New Concepts of Seismic Input Definition for Nuclear Power Plant Design in the FRG

G. König
Technische Hochschule Darmstadt, Institut für Massivbau, Alexanderstr. 5, D-6100 Darmstadt, Germany
H.H. Klein
Ph. Holzmann AG, Taunusanlage 1, D-6000 Frankfurt/Main, Germany

ABSTRACT

The paper summarizes recent activities in the Federal Republic of Germany in order to define more realistic seismic input data for the aseismic design of nuclear power plants. Therefore strong motion accelerograms representative for extreme earthquakes at German sites are evaluated statistically with respect to frequency content, strong motion duration and scaling parameters. The results of the regression analyses lead to the definition of seismic input by a spectral density representation, which is completely defined as nonstationary random process by total acceleration energy, strong motion duration and shape function to describe the frequency content. All used parameters are evaluated depending on site intensity and local soil conditions.

1. INTRODUCTION

For the definition of seismic loads of nuclear power plants in the FRG the following procedure was practised in the past and present:

- Using a standard free-field response spectrum shape, which is primarily based on Californian registrations and similar to US R.G. 1.60 - shape.
- Scaling this shape by the peak ground acceleration as function of suggested MSK - intensity at site.

This method has the following disadvantages:

- The shape of the response spectrum is dependent from magnitude and hypocentral distance of the registration. So reference earthquakes used to derive engineering parameters should correspond more closely to the condition under which destructions are expected in our country. These are earthquakes of magnitudes 4.5 - 6.5 and short hypocenter distance. Most of the Californian earthquakes do not fulfill these conditions.
- Another problem is the scaling of the spectra according to the expected intensity. Although the data base for the derivation of relations between the maximum ground acceleration and the MSK intensity increases in recent times it is evident, that the correlation between both quantities shows

large scatter and ground acceleration may not be a good scaling factor at all.

- Standard response spectra do not take into account differences in subsurface conditions at the site, which are of strong influence on the shape function, as statistical evaluations in the U.S. have shown (see, for example, Shannon and Wilson [1])

So, one part of the activities in order to define more realistic seismic input data consists in deterministic studies on the properties of response spectra representative for German sites. Especially the influence of site intensity and local soil conditions on frequency content and strong motion duration is analysed. The results of these activities are summarized by D. Hosser [2]. The following reports about another objective: The check of various scaling parameters for their correlation with macroseismic intensity by statistical evaluations and in consequence the development of a new concept of seismic input definition.

2. RESULTS OF STATISTICS

The data base consists of 113 time histories with magnitudes between 4.5 and 6.5 and focal distances less than 25 km. The available accelerograms of the Friuli, El Asnam and Korinth earthquakes are classified to four intensity classes (I=5.5±0.5;6.5±0.5;7.5±0.5;8.5±0,5) and 3 subsoil classes (rock, medium stiff soil, soft soil). The macroseismic intensity is calculated by the Kövesligethy - formula resp. by the magnitude - focal distance - intensity relationship of Ahorner [3], which is appropriate for European earthquakes:

$$I(MWA,R) = 1.5 \cdot MWA + 2 - 3 \cdot \log R - 1.3 \cdot \alpha \cdot (R-10) \qquad \text{eq. (1)}$$

with I = local intensity, MWA = Wood-Anderson-Magnitude,
R = focal distance.

Concerning the scaling parameters the regression analyses show the best correlation between intensity and acceleration energy E, which is defined as

$$E = \int_0^\infty a^2(t)dt \qquad \text{eq. (2)}$$

and proportional to the Arias-intensity. Besides E and maximum ground acceleration AMAX nine other scaling parameters have been tested as Spectrum Intensity, RMS - value, kinetic energy and fatigue parameters of linear and nonlinear oscillators. In comparison with AMAX the coefficient of correlation is increasing from 0.74 to 0.86 by using the acceleration energy with respect to the subsoil conditions.

For illustration, fig. 1 shows the regression lines ± one standard error for AMAX and E as function of intensity. The 50 % fractile values result from the following equations:

$$\text{AMAX}\ (\text{m/s}^2) = 10^{-2.37\ +\ 0.308\cdot I} \qquad \text{eq. (3)}$$

$$E\ (\text{m}^2/\text{s}^3) = 10^{-5.71\ +\ 0.754\cdot I} \quad \text{for medium stiff soil} \qquad \text{eq. (4)}$$

The strong motion duration TTB was found to be primarily dependent from focal distance. So by only using nearfield records the calculated strong motion duration covers the range between 2 s (at hard rock sites) up to 4 s (at alluvial sites), which is much shorter than estimated on the basis of American publications.

For the definition of TTB the modified proposal of Trifunac/Brady was used:

$$TTB = T_E - T_A \qquad \text{eq. (5a)}$$

with

$$T_A \text{ by } \int_0^{T_A} a^2(t)dt = 0.05\cdot E \qquad \text{eq. (5b)}$$

$$T_E \text{ by } \int_0^{T_E} a^2(t)dt = 0.75\cdot E \qquad \text{eq. (5c)}$$

For medium stiff soils TTB can be calculated by the formula

$$TTB\ (\text{s}) = -0.5 + 0.4\cdot I \qquad \text{eq. (6)}$$

For soft soil sites add 0.7 s, for rock sites subtract 0.7 s.

The frequency content of the seismic excitation was found to be strongly dependent from local soil conditions and secondly from intensity level. For the description of the frequency content Fourier-spectra (FS) of the freefield - acceleration $|A(\omega)|$ have been used. Fig. 2 shows medium Fourier - spectra for the three soil classes, calculated from normalized (to unit acc.-energy) FS. The amplification of the amplitudes in the frequency range between 1-5 Hz for medium stiff and soft soils is evident. The center frequency tends to decrease with increasing intensity; in general, the frequency content is much narrower than suggested by standard response spectra.

Especially for the calculation of nonlinear systems the representation by Kanai - Tajimi - Spectra, fitted by least-square-method, was found as sufficiently simple and realistic approach in the frequency range of interest between 0.5 and 25 Hz. It is defined by

$$|A(\omega)|^2 = \frac{(1+4\xi_g{}^2\cdot(\omega/\omega_g)^2)\cdot A_0}{(1-(\omega/\omega_g)^2)^2+4\xi_g{}^2(\omega/\omega_g)^2} \qquad \text{eq. (7)}$$

with A_0 = scaling factor,

ω_g, ξ_g = parameters representing eigenfrequency and damping of the soil.

Neglecting the dependance from intensity, ω_g and ξ_g can be defined in the following way:

soil condition	hard	medium	soft
KT-frequency ω_g(rad/s):	44	24	16
KT-damping ξ_g (-) :	in general 0.25		

Another interesting result is the close correlation between E and AMAX. This relationship should serve to control artificial generated time histories whether they are realistic or not. The regression curve (fig. 3) is defined by

$$\log E = 2.35\cdot\log AMAX - 0.35 \qquad \text{eq. (8)}$$

Fig. 4 shows, for example, an artificial acceleration time history, which might be used for the calculation of nonlinear systems by time integration methods. It is compatible with US R.G. 1.60 standard spectrum and scaled to maximum acceleration = 1 m/s^2. The regression line then leads to a required value of $E = 0.45\ m^2/s^3$. So the real value of $2.29\ m^2/s^3$ is by the factor 5 or about one intensity degree too high. As especially for stiffness degrading systems the energy input is of great influence on the behaviour of the structure, it must be recognized, that the shown time history is inapplicable for representing earthquakes in the FRG.

3. DEFINITION OF SEISMIC INPUT

The result of the regression analyses lead to the description of the seismic input by a spectral density representation, as response spectra cannot be scaled by acceleration energy. For nearfield events the definition of the load as nonstationary random process by total acceleration energy E, strong motion duration TTB and shape function for the FS $|A(\omega)|$ was found to be sufficiently exact. It offers the opportunity for the direct determination of the statistical properties of the response process. In addition, it is possible to use analytically determined FS instead of the empirical ones by determination of the transfer function of the subsoil.

The computation of the seismic load is done in the following steps:
- Required information: local intensity I and soil condition (A-M-R)
- Calculation of E (in accordance to eq. (4) for medium stiff soils)
- Calculation of TTB in accordance to eq. (6)
- Scaling of the FS, which is appropriate for the I-soil-combination by

$$E \overset{!}{=} 2\cdot\int_{0}^{25Hz} |A(\omega)|^2\, df \qquad \text{eq. (9)}$$

- Calculation of the one-sided power spectral density

$$S_x(\omega) = \begin{cases} \frac{1}{TTB}\cdot 2\cdot|A(\omega)|^2 & \text{for } 0 \leq t \leq TTB \\ 0 & \text{otherwise} \end{cases} \qquad \text{eq. (10)}$$

So the seismic load is completely defined. For nonlinear oscillators an enveloppe, reflecting the increase and decrease of the variance of the process, is proposed. The neglection of the frequency shift of the random process is admissible because of the short duration of the excitation and so only valid for nearfield earthquakes.

For the calculation of the structural response the transient character of the process must be taken into consideration. For linear oscillators the determination of probabilistic response spectra by using time-dependent transfer functions and peak factors corresponding to the proposals of Vanmarcke [4] was found to be appropriate; the mean difference between probabilistic and deterministic spectral amplitudes was lower than 5 %.

Referring to Baber/Wen[5] the load definition can also be used for the evaluation of the response of stiffness degrading, nonlinear hysteretic systems, including the determination of the dissipated energy during the earthquake, which seems to be an important factor for describing the severity of building damage.

4. SUMMARY AND CONCLUSIONS

By the statistical analysis of European nearfield registrations it was possible to improve seismic load description especially for sites in the FRG:

- the poor correlation between maximum acceleration and intensity is replaced by the connection between acceleration energy and intensity with respect to the soil conditions.
- the strong motion duration is primarily dependent from focal distance and so clearly shorter than usually suggested.
- the frequency content of the excitation is soil-dependent and will be described by Fourier-amplitude-spectra.

So the excitation can be defined as nonstationary random process, allowing the calculation of the response of linear and nonlinear oscillators in statistical terms and also the generation of realistic artificial time histories.

REFERENCES

/1/ Shannon, Wilson Inc.: Statistical Analysis of Earthquake Ground Motion Parameters. NUREG - Report No. CR-1175, 1979.

/2/ Hosser, D.: Seismic Load Assumptions in Low Seismic Zones. Paper K 1/4 to the 8th SMIRT Conference, Brussels, 19 - 23 August 1985.

/3/ Ahorner, L.: Seismicity and Neotectonic Structural Activity of the Rhine Graben System in Central Europe.-In: Ritsema/Gürpinar (eds.), Seismicity and Seismic Risk in the Offshore North Sea, pp. 101-111. Reidel Publ. Comp. Dordrecht, 1983

/4/ Vanmarcke, E.H.: Seismic Risk and Stochastic Seismic Analysis of Structures. Proceedings of the TUB-MIT Seminar, Berlin 1982.

/5/ Baber,T.T.,Wen,Y.K.: Stochastic Equivalent Linearization for Hysteretic, Degrading, Multistory Structures. Report No. UILU-ENG-80-2001, University of Illinois, 1980.

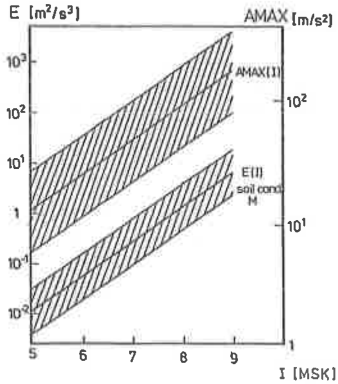

fig. 1 : Regression lines ± 1 standard error for AMAX and E (soil cond. M) as function of intensity

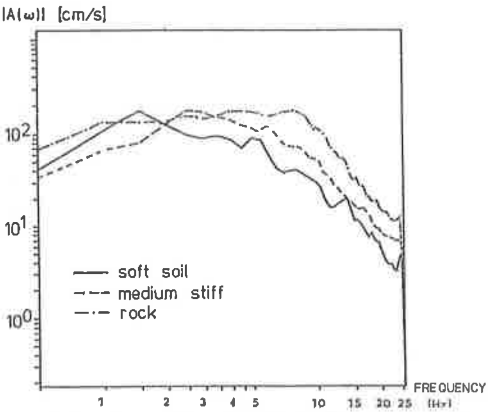

fig. 2 : Mean Fourier Spectra for different soil conditions

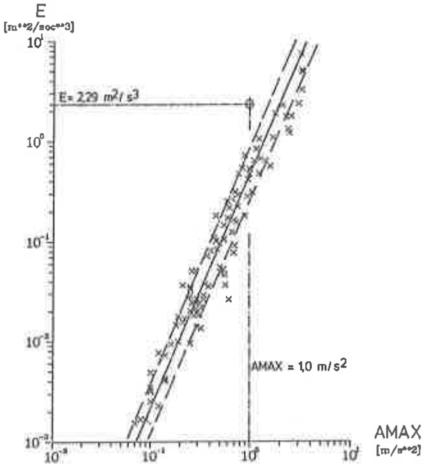

fig. 3 : E - AMAX- relationship, regression line ± 1 standard error.

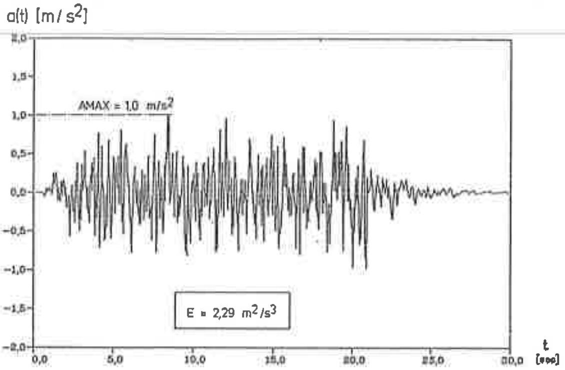

fig. 4 : Artificial generated acceleration time history, compatible with US R.G. 1.60 standard spectrum.