Comprehensive Risk Assessment of Basic Services and Transport Infrastructure

101004830 - CRISIS - UCPM-2020-PP-AG

Cross-Border Multi Hazard Assessment
Definition of inputs for risk assessment

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

The present report describes the activities carried out to select the ground motions (i.e. accelerograms) that will be used as input for dynamic analysis in the three countries that make up the CRISIS case-study.

According to Eurocode 8, the design and assessment regulations in Europe, recorded accelerograms to be used for dynamic analyses need to be representative of the seismicity of the site and adequately justified in terms of the seismic source characteristics, the geological and geotechnical conditions of the recording site, the expected magnitude, the distance from the source and the peak horizontal acceleration expected at the site. They may be linearly scaled within certain reasonable limits to avoid potential bias in analysis results to match a target response spectrum in the range of periods of interest for the problem under examination.

The target response spectrum for record selection can be a code design spectrum, which usually follows a uniform hazard (UHS), or a conditional spectrum (CS) conditioned on a certain period of vibration.

The UHS is computed from a probabilistic seismic hazard analysis (PSHA), and spectral amplitudes characterise it at all periods with the same probability of being exceeded. It comprises contributions from all possible earthquakes that can affect the hazard at a given site. Therefore, it is not representative of a single earthquake ground motion since real accelerograms do not usually have energy content as broad as that of the UHS but rather an envelope of all possible contributions. Consequently, when the selected accelerograms considering the UHS are used as input to structural analyses, they tend to produce conservative estimates due to the overly aggressive nature of their spectral content (Baker and Cornell, 2006).

An alternative to the UHS is the CS, which represents the expected response spectrum conditioned on the exceedance of a target spectral acceleration value at the period of interest. The target spectral acceleration value can be taken from the PSHA (i.e., the ESHM13 - SHARE model). It can be associated with a dominant earthquake, i.e., the one with magnitude and source-to-site distance that most significantly contributes to that hazard level. The dominant earthquake can be identified as the mean magnitude/distance pair obtained from the disaggregation analysis. Baker (2011) demonstrated that the CS is an appropriate target spectrum when performing dynamic analysis of structures. However, the CS depends on the choice of the period of interest, which depends on the objective of the analysis.

In this study, we considered the CS as the target response spectrum. The periods of interest were selected considering the periods of vibration of selected target structures, such as schools, hospitals, and bridges, which were selected at different locations in the cross-border region.

The selected accelerograms will be used for simulation of structural behavior of the selected objects, with the final to identify reliable buildings that would survive the earthquake and which would consequently be used as shelters in earthquake cases.

2. Sites of interest

Few representative sites were selected in each country in order to select suitable ground motions.

2.1. N. Macedonia

The selected sites in N. Macedonia corresponds to three different types of structures, namely a school, a hospital and a bridge, as illustrated in Figure 1. They are located on sites with different EC8 ground categories.

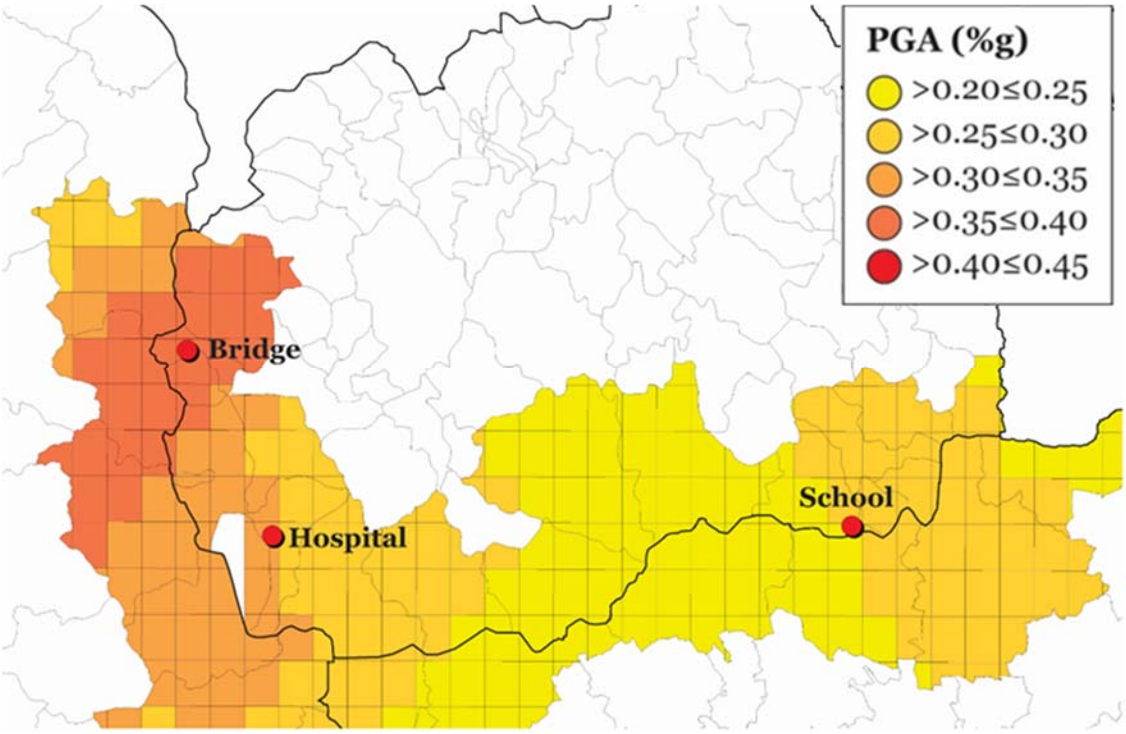

Figure 1 Location of selected structures in N. Macedonia cross border region superimposed on the ESHM13 map associated to the 475 years return period (mean hazard model).

The main characteristics (latitude, longitude, Peak Ground Acceleration – PGA - from the SHARE model associated to the 475 years-return period, average shear wave velocities in the first 30 meters of the soil profile - V_{s30}, EC8 soil class and range of relevant periods of vibration), of the selected sites are listed in Table 1.

Table 1 Selected locations in N. Macedonia cross border region.

#	Location	Longitude (°)	Latitude (°)	PGA on rock (g)	V_{s30} (m/s)	EC8 Class	T (s)
1	Bridge - Debar	20.568760	41.522210	0.38	534	B	0.20-3.00
2	Hospital - Ohrid	20.817690	41.116810	0.30	467	B	0.05-0.50
3	School - Gevgelija	22.504720	41.142240	0.25	294	C	0.05-0.50

2.2. Albania

The selected sites in Albania corresponds to three different types of structures, namely a school, a hospital and a bridge, as illustrated in Figure 2.

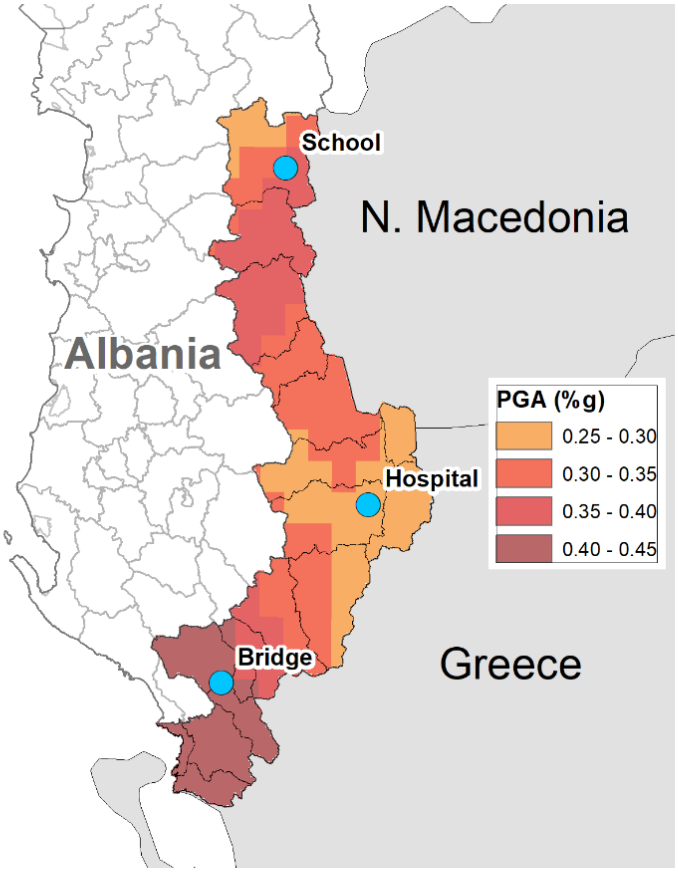

Figure 2 Location of selected structures in Albania cross border region superimposed on the ESHM13 map associated to the 475 years return period (mean hazard model).

The main characteristics (latitude, longitude, PGA from the SHARE model associated to the 475 years-return period, V_{s30}, EC8 soil class and range of relevant periods of vibration), of the selected sites are listed in Table 2.

Table 2 Selected locations in Albanian cross border region.

#	Location	Longitude (°)	Latitude (°)	PGA on rock (g)	Vs30 (m/s)	EC8 Class	T (range)
1	Bridge - Gjirokastër	20.17622952	40.04049199	0.40 - 0.45	494	B	0.20-3.00
2	Hospital - Korça	20.78599084	40.61162876	0.25 - 0.30	479	B	0.05-0.50
3	School - Peshkopi, Dibër	20.42994975	41.68350956	0.30 - 0.35	556	B	0.05-0.50

2.3. Greece

The sites that have been selected for Greece (Figure 3) represent six sites of the Greek territory of the cross-border region, where there are important critical infrastructures (e.g. schools, hospitals and bridges). The main characteristics (latitude, longitude, PGA from the ESHM13 model associated to the 475 years-return period and EC8 soil class) of the selected sites are listed in Table 3. Seismic hazard for these sites was computed considering V_{s30}=600 m/s for soil class B and V_{s30}=360 m/s for soil class B/C.

Table 3 Selected locations in Greek cross border region.

#	Main city	Longitude (°)	Latitude (°)	PGA on rock (g)	EC8 class
1	Konitsa	40.045556	20.74889	0.28	B
2	Florina	40.7824	21.4089	0.24	B
3	Kastoria	40.518131	21.26876	0.23	B
4	Kilkis	40.9833	22.8667	0.28	B
5	Polykastro	40.997881	22.5709	0.25	B/C
6	Sidirokastro	41.233333	23.38333	0.24	B

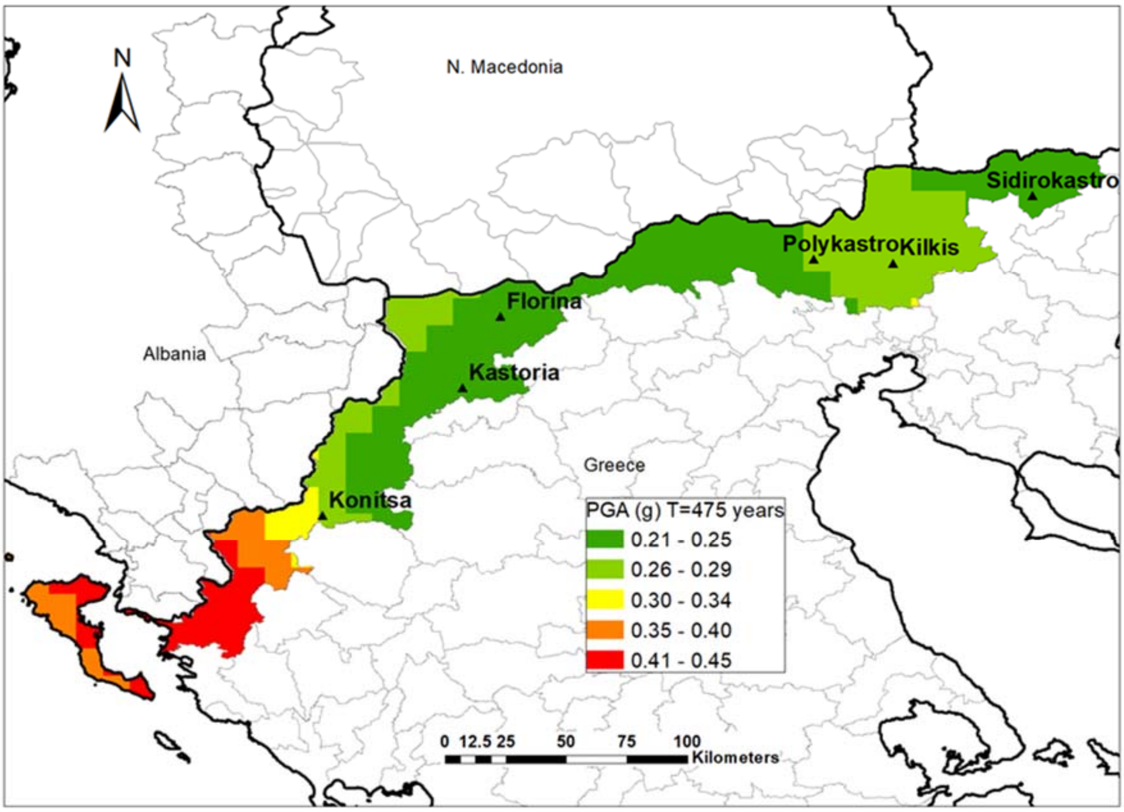

Figure 3 Map of selected locations in Greek cross border region superimposed on the ESHM13 map associated to the 475 years return period (mean hazard model).

3. Seismic hazard

3.1. Site-specific PSHA

Site-specific hazard computations were carried out by running the PSHA using ground motion prediction equations (GMPE) that account for site effects. This approach produces a generic assessment of the hazard at the surface, based on proxies of the amplification, such as soil categories or the V_{s30}.

Site-specific calculations were carried out for the selected sites using the OpenQuake input files of the 2013 European seismological hazard model (ESHM13), usually referred to as the SHARE model (Woessner et al., 2015). Seven return periods (RT) were selected to carry out the analyses. They are listed in Table 4.

Table 4 Return periods and corresponding probability of exceedance chosen for the site-specific hazard study.

	Return Period (years)	Probability of Exceedance
1	98	40% in 50 years
2	224	20% in 50 years
3	475	10% in 50 years
4	975	5% in 50 years
5	2475	2% in 50 years
6	4975	1% in 50 years
7	9975	0.5% in 50 years

Another aspect required in a site-specific hazard assessment is the choice of the Intensity Measure (IM). That is, a measure used to characterize the severity of ground shaking, which will later be associated with different levels of damage when deriving fragility curves. There are different types of IMs, with each one possessing their own inherent advantages and disadvantages. One aspect that is typically desirable from any IM is for it to be efficient, meaning that is should be a relatively accurate predictor of the structural response and, subsequently, of the damage. This characteristic typically leads to IMs defined in terms of the modal properties of the structure, with the first mode spectral acceleration, $Sa(T_1)$, being a popular choice in building assessment, since the response of the building is generally dominated by the first mode response. Ground motion records can subsequently be selected and conditioned to that specific period using some conventional tools (e.g. conditional spectrum) and the numerical analysis subsequently conducted.

The seven IMs that have been selected for this study (see Table 7) reflect the dominant periods of the selected structures (bridges, hospitals and schools) at the border region. In the case of schools, hospitals and bridges, a range of values of conditioning period would suffice considering a single dominant mode of vibration. The usual type of hospitals and schools built in the border region are of 1-4 stories for which the natural periods range from 0.1-0.4 second. On the other hand, the bridge structures are slender structures whose natural periods reach 1.0 seconds.

Table 5 Intensity measures chosen for the site-specific hazard study. PGA indicates the Peak Ground Acceleration, SA is the Spectral Acceleration at the period written in parenthesis.

	Intensity measures
1	PGA
2	SA(0.1 s)
3	SA(0.3 s)
4	SA(0.6 s)
5	SA(1.0 s)
6	SA(2.0)
7	SA(3.0 s)

3.2. Disaggregation analysis

The disaggregation analysis of the hazard was also performed for the acceleration levels corresponding to the intensity measures and return periods listed in Table 4 and Table 6Table 5. The disaggregation analysis was used to identify the earthquake scenarios (i.e. magnitude and distance) that contribute most to a given hazard level at the specific locations corresponding to the sites identified in Section 2.

The disaggregation analyses were performed using only one branch of the logic tree used to compute the site-specific PSHA. The reason for this choice is that the full logic tree would have required running the disaggregation analysis for a very large number of branches, thus causing computational memory problems. The total number of branches of the ESM13 model is 1280. Therefore, the disaggregation analysis was performed using only one branch of the ESHM13 model, namely the branch constituted by the area source model (which received the largest weight in the ESHM13 logic tree framework), the GMPE by Akkar and Bommer (2010) for active tectonic and stable continental regions and the GMPE by Zhao et al. (2006) for subduction zones.

4. Selection of accelerograms

The record selection was performed for each selected site in North Macedonia, Albania and Greece (Section 2), for each of the 7 considered return periods (Table 4) and the 7 IMs of interest (Table 5), for a total of 147 record selections for North Macedonia and Albania and 294 record selections for Greece.

The selection of accelerograms was performed using the code haselREC (HAzard-based SELection of RECords) (Zuccolo et al., 2021), which is freely available on GitHub (https://github.com/elisa82/haselREC). haselREC is a useful open-source tool for OpenQuake users, able to select and scale recorded accelerograms according to the CS.

The CS is computed internally by the code using:

- a GMPE selected by the user, along with a representative focal mechanism (normal), a depth (13 km) and a V_{s30} value. In this study, we used the GMPE by Akkar and Bommer (2010) in order to be consisted with the GMPE adopted for the disaggregation analysis, along with a normal focal mechanism, a depth of 13 km and V_{s30} values consistent with those identified in Section 2;

- a dominant earthquake (with magnitude and distance obtained from the disaggregation analysis, paragraph 3.2), and

- the correlation coefficients between the spectral acceleration at different periods (Akkar et al., 2014, in this study).

Concerning the ground motion database, we used a composite database made up by the PEER NGA-West2 database (https://ngawest2.berkeley.edu/) and the Engineering-Strong Motion (ESM) database (https://esm.mi.ingv.it/, Luzi et al., 2016). The PEER NGA-West2 database was adopted to increase the number of available recordings, especially at moderate-to-large magnitudes. Only free-field ground motions with appropriate values of earthquake depth, magnitude, epicentral distance and Vs30 (or, if not available for the ESM database, EC8 soil category). The maximum allowed hypocentral depth was set to 30 km to be consistent with the shallow crustal tectonic regime, which is the prevalent tectonic regime of the countries under investigation. The allowed Vs30 range was set in order to be consistent with the soil category of the site under investigation: 180 m/s ≤ Vs30<360 m/s for EC8 soil category C, 360 m/s ≤ Vs30<800 m/s for EC8 soil category B and 180 m/s ≤ Vs30<800 m/s for EC8 soil category B/C. The magnitude and distance ranges are defined in the code as radii centered on the mean magnitude (Mdisag) and distance (Ddisag) obtained from the disaggregation analysis. Due to the high number of record selections to perform, the selection was set as automatic as possible. Therefore, the magnitude and distance ranges, as well the maximum allowed scale factors (SF), were set to be dependent on the return period (RT), as given in Table 6.

Table 6 Selection parameters adopted for the selection of suitable ground motions.

RT (years)	Max SF	Allowed Magnitudes	Allowed Distances
98	2.0	Mdisag±0.50	Ddisag±50 km
224	2.5	Mdisag ±0.50	Ddisag ±50 km
475	3.0	Mdisag ±0.50 (for North Macedonia and Greece), Mdisag ±0.75 (for Albania)	Ddisag ±50 km (for North Macedonia and Greece), Ddisag ±75 km (for Albania)
975	3.5	Mdisag ±0.75	Ddisag ±75 km
2475	4.0	Mdisag ±0.75	Ddisag ±75 km
4975	4.5	Mdisag ±1.00	Ddisag ±100 km
9975	5.0	Mdisag ±1.00	Ddisag ±100 km

A set of 30 response spectra (corresponding to 30 two-components recordings) was selected for each considered site, return period and IM.

Examples of record selection from the three countries, different return periods and IMs are provided in the next paragraphs. All the record selections performed for this project are available in the SharePoint site of the project.

4.1. Record selection example for North Macedonia

An example of record selection for the selected bridge in Debar (North Macedonia), the PGA as intensity measure and the return period of 475 years, is shown in Figure 4, while the metadata details are listed in Table 7.

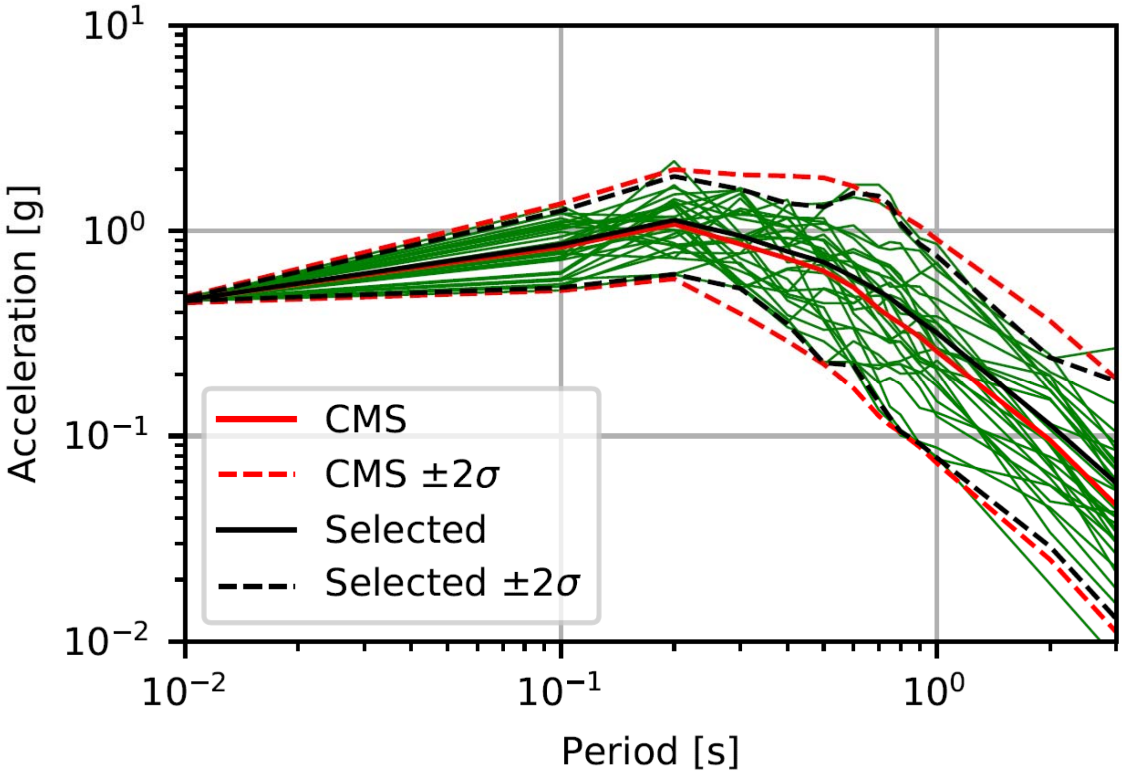

Figure 4. Conditional spectrum PGA-based record selection performed for the selected bridge in Debar (North Macedonia), considering the 475-year return period. The 30 green lines are the response spectra of selected ground motions, while the black lines represent their distribution. The red lines represent the target conditional spectrum. Solid lines: average spectrum, dashed lines: average spectrum values ±2 standard deviations).

Table 7. Metadata of the accelerograms selected for the selected bridge in Debar (North Macedonia), considering the 475 years - return period. The reference PGA value is 0.46 g, the mean magnitude from disaggregation is 6.27 and the mean distance from disaggregation is 10.89 km. NGA-West 2 recordings are identified through the ID of the recording, while ESM recordings are identified through the event ID and station code. The recording sites are characterised by 360 m/s≤Vs30<800 m/s or by Eurocode 8 soil category B.

#	Source	Event ID (ESM)	Station Code (ESM)	Record ID (NGA)	Magnitude	Distance	SF
1	NGA-West2	-	-	2391	5.9	16.24	1.25
2	NGA-West2	-	-	2655	6.2	24.47	2.4
3	NGA-West2	-	-	4133	6	17.84	0.99
4	ESM	ME-1979-0012	BUD	-	6.2	8.3	2.29
5	NGA-West2	-	-	2623	6.2	25.67	2.92
6	NGA-West2	-	-	694	5.99	32.34	2.05
7	NGA-West2	-	-	1023	6.69	44.77	2.35

8	NGA-West2	-	-	2628	6.2	0.51	1.05
9	NGA-West2	-	-	1020	6.69	40.65	2.1
10	NGA-West2	-	-	963	6.69	40.68	0.9
11	ESM	GR-1995-0047	AIGA	-	6.5	23.6	0.96
12	ESM	ME-1979-0012	PET	-	6.2	17	2.08
13	NGA-West2	-	-	1006	6.69	18.62	1.16
14	NGA-West2	-	-	164	6.53	24.82	2.67
15	ESM	EMSC-20160824_0000006	NRC	-	6	15.3	1.27
16	NGA-West2	-	-	495	6.76	6.8	0.39
17	NGA-West2	-	-	1078	6.69	14.66	1.77
18	NGA-West2	-	-	4097	6	31.53	1.48
19	NGA-West2	-	-	3475	6.3	8.8	0.83
20	NGA-West2	-	-	4128	6	8.75	2.24
21	ESM	IT-2009-0009	AQA	-	6.1	5	1.1
22	NGA-West2	-	-	33	6.19	40.25	1.59
23	NGA-West2	-	-	57	6.61	25.36	1.59
24	NGA-West2	-	-	265	6.33	33.73	0.74
25	NGA-West2	-	-	2622	6.2	20.51	1.46
26	NGA-West2	-	-	340	6.36	36.49	2.79
27	ESM	EMSC-20161026_0000095	NRC	-	5.9	13.2	1.44
28	NGA-West2	-	-	3474	6.3	12.26	0.65
29	NGA-West2	-	-	249	5.94	12.02	1.17
30	NGA-West2	-	-	4132	6	19.64	1.74

4.2. Record selection example for Albania

An example of record selection for the selected hospital in Albania, the Spectral Acceleration at 0.6 s as intensity measure and the return period of 975 years, is shown in Figure 5, while the metadata details are listed in Table 8.

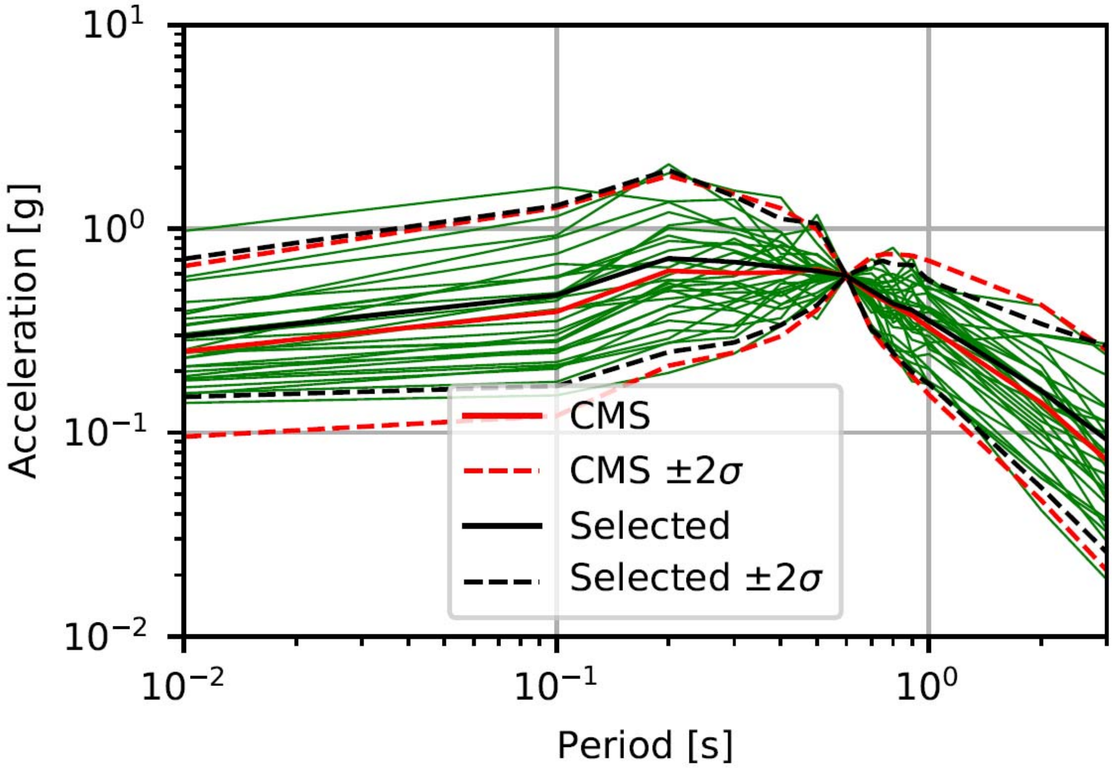

Figure 5. Conditional spectrum SA(0.6s)-based record selection performed for the selected hospital in Albania, considering the 975-year return period. The 30 green lines are the response spectra of selected ground motions, while the black lines represent their distribution. The red lines represent the target conditional spectrum. Solid lines: average spectrum, dashed lines: average spectrum values ±2 standard deviations).

Table 8. Metadata of the accelerograms selected for the selected hospital in Albania, considering the 975 years - return period. The reference SA(0.6s) value is 0.59g, the mean magnitude from disaggregation is 6.80 and the mean distance from disaggregation is 15.87 km. NGA-West 2 recordings are identified through the ID of the recording, while ESM recordings are identified through the event ID and station code. The recording sites are characterised by 360 m/s≤Vs30<800 m/s or by Eurocode 8 soil category B.

#	Source	Event ID (ESM)	Station Code (ESM)	Record ID (NGA)	Magnitude	Distance	SF
1	ESM	ME-1979-0003	PETO	-	6.9	19.7	0.45
2	NGA-West2	-	-	2980	6.2	71.23	2.59
3	NGA-West2	-	-	2742	6.2	36.11	1.4
4	NGA-West2	-	-	2457	6.2	25.52	1.84

5	NGA-West2	-	-	1078	6.69	14.66	1.47
6	NGA-West2	-	-	2712	6.2	36.15	1.95
7	NGA-West2	-	-	731	6.93	62.31	1.91
8	ESM	EMSC-20161030_0000029	TRL	-	6.5	43.7	2.24
9	NGA-West2	-	-	336	6.36	38.33	2.42
10	NGA-West2	-	-	990	6.69	39.15	2.1
11	ESM	IT-1980-0012	STR	-	6.9	33.3	1.09
12	NGA-West2	-	-	3279	6.3	71.66	3.08
13	NGA-West2	-	-	1085	6.69	13.6	0.64
14	NGA-West2	-	-	164	6.53	24.82	1.47
15	NGA-West2	-	-	5681	6.9	51.75	2.85
16	NGA-West2	-	-	3264	6.3	42.99	3
17	ESM	EMSC-20161030_0000029	NRC	-	6.5	4.6	0.76
18	NGA-West2	-	-	825	7.01	10.36	0.68
19	NGA-West2	-	-	3503	6.3	41.24	2.71
20	NGA-West2	-	-	1030	6.69	52.21	2.84
21	ESM	ME-1979-0012	BUD	-	6.2	8.3	0.92
22	NGA-West2	-	-	1005	6.69	32.72	1.93
23	NGA-West2	-	-	2739	6.2	14.51	1.91
24	NGA-West2	-	-	963	6.69	40.68	0.55
25	NGA-West2	-	-	1787	7.13	26.53	1.15
26	NGA-West2	-	-	3268	6.3	49	1.64
27	NGA-West2	-	-	3867	6.3	65.45	2.7
28	NGA-West2	-	-	3026	6.2	54.89	3.28
29	NGA-West2	-	-	3307	6.3	71.7	1.26
30	NGA-West2	-	-	2629	6.2	5.57	1.72

4.3. Record selection example for Greece

An example of record selection for Polykastro (Greece), the Spectral Acceleration at 0.3 s as intensity measure and the return period of 2475 years, is shown in Figure 6, while the metadata details are listed in Table 9.

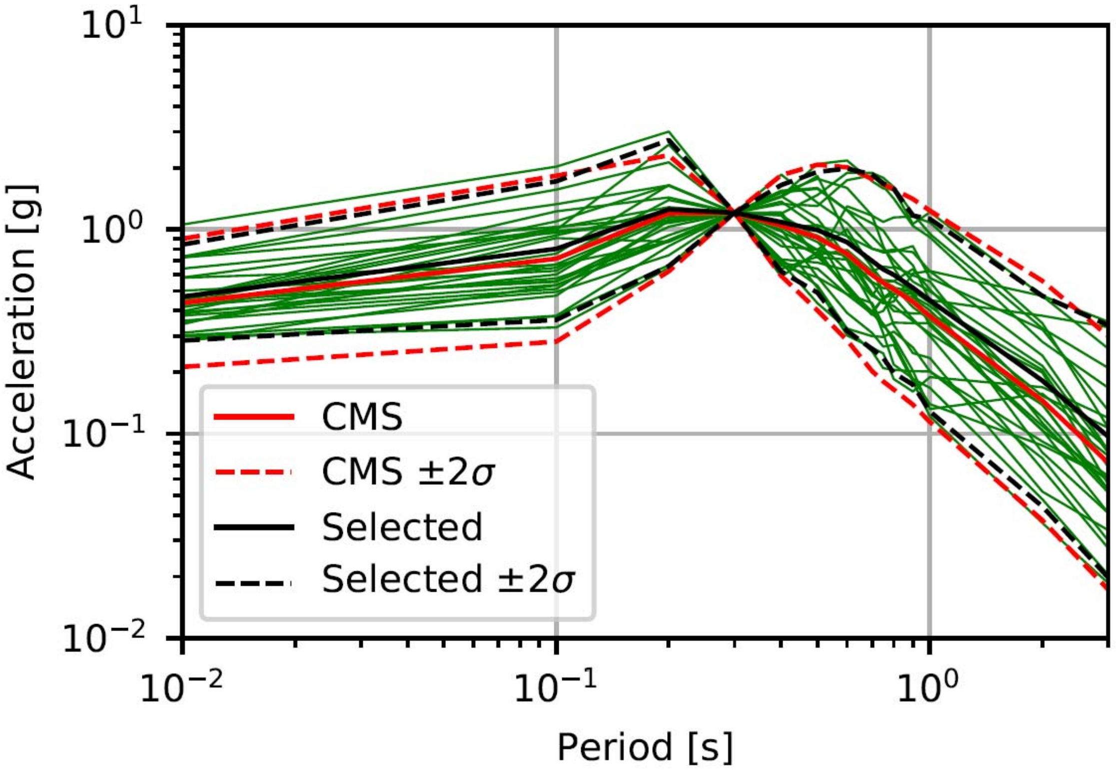

Figure 6. Conditional spectrum SA(0.3s)-based record selection performed for Polykastro (Greece), considering the 2475-year return period. The 30 green lines are the response spectra of selected ground motions, while the black lines represent their distribution. The red lines represent the target conditional spectrum. Solid lines: average spectrum, dashed lines: average spectrum values ±2 standard deviations).

Table 9. Metadata of the accelerograms selected for Polykastro (Greece), considering the 2475 years - return period. The reference SA(0.3s) value is 1.21 g, the mean magnitude from disaggregation is 6.62 and the mean distance from disaggregation is 11.62 km. NGA-West 2 recordings are identified through the ID of the recording, while ESM recordings are identified through the event ID and station code. The recording sites are characterised by 180 m/s≤Vs30<800 m/s or by Eurocode 8 soil category B/C.

#	Source	Event ID (ESM)	Station Code (ESM)	Record ID (NGA)	Magnitude	Distance	SF
1	NGA-West2	-	-	3032	6.2	54.79	2.47
2	NGA-West2	-	-	5495	6.9	39.2	1.35
3	NGA-West2	-	-	1031	6.69	52.44	3.94

4	NGA-West2	-	-	3564	5.9	29.43	2.68
5	ESM	IT-1980-0012	STR	-	6.9	33.3	1.38
6	NGA-West2	-	-	3565	5.9	29.3	3.61
7	ESM	EMSC-20161030_0000029	NRC	-	6.5	4.6	0.81
8	NGA-West2	-	-	736	6.93	61.49	3.19
9	NGA-West2	-	-	2936	6.2	76.42	3.64
10	NGA-West2	-	-	580	7.3	74.24	3.33
11	NGA-West2	-	-	311	5.9	31.99	3.98
12	NGA-West2	-	-	1078	6.69	14.66	1.78
13	ESM	EMSC-20161026_0000095	NRC	-	5.9	13.2	3.32
14	NGA-West2	-	-	1032	6.69	52.67	2.89
15	NGA-West2	-	-	165	6.53	18.88	2.41
16	NGA-West2	-	-	5652	6.9	37.95	1.59
17	NGA-West2	-	-	4081	6	13.76	3.15
18	NGA-West2	-	-	754	6.93	30.89	3.57
19	NGA-West2	-	-	963	6.69	40.68	0.87
20	ESM	EMSC-20161030_0000029	CIT	-	6.5	26.8	1.54
21	NGA-West2	-	-	164	6.53	24.82	1.99
22	NGA-West2	-	-	4126	6	7.17	1.01
23	ESM	ME-1979-0003	PETO	-	6.9	19.7	1.22
24	ESM	ME-1979-0012	KOTZ	-	6.2	21.7	3.3
25	NGA-West2	-	-	3210	6.2	71.18	3.54
26	NGA-West2	-	-	3566	5.9	29.91	3.9
27	NGA-West2	-	-	308	5.9	30.5	3.77
28	NGA-West2	-	-	306	5.9	30.31	3.41
29	NGA-West2	-	-	3474	6.3	12.26	0.5
30	NGA-West2	-	-	828	7.01	4.51	1.16

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[1] Akkar, S., and J.J. Bommer (2010). Empirical equations for the prediction of PGA, PGV and spectral accelerations in Europe, the Mediterranean region and the Middle East, Seismol. Res. Lett. 81, 195–206.

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