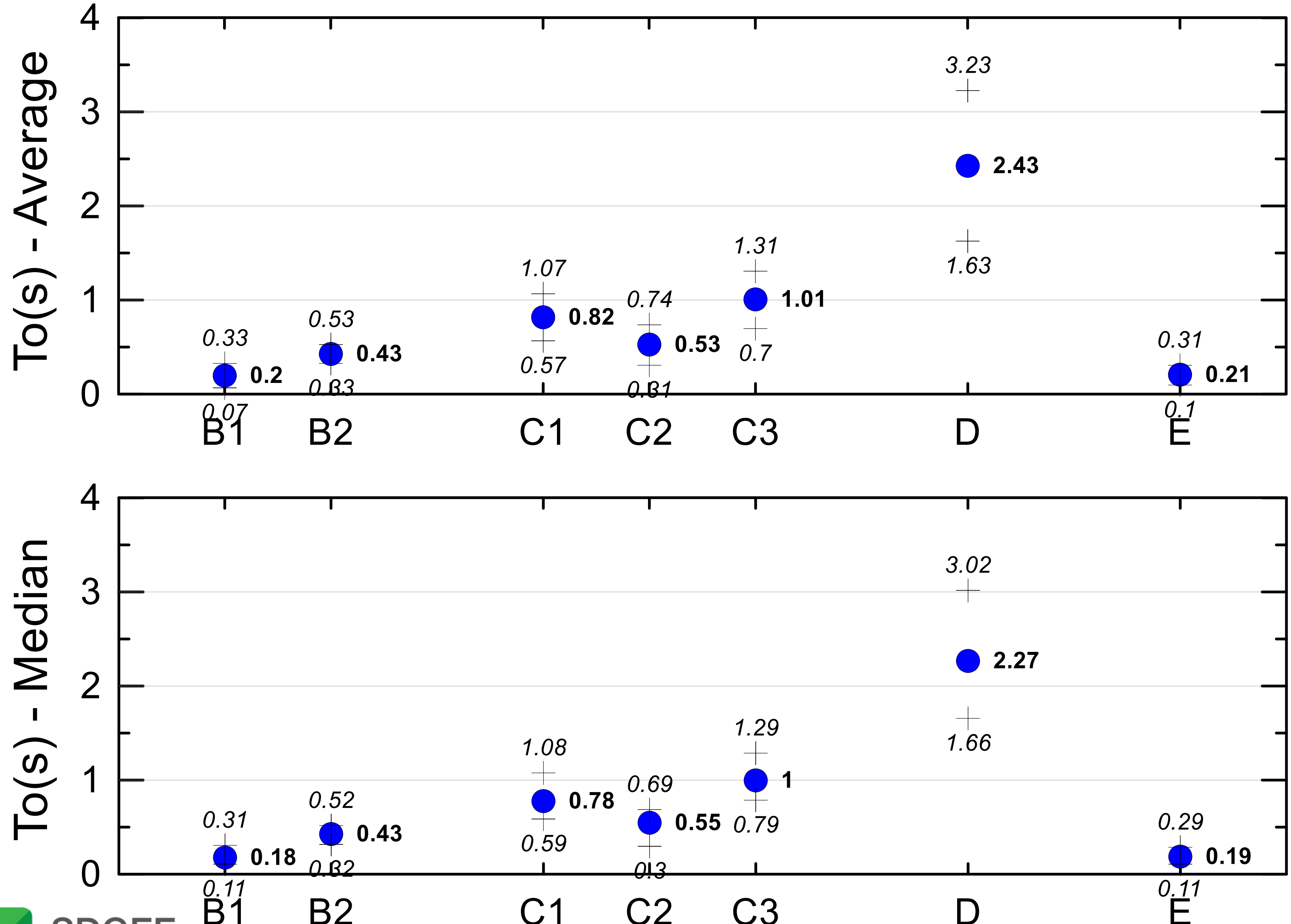
- 3,666 records from 536 stations from Greece, Italy, Turkey, Japan and USA with a well-documented soil profile up to the seismic bedrock (Vs>800m/s)



Pitilakis et al. (2013)

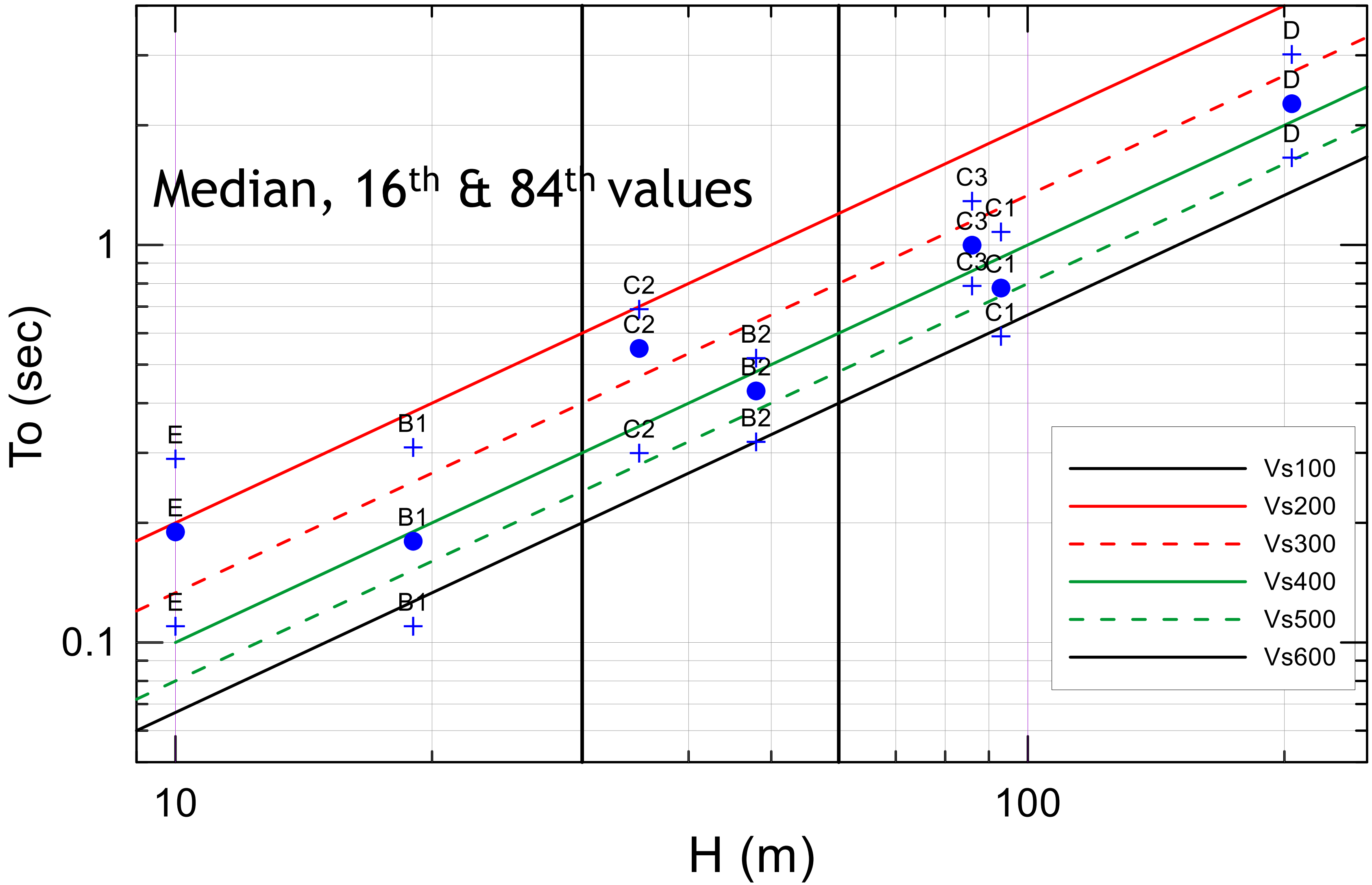

800
600
400
200
0
Vs,av - Average
562
455
349
529
454
380
579
507
436
382
332
281
397
351
305
463
335
207
288
226
165
B1
B2
C1
C2
C3
D
E
800
600
400
200
0
Vs,av - Median
548
451
353
509
428
399
566
507
427
379
346
281
389
346
309
464
335
197
281
216
162
B1
B2
C1
C2
C3
D
E


Vs,30 - Average
800
600
400
200
0
B1
B2
C1
C2
C3
D
E
720
568
415
464
386
309
435
360
284
388
307
227
344
262
180
308
230
152
599
462
325
Vs,30 - Median
711
542
419
460
367
318
435
350
295
389
281
243
315
255
196
302
219
149
570
456
336



To(s) - Average
To(s) - Median
B1
B2
C1
C2
C3
D
E
0.2
0.43
0.82
0.53
1.01
2.43
0.21
0.18
0.43
0.78
0.55
1
2.27
0.19

T_0(sec)-H(m)



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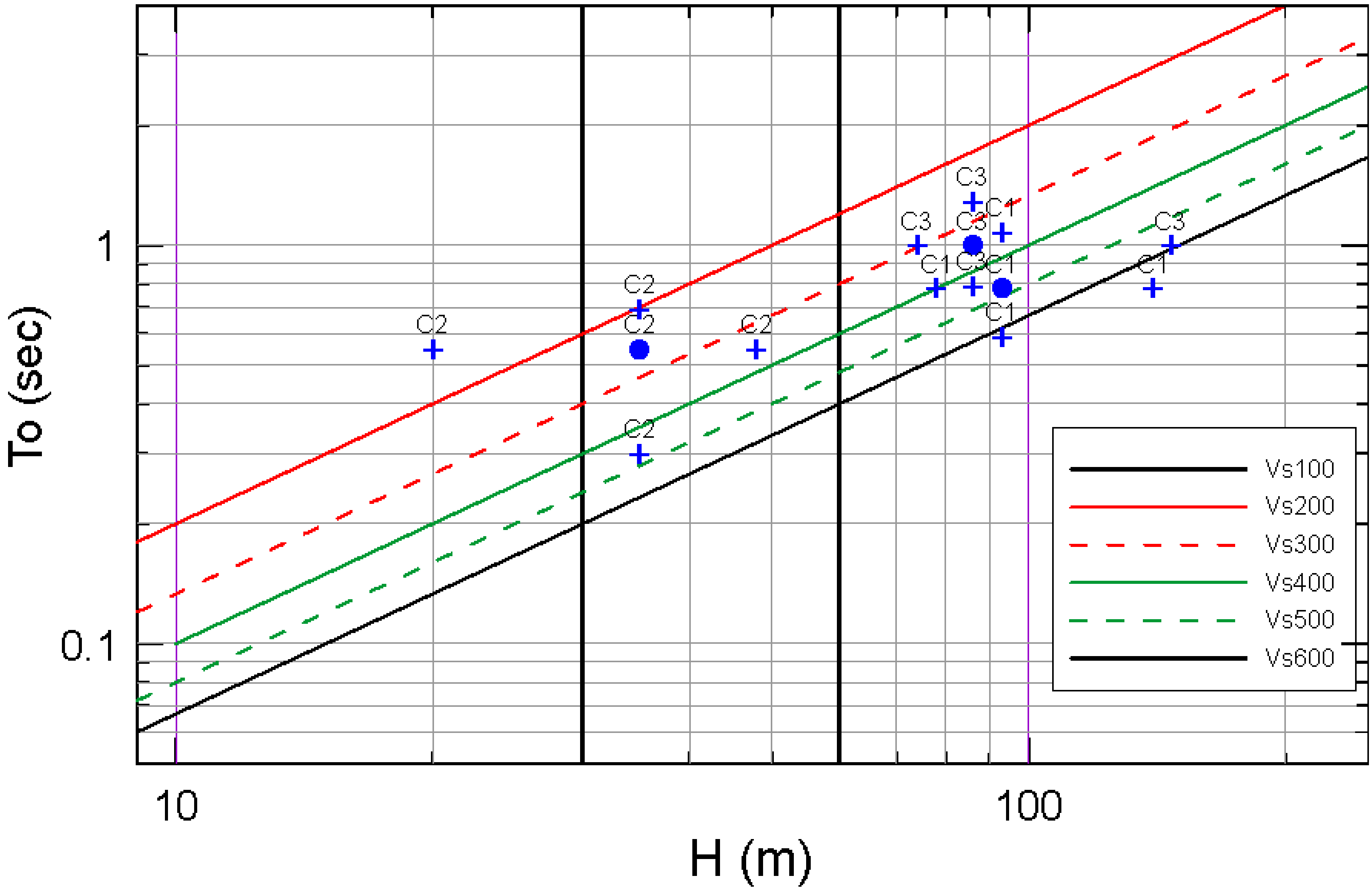
T_0(sec)-H(m)



To (sec)
H (m)
1
0.1
10
100
C1
C2
C3
Vs100
Vs200
Vs300
Vs400
Vs500
Vs600

Site categorization

The main parameters

- The **fundamental period** of soil deposit, $\mathbf{T_0}$
- The **average shear wave velocity** of the entire soil deposit to the "seismic bedrock", $\mathbf{V_{s,av}}$ or the **average shear wave velocity of the upper 30m** of the soil profile, $\mathbf{V_{s,30}}$
- The **thickness of the soil deposit** (i.e. depth to the "seismic" bedrock - Vs>800m/s), **H**

together with appropriate descriptive parameters of the geotechnical conditions namely

- the **dominant soil profile description** and average values of **standard penetration test blow count $\mathbf{N_{SPT}}$**
- **plasticity index PI**
- **undrained shear strength $\mathbf{S_u}$** over depth H

Parameters derived from other field tests like the cone penetration test or pressumeter may be also used. In case of absence of direct measurement of these parameters adequate correlations may be used.

Site categorization

The fundamental period of soil deposit, T_0, and the average shear wave velocity of the entire soil deposit, $V_{s,av}$, are defined by the following expressions:

$$T_0 = {}^{4H}/_{V_{s,av}}$$

$$V_{s,av} = \frac{H}{\sum_{i=1,N_b} {}^{h_i}/_{V_i}}$$

where h_i and V_i denote respectively the thickness and shear-wave velocity of the i -th layer, in a total of N_b layers from the surface to the “seismic” bedrock

The value of the average shear wave velocity of the upper 30m of the soil profile, $V_{s,30}$, is defined by the following equation:

$$V_{s,30} = \frac{30}{\sum_{i=1,N} {}^{h_i}/_{V_i}}$$

where N is the number of layers existing in the top 30m

Site categorization

To obtain $\mathbf{T_0}$ and $\mathbf{V_{s,av}}$ or $\mathbf{V_{s,30}}$ from equations invasive (in-hole measurements) or non-invasive (e.g. surface-waves analysis) techniques at small strains should be preferred.

H may be available from geological, geophysical or geotechnical information.

The sites are classified into six basic categories (A, B, C, D, E and X) with sub-classes for site class B and C

Site specific ground response studies should be carried out in the following cases:
- For site conditions matching site class X for the definition of the seismic action and sites susceptible to soil liquefaction and soil failure under the seismic action
- For buildings of importance class III and IV in soft soil sites ($V_{s,30}$ <200m/s) generally classified in site classes D or E
- When site conditions cannot be clearly associated to standard site categories

New proposal for site – soil classification scheme

	Description	T_0	Remarks
A	-Rock formations -Slightly weathered / segmented rock formations (thickness of weathered layer <5.0m) -Geologic formations resembling rock formations in their mechanical properties and their composition (e.g. conglomerates)	$\leq 0.2s$	Hard rock $Vs_{,av}$ >1500 m/s Rock like formations: $V_{s,av}$ or $V_{s30} \geq 800$ m/s Surface weathered layer (if any with H<5m): $V_{s,av} \geq 300$ m/s

New proposal for site – soil classification scheme

	Description	T_0	Remarks	
B	-Soft rock formations -Formations which resemble to soft rock in their mechanical properties (e.g. stiff marls) -Very dense sand-gravels -Hard and very stiff clays **H<30m**	0.1-0.3s ≤ 0.3s	$V_{s,av}$: 350-600 m/s $V_{s,30}$: 400-760m/s N-SPT > 50 S_u> 150 KPa	**B1**
	-Soil formations of very dense sand – sand gravel and/or very stiff/ to hard clay, of homogenous nature, whose mechanical properties increase with depth **30m<H<60m**	0.3-0.6s ≤ 0.6s	$V_{s,av}$: 400-550 m/s $V_{s,30}$: 350-500m/s N-SPT > 50 S_u> 150 KPa	**B2**

New proposal for site – soil classification scheme

	Description	T_0	Remarks	
C1	Soil formations of dense sand – sand gravel and/or stiff clay, of great thickness (> 60.0m), whose mechanical properties and strength are constant and/or increase with depth **H>60m**	0.6-1.0s ≤ 1.0s	$V_{s,av}$: 400-600 m/s V_{s30} :350-450 m/s N -SPT> 50 S_u > 150 KPa	**C1**
C2	Soil formations of medium dense sand – sand gravel and/or medium stiffness clay (PI > 15, fines percentage > 30%) **20m <H< 60m**	0.3-0.7s ≤ 0.8s	$V_{s,av}$: 250-450 m/s V_{s30} :250-400 m/s N -SPT> 20 150KPa> S_u > 70 Kpa	**C2**
C3	Like C2 but with great thickness **H>60m**	0.7-1.4s ≤ 1.4s	$V_{s,av}$: 300-500 m/s V_{s30} :200-350 m/s N -SPT> 20 150KPa > S_u > 70 Kpa	**C3**

New proposal for site – soil classification scheme

	Description	T_0	Remarks
D	-Recent soil deposits of substantial thickness (up to 60m or more), with the prevailing formations being soft clays or/and clays with a thickness h>3.0m, of high plasticity index (PI>20), high water content (W>40%) and low values of strength parameters (Su<25KPa) - Recent soil deposits of substantial thickness (up to 60m), with prevailing loose sandy to sandy-silty formations with a substantial fines percentage (not to be considered susceptible to liquefaction) - Soil formations of great overall thickness (> 60.0m), interrupted by layers of soft soils of a small thickness (5 – 15m), up to the depth of ~40m, within soils (sandy and/or clayey, category C) of evidently greater strength, with $V_{s,av} \geq 300$ m/sec	≤ 1.4s ≤ 1.4s 1.4-3.0s ≤ 3.0s	$V_{s,av}$: 200-400 m/s V_{s30} :150-300 m/s N-SPT < 20 S_u < 70KPa

New proposal for site – soil classification scheme

	Description	T_0	Remarks
E	Surface soil formations of small thickness (5 - 20m), small strength and stiffness, likely to be classified as category C and D according to its geotechnical properties, which overlie category A formations ($V_{s,av}$ ≥800 m/sec)	0.1-0.5s ≤ 0.5s	$V_{s,av}$: 160- 300 m/s
X	Loose fine sandy-silty soils beneath the water table, susceptible to liquefaction (unless a special study proves no such danger, or if the soil's mechanical properties are improved) Soils near obvious tectonic faults Steep slopes covered with loose lateral deposits Loose granular or sot silty-clayey soils, provided they have been proven to be hazardous in terms of dynamic compaction or loss of strength. Recent loose landfills Soils with a very high percentage in organic material Special soils requiring site-specific evaluations		

Seismic action

Territories shall be mapped depending on the local seismic hazard.

The seismic hazard is described in terms of two parameters, namely:

- $S_{s,ref}$, the reference maximum spectral acceleration, corresponding to the constant acceleration branch of the horizontal 5% damped elastic response spectrum
- $S_{1,ref}$, the reference spectral acceleration at the vibration period T = 1 s of the horizontal 5% damped elastic response spectrum

$S_{s,ref}$ and $S_{1,ref}$ are given for the reference return period for example 475y or 10% probability of exceedence in 50 years

Horizontal elastic response spectrum

For the **horizontal components of the seismic action**, the elastic response spectrum $S_e(T)$ is defined by the following expressions:

$$0 \le T \le T_A : S_e(T) = \frac{S_S}{F_0}$$

$$T_A \le T \le T_B : S_e(T) = \frac{S_S}{T_B - T_A}\left[\eta \cdot (T - T_A) + \frac{T_B - T}{F_0}\right]$$

$$T_B \le T \le T_C : S_e(T) = \eta \cdot S_S$$

$$T_C \le T \le T_D : S_e(T) = \eta \cdot \left[\frac{S_1 \cdot T_1}{T}\right]$$

$$T \ge T_D : S_e(T) = \eta \cdot T_D\left[\frac{S_1 \cdot T_1}{T^2}\right]$$

where

$S_e(T)$ is the elastic response spectrum;

T is the vibration period of a linear single-degree-of-freedom system;

S_s is the maximum response spectral acceleration (5% damping) corresponding to the constant acceleration range of the elastic response spectrum;

S_1 is the 5% damping response spectral acceleration at the vibration period $T_1 = 1$ s;

T_1 T_1=1 s;

T_A is the short-period cut-off associated to the peak ground acceleration;

F_0 is the ratio of S_s with respect to the peak ground acceleration;

$T_C = \left[\frac{S_1 \cdot T_1}{S_S}\right]$ is the upper corner period of the constant spectral acceleration range;

$T_B = \left[\frac{T_C}{\kappa}\right]$ is the lower corner period of the constant spectral acceleration range, with 0,05 s $\le T_B \le 0.1$ s, whatever value of T_C

κ is the ratio of T_C and T_B;

T_D is the corner period at the beginning of the constant displacement response range of the spectrum;

η is the damping correction factor, with a reference value of $\eta = 1$ for 5% viscous damping

Horizontal elastic response spectrum

Recommended values for seismic hazard parameters
defining the elastic response spectrum

T_A (s)	κ (*)	F_0(**)	T_D (s)
0,03	**5.0**	**2.5**	2 if $S_{1RP} \le 0{,}1g$ $1+10 \cdot S_{1RP}$ if $S_{1RP} > 0{,}1g$

F_0 may take higher values e.g. 2.75 for site categories E in particular of low seismicity regions.

The spectral accelerations S_s and S_1 are defined as follows:

$$\mathbf{S_s = F_T \times F_B \times F_s \times S_{sRP}}$$
$$\mathbf{S_1 = F_T \times F_B \times F_1 \times S_{1RP}}$$

where

F_s is the short period site amplification factor
F_1 is the intermediate period (T1 = 1 s) site amplification factor
F_T is the topography amplification factor
F_B is the basin (or valley) period dependent amplification factor

The site amplification factors **Fs and F1** are **soil and intensity dependent**

Horizontal elastic response spectrum

Period independent topography and period dependent basin amplification factors, FT and FB respectively should be applied (with values to be defined).

The value of the damping correction factor η should be determined by the expression:

$$\eta \;\; = 10/(5+\xi) \geq 0.55$$

where η is the viscous damping ratio of the structure, expressed as a percentage. For η values larger than 28% this formula should be replaced by:

$$\eta = \frac{1}{0.85 + 3\xi - 2.8\xi \; \exp\left[-3T/(T_c\xi)\right]}$$

Elastic displacement response spectrum

The elastic displacement response spectrum, SDe(T) is given by the following expressions:

$$T \le T_E:\ S_{De}(T) = S_e(T)\left[\frac{T}{2\pi}\right]^2$$

$$T_E \le T \le T_F:\ S_{De}(T) = S_e(T_D)\left[1+\left(\frac{F_L}{F_1}-1\right)+\frac{T-T_E}{T_F-T_E}\right]$$

$$T \ge T_F: S_{De}(T) = S_e(T_D)\cdot\frac{F_L}{F_1}$$

$S_e(T)$ is the elastic response spectrum

T_E=max[T_D, 6 s], T_F=10 s;

F_L is the long period site amplification factor given as a function of F_1 (in parenthesis the site class):

$F_L = F_1$ (A), $F_L = 0.9 \cdot F_1$ (B1, B2 and C1), $F_L = 0.75 \times F_1$ (C2 or C3), $F_L = 0.6 \times F_1$ (D or E)

Soil amplification factors

- The soil factors proposed by Pitilakis et al. (2013) were properly adjusted to include the nonlinear term developed by Seyhan and Stewart (2014) and adopted in the Boore et al. (2014) GMPE:

$$F_{S,B} = \ln(F_{lin}) + \ln(F_{nl})$$

$$\ln(F_{nl}) = f_1 + f_2 \ln\left(\frac{PGA_r + f_3}{f_3}\right)$$

$$f_2 = f_4\left[\exp\left\{f_5\left(\min(V_{S30}, 760) - 360\right)\right\} - \exp\left\{f_5\left(760 - 360\right)\right\}\right]$$

f_1=0, f_3=0.1, f_4, f_5=period-dependent constant values

- Site amplification factors F_s and F_1 are proposed for the different site classes and for distinct values of S_{sRP} at rock site conditions representing very low-low, medium and high seismicity (S_{sRP}=PGA_r•F_0).
- Nonlinear terms are estimated for increasing S_{sRP} values using the properly estimated GMPE coefficients for short (F_s) and intermediate period (T=1s) (F_1)

New Soil factors

Fs Factors

Site class	S_{sRP} maximum response spectral acceleration at short period on site class A in g[a]					
	S_{sRP} <0.25 ([c])	S_{sRP} =0.25	S_{sRP} =0.5	S_{sRP} =0.75	S_{sRP} =1.0	S_{sRP} ≥1.25
A	1.00	1.00	1.00	1.00	1.00	1.00
B1	1.30	1.30	1.20	1.20	1.20	1.20
B2	1.40	1.30	1.30	1.20	1.10	1.10
C1	1.70	1.60	1.40	1.30	1.30	1.20
C2	1.60	1.50	1.30	1.20	1.10	1.00
C3	1.80	1.60	1.40	1.20	1.10	1.00
D[b]	2.20	1.90	1.60	1.40	1.20	1.00
E[b]	1.70	1.60	1.60	1.50	1.50	1.50
X[b]	-	-	-	-	-	-

[a] Use straight line interpolation for intermediate values of S_{sRP}.

[b] Site-specific geotechnical investigation and dynamic site response analyses shall be performed under conditions defined in this document

[c] Dynamic soil response practically in the elastic range

New Soil factors

F_1 Factors

Site class	S_{sRP} maximum response spectral acceleration at short period on site class A in g[a]					
	S_{sRP} <0.25 [c]	S_{sRP} =0.25	S_{sRP} =0.5	S_{sRP} =0.75	S_{sRP} =1.0	S_{sRP} ≥1.25
A	1.00	1.00	1.00	1.00	1.00	1.00
B1	1.40	1.40	1.40	1.40	1.30	1.30
B2	1.60	1.50	1.50	1.50	1.40	1.30
C1	1.70	1.60	1.50	1.50	1.40	1.30
C2	2.10	2.00	1.90	1.80	1.80	1.70
C3	3.20	3.00	2.70	2.50	2.40	2.30
D[b]	4.10	3.80	3.30	3.00	2.80	2.70
E[b]	1.30	1.30	1.20	1.20	1.20	1.20
X[b]	-	-	-	-	-	-

[a] Use straight line interpolation for intermediate values of S_{sRP}.

[b] Site-specific geotechnical investigation and dynamic site response analyses shall be performed under conditions defined in this document

[c] Dynamic soil response practically in the elastic range

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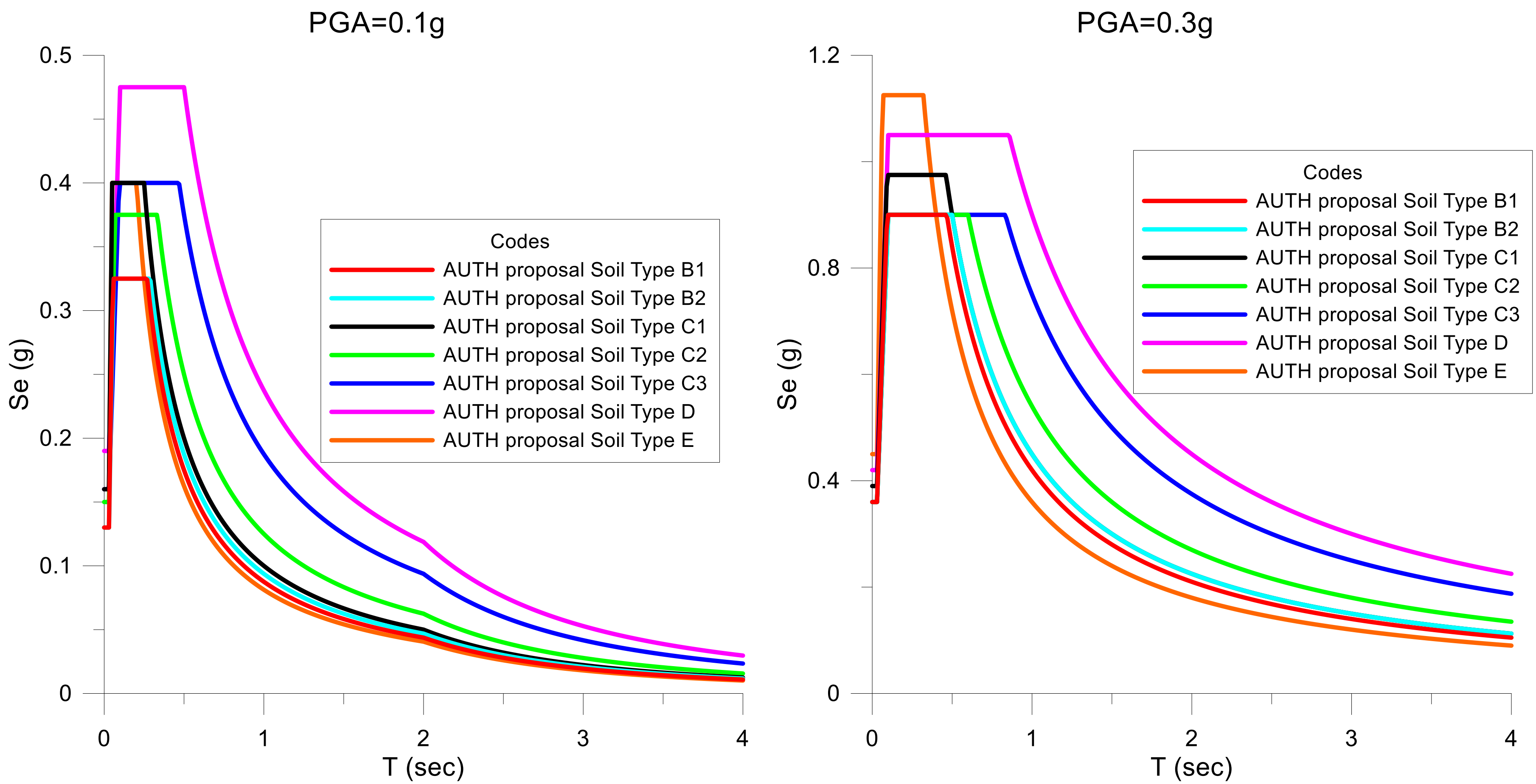
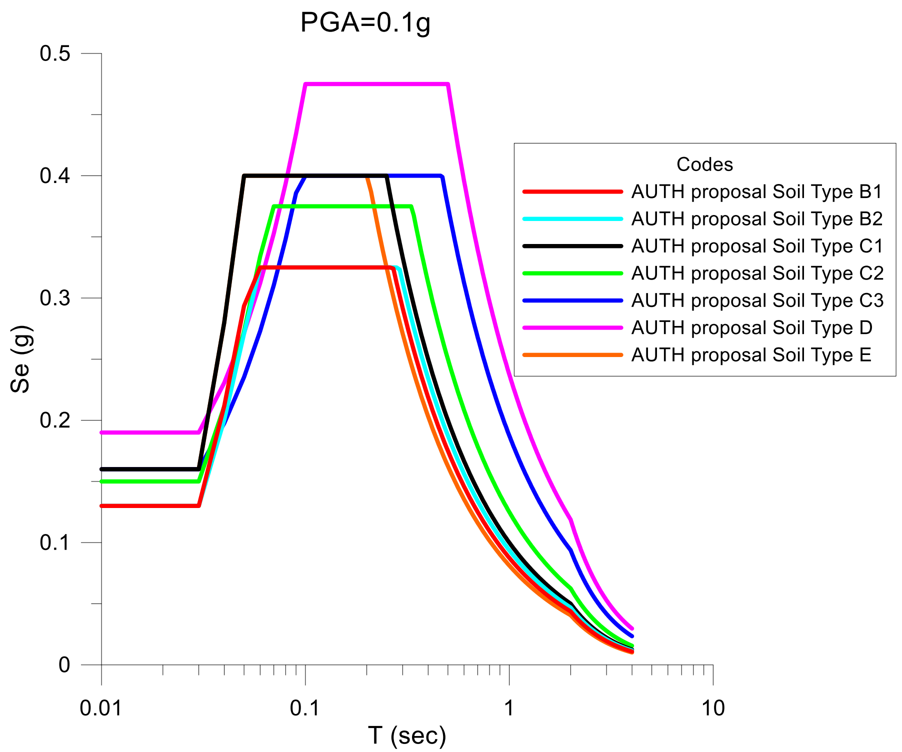
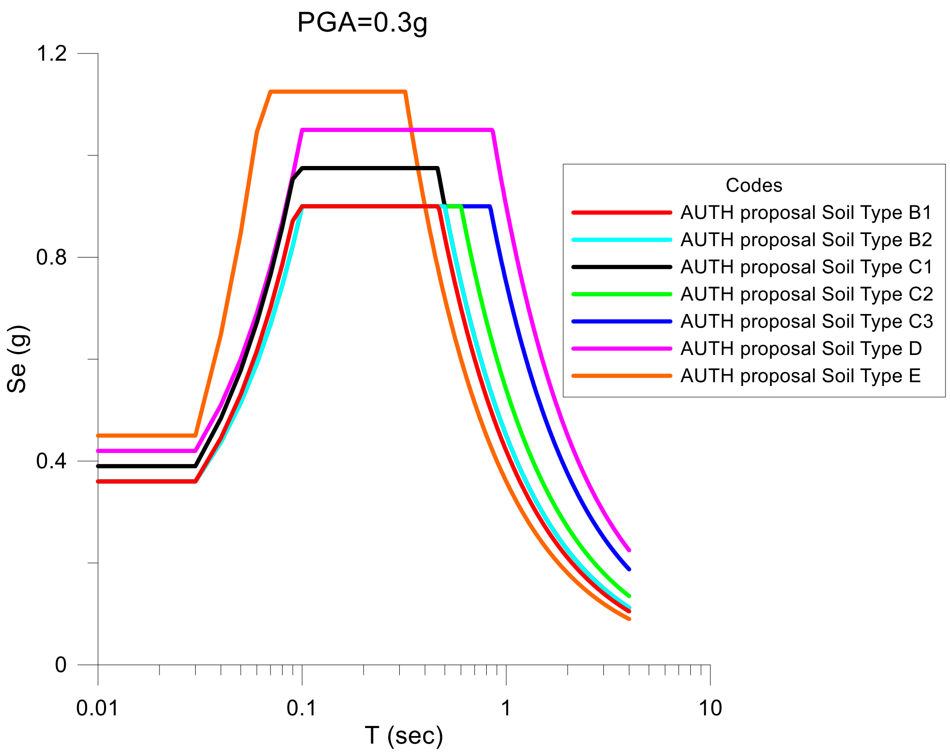
Elastic response spectra

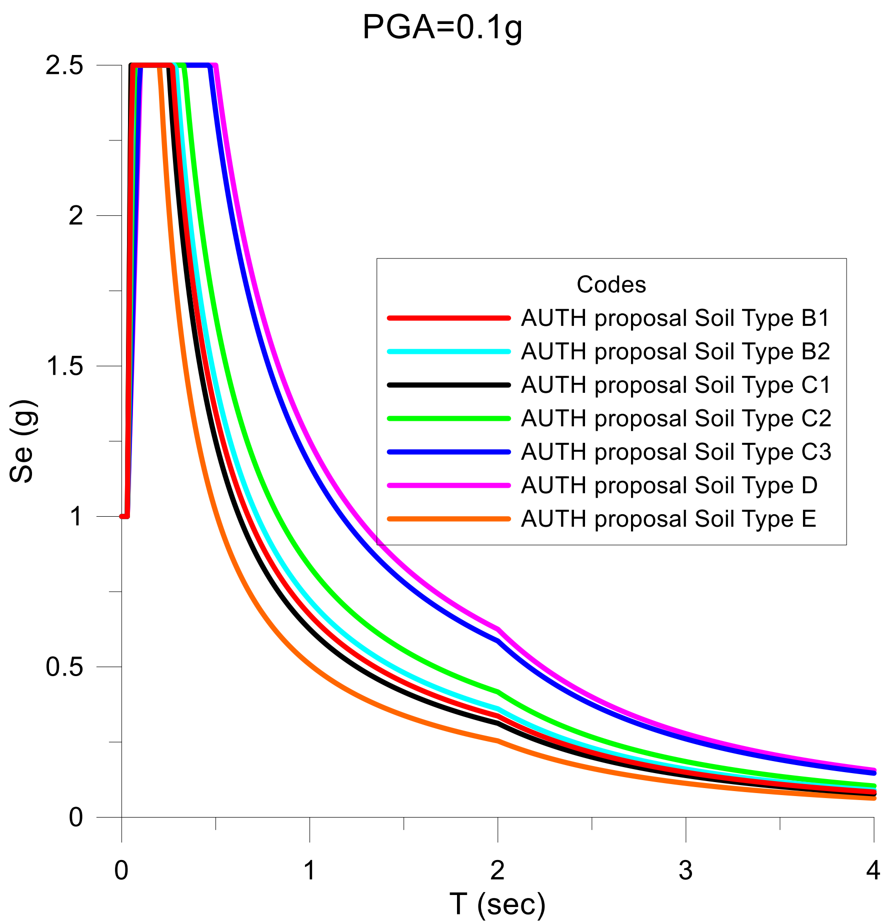


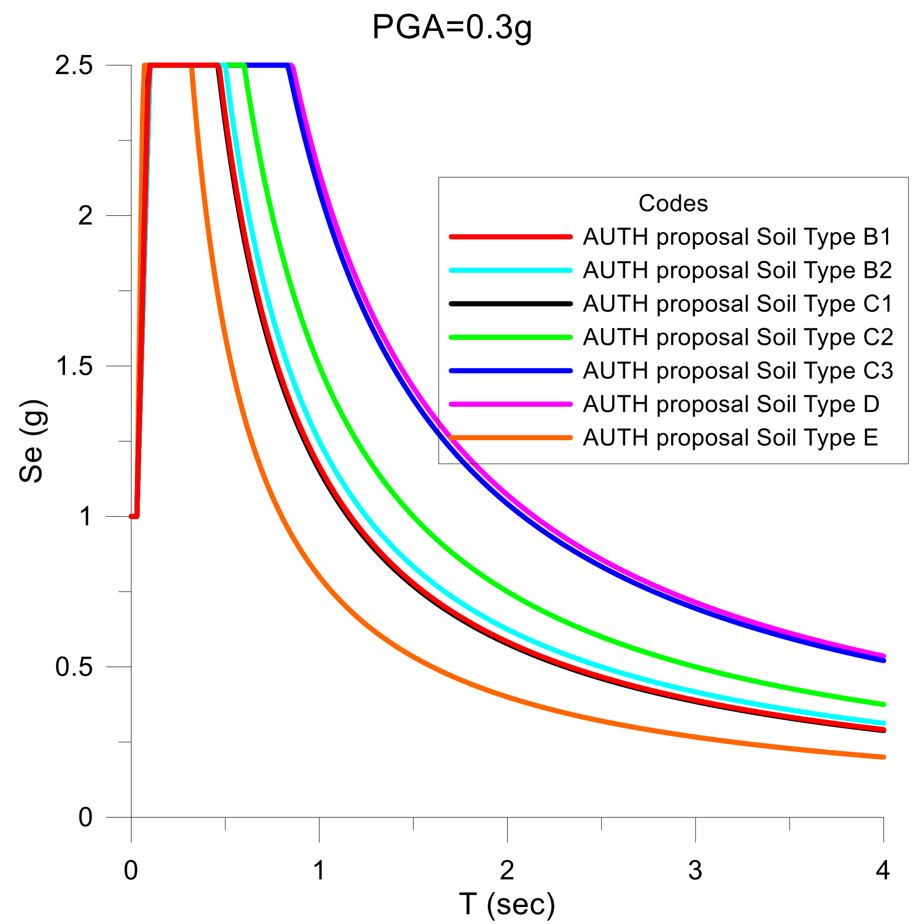
Elastic response spectra



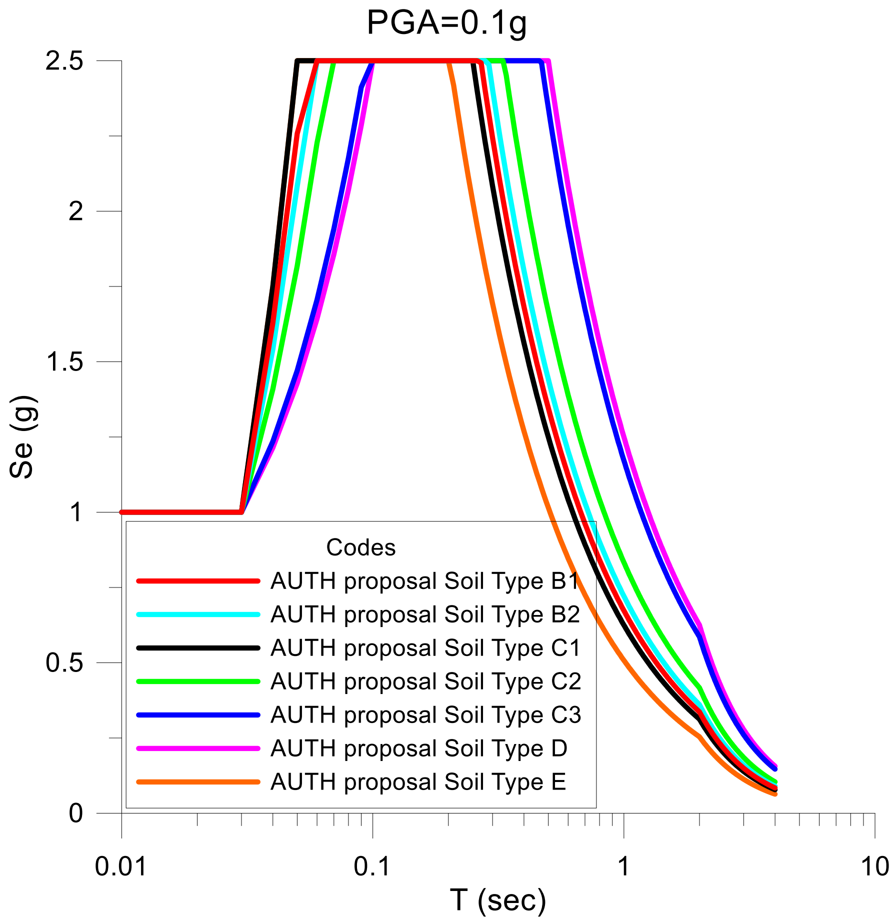


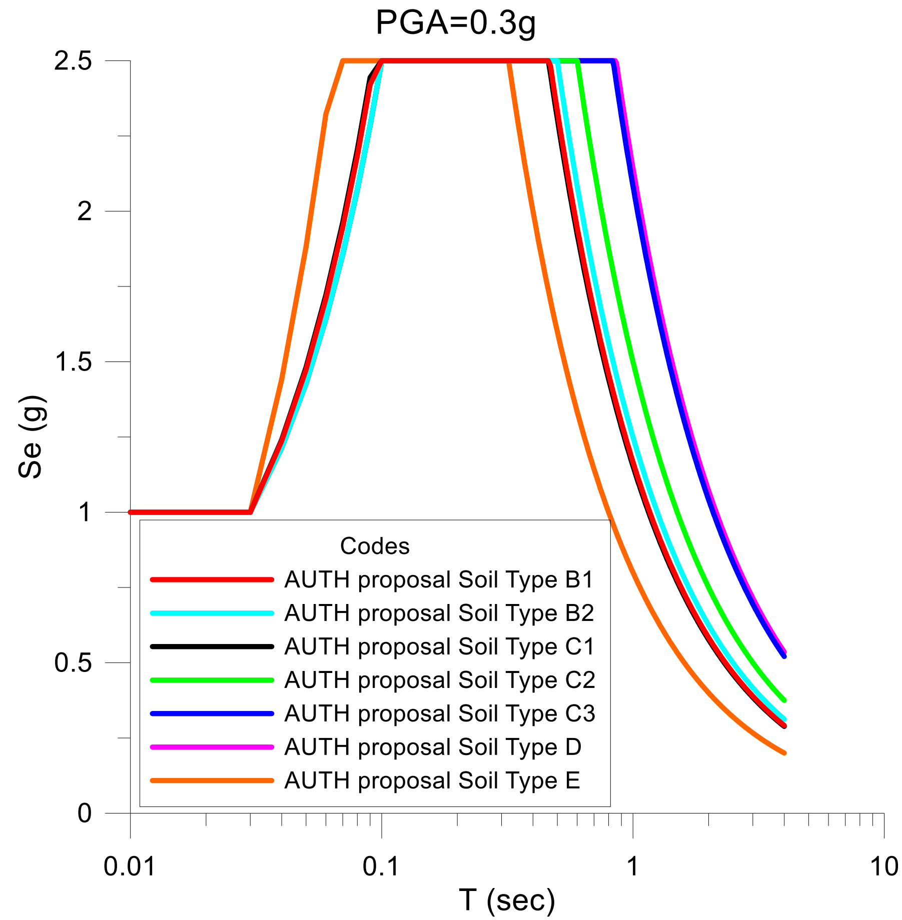
Normalised elastic response spectra





Normalised elastic response spectra





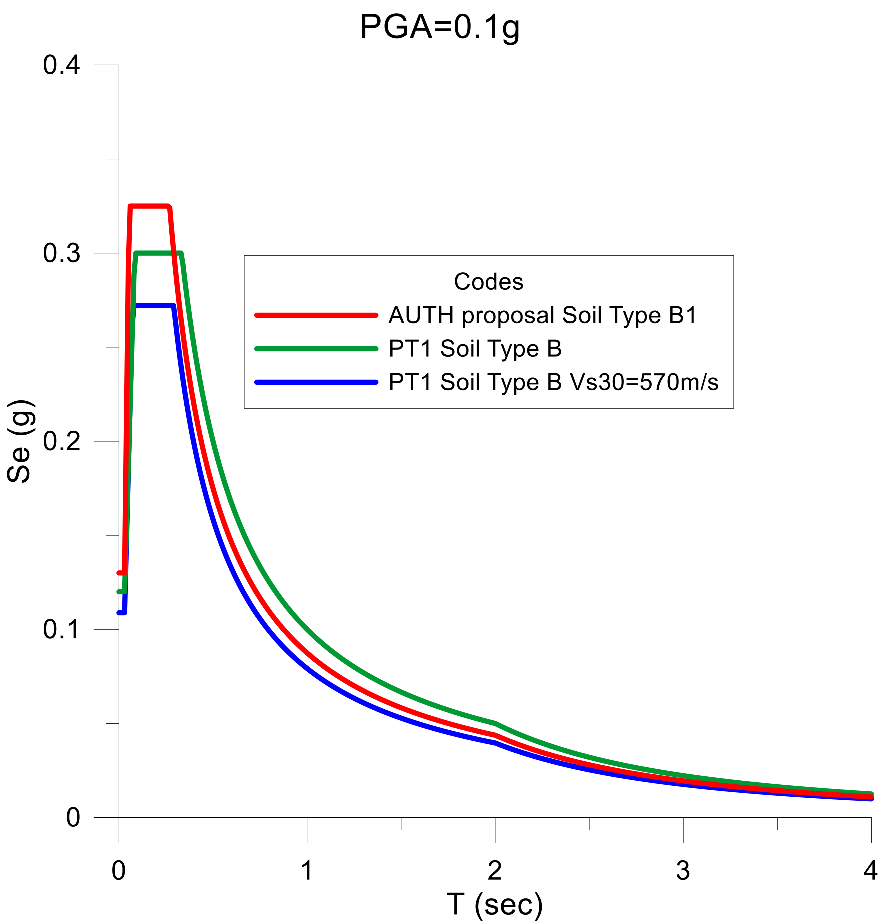
Advantages of the proposed site conditions and seismic actions compared to the proposal of PT1

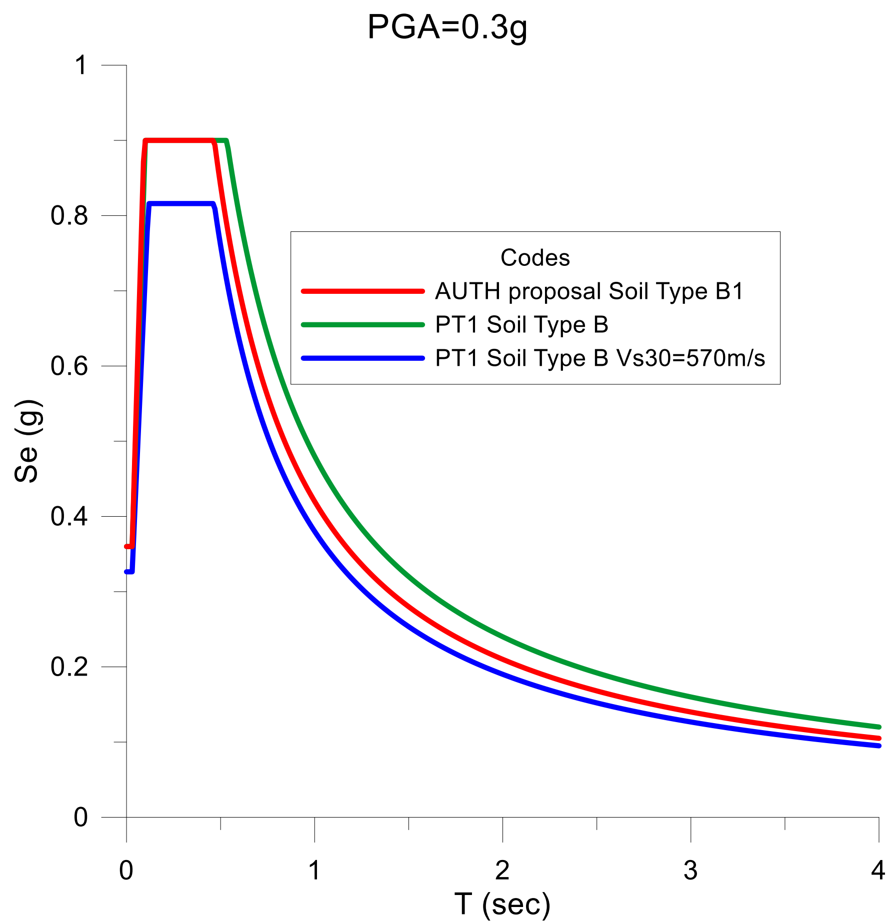
New site/soil classification

- **Easily understandable and applied** by the engineering community compared to the rather complicated scheme and procedure proposed in PT1 draft

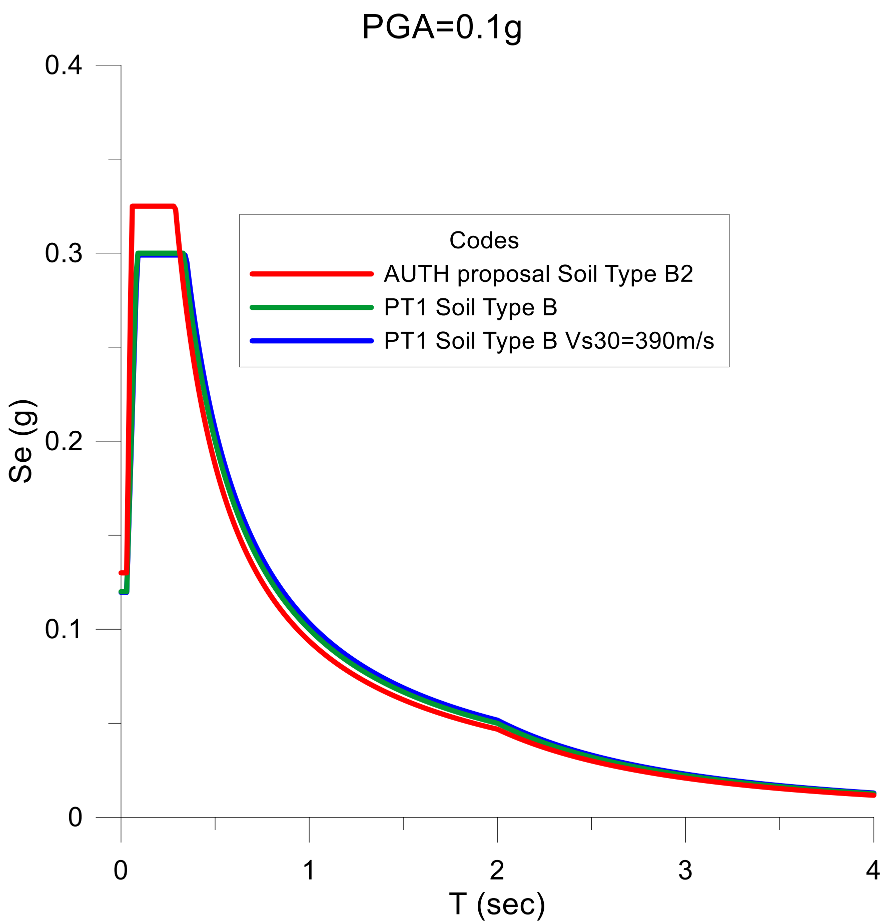
- Fulfills all basic requirements of the ongoing revision of EC8 Part1 and is **compatible** in its conceptual axis **with the most advanced and modern international seismic codes**.

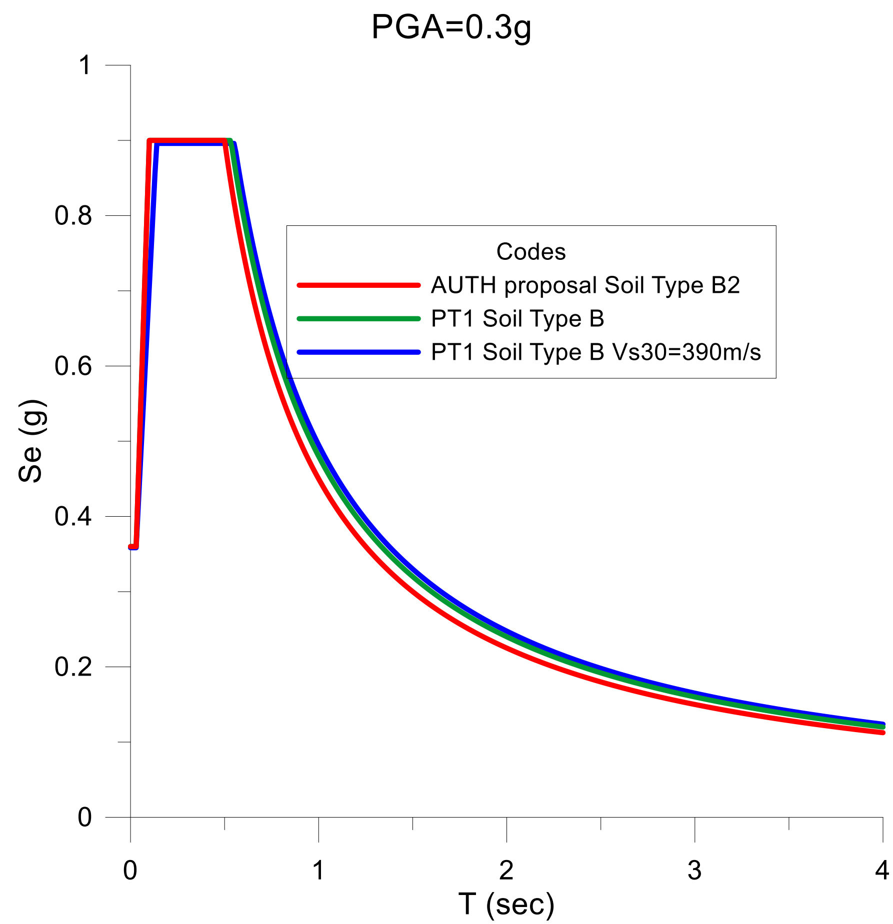
Design response spectra comparison



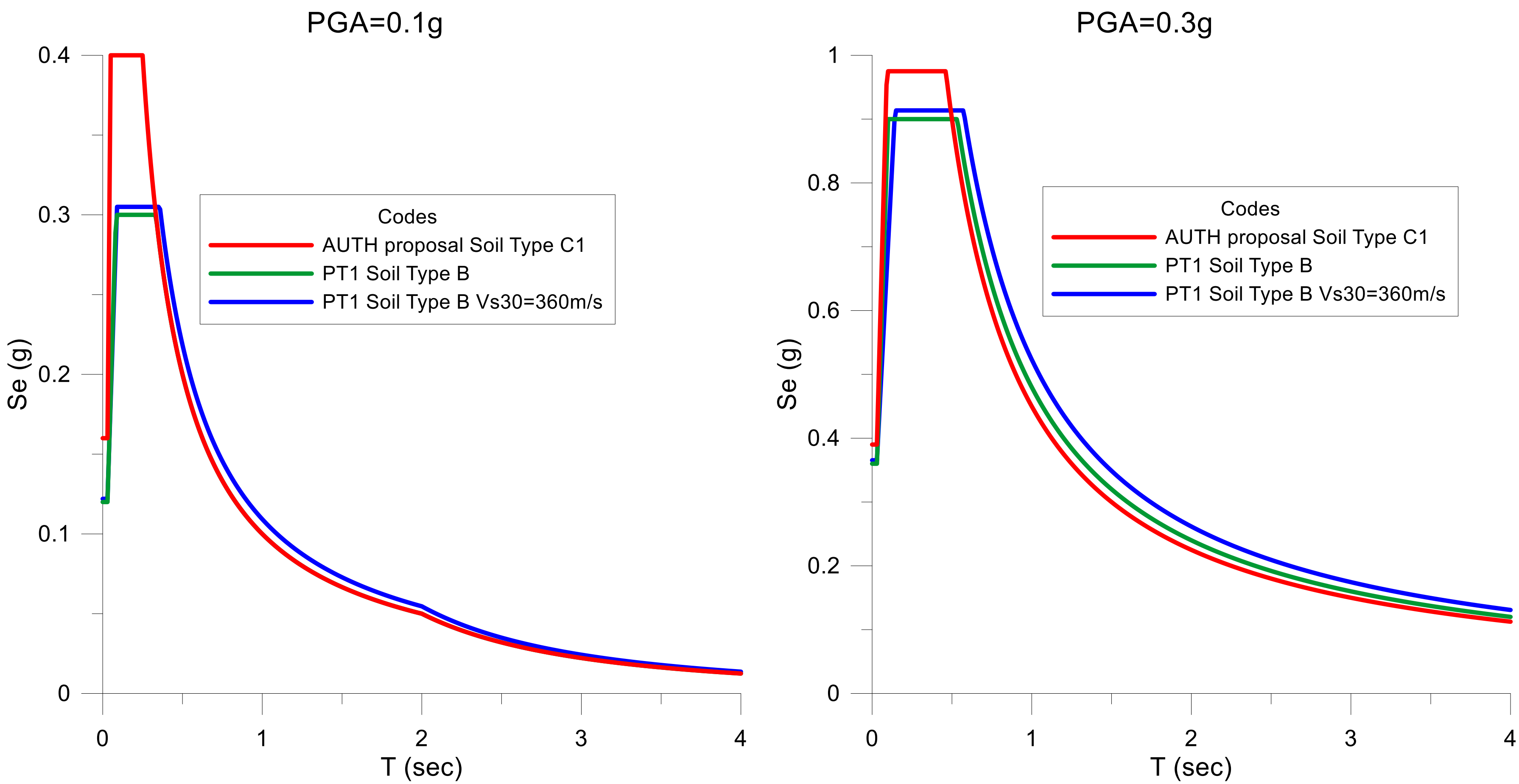


Design response spectra comparison





Design response spectra comparison



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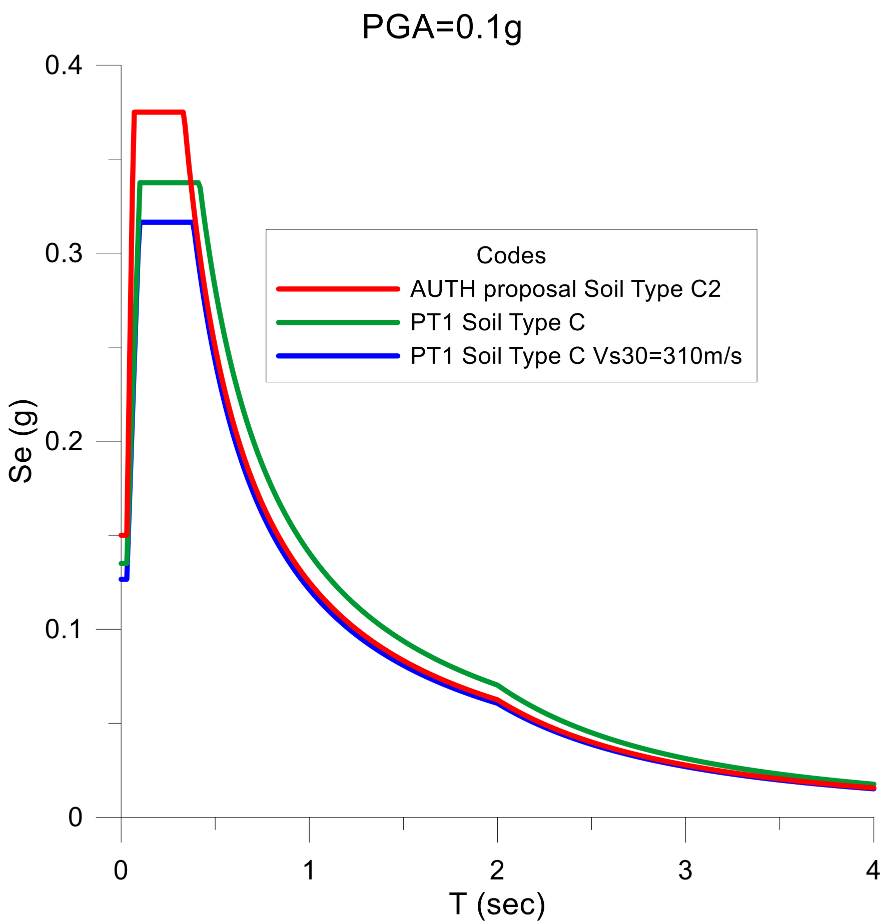
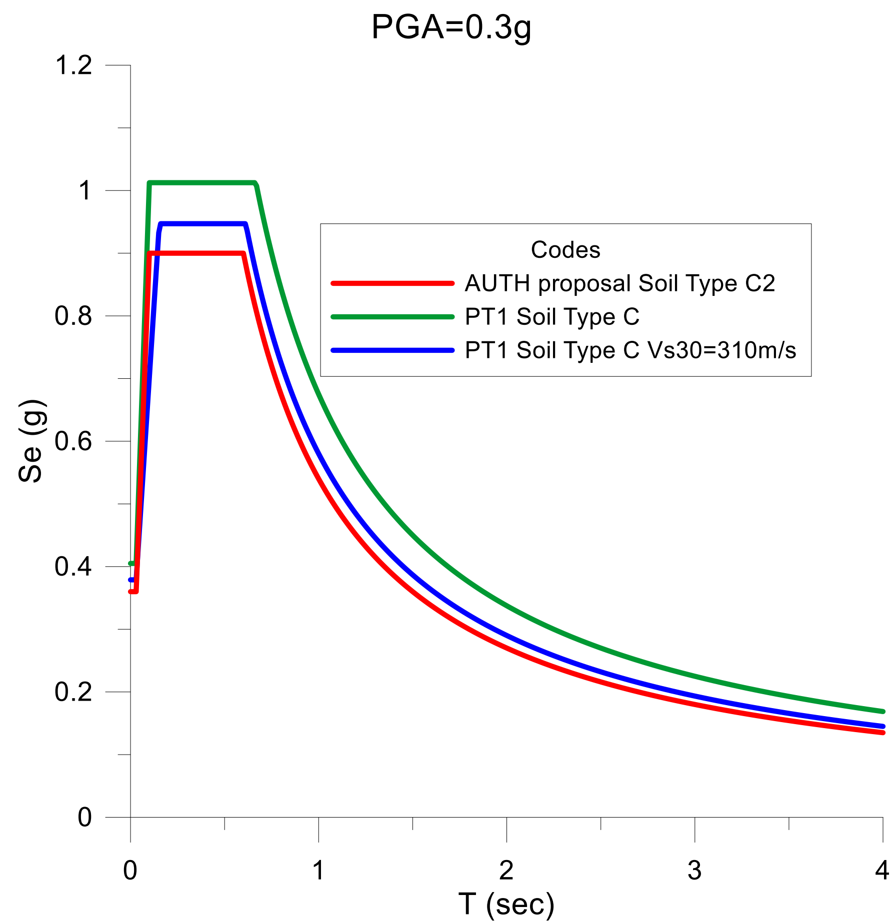
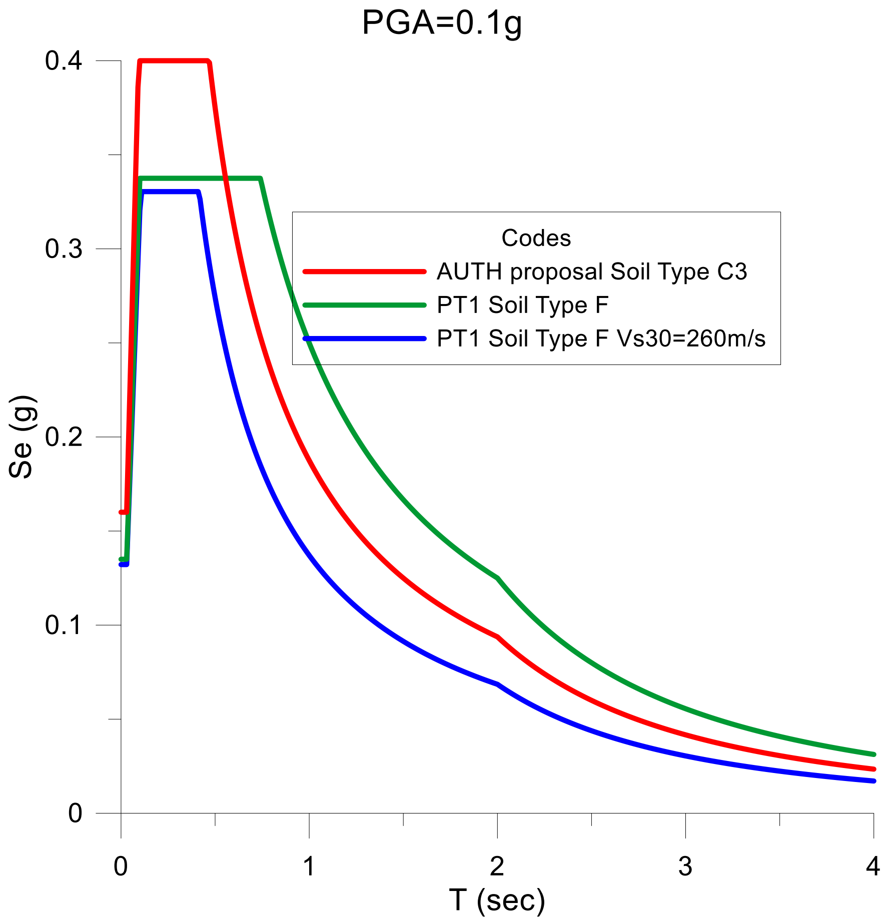
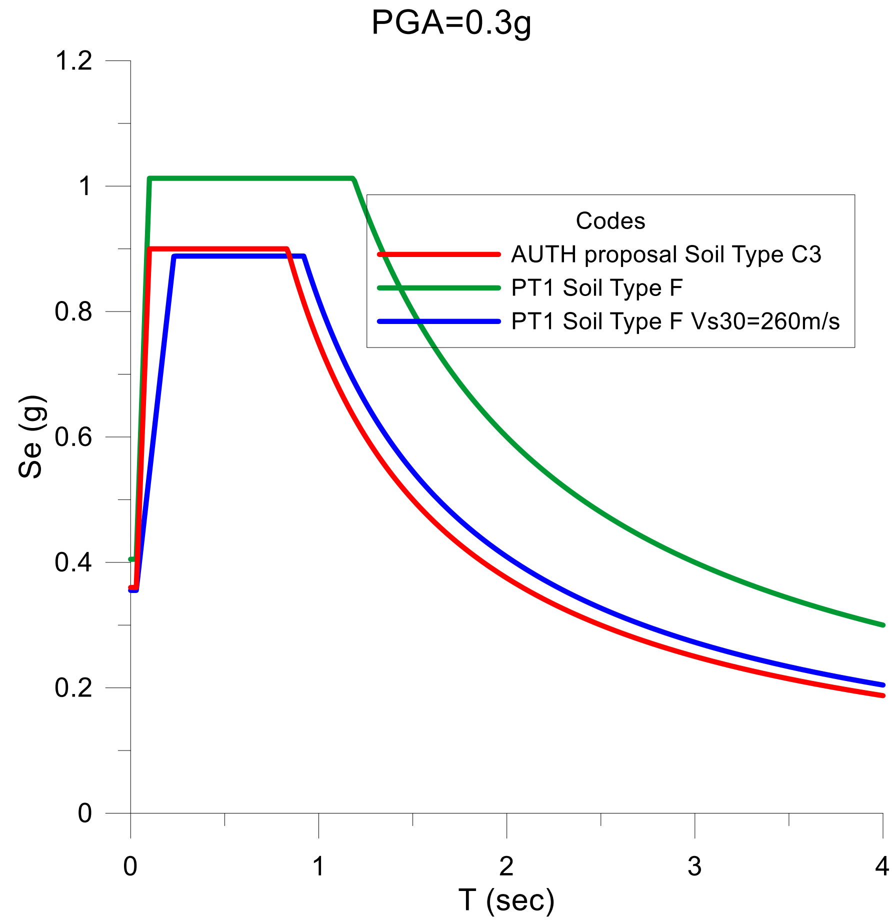


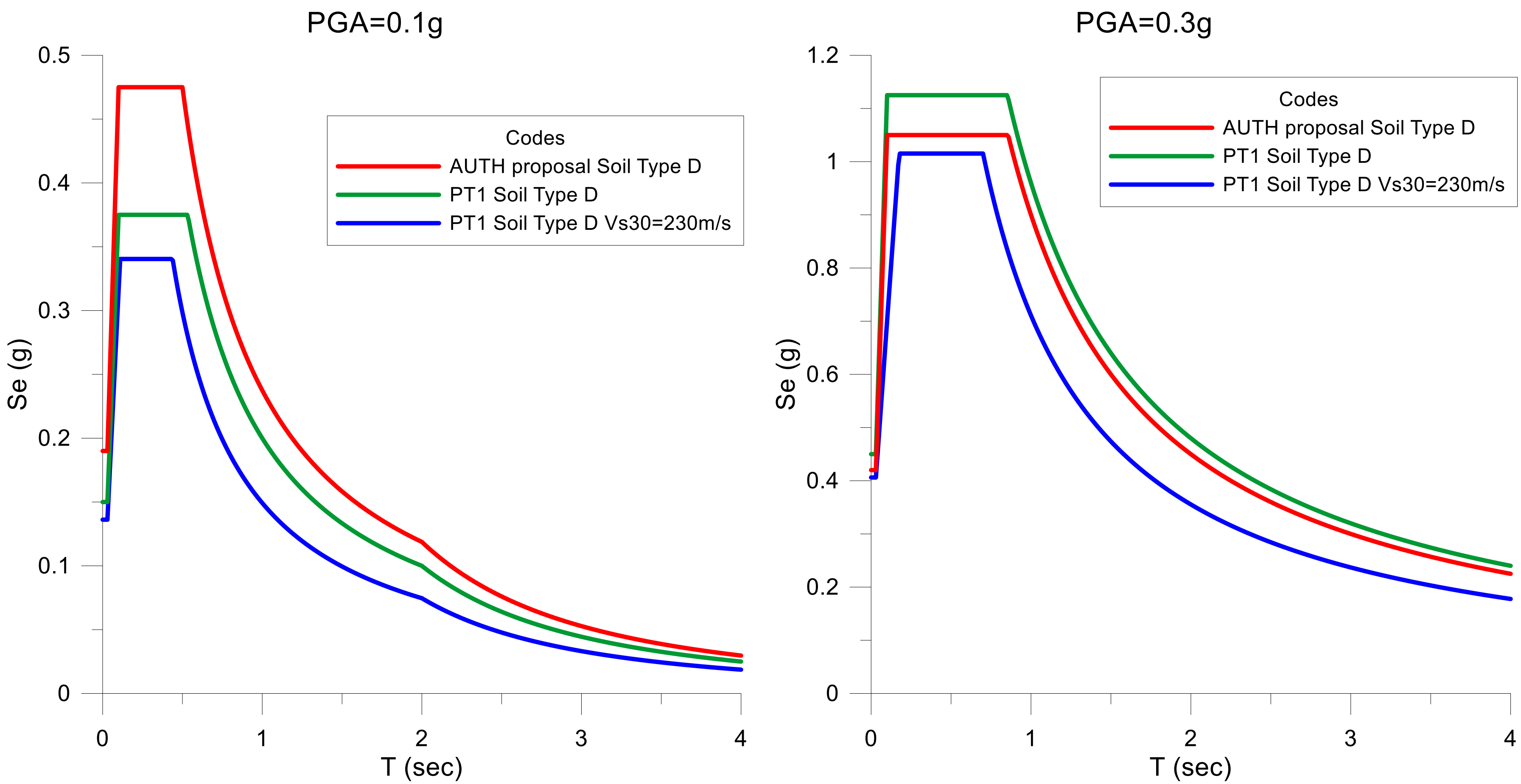


Design response spectra comparison

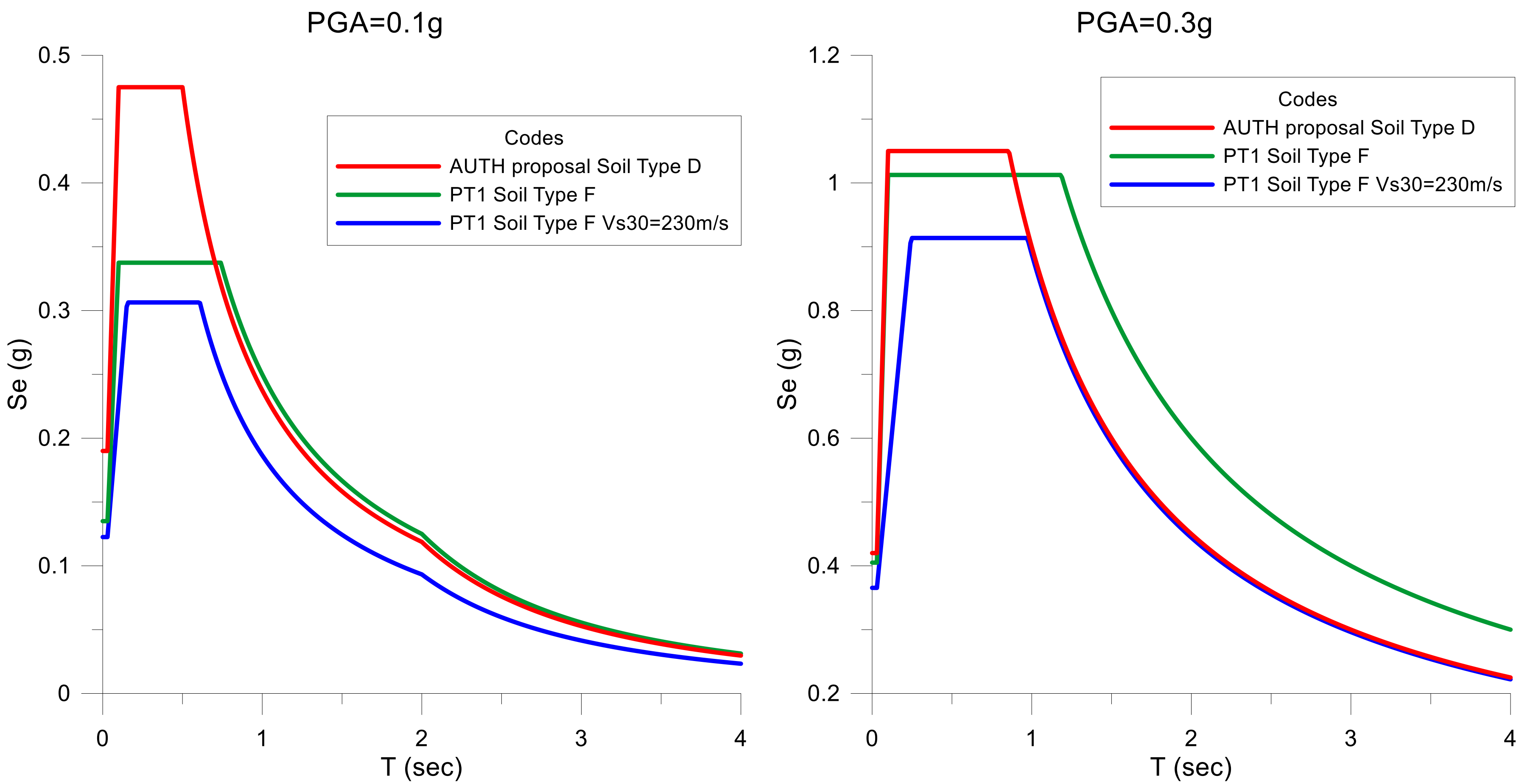




Design response spectra comparison



Design response spectra comparison



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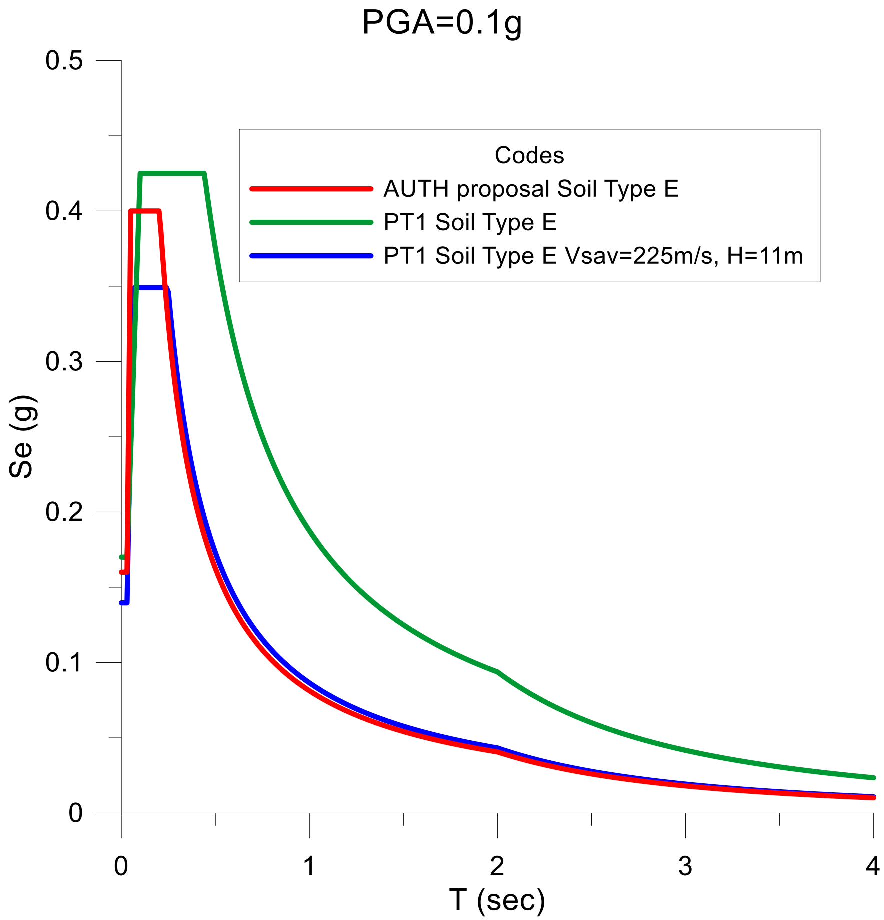
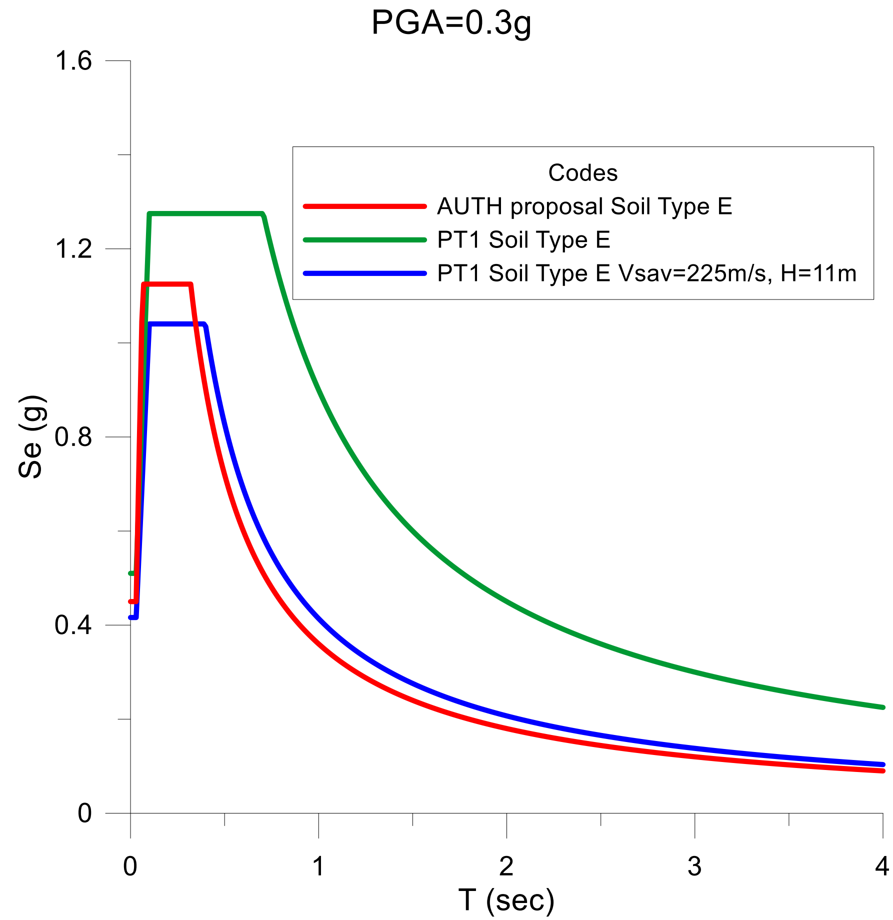
Design response spectra comparison





Summary

- New soil classification scheme with period and intensity depended amplification factors, using exclusively worldwide records and stations of well known soil conditions (500 stations and 3.500 records)
- Reference Ground Motion: Vs,rock > 800m/s (SHARE-SERA)
- Introduction of 2 intensity measures instead of only one (PGAr) i.e. spectral values Ss (at 0.1-0.2s) and S1 (at 1.0s)
- Amplification factors (F_s and F_1) of S_s and S_1 for increasing PGA_r values (0.1g->0.5g)
- Soil classes: A, B, C, D, E and X with sub-classes for soil class B and C
- Soil classification according to: geotechnical description (SPT, PI, Su etc), thickness (H), $V_{s,30}$ or/and $V_{s,average}$ and T_o.

Further validation, sensibility analysis and cross-check with available experimental data and records is deemed necessary.

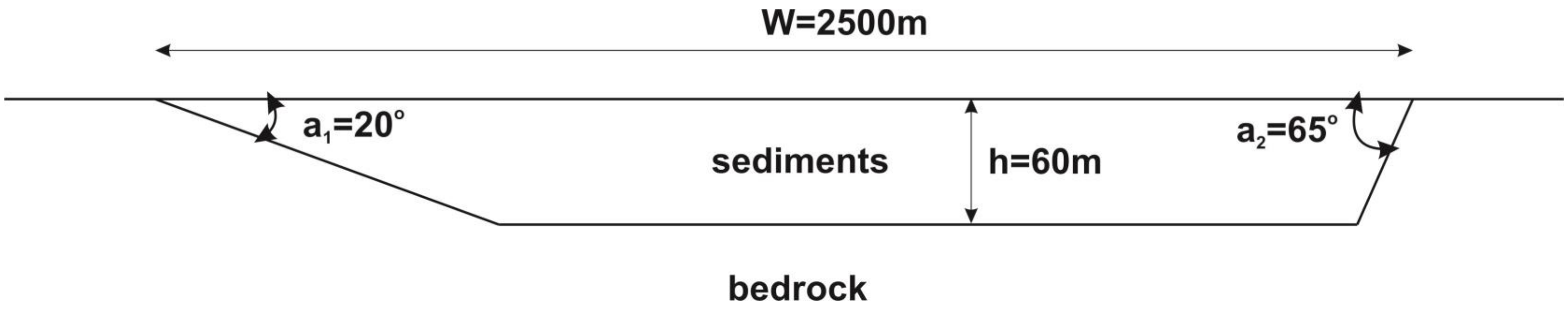
Further needs

- Spectral values at very long periods (T>4sec up to 15sec)
- Velocity spectra (in particular for long periods)
- Displacement spectra (in particular for long periods)
- Valley, basin and topographic effects
- Slope and topographic effects
- Decisions (and conditions) regarding the possibility of a EU States to adopt a zoning approach and national based soil classification schemes and amplification factors
- Describe conditions and criteria for the cases where special studies should be needed and recommended for example for soil type D (and E) eventually in relation also to the typology and importance of the structure (not mandatory)
- Take care of "special cases" for example very deep basins

Aggravation factors
to account for basin
and valley effects

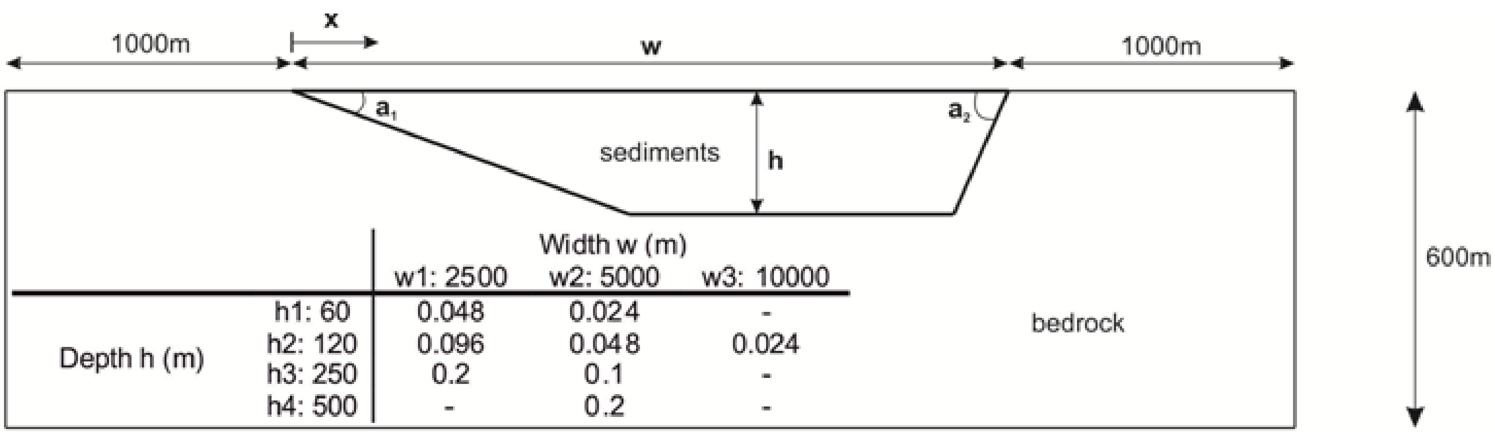
Numerical analyses

- Numerical parametric analyses of the 2D seismic response of sediment-filled basins for vertically incident plane waves with SV polarization.
- Numerical codes:
  - 2DFD_DVS finite difference code (Moczo et al., 2007; Moczo et al., 2004; Kristek and Moczo, 2003; Kristek et al., 2002) for viscoelastic analyses of homogeneous basins (96 models x 9 input motions)
  - ABAQUS finite element code (ABAQUS, 2010) for nonlinear analyses of inhomogeneous basins (6 models x 6 input motions x 3 levels of shaking)
- Verification of the efficiency of the two codes in reproducing complex 2D as well as 1D site response before proceeding with the analyses.



Parametric analyses

- 96 trapezoidal basin models:
  - 32 geometrical configurations, described by their width, w, depth, h and sloping edge angles, a1-a2

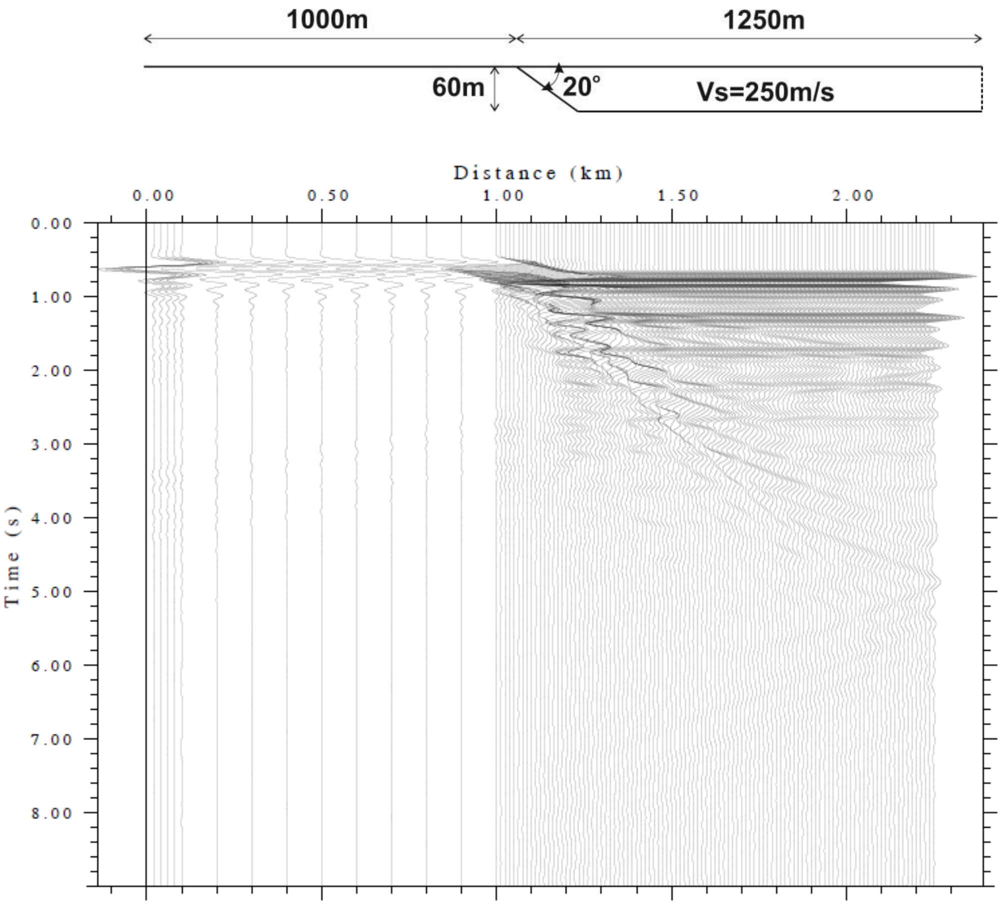


  - Elastic bedrock
  - 3 materials for sediments:

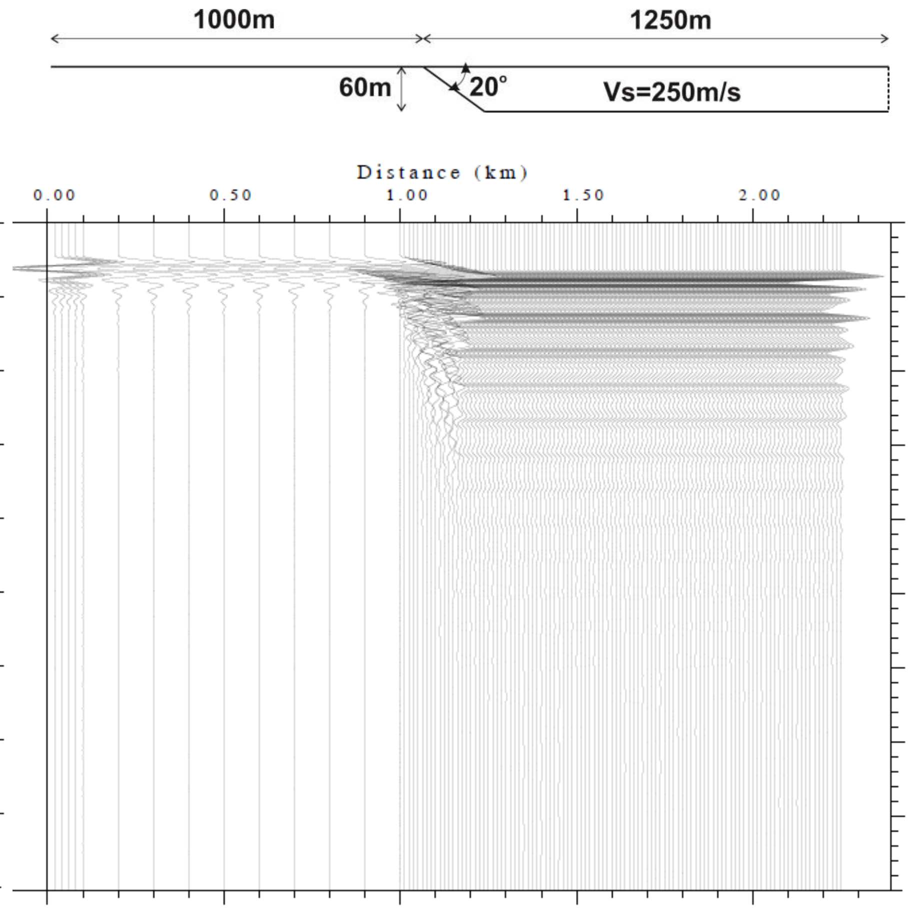
	Material property	Material 1	Material 2	Material 3
Sediments	S-wave velocity (V_s in m/s)	250	350	500
	Quality factor of S-waves (Q_s)	25	35	50
	P-wave velocity (V_s in m/s)	1600	1750	2000
	Quality factor of P-waves (Q_p)	50	70	100
	Density (ρ in kg/m^3)	2000		

Parametric analyses

2D analysis



1D analysis



Aggravation factors

- The additional effect of the 2D response at different locations at the surface of the basin with respect to the corresponding 1D response of the isolated soil columns in each location is quantified through a period-dependent seismic aggravation factors (AGF):

$$AGF(T) = \frac{\text{Spectral acceleration from 2D analysis}}{\text{Spectral acceleration from 1D analysis}}$$

Chávez-García and Faccioli (2004)

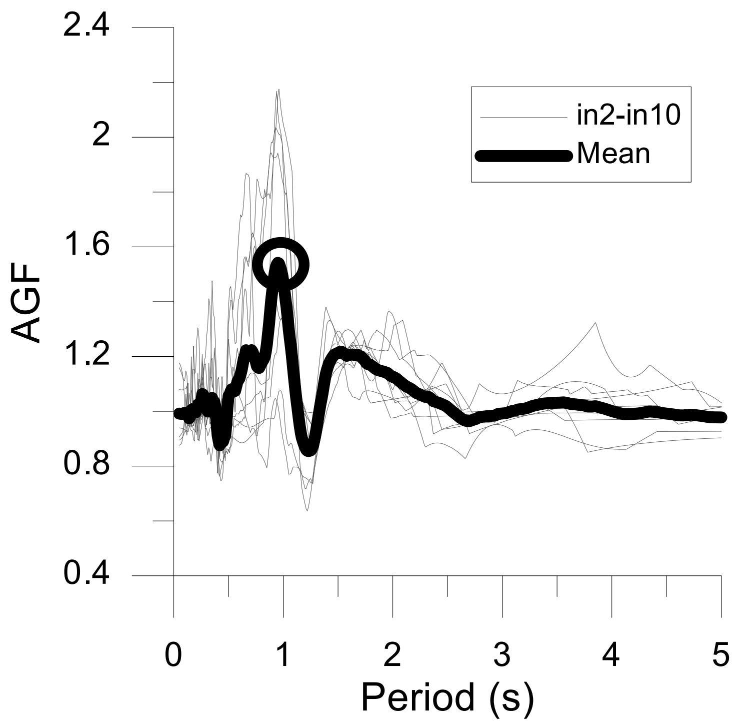
- A period-dependent aggravation factor is computed at each receiver for each model and each input.

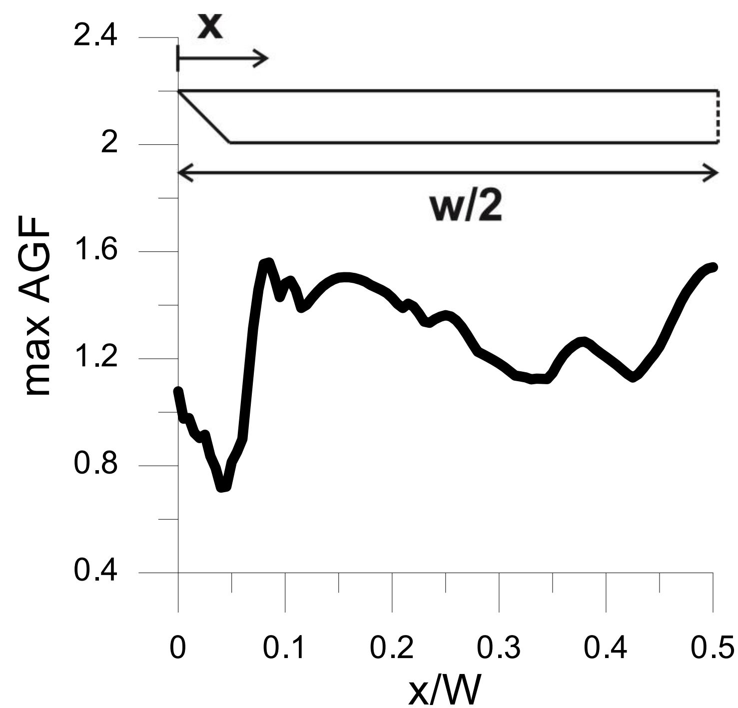
- For each model, the average period-dependent aggravation factor is calculated from the 9 accelerograms at each receiver.

- The maximum value of the average period-dependent aggravation factor at each receiver is identified.

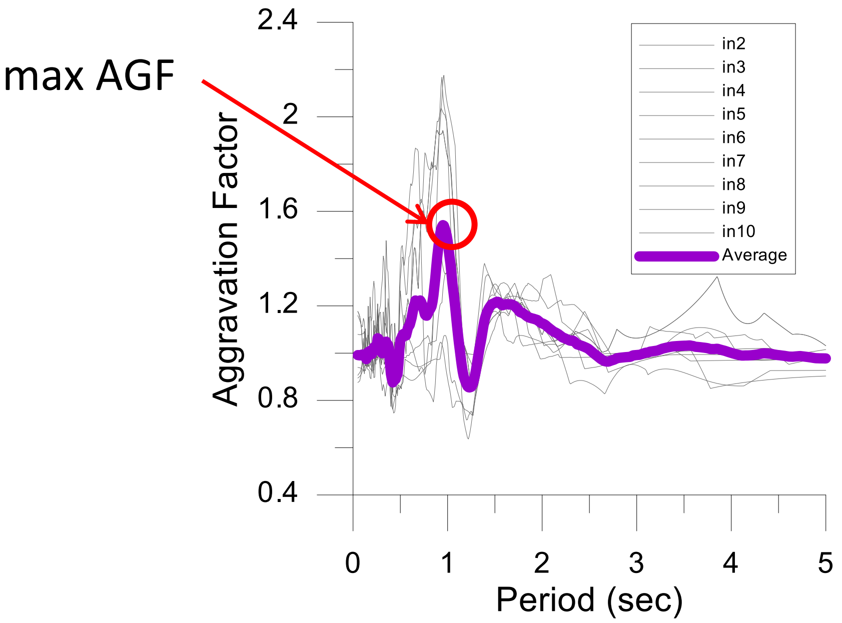
Maximum AGF

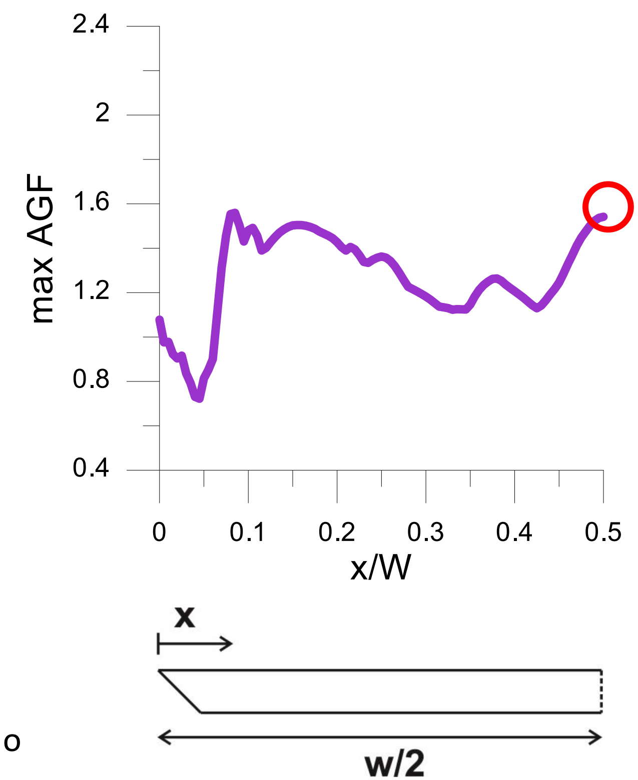
- A period-dependent AGF was computed at each receiver for each input.
- An average period-dependent AGF was calculated at each receiver over the nine input motions.
- The maximum value of the average period-dependent AGF at each receiver was identified.
- Maximum *AGF* for all receivers were plotted along the basin width.





Maximum aggravation factors



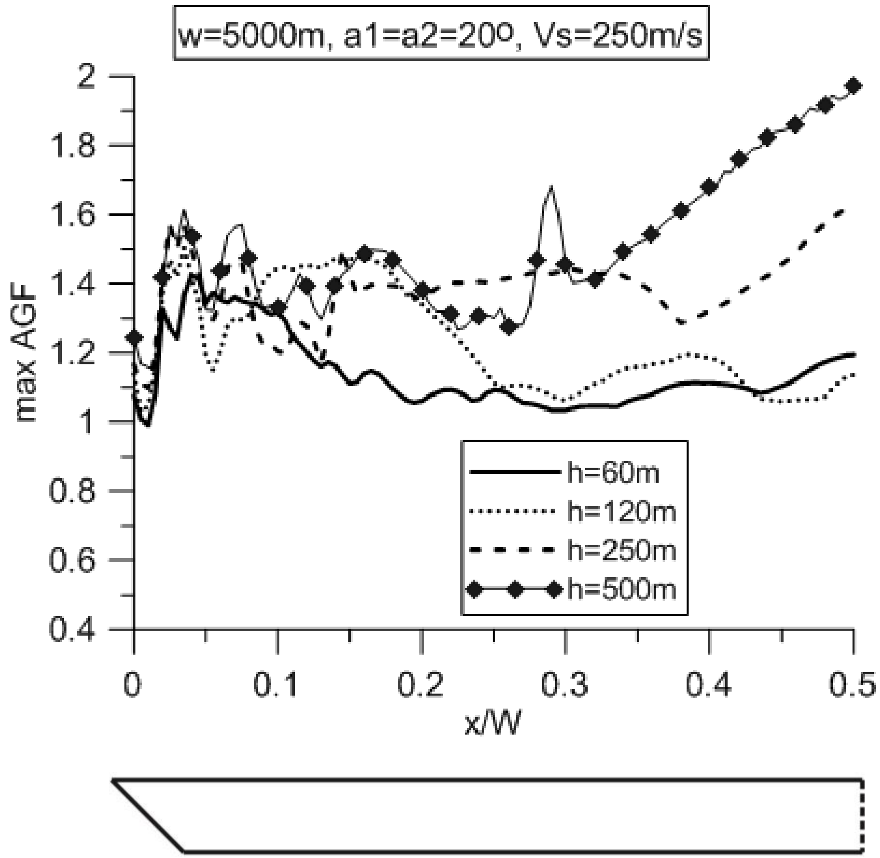


w=2500m, h=120m, Vs=350m/s, a1=a2=45º

center of basin (x/w=0.5)

Maximum aggravation factors

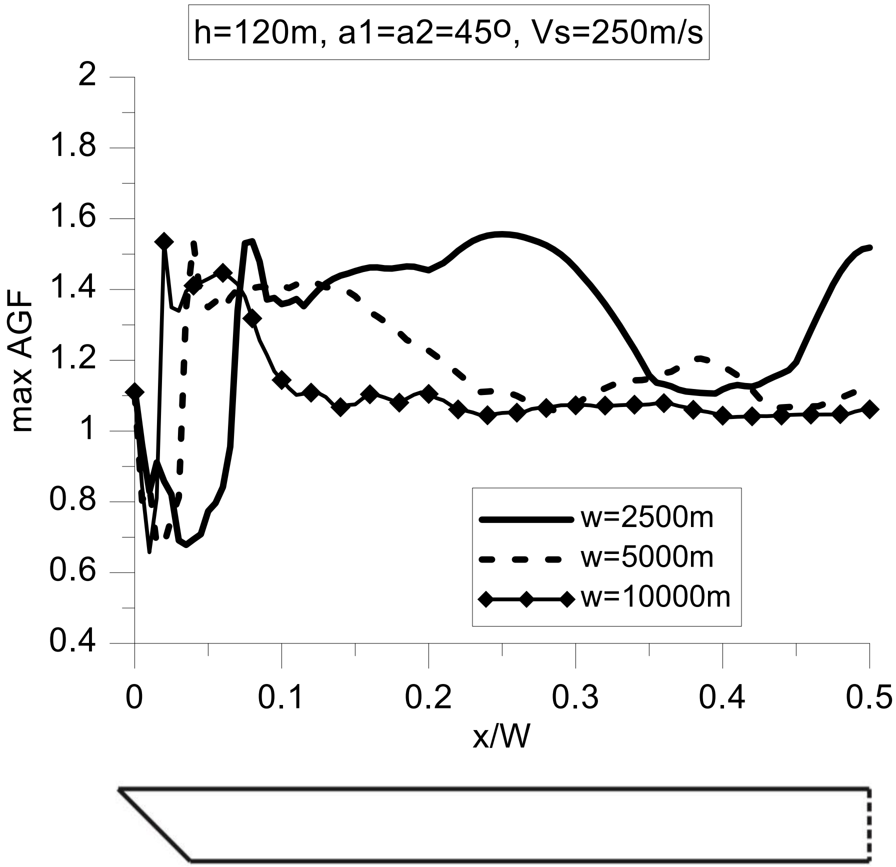
Influence of basin thickness (h)



- Increase of thickness → higher AGF, especially for sediments with low Vs

Maximum aggravation factors

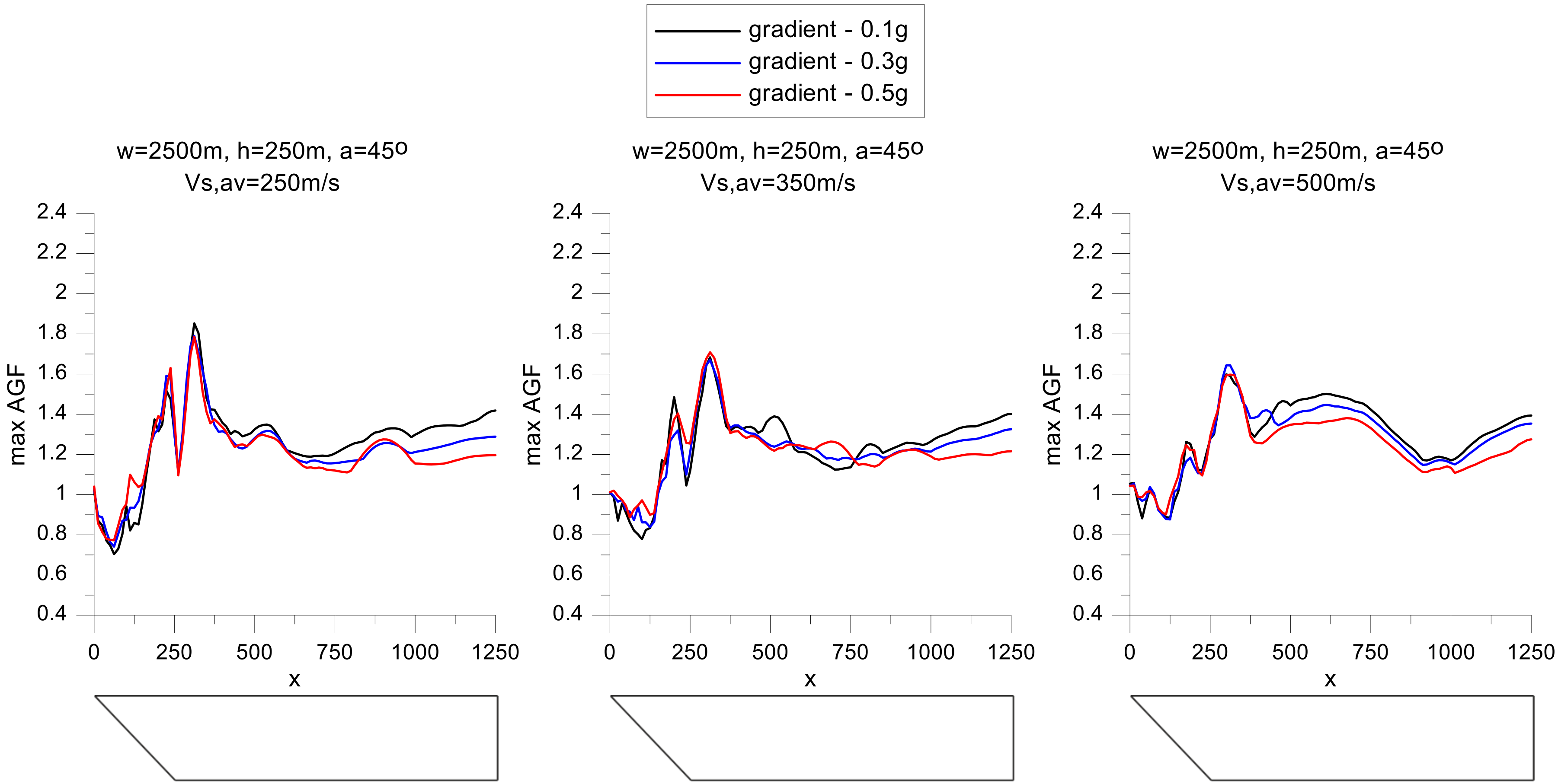
Influence of basin width (w)



- Increase of width →smaller AGF at the center of the basin

Maximum aggravation factors

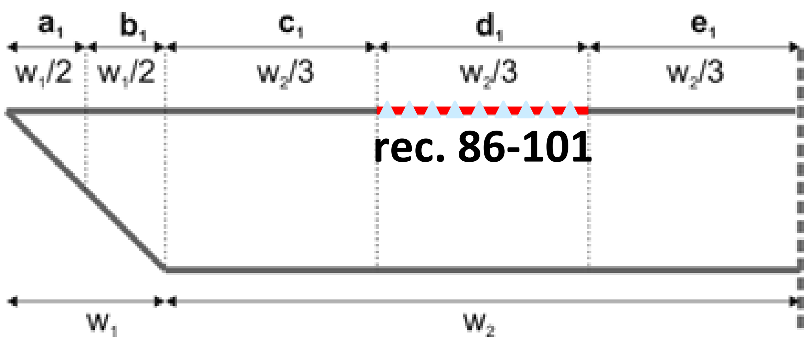
Effect of soil nonlinearity



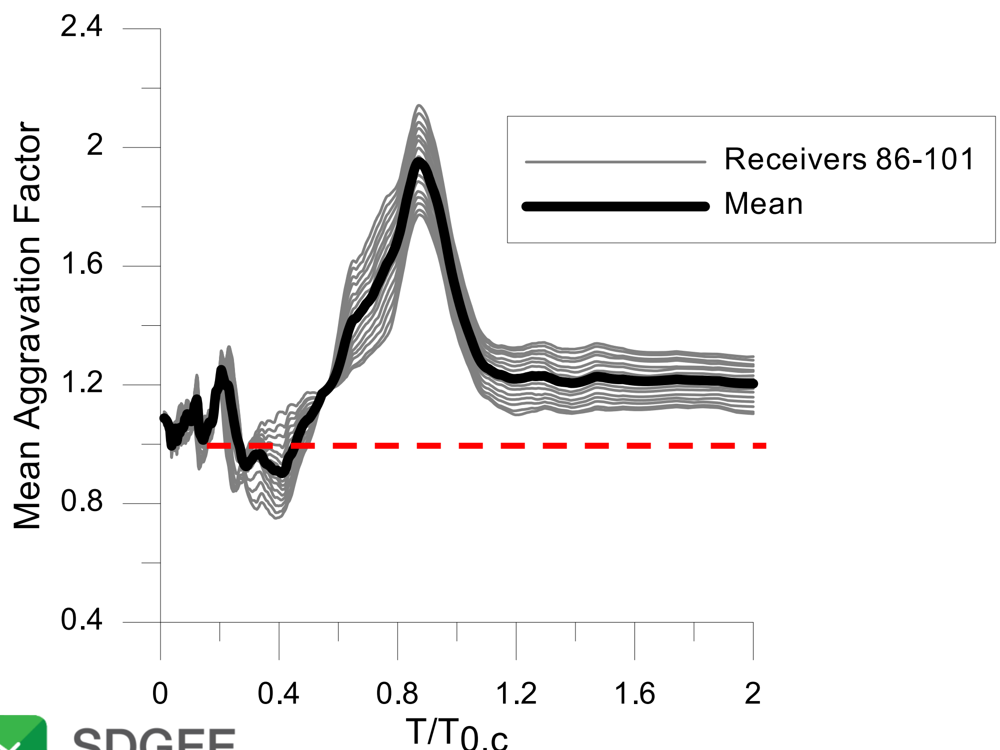
Riga (2015)

- Consideration of soil nonlinearity for the sediments material does not affect the estimated aggravation factor significantly (small decrease of AGF far from the basin edge and minor increase close to the basin edge)

Towards practical recommendations: Spatial distribution of AGF



Symmetrical models:



Region d1 of model w1h3a1Vs1
w=2500m
h=250m,
a1=a2=20°
Vs=250m/s

$T_{0,c}=4h/Vs$
(1D fundamental period
at the flat part of the basin)

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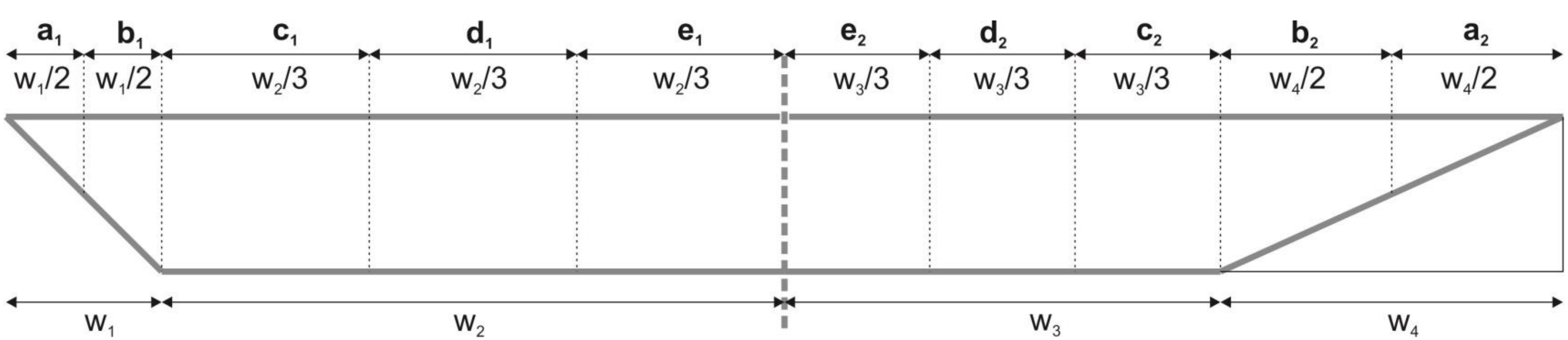
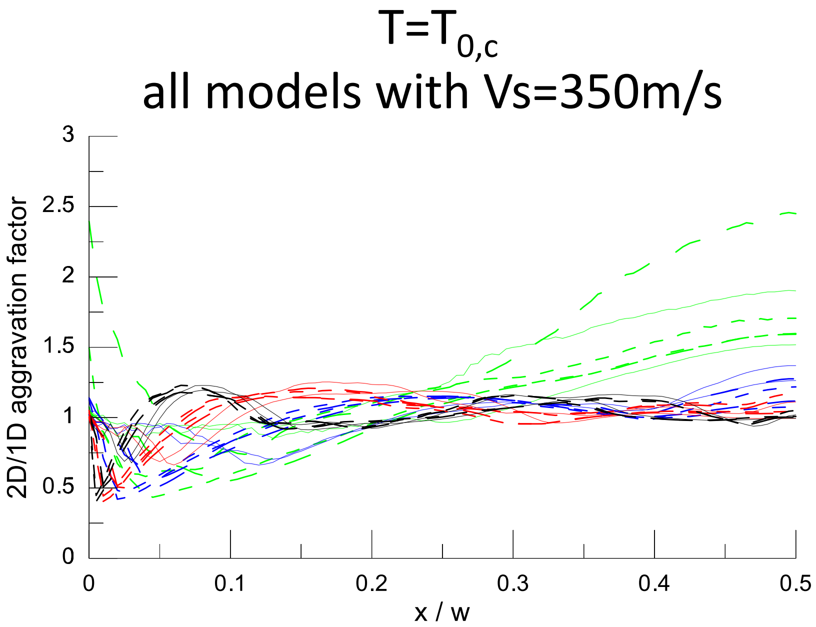
Mean aggravation factors for specific regions

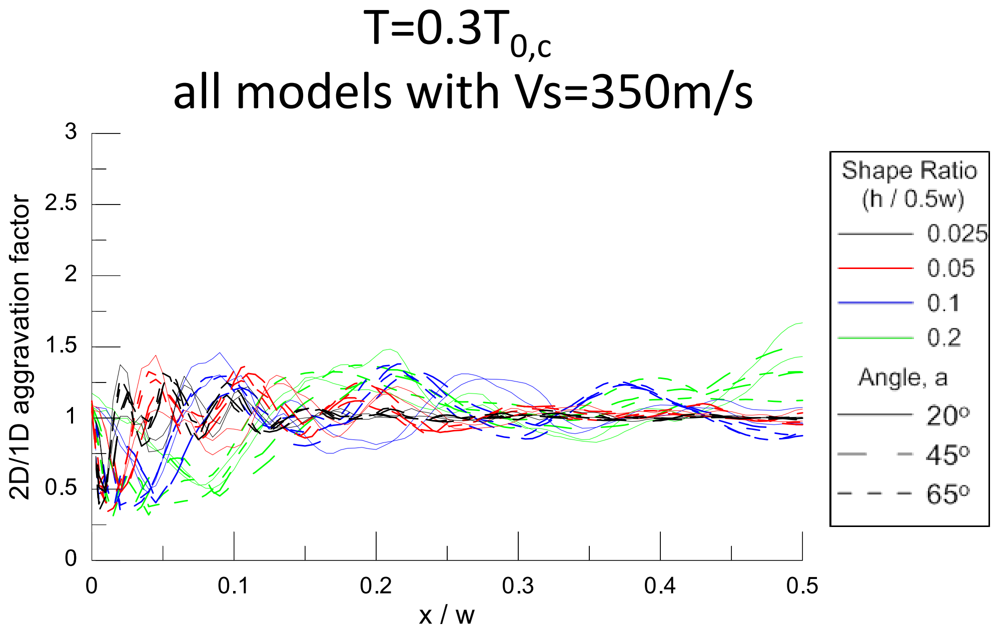
- Shallow and medium-thickness basins (thickness of 60m or 120m):
  - Symmetrical models: regions **c1** and **d1** are the most affected
  - Non-symmetrical models: region c1 is the most affected
  - Maximum AGF ~1.1-1.5
- Deep basins (thickness of 250m or 500m):
  - Symmetrical models: regions **a1** and **e1** are the most affected
  - Non-symmetrical models: regions e2 and c2 are the most affected
  - Maximum AGF ~1.4-2.4



Period-dependency of AGF

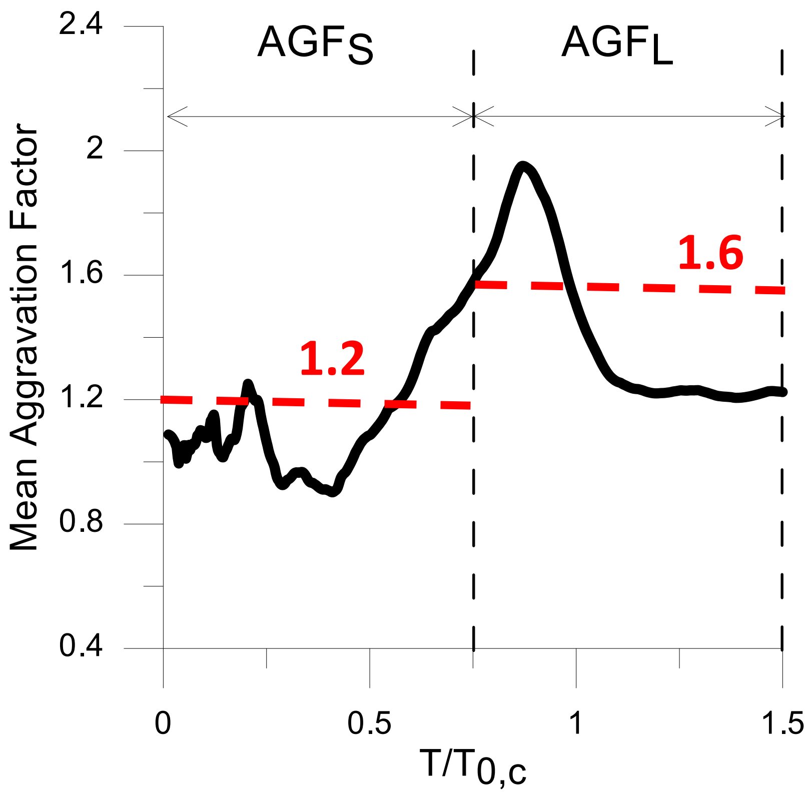
- So far, maximum aggravation factors have been mainly presented
- However, there is a strong period-dependency of AGF





Towards practical recommendations for EC8

Region d1 of model w1h3a1Vs1
(w=2500m, h=250m, a1=a2=20°, Vs=250m/s)



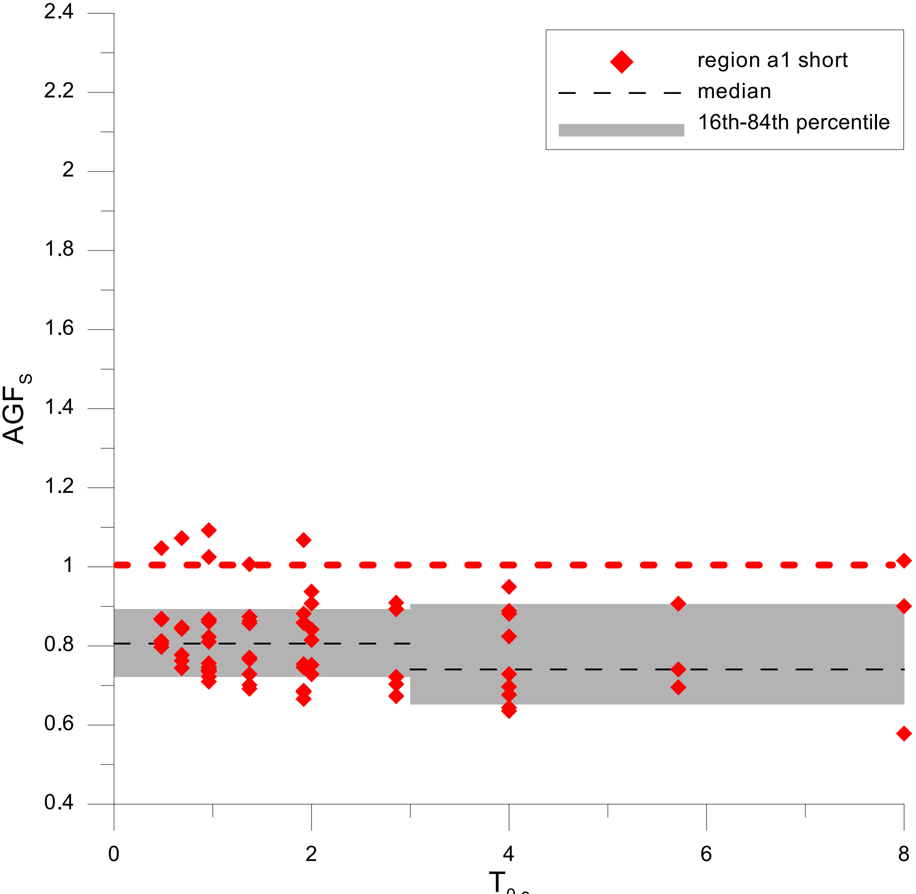
- Short-period average for periods less than $0.75T_{0,c}$:

  $AGF_S=1.2$

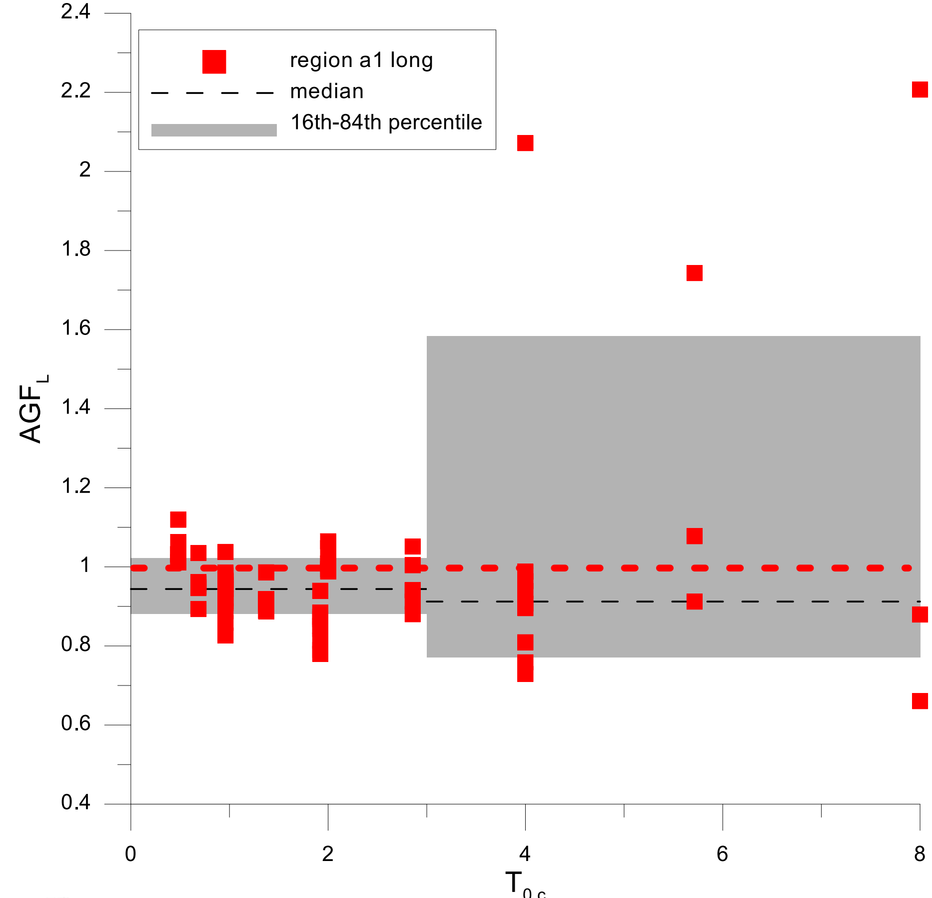
- Long-period average for periods between $0.75T_{0,c}$-$1.50T_{0,c}$:

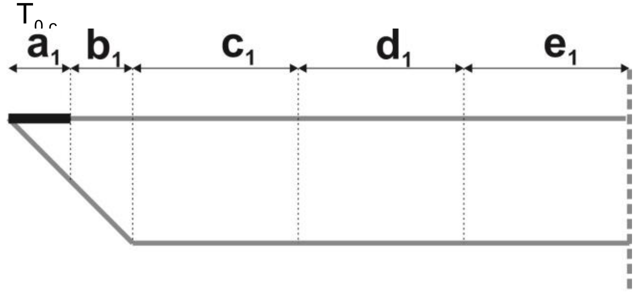
  $AGF_L=1.6$

Short-period average AGF_S

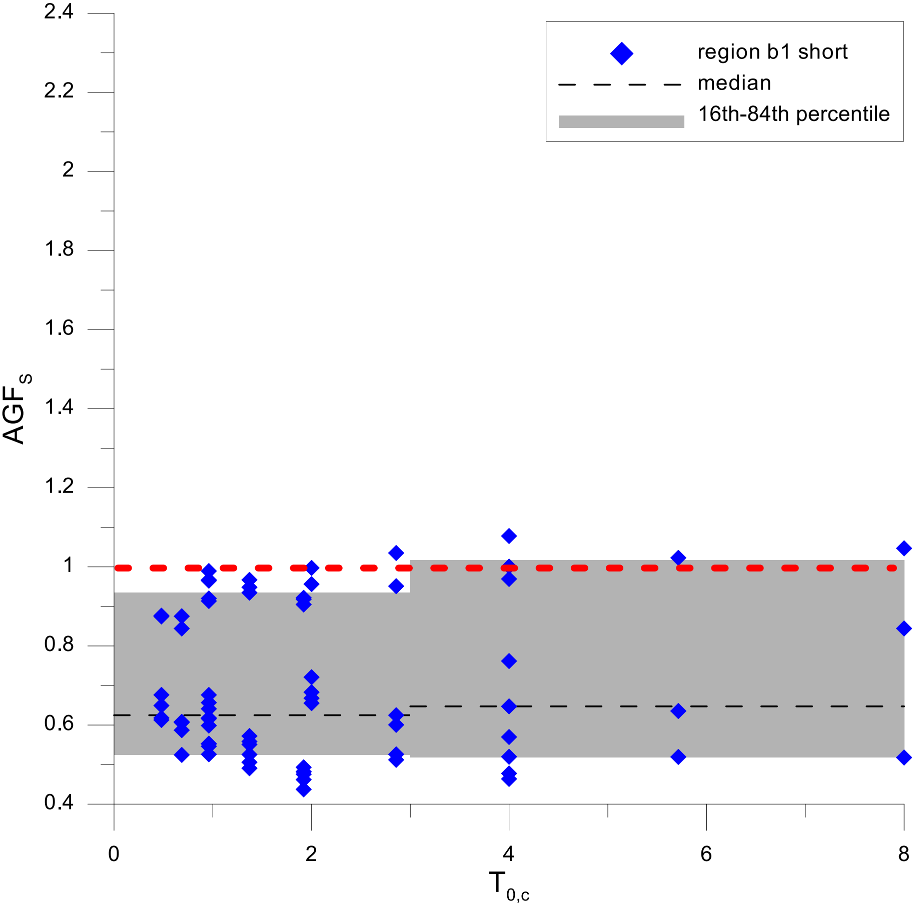


Long-period average AGF_L

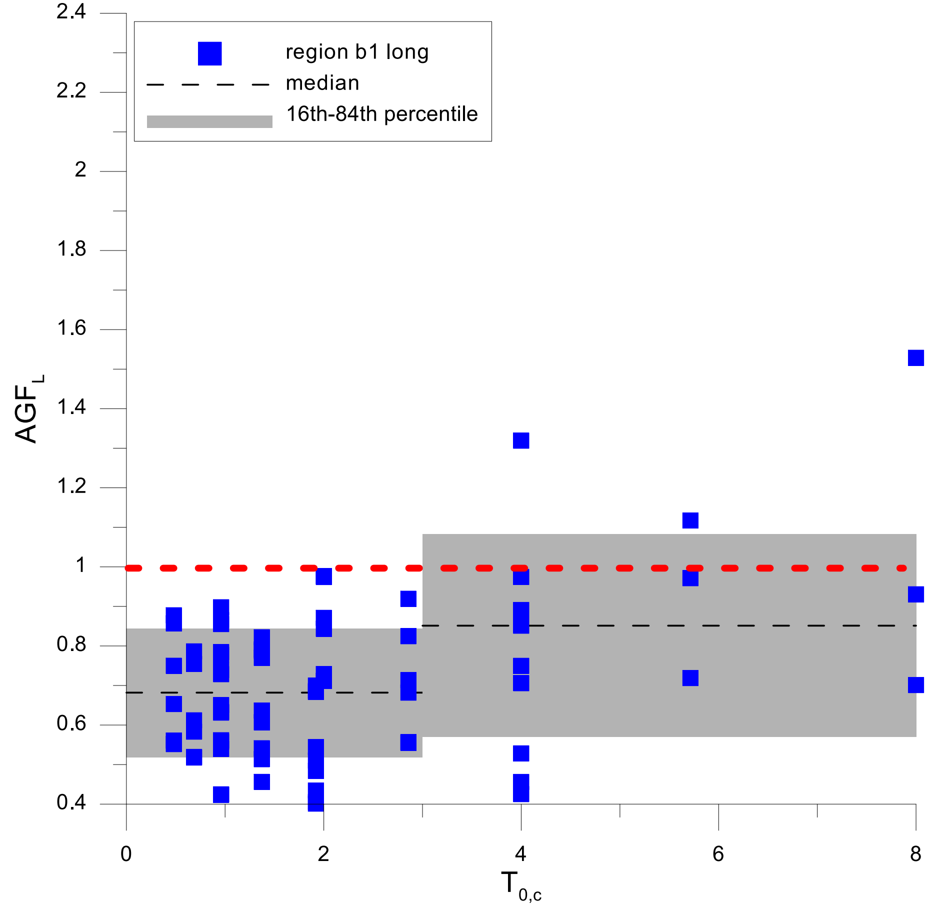


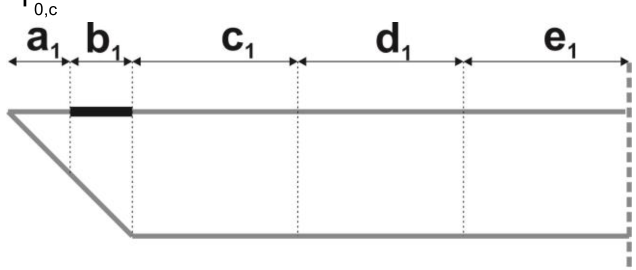


Short-period average AGF_S



Long-period average AGF_L





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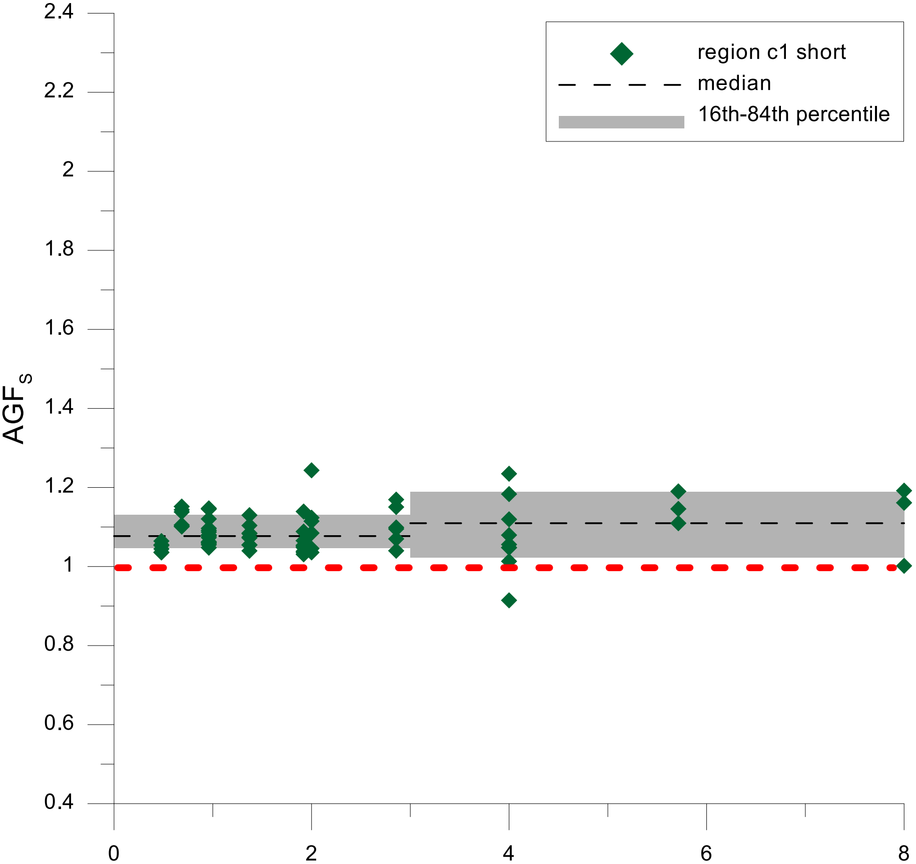
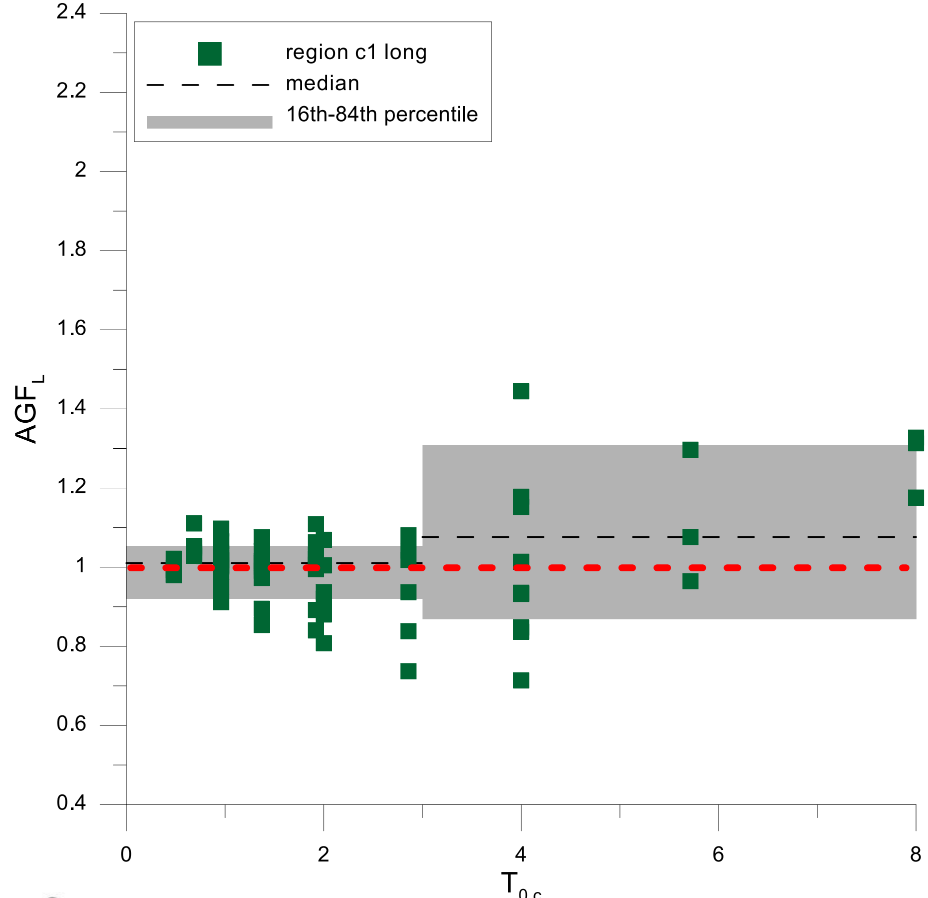
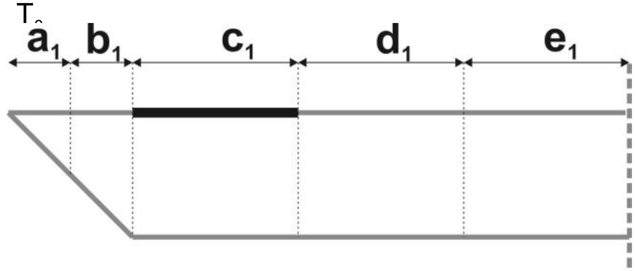
Short-period average AGF_S

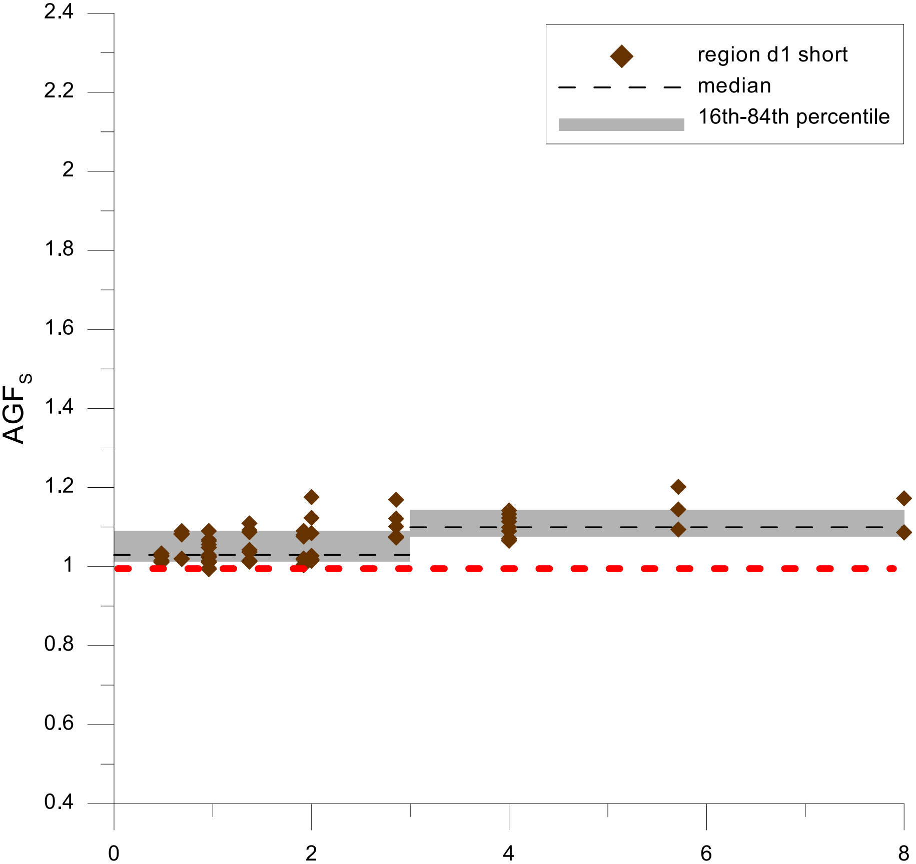


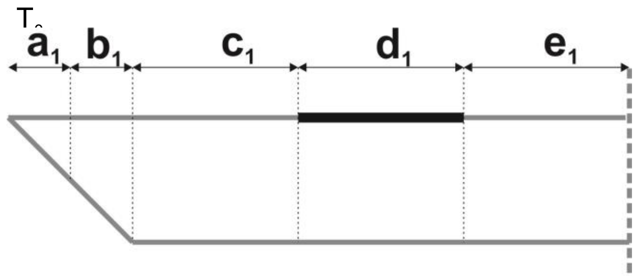
Long-period average AGF_L



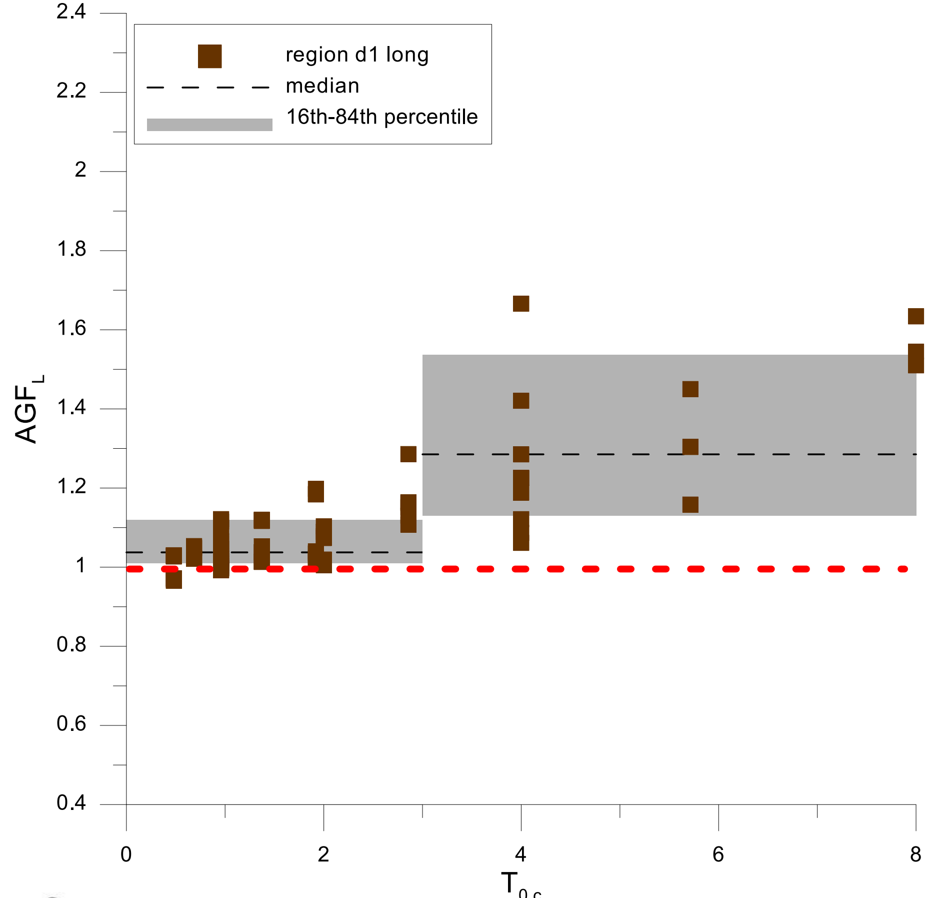


Short-period average AGF_S





Long-period average AGF_L



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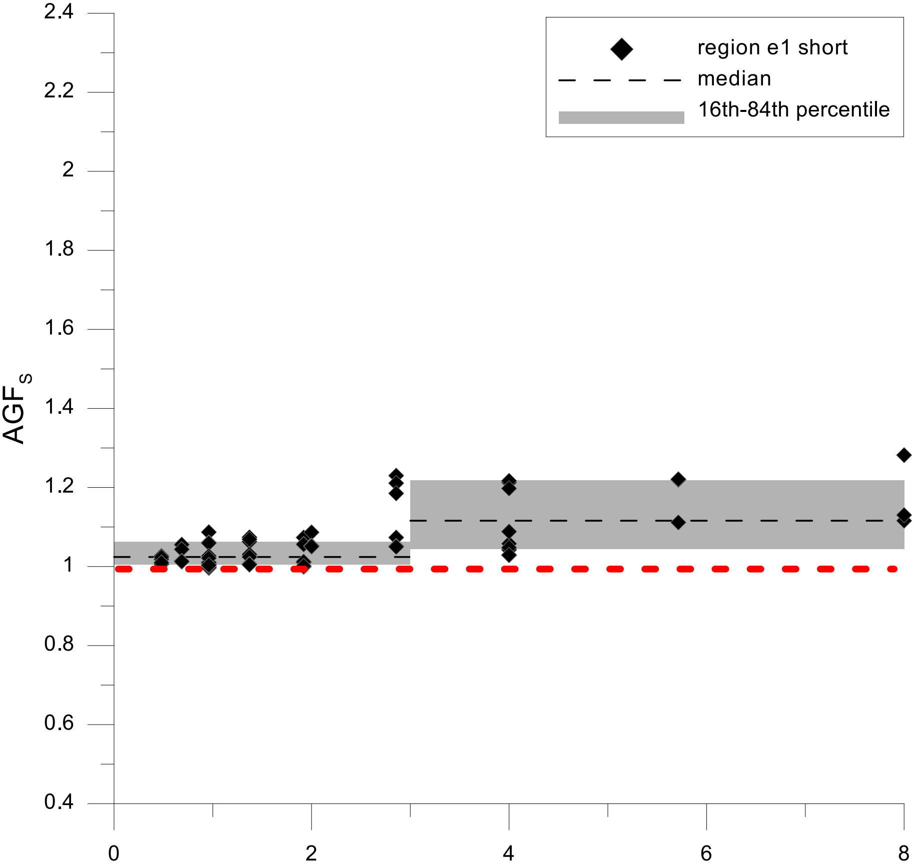
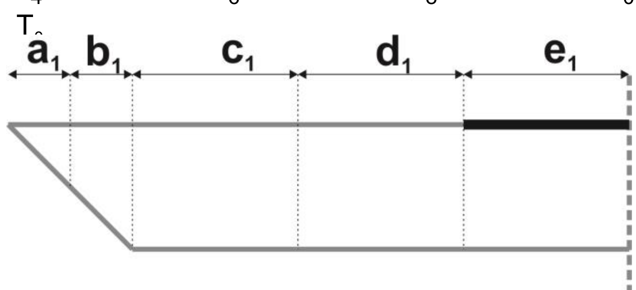
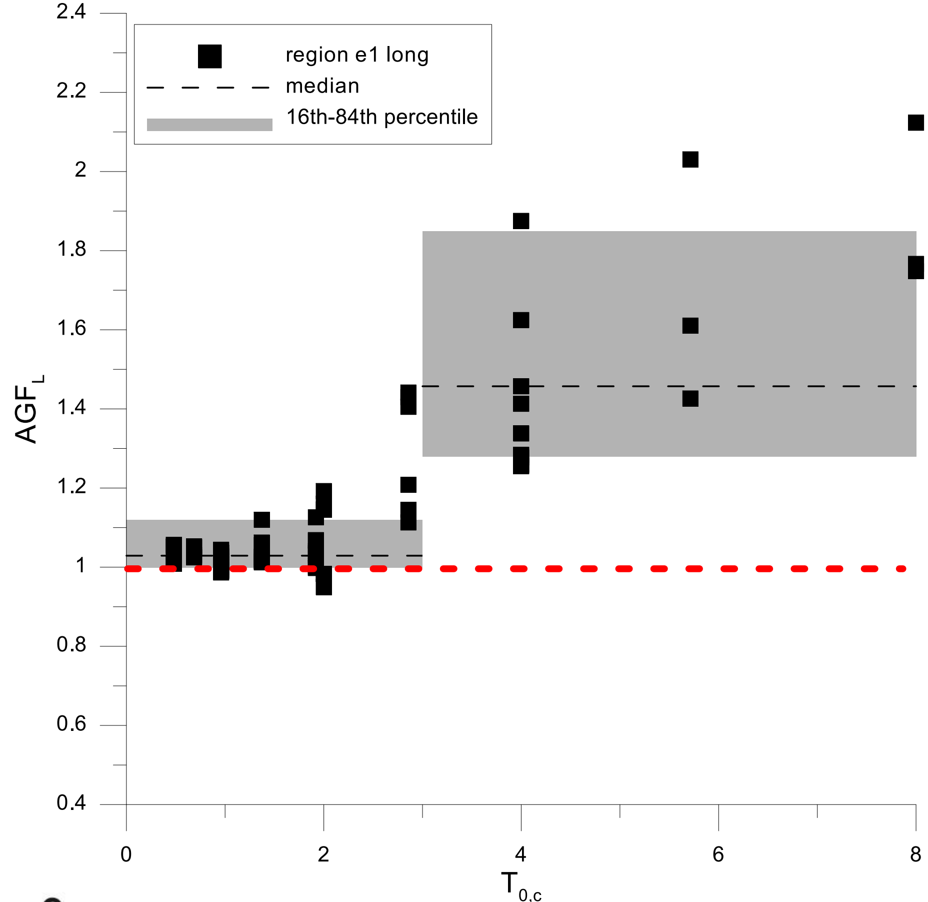
Short-period average AGF_S





Long-period average AGF_L



Recommendations for EC8

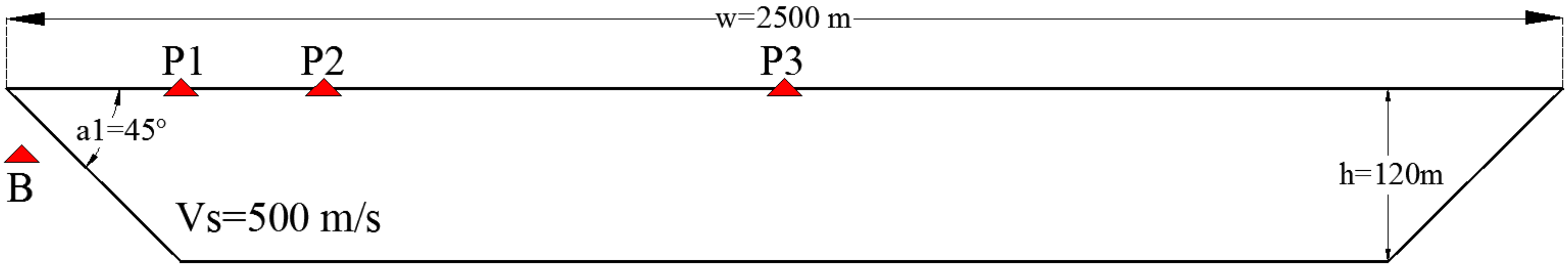
Short-period average AGF_S

$T_{0,c}$		Region a1	Region b1	Region c1	Region d1	Region e1
$T_{0,c}$<3.0s	median	0.81	0.62	1.08	1.03	1.02
	84th	0.89	0.94	1.13	1.09	1.06
$T_{0,c}$≥3.0s	median	0.74	0.65	1.11	1.10	1.12
	84th	0.91	1.02	1.19	1.14	1.22

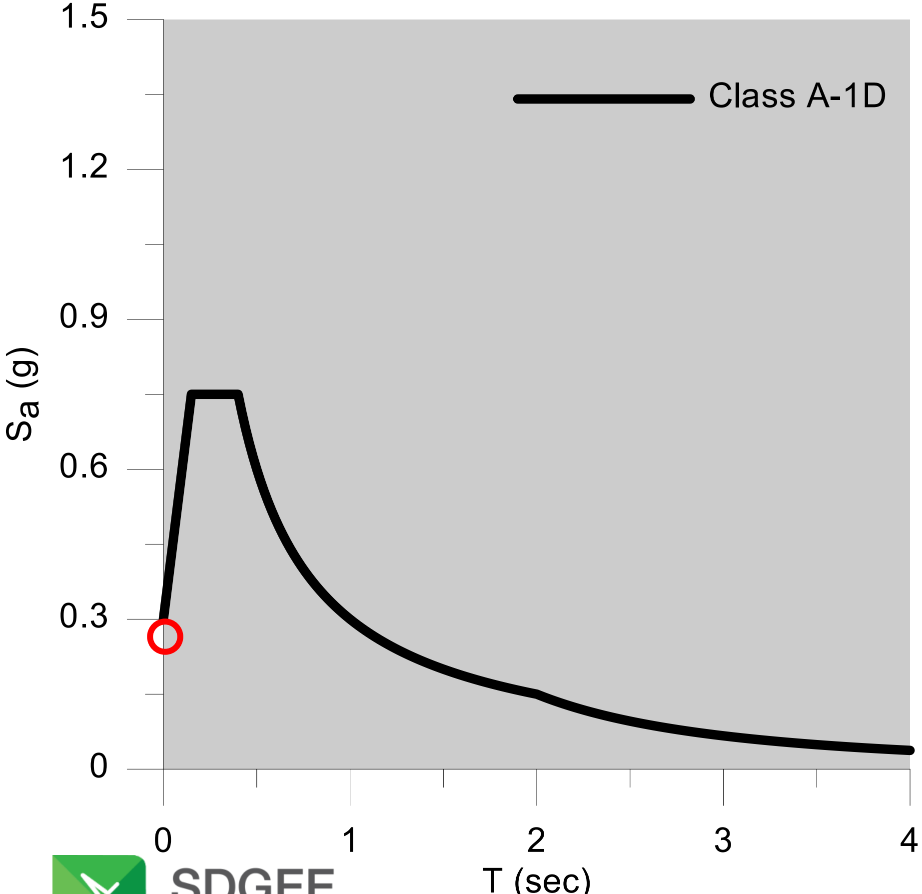
Long-period average AGF_L

$T_{0,c}$		Region a1	Region b1	Region c1	Region d1	Region e1
$T_{0,c}$<3.0s	median	0.94	0.68	1.01	1.04	1.03
	84th	1.02	0.84	1.05	1.12	1.12
$T_{0,c}$≥3.0s	median	0.91	0.85	1.08	1.29	1.46
	84th	1.58	1.08	1.31	1.54	1.85

Example: Definition of input motion across a basin



PSHA (SHARE): PGA and UHS at rock-site conditions for SEE: a_g=0.3g



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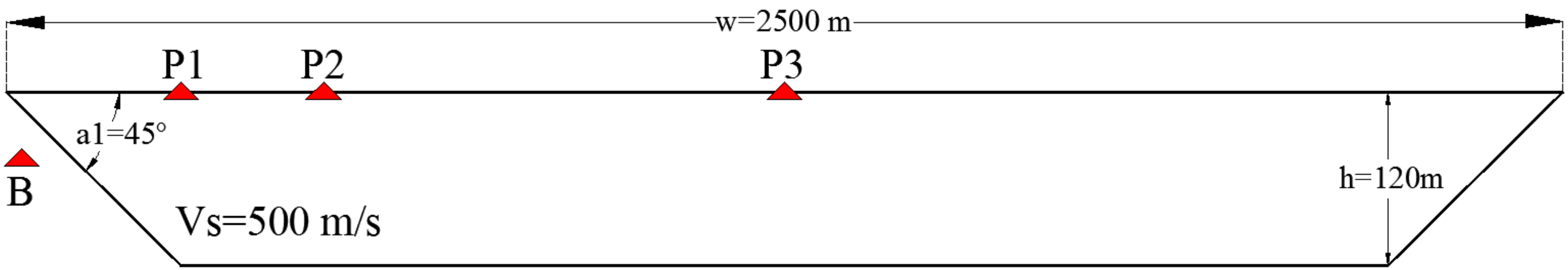
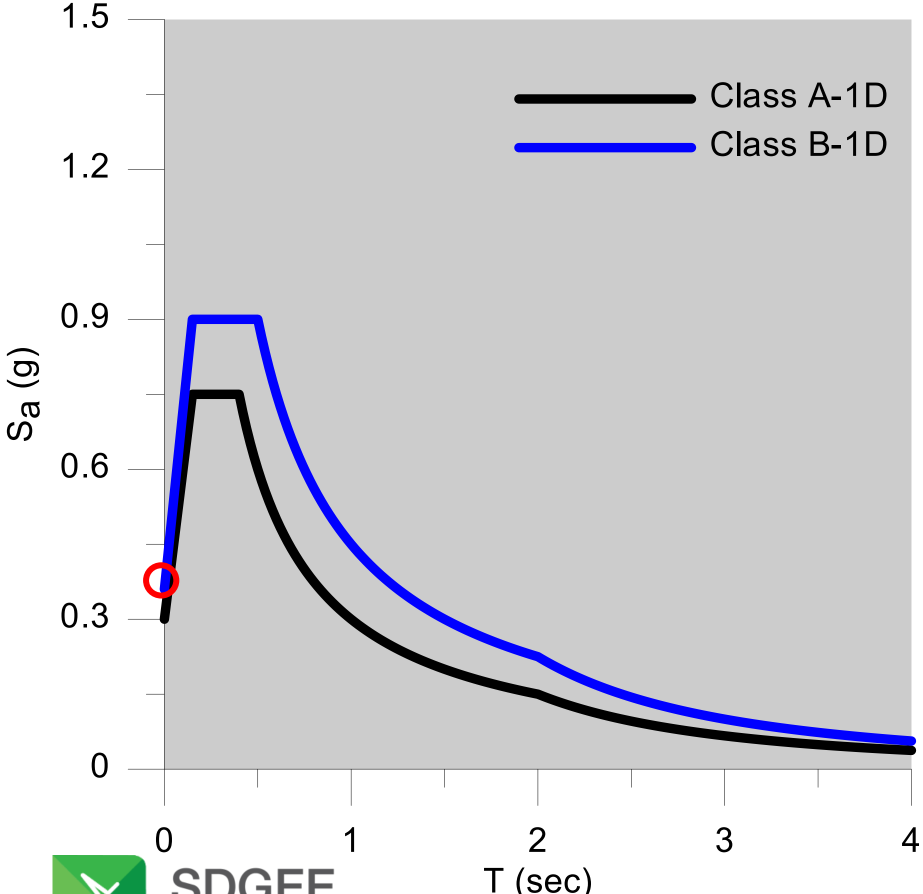
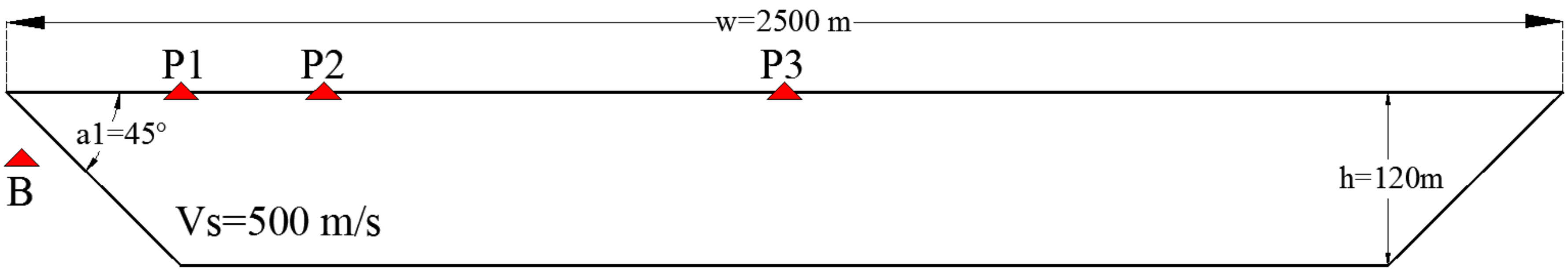


PSHA (SHARE): PGA and UHS at rock-site conditions for SEE: a_g=0.30g

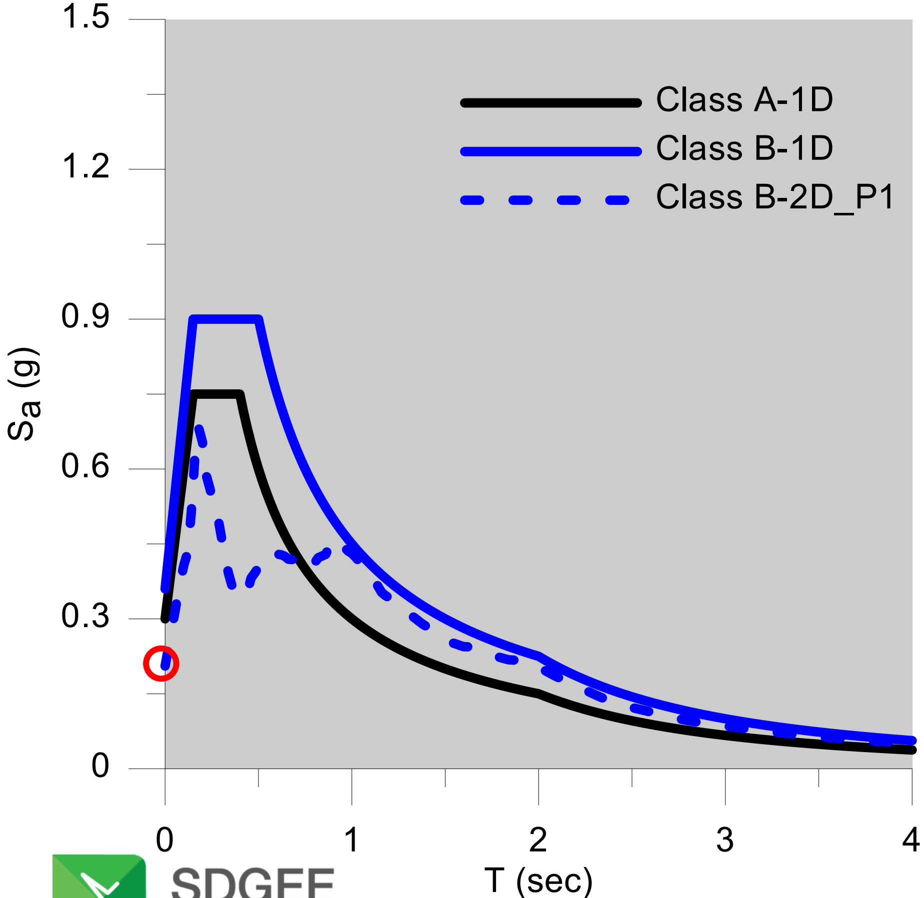


Bedrock: PGA=0.30g

PGA=0.36g



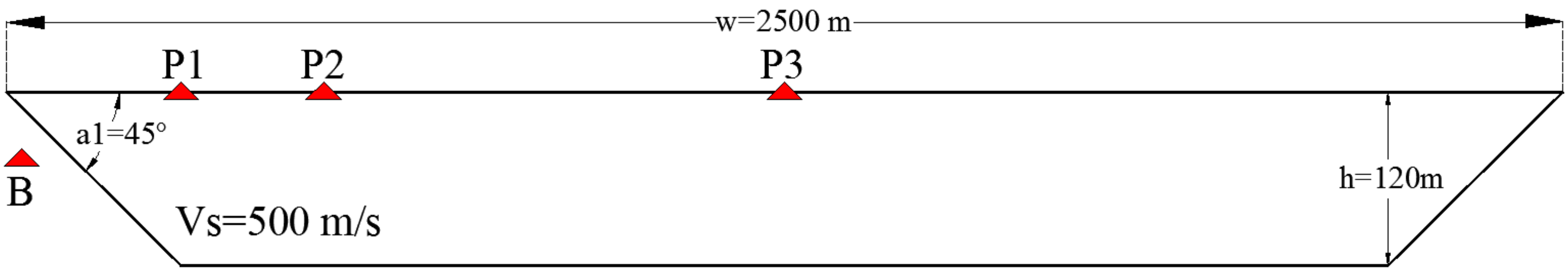
PSHA (SHARE): PGA and UHS at rock-site conditions for SEE: a_g=0.3g



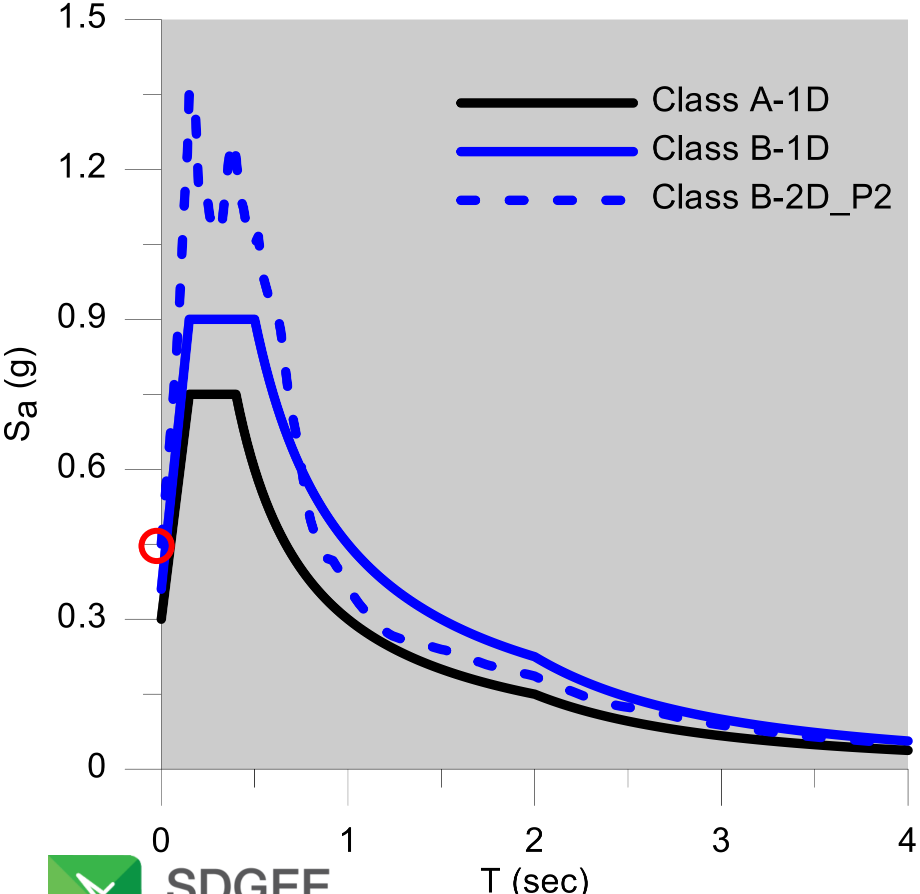
Bedrock: PGA=0.36g

P1

PGA=0.21g



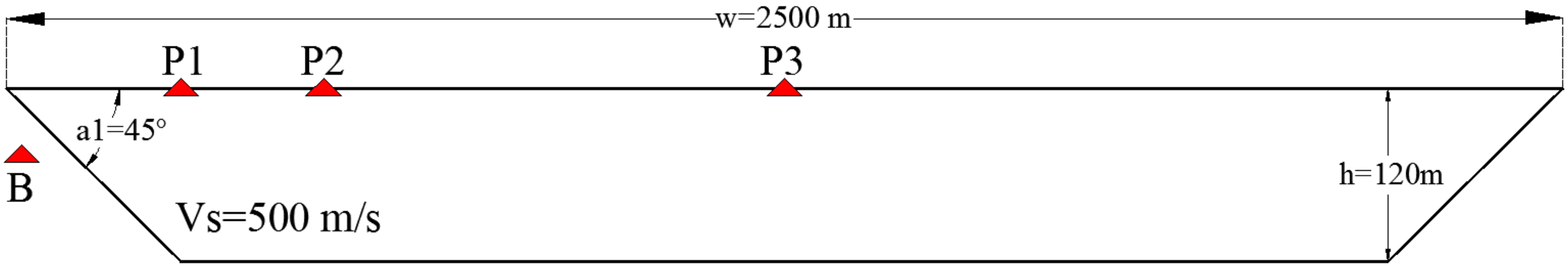
PSHA (SHARE): PGA and UHS at rock-site conditions for SEE: a_g=0.3g



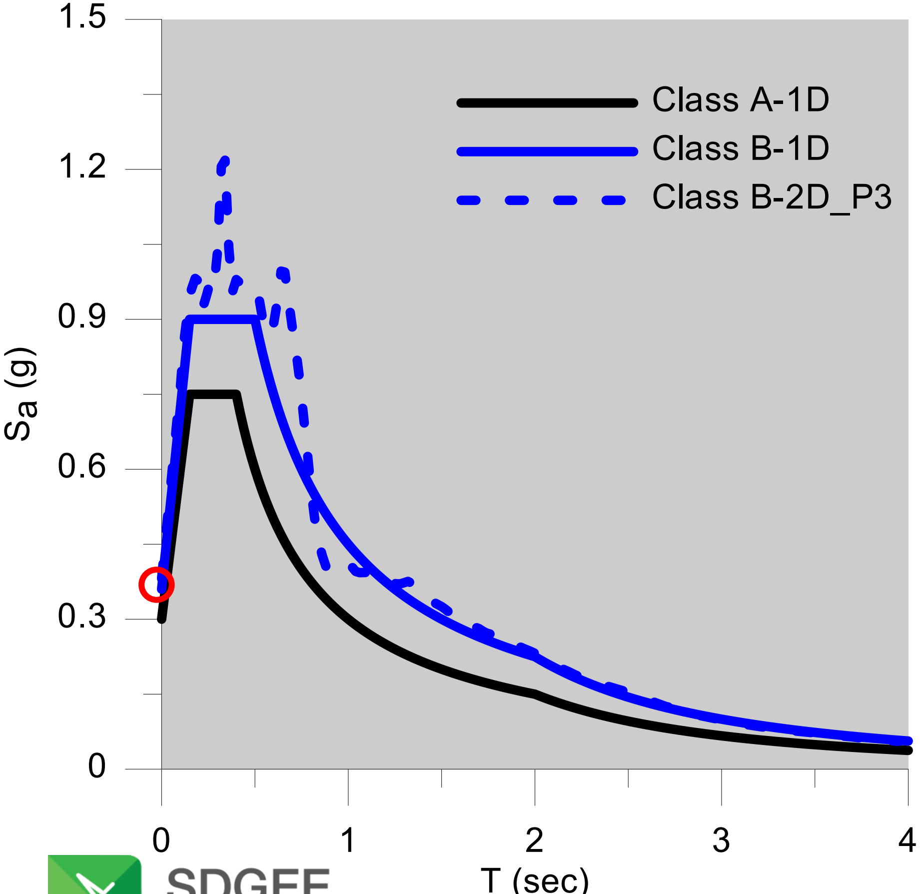
Bedrock: PGA=0.30g

P2

PGA=0.45g



PSHA (SHARE): PGA and UHS at rock-site conditions for SEE: a_g=0.3g



P3

PGA=0.38g

Conclusive remarks

- Proposals for improvement of EC8 design spectra:
  - Improved S factors for the current EC8 classification scheme→ need for an increase in S factors at least for soil class C
  - New site – soil classification scheme with corresponding period dependent elastic response spectra following the present EC8 seismicity classification in terms of PGArock
  - **New alternative to PT1 draft soil-site classification and site amplification factors for gradually increased seismic intensity in terms of spectral values Ss and S1**
- Proposal of extra aggravation factors (AGF) for complex subsurface geometry:
  - AGF are not uniform along the basin
  - AGF depend mainly on the dimensions of the basin (width, depth) and impedance - shear wave velocity of the sediments (uniform and gradient)
  - AGF are strongly site (along the basin) and period-dependent
  - **Short-period aggravation and long-period aggravation factors to account for the complex basin effects**.

Going Beyond Generic Site Factors

Seismic Code vs. Site-specific analysis

- Simplified procedure (Site factors Fa & Fv, Site classes)
  - Widely used but…

- Site-specific analysis is needed for
  - Hard Rock (different reference rock conditions, high frequency content)
  - Shallow reference Rock (<30m)
  - Non-US site conditions
  - Thick sections (> 30 m) of F, E, and E/D soils
  - Thick soil deposits (>>150m)
  - Thin sections (5-15m) of soil over hard rock
  - Special and critical structures

Hashash (2014)

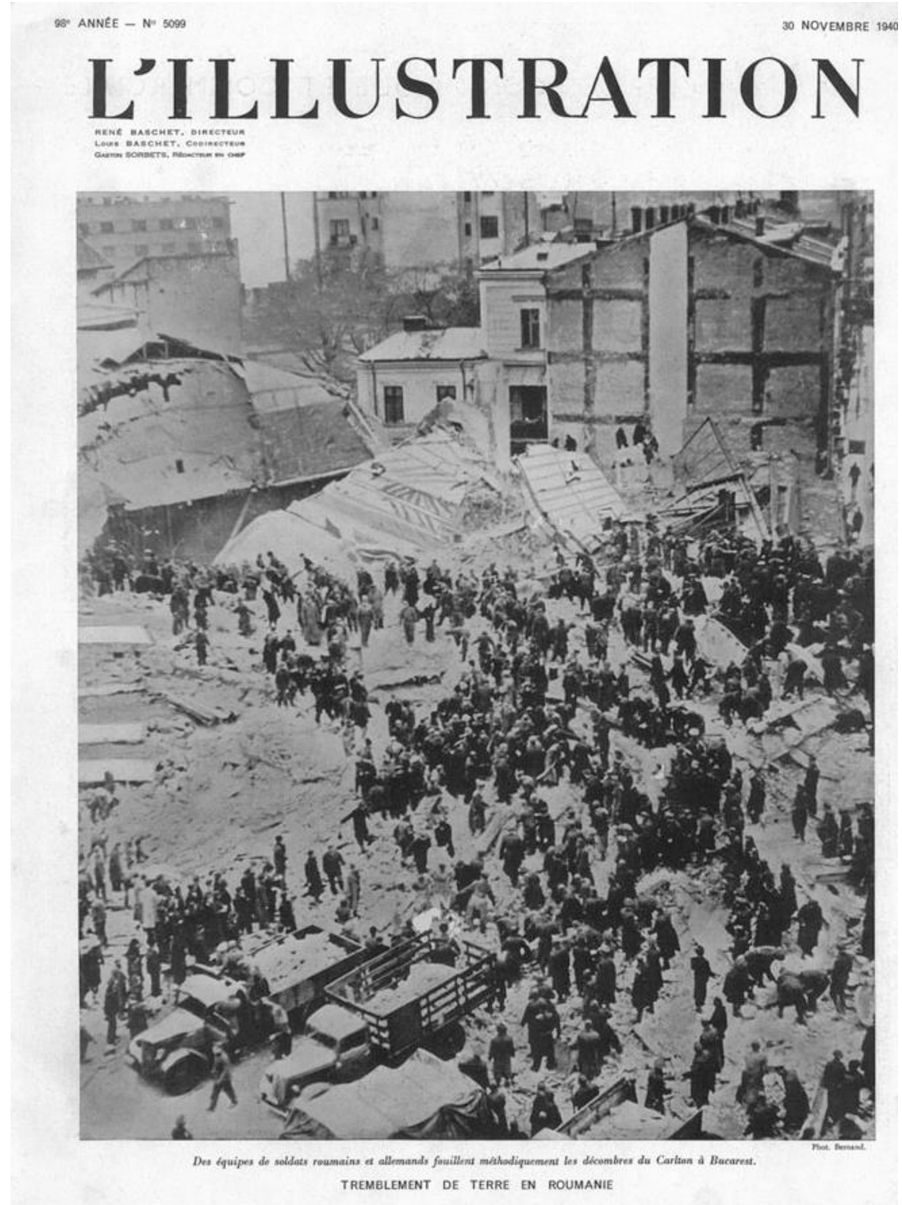
Need for Site-specific study

- Site Classification: If the subsurface conditions classify a site as Site Class F, the codes require a site-specific study.
- Cost Optimization: If the owner wants to reduce construction costs, a site-specific study can performed to reduce dynamic loads and the Seismic Design Category (SDC).
- Analysis Method: If the importance of a structure or the variability of subsurface conditions require parameters that are not readily available in codes, such as soil structure interaction parameters or time histories of acceleration

(Nikolaou 2008)

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

Collapse of the Carlton building–the tallest RC building in Bucharest:
11 storey, h = 47 m,
Death of 130 people


98e ANNÉE — N° 5099 30 NOVEMBRE 1940

L'ILLUSTRATION

RENÉ BASCHET, DIRECTEUR
LOUIS BASCHET, CODIRECTEUR
GASTON SORBETS, RÉDACTEUR EN CHEF

Phot. Bernand.

Des équipes de soldats roumains et allemands fouillent méthodiquement les décombres du Carlton à Bucarest.

TREMBLEMENT DE TERRE EN ROUMANIE

The 1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt
Radu Vacareanu • Constantin Ionescu

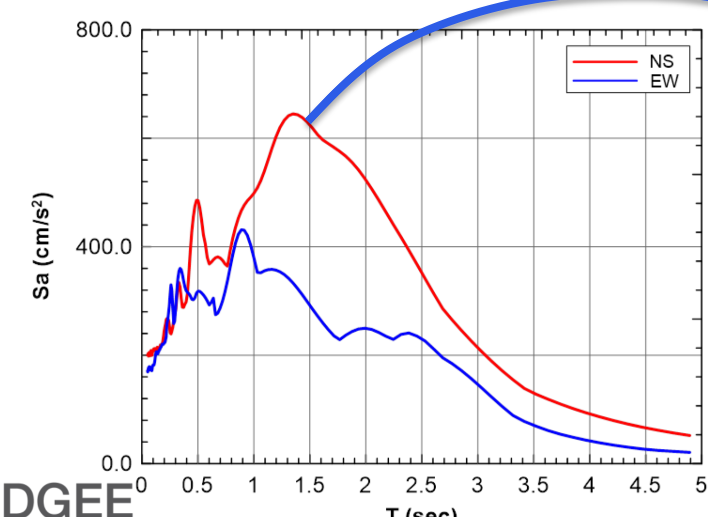
March 4, 1977, Mw=7.5, h=109 km

Killed 1,578 people (1424 in Bucharest)
Injured 11,221 people (7598 in Bucharest)

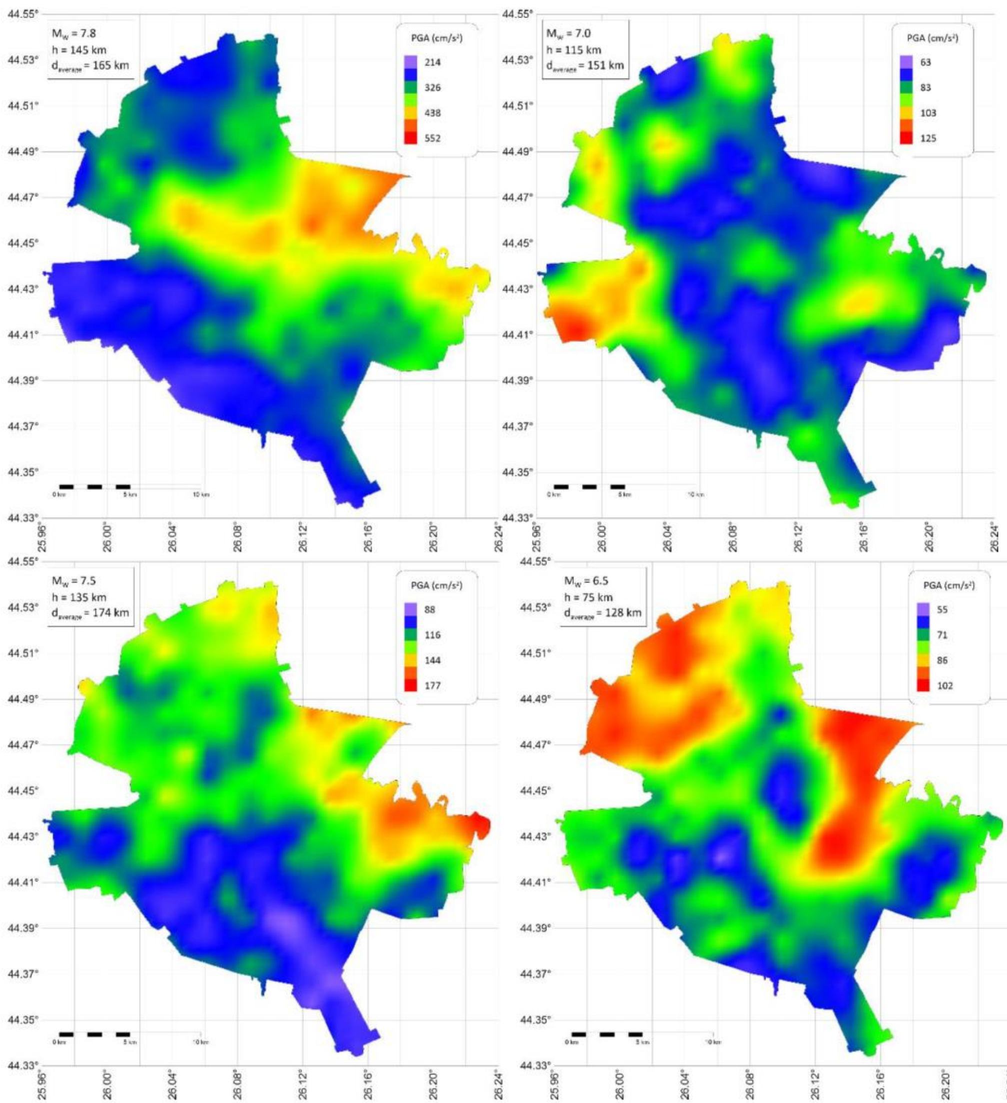
- Destroyed or seriously damaged 33,000 housing units
- Lesser damage to 182,000
- Destroyed 11 hospitals and damaged 448 others hospitals
- 32 tall buildings completely collapsed

The World Bank estimation of losses (Report 16.P-2240-RO, 1978):

- Total losses in Romania : 2.05 billion USD (100%)
- Construction losses : 1.42 (70%)
- Building and housing losses : 1.02 (50%)



Ground motion distribution across Bucharest



Mw = 7.8 & h = 145 km
Mw = 7.0 & h = 115 km
Mw = 7.5 & h = 135 km
Mw = 6.5 & h = 75 km
PGA : (0.06-0.6 g)

F.Pavel, I. Calotescu, R.Vacareanu, A-M. Sandulescu, 2017

Assessment of seismic risk scenarios for Bucharest

Economic losses

Scenario no.	M_W, h, d	Economic losses		Economic losses in bill. Euro from Pavel and Vacareanu (2016)
		Mean (bill. Euro)	COV	
1	$M_W = 7.0$, $h = 90$ km, $d = 120$ km	3.60	0.74	7.20
2	$M_W = 7.0$, $h = 150$ km, $d = 180$ km	1.78	0.82	5.04
3	$M_W = 7.5$, $h = 90$ km, $d = 120$ km	7.34	0.54	10.31
4	$M_W = 7.5$, $h = 150$ km, $d = 180$ km	3.93	0.72	7.68
5	$M_W = 8.0$, $h = 90$ km, $d = 120$ km	11.49	0.36	12.72
6	$M_W = 8.0$, $h = 150$ km, $d = 180$ km	7.18	0.55	10.09

F.Pavel, I. Calotescu, R.Vacareanu, A-M. Sandulescu, 2017

Assessment of seismic risk scenarios for Bucharest

Number of affected people

Scenario no.	M_W, h, d	Affected people		Affected people from Pavel and Vacareanu (2016)
		Mean	COV	
1	$M_W = 7.0$, $h = 90$ km, $d = 120$ km	9779	1.13	7086
2	$M_W = 7.0$, $h = 150$ km, $d = 180$ km	1888	0.97	3398
3	$M_W = 7.5$, $h = 90$ km, $d = 120$ km	14148	1.29	17780
4	$M_W = 7.5$, $h = 150$ km, $d = 180$ km	11942	1.09	8074
5	$M_W = 8.0$, $h = 90$ km, $d = 120$ km	46161	1.29	38282
6	$M_W = 8.0$, $h = 150$ km, $d = 180$ km	13480	1.32	16822

F.Pavel, I. Calotescu, R.Vacareanu, A-M. Sandulescu, 2017

Downhole Arrays in Earthquake Engineering

Seismic downhole array provide a unique source of information On actual soil behavior over a wide range of loading conditions

- Treasure Island, California
- Lotung, Taiwan
- Hualien, Taiwan
- Wildlife Refuge, Imperial County, California
- Port Island, Japan
- KiK-net ~700 locations, Japan
- EuroSeisTest, Greece

- ➢ Shear wave characteristics (correlation & spectral analyses)
- ➢ Variation of V_s with depth
- ➢ Site resonant frequencies and modal configurations
- ➢ empirical Green's function technique for predicted large earthquake ground motion using small events;
- ➢ Validations of 1D numerical modelling
- ➢ Dynamic properties of soils over a wide strain loading conditions

Seismic networks in Bucharest (Lungu et al., 2003)

INC – Downhole Array

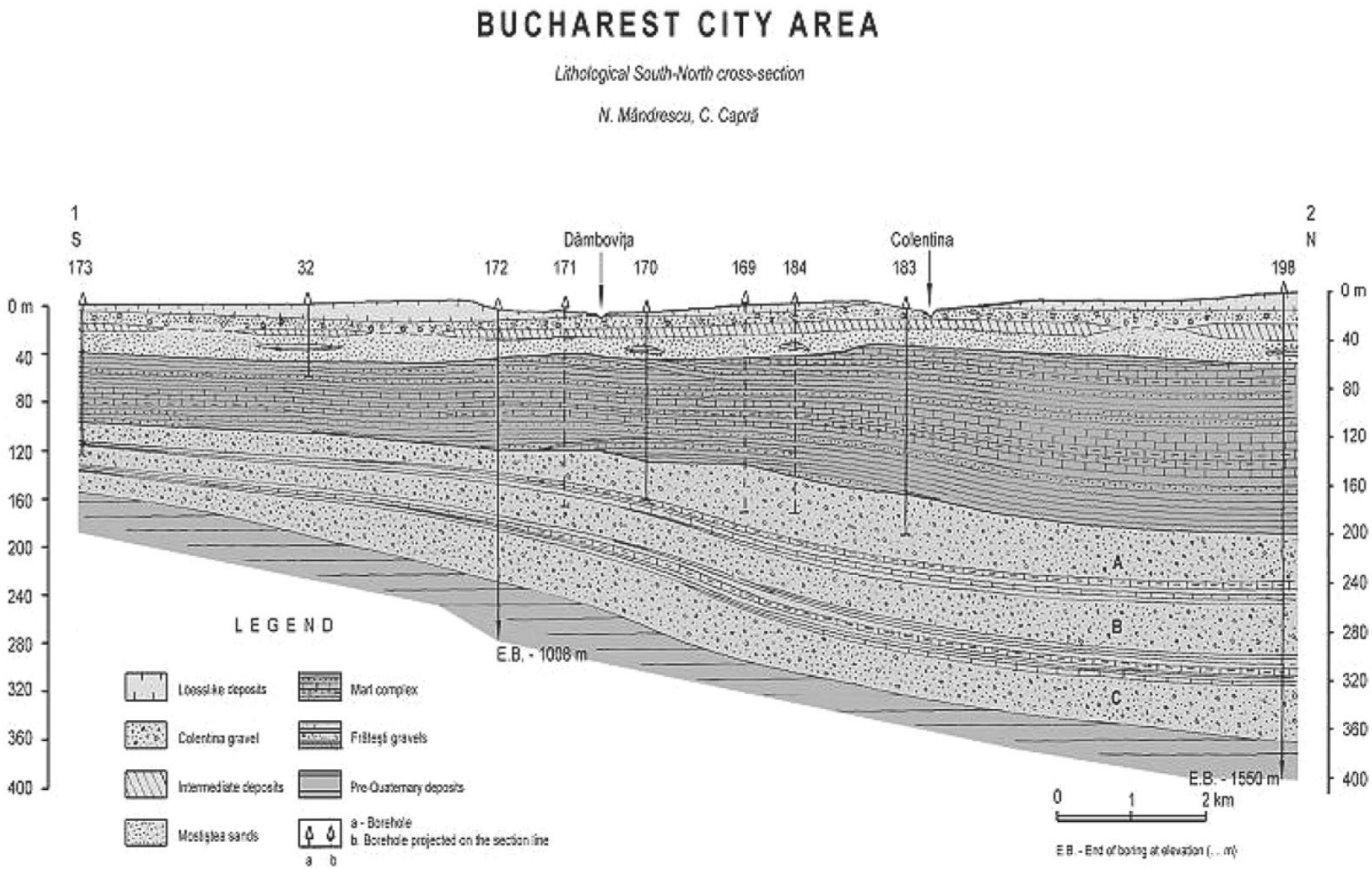
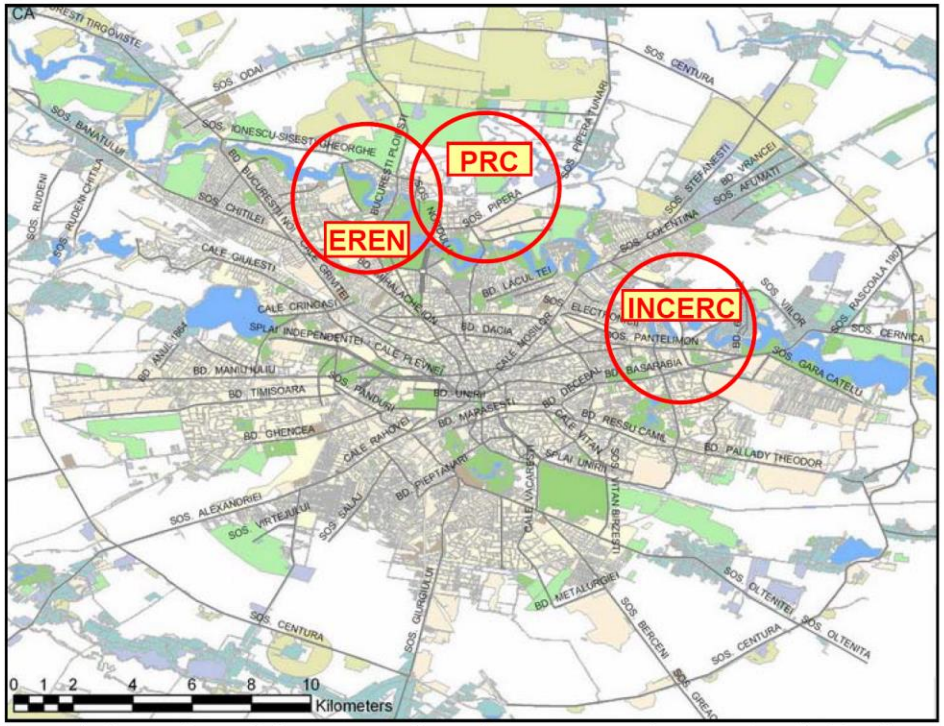
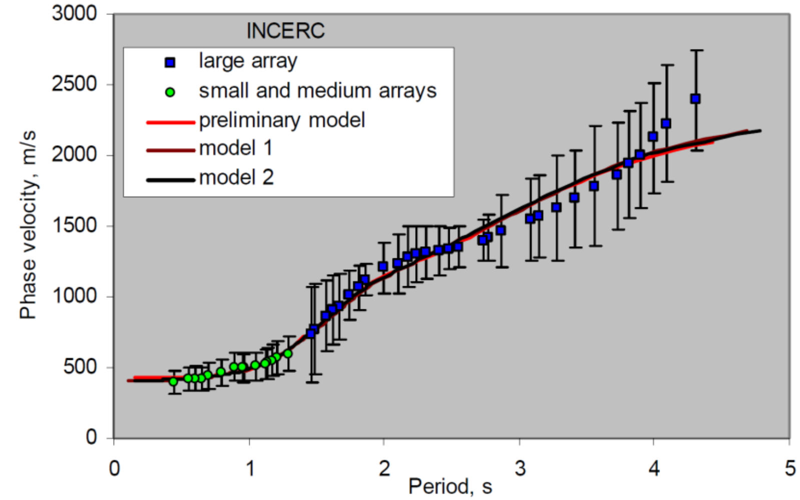


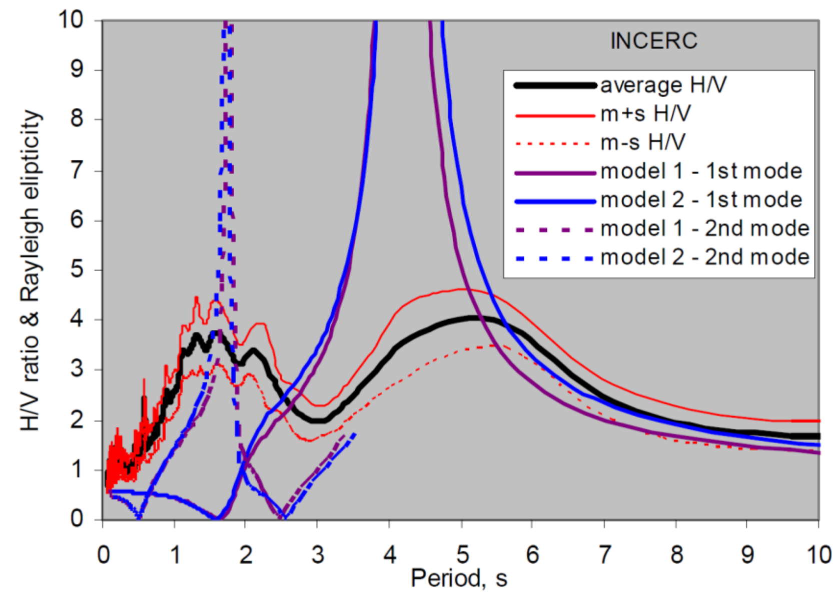
Fig. 1 – Lithological cross-section for Bucharest area (after Mandrescu *et al.*, 2004). One can notice the dipping of the sediments towards north.

(Zaharia et al., 2006)

SINGLE-STATION AND ARRAY MICROTREMOR MEASUREMENTS after YAMANAKA et al., 2007







Spac and F-K

Small, medium and large size arrays,

Station-to-Station distances up to about 3 km

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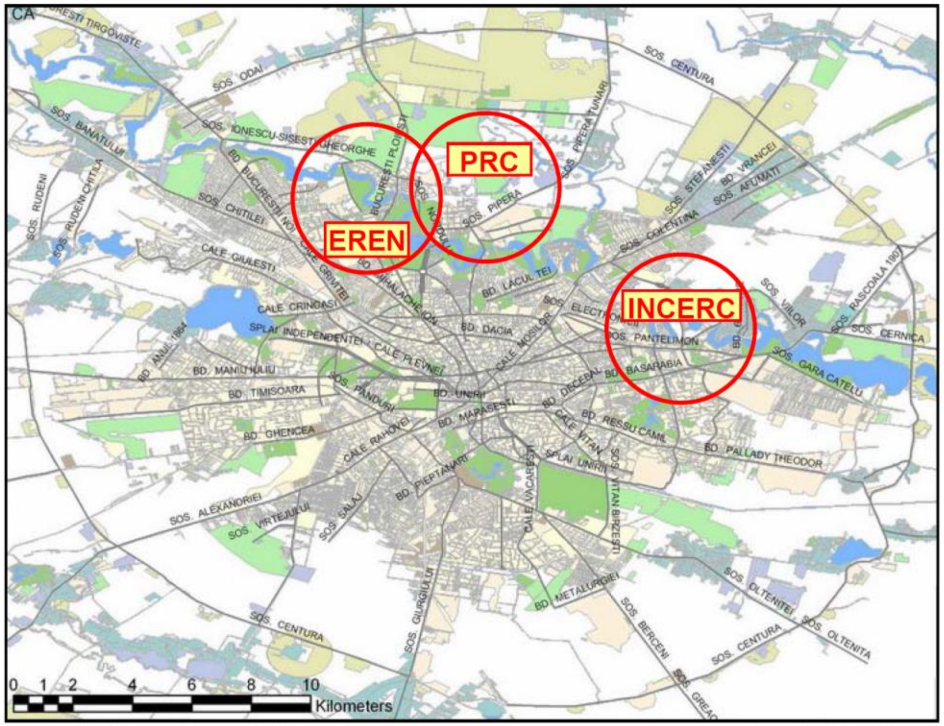
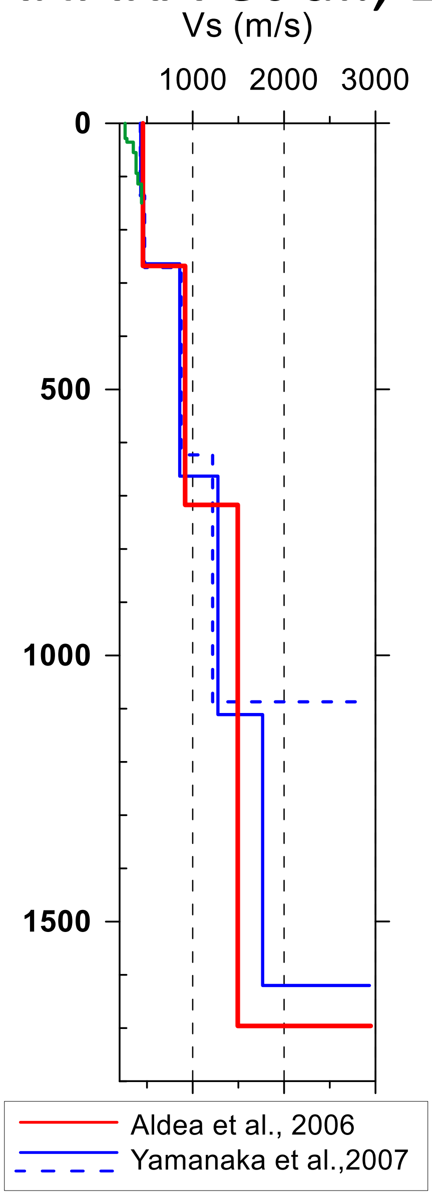
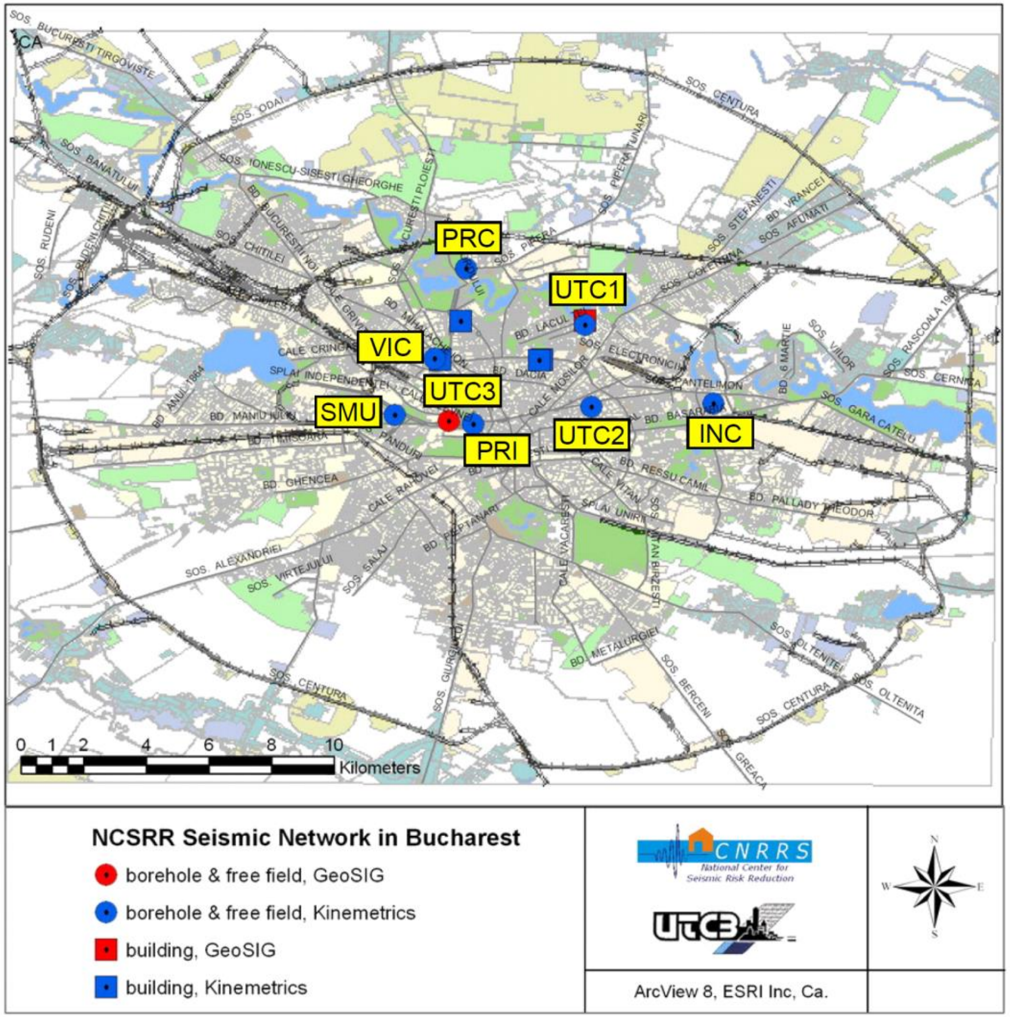
SINGLE-STATION AND ARRAY MICROTREMOR MEASUREMENTS after YAMANAKA et al., 2007





Proposed models explain in a satisfactory way the observed data

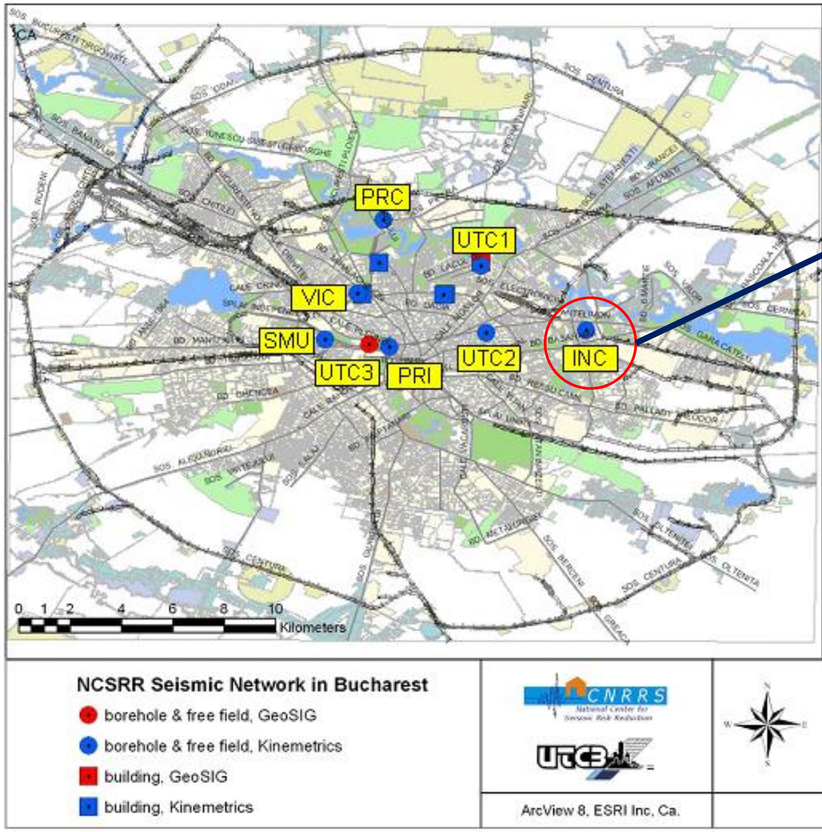
Downhole arrays in Bucharest

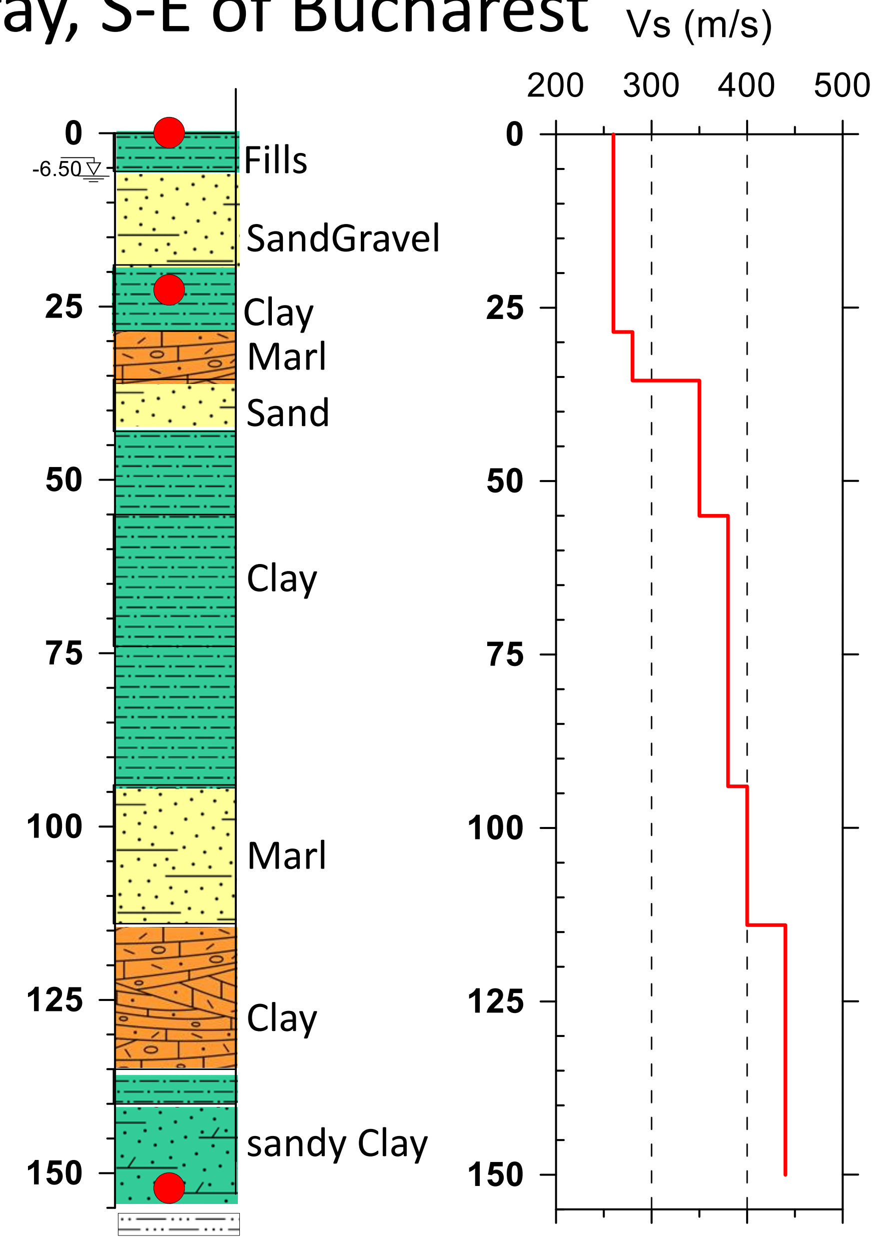


Station	B2-Z	Vs,30 (m/s)	Vs,52 (m/s)	Fo_SSR (Hz)
INC	-153m	309	326	0.7
UTC1	-78m	293	309	1.2
SMU	-70m	288	318	1.3
PRC	-68m	284	310	1.2
UTC2	-66m	270	302	1.4
PRI	-52m	219	258	1.5

ALDEA et al.,2007

INC – Downhole Array, S-E of Bucharest





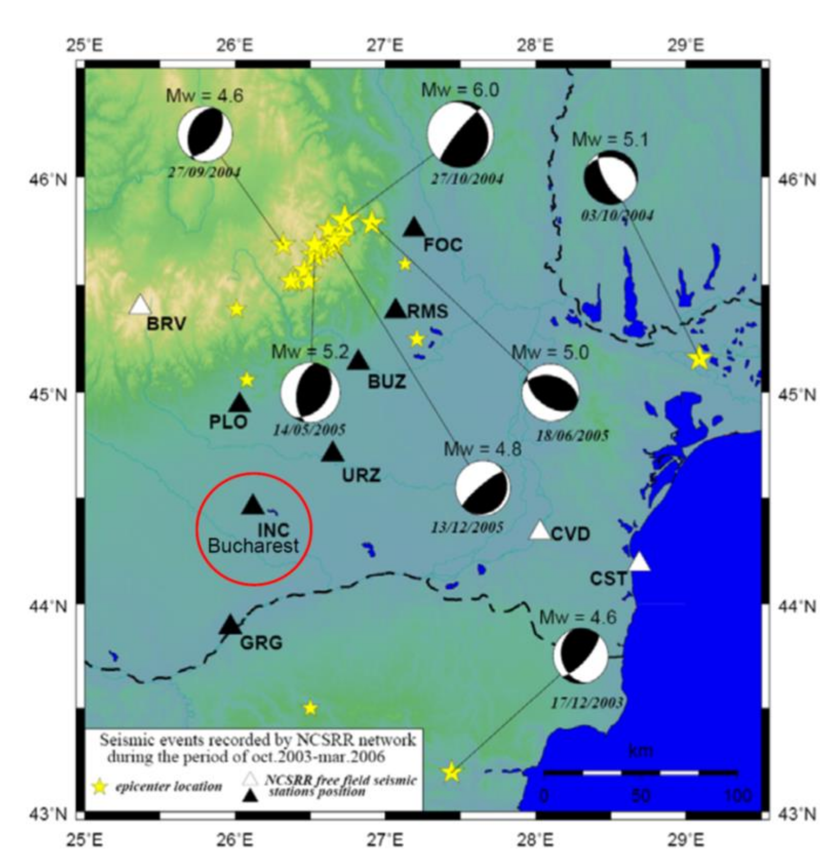
Acc.Sensors: 0m, -24m, -153m

F_o=0.65Hz (1.5s)
$V_{s,160}$=364m/s
$V_{s,30}$=270m/s

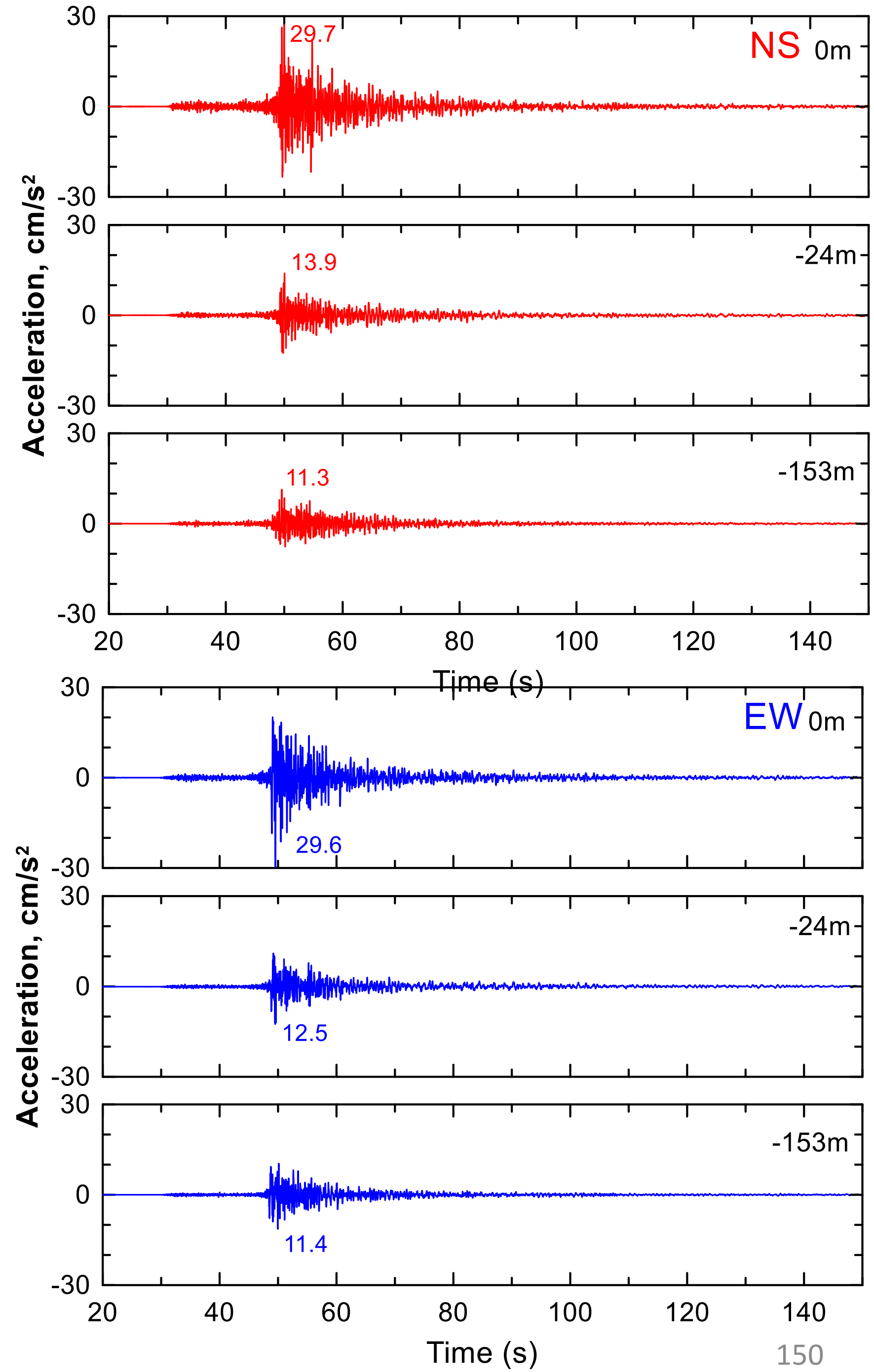
Aldea et al., 2006

INC – Downhole Array

27.10.2004 Vrancea earthquake, Mw=6.0, R=160km, Depth=105km



Aldea et al., 2007



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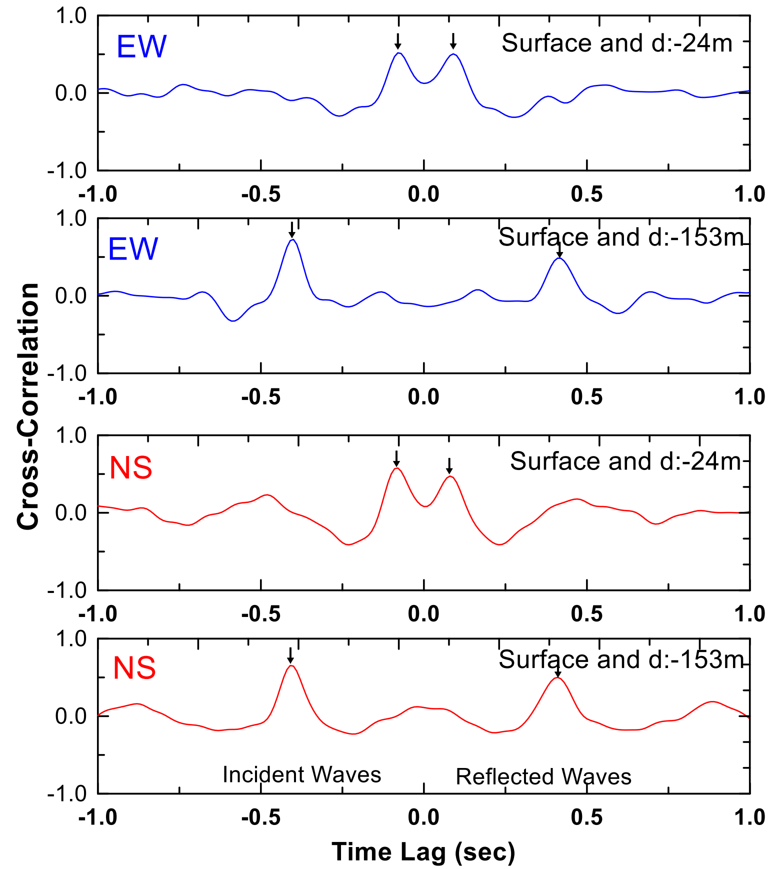
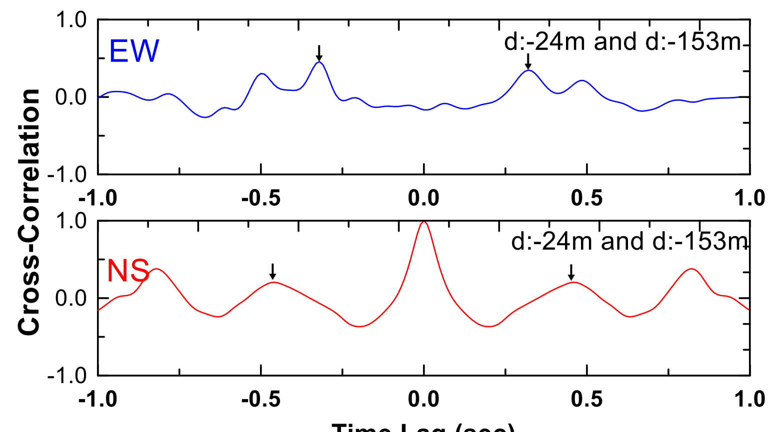
INC – Downhole Array – Application of Cross Correlation

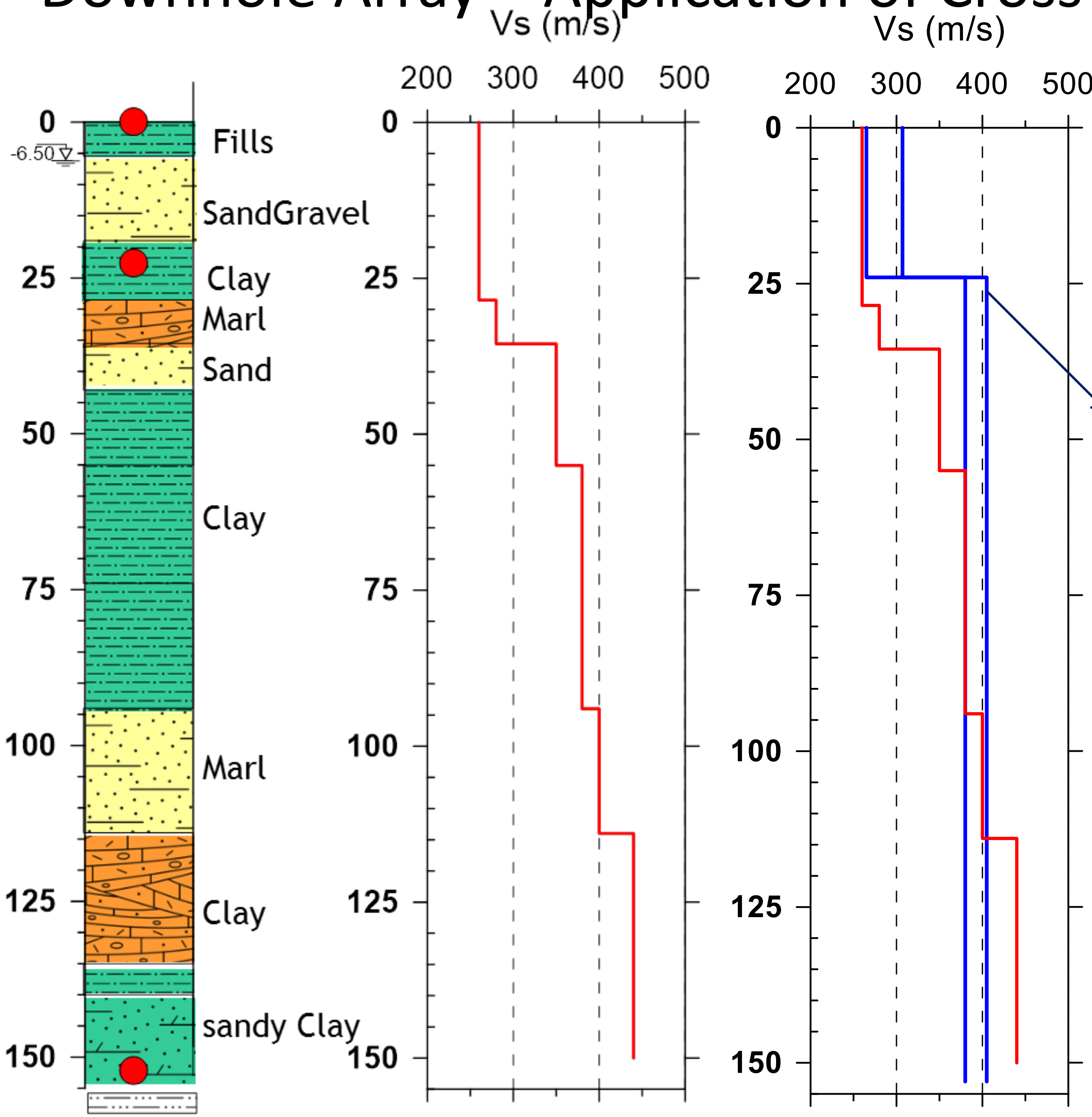
Validation of $V_{s,m}$ variation from actual records





Depth	EW				NS			
(m)	Incident		Reflected		Incident		Reflected	
	td(s)	Vs(m/s)	td(s)	Vs(m/s)	td(s)	Vs(m/s)	td(s)	Vs(m/s)
0.0-24.0	0.078	307	0.091	265	0.083	288	0.078	307
0.0-153.0	0.403	380	0.412	371	0.408	375	0.408	375
24.0-153.0	0.320	403	0.319	405	0.464	278	0.460	281

INC – Downhole Array – Application of Cross Correlation



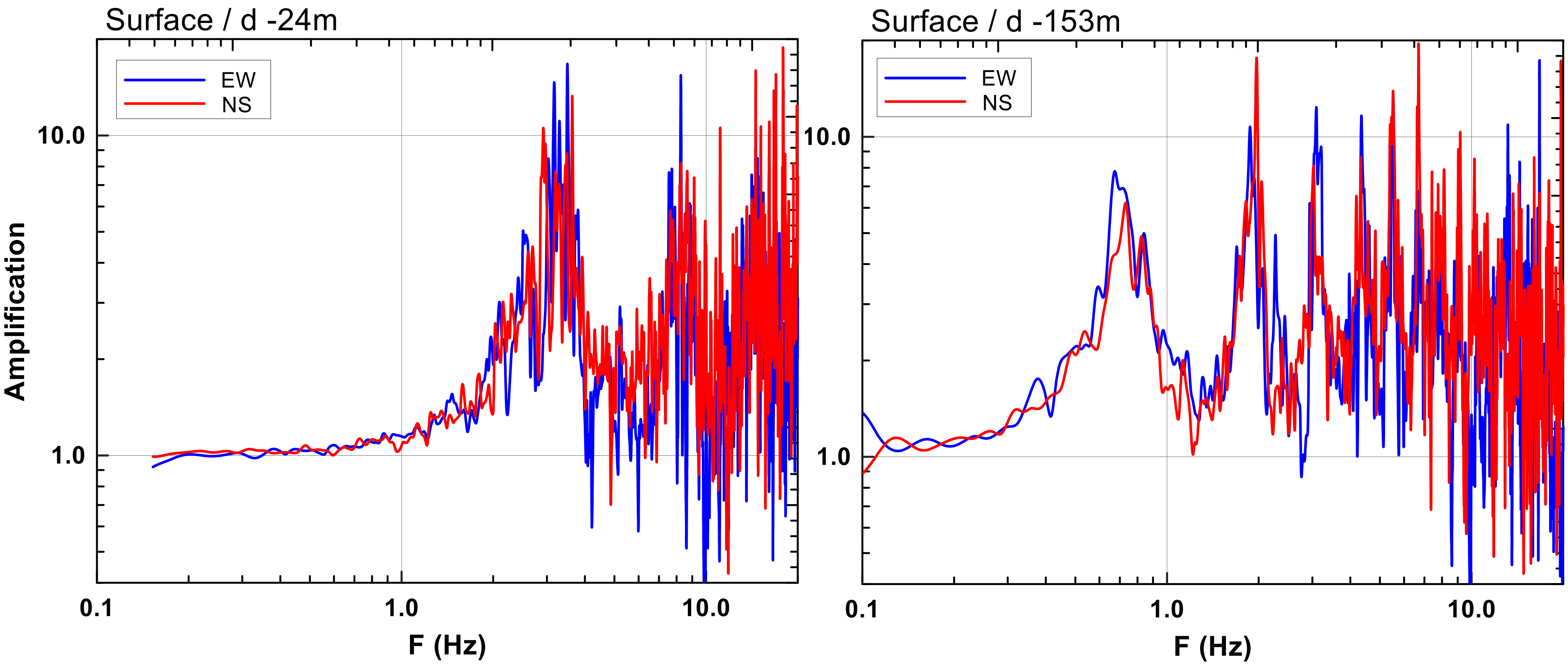
Vs determined from application of Cross-Correlation 27.10.2004 Record

Good agreement

Aldea et al., 2006

INC – Downhole Array -27/10/2004

Site Response Characteristics: Spectral Ratios



High Amplification at surficial layers

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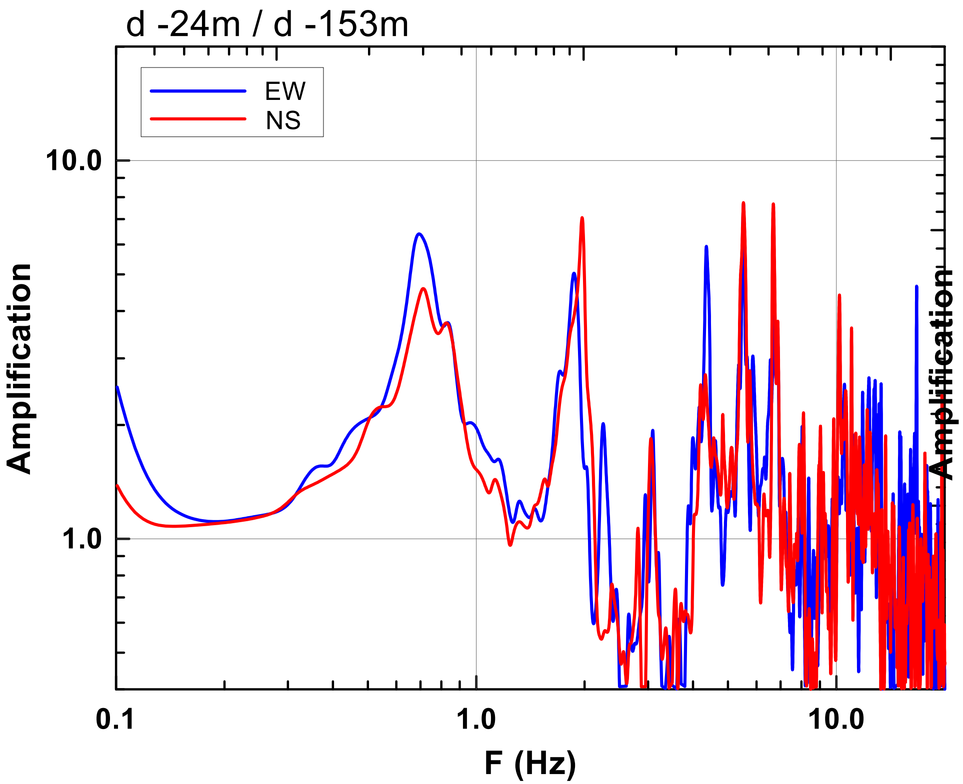
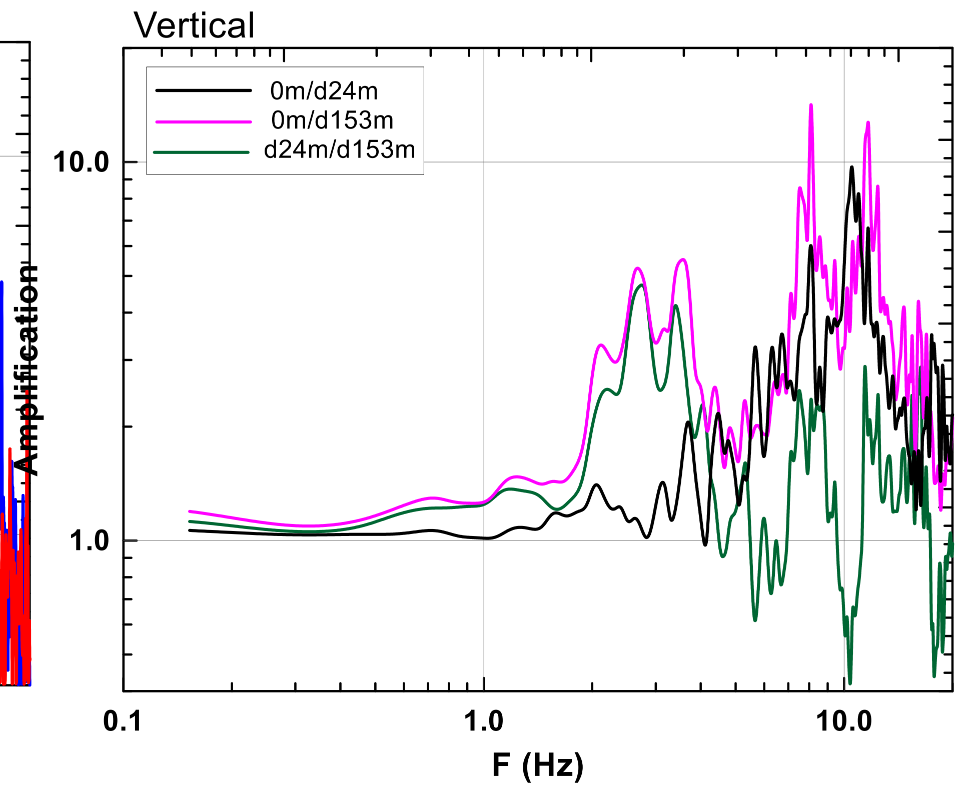
INC – Downhole Array -27/10/2004

Site Response Characteristics: Spectral Ratios



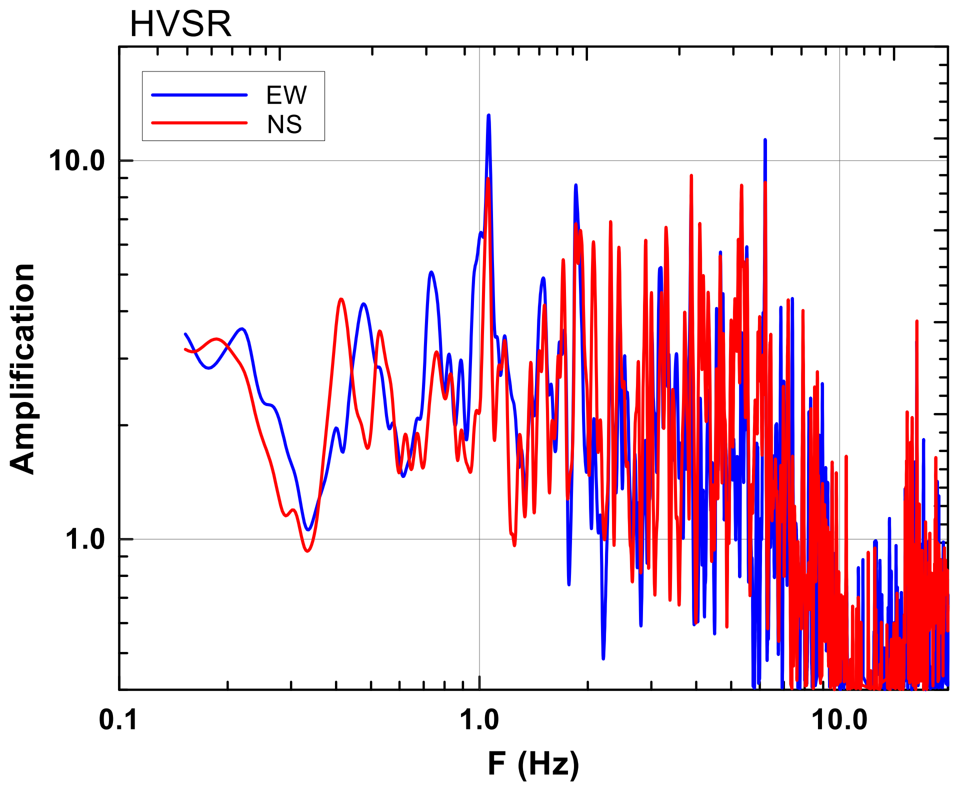


Amplification at fo

Amplifacation on surficial layers
At higher frequencies

INC – Downhole Array -27/10/2004

Site Response Characteristics: Spectral Ratios

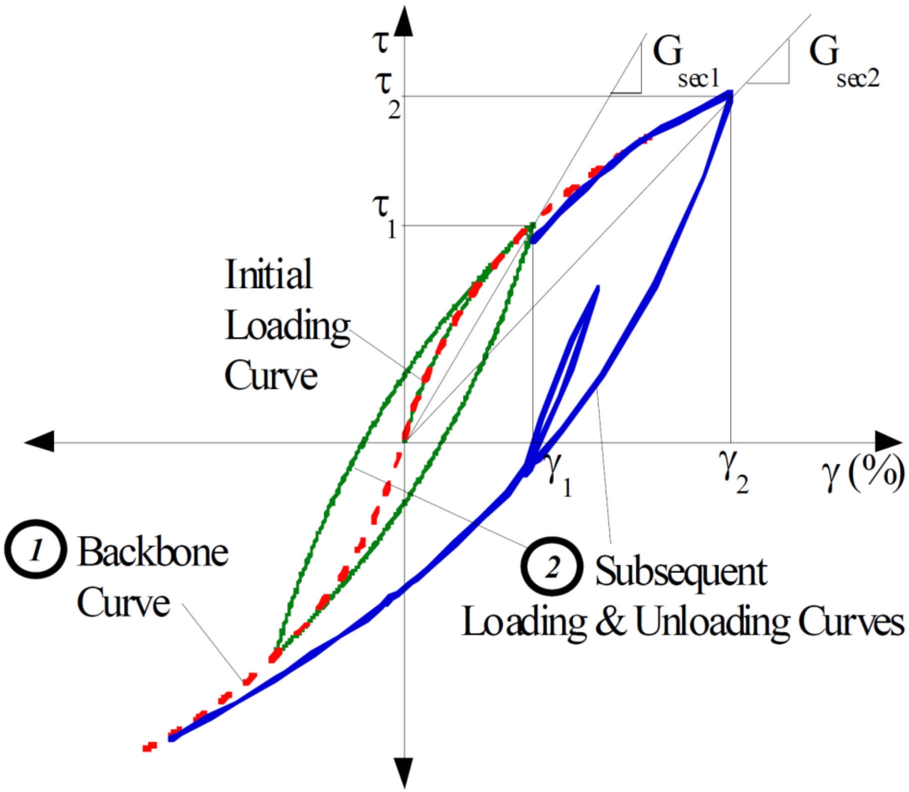


INC – Downhole Array - 27/10/2004

1D Equivalent Linear and Non-Linear Analysis – DeepSoil

Modified by Matasovic, 1993 the Konder & Zelesko, 1963 - Pressure depended model

1D Wave Propagation – Time Domain Solution



www.illinois.edu/~deepsoil

Modified Kondner-Zelasko (MKZ) model (Matasovic 1993)

1 $$\tau = \frac{\gamma \cdot G_0}{1 + \beta \left(\frac{\gamma}{\gamma_r} \right)^s}$$

2 $$\tau = \frac{2 \cdot G_0 \cdot \left(\frac{\gamma - \gamma_{rev}}{2} \right)}{1 + \beta \left(\frac{\gamma - \gamma_{rev}}{2 \cdot \gamma_r} \right)^s} + \tau_{rev}$$

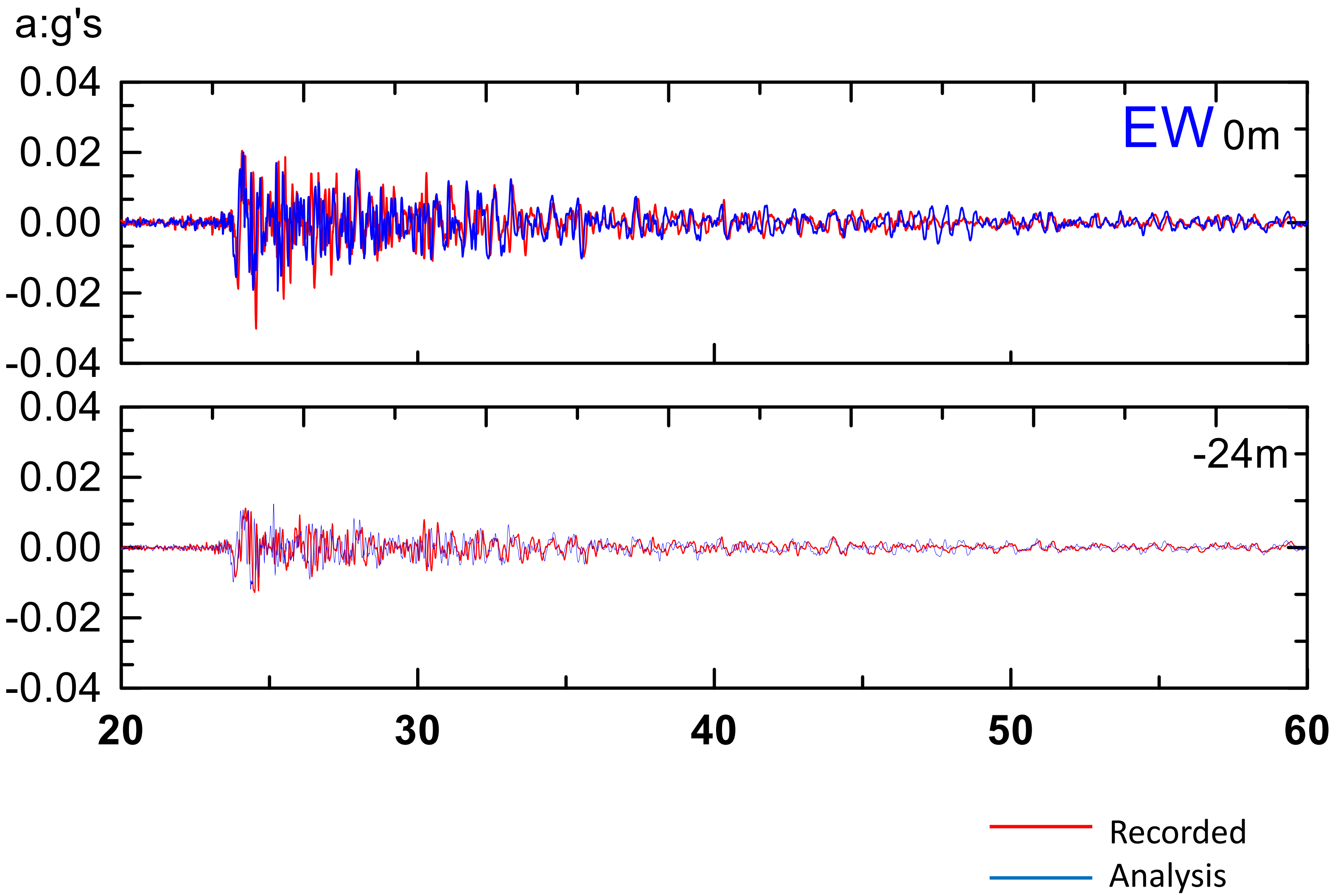
Dynamic Equation :

$$[M]\ddot{u} + [C]\dot{u} + [K]u = -[M]\ddot{u}_g$$

INC – Downhole Array - 27/10/2004

1D Equivalent Linear and Non-Linear Analysis – DeepSoil

Modified by Matasovic, 1993 the Konder & Zelesko, 1963 - Pressure depended model



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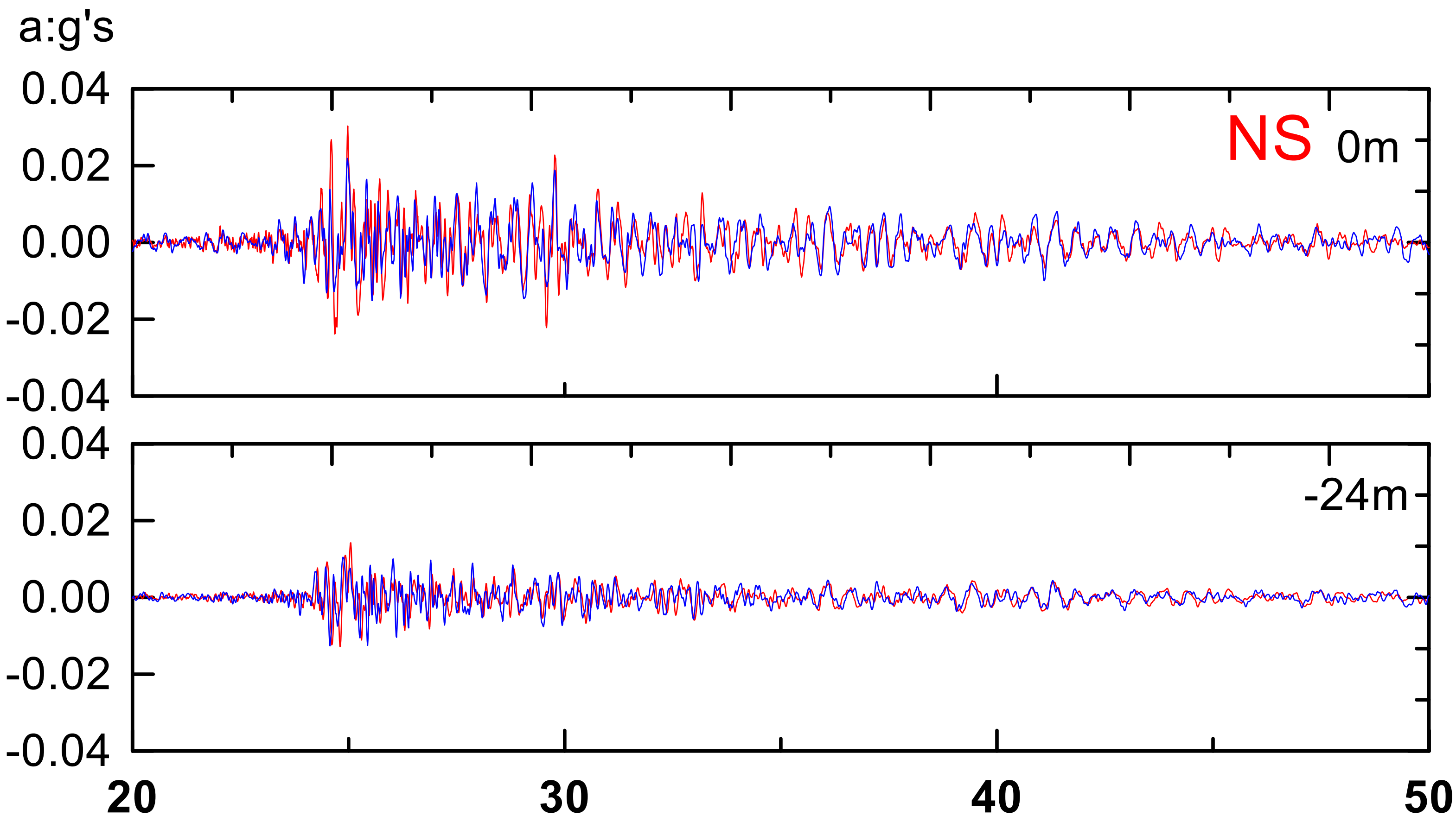
Non-Linear Analysis



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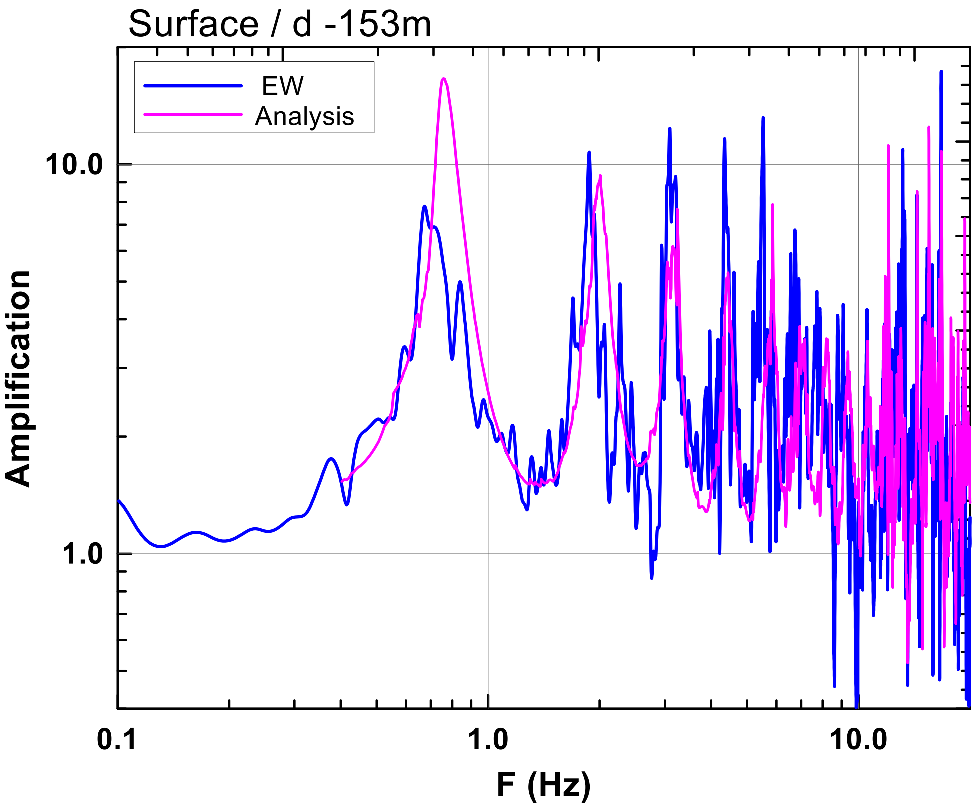

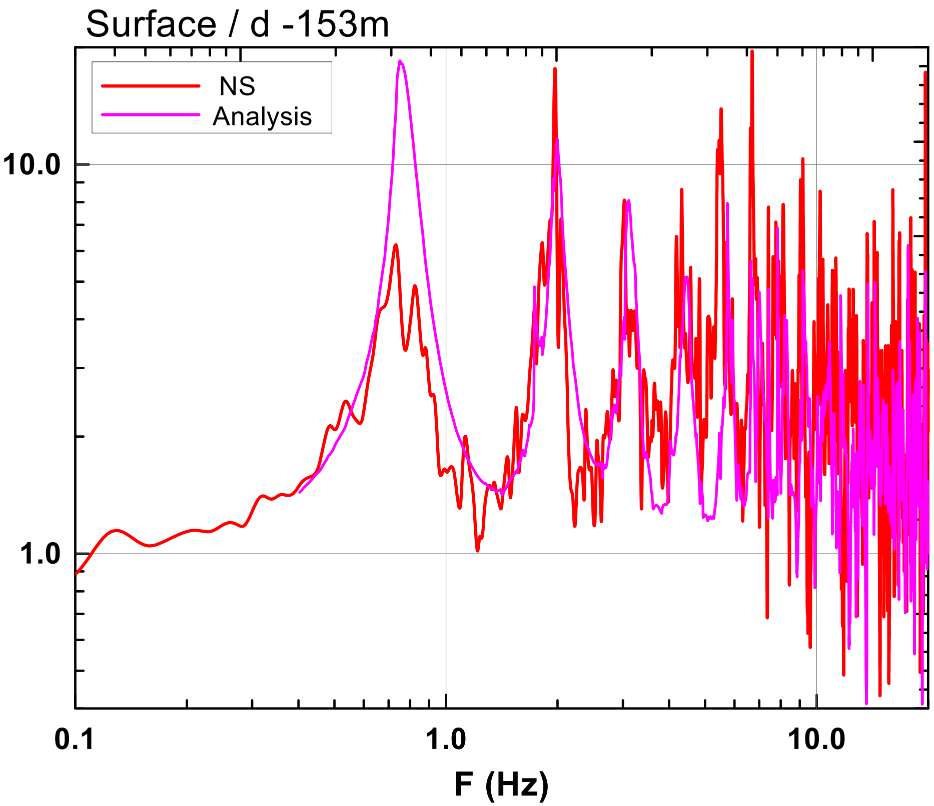

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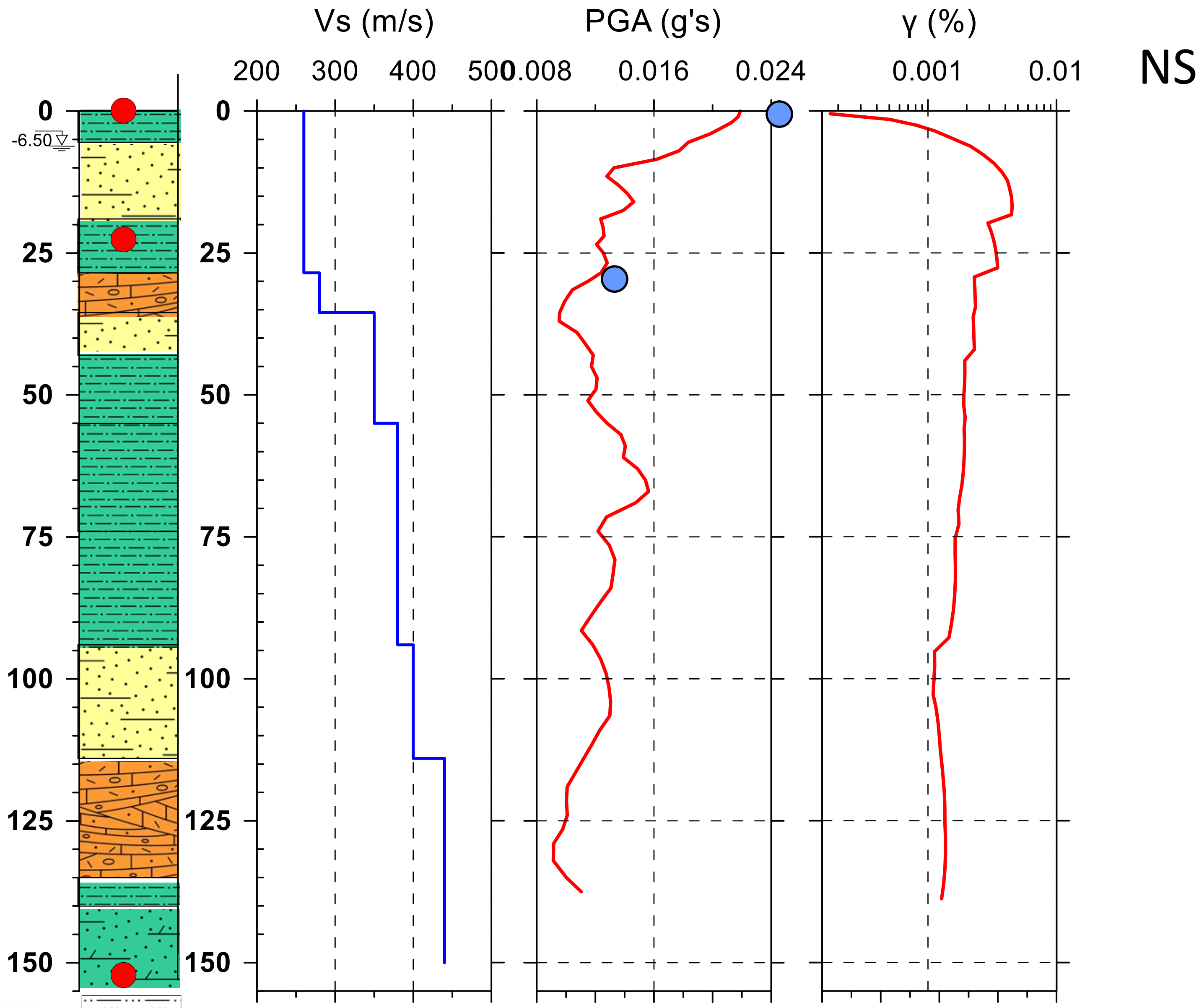

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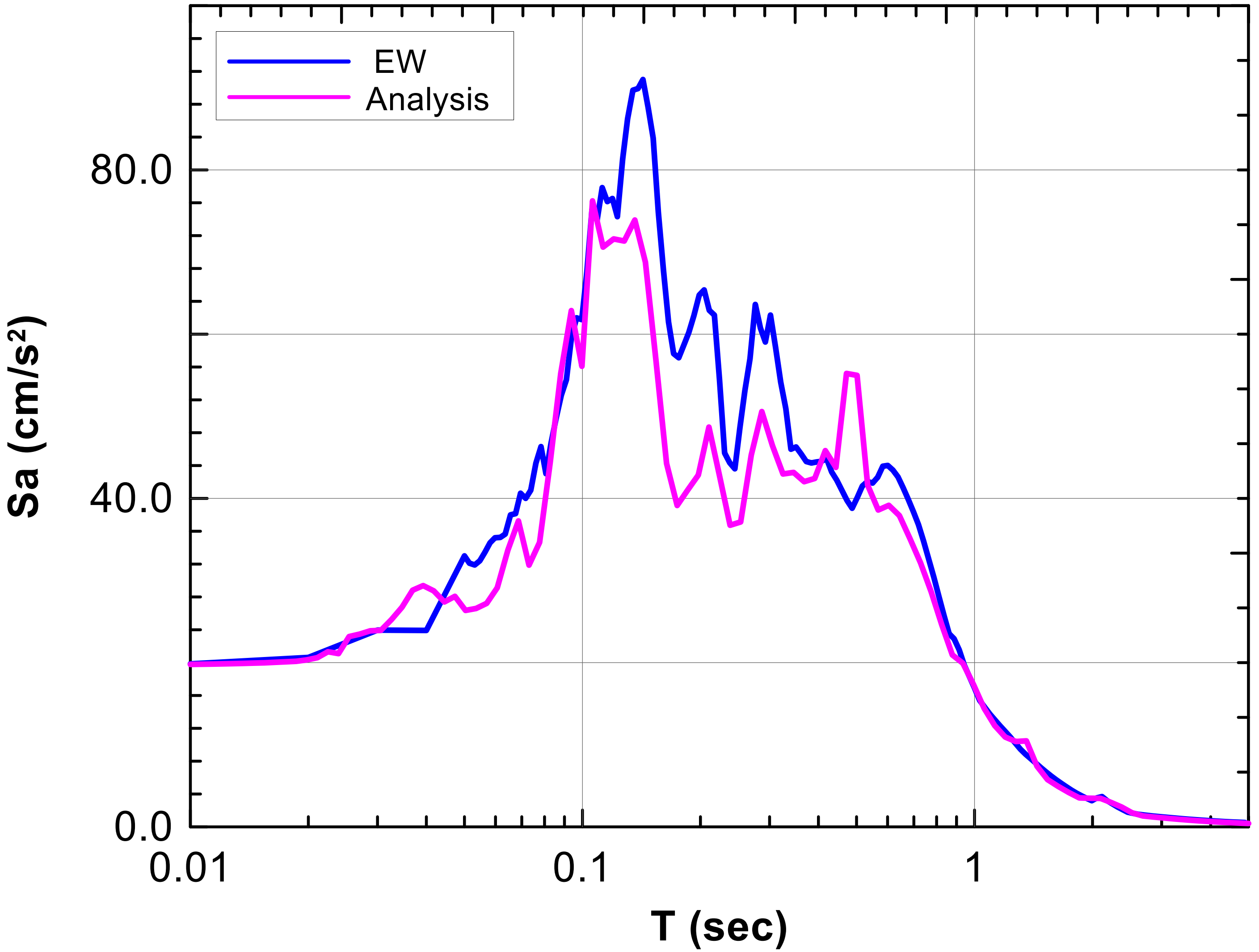
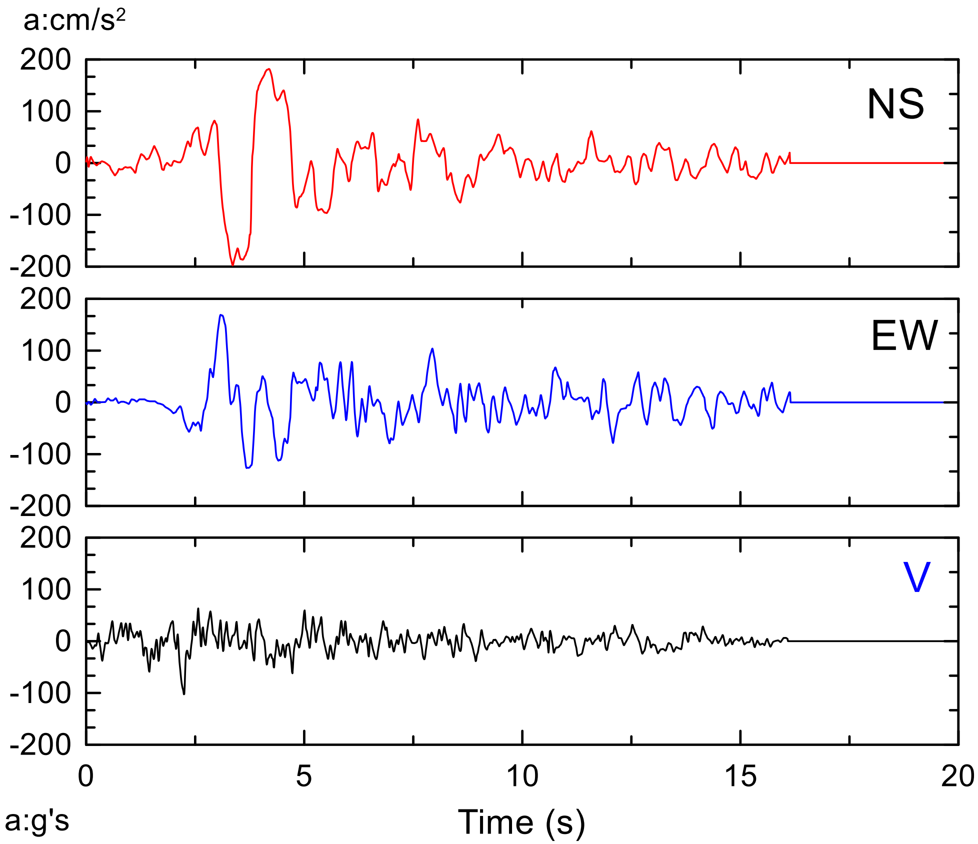
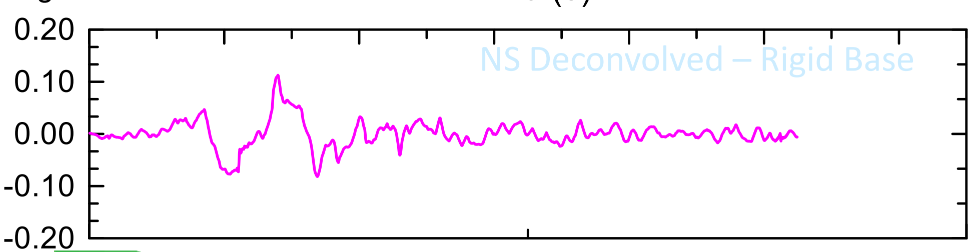
INC – Downhole Array - 27/10/2004

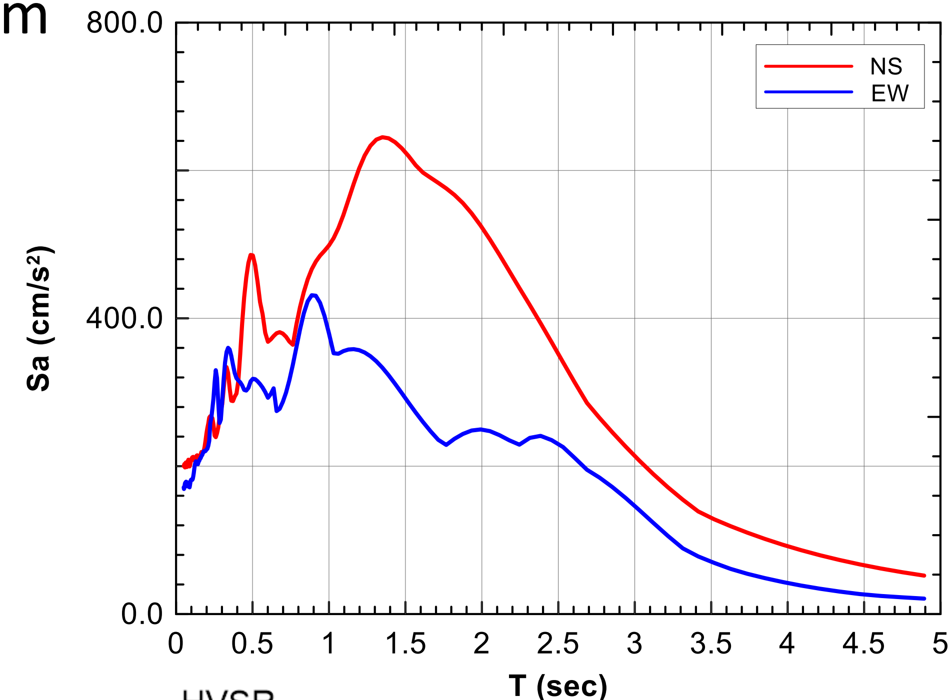


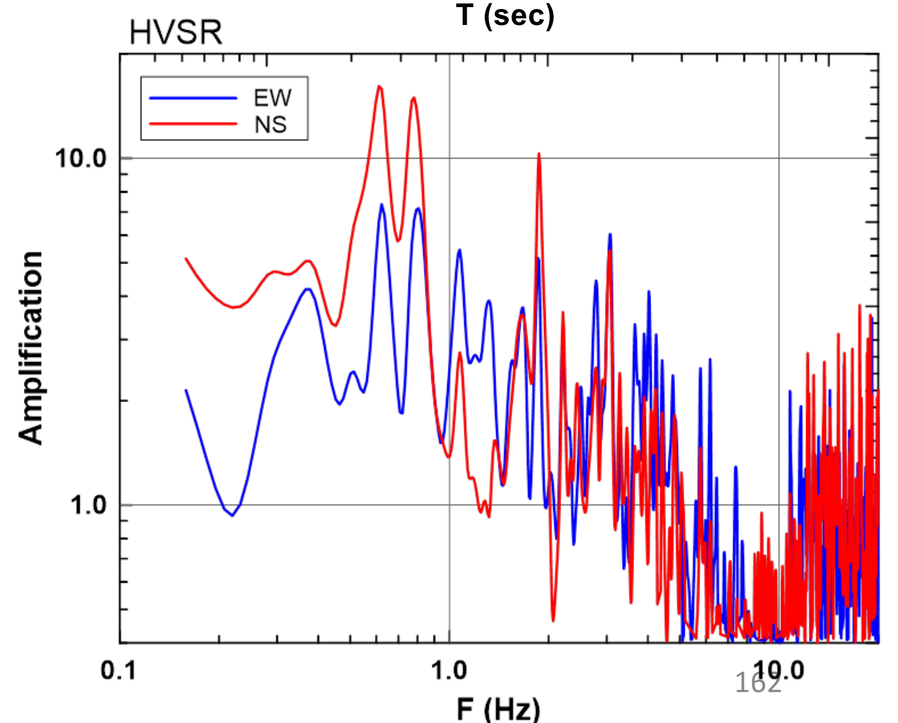
BRI – 1977 Record, Ms=7.05, R=161km

Bucharest-Building Research Institute
1977/03/04 19:21:54.000









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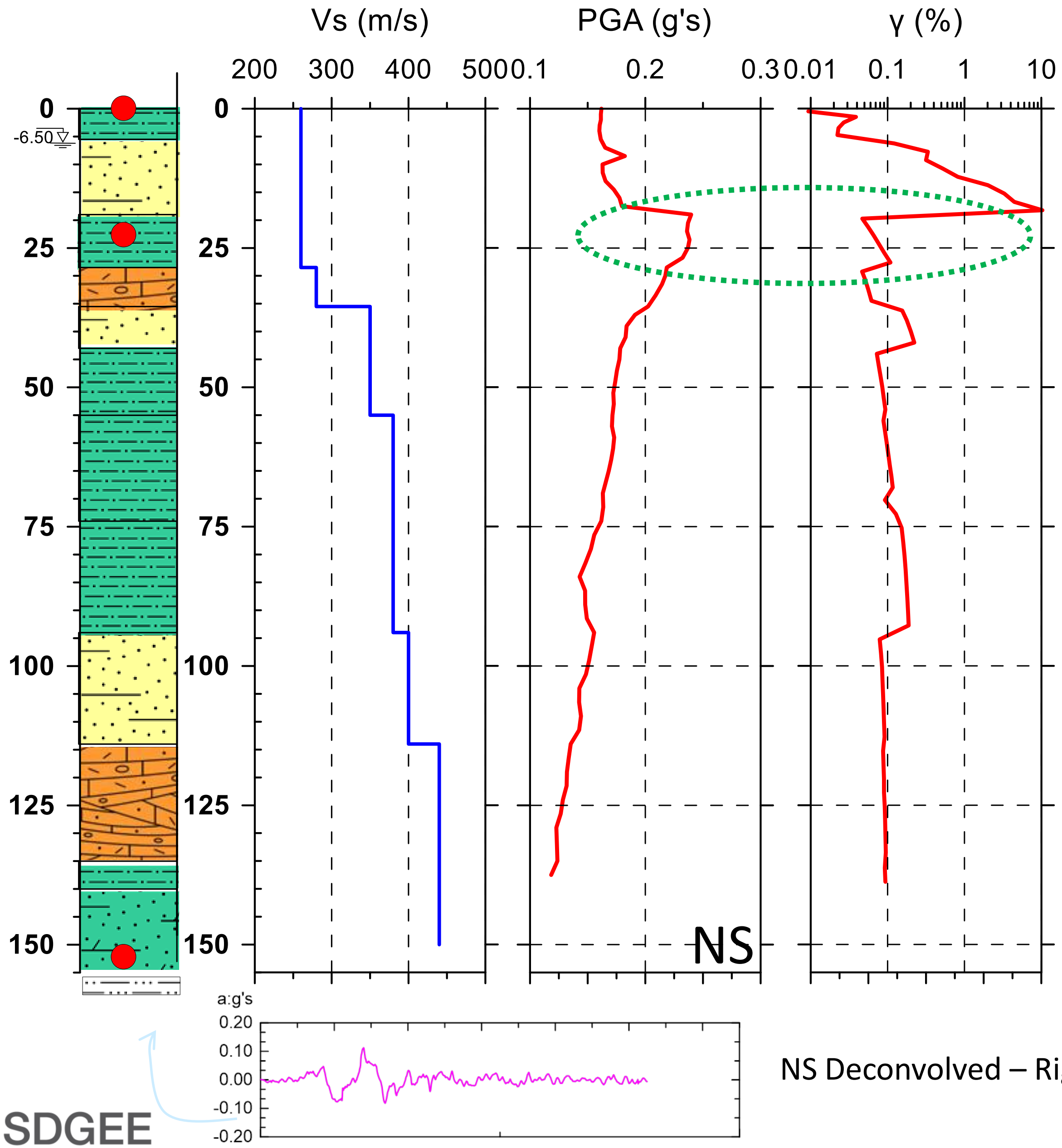
BRI – 1977 Record, Ms=7.05, R=161km



NS Deconvolved – Rigid Base

Extremely Large Induced Shear strains At upper 24m

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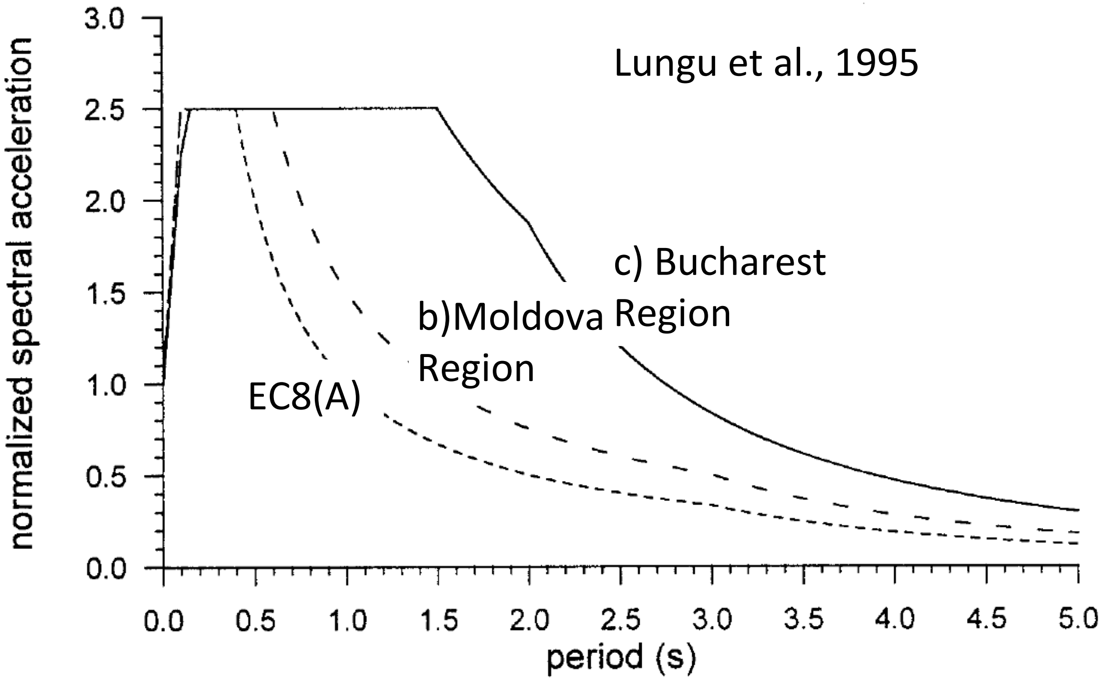
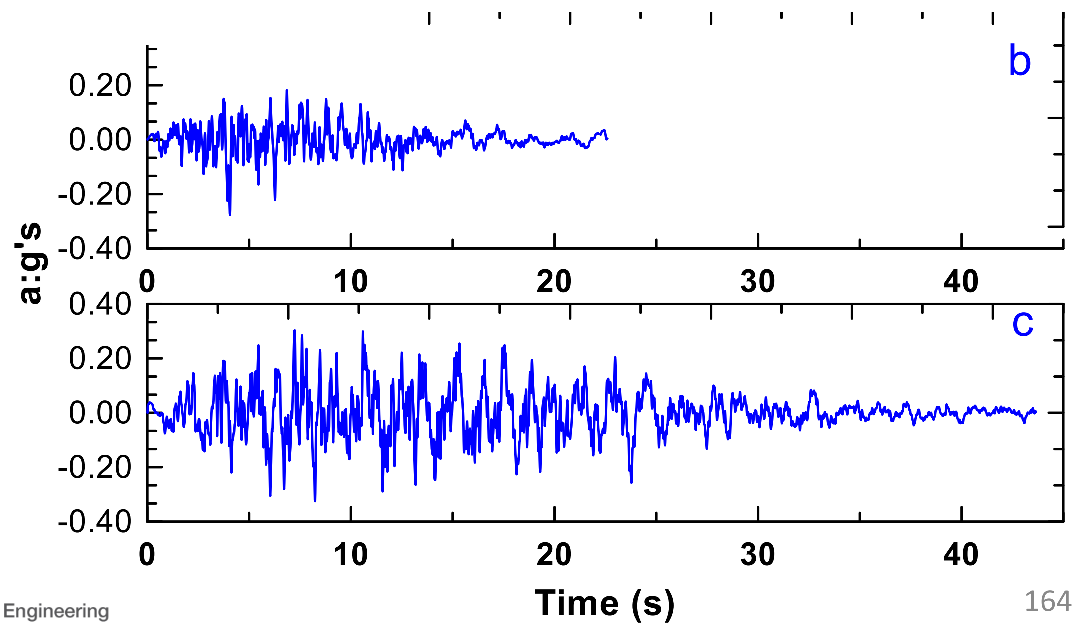
Development of Synthetic Time Histories

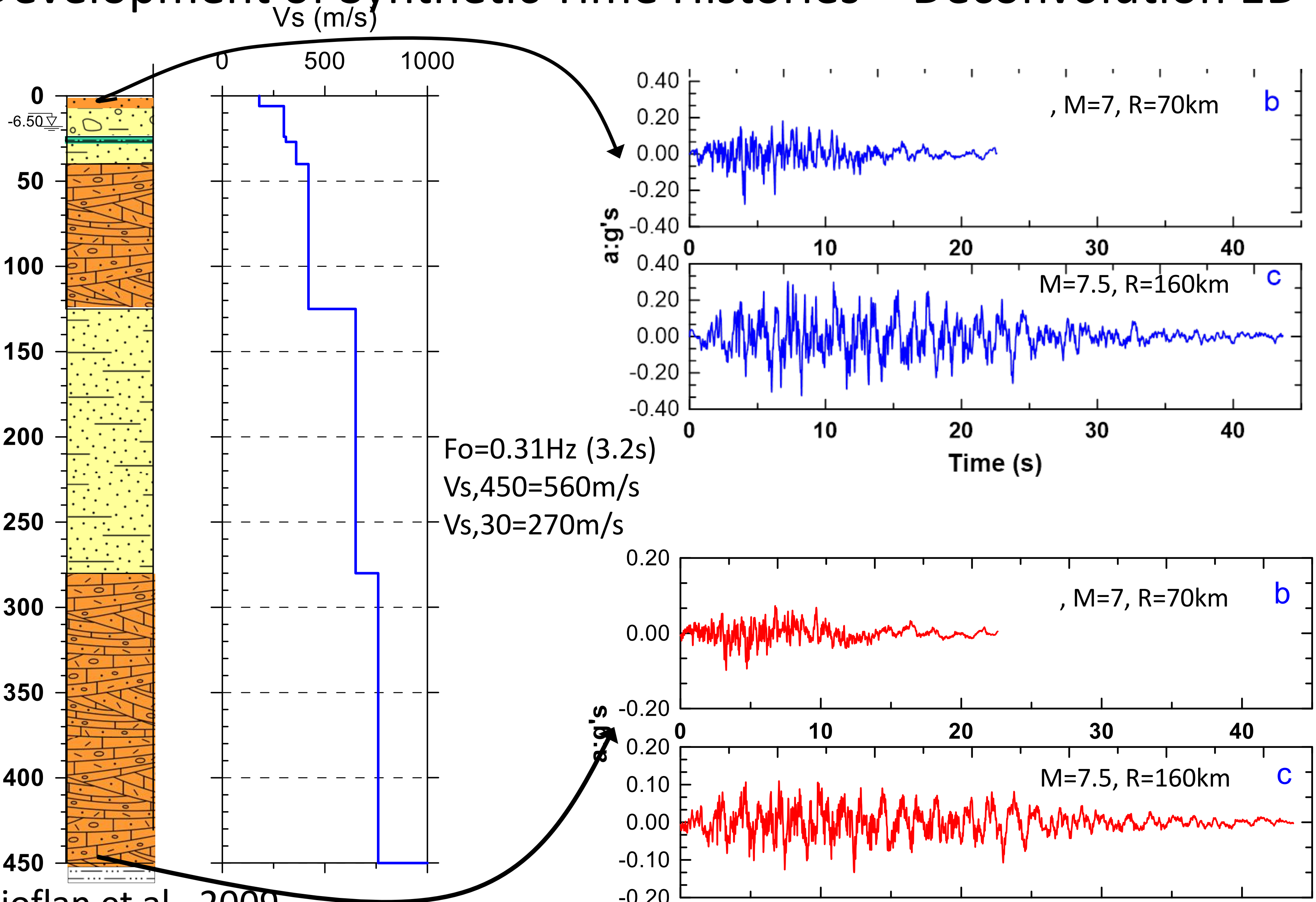


Two Scenarios – Generic Soil (Vs=310m/s), No Site Effects Halldorsson & Papageorgiou 2005:

b) Moldova Region,
Scaled PGA=0.2, M=7, R=70km
c) Bucharest Region,
Scaled PGA=0.3, M=7.5, R=160km

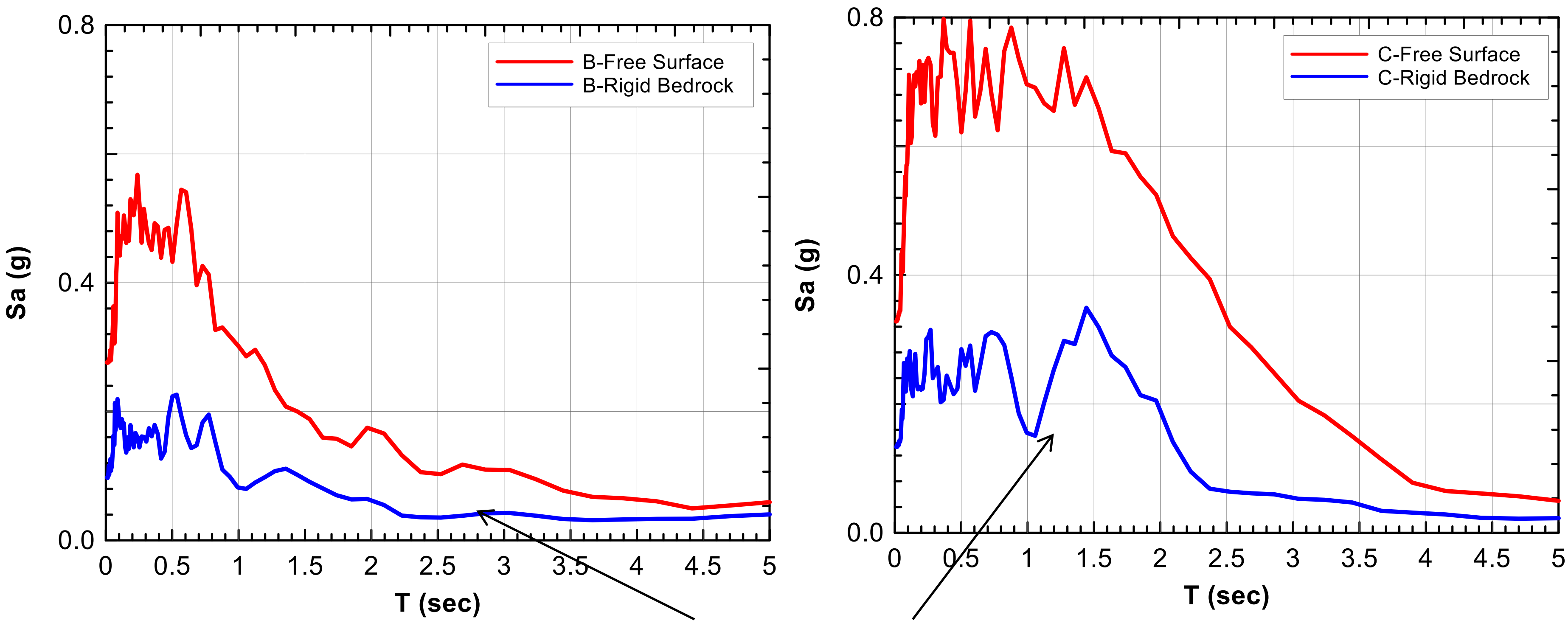


Development of Synthetic Time Histories – Deconvolution 1D-NL



Cioflan et al., 2009

Development of Synthetic Time Histories – Deconvolution 1D-NL

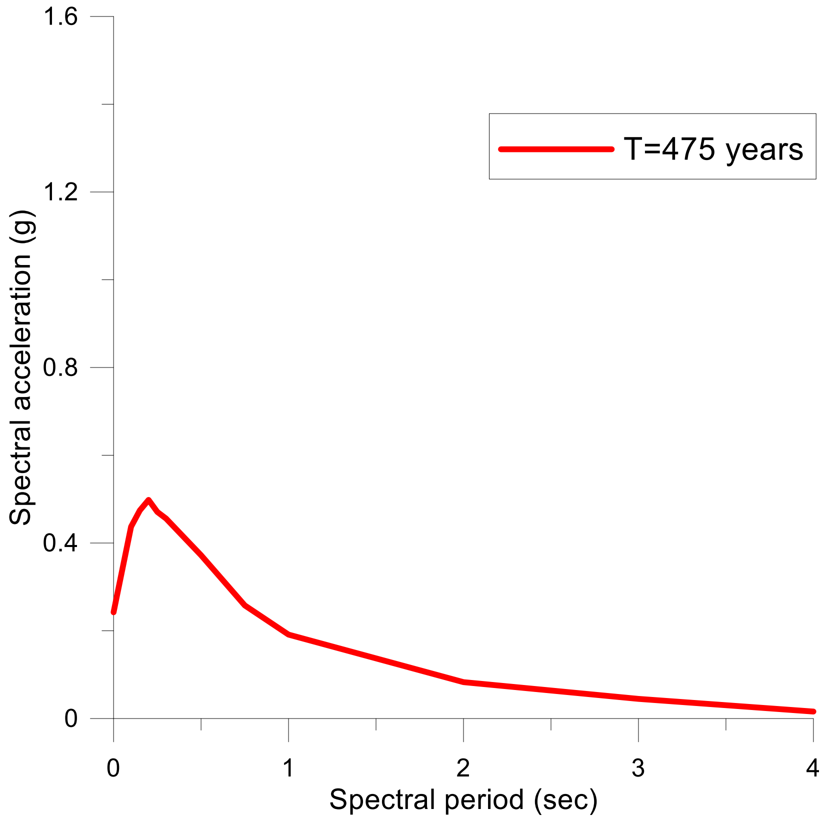


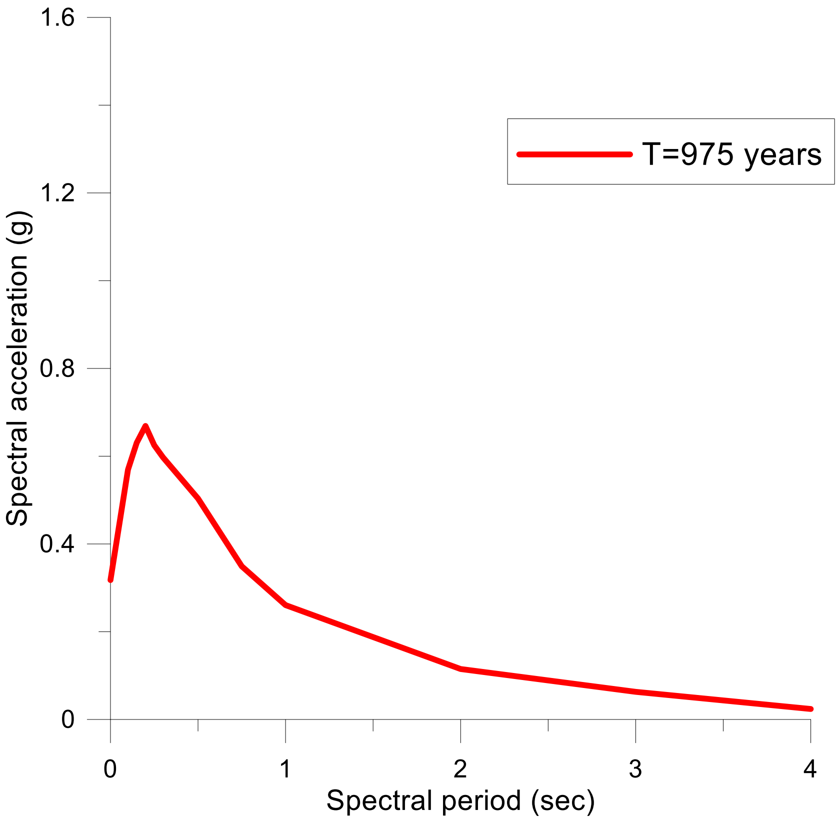
Input motion

Deconvolved 1D-NL Analysis

Uniform Hazard Spectra for Bucharest

Bedrock Vs>800m/s





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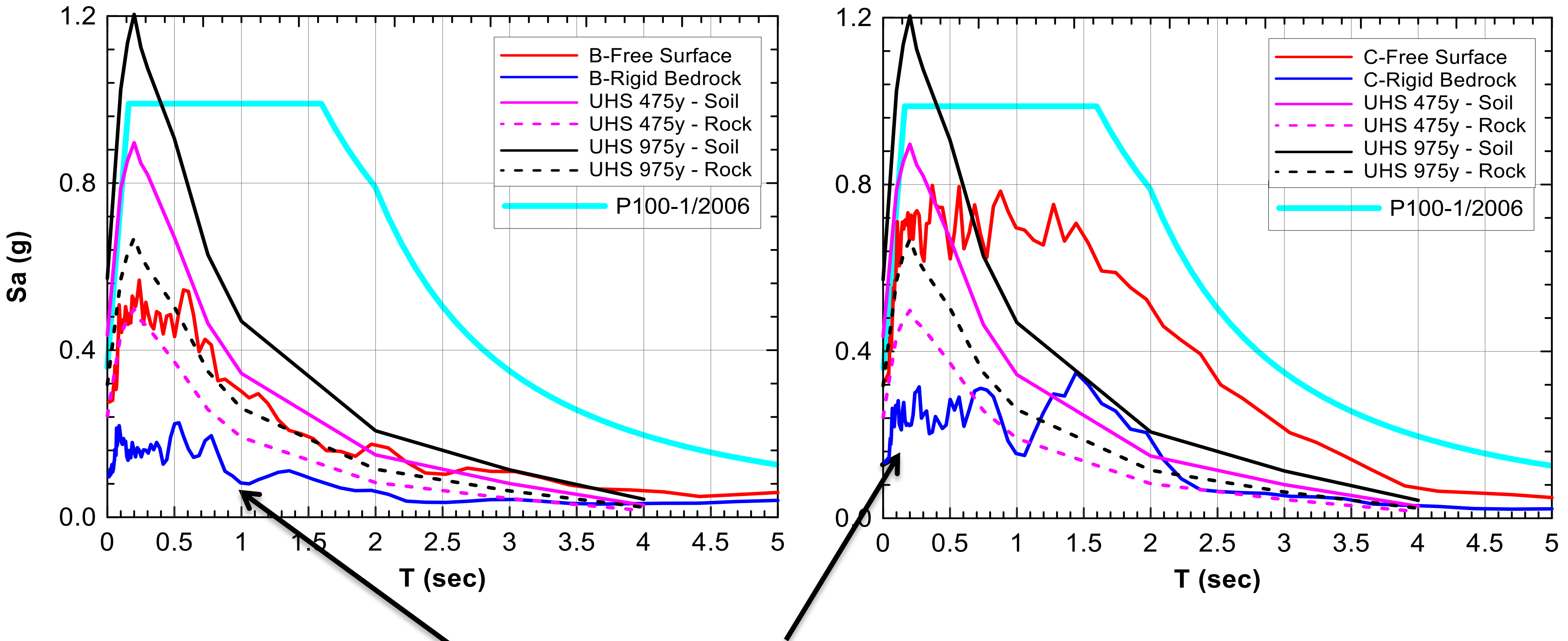
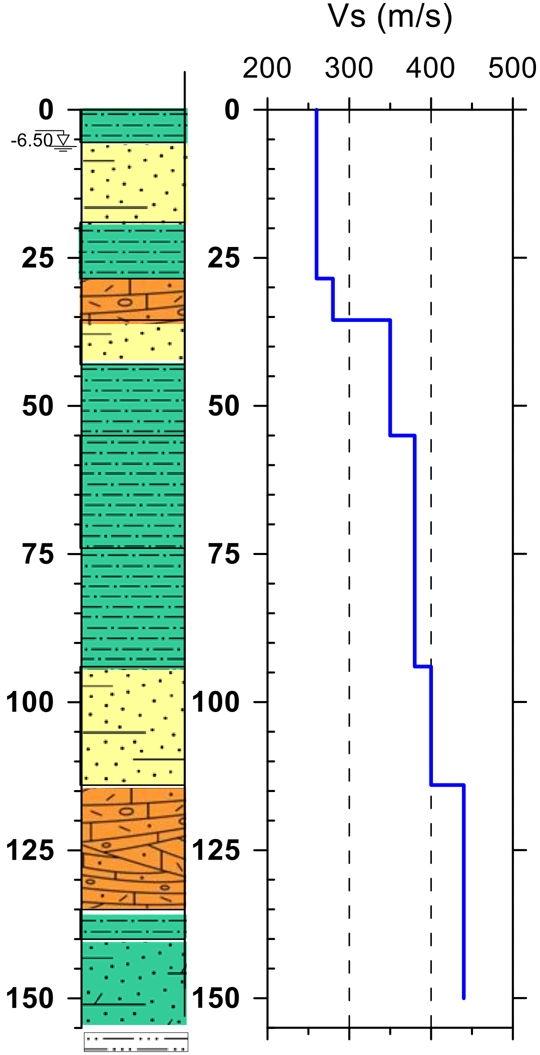
Development of Synthetic Time Histories – Deconvolution 1D-NL



Input motion
Deconvolved 1D-NL Analysis

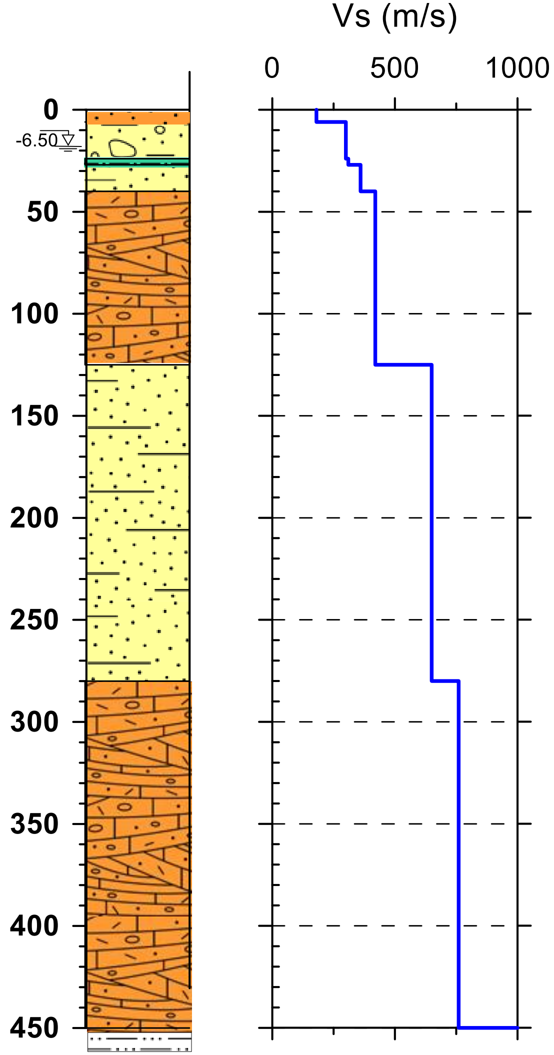
Response of Deep Soil Profiles

Model 1



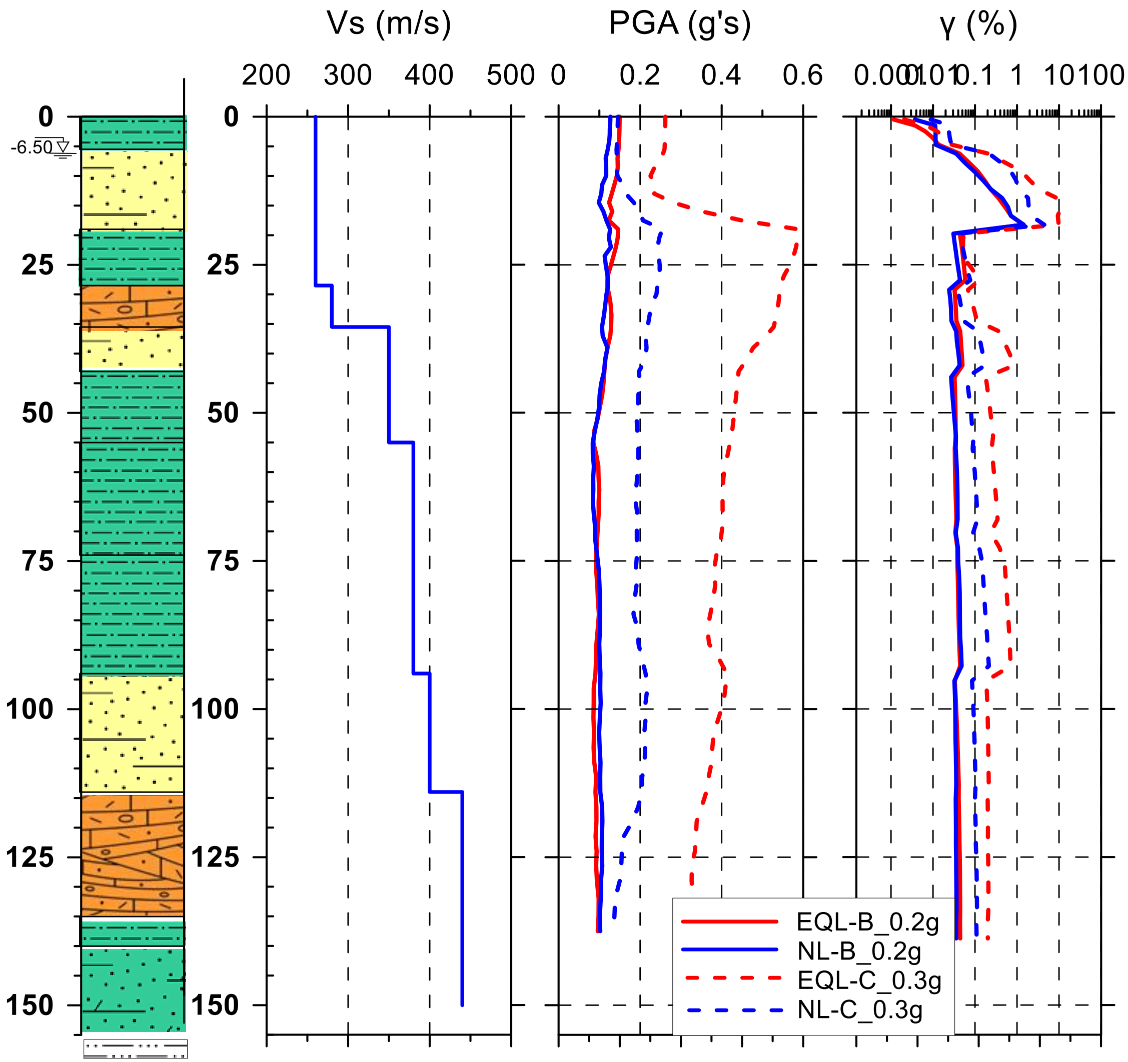
Fo=0.65Hz (1.5s)
Vs,160=364m/s
Vs,30=270m/s

Model 2

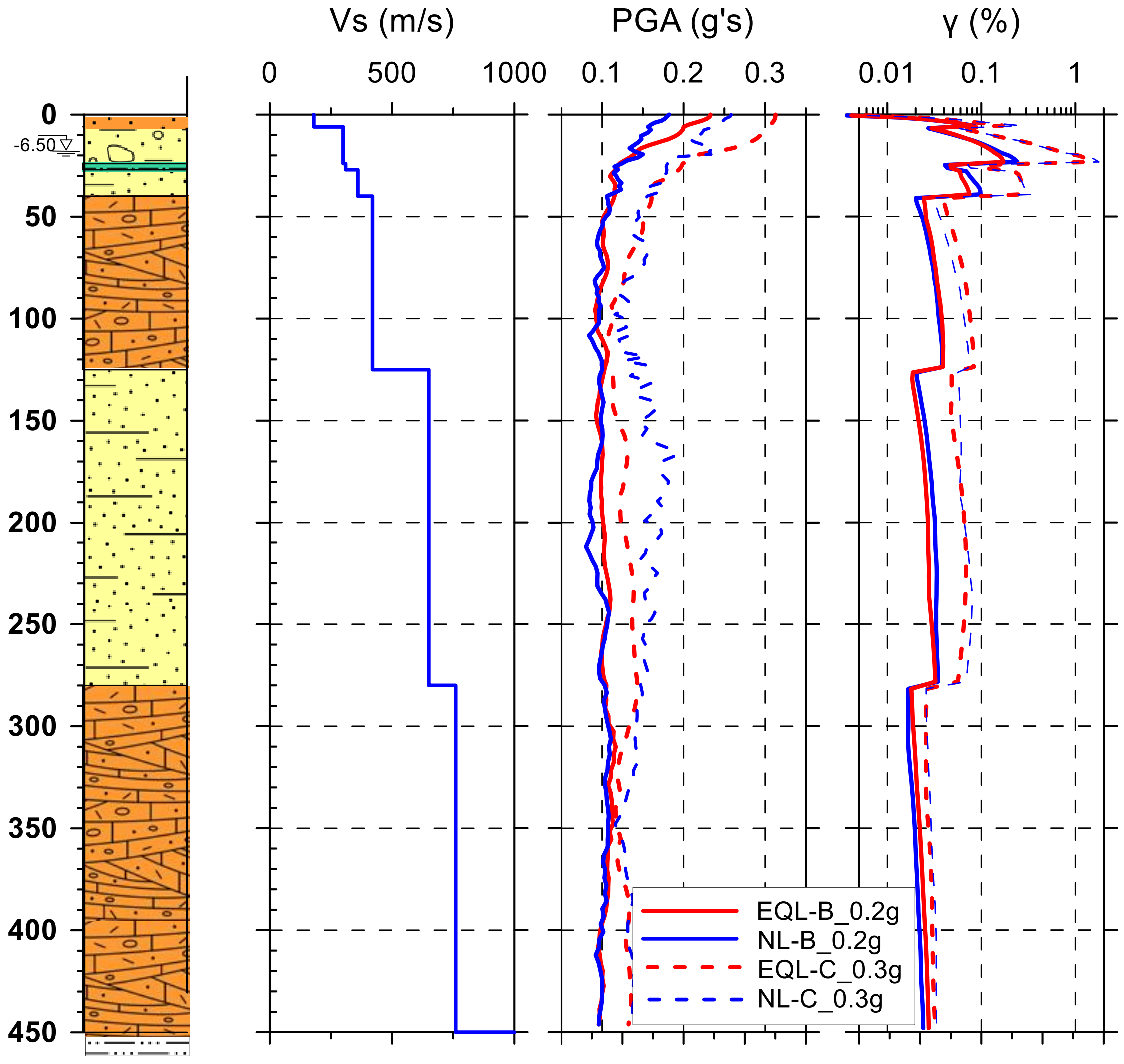


Fo=0.31Hz (3.2s)
Vs,450=560m/s
Vs,30=270m/s

Response of Deep Soil Profiles



Response of Deep Soil Profiles



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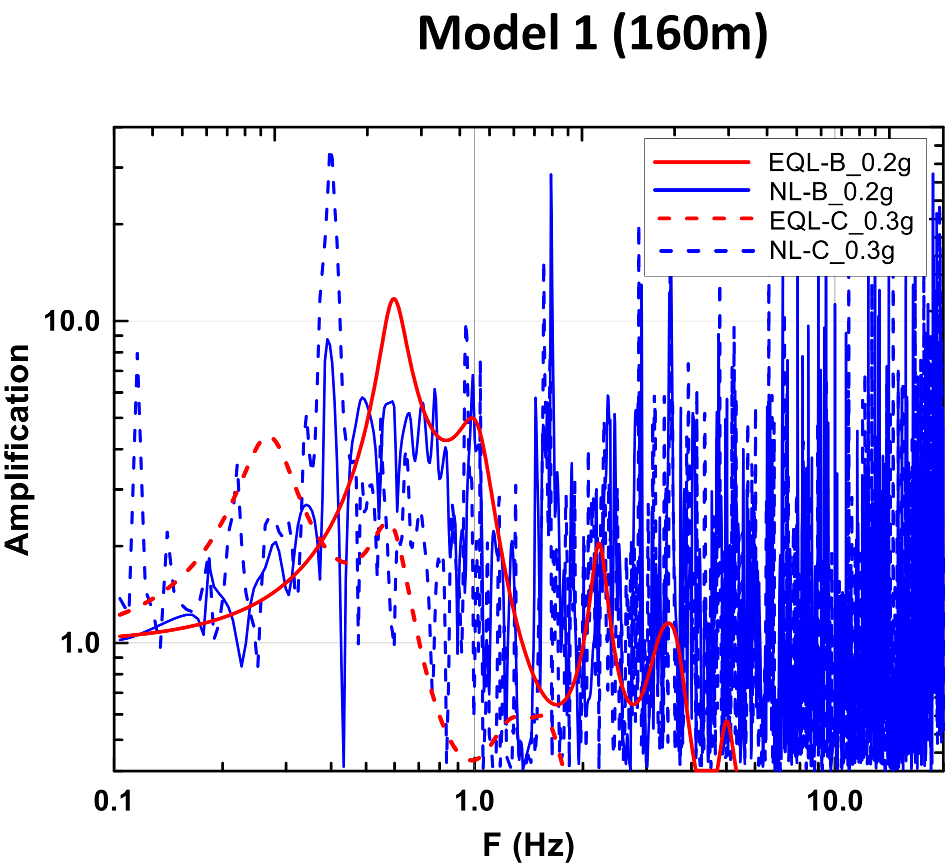
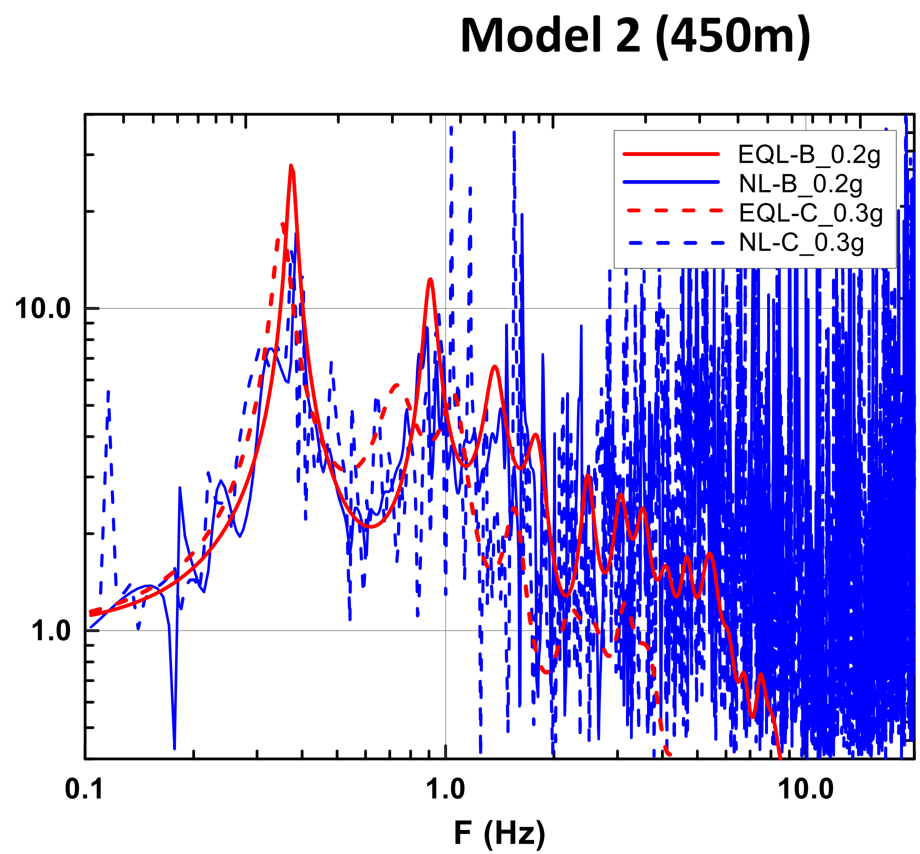
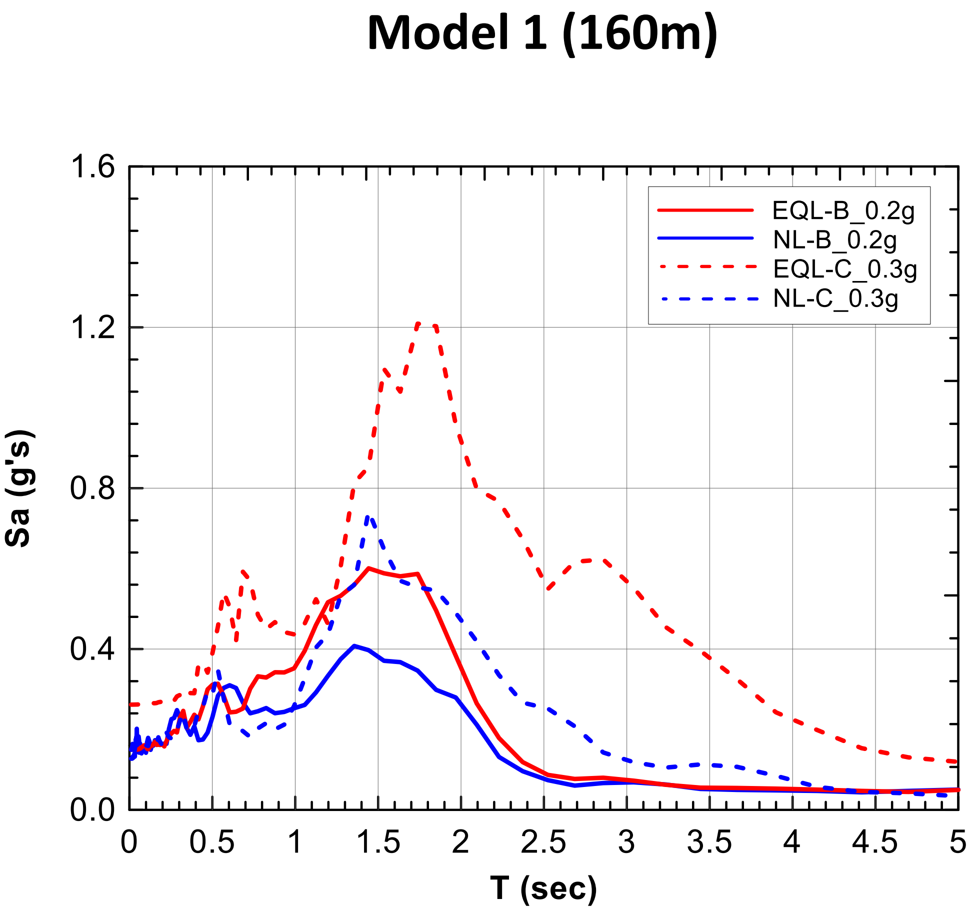
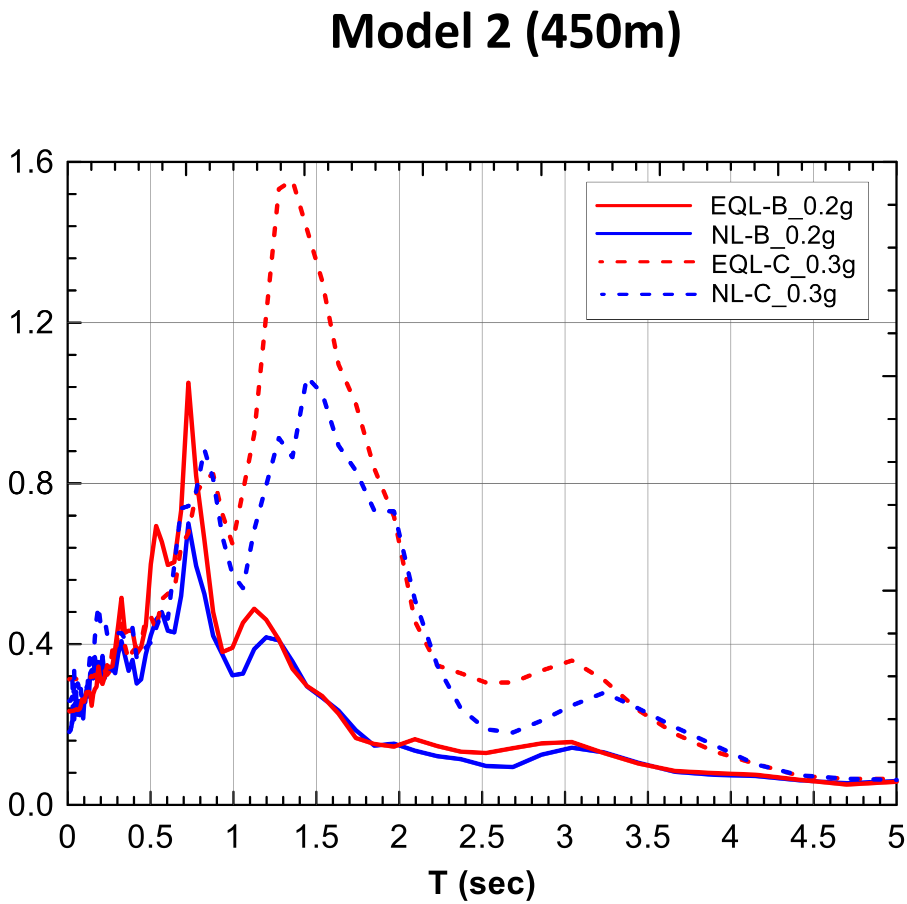
Response of Deep Soil Profiles



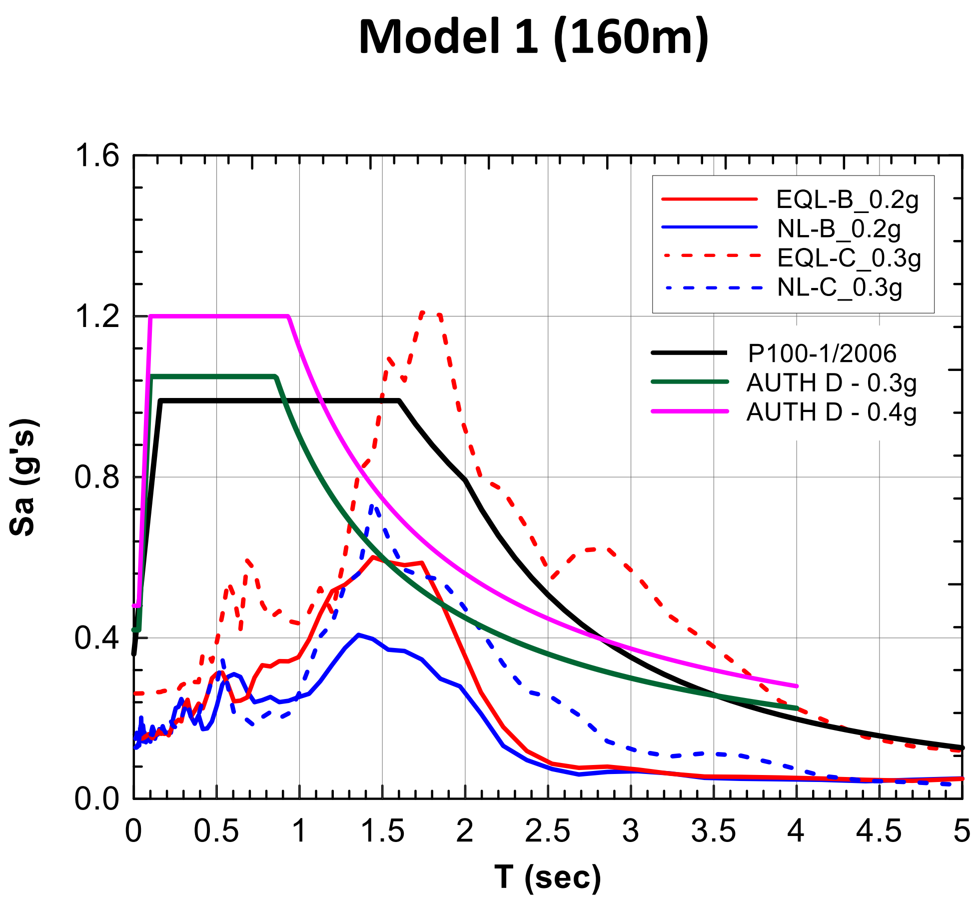


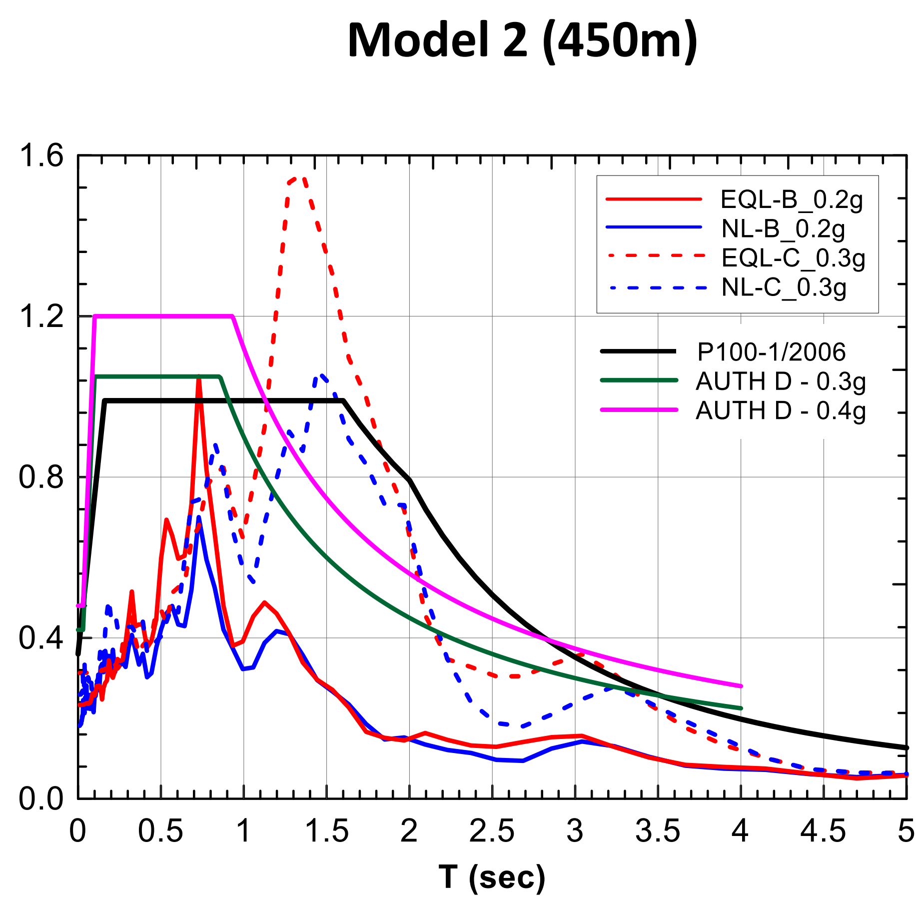
Response of Deep Soil Profiles





Response of Deep Soil Profiles





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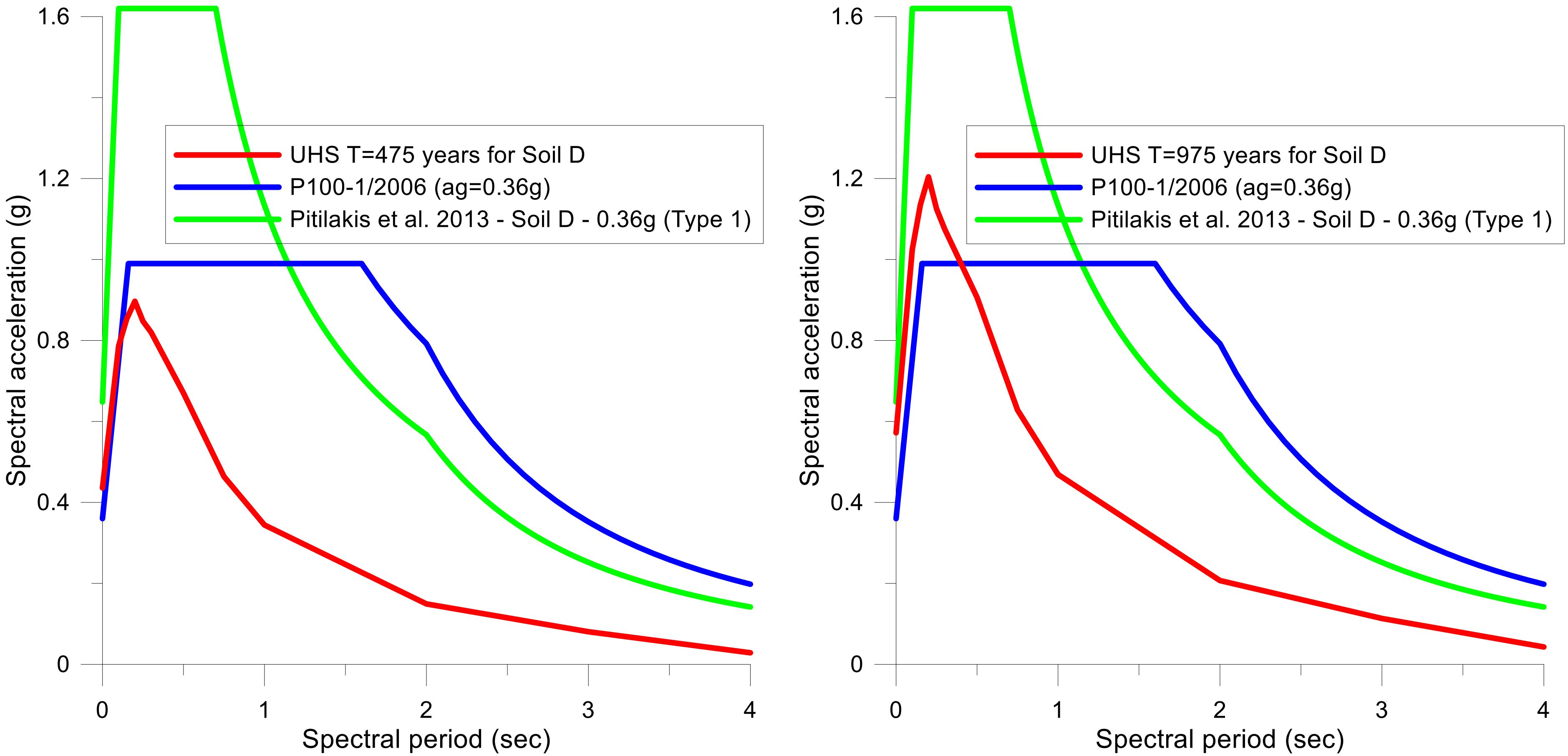
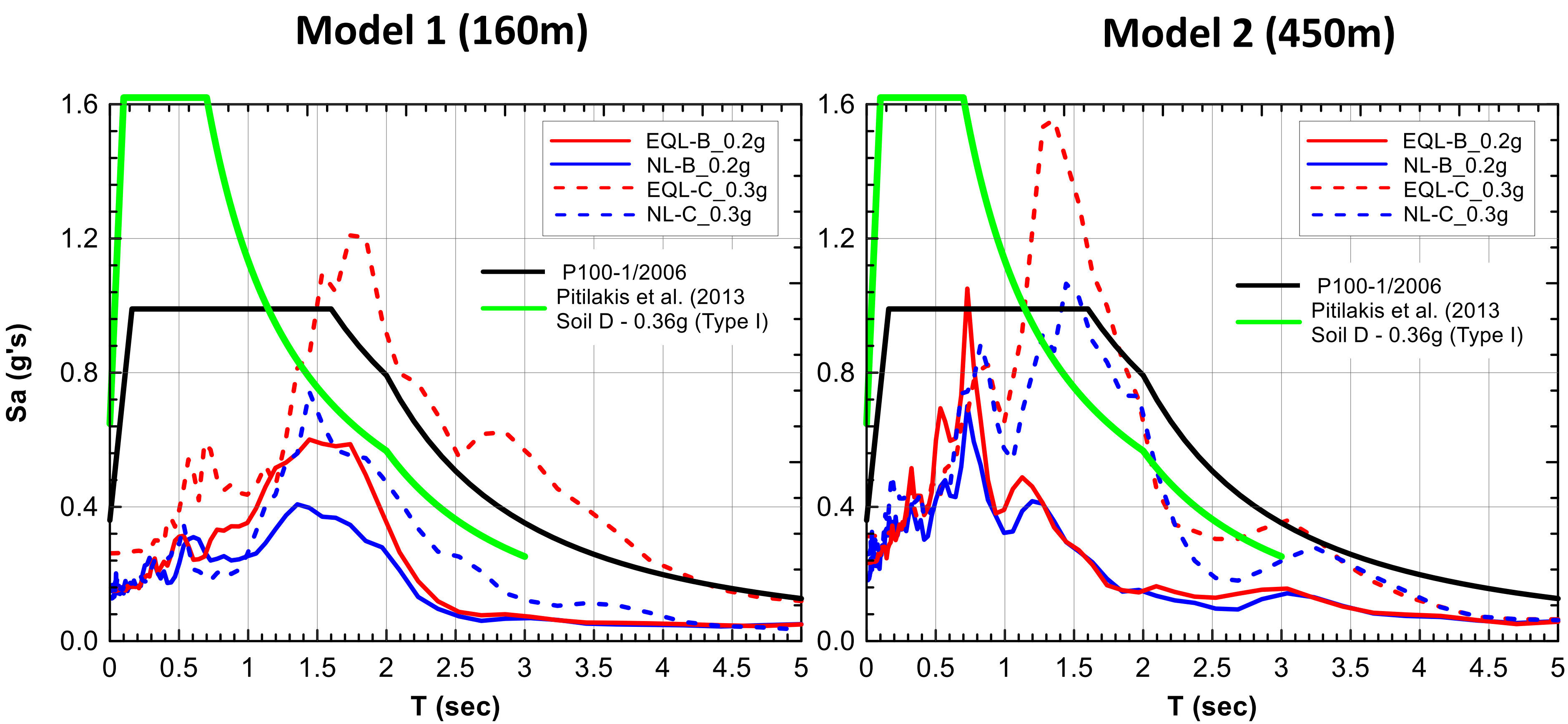
Comparisons of Spectra

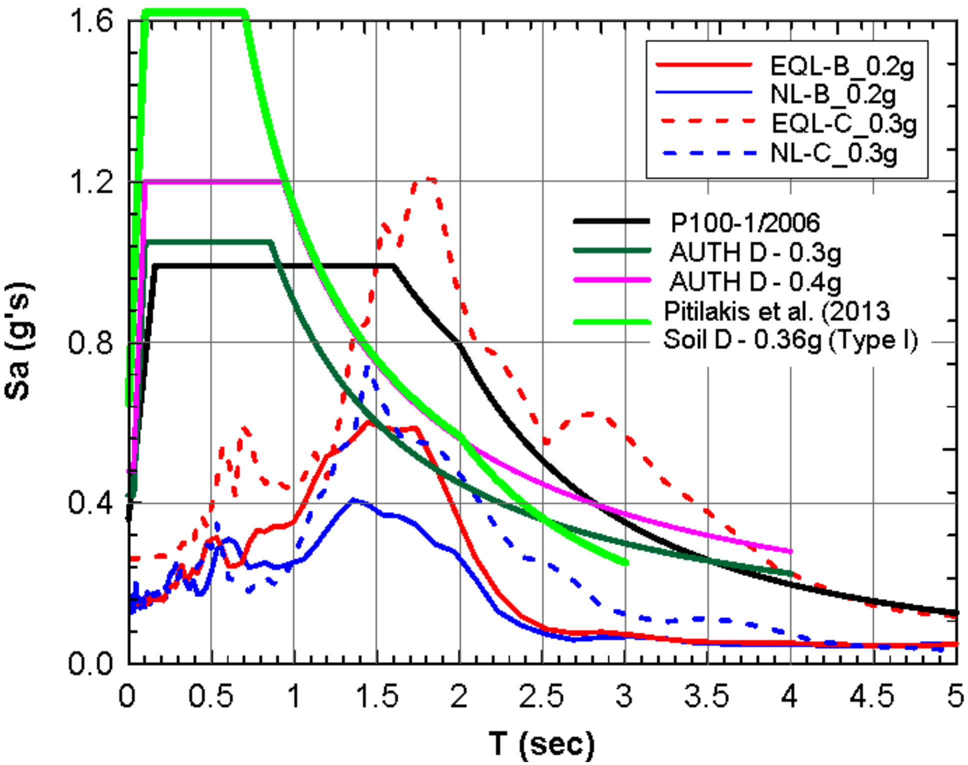


Comparisons of Spectra

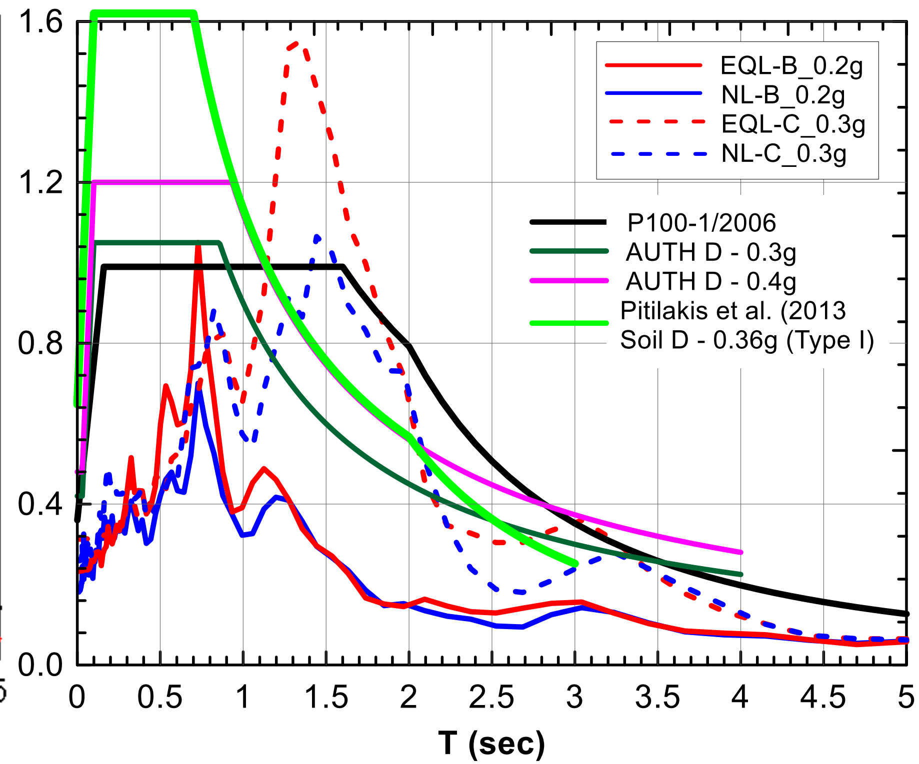


Comparisons of Spectra

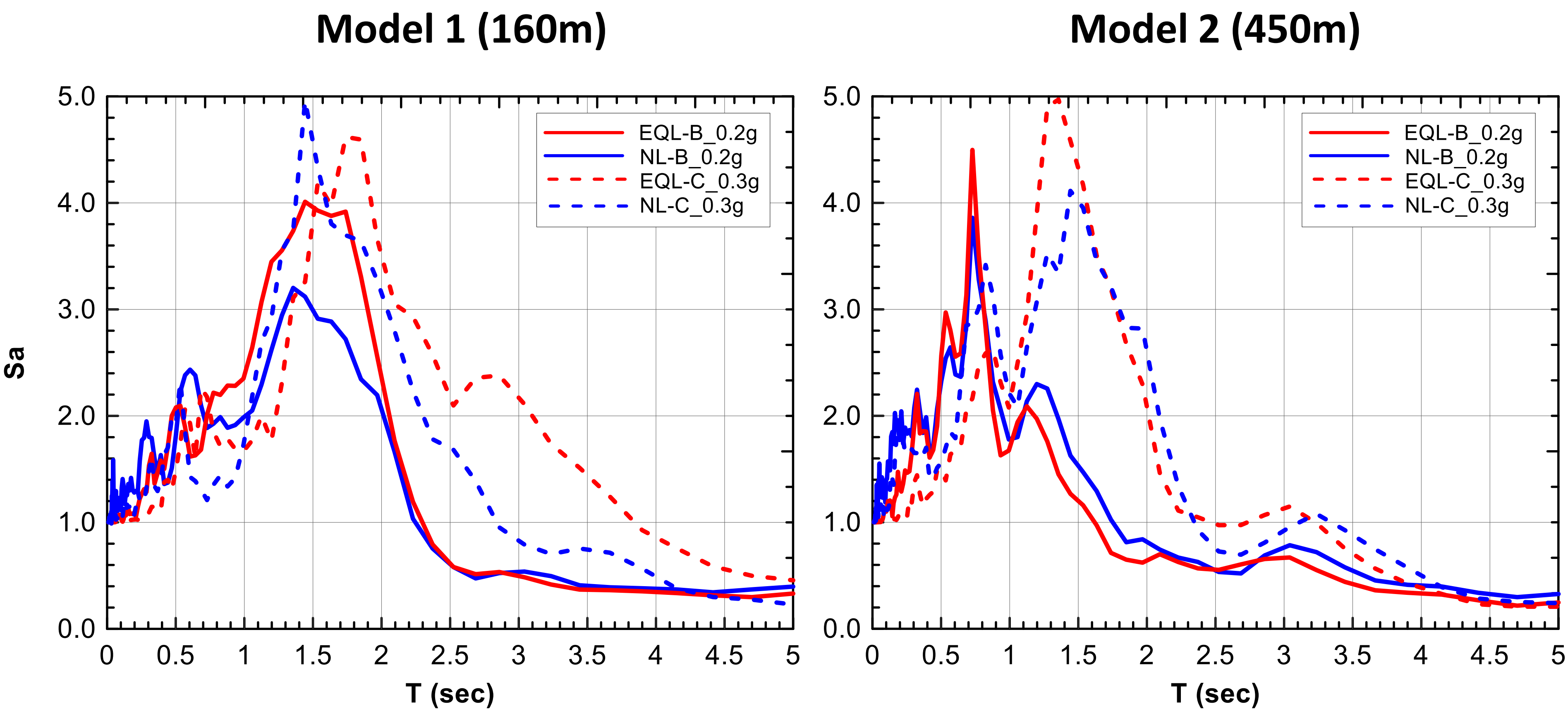
Model 1 (160m)



Model 2 (450m)



Response of Deep Soil Profiles



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