Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Harmonization of codes with respect to seismic hazard and seismic action for structures of different risk potential

J.Schwarz
College of Architecture and Civil Engineering, Weimar, Germany

G.Grünthal
Georesearch Centre, Potsdam, Germany

ABSTRACT: Investigation results are presented, being carried out to elaborate intensity-scaled and zoning map consistent descriptions of seismic actions. With respect to actual code developments (Eurocode 8) problems, which could arise from introduction of intensity- and subsoil-related design spectra and from transformation of smoothed curves into a normlike presentation, are discussed. Frequency-dependent coefficients are proposed, illustrating the qualitative influence of subsoil and intensity on spectra and the consequences of varying risk potential on seismic design actions.

1 INTRODUCTION

With respect to the unification and harmonization of seismic input data the following problems arise:
(1) assessment of seismic hazard and subdivision of seismic zones
(2) site-dependent and zoning-map consistent description of seismic action
(3) smoothing of spectra and deviation of normlike design spectra or parameters
(4) elaboration or adaption of design spectra in accordance with importance or level of risk potential of structures.

Methods and principles for solving these problems are considerd with respect to drafts of the Eurocode No 8. Subsequent proposals are results of a research work intended to the development of a seismic code, which was originally foreseen to be introduced for the Saxo- Thuringian earthquake region (Eastern Germany), Schwarz & Grünthal (1991).

2 SEISMIC HAZARD ASSESSMENT

2.1 Methods

For assessing of seismic hazard different methods are available, providing information on similar parameters. In fact, the results are of different quality and seldom comparable.

In the last years different types of zoning maps were elaborated for the study area Germany, which is characterized by a low or moderate seismic activity. The approaches to seismic hazard used are:
(a) deterministically, on the basis of maximally observed or expected intensities (DIN 4149, 1981),
(b) deterministically, but suggesting some probabilistic conclusions, on the basis of repeatedly observed maximum intensities (Grünthal 1987) or
(c) probabilistically, on the basis of fixed hazard levels and expressed in terms of the occurrence rates of macroseismic intensity within the life-time of buildings (Grünthal 1991).

The approach (b) is based on maps of maximum observed intensities for three consecutive time intervals (1000 A.D.- 1499, 1500- 1749, 1750- 1985). The probabilistic approach (c) has especially been developed for the study area for which numerous detailed macroseismic maps are available. They show for distinct areas typical increased intensities while other areas are characterized by an intensity decrease. These maps were digitized and directly used as input data for the special approach. Uncertainly known historical earthquakes are incorporated in this approach to hazard assessment as fuzzy information. The anomalies in shakeability known from macroseismic maps are consequently reflected in the resulting hazard maps. They were constructed on the basis of hazard curves (Fig.1) which were computed for sites having a 10x 10 km spacing. Comparing the results of approach (b) and approach (c), a detailed analysis of differences and consequences for design practice can be given.

The determination of a distinct level of seismic hazard is required a priori for probabilistic methods. When the parameter of the seismic hazard or zoning maps (here: the intensity) is based on different return periods, then the sites, for which the same macroseismic intensity is indicated, can incorporate a quite different seismic risk potential.

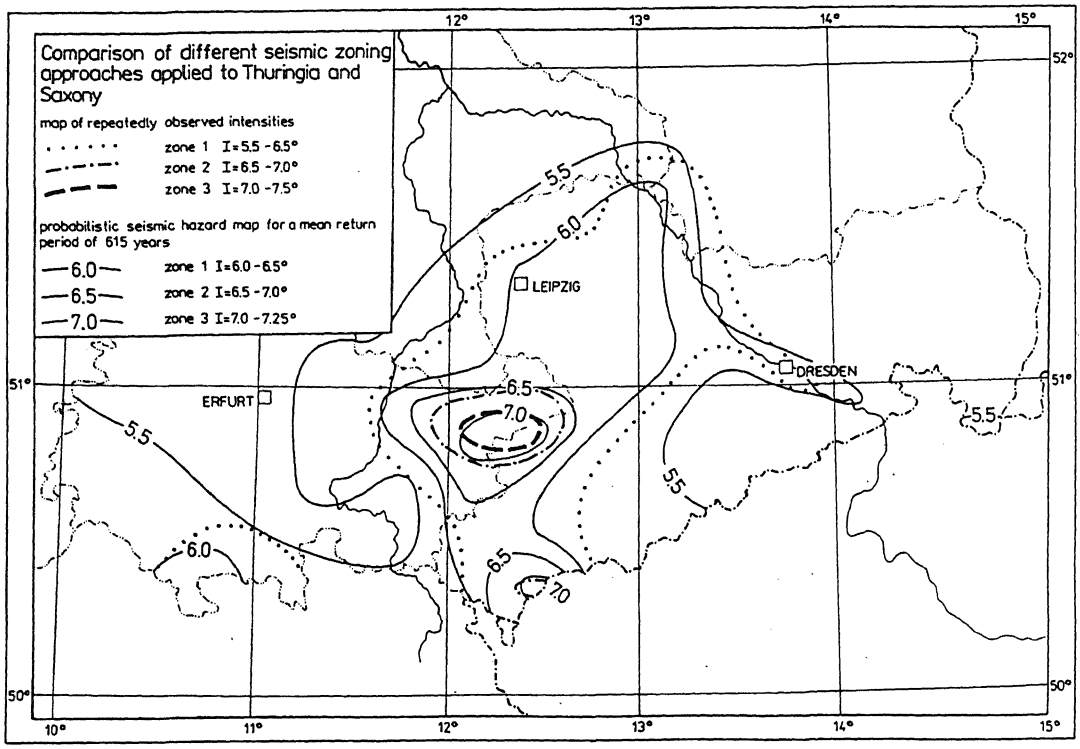


Figure 1. Comparison of different seismic zoning approaches applied to Thuringia and Saxony, Eastern Germany (Grünthal 1987, 1991)

Two seismic zoning maps were prepared for the planned code, defining those site intensities which will occurre with an exceedence probability of 15 per cent within 50 and 100 years, or in other terms, with mean return periods of 308 and 615 years. As it can be concluded from the actual world list of earthquake resistant regulations, the choose seismic hazard levels are within the range, currently used in other recent seismic codes.

2.2 Harmonization of seismic zoning maps

Before subdividing a region into seismic zones, it has to be decided which level of refinement is intended and which level is really necessary or significant. A final decision should be in correspondence with seismic activity and also with the historical periods of observation, avoiding a sophistication that cannot be justified.

The subdivision of the seismic hazard maps into seismic zones is based on intensity intervals of half a degree. But with respect to the intended European harmonization (Eurocode 8) the definition of earthquake zones should follow intervals of full intensity degrees.

In recent comments on draft of the Eurocode 8 basic parts it has been suggested, that two methods will be recommended for the harmonization of European hazard level and for the subdivision of seismic zoning maps:

(1) on the basis of maximum observed intensities or
(2) on the basis of mean return periods, which should be selected within a range of 500 to 1000 years.

It seems to be preferable to take an unique reference return period in the lower range of the given interval, e.g. for a probability of exceedence of 15 per cent within 100 years. Such a decision has several advantages. Only on the basis of such a procedure:

- problems along historically raised and still existing frontiers can be solved
- discrepancies in the field of economical competition can be suppressed
- the frequency of damage causing earthquakes can be implemented and
- only with the probabilistic procedure real prognostics can be stated.

Figure 1 illustrates contours (in terms of intensity) of elaborated seismic zones in the Saxo-Thuringian seismic province. They were proposed on the basis of the above shortly described approaches, i.e. repeatedly observed maximum intensities and the isolines of probabilistically developed maps (Grünthal 1991, Schwarz & Grünthal 1991).

Obviously, a good agreement between the results of both methods can be stated.

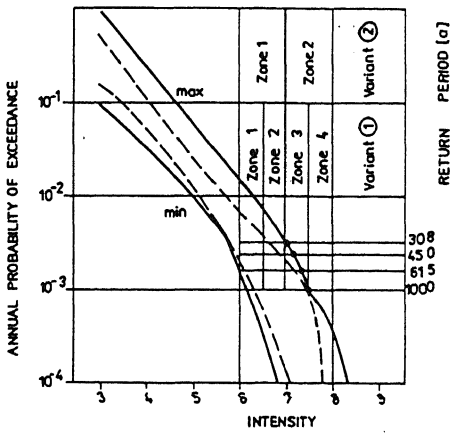


Figure 2. Envelopes of seismic hazard curves and the correlation between return periods of intensity and the subdivision of zones

This is not surprising, because the return period between 200 and 700 years- represented by the applied method of repeatedly observed intensities - is comparable with the mean return period of 615 years.

The correlation between the return period of macroseismic intensity and the subdivision of seismic zones gets practical importance when sites have to be classified into these zones. Fig. 2 shows the upper and lower envelopes of seismic hazard curves computed for sites within the seismic zones of the Saxo-Thuringian province (intensity 6°. or higher at the reference return period of 615 years). Two variants of zoning maps were investigated. Variant 1 is identical with the subdivision of zones according to the version of a draft of a new seismic code (Schwarz et. al. 1990); variant 2 represents the subdivision of seismic zones into intervals of full intensity degrees.

It can be concluded that sites of more moderate seismic activity react quite sensitively upon the seimic hazard level, and that they will belong to different zones, when the return period is varying within the before mentioned range of 500 to 1000 years. Sites of lower seismic activity are less affected by the variation of hazard level and will in the most cases remain within the same seismic zone.

3 SEISMIC ACTION - THE PROBLEM OF INTENSITY-RELATED DESIGN SPECTRA

3.1 Results of statistical investigations (for Central Europe)

It was intended to introduce into the seismic code a description of seismic action, which should be consistent with the kind of zoning parameter provided for design purposes. To

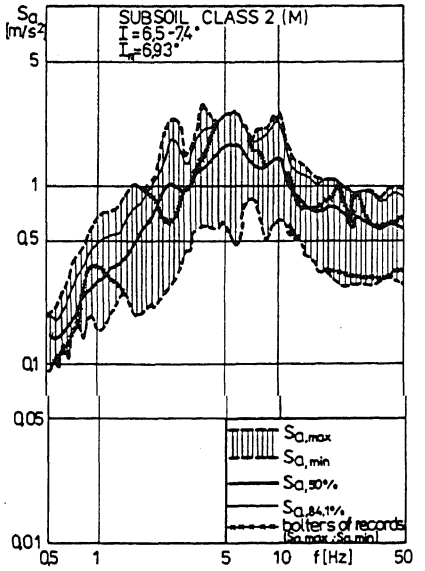


Figure 3. Results of statistical investigations: intensity class 6.5- 7.4°; medium stiff soils (subsoil class 2)

realize this aim, elastic free-field design spectra were predicted, being representative for different intensity levels (determined by earthquake zones) and for three classes of subsoil conditions.

Mainly data from Italian earthquakes were taken for this investigation and selected with respect to their magnitude and source distance. They were classified into four classes of intensity and three subsoil classes. As a whole, 12 data groups were statistically investigated (Schöbel 1989, Schwarz et.al 1990).

In general, the procedure is similar to former investigations, performed for German earthquake regions by Hosser et.al. (1987), but it differs with respect to the intervals of intensity and therefore the composition and the mean intensities of samples.

Meanwhile, for German earthquake regions several proposals for intensity- and subsoil-related design spectra are available.
A comparison of these design spectra is given by Schwarz (1991), Schwarz & Grünthal (1991). They can be regarded as an essential contribution to further discussions, which might arise from application of the Eurocode No 8 within European community.

It is clear, that the quality of such a statistical investigation strongly depends on the quality of the samples and the number of records within the groups. With respect to this "natural limitation" further improvement of the data base is a permanent task. The results have to be considered very carefully as indicators for a statistically evaluated tendency.

The great scatter of spectral amplitudes can be expressed in terms of "spectra of standard deviation" (Schwarz et.al. 1990) or in terms of envelopes of maximum and minimum spectral accelerations. In Fig. 3 the mean spectra of the statistical investigation are compared, representing the whole data of the subsoil class 2 (medium stiff) and the intensity class 6.5 - 7.4 and indicating the inherent statistical uncertainty of results. Additionally, spectra of single records, mostly differing from the mean spectra, and 84,1 percentile spectra are given. It can be concluded that often single events (bolters) alone are responsible for the great scatter of upper and lower limits (broken lines).

3.2 Intensity- and subsoil-related design spectra and amplification factors

Intensity- and subsoil-related amplification factors are introduced for better interpretation and understanding of results (Schwarz et.al. 1990, Schwarz 1991).

Intensity-related amplification factors r_I give the ratio of spectral acceleration between spectra of intensity (I+1) and intensity (I) within one subsoil class. They could be interpreted themselves as spectra of amplification factors and are comparable to the ratio of (frequency-independent) zoning or seismicity coefficients, commonly used in seismic codes.

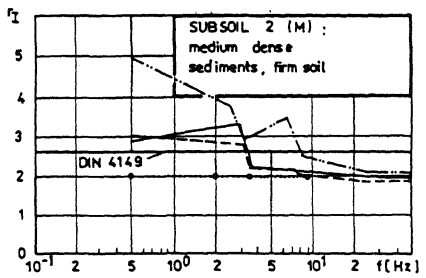


Figure 4. Intensity-related amplification factors r_I (I= 6.0°; subsoil class 2)

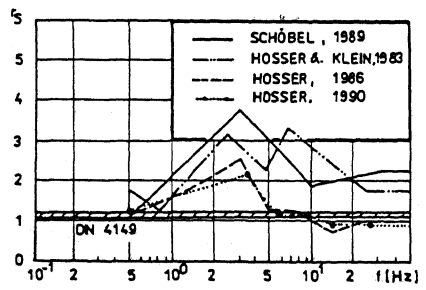


Figure 5. Subsoil-related amplification factors r_s (I= 6.5-7.5°; subsoil 2)

Subsoil-related amplification factors r_s give the ratio of spectral accelerations between the spectra for soil and those for rock conditions within one intensity class. They could be interpreted themselves as spectra of amplification factors, related to rock reference conditions and are comparable to soil coefficients or modifications, implemented by definition of subsoil-dependent parameters (control periods, exponents, upper limits of dynamic factors etc.) in seismic codes.

Figures 4 and 5 give an impression of those spectrum relations, comparing the proposed elastic design spectra for German earthquake regions with the ratio of factors, given by the German norm DIN 4149 (1981).

The spectral ratios can also be taken as an indicator of the plausibility of statistically deduced results and the quality of smoothing.

3.3 Problems of smoothing

For practical application it seems to be necessary to smooth the irregular curves of statistical investigation. It is a general practice to linearize spectra in tetralogarithmic coordinates and to achieve branches of spectra with constant amplification factors of ground motion.

It was one of the underlying assumptions of the selected procedure that correlations with ground motion should be avoided and that the acceleration should not serve as scaling parameter.

With respect to the results of statistical investigations two methods (variants) of smoothing were studied:

(1) matching statistical results closely (variant v1)

(2) refering closely to the shape of the commonly used type of the design spectrum (with a constant acceleration branch and a similar shape of intensity-related spectra within one subsoil class as minimum requirements, variant v2).

In general, (1) is only the preliminary stage of variant 2; but also (2) could get further modification, when the shape of spectra has to be defined in terms of control periods, amplification factors and scaling parameter. At the end of this procedure smoothed spectra are far away from the input spectra of statistical analysis.

Consequences of the smoothing are filtered out by calculating of intensity- and subsoil-related amplification factors, now existing between spectra of variants 1 and between spectra of variants 2 (Fig. 6).

3.4 Deviation of normlike parameters of seismic action

On the basis of smoothed variants of spectra the normlike representation can be predicted.

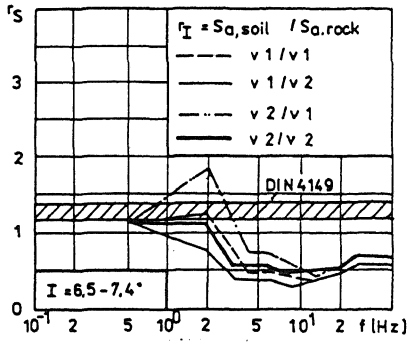
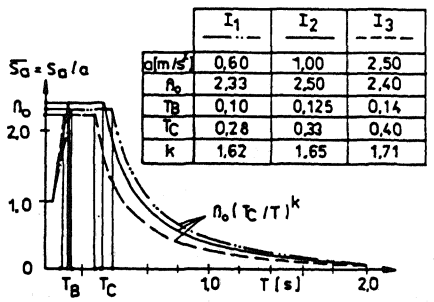


Figure 6. Subsoil-related amplification factors r_s (intensity class 6.5-7.4°; subsoil class 1, alluvium)



	I_1	I_2	I_3
a [m/s²]	0,60	1,00	2,50
η_0	2,33	2,50	2,40
T_B	0,10	0,125	0,14
T_C	0,28	0,33	0,40
k	1,62	1,65	1,71

Figure 7. Normlike representation of results for subsoil class 3 (rock)

A normlike represention means: decimal coordinates of the period of vibration T and the dynamic (spectral) coefficient, definition of parameters, determining subsoil-dependent branches and decay of amplification effects between control periods.

For transformation of spectra into the normlike form two methods were studied:

The first method follows the proposal by Schneider, Hosser and Keintzel (1990), recommended for harmonization of rules for the determination of seismic input data. The authors generally postulate a maximum amplification factor β_0 of 2.5; on this basis a more or less fictive scaling parameter (in terms of ground acceleration) is estimated from maximum spectral accelerations.

The second method takes the constant spectral acceleration in the range of higher frequencies as a "quasi-ground-acceleration". The amplifaction coefficients β_0 can be determined with this value (Schwarz 1991). By this way additional deviation from the original mean spectra can be limited.

Results of the second method are illustrated in Fig. 7 for variant 2 and for the subsoil class 3 (rock) demonstrating relatively uniform shapes and paramters of the spectra (dynamic coefficients) within the intensity classes. The differences become more evident when the other subsoil classes are regarded.

4 SEISMIC ACTION FOR STRUCTURES OF DIFFERENT RISK POTENTIAL

4.1 Correlation between seismic risk and seismic action

Seismic risk can be estimated on the basis of hazard curves, expressing the annual probability of exceedence or its inverse the return period of quantities like magnitude, peak ground motion or intensity.

The acceptable level of seismic risk has to be evaluated by national authorities, and it is quite dependent on the importance of the risk potential of structures.

Because of the different design philosophy and the noncomparable level of intended protection or seimic resistance, seismic codes for conventional buildings are to be distinguished from guidelines for high risk structures (nuclear or chemical plants, dams, special structures).

Questions arise, how it could logically be explained that for the same site structures are designed against quantitative and also qualitative different events. There should be only differences between the levels of hazard, structures should be designed for, and between the demands to the quality of structural behaviour (damage, extent of deformations).

The discrepancies between seismic input data become evident, when buildings/ elements of N.P.P. are classified into a lower category of risk level or when they should be analyzed according to codes of standard buildings.

Practically, various methods can be applied to cover the lack of harmonization in the field of description of seismic action.

Schemes in Fig. 8 shall transmit an impression of some basic ideas. Additionally, the frequency-dependent ratio between spectra of stronger earthquake E_2 (for structures of higher risk) and a weaker earthquake E_1 (for structure of normal risk) is indicated.

The simplest distinction of both earthquakes should follow risk estimates of ground motion or intensity. If a standard spectrum is taken, the ratio between events agrees with the ratio of deviating ground motion. If risk estimates are available for all types of ground motion (acceleration, velocity and displacement) the ratio of spectra is is linearized, but is varying in the ground motion controlled frequency ranges.

The double-earthquake design philosophy, coming from the design practice of US Nuclear facilities is illustrated as method 1 in Fig. 8. The structural resistance is taken into account, while defining design earthquakes (E_1, E_2) for elastic and elasto-plastic damping values. Differences in spectra are caused by differences in damping-related amplification factors and the ground motion, refering to different levels of seismic hazard (return periods).

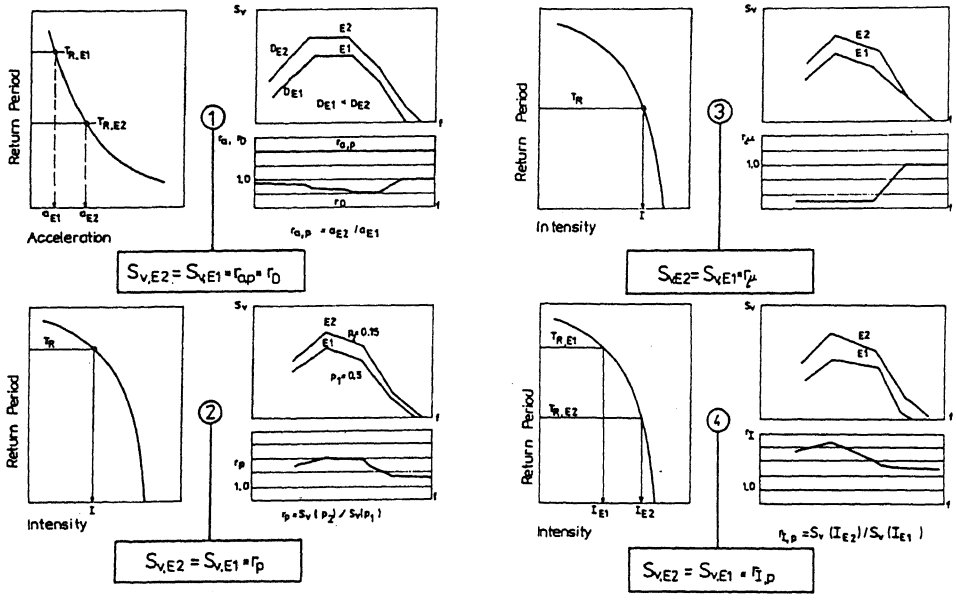


Figure 8. Definition of seismic action for structures of different risk potential (schematic representation of methods)

The other methods are characterized either by modifications to the design action (hazard levels, levels of non-exceedence of spectral values; method 2) or by adaption of the resistance capacity (ductility, inelastic deamplification; method 3), or, as it is practically often prefered, by modifications to both aspects. In Fig. 8 methods 2 and 3 are represented by an unique return period of intensity. The distinction between seismic action is reached by the definition of different probabilities of exceedence (p_1,p_2) of spectral amplitudes or by different inelastic deamplification factors r_u.

It seems to be more appropriate to modify the resistance side, when structures should sustain earthquakes with a different grade of damage. Otherwise, it seems to be preferable to modify the impact side, when different damage pattern are specified for different design earthquakes.

If intensity-related design spectra are used, the ratio of seismic action types reflects also the different quality of earthquakes and seismological parameters, causing high intensity ground motion (method 4). The predicted intensity- and subsoil-related spectra can be used for this method (Fig. 8).

4.2 Risk and Importance Factors

In this context it is interesting to note that the importance of standard buildings is taken into account without any relation to the seismic hazard level or the intended behaviour under design earthquake while amplifying seismic action with a so called importance factor.

Rationally, this factor can only be explained and interpreted as a substitution of not distinguished, but intended different seismic hazard levels. In that sense, importance factors are comparable to risk factors, which are related to a reference risk level (say of 150 years) and which indirectly express the difference of seismic action when higher or lower risk levels should come into consideration.

On the basis of hazard curves (see Fig. 2) risk factors can be evaluated and be compared with importance factors of seismic codes. It should be emphasized that the risk factor is not uniformely distributed within an earthquake region. Differences of hazard curves clearly indicate the variety of resulting risk factors.

It would be desirable, when decisions on the determination of importance factors will follow the real background of site-dependent risk estimates.

4.3 Results of statistical investigations

Differences between seismic action for structures of different risk potential are expressed in Fig. 8 by coefficients r_i, indicating the relevant parameter for classification of seismic action (i=a-acceleration, p-hazard level or probability of exceedence, I-intensity, u-ductility, D-damping).

These coefficients are determined as relations between proposed design spectra.

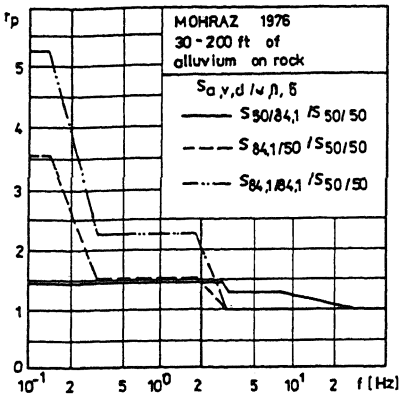


Figure 9. Relation between spectra for structures of different risk potential (ex.1)

Using results of statistical investigations it is possible to quantify the differences of seismic action, which could be expected, when independently of structure's risk potential the same sample of earthquake data is used.

Example 1: Results of statistical studies by Mohraz (1976)

Priority is given to the variation of the probability of exceedence of spectral values and ground motion. The 50 percentile spectrum is selected as reference seismic action.

Fig. 9 presents the ratio of spectra with an increased level of ground motions ($S_{84,50}$), with an increased level of amplification factors ($S_{50,84}$) or with increased levels of both ($S_{84,84}$) versus spectra with 50 percentile ground motion and amplification factors ($S_{50,50}$); ($S_{a,b}$: probability of exceedence of a- ground motion, b-amplification factors).

It can be concluded that differences in the displacement controlled frequency range are unrealistically high; in the other ranges maximum differences are in the range of a factor of 1.5 to 2.5. The results illustrate only one portion of qualitative changes within spectra, because the level of hazard remains unchanged. If these aspects, too, will be taken into account, a further increase of discrepancies should be expected.

Example 2: Results of statistical studies for German seismic regions

Intensity- and subsoil-related spectra in the version by Schöbel (1989) were analysed with respect to changes of mean spectra, when intensity was increased by one degree (method 4, Fig. 8) or when the 84.1 percentile spectral amplitudes were used (method 2, Fig. 8). The results are related to the proposed smoothed spectra. Figure 10 gives the calculated relations between seismic action types, which might be applied for structures of diffferent risk levels, for medium subsoil and for a reference intensity I of 7° (MSK). It can be concluded that design loads for structures of higher risk potential are

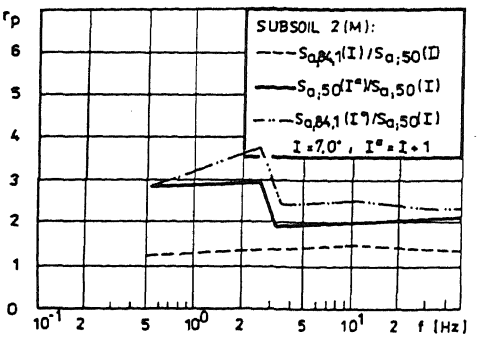


Figure 10. Relation between spectra for structures of different risk potential (ex.2)

increased by a factor of 2.0 and higher, when they are compared with the predicted seismic action for conventional buildings.

REFERENCES

Hosser, D. et. al. 1986. Realistische seismische Lastannahmen für Bauwerke II. Abschlußbericht. Institut für Bautechnik für Bautechnik. Berlin.

Hosser, D., Keintzel, E. & G. Schneider 1990. Proposal for harmonized rules for the determination of seismic input data. *Universität Karlsruhe.*

Grünthal, G. 1987. Einteilung des Territoriums der DDR in Erdbebenzonen. Zentralinstitut für Physik der Erde Potsdam.

Grünthal, G. 1991. Die seismische Gefährdung im östlichen Teil Deutschlands und deren Berücksichtigung in erdbebengerechten Baunormen. *DGEB- Publikation 5*, Zentralinstitut Physik der Erde: 9- 38. Potsdam.

Mohraz, B. 1976. A Study of Earthquake Response Spectra for Different Geological Conditions. *Bull. Seis. Soc. Am.* 66: 915-935.

Schöbel, B. 1989. Ableitung standortspezifischer Strong- Motion- Aussagen für das Territorium der DDR. Zwischen- und Abschlußbericht 1989; Aktualisierung 1991. Zentralinstitut für Physik der Erde Potsdam.

Schwarz, J. 1991. Probleme bei der Einführung intensitätsbezogener Erregungsdaten. *DGEB-Publikation 5*, Zentralinstitut Physik der Erde: 69- 84. Potsdam.

Schwarz, J. & G. Grünthal. 1991. Beschreibung der seismischen Einwirkungen in den Vorschriften allgemeiner Hochbauten. Teil 2. Ableitung einer neuartigen Vorgehensweise für das Erdbebengebiet im Osten Deutschlands. *Bauplan., Bautech.* 45, 10: 443- 459.

Schwarz, J., Goldbach, R., Grünthal, G. & B. Schöbel 1990. Development of Earthquake Resistant Regulations- The New Seismic Code of the GDR. *Proc. 9th ECEE*, Vol. I: 74- 83. Moscow.