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Seismic hazard assessment in Greece based on strong motion duration

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ABSTRACT: Recognizing the importance of strong ground motion duration in seismic hazard, the available strong motion records of shallow events in the area of Greece were used for the estimation of duration for various threshold levels of the horizontal ground acceleration. The measurements were made by the use of the corrected data and a relation was derived between this duration and the surface wave magnitude, the epicentral distance, the soil conditions and the threshold level considered. The strong motion duration determined by this relation was used as a parameter for the seismic hazard assessment. The McGuire's EQRISK computer program was used for 7 selected cities in the area of Greece which are affected mostly by shallow events. The results are consistent with those obtained in terms of peak ground acceleration.

1 INTRODUCTION

One of the main parameters characterizing the strong earthquake motion is duration. This duration, determines the nμmber of loading cycles during vibration and together with the overall amplitudes of the induced response may have a major contribution in governing the results of any response to strong earthquake ground motion (Bertero, 1991). Moreover the strong motion duration is a sensitive function of wave frequency, amplitude threshold and earthquake size.

Because of its interest to engineers and seismologists, several studies have been made on characteristics of the duration of earthquake ground motions. Pioneering studies on the problem can be considered those of Esteva and Rosenblueth (1964), Housner (1965) and Bolt (1974). Some new attempts have considerably improved our knowledge on this problem (Trifunac and Brady, 1975; Dobry et al., 1978; McGuire and Barnhard, 1979; McCan and Shah, 1979; Vanmarcke and Lai, 1980; Theofanopoulos and Drakopoulos, 1986; Kawashima and Aizawa, 1989; Sarma and Casey, 1990; Margaris et al., 1990.

In the present paper, the strong motion duration (S.M.D.) of shallow earthquakes in the area of Greece were used. This S.M.D. as calculated for various levels of strong ground motion (for the horizontal components) in the range 0.02g-0.10g is that called by Bolt (1974) bracketed duration. The elaboration of S.M.D. data shows that a linear relation is valid between the logarithm of the S.M.D. and the size of the earthquake, the lofarithm of distance, the soil conditions and the level of the strong motion amplitude considered. Presuming that the S.M.D. can be used as a parameter in the hazard assessment, this relation was applied in the EQRISK computer program (McGuire, 1976), for "soil" sites (S=0) and threshold level 0.02g in seismic hazard assessment for 7 sites of the area of Greece which are mainly affected by shallow earthquakes.

2 DATA USED AND METHODOLOGY

A data set of 107 horizontal accelerogram components from 39 shallow earthquakes in Greece (with surface wave magnitudes $4.5 \leq M_s \leq 7.0$, epicentral distances $1Km \leq R \leq 128km$ and focal depths $h \leq 18Km$) has been used in this analysis. Each accelerogram has been classified by local surface geology as "alluvium" or "rock" (Theodulidis and Papazachos, 1990;

Theodulidis et al., 1992; Pitilakis et al., 1992).

The definition of bracketed duration, D, that is, the time between the first and last excursion of the absolute value of acceleration above a prescribed level (e.g. $\geq 0.05g$), has been utilized in this paper. Bracketed durations for the thresholds 0.02, 0.035, 0.05, 0.065, 0.08 and 0.10g have been measured from published corrected accelerograms (Brady et al., 1978; Carydis et al., 1982, 1983; Margaris et al., 1989; Anagnostopoulos et al., 1987; Pitilakis et al., 1992; Theodulidis et al., 1992). Figure (1) shows the distribution of

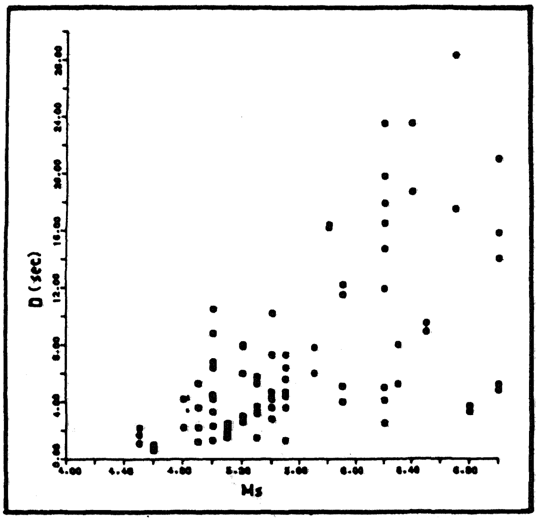

Fig.1 Distribution of S.M.D., D, versus surface wave magnitude, M_s.

data for level of bracketed duration $L \geq 0.02g$ in respect to magnitude and figure (2) in respect to distance. The lack of bracketed duration values greater than about 6 sec for distances between 30Km and 100Km is apparent. The number of observations for the various levels (L=0.02, 0.035, ..., 0.10) are 93, 77, 67, 54, 42, and 37, respectively. Near field data $R \leq 30$Km, from earthquakes with magnitudes $M_s \geq 6.0$ are quite few.

Assuming a logarithmic dependence of strong motion duration on magnitude (Dobry et al., 1978), the following relation has been examined:

$$\log D = a_1 + a_2 M \qquad (1)$$

for the six aforementioned levels, by using the total data set with $M_s \geq 4.5$.

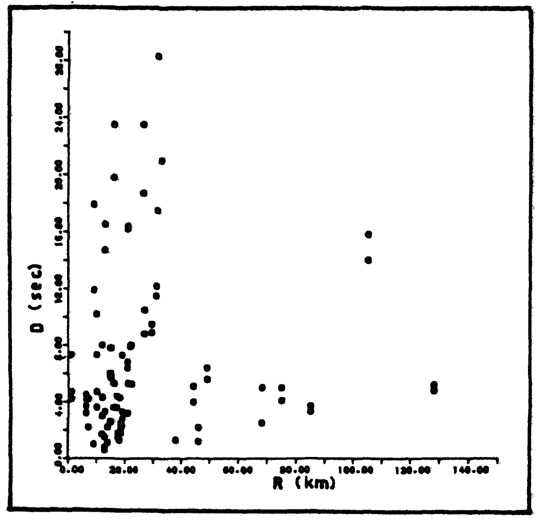

Fig.2 Distribution of S.M.D., D, versus epicentral distance, R.

The coefficients of equation (1) take the values $a_1=-1.26$, $a_2=0.35$. In figure (3), this relation is fitted to the observations for level L=0.02g. Similar plots have been made for the rest of the levels. It has

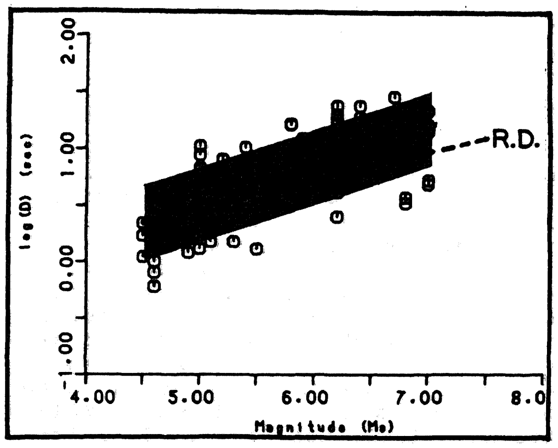

Fig.3 Comparison of S.M.D., D, and rupture duration, R.D., versus surface wave magnitude, M_s.

been observed that the best correlation with the rupture duration versus magnitude relation (Papazachos and Papazachou 1989) occurs for the level L=0.02g.

Assuming that the coefficient $a_2=0.35$ from equation (1) to be valid for the rest of the levels examined, the intersection coefficient a_1 was determined for each of all six levels. In figure (4), the six coefficients, a_1, are plotted versus the threshold level of acceleration. Least squares' method gives the relation:

$$a = -1.22 - 10.57L \qquad (2)$$

with a correlation coefficient r= 0.92.

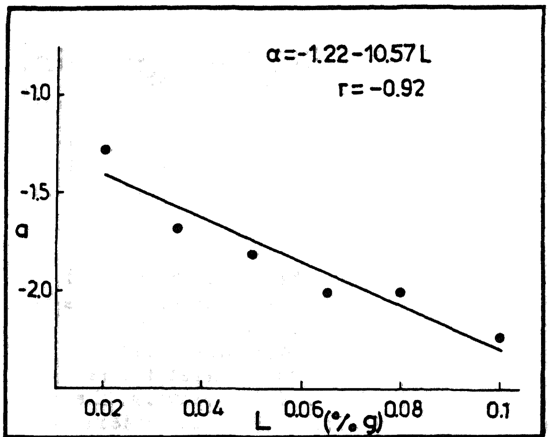

Fig.4 Coefficient a, versus threshold level of acceleration, L.

The adopted final model for data regression analysis was of the form (McGuire and Barnhard, 1979; Kawashima and Aizawa 1989):

$$\ln D = c_1 + c_2M_s + c_3\ln(R+R_0) + c_4S + c_5L + \sigma_{\ln D}P \qquad (3)$$

where M_s is the surface wave magnitude, R the epicentral distance, S a binary variable which takes values 1 for "rock" and 0 for "alluvium", L the relevant level of the predicted duration and P is 0 for 50 percentile and 1 for 84 percentile level of non-exceedence, considering normal distribution of the residuals. Scaling coefficients $c_1, ..., c_5$ are to be calculated from regression analysis and $\sigma_{\ln D}$ is the residuals root mean square resulting from equation (3). Coefficient R_0, which accounts for saturation with distance, has been adopted from peak ground acceleration attenuation relation for shallow earthquakes in Greece and is equal to 15Km (Theodulidis and Papazachos, 1990).

Given the magnitude coefficient c_2, as it has been determined by equation (1), the rest of the scaling coefficients were determined in the following three steps. In the first step, the distance coefficient c_3 was calculated, by using only the sample with bracketed duration level $L \geq 0.02g$ and magnitude $M_s \geq 6.0$. These data cover a wide range of distance $9Km \leq R \leq 128Km$, and the epicenters were calculated with high accuracy. In the second step, the coefficient c_4 of soil conditions was calculated, by using the sample with $L \geq 0.02g$ and magnitude $M_s \geq 5.0$, because these earthquakes are of engineering interest. In the third step, the bracketed duration level coefficient c_5 was determined, by using, from the total data set, only the data concerning the earthquakes with magnitude $M_s \geq 6.0$.

Based on the above calculated scaling coefficients of equation (3) the resulting relation is:

$$\ln D = 1.84 + 0.81M_s - 1.04\ln(R+15) - 0.19S - 27.7L + 0.76P \qquad (4)$$

In figure (5), a comparison between relation (4), for threshold level L=0.05g and two different soil conditions (S=0: soil and S=1: rock) and the relevant one based on Japanese strong motion data (Kawashima and Aizawa, 1989) is shown for M_s=6.5.

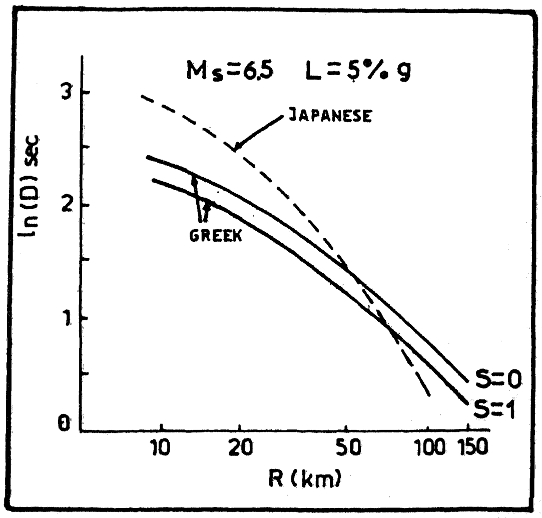

Fig.5. Comparison between the Greek, for two soil conditions (solid lines) and Japanese (dashed line) S.M.D. reducted to M_s=6.5, and L=5%g.

3 STRONG MOTION DURATION HAZARD ANALYSIS

The probabilistic analysis of earthquake ground shaking has become a standard procedure in Engineering Seismology for seismic risk assessment. Although considerable uncertainties are presented in a seismic hazard analysis (Cornell, 1968), the methodology of estimating the probability of exceedence of strong ground shaking is a useful tool in engineering practice.

Probabilistic seismic hazard maps have been published for various regions of the world by using similar strong motion parameters, such as P.G. acceleration or velocity, macroseismic intensity, RMS acceleration, etc (Algermissen et al., 1982; Kavazanjian et al., 1985). The S.M.D. is a vital parameter which should be mapped as well, in order to better estimate the seismic hazard at a site. The purpose of the present study is to determine first with what accuracy S.M.D. can be predicted and used in seismic hazard analysis, and second how it is correlated with the seismic hazard in terms of other strong motion parameters.

The methodology for performing probabilistic seismic hazard assessment has been described by several authors (McGuire, 1976; Mortgat and Shah, 1979). Based on the methodology proposed by McGuire (1976), probabilistic seismic hazard assessment was performed for various sites in Greece using S.M.D. as a hazard parameter.

The seismotectonic model used is the one proposed by Papazachos (1991), which considers 68 seismic sources of shallow earthquakes and is based on instrumental as well as historical data. The relation (4) was used for describing the dependence of the S.M.D. as a function of distance and magnitude for soil conditions "alluvium" (S=0) and threshold level L=0.02g. The calculations were performed by the EQRISK computer program (McGuire, 1976), for 7 sites in Greece, with different seismic hazard levels, as these levels were derived in terms of P.G. acceleration, P.G. velocity and macroseismic intensity (Papazachos et al., 1992). Figure (6) shows the expected P.G. accelerations as a function of the return period for these seven sites, (1:Argostoli, 2:Zakynthos, 3:Larissa, 4:Thessaloniki, 5:Patras, 6:Athens and 7:Kozani). The formula used for the attenuation of the peak ground acceleration was the one proposed by Theodulidis and Papazachos (1990), with seismotectonic model that used for the S.M.D. hazard analysis.

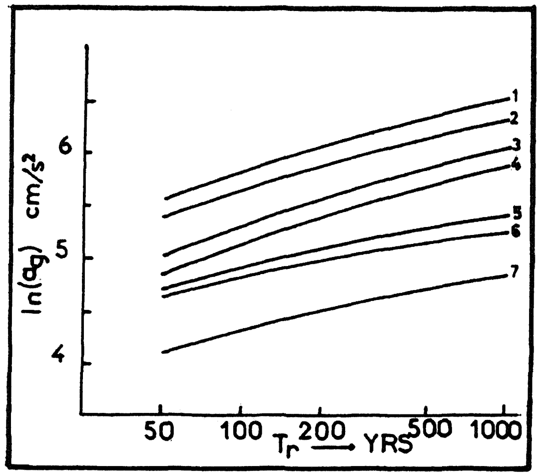

Fig.6. Seismic hazard curves of P.G. acceleration versus the mean return period, T_r, for the 7 examined sites in Greece.

The results of the hazard analysis in terms of the S.M.D. versus the mean return period, T_r, in years are presented in graphical form in figure (7) for the 7 aforementioned sites. From this figure and figure (6), one can observe that the hazard results obtained on the basis of two independent methods are very similar.

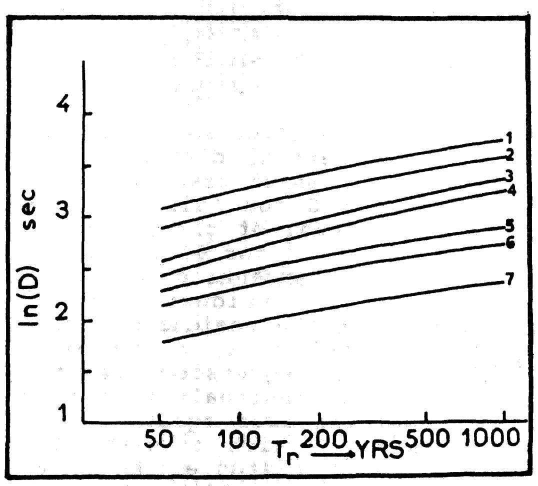

Fig.7. Seismic hazard curves of S.M.D. versus the mean return period, T_r, for the 7 examined sites in Greece.

In table (1) the results of the hazard analysis in terms of P.G. acceleration for return periods 50 and 500 years are given together with those obtained using the S.M.D. as hazard parameter for comparison.

Table 1. Results of the seismic hazard assessment for 7 sites in Greece in terms of S.M.D. and P. G. acceleration for T_r=50 and T_r=500 years.

Site id	T_r=50yrs S.M.D. (sec)	P.G.A. cm/sec^2	T_r=500yrs S.M.D. (sec)	P.G.A. cm/sec^2
1	21	266	37	576
2	19	220	31	476
3	14	151	25	342
4	12	116	22	297
5	10	112	17	201
6	9	110	14	178
7	6	60	9	111

4 CONCLUSION

The S.M.D. of the earthquakes in the area of Greece, D, versus the surface wave magnitude, M_s, is correlated quite well with the rupture duration versus M_s, for a certain threshold level of acceleration and magnitude range $5.0 \leq M_s \leq 7.5$. This correlation can give useful information concerning the total rupture time of earthquakes.

The estimation of S.M.D. as a function of surface wave magnitude, epicentral distance, local site geology and threshold level of acceleration is in good agreement with that derived from Kawasima and Aizawa (1989) who used an extent catalogue of Japanese strong motion data.

The seismic hazard analysis results in terms of S.M.D. are consistent with results of similar analysis in terms of P.G acceleration. This shows that zonation based S.M.D. is also valid, encouraging the incorporation of expected S.M.D. in seismic hazard maps.

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