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SCALING OF NORMAL FAULTING EARTHQUAKE RESPONSE SPECTRA IN GREECE

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ABSTRACT

A data set of 8 strong motion records produced by normal faulting earthquakes are scaled in order to predict future ground motions at a site 20 Km away from a normal fault capable to produce an earthquake of surface wave magnitude equal to 5.5 and 6.5, respectively. The proposed spectra were also compared with the results based on a different methodology. In spite of the scatter in the scaled spectra, the predicted spectra seem to represent, within acceptable errors, quite accurately this type of ground motion for future earthquakes in Greece, as it was shown from the comparison of these spectra with spectra obtained using accelerograms of recent earthquakes. The near source effects and soil conditions seem to strongly influence the obtained records which differ considerably from the average spectra.

ΠΕΡΙΛΗΨΗ

Οκτώ επιταχυνσιογράμματα απο σεισμούς που προέρχονται από κανονικά ρήγματα χρησιμοποιούνται προκειμένου να προβλεφθεί η ισχυρή σεισμική κίνηση σε μια θέση που απέχει 20 Km από ένα κανονικό ρήγμα που μπορεί να δώσει σεισμό μεγέθους 5.5 και 6.5.

Τα προτεινόμενα φάσματα συγκρίθηκαν επίσης και με αντίστοιχα φάσματα διαφορετικής μεθοδολογίας. Αν και τα φάσματα που προέκυψαν παρουσιάζουν διασπορά, εντούτοις φαίνεται ότι προσομοιάζουν ικανοποιητικά τις μελλοντικές ισχυρές κινήσεις από τέτοιους σεισμούς στη χώρα μας, όπως προκύπτει από τη σύγκριση των προτεινόμενων φασμάτων με αντίστοιχα ανηγμένα φάσματα πρόσφατων σεισμών. Η επίδραση της εστίας στις εγγραφές του κοντινού πεδίου και οι τοπικές εδαφικές συνθήκες επηρέασαν σημαντικά τα φάσματα, τα οποία παρουσίαζαν σημαντικές διαφορές από τα μέσα φάσματα.

INTRODUCTION

The characterization of earthquake strong motion for engineering purposes requires the level of shaking, its frequency content and the significant duration of motion. The frequency content is most usually defined by the shape of a response spectrum, while the level of motion has been defined by parameters such as peak ground acceleration or Housner's spectral intensity (Housner, 1970). Several studies of strong ground motion records are available, showing the values and ranges of variation if the level of shaking and the frequency content, as well as the influence of

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magnitude, distance to source and site conditions on these parameters (Donovan, 1972; Espinosa, 1977; Theodulidis, 1991; Theodulidis and Papazachos, 1992, 1994).

A thorough assessment of the seismic risk associated with any structure requires first a careful assessment of seismic hazard (seismic ground motion as a function of probability) and subsequently an assessment of the response of the structure, in question, to this range of ground motions. Such an assessment will provide information on the consequences to the public i.e. the hazard to the public.

The seismic activity in Greece (Aegean and the surrounding area) has a long documented history and many of the reported earthquakes have caused great destruction and many casualties (Papazachos and Papazachou, 1989). Consequently, earthquake hazard analysis in this region is of great importance.

Many people have worked in the seismic hazard assessment in the broader Aegean area, among which are Galanopoulos (1968), Algermissen et al. (1976), Drakopoulos (1977), Makropoulos (1978), Papaioannou (1984), Papazachos et al. (1992, 1993), Papaioannou et al. (1992).

In the present paper, a procedure is described for the evaluation of response spectra in Greece based on strong motion records. Since peak acceleration is the parameter greatly used by the engineers for static seismic design, as well as a scale factor for response spectra and because its attenuation relations have been more extensively studied, we shall restrict our demonstrations explicitly to the use of this parameter.

AVERAGE RESPONSE SPECTRA IN GREECE

In the following, we use an analysis to estimate future ground motions in Greece using the recorded accelerograms. In order to make an a-posteriori comparison we use the records up to 1984 caused from normal earthquakes.This type of faulting is dominated over the mainland of Greece (Papazachos et al., 1991). The premise of this study is the assumption that future ground motions will be similar to those that have been already observed in previous earthquakes. For this reason, peak ground acceleration was chosen as the single parameter characterizing ground motion. A data set of 8 strong motion records from past earthquakes in Greece were used and the relevant information is given in table (I). All accelerograms correspond to free field conditions on soft alluvium type soils. The records have been corrected and analyzed to obtain the response spectra, by the staff of the National Technical University of Athens and are published in Brady et al. (1978), Carydis et al. (1982), (1983).

It is true, however, that the present data set is small to encompass the wide variation in tectonic and site conditions which may be encountered. In order to alleviate to some degree this problem, we decided to scale only those records which are appropriate for the conditions of a particular design earthquake.

The procedure suggested by Guzman and Jennings (1976) is adopted in the present study, which involves scaling records with attenuation formulae which are based upon a characterization of peak acceleration. For this purpose, the following attenuation law for peak acceleration proposed by Papaioannou (1984), is used:

$$lnA = 8.69+0.89\ M_S - 2.37\ \ln\ (\Delta+23) \qquad (1)$$

where A is measured in cm/sec2, Δ in km and Ms is the surface wave magnitude. The data set of records chosen for scaling, Table (I), corresponds to shallow

Table I: Information on the strong motion records used in this study.

No	Name-Date-Location	Δ(km)	Ms	Soil-Instr.	PGA (cm/sec2)
1	PAT1 Jan. 29, 1974 15:12:43 Patras, 38.3°N, 22.0°E	17	4.4	Alluvium SMA-1	48
2	PAT2 Apr. 4, 1975 05:16:18 Patras, 38.1°N, 22.1°E	32	5.5	Alluvium SMA-1	60
3	XYL May 13, 1975 00:22:50 Xylocastro 38.2°N, 22.7°E	15	4.3	Alluvium SMA-1	50
4	COR1 Oct. 12, 1975 08:23:10 Corinthos 37.9°N, 23.1°E	16	5.0	Alluvium SMA-1	87
5	THES1 July 4, 1978 22:23:28 Thessaloniki 38.3°N, 22.0°E	17	5.1	Alluvium SMA-1	89
6	THES2 June 20, 1978 20:03:34 Thessaloniki 38.3°N, 22.0°E	30	6.5	Alluvium SMA-1	160
7	COR2 Feb. 24, 1981 20:53:37 Corinthos 38.1°N, 22.9°E	20	6.7	Alluvium SMA-1	314
8	COR3 Feb. 25, 1981 02:35:54 Corinthos 38.1°N, 23.1°E	20	6.3	Alluvium SMA-1	220

normal faulting earthquakes and cover a wide variety of magnitudes. In order to perform the scaling, we have grouped the records in two sets. One set corresponding to the records of the small magnitude earthquakes, (listed as 1 to 5 in Table I) and another one for the large magnitude earthquakes (number 6 to 8 in Table I). Perhaps, the most difficult problem to address involves estimation of ground motion at sites which lie close to the source of a large earthquake, since there is virtually no data for such circumstances. Lacking direct measurements we are forced to hypothesize what the ground motion might be based upon indirect information. All the records which are scaled here correspond to normal dip slip earthquakes. In order to keep the number of assumptions and sources of error to a minimum, we tried to use records which required as little scaling as possible.

Therefore, beginning from these thoughts, we assumed a site which lies at a distance of 20 Km away from a normal fault, having dimensions appropriate to produce an earthquake with a surface wave magnitude equal to 5.5 in the first case and to 6.5 in the second. In both cases, the site conditions are assumed to be of alluvium hardness. Records numbered 1,2,3,4,5 (Table I) are scaled for the postulated 5.5 magnitude earthquake, while records numbered 6,7,8 for the postulated 6.5 earthquake.

The next step was to compute the expected ground acceleration at the site, Asite, for the two postulated earthquakes using equation (1). This scaling function predicts peak values of ground acceleration equal to 0.11 g for the 5.5 and 0.28g for the 6.5 postulated earthquakes, respectively, occurring at a distance of 20 Km from the site.

The scaling factor, S, with which each record was multiplied, was found by the relation:

$$S = \frac{A_{site}}{A_i} \qquad (2)$$

where A_i is the computed acceleration at each station for the given magnitude and distance from the source.

Table (II) summarizes the values of the scaling factors for each of the records used. The response spectra of each station were hand digitized for the period range 0.05 - 5sec, with digitization step equal to 0.01 sec. The reading at each period was multiplied by the corresponding scaling factor. The end of this process was an ensemble of records, which should be representative of the types of motion expected at the study site. We have scaled the records of the horizontal components only, both longitudinal and transversal for each station, and for 0,2,5,10,20% of the critical damping. Since the derived scaled spectra were identical, the averaged ones from both horizontal components of each station were used.

The above mentioned procedure provides a representative sample of the types of motions which have occurred for conditions similar to those at the study site. The way in which the set of scaled records is used for design depends upon the particular application. In our case, the output of this analysis is a free-field design response spectrum of absolute acceleration. This was chosen to be the average spectrum of all the scaled spectra.

Table II: Computed values of the scaling factors for each record used in this analysis. (Numbers correspond to Table I, see text for further information).

No	Station Name	Scaling Factor	No	Station Name	Scaling Factor
1	PAT1	2.25	5	THES1	1.21
2	PAT2	1.80	6	THES2	1.64
3	XYL	2.16	7	COR2	0.84
4	COR1	1.24	8	COR3	1.20

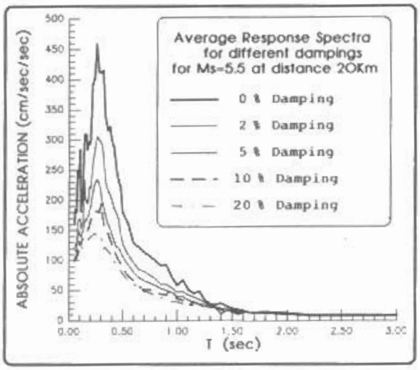

Fig.1: *Average response spectra of five records from normal fault earthquakes which are scaled to a distance of 20 km and a magnitude of 5.5.*

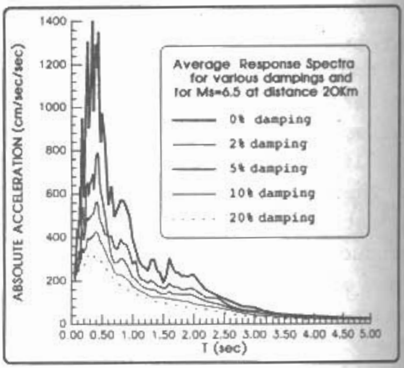

Fig. 2: Average response spectra of three records from normal fault earthquakes scaled to a distance of 20 km and to a magnitude of 6.5.

Figures (1) and (2) represent the free field design response spectra (for 0, 2, 5, 10, 20% dampings) for the postulated earthquake of magnitude 5.5 and 6.5, respectively. It is observed that the peak values for the 5.5 magnitude earthquake are found in the short periods (0.25) while for the 6.5 magnitude earthquake are shifted to the longer periods (0.5). This is in agreement with the well known observation according to which the lower magnitude earthquakes are relatively richer in high frequency energy compared to the larger magnitude earthquakes.

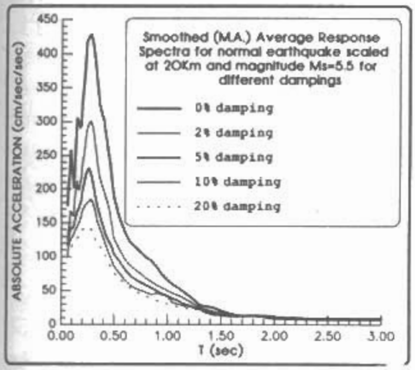

Fig. 3: Smoothed version of the response spectra of fig.1 using a moving average filter.

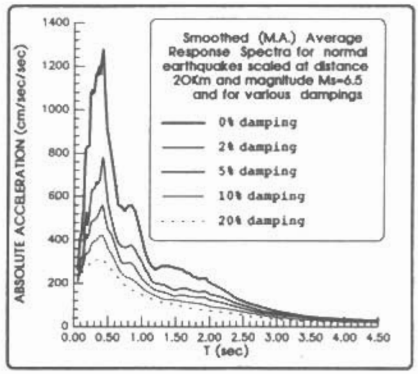

Fig. 4: Smoothed version of the response spectra of fig. 2 using a moving average filter.

Figures (3) and (4) represent the smoothed versions of figures (1) and (2), respectively, using a moving average filter.

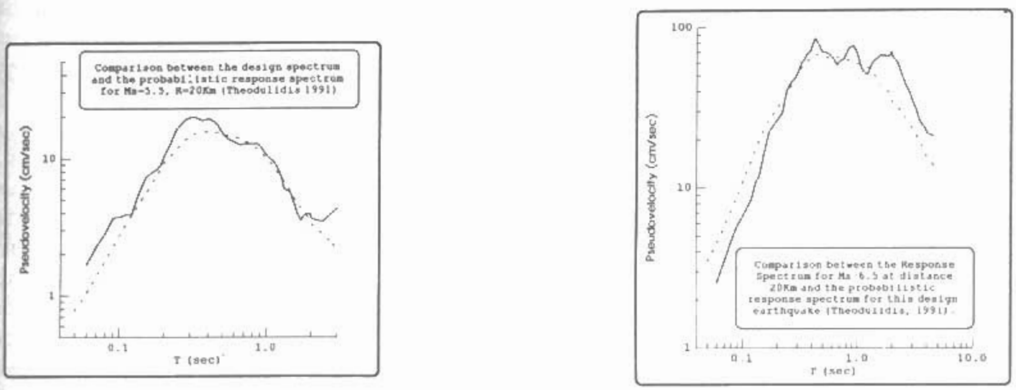

Fig. 5: Comparison between the average response spectrum and the corresponding probabilistic response spectrum (Theodulidis, 1991) for design earthquake with Ms=5.5 at a distance of 20 Km (5a) and design earthquake with Ms=6.5 at a distance of 20 Km (5b).

Figure (5 a,b) shows a comparison between the smoothed response spectra in figures (3) and (4) for 0% damping (continuous line) with the probabilistic response spectra for the two postulated earthquakes according to Theodulidis (1991) (hatched line). It is obvious that the two methods give almost similar

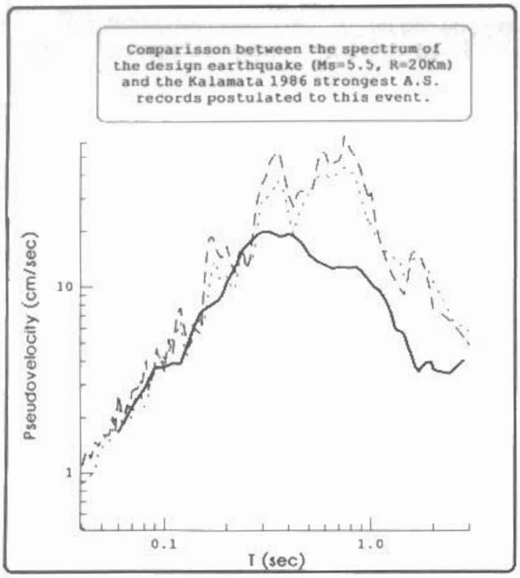

Fig. 6: Comparison between the average response spectrum (Ms= 5.5, R=20 Km, continuous line) and the Kalamata 1986 records of the strongest aftershock, postulated to the previous event (hatched lines).

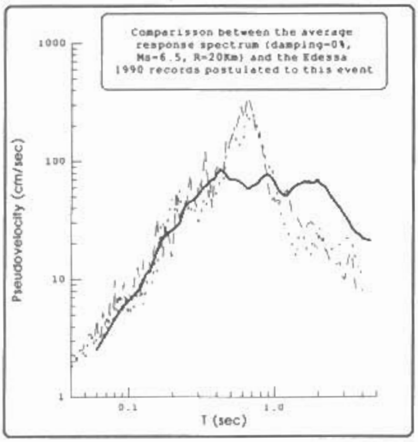

Fig. 7: Comparison between the average response *spectrum (Ms= 6.5, R=20* Km, continuous line) and the Edessa 1990 records postulated to the previous event (hatched lines).

results, even though the data set used in the second case was much greater.

In order to examine some uncertainties of the method, we scale the response spectra of recent normal faulting earthquakes (after 1984) to the two design earthquakes. Four records were used. The first, second and third were those obtained from the Kalamata main shock (Sept, 13, 1986, Ms=6.1) and its largest aftershock (Ms=5.5). The epicentral distance of the first one was about 15 Km, while the aftershock was very close to Kalamata. The response spectra of the main shock (postulated to an event of magnitude Ms=6.5 recorded at 20Km) was found in a very good agreement with the proposed average response spectrum. A good agreement was also found for the records of the strongest aftershock recorded at Messini. Some differences were observed in the comparison of the record of the strongest aftershock recorded at Kalamata. Figure (6) show the proposed average response spectrum for an earthquake of magnitude Ms=5.5 recorded at 20Km (continuous line) and the response spectra of the postulated two horizontal components of the strongest Kalamata earthquake recorded at the city (hatched lines). It can be seen that for periods T<0.2 sec there is a good agreement, while for higher periods the average spectrum predicts much smaller spectral values. This is probably due to the fact that the recording site was within the deformation area of this earthquake and for this reason the records were strongly influenced by the near source effects. Figure (7) shows the postulated response spectra of the two horizontal components (for damping 0%) of the Griva earthquake (Dec. 21, 1990; Ms=5.9) recorded *at Edessa (hatched lines) and the average* response spectrum of figure (3) drawn by continuous line. The three spectra seems to match well for periods T<0.35 sec. For higher periods the difference is important and is most probably due to the local site conditions. Lekidis et al. (1991) concluded that the predominant period of the local site conditions (T=0.5 sec) influenced considerable the record, even though they also discuss that the dynamic soil-structure interaction affected the records.

The scaled response spectra for the records in our ensemble even though they show a scatter, which sometimes exceeds an order of magnitude, they appear to accurately represent our ability to parameterize strong ground motion in terms of magnitude and, epicentral distance for a given type of faulting. As it is obvious from the comparison shown in figure (7), these average spectra must be scaled in an appropriate way in order to consider finally also the local site conditions if they are available. This is due to the fact that the local site conditions affects strongly the frequency content of the ground motion and consequently the degree of damage.

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