DESIGN RESPONSE SPECTRA FOR CENTRAL EUROPE

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SUMMARY

Some information contained in the Friuli records from 1976 is used for deriving design response spectra. They are defined in analytical form as a result from various averaging and smoothing procedures.Two categories of soil conditions are considered. Plots of the influence of damping on the response spectral amplitudes are provided.Due to similar tectonic conditions between Friuli and other sites along the border lines of the Alps the results are felt to be widely useful for Central Europe.

INTRODUCTION

In 1976 the Friuli region in Italy was hit by a series of earthquakes.The main shocks occured on 6 May (M = 6,5), 11 September (M = 5,9) and on 15 September (M = 6,1).The induced damage was desastreous in the epicentral region around the city of Gemona, but also affected southern parts of Austria as well as northern parts of Yugoslavia.

A large number of records were taken by CNEN and ENEL stations at various locations in northern Italy (Ref.1). The general feature of the accelerograms was a rather short strong motion duration lying between 2 and 5 seconds. Most records had a quick build-up of acceleration time history after beginning.

The soil conditions of the recording stations (Ref.2) can be classified as follows

- fractured complex of limestone and dolomite
- Thin layers (around 3 m) of tuff or talus overlying heavily fractured limestone
- thick alluvial deposits (gravel,sand and silt)

Thus, the Friuli records offered a chance to eventually update earthquake input data currently used in design in central parts of Europe. There the major faults run along the border lines of the Alps and are characterised by a small to moderate seismicity.For this area the lack of strong motion data is rather severe.Therefore, a study has been undertaken within the Austrian Association for Earthquake Engineering (OGE) dealing with an analysis of Friuli records.The results are felt to be

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useful for many other sites in Central Europe as well, where similar tectonic conditions are encountered.

For that purpose a set of totally twentyone three-component records has been selected from the uncorrected data (Ref.1) during the study(Ref.3) The records can be divided into two subsets.

The first subset includes various records taken at different stations with different soil conditions, but all originating from the main shock on 6 May, 1976 ("one sender - different receivers").The subset consists of records with CNEN Nos. 029,030,031,033,035,036,037,038 and 039. The epicentral distance ranges from 27 to 180 km with peak ground accelerations (PGA) going from 0,37 g down to 0,01 g.

The second subset includes various records from Tolmezzo station (fractured limestone) originating from different events ("one receiver-different senders").The subset consists of records with CNEN Nos.028,038, 040,042,047,054,063,064,075,076,083 and 092).The epicentral distance varies between 0,37g and 0,007g.

For data processing (baseline correction and correction of digitisation errors) a modified version of the Caltech standard strong motion data processing routine was employed. These modifications were first proposed by Basily and Brady (Ref.4). The parameters for the correction filters have been selected individually for each accelerogram (Ref.3).

After data correction a variety of characteristics of strong ground motion has been analysed (e.g.,response spectra, peak factors, power spectral density functions of associated stationary ground motion, time-evolution behaviour). The results are summarized in Ref. 3.

In this paper the emphasis is given to response spectra, since they are widely used in design and are also defined in some codes.Response spectra are sometimes also used as starting point for either time history or random vibration analysis.

In the following analysis we restrict to elastic response spectra. There are several methods available for transforming elastic into inelastic response spectra (e.g.,Ref.5). However, for inelastic structures the application of standard rules for summations of peaks based on inelastic response spectra is not recommended.

RESPONSE SPECTRA

First, a response spectrum was computed from each corrected accelerogram. After scaling all spectra to a common PGA mean response spectra were evaluated for each subset.(Other scaling criteria lead to nearly identical results).Fig. 1 shows the horizontal response spectra for both subsets of records.There it can be seen that the spectrum belonging to a common "receiver" is much narrower in frequency content than the other one.Thus, the potential merit of a detailed site study can be seen.Without such knowledge of local geological and soil conditions a rather broad design response spectrum has to be employed. Further investigations related to the characteristic shape of response spectra for various soil conditions are therefore desirable.

Smooth Response Spectra

For design purposes smooth response spectra are required. Often such spectra are defined as piecewise linear functions (in a logarithmic scale of both frequency and pseudo-spectral-velocity).

In the present analysis a polynomial expansion is applied for the pseudo-spectral-velocity SV

$$x = (2 \ln /2)/\ln 65 - 1$$

$$SV = \frac{A}{A_o} \sum_{i=0}^{n} a_i x^i$$

where A denotes the PGA and A_o was selected with 5% of g. The coefficients are found from a least mean square error fit. For the types of spectra investigated a number of summation terms n = 7 was found to be adequate.

Design Response Spectra

Due to the limited number of records only two categories of soil conditions are investigated:

- rock sites
- soil sites (including soft and stiffened soils).

For both soil categories and horizontal as well as vertical components design response spectral shapes were obtained from

a) scaling all spectra to common PGA

b) evaluating the "mean + 1 sigma" spectra within each category

c) applying the smoothing procedure for the "mean + 1 sigma" spectra.

The mean + 1 sigma spectrum corresponds to a 84th percentile spectrum or has a probability of exceedance of 16%.

For a damping value of 5% of critical damping the following coefficients are obtained for the design spectral shape functions SV:

a_i / i	horizontal motion		vertical motion	
	rock sites	soil sites	rock sites	soil sites
0	1,862	2,008	1,598	1,766
1	- 1,281	- 0,649	- 0,902	- 1,163
2	- 3,086	- 2,976	- 1,055	0,820
3	0,640	- 3,746	- 0,618	- 3,825
4	0,929	4,114	- 0,754	- 4,046
5	0,177	4,433	1,051	6,272
6	- 0,649	- 3,335	- 0,649	1,328
7	- 0,134	- 1,555	- 0,348	- 2,761

The resulting design spectra for damping values of 0,2,5 and 10 % are displayed in Fig. 2.

When comparing the spectra for the horizontal components a larger spectral intensity for soil sites can be observed. Whereas the spectral shape function for rock sites has a maximum around 2.5 Hz and falls off significantly to both tails, the spectrum for soil sites remains fairly constant beween 0.5 and 5 Hz.This implies that particularly for tall buildings with low natural frequencies on soil sites rather large amplification factors are obtained. Even in the acceleration regime the "mean + 1 sigma" spectrum for soil sites exceeds that for rock sites.This observation has not been made when "mean" spectra are considered only.

Different spectral shape functions for both site categories are also found for the vertical components.For soil sites a distinct maximum around 0.7 Hz and for rock sites a flat maximum between 1 and 5 Hz is observed. The Nuclear Regulatory Guide spectrum (Ref.6) is close to the present results only for horizontal components on rock sites. All spectra remain clearly below the NRG spectrum in the displacement regime, which is at least partly attributed to the shorter duration of strong ground motion here, as compared to U.S. earthquakes.

Influence of Damping

Four distinct damping values have been used in Fig.2. For a set of selected frequencies the influence of damping on the spectral amplification factors for the velocity response is plotted in Fig.3. All amplification factors were scaled to the value for 5% damping. The results hold for both horizontal and vertical components. The spectra for soil sites are more sensitive to variations in damping than for rock sites.

CONCLUSIONS

For the purpose of comparison the present results were plotted in Fig. 4 taken from Ref. 6. There the normalized "mean + 1 sigma" acceleration spectra are given as a result from an analysis of 104 U.S. records. In this study 26 records for rock sites and 16 records for soil sites were analysed.The main findings of this comparison are that

-the maximum spectral acceleration for rock sites is about 2.8 a_{max} and much lower than for U. S. spectra.(For the maximum "mean" spectral acceleration a value of 2.25 a_{max} has been found.) For periods exceeding 1 second the present results decrease much faster than for U.S. spectra.

-the maximum spectral acceleration for soil sites is about 3.6 a_{max}, which is nearly identical to the value for U.S. spectra.(The corresponding maximum value from the "mean" spectrum is 1.8 a_{max}). For a wide range of periods the present results for soil sites is close to the reference result for stiff soils.

- for both soil and rock sites the maximum spectral acceleration occurs around a period of 0.3 seconds.

- the NRG spectra are nearly always very conservative for rock sites and only acceptable for soil sites in Central Europe for periods above 0.5 seconds.

-the maximum spectral acceleration currently applied in Central European Codes (1.5 in Germany and 1.6 in Austria) is too low in view of the present results unless sufficient ductility is provided in the structure.

The present results provide design response spectra for rock and soil sites in Central Europe with similar tectonic and geological conditions to Friuli. However, these results are still based on a limited set of data and have to be updated again, if new information becomes available.

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Comparison of Spectral Acceleration Functions for 5% Damping

a) *from Ref.6*

b) present results

SOIL SITES(16 Rec.)

ROCK SITES(26 Rec.)

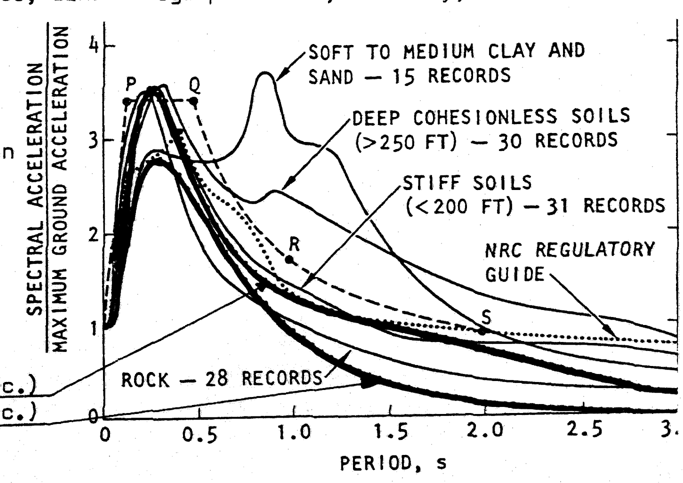

FIGURE 4

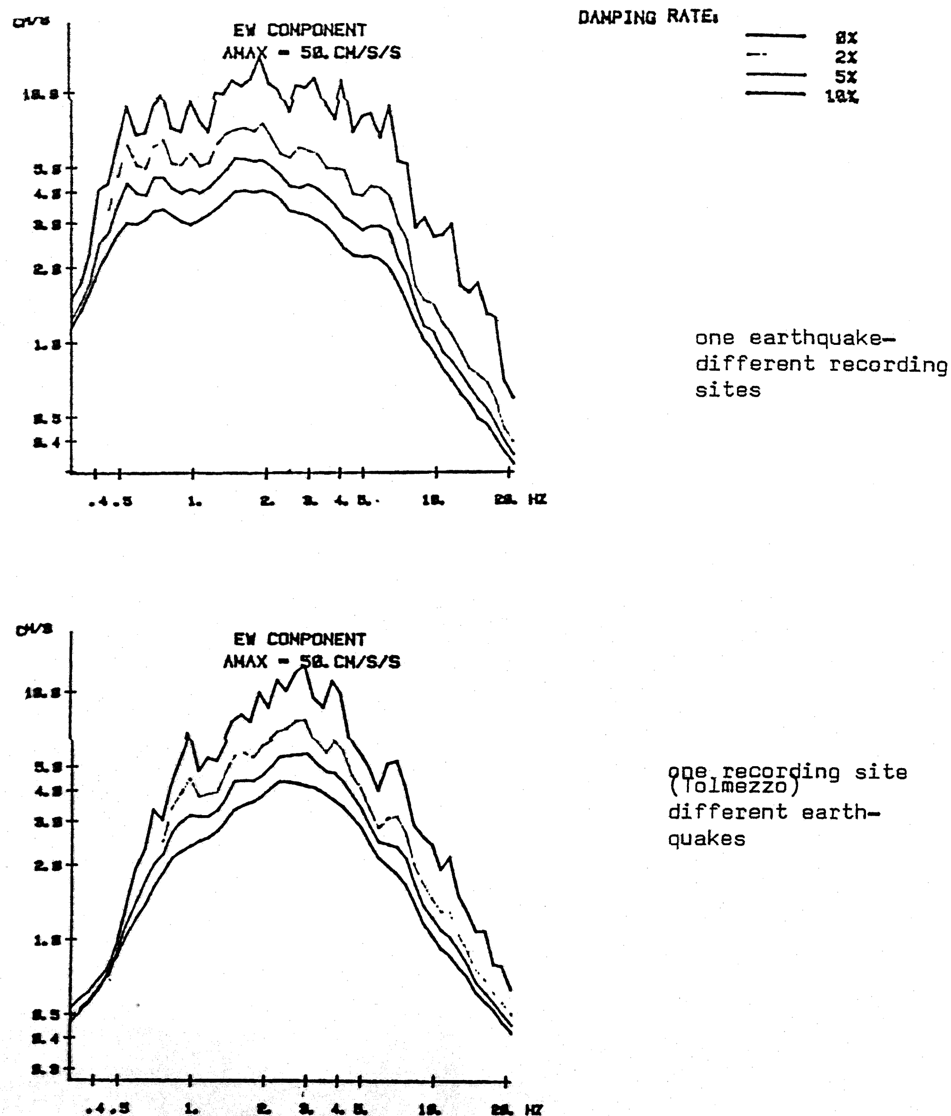

FIGURE 1

Mean Pseudo - Velocity - Response Spectra for
Two Categories of Friuli Earthquakes 1976

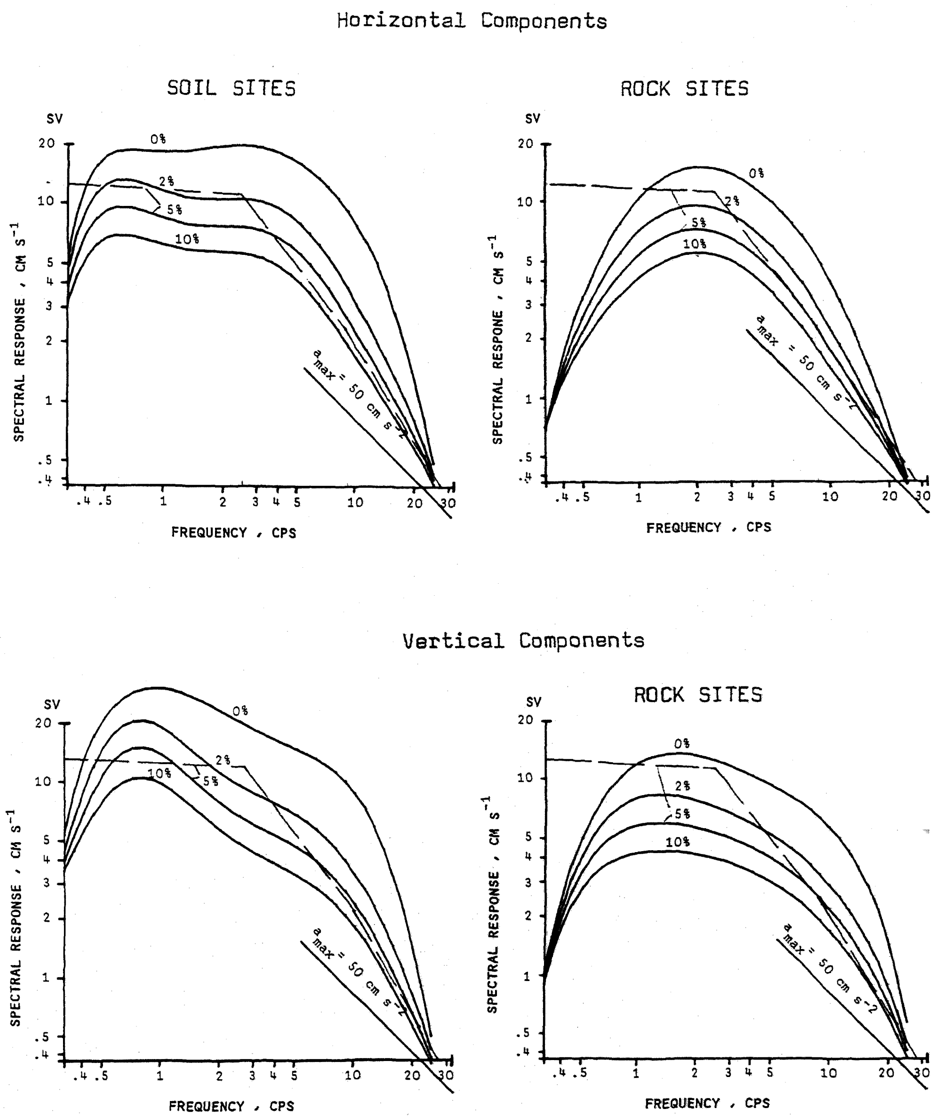

FIGURE 2
"Mean + 1 sigma" Design Response Spectra
(— — NRC Regulatory Guide Spectrum)

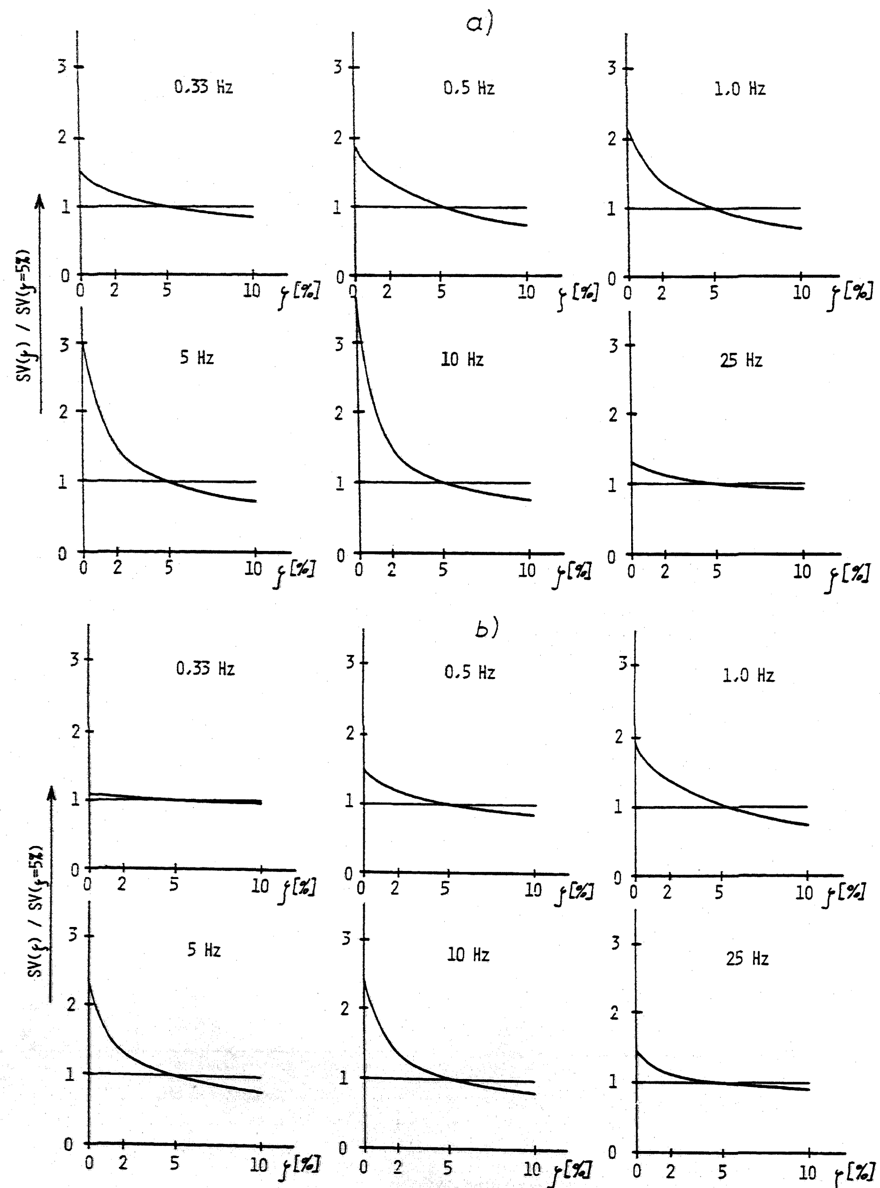

FIGURE 3

Influence of Viscous Damping Coefficient on Spectral Amplification Factors for Various Natural Frequencies

a) for soil sites b) for rock sites