INFLUENCE OF SEISMIC AND SITE CONDITIONS ON EQUIPMENT RESPONSE

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SUMMARY

A scheme is proposed for calculating earthquake induced motions directly from given source parameters within baserock. Thus it is possible to take site dependent parameters -i.e. magnitude, source radius, focal distance and local soil conditions - as input data. Fourier phase spectra and artificial time histories are not necesarry to yield floor response spectra. The current uncertainties of this calculation scheme are pointed out.

DEFINITION OF PROBLEM

Present design of nuclear power plants is commonly based on standard design response spectra (DRS) and a site dependent zero period acceleration (zpa) set by an experienced geophysicist. For areas having a low seismicity as compared to the western part of the United States such a way of defining the design yields input data being more conservative than necessary. Thus regional investigations are carried out in W. Germany to gain more knowledge about the seismic activity north of the Alps.

First results show that in this region it is more adequate to take the top of the base rock as a regional datum instead of the surface. Secondly there is the question in which form the top-of-baserock data should be passed to the engineer. After having defined the magnitude of the assumed earthquake and its focal distance to the site the geophysicist can reliably express a Fourier spectrum (FAS) at top of the base rock by using a source model /1, 2/. The common way of defining a regional DRS together with a zpa and then generating artificial time histories by the engineer will presumably include a margin of conservativity similar to using standard input data as mentioned at the beginning. Hence a calculation scheme which allows to use the geophysically derived FAS as input parameter and then converts the final FAS for the interesting building nodes into floor response spectra (FRS) is a more adequate solution.

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In the next two sections such a calculation scheme in the frequency domain is described. The numerical values are design data for a stiff soil site and an alluvium site. The difference is shown between such a site specific calculation and the results obtained by standard design. In the last section those steps of the calculation scheme are enlightened which have uncertainties still to be reduced.

CALCULATION SCHEME

The flowchart of the calculation scheme is shown in Fig. 1. For the formulas below the following symbols are used:

$\tilde{a}(f)$	= FAS of acceleration at top of baserock
$\tilde{a}_B(f)$	= FAS of acceleration for interesting building node
a_{rms}	= root mean square acceleration at top of baserock
a_{max}	= maximum acceleration at top of baserock
f	= frequency
f_o	= corner frequency for a seismic source
f_{max}	= frequency for defining the zpa level
h	= thickness of sedimentary layer
p	= probability of exceedance
r	= radius of seismic source
D	= damping of sedimentary layer
$F_o(\omega_o)$	= peak factor of response spectrum
F_{zpa}	= zpa factor of response spectrum
$H(\omega, \omega_o)$	= transfer function of SDOF system
M_o	= seismic moment
ML	= surface wave magnitude
MWA	= local magnitude
Q	= Q-factor of baserock
R	= hypocentral distance
$R_o(\omega_o)$	= response spectrum
$R_{\vartheta\phi}$	= radiation pattern of seismic source
T	= effective earthquake time duration
β	= shear wave velocity
ρ	= density
σ	= standard deviation
$\dot{\sigma}$	= time derivative of standard deviation
ω	= circular frequency
ω_o	= eigenfrequency of SDOF system

Providing the magnitude, source radius and focal distance of the site, it is then possible to define the Fourier amplitude spectrum of the acceleration in the far field of a circular seismic source (Brune's model) /1, 2/:

$$\tilde{a}(f) = R_{\Theta\phi} \frac{\pi \cdot M_0 \cdot f^2}{\rho \cdot R \cdot \beta^3} \exp\left(-\pi f \cdot R / Q \cdot \beta\right) \qquad f \leq f_0 \qquad (1a)$$

$$\tilde{a}(f) = R_{\Theta\phi} \frac{\pi \cdot M_0 \cdot f^2}{\rho \cdot R \cdot \beta^3} \frac{f_0^2}{f^2} \exp\left(-\pi \cdot f \cdot R / Q \cdot \beta\right) \qquad f \geq f_0 \qquad (1b)$$

where the corner frequency $f_o = \frac{2.34 \cdot \beta}{2 \cdot \pi \cdot r}$ (2)

These formulas allow to calculate the FAS ground acceleration on top of the baserock. Given h_i, ρ_i, β_i, and D_i for each sedimentary layer, the convol ution with the transfer function of the sedimentary layers yield the FAS of free field acceleration /3/. After convolution with the building transfer function, the FAS $\tilde{a}_B(f)$ for a specific node is obtained.

For the design of components the engineer needs response spectra. These response spectra can be calculated without referring to the so far unknown Fourier phase spectra using the following relation /4/:

$$R_0(\omega_0) = \sigma(\omega_0) \cdot F_0(\omega_0) \qquad (3)$$

where the square of the standard deviation is given:

$$\sigma^2(\omega_0) = \int_{-\infty}^{+\infty} H(\omega, \omega_0) \cdot H^*(\omega, \omega_0) \cdot \tilde{a}^2(\omega)\, d\omega \qquad (4)$$

and the amplitude factor:

$$F_0(\omega_0) = \left[-2 \ln\left\{-(\pi/T)(\sigma/\dot{\sigma}) \ln(1-p)\right\}\right]^{\frac{1}{2}} \qquad (5)$$

In the following calculations T was set 10 sec. and p equals 0.05. In addition the maximum acceleration on top of the baserock /5/ is determined by:

$$a_{max} = a_{rms} \cdot \left[2 \cdot \ln\left(\frac{2 \cdot Q \cdot \beta}{\pi \cdot R \cdot f_0}\right)\right]^{\frac{1}{2}} \qquad (6)$$

where $$a_{rms} = R_{\Theta\phi} \frac{\pi \cdot M_0 \cdot f_0^3}{\rho \cdot R \cdot \beta^3} \cdot \left[\frac{Q \cdot \beta}{f_0 \cdot \pi \cdot R}\right]^{\frac{1}{2}} \qquad (7)$$

Hence follows the factor:

$$F_{zpa} = \frac{a_{max}}{R_0(2\pi f_{max})}$$

This is used to adjust the zpa level of the response spectrum at each step of the calculation scheme.

DESCRIPTION OF RESULTS

Table 1 contains the site specific earthquake parameters and the standard design values, too. The magnitudes have to be converted into seismic moments. This is done using the relation:

$$\log M_o = 1.1\ MWA + 10.4 \quad (M_o\ [NM])$$

This relation was derived from 27 central European earthquakes which took place between 1977 and 1983 /6/.

Fig. 2 shows the FAS of acceleration on top of the baserock. The corresponding response spectra (damping 7 %) in Fig. 3 were calculated by means of equation (3) and then adjusted to the zpa level given by F_{zpa}. The value of f_{max} was chosen 33 Hz.

Figs. 4 and 5 shows the transfer fuctions from the top of the baserock to the surface. Response spectra (Figs 6 to 8) were calculated from the FAS of the surface and adjusted by F_{zpa}. Into these plots the standard design spectra are drawn.

Floor FAS were calculated using typical transfer functions of absolute acceleration including SSI effects for the selected structure and foundation soil. Figs. 9 to 12 contain FRS being calculated from floor FSA for node 10 (foundation level) and for node 326 (top of building). The site specific results are compared with those derived from standard input data (c.f. table 1).

DISCUSSION OF RESULTS

Although the results derived by means of the site specific parameters are lower than those using standard design values, the question is set forth which steps may need further investigations. Thus the following points have to be considered:

- $R_{\Theta\phi}$ in equation 1a, 1b has been set equal to 1. Yet the theoretically derived value is 0.85 /2/.
- The used relation between local magnitude MWA and the seismic moment M_o is the most recent one for central Europe. Still there is another relation between the surface wave magnitude ML and the seismic moment:

  $$\log M_o = 1.18\ ML + 10.94$$

  From the engineering point of view both relations cannot reliably be transferred into each other because the following relation is only approximately valied: $MWA \approx ML + 0{,}5$

Moreover there is a relation dervired from earthquakes in the Friuli region: $\log m_o = 1.3 \text{ MWA} + 9.3$.
This is considered to be valid for central Europe, too. It would result in sightly higher seismic moments.

- The use of the factor F_{zpa} for adjusting the zpa level of response spectra was found by experience and needs to be theoretically verified.
- The factor F_{zpa} is based on the parameter a_{max} because the ratio between predicted and observed a_{rms} scatters in a range between 1 and 6 for rock and stiff soil sites /2/. The values of a_{max} are approximately 3 times higher than a_{rms}.

Despite of the encouraging results yielded with the proposed calculation scheme the engineer should be aware of scattering in the geophysical input data and its influence on the FRS.

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Tab. 1: Site dependent geopnysical input data

Case	Allu 1	Allu 2	Stiff 1	Stiff 2
Load	SSE	SSE	OBE	SSE
	Standard design values:			
Spectra	KTA spectra (derived from horiz. USNRC spectra)			
zpa m/s^2	3	3	0.9	1.7
	Site specific values (defined):			
MWA	5.3	6.4	5.0	6.1
f Hz	0.73	0.33	1.1	0.48
R km	4	21	15	18
ß m/s^2	3400	3400	3400	3400
ϱ kg/m^3	2700	2700	2700	2700
Q	200	200	200	200
	Site specific values (calculation):			
m_o NM	$1.7 \cdot 10^{16}$	$2.8 \cdot 10^{15}$	$8 \cdot 10^{15}$	$1.3 \cdot 10^{17}$
a_{rms} m/s^2	0.42	0.078	0.076	0.12
a_{max} m/s^2	1.33	0.22	0.19	0.33

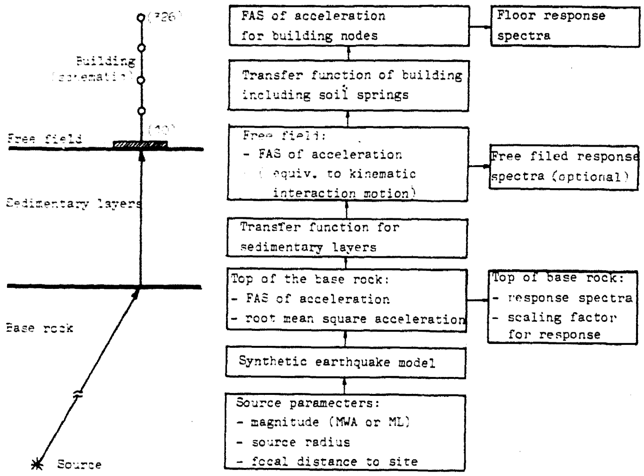

Fig. 1: Calculation schemee

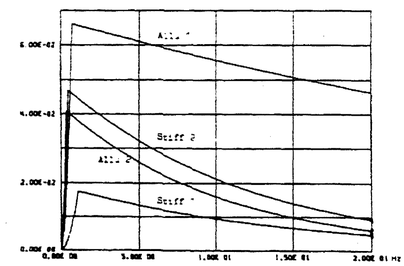

Fig. 2 FAS of acceleration at top of base rock

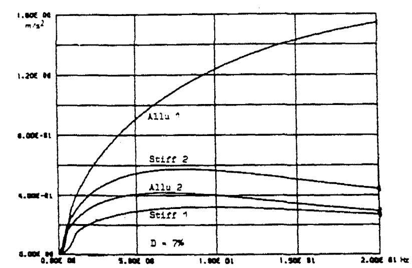

Fig. 3 Response spectra of acceleration at top of base rock

Fig. 2+3: Fourier amplitude spectra and response spectra for top of baserock

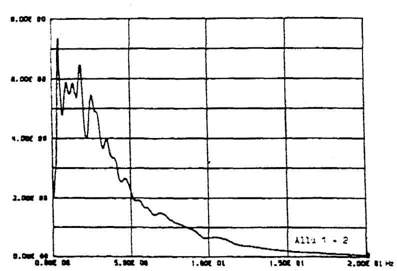

Fig. 4 Transfer function for Alluvium sediments

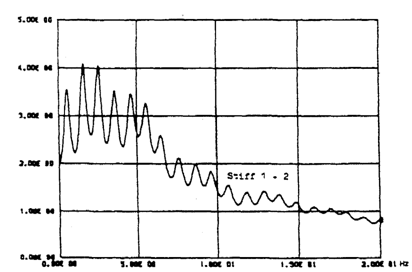

Fig. 5 Transfer function for stiff soil sediments

Fig. 4+5: Transfer functions for sedimentary layers

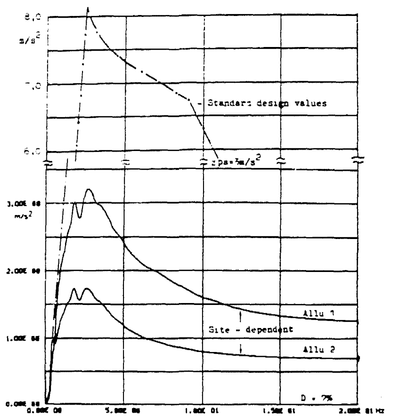

Fig. 6 Free field response spectra of acceleration cases Allu 1 + 2

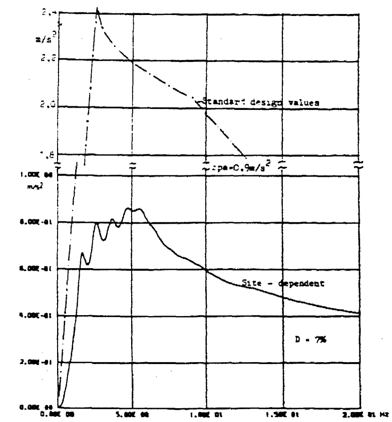

Fig. 7 Free field response spectra of acceleration for case Stiff 1

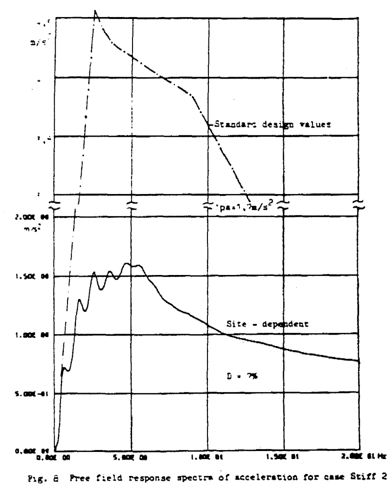

Fig. 8 Free field response spectra of acceleration for case Stiff 2

Fig. 6-8: Comparison between standard and site-dependent free field response spectra

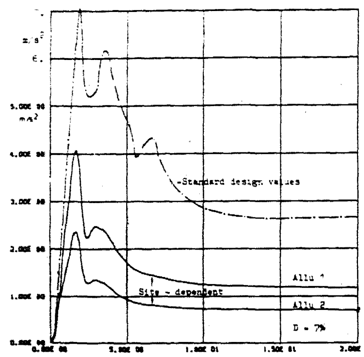

Fig. 9 Floor response spectra for node 10, cases Allu 1 + 2

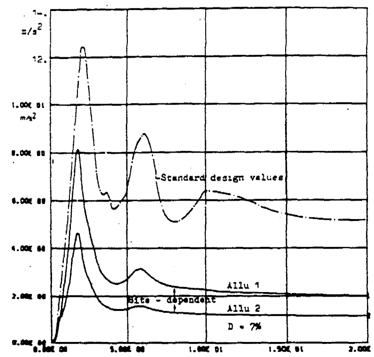

Fig. 10 Floor response spectra for node 326, cases Allu 1 + 2

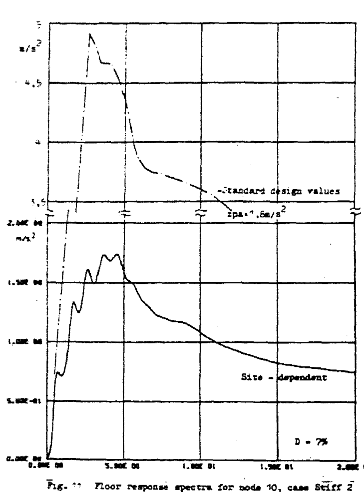

Fig. 11 Floor response spectra for node 10, case Stiff 2

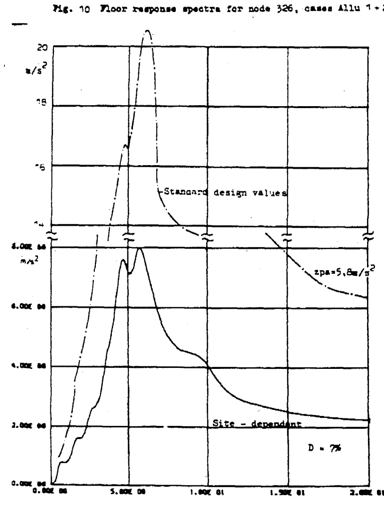

Fig. 12 Floor response spectra for node 326, case Stiff 2

Fig. 9-12: Floor response spectra for loadcase SSE: Comparison between spectra derived by standard input values and site-dependent input values