EARTHQUAKE GROUND MOTION AND SEISMIC DESIGN SPECTRA: STATISTICAL ANALYSIS OF THE SPECTRAL SHAPE PARAMETERS

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ABSTRACT

In this contribution, we provide the results of a systematic statistical analysis of earthquake recordings as a function of earthquake magnitude and source-to-site distances for different soil classes (described by shear wave velocity averaged over 30m - \(V_{S30}\) ranges) and with reference to the Swiss National Seismic Design Code (SIA 261, 2014). We compare the pseudo-acceleration response spectra for various soil classes with the shape of the design spectrum specified by the Swiss Seismic Design Code (SIA 261). This comparison is achieved in few steps: (1) compilation of a ground motion dataset; (2) extraction of uniform hazard spectra (UHS) for a mean return period (i.e. 475 years) for given sites; (3) evaluation of dominant earthquake scenarios for UHS periods, by disaggregating the seismic hazard; (4) selection of earthquake recordings matching the dominant magnitude-distance scenarios; (5) normalization of the eligible response spectra to peak ground acceleration; (6) weighting the response spectra according to the number of records in each magnitude-distance bin as well as by the corresponding contribution to the hazard level of the magnitude-distance bins; and finally (7) reconstruction of design spectrum for different soil classes. The analysis is concluded with comparison plots of the eligible elastic response spectra for magnitude and distance bins and SIA 261 design spectra for specified soil classes.

The spectral parameters resulted from the statistical evaluation of pseudo-acceleration response spectra (5% damping) for various soil classes are in a relative agreement with the spectral parameters of the design spectrum. However, elastic design spectra specified by SIA 261, appear to be often exceeded by new ground motion data, within specific range of spectral periods and soil classes. The observed discrepancies are due to various factors including limitation of earthquake recordings within specific magnitude distance bins (e.g. large magnitude recordings in the near-field), errors associated with the recordings metadata, uncertainties of the earthquake parameters and definition of specific earthquake scenarios.

Keywords: ground motion; elastic design response spectra, seismic hazard disaggregation; ground motion selection; Swiss Seismic Design Code – SIA 261

1. INTRODUCTION

Parameters defining the shape of the seismic design spectra are of great importance as they control the level of structural design, hence the building performance during an earthquake. Typically, the spectral parameters are derived either from statistical analyses of ground motion recordings or evaluation of ground motion prediction equations (GMPEs). Often, the results of seismic hazard analysis, i.e. uniform hazard spectra (UHS), are also used to define and/or calibrate the shape parameters of the seismic design spectra. Regardless of which procedure is used to formulate the design spectra, the influence of site conditions on the seismic design formulation requires particular attention.

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Local site conditions are prescribed in seismic design regulations by alternative formulation of elastic response spectra for different soil classes (empirically described by shear wave velocity averaged over 30m - $V_{s30}$ ranges) and through period independent “amplification soil coefficient”, i.e. S (Eurocode 8 (CEN 2004), Swiss National Seismic Design Code - SIA 261, 2014). Other controlling parameters of the design spectrum shape are the so-called corner-periods ($T_b$, $T_c$ and $T_d$) and normalization factors (horizontal design acceleration). However, the effects of local site conditions on ground motion are difficult to be described and quantified in unique classes due to uncertainties and variability of underlying deposits in terms of S-wave velocity profiles, properties of rock basement, stratigraphy and thickness, nonlinearity and damping properties of the material, mechanical impedance in soil, etc.

In this contribution, an alternative procedure to account for the effect of local site effects on seismic design is conducted. This procedure is based on a systematic statistical analysis of earthquake recordings as a function of earthquake magnitude and source-to-site distances for different soil classes (described by $V_{s30}$ ranges) in conjunction with seismic hazard outputs.

An earthquake recordings dataset is compiled from existing open-to-access resources and then criteria for selecting of eligible earthquake recordings are defined on the basis of site-specific (controlling earthquake) scenarios obtained either deterministically or probabilistically. A deterministic scenario requires definition of a magnitude and source to site distance pair, whereas in a probabilistic framework, the earthquake scenarios are defined as magnitude and source-to-site distance pairs obtained by disaggregating the seismic hazard. The uniform hazard spectra (UHS) is used to describe the site-specific hazard level and the disaggregation has to be carried out for all individual spectral ordinates.

The general approach to compare site-specific elastic pseudo-acceleration response spectra (with 5% damping) and seismic design spectra at various locations in Switzerland, comprises several steps: (1) compilation of a unified ground motion dataset; (2) extraction of the uniform hazard spectra for a mean return period equivalent with the design spectrum, i.e. 475 years; (3) evaluation of the dominant earthquake scenarios (magnitude-distance) for each spectral ordinates of the UHS, by disaggregating the seismic hazard; (4) selection of earthquake recordings based on the dominant scenarios; (5) quantify the effect of records number in magnitude distance bin by using the median of the eligible recordings; (6) weighting the median of the eligible recordings per magnitude-distance bins by their corresponding percentage contribution to the hazard level, and finally (7) reconstruction of design spectrum for different soil classes. The analysis is concluded with comparison plots of the eligible elastic response spectra for magnitude and distance bins and SIA 261 design spectra for specified soil classes.

The above procedure is applied for Switzerland, using input of the latest seismic hazard model for Switzerland (SUlhaz15, Wiemer et al 2016), specifically the site-specific equal probability spectra and the identified scenarios from hazard disaggregation. A mean return period of 475 years as specified by the SIA 261 is considered. Hereinafter, we summarize the main elements of the analysis, the key findings and comments of the comparison between the eligible elastic response spectra, selected to describe the site-specific hazard level and the elastic design spectra of SIA 261. The analysis was carried out for 25 cities in Switzerland, located in different seismic zones, however in the interest of space, we provide the results only for four cities, Zurich (zone 1, SIA 261), Chur (zone 2, SIA 261), Basel (zone 3a, SIA 261) and Sion (zone 3b, SIA 261).

2. EARTHQUAKE RECORDS DATABASE

Switzerland is a region of low to moderate seismicity, large earthquakes are possible ($M_w$ 6.6 Basel in 1356, $M_w$ 6.2 Visp in 1855) however not many ground motion recordings are available. Thus, given the limited number of records for the region, additional information is required. Every year, the number of earthquake strong-motion recordings are constantly increasing due to technological advance of recording sensors and improvements of seismic networks, thus the use of worldwide data might be appropriate for this task. Several strong-motion resources are available, e.g. New European Strong
Motion Database (Luzi et al 2016), NGA East (PEER 2014/17), and West databases (PEER 2013/3), Japanese Strong Motion Database (K-NET and KiK-net, http://www.kyoshin.bosai.go.jp), and Italian Strong Motion Database (http://itaca.mi.ingv.it, Luzi et al 2008). Hereinafter, we adopt existing and open-access datasets compiled within the framework of three regional projects: the SHARE project (http://www.share-eu.org, Giardini et al 2013, Yenier et al 2010), RESOURCE (http://www.resource-portal.eu, Akkar et al 2014a) and EMME project (http://www.efehr.org/emme14, Danciu et al 2016, Akkar et al 2014b). Additionally, the PEER NGA-West 02 (https://ngawest2.berkeley.edu, PEER 2013/3) is also considered. However, these four resources provide acceleration response spectra with 5% damping for earthquakes recorded worldwide suitable to describe the seismotectonic context of Switzerland. Note, that it is difficult to verify the accuracy of the metadata of all entries of these datasets, hence we assumed that the compilers of the original dataset already checked the metadata of these earthquake recordings. Thus, this is a strong assumption and the reliability of the quality of the metadata cannot be assured; which might be seen as limitation of the unified ground motion dataset.

Figure 1. Distribution of the unified strong-motion dataset (left) as compiled from four datasets: NGA (PEER2014/17), Resource (Akkar et al, 2014a), SHARE (Yenier et al 2010) and EMME (Akkar et al 2014b). Frequency of $V_{s30}$ values for the earthquake recordings of the unified strong motion dataset are illustrated in the right panel; the soil classification corresponds to those recommended by SIA 261.

Distribution of the earthquake recordings per magnitude and distance bins is presented in Figure 1. As it can be observed, the number of the earthquake recordings is not uniform with relatively large number of recordings for low to moderate magnitude earthquakes ($M_w \sim 4.0$ to $5.5$) and moderate distances ($10$ to $50$ km). SHARE and NGA West 2 datasets provide a significantly larger number of recordings for moderate to large earthquakes ($M_w > 6.0$), when compared with the EMME and RESOURCE, respectively. However, these events are recorded at about the same distance (~ $40$ to $50$ km). To identify eligible earthquake recording from each of the four datasets, the following criteria were used:

- Available metadata (e.g. distance, earthquake magnitude, station $V_{s30}$);
- Pseudo-elastic response spectra estimated for the entire period range (0.05 to 4.0s);
- Two horizontal components from each record;
- Earthquakes occurring in active shallow crust;
- Earthquake magnitude (moment magnitude, $M_w \geq 4.0$);
- Source to station distance - epicentral distance ($R_{epi} \leq 150$ km);
- Focal depth $\leq 50$ km;

To remove non-damaging ground motions an extra filter was applied for elastic pseudo-acceleration at 0.1s, (it is required that $SA (0.1s) > 0.03g$). A sensitivity analysis was conducted for this filter, and it was found that the value for this threshold significantly affects the number of records. If all records are considered the total number of earthquakes in the unified dataset is about 25 000, when the filter is
applied, the number is reduced to half (~12100). Hereafter, we will refer to the former as the full dataset, and the latter as the dataset of elastic response spectra of engineering significance.

Classification of the recordings as a function of the assigned Vs30 is presented in Figure 1, right panel. There are 3210 records on Class D (Vs30~ 150 to 300 m/s), 4880 records in class C (Vs30~ 300 to 500 m/s), 2892 records in Class B (Vs30~ 500 to 800 m/s) and about 1066 records are part of class A (Vs30 > 800m/s). Some limitations of the database worth to be mentioning are non-homogenous processing techniques of the ground motion records and the use of various algorithms when computing the acceleration response spectra (5% damping). Overall, the final number of earthquake recordings as well as their distribution per soil classes is reasonable for the statistical analysis of the spectral shape.

3. EARTHQUAKE SCENARIO AND GROUND MOTION SELECTION

The 2015 updates of the Swiss Seismic Hazard (SUIhaz2015, Wiemer et al., 2016) provide the basis for describing the seismic hazard output (i.e. UHS) and the corresponding earthquake scenarios. Generally, seismic hazard output, such as uniform hazard spectra (UHS) are directly linked to the seismic design spectra, as they provide the spectral shape with an equal probability of exceedance (i.e. 10% in 50 years or its equivalent mean return period of 475 years). Hereinafter, the UHS at given sites are used to evaluate the contributing earthquake scenarios (magnitude-distance pairs) specific to each spectral ordinate (i.e. 0.05 to 4.0s). It is well accepted, that the UHS represents the envelop of various scenarios, e.g. small and frequent magnitude earthquakes occurring at close distances are controlling the hazard for short periods. In contrast, the large and infrequent magnitudes from long distances are dominant for the hazard estimates of the longer spectral periods. Thus, for the purpose of this analysis, we disaggregate the seismic hazard for every spectral ordinate of the UHS at various locations in Switzerland for a single mean return period (i.e. 475 years). Details of the analysis are presented in the next section.

3.1 Seismic Hazard Disaggregation

Disaggregation of the seismic hazard is a technique that allows identifying the earthquake scenarios that significantly contribute to a specified exceedance probability of ground motion levels. Ground motion is typically represented by ground motion parameters, such as PGA or elastic pseudo-acceleration response spectra at different periods (frequencies). The disaggregation technique identifies relevant earthquake scenarios by earthquake magnitude and source-to-site distance pairs, taking into account ground-motion prediction equations (GMPEs) and their aleatory variability (Bazzurro and Cornell 1999). OpenQuake (Pagani et al. 2014) was used to compute the 2015 updates of the seismic hazard for Switzerland. Because the ground-motion logic trees used in the SUIhaz2015, is rather complex (e.g. the ground-motion logic tree accounts for 28 GMPEs) we used a random sampling technique for seismic hazard disaggregation.

The sampling technique of OQ-hazard engine (i.e. version 2.7), allows sampling parts of the logic tree according to weights of the end-branches: the end-branches with higher weights are sampled more often than the end-branches with lower weights. A sensitivity analyses carried out for 10, 20, 50 and 100 samplings indicated the latter as stable for the purposes of the analysis. Given the complexity of the source model logic tree, we choose 100 samples as a reasonable trade-off between complexity of the model and computational demand. In summary, the disaggregation of the seismic hazard is performed for thirteen spectral ordinates, including PGA and the corresponding spectral ordinates T(s) = 0.05 to 4sec. A mean return period of 475 years (i.e. a 10% probability of exceedance in 50 years) was considered and 100 samples (end-branches) of the entire logic tree. The definition of the earthquake scenarios for four cities, Zurich (zone 1, SIA 261), Chur (zone 2, SIA 261), Basel (zone 3a, SIA 261) and Sion (zone 3b, SIA 261) is introduced and discussed in the next section.
2.4 Earthquake Scenario Definition

To define the dominant scenarios for specific ground-motion levels and parameters, we use a composite matrix of magnitude (M) – distance (R) scenarios, fully aggregated from the 100 logic-tree samples and reported as median MR values. Note that the median describes the middle value of every bin of the composite matrix scenarios of the entire UHS. The controlling MR scenarios are obtained by following the next steps:

a) Perform the disaggregation of the seismic hazard level corresponding to a mean return period of 475 years for PGA and spectral ordinates 0.05 to 4.0s of pseudo-acceleration response spectra.

b) Given the 100 logic tree samples (logic tree end-branches), estimate the median percentage contribution for every MR-bin and for every intensity measure type.

c) Aggregate the matrixes of median values corresponding to all intensity measure types; this matrix will represent the composite matrix of scenarios representative to all scenarios of the entire UHS, that is, every MR bin is a mutually exclusive event (Figure 2).

An important discussion point has to be addressed. The 2015 updates of the Swiss hazard model (Wiemer et al 2016) are for a reference rock (Vs30 = 1100m/s, kappa = 0.016s). When disaggregating the hazard levels for a given mean return period, the scenario will be representative for that particular level of hazard on reference rock (Danciu and Fäh 2017). As long as non-linear site response does not affect the ground motion, disaggregation at reference rock is identical to disaggregation at soil sites. For Switzerland at a 475 years mean return period, non-linear site response is not important, and we can assume disaggregation on rock to be the same as on soil.

2.4 Ground Motion Selection Criteria

The basic criteria for searching and selecting ground motions are formulated on the basis of earthquake source parameters of earthquake scenarios defined in the previous section. We used bins of 0.20 Mw and R = 5 km as used in SUIhaz15 as well as in the disaggregation of 475 year - hazard levels.
Next, the selected records are organized according to the $V_{s30}$ values of soil classes (A, B, C and D) defined in SIA 261. To classify the records according to their $V_{s30}$ information, we assumed that the compilers of the original dataset already checked the metadata of these earthquake recordings. However, this is an assumption and the reliability of the quality of the metadata cannot be assured; thus, this might be seen as limitation of the current investigation.

Another important factor to consider when comparing the eligible response spectra and elastic design response spectra is the effect of the number of earthquake records per bin. To quantify this effect, the median of eligible response spectra per MR bins is used. Furthermore, the median response spectra of each MR bin are weighted to reflect the contribution of each MR bin to the specified hazard level (described by the UHS). The weighting factor for every MR bin is obtained by renormalizing the total contribution rates of the MR bins for specific hazard level. The weighted mean is recommended as the measure of the statistical central tendency of the eligible records. However, we also provide the median and the 84th percentile of the entire population of median values per MR bins, as they are intuitive statistical measures of central tendency of the eligible records. Finally, the selected statistical measures of the earthquake recordings, more precisely their elastic response spectra are compared with the design response spectra for various soil classes. The results of this comparison are given in the next section.

Figure 3. Elastic response spectra normalized to PGA (light blue lines) for SIA 261 soil classes: A, B, C and D and the corresponding normalized design spectrum (black lines). Median (red line) and 84th percentile (red-dashed line) of data are normalized to PGA value (equals unity) and represented with the red dot.
4. STATISTICAL ANALYSIS OF EARTHQUAKE RECORDINGS

4.1 Statistical Analysis of Spectral Shape: Empirical Data

For this statistical investigation, the elastic response spectra (5% damping) of the unified dataset of earthquake recordings are normalized to the corresponding PGA values for each soil classes. Both horizontal components are considered and the resulting normalized spectra are analyzed by comparison to the SIA 261 recommended design spectra. The data selection is not magnitude or distance dependent, but $V_{s30}$ driven. Given the soil classes definition of SIA 261, the following number of recordings were retained form each soil class: 1066 for soil class A, 2892 for soil class B, 4880 for soil class C and 3210 for soil class D. Figure 3 shows the comparison of the elastic pseudo-acceleration response spectra normalized to PGA with the normalized seismic design spectra grouped in the considered soil classes. Overall, the median of all normalized spectra is lower than the SIA 261 design spectrum for all site classes. In a particular period, range around 0.1s, about 50% of the compiled elastic response spectra are lower than the SIA 261 design spectra whereas 50% of the eligible elastic response spectra are higher than the SIA 261 design spectra. SIA 261 recommends a constant value of 2.5 for the PGA – plateau, independently of the soil classes and magnitude distance scenarios. When the 84th percentile is considered, differences are evident, for soil classes A, B, C, more evident for short periods. The 84th curve exceeds the design spectra at very short periods ($T < 0.25s$) for soil class A, and periods $T < 0.5s$ for soil classes B and C. For soil class D, the 84th percentile exceeds entirely the corresponding design spectrum specified by SIA 261.

4.2 Statistical Analysis of Spectral Shape: Scenario Specific

In the UHS – specific scenarios, the MR bins guide the selection of the eligible earthquake recordings for every soil class of SIA 261. As it can be recalled from Figure 1 (left panel), there is an uneven distribution of records in every MR bin, thus it can be expected that the number of records per bin will affect the results. As mentioned before, we quantify the effect of the number of eligible records per MR bins, by use of the median of eligible records per MR bins which are further weighted by a factor obtained by renormalizing the total contribution rates for the selected MR bins.

Figure 4 (1st column) shows the comparison of median response spectra with elastic design spectra of the four soil classes SIA 261 for Zurich (SIA 261 Zone 1). The controlling magnitude scenarios for the entire UHS are 4.0 to 6.25 and the distance range 0 to 85 km. Median spectra of all MR bins are plotted together with the median and 84th percentile. When compared with the elastic design spectra, the median values are exceeding the design spectra at short periods, below $T_B$ for all soil-classes. The 84th percentile of pseudo-acceleration response spectra for soil class A, B and C is above the design spectra for the period range smaller than about $T_C$, whereas for soil class D the entire period range is exceeded. Similarly, the weighted mean (i.e. obtained by normalizing the median values as function of number of recordings in each MR bin) exceeds design spectra for soil-classes A, B, C and D, where exceedance covers the periods up to $T_C$. Such discrepancies might indicate that the seismic design spectra for SIA 261 zone 1, might not be conservative for parts of the spectra with periods smaller than $T_C$.

The comparison of the spectra is given in Figure 4 (2nd column) for Chur (SIA 261, zone 2). At short periods, bellow $T_B$ the median and weighted mean of the eligible response spectra are matching or slightly exceeding the design spectra. This effect is more evident for soil-class C whereas for soil-class D, the design spectrum is higher than both median and weighted mean of the eligible records. These results might indicate that the spectral shape parameters for zone 2 are consistent with the observations.

A similar trend is observed for Basel (SIA 261, zone 3a) given in Figure 4 (3rd column), where the median and the weighted mean of the eligible response spectra consistent with the controlling scenarios of the UHS are below the design spectra. This might indicate a suitable design spectra definition for the soil-classes and level of seismicity of zone 3a (SIA 261, 2014).
Figure 4. Comparison of response spectra with design spectrum (Zurich – 1st column, Chur – 2nd column, Basel – 3rd column and Sion – 4th column) for $V_{S30} > 800$ m/s - Class A, $V_{S30} \sim 300-500$ m/s - Class C, $V_{S30} \sim 150-300$ m/s - Class D, SIA 261. Light blue spectra are the median of eligible spectra within each MR bin, the black line is the design spectrum, the red line is the median of all eligible records, the dashed red line is the 84th percentiles of all eligible records and the magenta dashed line is the weighted mean of all spectra. The vertical black lines represent the corner periods (from left to right: $T_b$, $T_c$ and $T_d$) of the design spectrum.
The same observation applies to Sion (SIA 261, zone 3b) given in Figure 5, where the plots show the scenario specific response spectra and the elastic design spectra of zone 3b. The elastic design spectra are consistently higher than the median and weighted mean of the selected records for every soil-class, with the exception of a small period range for soil class C.

Note, that the elastic design spectra rise to the range of the 84th percentile for soil-class A, whereas for soil-class B, C and D, the elastic design spectra are exceeded below Tc. Hence, the elastic design spectra formalized by SIA 261 for zone 3a (Basel) and 3b (Sion) appear more conservative in respect to selected and analyzed pseudo-acceleration response spectra. It shall be noted, that the number of earthquake recordings are dependent on the MR scenarios, which are UHS dependent. Often, the scenarios are described by MR bins specific to two parts of the spectra (bellow TB, TC controlled by low magnitude events with short to moderate distances, and above TC defined by moderate to large magnitudes at larger distances).

Figure 5. Comparison of response spectra with design spectrum for Sion for Vs30 > 800 m/s - Class A, SIA 261, Vs30 ~ 300-500m/s - Class C, SIA 261, Vs30 ~ 150-300 m/s - Class D, SIA 261. Light blue spectra are the median of eligible spectra within each MR bin, the black line is the design spectrum, the red line is the median of all eligible records, the dashed red line is the 84th percentiles of all eligible records and the magenta dashed line is the weighted mean of all spectra. The vertical black-lines represent the corner periods (from left to right: Tb, Tc and Td) of the design spectrum.
5. CONCLUSIONS

In this contribution, we presented the results of a statistical investigation of ground motion recordings of earthquakes occurring worldwide in similar seismotectonic environment observed in Switzerland. A unified strong motion dataset comprising data and information from open-access strong motion datasets (e.g. PEER NGA-West, SHARE, RESOURCE and EMME Projects) is compiled and used. Given this large strong motion dataset (~25 000 records) and the site-specific earthquake scenarios from the 2015 updates of the Swiss seismic hazard model (Wiemer et al 2016), the comparison between the eligible elastic acceleration response spectra and seismic indicate noticeable differences for different soil classes (A, B, C and D). To summarize, the key findings of the study include:

- Elastic design spectra specified by SIA 261, appear to be often exceeded by new ground motion data, within specific range of spectral periods and soil classes. The differences are evident for periods smaller than 0.2s for soil class A (rock) and increasing discrepancies on spectral values for soil classes (C and D) evident for periods smaller than 0.5s.

- This general trend is overall consistent with the trend observed for other cities in Switzerland, as is given in Figure 6, where the weighted mean (continuous lines) of the median of eligible recordings per MR bins corresponding to the site-specific UHS are compared with the design spectra (dashed lines) corresponding to the seismic zones of SIA 261. The color scheme links the cities with their corresponding seismic zones. The median (given by the red curve) of all median elastic response spectra of all MR bins is lower than the design spectra, whereas the weighted mean, aggregating all median spectra for MR bins, exceeds the design spectra below $T_C$ for all soil-classes. It should be taken into account that the weighted mean quantifies for the contribution of each MR bin to the specified seismic hazard level, thus a more robust measure than the median of all median spectra per MR bin. Further, when the 84th percentile of median elastic pseudo-acceleration response spectra of all MR bins is considered, it can be observed that it exceeds also the entire design spectra for soil-class B, C and D, whereas for the soil-classes A the exceedance occurs up to $T_C$.

- Seismic design spectra zone 1 of SIA 261 requires further investigation for all soil classes as scenario-specific hazard level of $RP=475years$ indicates eligible pseudo-acceleration response spectra exceeding the elastic design spectra of SIA 261.

- The comparison for zones 2 (e.g. Chur, Thun) and 3a (e.g. Basel) suggests that adjustments of the spectra shape of the design spectra bellow $T_C$ for soil-classes B, C and D. The medians of aggregated elastic response spectra for all bins are below the seismic design spectra for all soil classes. The 84th and the weighted mean of all data exceed the design spectra at short periods (up to periods around $T_C$) of the design spectra for soil-classes B, C and D, whereas for soil-class A, they are lower than the design spectrum values. An identical trend is also observed for Basel (SIA 261, zone 3a).

- Comparison results for zone 3b (e.g. Sion, Martigny) indicate also adjustments of the spectra shape bellow $T_C$ for soil-classes B and C. The design spectra are higher when compared to the previous cases. For soil-class C, the weighed mean and the 84th percentile of the earthquake recordings per MR bins surpass the design spectrum bellow $T_C$.

- Elastic response spectra classified as soil-class C rises above elastic design spectra for all SIA 261 seismic zones, suggesting a revision of the spectral shape parameters for this soil class. This might suggest also that the soil classification is questionable as the metadata of the records could not be entirely validated; thus, the observations indicate that the uncertainties of the $V_{s30}$ for this particular subset of the unified strong motion dataset might be higher than of the other classes.

We shall note that the analysis provided here focuses on elastic design spectra that apply for normal buildings. Moreover, the findings, comments or statements provided in this study do not automatically translate into new design parameters applicable to any seismic design for the investigated region. They are meant to be informative and supportive to the review panel of SIA 261 in Switzerland.
Figure 6. Comparison of the weighted mean (continuous lines) of the median of eligible recordings per MR bins corresponding to the site-specific UHS of several cities - Zurich, Bern, Lucerne, St. Gallen, Lausanne, Geneva, Lugano – zone 1; Chur, Thun – zone 2; Basel – zone 3a; Sion and Martigny – zone 3b with the corresponding design spectra (dashed lines) recommendations of SIA 261. The soil classes (A, B, C and D) of SIA 261 are used as a reference for the comparison.

7. REFERENCES


