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SEISMIC HAZARD RELATED REPRESENTATIONS OF SEISMIC ACTION - NEW APPROACHES AND THEIR APPLICATION TO LOW SEISMICITY REGIONS OF CENTRAL EUROPE

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ABSTRACT

Hazard-consistent seismic design actions can be predicted for the low seismicity regions in central Europe if the relationships for the attenuation of spectral amplitudes are properly selected. Attenuation relations of spectral accelerations for European conditions are necessary to develop a new generation of seismic hazard maps indicating spectral values for typical control periods. Assuming that the records from the Roermond earthquake are representative for central European earthquake regions, attenuation relations for peak and spectral accelerations are compared to obtain an impression on their applicability. As a result of preliminary investigations spectral acceleration probability distribution for seismic zones according to Eurocode 8 are presented. On the basis of these studies effective accelerations can be estimated.

KEYWORDS

attenuation of peak and spectral acceleration, effective acceleration, hazard curves, low seismicity regions, pre-normative research, probabilistic methods of seismic hazard assessment, seismic code provisions, strong-motion records, zoning maps

CURRENT SEISMIC HAZARD ASSESSMENT PROJECTS

A revaluation of the seismic hazard of central Europe has been carried out in the frame of the Global Seismic Hazard Assessment Program (GSHAP), Giardini and Basham (1993). This activity strongly coincides with those aiming at the preparation of seismic zoning maps for the National Application Documents of the Eurocode 8 (ENV 1998-1-1), the harmonized building code for the countries being members of the European Union or EFTA.

Seismicity data

The seismic activity of central Europe is moderate to low. Damaging events are rare - but they reach such a strength and frequency in certain areas that antiseismic measures have to be taken into account. The largest events observed have reached maximum observed intensities of *IX*.
Fig. 1 shows the epicentres of known damaging earthquakes in the study area. The clear majority of these events is connected with well defined seismogenic zones. The process of the creation of the joint basic seismicity working file is described in Grünthal (1994, 1995).

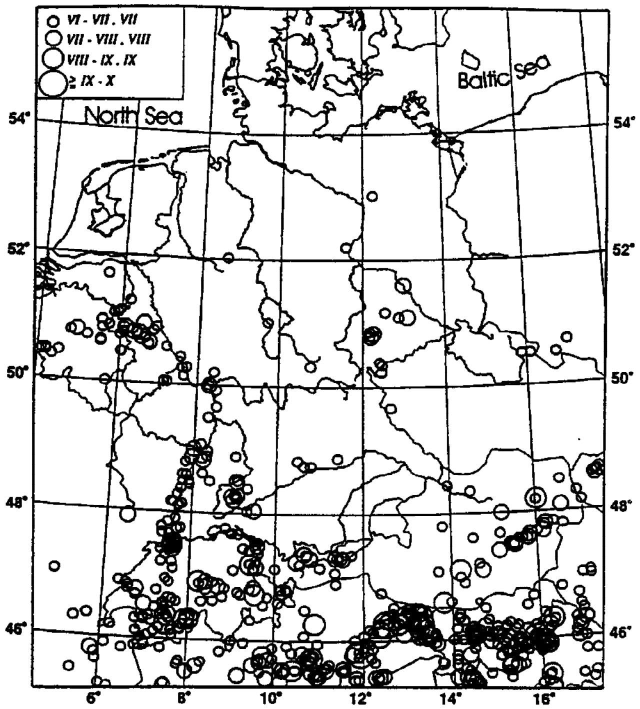

Fig. 1. Epicentres of known damaging earthquakes in central Europe

Seismicity data have been made homogeneous first with respect to epicentral intensity:
(1) The clear majority of earthquakes which have an essential importance for hazard assessment within long lasting earthquake history, are primarily known by their intensity only. Correlations between epicentral or maximum intensity and magnitude are extremely poor. Appropriate regression relations are still under preparation between isoseismal areas A of certain intensities (log A) versus log M. (2) Reliable ground acceleration-attenuation relations depending on local magnitude ML are lacking. There is no bias to the use of the intensity as shaking parameter both for hazard maps as well as for earthquake strengths. (3)The use of intensity enables comparisons with results of earlier studies in the central European countries. These studies are in process, notwithstanding the computation of hazard maps in terms of physical strong motion parameters.

Procedure

The first step of the procedure of seismic hazard assessment was the analysis of data completeness over time. Its knowledge is of essential importance for a proper statistical treatment of the data. Different gross regions have been selected, characterized by geographical and cultural aspects, wherein completeness of earthquake data has been analyzed using different approaches (Grünthal *et al.* 1994, 1995). The delineation of more than 90 seismic source regions within the study area has been performed according to well defined seismotectonic criteria.
A characteristic focal depth was introduced for each source zone. It was derived from the depth determinations of the strongest events. The attenuation relations are chosen according to the characteristic focal depths in the range from 5 to 20 km. The upper bound intensity is fixed well above the largest historical earthquake in each source region. It is set to intensity values always equal or greater than *VII*. Fairly well established intensity-frequency relations (logN=a-bN) in form of linear fits have been found for nearly all zones. The seismic hazard computations are performed with the computer codes from McGuire (1976) and SEISRISK III (Bender and Perkins, 1987).

Results

The hazard maps were computed especially for an annual occurrence or exceedance probability of 0.1 within 50 years. This is the required hazard level both for GSHAP and Eurocode 8. Such a hazard map for central Europe has been presented by Grünthal *et al.* (1995). The resulting intensities for this hazard level are in the range of 6.5- 8.0 in the Alpine area north of Italy, while the following values have been computed for the seismic regions of Germany: Rhine area: 6.5-7.5, Swabian Alb: 7.0-8.0, Franconian Alb: 6.5, and eastern Thuringia: 6.5-7.0.
For the application of Eurocode 8, national territories have to be subdivided into seismic zones, depending on the local hazard (ENV 1998-1-1). Possible classifications of seismic zones in Germany could cover intensity ranges of 7.0 -7.5 and above. The shapes of hazard curves for these possible seismic zone ranges are shown in Figs. 2 a and b. As it can be concluded, the assumption of a constant hazard in each zone is not justified. Per definition, how they haven been selected, hazard curves have a narrow taille at the occurrence probability of 1/475 p.a. The scatter is considerably large in hazard ranges of small mean return periods.

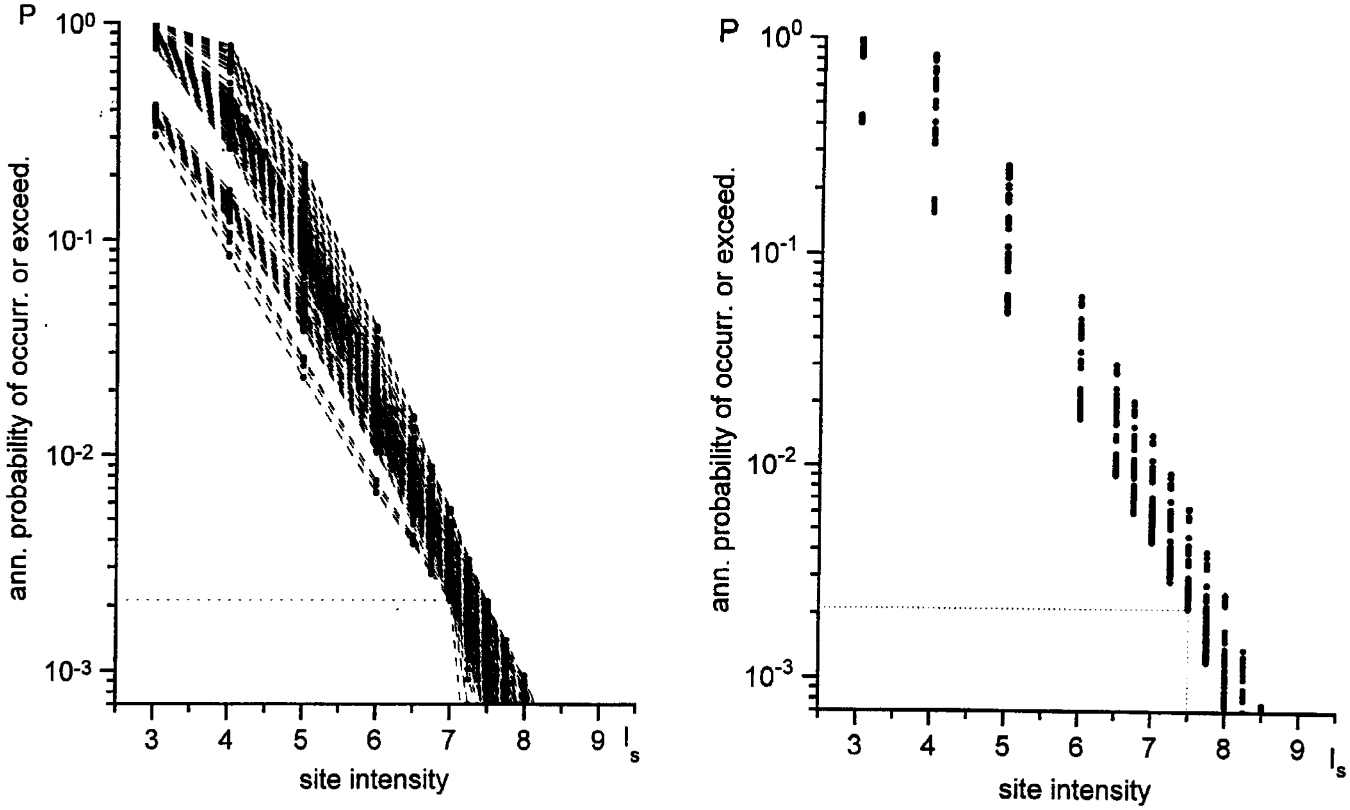

Fig. 2. Hazard curves (return period of T_R = 475 years) for grid points of a 0.1° x 0.1° net in the area matching the intensity ranges:
a) I_s = 7.0 - 7.5 b) I_s = 7.5 - 8.0

As it can be concluded from Figs. 2 a and b, the assumption of a constant hazard is not justified in reality. Furthermore, for the application of Eurocode 8, the hazard has to be described in terms of a single parameter: the value a_g of the effective peak ground acceleration in rock or firm soil (ENV 1998-1-1). These accelerations are used as scaling parameters for standard elastic response spectra. Though the parameters describing these spectra shall ensure a uniform probability of exceedance over all periods, their definition as "uniform risk spectra" seems not to be justified because the risk from relevant seismic sources is not uniformly accounted for.

SEISMIC ACTION IN CENTRAL EUROPEAN EARTHQUAKE REGIONS

Strong Motion Data from the 1992 Roermond Earthquake

The number of strong-motion records of central European earthquakes that reach a level of ground shaking which causes damage (site intensity greater than *VI*) is rather limited. Therefore, it is of special interest to study this scarce strong motion database in detail, especially from an engineering point of view.
The last damaging earthquake (ML=5.9) occurred in the southernmost part of the Netherlands near to the border to Germany in the western part of the Lower Rhine Embayment on April 13, 1992. This earthquake belongs to one of the largest earthquakes which have ever been observed in central Europe. Strong motion data of this event have been recorded by the network of the Department of Earthquake Geology of the Geological Institute of the University of Cologne (Ahorner 1993), while aftershocks have been recorded also by other teams and were extrapolated on the level of the main shock (Gariel *et al.* 1993). Figs. 3 a and b show the comparison of these data with those of previous investigations of peak ground acceleration attenuation (Ambraseys 1994, Joyner and Boore 1981). For this event, horizontal and vertical accelerations are fairly well represented by the empirical correlations especially for sites located far from the source. Nearly all recorded peak values fall into the range which is provided by mean (± 1σ standard deviation) accelerations.

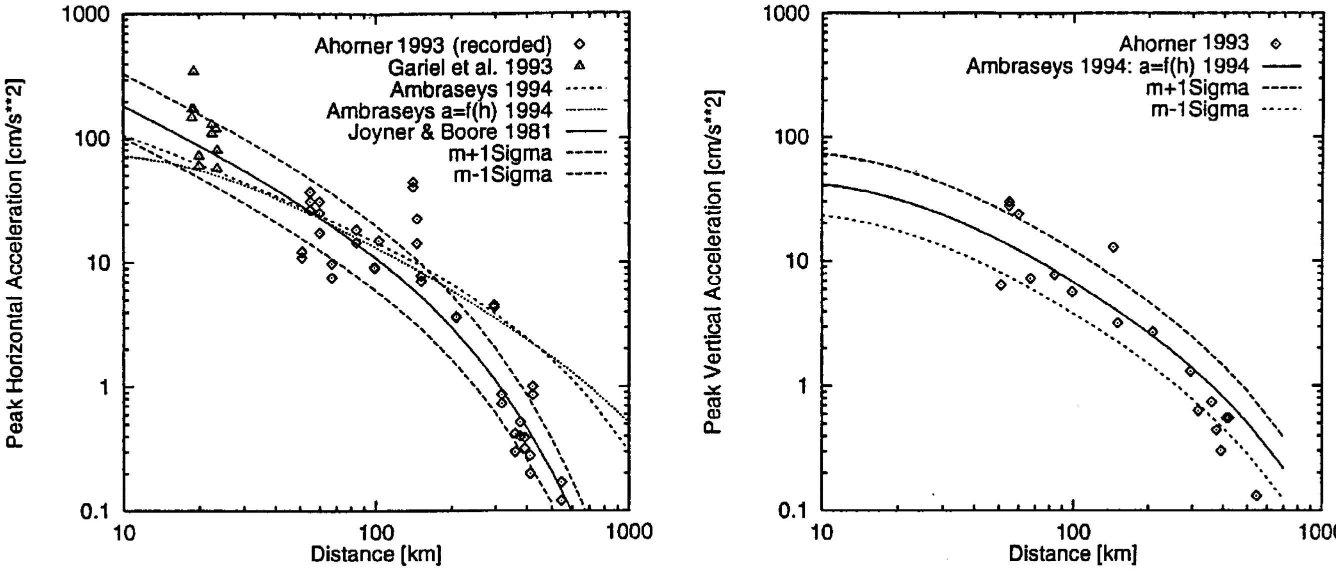

Fig. 3. Attenuation of peak ground acceleration recorded during the 1992 Roermond earthquake:
a) horizontal components b) vertical components

No strong motion data were recorded in the near-field. The TGA station is 55 km away and, thus, one of the nearest to the epicentre of the Roermond earthquake. As it can be concluded from the isoseismal map of the Roermond earthquake a macroseismic intensity I (MSK, EMS) = *V - VI* was observed at this site. Records from station sites with an intensity I ≥ *V* were considered only for comparing the frequency content (amplitudes and spectrum shapes) of strong-motion data with results from statistical investigations based on different data sets. Horizontal resultants of spectral accelerations are computed following the concept of vector sum spectra (cf. Geomatrix Consultants 1994, Schwarz and Ahorner 1995). The vector sum is defined as the time series peak of a vector sum of x and y components of horizontal ground motion and can thus be considered as the maximum horizontal ground motion experienced in any direction. The vector spectrum amplitude S_{av} (T) at period T is defined by eq. (1) where $S_{a,H1}(T, t)$, $S_{a,H2}(T, t)$ are the spectral acceleration responses at time t for horizontal components (H1) and (H2), respectively:

$$S_{av}(T) = max\,[S_{a,H1}^{\,2}(T, t) + S_{a,H2}^{\,2}(T, t)]^{0.5} \qquad (1)$$

The resultant horizontal spectra for the records at stations TGA and KOE are shown in Figs. 4a and 4b.

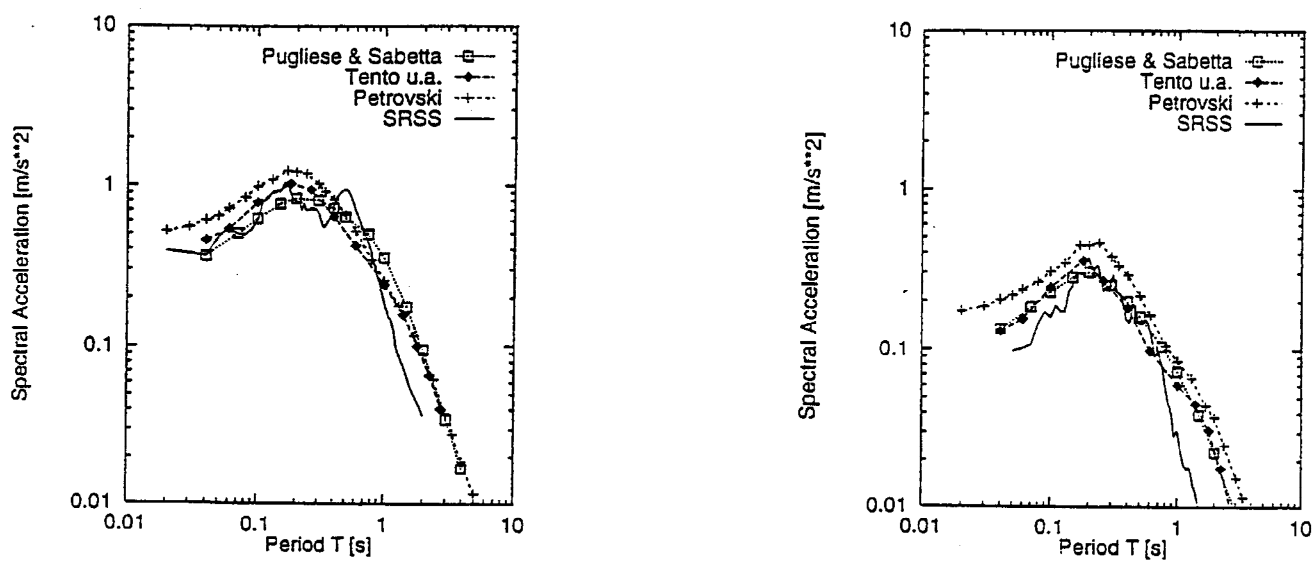

Fig. 4. Resultant horizontal accelerations response spectra of the 1992 Roermond earthquake and spectra after Schwarz and Ahorner (1995):
a) station TGA (R = 55 km; soil) b) station KOE (R = 151 km, rock)

Considering eq. (1), it can be assumed that the spectral responses of both horizontal components are calculated by the SRSS-superposition rule. It seems to be suitable to apply other rules as well (Schwarz and Ahorner 1995). In Figs. 4a and 4b, spectra of the Roermond earthquake are compared with the magnitude- and distance-related spectra (mean values) according to proposals by Petrovski (1986), Pugliese and Sabetta (1989), and Tento *et al.* (1992).The results support the conclusion that the predicted or expected seismic action coincides sufficiently with the parameters of the ground motion recorded during the 1992 Roermond earthquake. For more details with respect to investigations into the available strong motion database, we refer to Ahorner (1993), Schwarz and Ahorner (1994, 1995).

Seismic hazard-related representations of seismic action require a set of attenuation relations for predicting spectral ordinates of strong ground motion. These attenuation laws should inherently represent central European conditions and should be applicable to low seismicity regions. For this purpose, spectral accelerations, corresponding to the magnitude of the Roermond earthquake, were computed from proposals taking into account strong-motion data obtained mostly in Europe. These spectral accelerations are compared with the single data points calculated from the Roermond earthquake records (stations TGA, BUG, KOE, BGG).

Spectral accelerations for the periods T = 0.1 s, 0.3 s and 1.0 s are evaluated within a period range of ± 0.1 T in steps (period increment) of 0.01 s (example T = 0,3 s: spectral amplitudes are predicted at seven periods between T = 0.27 s and T = 0.33 s). Figs. 5a and 5b show the average values of the horizontal resultants (SRSS) and components (mean), and the single spectral accelerations at the periods T = 0.3 s and 1.0 s. The horizontal component with the larger peak acceleration is denoted as H1. The selected periods can be regarded as control periods of commonly used design spectra: T = 0.1 s and 0.3 s are typical periods for the amplified plateau-like range of ground motion; spectral values for T = 1.0 s provide useful information about the decline of spectral acceleration for higher periods. Similar investigations were performed using attenuation relations elaborated on the basis of non-European and more or less specific regional data samples (Japan, Western Northern America, Eastern Northern America and others).

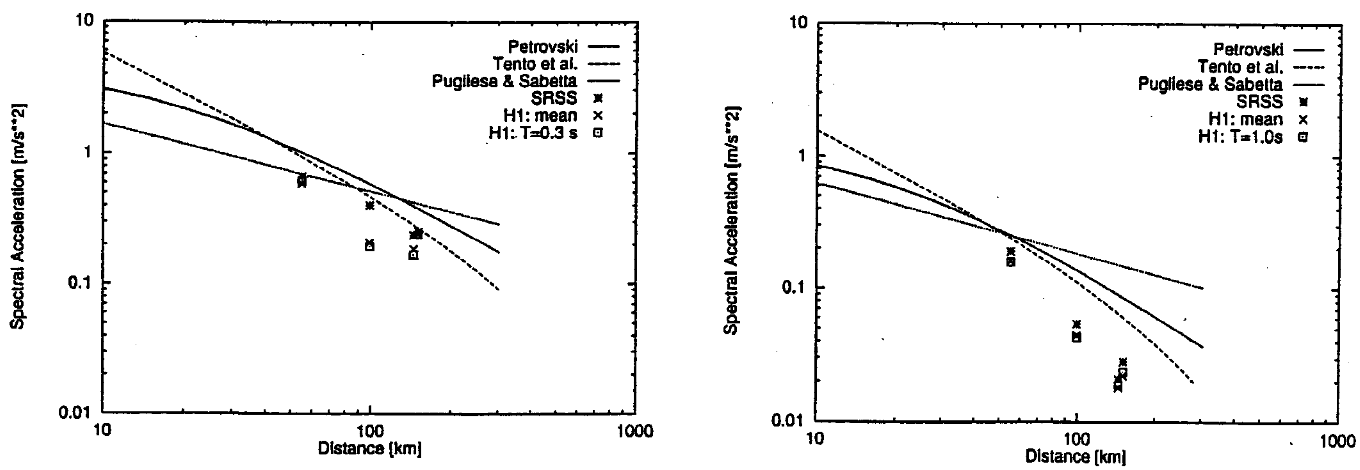

Fig. 5. Attenuation of spectral accelerations of the 1992 Roermond earthquake and attenuation functions from data sets mainly composed of European earthquake records:
a) period T = 0.3 s b) period T = 1.0 s

Recently, methods have been developed for the estimation of uniform hazard spectra on the basis of regionally recorded (specific) ground motion. Such methods provide the basis for the elaboration of qualitatively new series of probabilistic seismic hazard maps which are indicating the five percent damped spectral response accelerations at discrete periods (i.e. 0.3 s and 1.0 s). Under the assumption that acceleration response spectra with distinctive regional shapes and attenuation laws can be derived, new hazard-consistent representations of seismic action can be incorporated into building codes (cf. Algermissen and Leyendecker 1992, Donavan 1988). It is intended to develop such seismic hazard (zoning) maps for central European earthquake regions.

Zone-related approaches, still in use in central Europe, are based on hazard assessments in terms of macroseismic intensity and its crude correlation with peak or effective ground motion. A hazard-consistent description of seismic action has to take account of spectral characteristics of ground motion for a certain hazard level and, therefore, should inherently express the frequency characteristics of events with different intensity classes or magnitude-distance categories.

On the basis of the above presented probabilistic seismic hazard assessment for German earthquake regions and the selected probability of occurrence of 10 % within 50 years (return period T_R = 475 a, P = 0.0021 a^{-1}) it was decided to consider intensities greater than *VI*. Only seismic near-field events with distances R lower than 30 km and magnitudes M in a range between 4.5 and 6.5 can cause shaking effects which are important for building design. Typical pairs of magnitude and distance conditions have to be evaluated in order to correlate intensity with hazard-consistent representations of seismic action (elastic acceleration response spectra) for intensities of each possible zone. Only a distance range from 10 to 25 km is considered. Magnitudes are estimated according to correlations M = f (I,R) following proposals made by Devilliers and Mohammadioun 1981, Mohammadioun 1994, and Ahorner and Rosenhauer 1983 (for the Lower Rhine Embayment and a depth of source of 10 km).

Attenuation relations for spectral accelerations are selected according to the studies on the 1992 Roermond database (Figs. 4 and 5). Thus, and in a preliminary stage of investigations, spectral accelerations are calculated using the results from statistical investigations by Pugliese and Sabetta 1989 (PS), Tento *et al.* 1992 (TFM), Petrovski 1986 (P) and Ambraseys *et al.* 1996 (ASB). (It should be noted that only two of these spectra represent rock conditions; for the spectra by Tento et al. (1992) and Petrovski (1986), a precise classification is not available, references indicate that these spectra represent "moderate" subsoil conditions.)

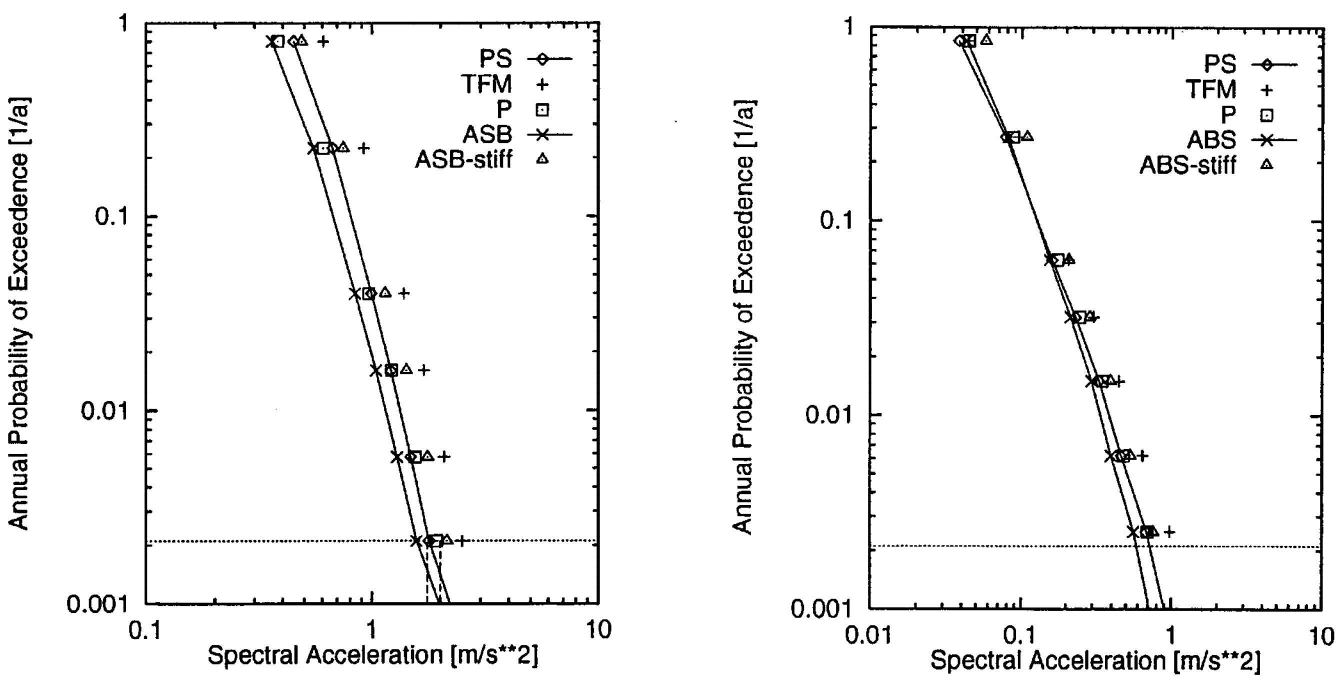

Fig. 6 Probability distribution of spectral acceleration for regions of one seismic zone (upper bounds according to Fig. 2) for a return period of T_R = 475 a (zoning hazard level):
(a) period T = 0.3 s ($7.0 \le I_s \le 7.5$) (b) period T = 1.0 s ($I_s \ge 7.5$)

Probability distributions of spectral acceleration for the different seismic zones are evaluated for two periods: T = 0.3 s and T = 1.0 s. Figs. 6a and 6b illustrate the increase of spectral acceleration at selected periods versus site intensity in dependence on the upper bound hazard curves for seismic zones in Germany which fall into a zoning interval of intensity $7.0 < I_s \le 7.5$ or $I_s \ge 7.5$ (zone of highest seismicity), cf. Figs 2a and 2b. These probability distributions of spectral accelerations represent the mean values within the distance range considered (10 - 25 km) and are based on the correlation given by Devilliers and Mohammadioun (1981). Spectral accelerations for bedrock conditions are shown by the modified hazard curves (linespoints). Dots indicate the values for less stiff subsoil.

The period denoted with T* should be used for scaling the elastic spectra according the hazard-consistent seismicity factor (spectral acceleration of zoning maps) subsequently. For this study a period T*= 0.3 s is defined which is in a reasonable relation to new concepts of seismic hazard maps and proposed design spectra (Algermissen and Leyendecker 1992, Donovan 1988, Hutchison 1986). Spectral accelerations $S_{a,T*}$ are not identical with the maximum amplitudes of the spectrum. They more or less represent an average spectral value of the plateau between the control periods T_C and T_B of the EC 8 standard spectra. A final decision on the most appropriate scaling period for central European regions should be supported by the results of forthcoming studies.

EVALUATON OF EFFECTIVE ACCELERATIONS FOR EUROCODE 8

Determination of Effective Accelerations

One of the crucial points of the Eurocode 8 is the introduction of effective accelerations which have to be incorporated into the National Application Documents (NAD). Three main groups for determining effective accelerations can be distinguished, whereas different realizations (methods) seem to be practicable.
The first group of methods is related to ground acceleration. Methods of the second group underline the importance of spectral accelerations within the amplified and more probable range of building periods.

Methods of group 1: $a_{eff} = a\ r_{a,1}$ (2)

Peak ground acceleration a is predicted using correlations with intensity (method 1a), or with magnitude and distance (method 1b). Lower bounds of the deamplification factor $r_{a,1}$ are in the range of 0.6 to 0.7.

Methods of group 2: $a_{eff} = S_a\ r_{a,2}$ (3)

Spectral acceleration of the amplified period range is taken from intensity-related spectra (method 2a), or spectra for the relevant magnitude and distance conditions (method 2b). The factor $r_{a,2}$ is in the range of 0.4 to 0.5, depending on the reference spectrum and on the amplification of ground motion (eq. 4). These four methods are applied for the German NAD according to EC 8 ($a_{eff} = a_g$), Schwarz (1996).
Furthermore, procedures of a third group are studied or derived, taking into account the cyclic characteristics of ground motion (Bolt and Abrahamson 1982) and of SDOF-responses (Kawashima and Aizawa 1986). For practical application, it will be necessary to define a suitable number of response cycles indicating the appropriate or effective level.

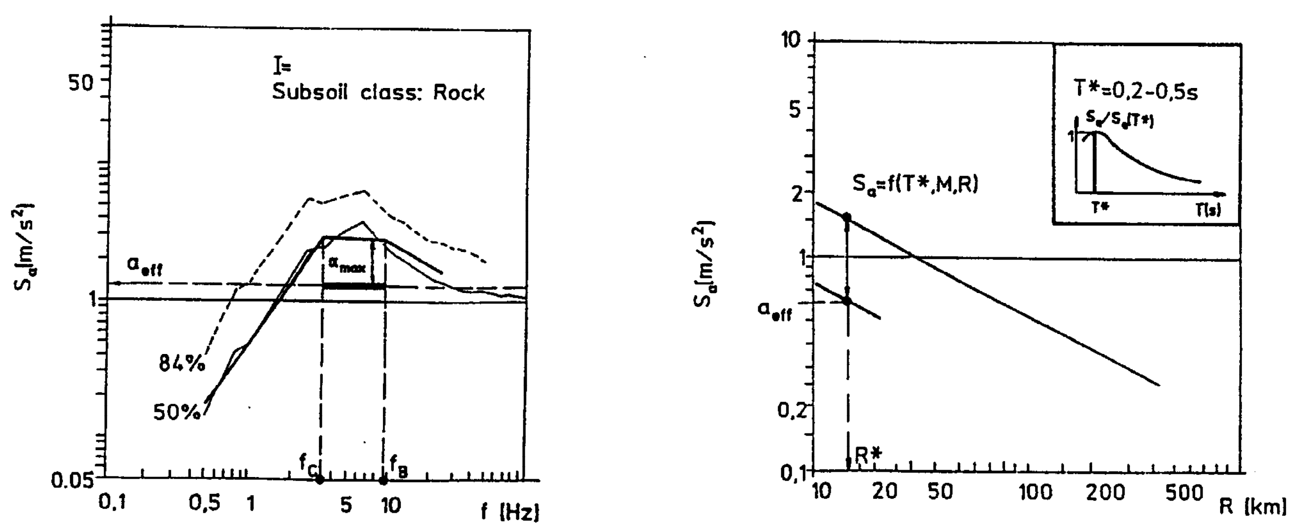

Fig. 7. Determination of effective peak ground accelerations (Schwarz 1996):
a) method 2a ($\alpha_{max} \cong \beta_o$) b) method 2b

The determination of effective acceleration following the methods of group 2 is illustrated in Fig. 7. Method 2b has been recently proposed and applied to central European low seismicity regions by Schwarz (1996). The basic steps of the procedure follow the prediction of spectral acceleration at the scaling period T*= 0.3 s and at the hazard level of the reference return period (Fig. 6). Effective accelerations are now defined by the ratio between spectral accelerations $S_{a,T*}$ and by the amplification factor of EC 8 standard spectra ($ß_o$):

$$a_{eff} = S_{a,T*} / ß_o \tag{4}$$

The above mentioned methods have been applied to evaluate effective accelerations for intensities 6.5, 7.0, 7.5 and 8.0 (according to the definition in the current German Seismic Code DIN 4149). The probable range of effective accelerations is given in Table 1 (Schwarz 1996), recognizing the large scatter of results caused by the uncertainty of the correlation between intensity and magnitude. Surprisingly, the scatter between the results according to the four methods is not very large. The final decision on the NAD values should consider results obtained by different methods (control of plausibility).

Table 1. Range of effective accelerations a_g or a_{eff} [m/s²]

Zone i DIN 4149 (Intensity I_s)	Method 1a	Method 1b	Method 2a	Method 2b
1 (6.5)	0.50-0.55	0.65-0.85	0.50	0.50-0.60
2 (7.0)	0.70-0.90	0.80-1.05	0.70	0.60-0.85
3 (7.5)	0.95-1.35	1.00-1.30	1.15	0.70-1.15
4 (8.0)	1.25-2.10	1.20-1.60	1.60	0.85-1.50

The probability distributions of spectral accelerations in Figs 6a and b enable a new approach to determine effective accelerations. Hazard-consistent values of each zone can be calculated at certain hazard levels taking account to the scatter of spectral accelerations. The effective accelerations evaluated in such a way are representative for the regions combined in seismic zones. The dashed vertical lines in Fig. 6a, intersecting the horizontal dotted line of the hazard level proposed for German NAD (P = 0.0021 a^{-1}), indicate spectral accelerations $S_{a,T*=0.3\,s}$ according to eq. (4) with $ß_o$ = 2.5 and effective accelerations from table 1. They are in good agreement with the values provided by the probability distributions of spectral accelerations for rock conditions.

CONCLUSIONS

Hazard-consistent seismic design actions can be predicted also for the low seismicity regions in central Europe if the relationships for the attenuation of spectral amplitudes are properly selected. Assuming that the records from the Roermond earthquake are representative for central European earthquake regions, attenuation relations for peak and spectral accelerations are compared to obtain an impression on their applicability. The definition of typical attenuation relations of spectral accelerations for European conditions is necessary in order to develop a new generation of seismic hazard maps indicating spectral values for typical control periods. As results of preliminary investigations spectral acceleration probability distribution for seismic zones according to Eurocode 8 are presented. On the basis of these studies effective accelerations can be redicted, recognizing the scatter of hazard curves within one seismic zone.

REFERENCES

Ahorner, L. (1993). Gemessene Bodenbeschleunigungen beim Roermonder Erdbeben am 13. April 1993. *Bauingenieur* 68, 201 - 205.

Ahorner, L. and W. Rosenhauer W. (1978). Seismic risk for the Upper Rhine Graben and its vicinity. *J. Geophys.* 44, 481 - 497.

Algermissen, S. T. and E. V. Leyendecker (1992). A technique for uniform hazard spectra estimation. In: *Proceed. 10th WCEE* Madrid, Vol. 1, 391-397, Balkema, Rotterdam/Brookfield.

Ambraseys, N. N., K. A. Simpson and J.J. Bommer. Prediction of horizontal response spectra in Europe. (prepared for publication in: Earthquake Engineering and Structural Dynamics).

Bolt, A. B. and N. A. Abrahamson (1982). New attenuation relations for peak and expected accelerations of strong ground motions. *Bull. of the Seism. Soc. of America* 72, Vol. 6, 2307 - 2321.

Devilliers, C. and B. Mohammadioun (1981). French methodology for determinating site adopted SMS (Seisme Majore de Securite). In: *Proc. 6th SMiRt* Paris 1981

Donovan, N. (1988). Uniform risk zoning- a simplified approach. In: *Proceed. 9th WCEE*, Vol. V, 1063-1068, Tokyo.

ENV 1998-1-1. Eurocode 8 - Design provisions for earthquake resistance of structures -Part 1-1: General rules - Seismic actions and general requirements for structures. CEN, October 1994.

Gariel, J. C., C. Horrent, D. Jongmans and T. Camelbeeck (1994). Strong ground motion computation of the 1992 Roermond earthquake, the Netherlands, from linear methods using locally recorded aftershocks. In: *Geologie en Mijnbouw* 93-94, 315 - 321, Kluwer Academic Publishers.

Geomatrix Consultants (1994). Review of Seismic Design Response Spectra. Revithoussa LNG Terminal, Greece. Prepared for Dyckerhofff & Widmann München, Germany.

Grünthal, G. (1994): The GSHAP-Regional centre in Potsdam: Progress report. Proceedings of the XXIV General Assembly of the European Seismological Commission, Athens, 19 - 24, Sept. 1994 (in press).

Grünthal, G., Ch. Bosse, D. Mayer-Rosa, E. Rüttener, W. Lenhardt and P. Melchiar (1994). Across-boundaries seismic hazard maps in the GSHAP-region 3 - case study for Austria, Germany and Switzerland. In: *Procceed. XXIV General Assembly of the European Seismological Commission*. Athens.

Grünthal, G. D. Mayer-Rosa, W. Lenhardt (1995): Joint strategy for seismic hazard assessment; Application for Austria, Germany, and Switzerland. XXI General Assembly IUGG, Boulder, Colorado, USA. 2-14 July 1995.

Hutchison, D. L. (1986). Draft revision of NZS 4203: 1984: Seismic Provision. *Bull. of the New Zealand National Soc. of Earthquake Engineering* 19, Vol. 3, 158 - 165.

Joyner, W. B. and D. M. Boore (1981). Peak acceleration and velocity from strong-motion records. *Bull. of the Seism. Soc. of America* 71, Vol. 6, 2011 - 2038.

Kawashima, K. and K. Aizawa (1986). Earthquake response spectra taking account of number of response cycles. Earthquake Engineering and Structural Dynamics 14 , 185 - 197.

Mohammadioun, G. (1995). Calculation of site-adapted reference spectra from statistical analysis of an extensive strong-motion data bank. *Proceed. 10th ECEE* (Duma, Ed.) Vienna 1994, 177 - 181, Balkema, Rotterdam/Brookfield.

Petrovski, D. (1986). Probabilistic approach for evaluation of seismic design parameters. IAEA Specialist Meeting on Earthquake Ground Motion and Antiseismic Evaluation of Nuclear Power Plants, Moscow.

Pugliese, A. and F. Sabetta (1989). Stima di spettri di risposta da registrazioni di forti terremoti italiani. *ingegneria sismica* 6, Vol. 2, 3 - 14.

Schwarz, J. (1996). Effektivbeschleunigungen für seismische Gefährdungszonen nach EC 8. Bericht zum Forschungsvorhaben im Auftrage des Instituts für Bautechnik Berlin.

Schwarz, J and L. Ahorner (1994): Conclusions from actual strong motion records in Central Europe for Engineering design practice. Strong Motion '94, Symposium on Acquisition and Evaluation of Strong round Motion Data. 4 November 1994, 40-44, Bern.

Schwarz, J. and L. Ahorner (1995). Actual strong motion records in Central Europe - Conclusions for Engineering design practice, In: *Proceed. 5th SECED* (A.S. Elnashai, Ed.) Chester 1995, 303-310, A.A. Balkema/Rotterdam/Brookfield.

Tento, A., L. Franceschina and A. Marcellina (1992). Expected ground motion evaluation for Italian sites. In: *Proceed. 10th WCEE* Madrid, Vol. I, 489 - 494, Balkema, Rotterdam/Brookfield.