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CONSIDERATION ON THE DESIGN VELOCITY RESPONSE SPECTRA ALONG THE PRINCIPAL AXES

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SUMMARY

In this study, ratios of the velocity response spectra among the three recorded components of an earthquake motion or among the recorded components and the transformed principal components have been investigated. Special attention has been paid to the ratios between the major principal component and the recorded horizontal component with the maximum acceleration, between the intermediate component and the major principal component and finally, between the recorded vertical component and the major principal one. Correlations have been established among these ratios and representative earthquake parameters. Relationships have been also developed to describe the quantitative dependence of these ratios on the independent variables such as, earthquake magnitude, distance to the fault and period.

INTRODUCTION

The synthetic earthquake ground motions are generated to be compatible with appropriate design response spectra (D.R.S.). In the seismic design of specific structures, such as nuclear power facilities, long span shells etc., are required three components of the input ground motion. The D.R.S. for horizontal components has been usually defined through the analysis of the characteristics of, (a) the largest of the two horizontal components or (b) both components. However, it is well known that the strongest axis from the view point of input energy does not coincide with an arbitrary set of orthogonal axes along which the earthquake motions are usually recorded. Therefore the concept of the principal axes should be introduced. The major principal axis provides the maximum value of the mean root square acceleration and consequently the maximum input energy.

On the other hand, the recent experience suggests that the spectral values of vertical components have been observed to be equal or exceed the corresponding values of horizontal components at a certain range of frequencies, for ground motions due to moderate-to-large near field earthquakes. In the present research, will be examined the relation between the velocity response spectra (V.R.S.) defined by the use of principal axes of a recorded earthquake motion and those defined by the other researchers. Furthermore, will be examined the relation between the V.R.S. of the intermediate principal and vertical axes with the corresponding V.R.S. of the major principal axis.

In the recent years, considerable interest has been focused on the empirical prediction of various parameters. Emphasis was placed on the prediction of parameters which govern the characteristics of the strong earthquake motion, such as peak values of acceleration, velocity, displacement, strong motion duration, response spectrum etc., mainly for horizontal component. In this study, the spectral ratios between the various components of earthquake motions were examined to give the appropriate response spectra.

DATA BASE

A set of 108 strong earthquake motion records (324 components) obtained at rock sites in U.S., Mexico and Japan were used in this study. The used records correspond to a range of earthquake magnitudes between 5.0 and 8.1, and to distances to the fault between 4 and 484 Km.. Although the earthquake mechanism or the travel path conditions for various earthquakes recorded at the three countries may be different, it was considered more relevant to take into account all these records in order to obtain general information about their spectral characteristics.

Since magnitude scales used in the three countries may be different, one of our main problems was the magnitude scale uniformity. In this paper, the magnitude scale (M) used was similar to that used by Campbell (Ref. 1). It was defined as surface wave magnitude (M_s) when both local magnitude (M_l) and (M_s) were greater than or equal to 6.0 and it was defined as local magnitude when both M_l and M_s were below the above value. In the case of earthquakes recorded in Japan, there was not sufficient information for both M_l or M_s for some records, because the Japan Meteorological Agency magnitude (M_{JMA}) is widely used. In this case the M_l or M_s were estimated from M_{JMA} by the use of empirical relationships among the magnitude scales (Ref. 2).

The used records were also restricted to recording stations where estimation of the closest distance between the station and the ruptured fault was available or could be determined. This distance estimation of distance leads to more realistic estimation of the spectral ratios from empirical relationships, because in the case of a future event this kind of estimates are only available. In Fig. 1, the relation between the magnitude and the distance to the fault of the earthquakes used in this study is shown.

METHOD

It is well known that the two horizontal components of a ground motion can be rotated to any direction without losing the original information. Principal axes (Ref. 3) for the horizontal plane (major, intermediate) are defined as the axes along which the horizontal components of ground motions have the maximum and minimum values of variances and covariances approximately equal to zero. Examination of real accelerograms reveals that the major principal axis points in general to the direction of the center of energy release.

The horizontal components of the earthquake records were transformed into principal axes. Then, for the purpose of comparison the velocity response spectra of the major, intermediate, vertical axes and the recorded horizontal axis with the largest peak acceleration, were calculated with the damping 0.05 over a range of periods between 0.04 and 20.0 second. Moreover, the ratio values between the velocity response spectra, for major and maximum horizontal components (R_{1s}) for intermediate and major components (R_{21}) and for vertical and major (R_{31}) components were obtained.

In Fig. 2 and Fig. 3, the above mentioned spectral ratios for near and far field earthquakes are presented. It can be noticed that the ratio values between vertical and major principal axis is greater than unit at high frequency ranges for near field earthquakes. In contrast, the ratios are almost constant for the far field ones and considerably less than unit.

In Fig. 4, 5 and 6, the solid lines represent the ensemble mean values and the dot lines the period dependent standard deviation for the spectral ratios R_{1s}, R_{21} and R_{31} respectively. From these figures can be clearly understood the dependence of the spectral ratios on the period.

REGRESSION ANALYSIS

A weighted linear regression analysis of the ratios R_{1s}, R_{21} and R_{31} for 100 different values of the period was conducted. The mathematical relationship used in this study is expressed by the following equation.

$$RAT(T,M,R) = a(T) + b(T)M + c(T)R \tag{1}$$

where RAT is the ratio between spectra, T is the period, M is the magnitude, R is the distance to the fault, and a(T), b(T) and c(T) are regression coefficients which are functions of the period.

The weighting scheme proposed by the authors (Ref. 4) was used. This weighting scheme is based on the consideration for both magnitude and distance to the fault. Weights were assigned to each record in order to control the influence of the well recorded events in the data base.

The regression results for a(T), b(T) and c(T) are shown in Fig. 7, 8 and 9 respectively. It can be noticed that the regression coefficients a(T), b(T) and c(T) cannot be easily expressed as functions of the period (T). In Fig. 10 and Fig. 11, are shown spectral ratios estimated from the empirical relationship (1) for magnitude 6.0, distance 5 Km. and magnitude 8.0, distance 100.0 Km. respectively.

The spectral ratio values resulted from the empirical relationship (1) do not fluctuate greatly over a wide range of period. For this reason, straight lines which are functions of period (T) were fitted to the obtained results. The fitted straight lines are expressed by the following equation.

$$RAT(T/M=\text{const. and } R=\text{const.}) = D(M,R)+E(M,R)\log(T) \tag{2}$$

where D(M,R) and E(M,R) are regression coefficients for given magnitude and distance.

In Table 1 are summarized the results for the coefficients D(M,R) and E(M,R) for magnitudes 6.0, 7.0 and 8.0 and for distances 5.0, 50.0 and 100.0 Km.. For other values of magnitude or distance to the fault, the D(M,R) and E(M,R) can be calculated by interpolation from values in the table. In cases of R_{1s} and R_{21} continuous straight lines over the total range of periods were fitted. In the case of R_{31} were fitted two different lines, the first one for the range up to about 0.16 second, and the second line for the rest of periods. In Fig. 12 is shown an example of the fitted lines expressed by the equation (2) for magnitude 6.0 and distance 5.0 Km..

CONCLUSIONS

The ratios of velocity response spectra between the major principal and the recorded horizontal component with the maximum acceleration (R_{1s}), between the intermediate and the major component (R_{21}) and between the recorded vertical and major principal component (R_{31}) were examined. The mean values and the standard deviations of these ratios over a wide range of periods, were equal to (μ=1.11, σ=0.31), (μ=0.91, σ=0.35) and (μ=0.55, σ=0.31) respectively. From these results it can be concluded that the values of the mean design response spectra for the horizontal components proposed up to now by various authors must be increased by about 10% to 20% depending on the earthquake magnitude and the distance to the fault. The ratio R_{21} between the intermediate and the major axis does not change significantly for various values of magnitude and distance. The ratio R_{31} between the vertical and the major principal axis becomes larger than unit for periods less than about 0.16 second, decreasing with the increase of the distance. For longer periods the ratio R_{31} has a mean value of 0.53, decreasing also with the distance but at a slow rate.

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Table 1 Values of the regression coefficients D(M,R) and E(M,R)

R \ M	6.0			7.0			8.0			
	D	E	T	D	E	T	D	E	T	
5.0	1.1016	-0.021556	0.04-20.0	1.1409	-0.022561	0.04-20.0	1.1802	-0.023566	0.04-20.0	MAJOR/MAX.HORI.
	0.96064	0.015293	0.04-20.0	0.95034	0.015838	0.04-20.0	0.94004	0.016383	0.04-20.0	INTER./MAJOR
	-0.30249	-1.0673	0.04-0.16	-0.31845	-1.0225	0.04-0.15	-0.33441	-0.97776	0.04-0.14	VERT./MAJOR
	0.56804	0.019625	0.16-20.0	0.55088	0.028434	0.15-20.0	0.53372	0.037243	0.14-20.0	
50.0	1.0895	-0.018821	0.04-20.0	1.1288	-0.019826	0.04-20.0	1.1681	-0.020831	0.04-20.0	MAJOR/MAX.HORI
	0.94611	0.014836	0.04-20.0	0.93581	0.015380	0.04-20.0	0.92551	0.015925	0.04-20.0	INTER./MAJOR
	-0.18038	-0.93325	0.04-0.18	-0.19634	-0.88848	0.04-0.17	-0.21230	-0.84372	0.04-0.16	VERT./MAJOR
	0.54419	0.031771	0.18-20.0	0.52703	0.040580	0.17-20.0	0.50988	0.049389	0.16-20.0	
100.0	1.0761	-0.015781	0.04-20.0	1.11153	-0.016786	0.04-20.0	1.1546	-0.017791	0.04-20.0	MAJOR/MAX.HORI.
	0.92997	0.014327	0.04-20.0	0.91967	0.014872	0.04-20.0	0.90937	0.015417	0.04-20.0	INTER./MAJOR
	-0.044704	-0.78432	0.04-0.21	-0.060663	-0.73955	0.04-0.20	-0.076623	-0.69479	0.04-0.18	VERT./MAJOR
	0.51769	0.045267	0.21-20.0	0.50053	0.054076	0.20-20.0	0.48338	0.062885	0.18-20.0	

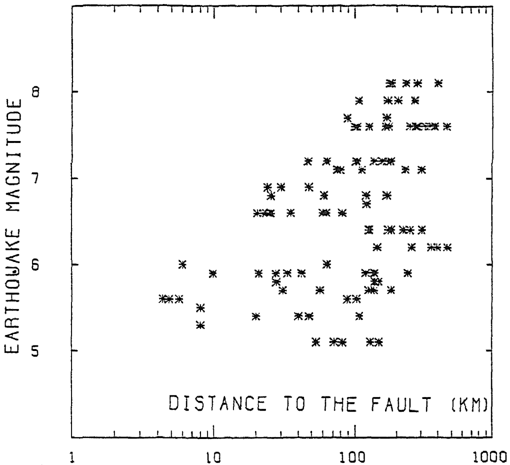

Fig. 1 Relation between magnitude and distance to the fault of the data set

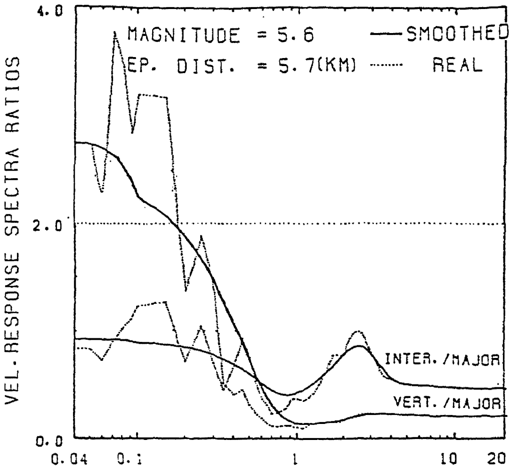

Fig. 2 Ratios of the velocity response spectra for a near field earthquake

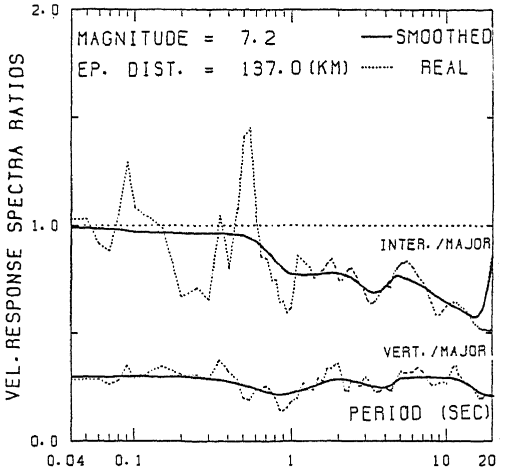

Fig. 3 Ratios of the velocity response spectra for a far field earthquake

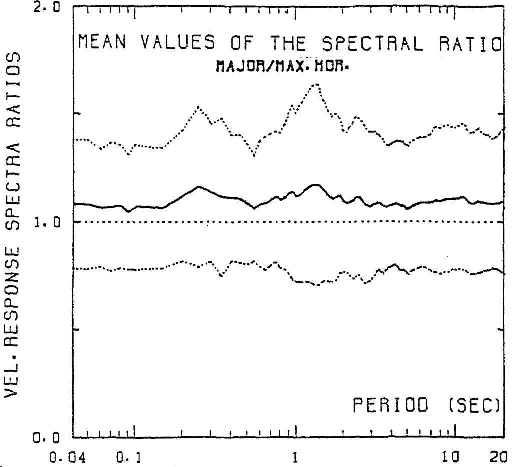

Fig. 4 Mean values of the V.R.S. ratios between major and maximum horizontal axis

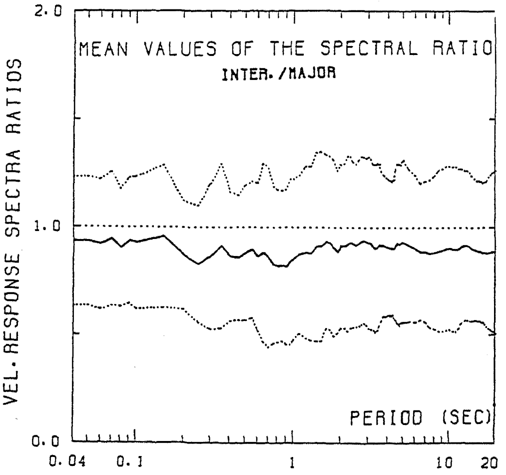

Fig. 5 Mean values of the V.R.S. ratios between inter. and major principal axis

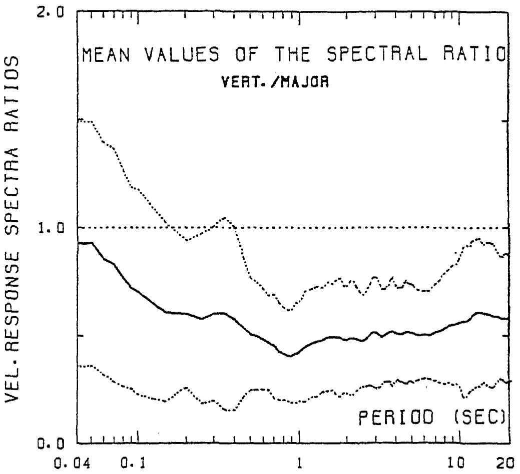

Fig. 6 Mean values of the V.R.S. ratios between vertical and major principal axis

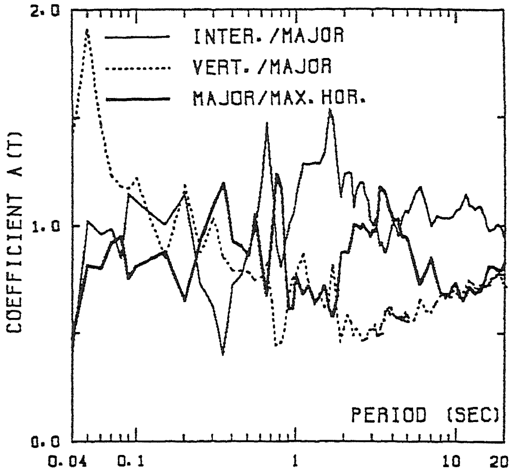

Fig. 7 The regression coefficient a(T)

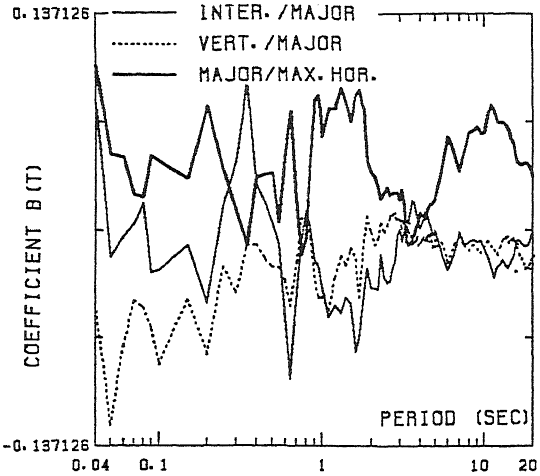

Fig. 8 The regression coefficient b(T)

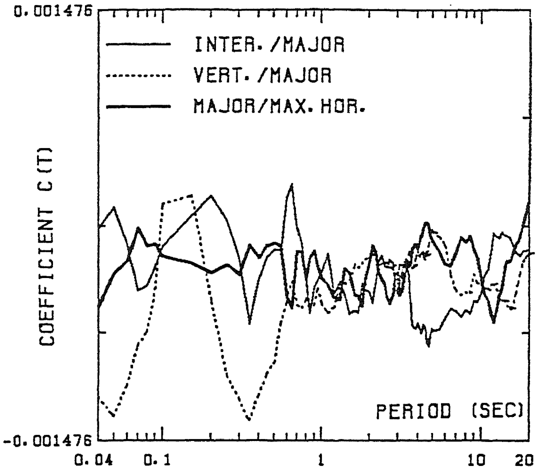

Fig. 9 The regression coefficient c(T)

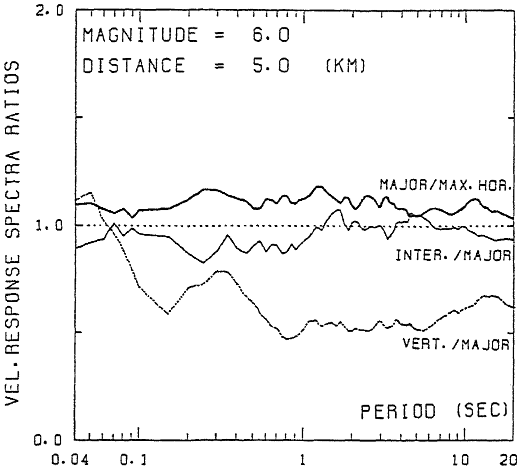

Fig. 10 Ratios of the (V.R.S.) estimated for magnitude 6.0, distance 5 Km.

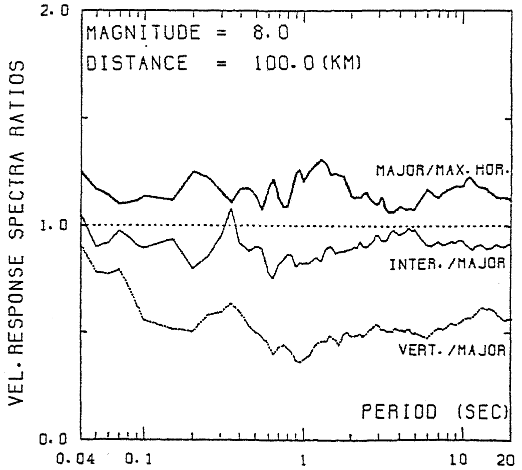

Fig. 11 Ratios of the (V.R.S.) estimated for magnitude 8.0, distance 100.0 Km

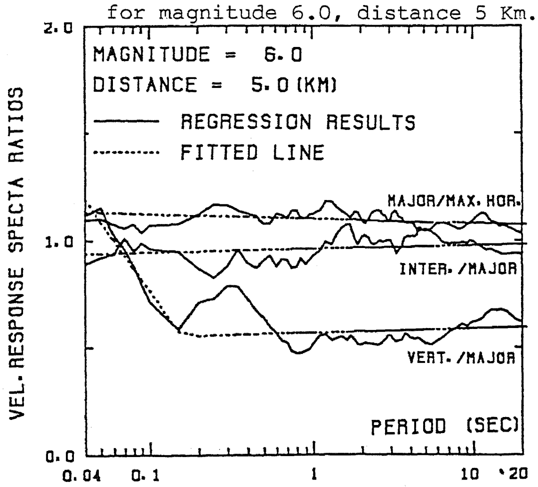

Fig. 12 The regression analysis result fitted for magnitude 6.0, distance 5 Km.