Seismic Load Assumptions in Low Seismic Zones

D. Hosser
König und Heunisch, Beratende Ingenieure, Letzter Hasenpfad 21,
D-6000 Frankfurt/Main 70, Germany

Abstract

A procedure for the determination of realistic site-specific load assumptions for nuclear power plants in low seismic zones is presented. A macroseismic site analysis yields i) a probabilistic definition of the site intensity of the design earthquake and ii) the ranges of magnitudes and focal distances which mainly contribute to this intensity. The subsoil conditions at the site are assigned to one of three classes: medium, alluvium or rock. Based on these criteria representative strong motion records are selected from an earthquake data bank containing primarily near-field registrations typical for European sites. The response spectra or Fourier spectra of the selected accelerograms and the duration of strong motion are evaluated statistically yielding site-specific specifications of frequency content and duration of ground motion serving as basis for aseismic design.

1. Introduction

During the last decade, seismic loadsfor the design of nuclear power plants were determined as follows:

- the site intensity I (MSK-scale) was defined - in most cases determinisitically - based on the seismicity of a region in the past
- a peak ground acceleration a_o was assigned to this intensity with the help of a relation $a_o = f(I)$ which is derived from international data
- a standard response spectrum shape similar to the U.S. Reg. Guide 1.60 shape is scaled with the peak acceleration .

This procedure suffered mainly from the following facts:

- the site intensity was not correlated with a fixed occurence rate and therefore the safety level of aseismic design was different at sites of different activity
- the peak ground acceleration is only weakly correlated with the effect of an earthquake on typical plant buidlings, especially in the near-field range
- the standard spectrum shape is mainly based on Californian strong motion registrations which are not representative for German sites with respect to magnitude,focal distance and focal depth;furthermore the important influence of subsoil conditions is neglected
- the same holds for the intensity-peak acceleration relationship and for the magnitude-strong motion duration relation.

Therefore a common research project of German seismologists and civil engineers [1] - sponsored by the Institut für Bautechnik and managed by König und Heunisch, Consulting Engineers - aimed at a comparison of methods and data which are presently available for the definition of more realistic seismic load assumptions and at the development of a methodology which is appropriate for low seismic zones. The research project had four subtasks performed by different research groups:

- revaluation of historic earthquakes in Germany to get macroseismic data for a probabilistic site analysis for about 800 sites in the FRG in order to calculate intensity-frequency distributions and related ranges of macroseismic parameters
  (this work was conducted by Prof. Ahorner of Erdbebenstation Bensberg of the University of Cologne together with Dr. Rosenhauer of Interatom GmbH, Bergisch-Gladbach)
- determination of synthetic base spectra with the help of analytical models and calculation of transfer functions of the soil layers
  (this part was treated by Prof. Schneider of the University of Stuttgart)
- classification of the local subsoil conditions and determination of empiric base spectra (hard rock spectra) as input for dynamic analyses of soil or soil-structure models
  (this work was done by Prof. Berckhemer of the University of Frankfurt together with König und Heunisch, Consulting Engineers)
- completion, documentation and evaluation of a strong motion data base with respect to free-field response spectra and strong motion duration
  (this work was performed by König und Heunisch, Consulting Engineers together with the Institut für Massivbau of the Technical University of Darmstadt).

The present paper summarizes mainly aspects of the first and last subtask and compares the results with specifications according to the former procedure.

2. Probabilistic seismic site analysis

The historic earthquakes in the Federal Republic of Germany and its vicinity were reevaluated with respect to the focal parameters magnitude M, focal depth h, epicentral intensity I_o and intensity attenuation with increasing focal distance. From this study mean relationships between magnitude and focal depth and between magnitude, focal distance R and site intensity I were derived with related random variations (± 1 σ bounds). Furthermore the whole area of the FRG was subdivided in focal zones the different activity of which was described by special magnitude-frequency distributions. These informations were used as input for a probabilistic site analysis with the help of Monte-Carlo simulations. More details of the methods used are given in [2].

The analysis systematically performed for about 800 sites in the FRG revealed two important results:

i) the annual exceedance rates of site intensity λ (>I)

ii) the most probable focal parameters M, R and h leading to each site intensity with ± 1 σ bounds.

In [1] these results were used to draw seismic risk maps for the FRG indicating the site intensities I which are exceeded with a given annual probability, e. g. 10^{-4} - 10^{-5}/a for a safe shutdown earthquake (SSE). For application to a special site a more detailed focal zone model of the region of interest may be used which includes specific seismo-tectonic features.

As an example the intensity-frequency curve $\lambda(> I)$ for the site Biblis in the upper Rhinegraben according to [3] is depicted in fig. 1. A reasonable site intensity of the SSE could be $I = 7 - 7.5$; for the planned unit C of the plant an intensity $I = 7.5 - 8$ was defined referring to $\lambda(> I) = 5 \cdot 10^{-6}/a$. The focal parameters of the representative earthquakes are shown in fig. 2. A site intensity $I = 7.5$ primarily results from near-field earthquakes with magnitudes $M = 5.5 \pm 0.5$ and hypocentral distances $R = 11 \pm 4$ km; far-field earthquakes with magnitudes up to 6.5 and distances up to 35 km contribute only with some percent. The focal depth is generally below 20 km.

3. Strong motion data base

The strong motion data bank presently contains the following corrected records

- 711 accelerograms from Friuli, Campania and Ancona (Italy, 1976 - 1978)
- 15 accelerograms from El Asnam (Algeria, 1980)
- 6 accelerograms from Corinth (Greece, 1981)
- 63 accelerograms from Santa Barbara and Imperial Valley (USA, 1978 - 1979).

The necessary information on magnitude, focal depth, epicentral intensity, epicentral distance and subsoil conditions at the stations were taken from the literature. The site intensity was calculated, depending on the available data, either from eq. (1) or eq. (2):

$$I\ (M, R) = 1.5\ M + 2 - 3 \log R - 1.3\ \alpha\ (R-10) \qquad (1)$$

$$I\ (I_o, R) = I_o + 3 \log\ (h/R) + 3\ \alpha \log e\ (h-R) \qquad (2)$$

where M = Wood-Anderson-magnitude, I_o = epicentral intensity (MM- or MSK scale), R = hypocentral distance (km), h = focal depth (km) and $\alpha \approx 2.5 \cdot 10^{-3}$ (km^{-1}).

As an additional parameter the strong motion durations T were determined using the energy-related definition proposed by Trifunac and Brady :

$$T = T_E - T_A \qquad (3)$$

where

$$E_A = \int_o^{T_A} a^2\ (t)\ dt = 0.05 \qquad (4)$$

$$E_E = \int_o^{T_E} a^2\ (t)\ dt = 0.75 \qquad (5)$$

The subsoil conditions at the stations were assigned to one of the following subsoil classes (with v_p = pressure wave velocity):

A - soft soils, sand and clay
  $v_p < 1000$ m/s
M - medium dense sediments
  $v_p = 1000 - 3000$ m/s
R - sedimentary rock
  $v_p > 3000$ m/s

For comparison purposes a fourth class C - crystalline (base) rock - was introduced.

4. Statistical analyses

In [1] no special sites were considered. Therefore three site intensity classes were defined which cover the range of interest for German sites:

$I = 6.5 \pm 0.5$ $M = 4.5 - 6.5$ $R < 60$ km

$I = 7.5 \pm 0.5$ $M = 4.5 - 6.5$ $R < 40$ km

$I = 8.5 \pm 0.5$ $M = 4.5 - 6.5$ $R < 30$ km

For these intensity classes and the above-mentioned subsoil classes free-field response spectra or free-field Fourier amplitude spectra and durations of strong motion according to eq. (3) were analyzed statistically in order to determine 50-percentiles and logarithmic standard deviations of the spectra respective mean values and standard deviations of the strong motion duration. In all cases the coefficient of variation was about 60 %.

The smoothed 84 % free-field response spectra for subsoil class M and the three intensity classes are plotted in fig. 3. Figure 4 shows the subsoil-dependent spectra for intensity class $I = 7.5 \pm 0.5$. For comparison also the standard spectrum shape belonging to an intensity $I = 7.5$ ($a_o = 1.5$ m/s^2) is drawn; it differs from the other spectra mainly in the lower frequency range.

The mean strong motion durations alter only slightly with site intensity; therefore, for practical application, it is sufficient to take into account the dependence on the subsoil class yielding $T \approx 2$ s (for hard rock) up to $T \approx 6$ s (for soft soil). These values are smaller by more than a factor of 2 than those estimated in the past.

Based on free-field records from hard rock sites, also intensity-dependent Fourier amplitude spectra of acceleration were determined which may be used as an alternative seismic input definition at the base of the sediment layers (fig. 5). These empiric "base spectra" are advantageous especially for sites where detailed information on the subsoil profile and the dynamic soil parameters are available. In [1] the empiric base spectra were compared with synthetic base spectra derived in the second subtask; the analytic and statistical base spectra agree sufficiently well.

5. Conclusion

A procedure for the definition of realistic seismic load assumptions for nuclear power plants is presented which avoids most of the inconsistencies of the load assumptions specified in the past. The available seismological information is more completely taken into account in a probabilistic evaluation of the site intensity of the design earthquake and of ranges of magnitude, focal distance and focal depth typical for earthquakes of this intensity. The subsoil conditions are classified in one of the three subsoil classes - medium stiff soil, soft soil and hard rock. Based on these criteria, representative strong motion records can be selected from a strong motion data bank containing primarily near-field registrations. A statistical analysis of the free-field response or Fourier amplitude spectra and of the duration of strong motion yields the site specific seismic input description which may be used for aseismic design. Alternatively empiric intensity-dependent base spectra can be derived from Fourier amplitude spectra for hard rock sites. They are used to define the seismic input at the base of the sediment layers. The latter description of seismic load should only be used if detailed information on local subsoil conditions are available and shall be taken into account for an analytic or numeric calculation of the free-field motion.

References

/1/ Hosser, D. and H. Klein: Realistische seismische Lastannahmen für bauliche Anlagen mit erhöhtem Sekundärrisiko. Abschlußbericht eines Forschungsvorhabens im Auftrag des Instituts für Bautechnik, Berlin. König und Heunisch, Frankfurt, Dezember 1983.

/2/ Ahorner, L.: Seismicity and Neotectonic Structural Activity of the Rhine Graben System in Central Europe. In: NATO Advanced Study Institutes Series C, Vol. 99. D. Reidel Publishing Company, Dordrecht, Netherlands, 1982.

/3/ Ahorner, L. and W. Rosenhauer: Makroseismische Standortanalyse für den Standort Biblis. Contribution to Phase B of the German Risk Study for Nuclear Power Plants, Bensberg, 1984.

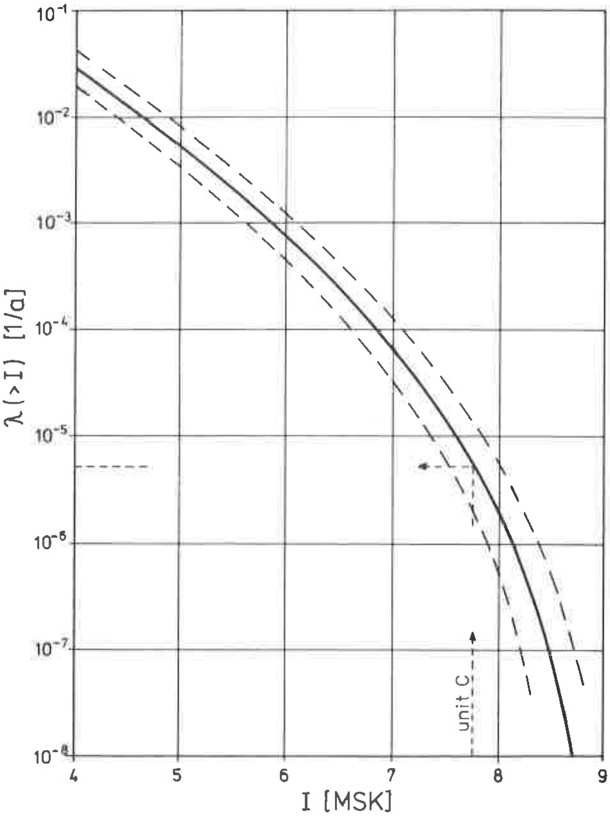

Fig. 1 Annual exceedance rate of intensity I at the site Biblis

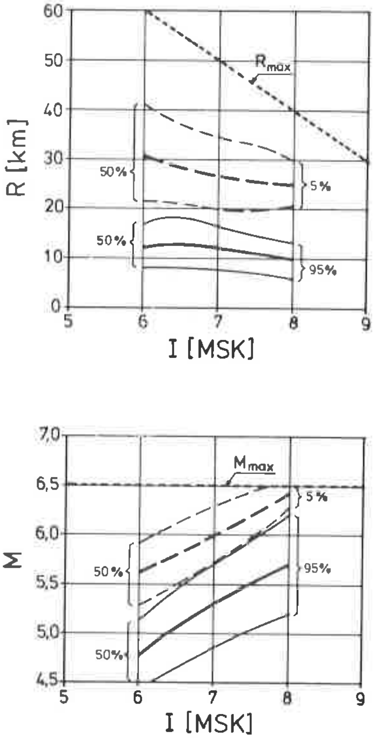

Fig. 2 Ranges of hypocentral distances and magnitude of the earthquakes representative for the site Biblis

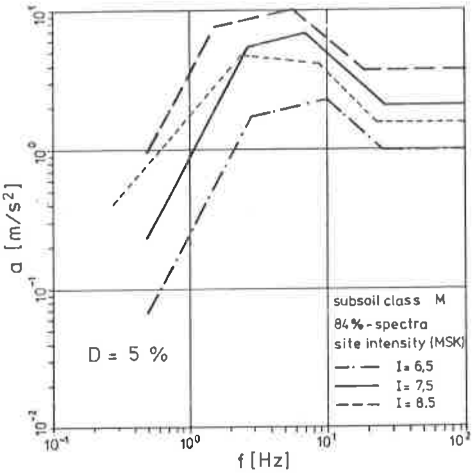

Fig. 3 Intensity-dependent free-field acceleration response spectra for subsoil class "medium"

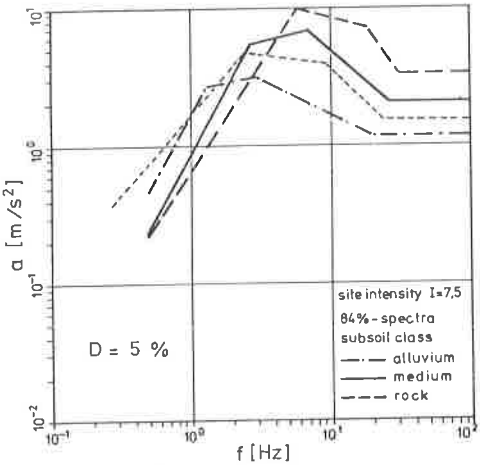

Fig. 4 Subsoil-dependent free-field acceleration response spectra for intensity class I = 7.5

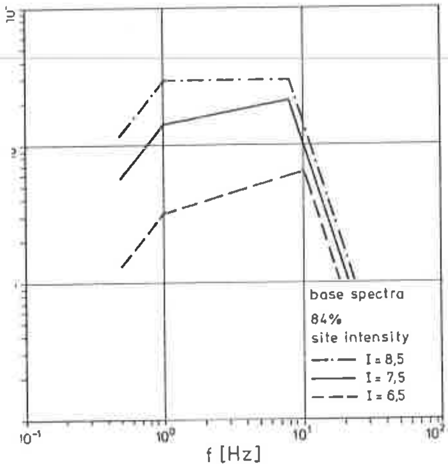

Fig. 5 Intensity-dependent empiric base spectra