HAZARD--CONSISTENT DESCRIPTION OF SEISMIC ACTION FOR A NEW GENERATION OF SEISMIC CODES: A CASE STUDY CONSIDERING LOW SEISMICITY REGIONS OF CENTRAL EUROPE

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SUMMARY

The aim this paper is to study hazard-consistent spectra for a set of 64 sites (data points) within Germany and to compare them with the so far discussed standard elastic response spectra for both, the Eurocode 8 (EC 8) and the proposed new German seismic code, which considers a greater variety of subsoil types. The mentioned 64 target points provide a good representation of the characteristics of all seismic zones on the basis of a new generation of probabilistic seismic hazard assessment (PSHA). The hazard consistent spectra were derived from classical PSHA and considering all uncertainties based on a logic tree approach. The used spectral acceleration relations rely entirely on European strong-motion data. Hazard-consistent spectra were determined also for mean hazard curves of the defined seismic zone levels. All studies were carried out for mean and 84%-fractile spectra as well as for stiff site conditions. It can be recognized that the hazard-consistent spectra are in much better relation or agreement with recently proposed spectra for seismic zones in Germany than the EC 8 spectra. The shapes of the hazard-consistent spectra show minor variation between the different seismic zones only. A new quality of hazard-consistent spectra could be derived from logic tree PSHA using the FRISK88M code [Risk Engineering Inc., 1996]. These results, which were also achieved from calculated magnitude-distance bins, are discussed as well.

INTRODUCTION

Currently, it is largely uncertain for many seismic areas to which extent spectra determined by probabilistic seismic hazard assessment (PSHA) are comparable with still recommended site-dependent design spectra of seismic codes. Furthermore, it might be surprising that despite of the availability of well developed PSHA tools a little or even no progress can be stated with respect to the elaboration and implementation of hazard-consistent spectra [1] within seismic codes for seismic regions of (Central) Europe. The lack of strong motion data and the need for appropriate attenuation functions may be reasons for this situation. Though, attenuation functions based on predominantly European strong motion datasets are available [e.g. Ambraseys et al., 1996]. It is largely unknown if their characteristics are able to reflect further regional peculiarities. From the limited data recorded during and after the M_W=5.4 Roermond earthquake 1992 (Netherlands / Germany), it was concluded that these attenuation functions may fail because of the observed rapid decline of ground and spectral accelerations at larger distances [Schwarz and Ahorner, 1995; Grünthal and Schwarz, 1996]. Furthermore, there is no unified procedure established to incorporate these hazard-consistent spectra into the simple structure of current building codes. Finally, no comparisons between the shape and amplitude level of code spectra and hazard-consistent spectra were published so far. Subsequently, the presented results of preliminary studies provide an impression on the modifications which have to be expected if the concept of hazard-consistent spectra is implemented within common seismic codes. As it can be concluded, hazard-consistent seismic design actions can be assigned also for low seismicity regions in Central Europe if the correlations for the attenuation of spectral amplitudes are properly selected. Differences in the hazard-consistent spectral accelerations have to be considered depending on the PSHA approaches used; i.e. the "classic" PSHA are in most cases not compatible with those which are calculated by taking into account fully the logic tree assumptions.

[1] The term "hazard-consistent spectra" is used here equally to the term "uniform hazard spectra" (UHS).

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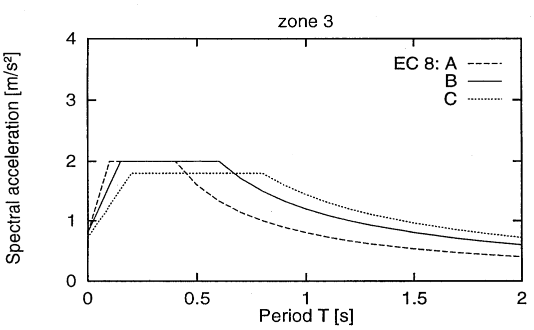
STANDARD ELASTIC RESPONSE SPECTRA ACCORDING TO EC 8 AND THE NATIONAL APPLICATION DOCUMENT TO THE EC 8

For the application of the Eurocode 8, the seismic hazard is described in terms of the effective peak ground accelerations a_g in rock or firm soil [ENV 1998-1-1]. These accelerations are used as scaling parameters for standard elastic response spectra. The so far recommended subsoil-dependent spectra are shown in Figure 1a for a zone 3 acceleration of a_g = 0.8 m/s² and for different soil factors and control periods. Despite of the discussions concerning the determination of "effective" peak accelerations [Schwarz 1996] for the draft of the National Application Document (NAD) to the EC 8 or the new German Seismic Code, effective peak accelerations are derived for the intensity ranges of the seismic zones of Figure 2 following a proposal by Schwarz [1996]. As an innovative part of the code, it is intended to introduce spectra, which consider combinations of three subsoil classes (denoted by 1, 2, 3) and three site conditions (A, B, C). Site peculiarities refer to the depth of sedimentary layers above bedrock [Schneider 1998]. Different seismic action types (spectra) follow from probable combinations of these classes. Therefore, different sets of soil profiles are studied considering variations of depth and shear wave velocities. Figure 1b provides an impression of the basic classification of spectrum shapes. Spectra are still under revision, and will be modified according to the outcome of ongoing studies on modifications of control periods and soil factors (plateau values), which are to be expected especially for combinations B2, B3 A3 and C3.



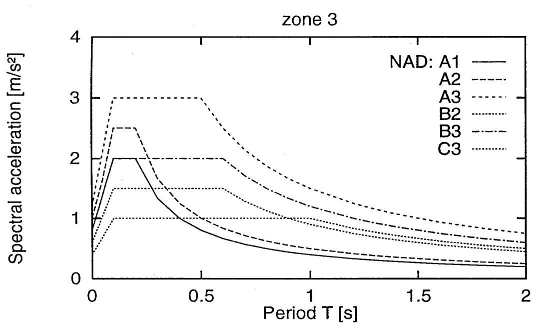


Fig 1a **Fig 1b**

HAZARD-CONSISTENT SPECTRA

Targets for the analysis of hazard - consistent spectra in relation to the new German seismic zoning map

The second generation of probabilistic seismic hazard assessment [Grünthal and Bosse, 1996] was the basis for the seismic zoning map for a non-exceedence probability of 0.9 within 50 years (Fig. 2) which will be implemented into the NAD to the EC 8 and into the new German seismic code DIN 4149 (new), respectively. For the purpose of this paper a set of target points was defined for studying the hazard-consistent spectra for the different seismic zones. They are shown as asterisks in the zoning map of Figure 2.

For reasons of compatibility with previous versions the seismic zoning map is layed out in terms of intensity with the following definitions: zone 3: I > 7.5; zone 2: 7.0 < I £ 7.5; zone 1: 6.5 < I £ 7.0.

In total, 64 data points are taken into account:

zone a (area beyond zone 0): 11 data points (dp); zone 0: 13 dp; zone 1: 23 dp; zone 2: 12 dp; zone 3: 5 dp. These points are closely spaced within zones of special importance.

Attenuation functions of spectral acceleration

For the purpose of this study attenuation functions of spectral acceleration are used, which were derived from strong-motion datasets with predominantly European events; i.e. the proposals by Ambraseys et al. [1996], Pugliese and Sabetta [1989], Sabetta and Pugliese [1996] and Petrovski [1986].

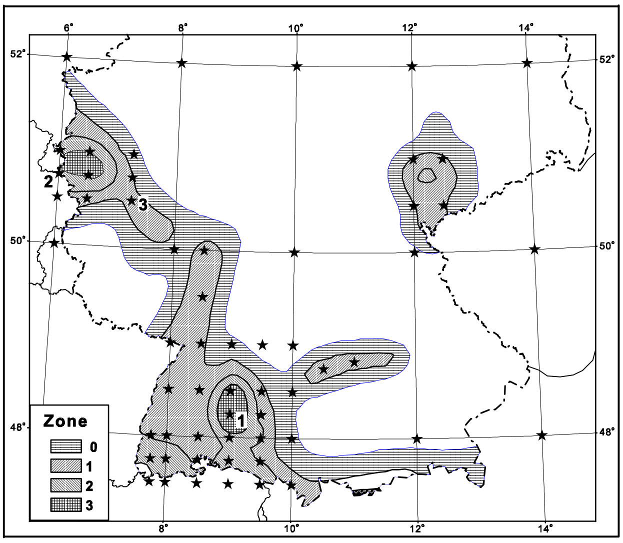


Fig 2

Figure 3a and Figure 3b represent spectra for earthquakes in Germany which can be regarded as representative events for zone 3, where earthquakes of intensities I > 7.5 are to be expected within the given probability level. In this century these events were repeatedly observed in the Swabian Alb (region where data point 1 is centred in Figure 2). It is assumed that for given source depths of 6 and 10 km an epicentral distance of 10 km would cause shaking levels relevant to building design. In Figures 3, these deterministically determined spectra are compared with results from PSHA for attenuation functions by Ambraseys et al. (1996), ASB, and Pugliese and Sabetta (1989), PS. Curves with

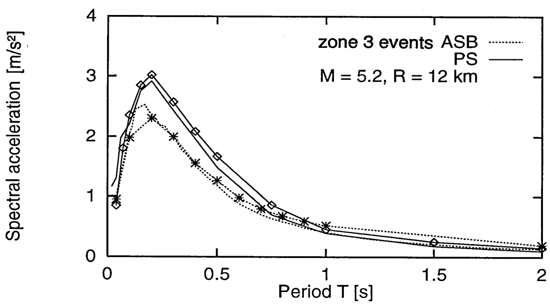


Fig 3a

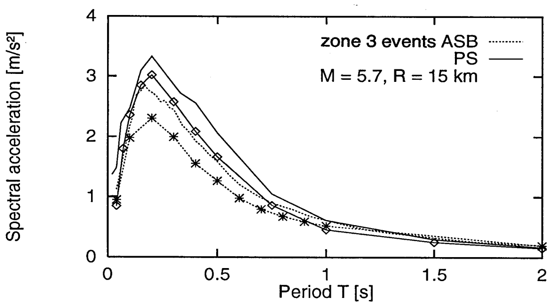
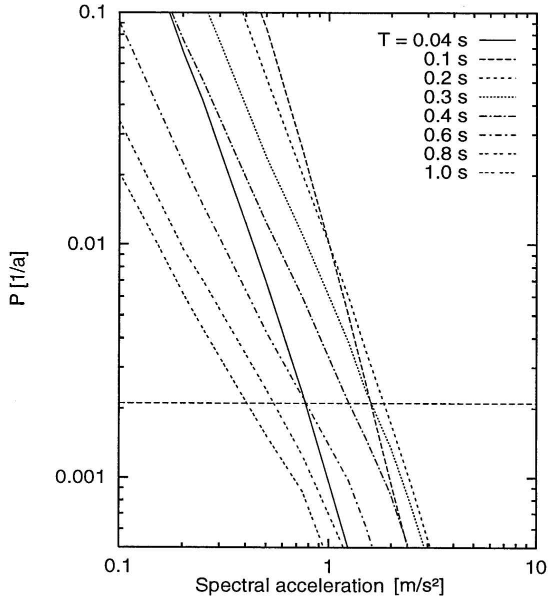


Fig 3b

special markers refer to the mean values of all zone 3 data points. From these graphs it can be concluded that a M=5.2 and R=12 km event seems to be a representative one for zone 3 (intensities I (EMS) > 7.5).

Characteristic hazard curves within seismic zones

Hazard curves in terms of spectral accelerations were evaluated for all data points of Figure 2 and for selected periods using the above mentioned attenuation functions (ABS, PS and Pet [Petrovski 1986]). For completing the information about hazard-consistent spectral accelerations similar curves were derived for the peak ground acceleration, too. It has to be stressed that attenuation functions for spectral and peak ground motion are in most cases determined by slightly different regressions and/ or datasets. This might be the reason for some inconsistencies between the level of spectral accelerations at low periods and the so called "zero-period" acceleration. PSHA were performed for different attenuation functions and with and without implementing the uncertainties (standard deviation s). Exemplary, hazard curves of spectral accelerations for data point 2 (zone 3) are given in Figure 4a for periods between T = 0.04 s (peak ground acceleration) and T = 1.0 s using the attenuation function by [Ambraseys et al., 1996] for stiff soil conditions (s=0).



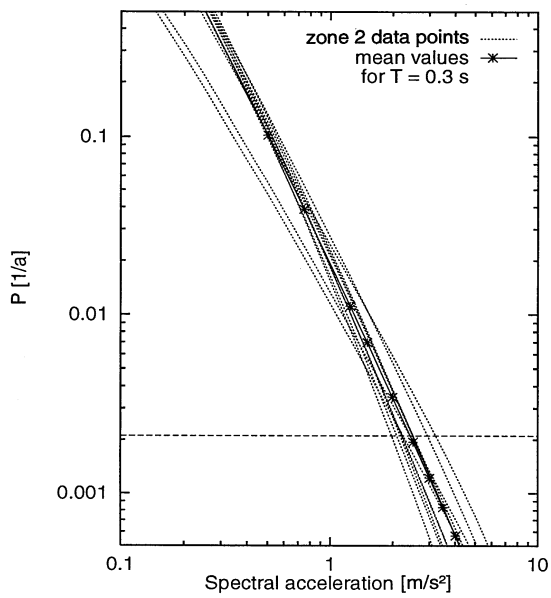
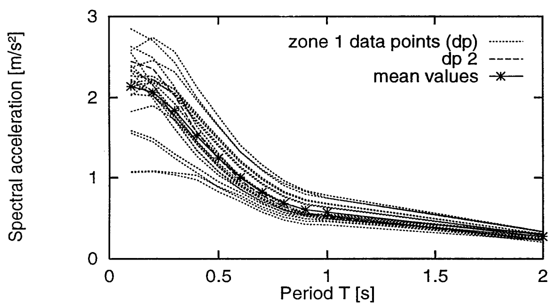


Fig 4a **Fig 4b**

Based on the hazard curves for the selected periods T of all data points the mean values have been determined, which are within a more or less pronounced scatter of results representative for each of these zones. The procedure is illustrated in Figure 4b for zone 2 and the period T = 0.3 s [Ambraseys et al., 1996], stiff soil. In Figure 4b the spectral accelerations are related to the 84%-fractile (s = 1, i.e. mean + 1_-standard deviation level). The recommended hazard level for conventional buildings (1/P = 475 years) is indicated by a broken horizontal line. Hazard-consistent spectra follow from the intersection of period-related hazard curves with this hazard level. Since selected periods are considered only, the resulting spectra are not complete with respect to the period range and just comparable with spectra from the individual attenuation functions at distinct periods.

Hazard-consistent spectra within seismic zones

Hazard-consistent spectra were derived for all 51 data points on the basis of single hazard curves and for the mean hazard curves of the seismic zones. The mean values of each zone are used to check the quality of code spectra and the reliability of the implemented tools and the procedure itself. Figures 5a and 5b show the elastic spectra for all data points belonging to zone 1 and zone 3, respectively. Additionally, the mean value spectra as well as spectra for selected data points are indicated. The mean value spectra (s = 0) can be regarded as the



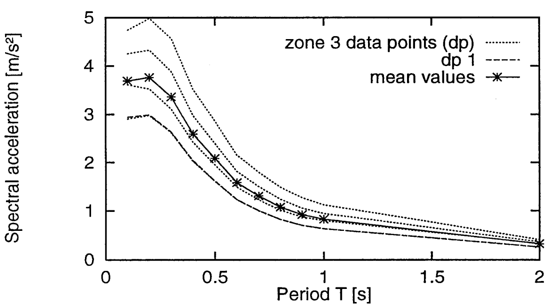


Fig 5a **Fig 5b**

representative spectrum for all data points/areas of each zone. These spectra are calculated for different attenuation functions and subsoil conditions. The examples in Figures 5a and 5b are derived using spectral accelerations according to the proposal by [Ambraseys et al., 1996] for s = 1.

Comparison of code spectra with hazard-consistent spectra

The mean spectra of all selected data points/ sites of the individual zones can be compared and subsequently discussed with respect to the recommended spectra which were determined on the basis of effective accelerations and site-dependent standardized shapes of code spectra (cf. Figures 1a and 1b).

In Figure 6a and Figure 6b mean spectra for rock and stiff soil conditions are compared for the mean values of zones 1, 2 and 3, and for s(af) = 0, i.e. only the mean values according to the attenuation equations are considered, which seems to be consistent with the given definition of Eurocode 8 (ENV 1998-1-1). In the Figures the scatter of spectral amplitudes within data points (dp) of one zone is neglected, i.e. it should be noticed that the spectral values are related to the level of s(dp) = 0. From these Figures, one can derive conclusions with respect to the level of spectral amplitudes which is inherently incorporated within the recommended EC 8 spectra. Besides this, it should be noticed that the derived hazard-consistent spectra are well

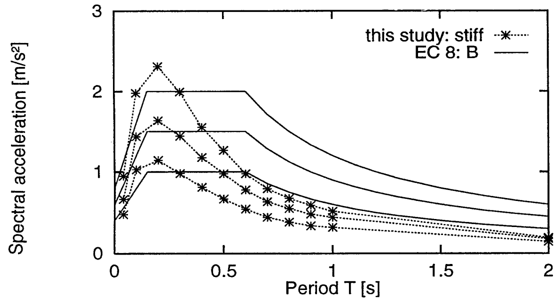


Fig 6a

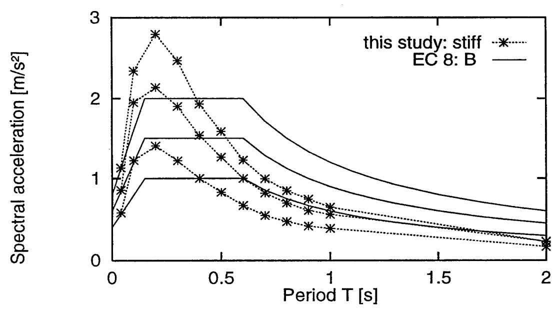


Fig 6b

separated. Furthermore, the ratio between spectral accelerations should be in an acceptable context with the ratios between elaborated and zone-related effective peak accelerations.

In Figures 7a and 7b comparisons of mean hazard spectra (s(af)=0; s(dp) = 0) are given for zone 1 and 3 additionally those spectra which one would obtain if the NAD (DIN 4149-new) spectra would be used. Figures 7a and 7b illustrate the quality of mean spectra which were evaluated for moderate to stiff soil conditions according to different attenuation laws. It is not surprising that the spectra are similar in shape but quite different with respect to the level of amplitudes. The results show a good agreement in the decline of the level of amplitudes for periods greater than 0.5 s. Slight differences can be observed for the plateau-range between the control periods. It should be noticed that, at the moment, no tools are available to consider the impact of significantly varying depths of sedimentary layers. The problem becomes evident, when comparing spectra for

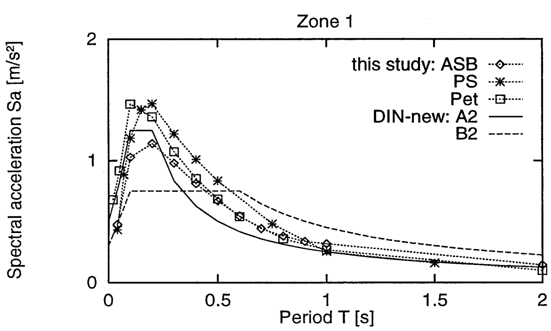


Fig 7a

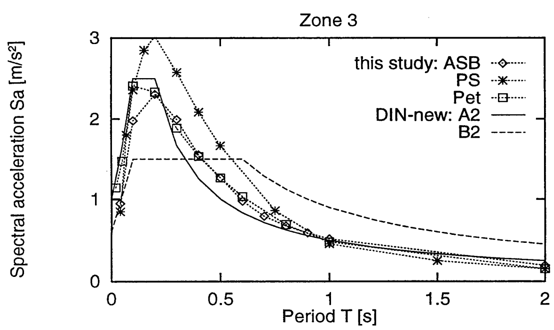


Fig 7b

stiff soil conditions with those of the DIN 4149-new, where for a site classified as "stiff soil" a combination of A2 and B2 is probable (Figures 7a, 7b). Therefore, any statement has to recognize the inherent limits of both approaches. Nevertheless, it can be concluded that the hazard-consistent spectra are in much better relation or agreement with recently proposed spectra for seismic zones in Germany than the EC-8 spectra. From a practical point of view, it has to be investigated in more detail if A2 or/and B2 combinations are equally or less dominant for each zone.

The question arises, which attenuation should be applied for the low seismic region of Central Europe. Approaches involving and equally weighting different attenuation functions lead to compromise solutions but will not satisfy regional peculiarities. It is one of the important tasks for forthcoming studies to derive new attenuation functions for such regions by considering strong motion data from recent events (i.e. Roermond earthquake 1992, Schwarz and Ahorner 1995).

THE NEW QUALITY OF HAZARD-CONSISTENT SPECTRA

General problems and questions

If some basic problems are solved, hazard-consistent spectra can replace the traditional code spectra. Problems concern the scatter of site-dependent spectral accelerations and the entire scaling procedure. Due to the consideration of different data points, there is, consequently, an uncertainty of spectral accelerations around the mean spectra of each zone. Figures 6a and b show sets of spectra of zones 1, 2 and 3: one set is related to the mean values of all data points, the other one describes the mean + 1 σ-standard deviation (84%-fractile) for a level of spectral values which were calculated with $\sigma = 0$ attenuation functions. With the uncertainty of spectral amplitudes within one zone, new questions of general design philosophy arise. Which level is appropriate for conventional buildings and in which case special site investigations are required? What decisions should be made when buildings of higher importance are involved?

It is common code practice to define normalized spectrum shapes which have to be scaled according to the zone-consistent level of seismic action. In general, the spectrum shapes will be uniform for all zones. Figure 8a and 8b show the normalized mean spectra for zones 1, 2 and 3. There are only slight differences between the recommended zones, i.e. there is only minor impact of far events which could cause more pronounced differences (see also magnitude-distance bins in Figures 9a and 9b).

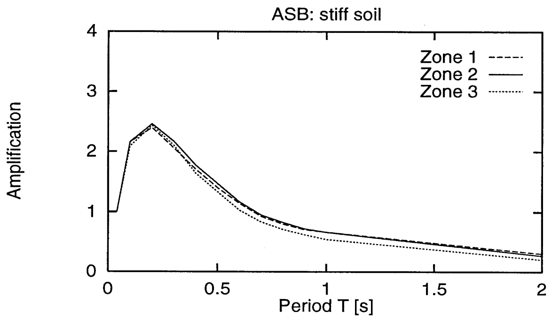


Fig 8a

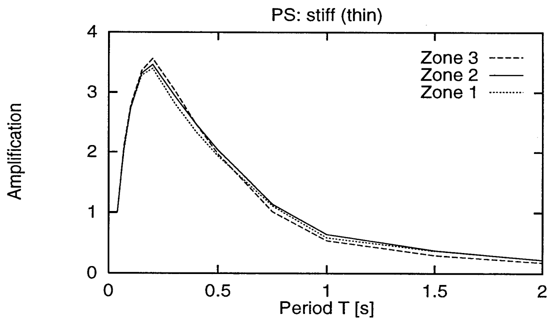


Fig 8b

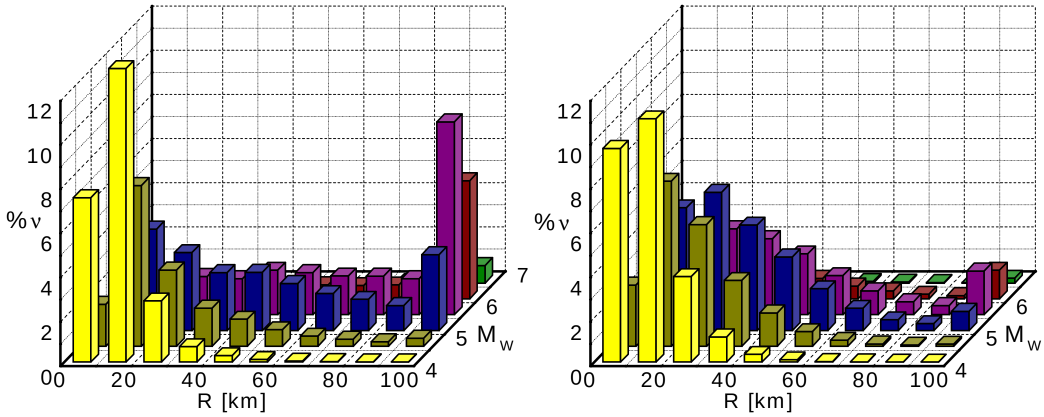


Fig 9

Spectra based on logic tree approaches

The presented hazard-consistent spectra were elaborated on the assumption that the relevant input parameters of the PSHA can be introduced as deterministic ones. Further progress can be achieved if the input parameters are considered more probabilistically taking into account logic tree assumptions [Grünthal et al., 1999]. Results of preliminary studies are given for data points 3 and 2 (Figures 9a and 9b). The Figures illustrate the seismic background using the contribution of magnitude-distance-bins. Results of PSHA with logic tree assumptions and ("classically") without are compared in Figures 10 a and 10 b using attenuation function for the data point 3 for rock and stiff soil [Ambraseys et al., 1996]. The response spectra are slightly reduced if logic tree assumptions are implemented. From the comparisons it can be concluded that classic mean PSHA spectra have to expected between the 50%- (s = 0; median) and the 84%-fractile spectra (s = 1).

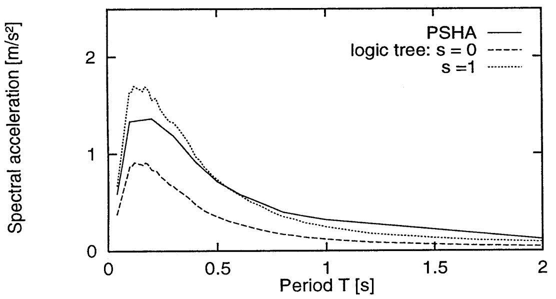


Fig 10a

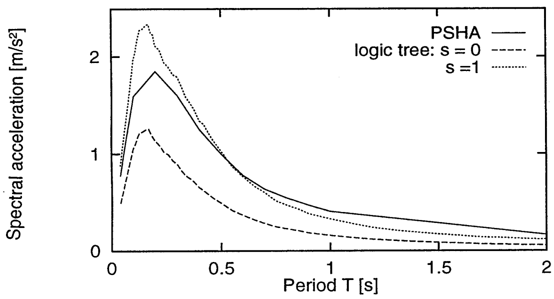


Fig 10b

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