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Site specific design motions at a site near Pyrgos city, western Greece

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ABSTRACT

Site specific design motions have been derived at the construction site of the new National hospital of Pyrgos, Western Greece. An analysis of the relevant contribution of all the seismic sources affecting the site, has been performed taking into account the detailed seismotectonic features of the region. By combining stochastic and deterministic methodologies, the expected basement acceleration time histories have been constructed taking into consideration both source and path effects. The results from a detailed shallow seismic reflection investigation were combined with the data from geotechnical investigations and were used to construct the site's model which was used in calculating the effect of the upper layers on the expected wavefield at the site. The amplification factor for the site was computed and the modified site specific design spectrum was computed according to the new Building Code of Greece. Finally the acceleration time history corresponding to the previous design spectrum was computed in order to be used in the dynamical analysis of the building.

1 Introduction

The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. This influence must be revealed and accounted in earthquake-resistant design. In this article the procedure for designing site specific motions for an area in western Greece is presented. The study area is located at the outskirts of the city of Pyrgos where the city's new hospital is planned (Fig.1). The city of Pyrgos, located near the Hellenic subduction zone and surrounded by several active faults (Fig.1) has experienced many earthquakes in the past. Recently a moderate magnitude earthquake took place 3km SE of the city (26 March 1993, M_s=5.2 Melis et al[8]). This earthquake caused considerable damage to the city's buildings. 370 houses had to be temporarily or permanently evacuated, one of them was the city's old hospital, Bouckovalas[1].

The procedure that we followed in deriving the site specific design motions is the following. Firstly, the seismotectonic regime was examined and the seismic sources capable of producing significant ground motions at the site were derived. Based on these results, synthetic ground motions for the site's bedrock were computed. A 1-D geological model of the site was constructed combining data from geotechnical and geophysical investigations. Finally, using SHAKE, Schnabel et al[11], the amplification factor for the site was computed and was used to modify the design spectra proposed by the new Building Code of Greece.

2 Geology of the area

The city of Pyrgos and its surroundings is characterised by intense neotectonic deformation (Fig.1) and high seismicity. More specifically this area is part of the Pyrgos neotectonic basin. The neotectonics of this area are characterised by three main trends of normal faulting which formed in Middle-Upper Miocene. In general we can classify three main categories of fault trends, NW-SE, E-W and NE-SW (Fig.1).

After the March 1996 earthquake a microzonation investigation was carried out in the city of Pyrgos. Following the results of that study, the geological formations underlying the Pyrgos city can be divided into the following three groups, Marinos et al[6].

Group I: Alluvial deposits. They cover the plain lowland and mainly consist of grey soft clays, brownish-grey silty sands and silts. The total thickness of these formations is less than 20m. In the southern and eastern parts of the town, their thickness becomes less than 5m, while in the northern and western parts it increases rapidly.

Group II: Pleistocene deposits. They cover the greater part of the Pyrgos city, with a thickness of 5-20m, and consist of brownish-red clays or silty sands with some fine gravels, and brown clayey sands in alteration with brownish-yellow sandy clays or sandy silts. Loose conglomerates are also developed locally.

Group III: Marly bedrock. It outcrops at the central part of the town and consists mainly of brownish-yellow, silty or sandy marls, becoming grey to greyish-blue in colour and more silty or clayey with increasing depth. These marls are thin-bedded at places and include interlayers of sands or sandy silts, sandstone and lignite up to 2m thick. Its thickness in the area of Pyrgos is well above 50m.

Group I (alluvial deposits) is exposed at the surface of the study area. Borehole results show also that the same formation continues up to a depth of 25m where these boreholes stop.

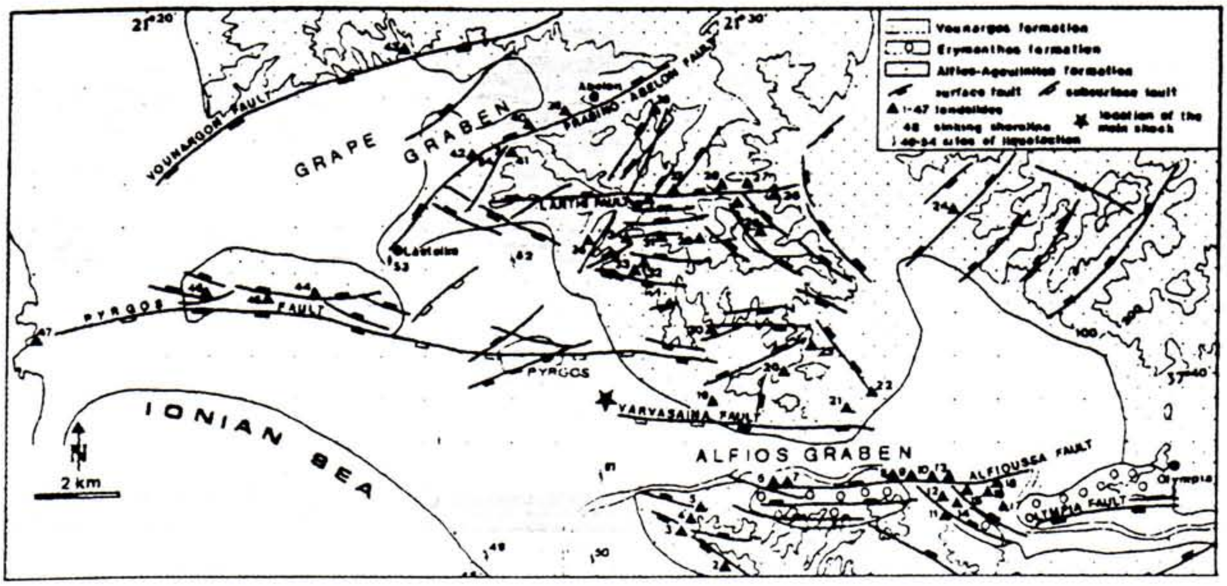


Figure 1: Simplified geological map of the Pyrgos Basin, including major faults and structures, after Koukouvelas et al[5].

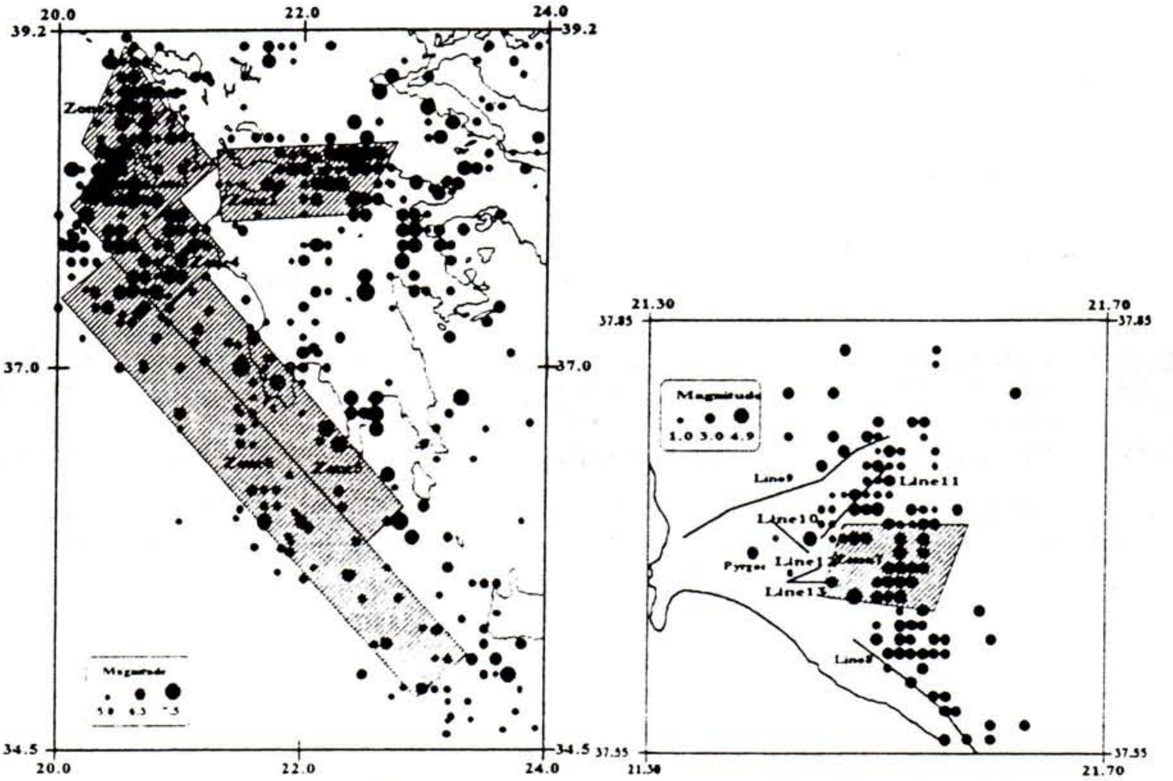
3 Probabilistic seismic hazard assessment for the area

A standard Probabilistic Seismic Hazard Analysis (PSHA) was conducted for the area of Pyrgos. The west Greece seismic sources, as proposed by Papazachos[10] were combined in the computation with local seismic sources (Fig.2a,b). Seismological and seismotectonic data recently available were used, in the definition of local seismic sources Melis et al[8], Koukouvelas et al[5].

In order to understand the contribution to the hazard, for each source, we followed the analysis proposed by McGuire[7]. The hazard was computed for two natural frequencies (1 and 10Hz) and the results where compared with each other to find out if one source dominates the hazard at both frequencies or if different sources dominate at different frequencies.

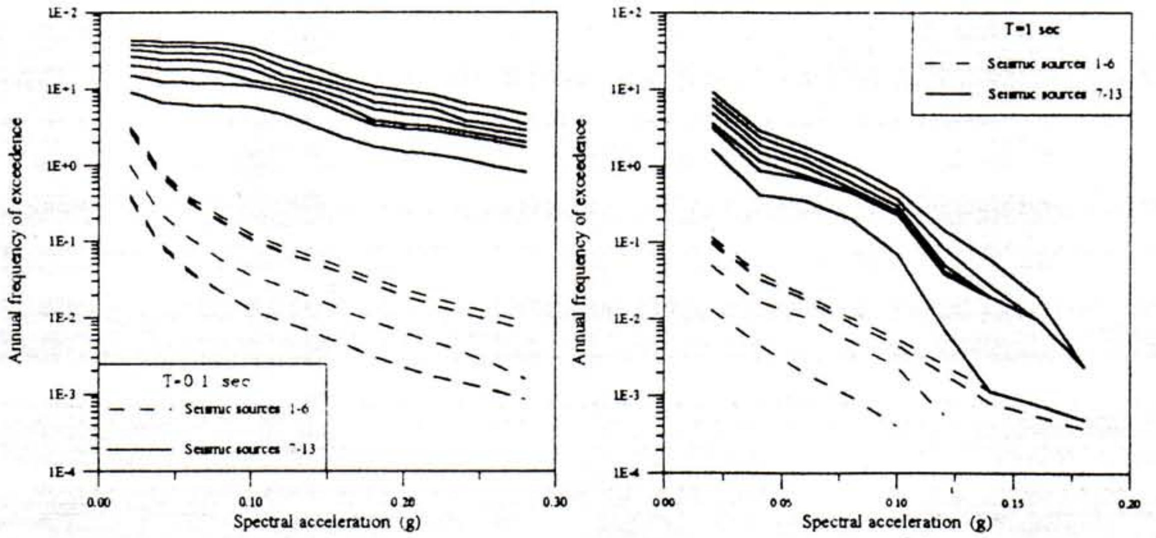
The seismicity parameters (a, b, M_{max}) required in the computations where derived using the technique proposed by Kijko & Sellevoll[4], combining historical and recent seismological data. The attenuation functions used were the PSV and PHA attenuation equations, recently proposed by Theodulidis & Papazachos[12,13] for Greece.

The PSHA results are presented in Fig.3a,b. As it can be seen, the hazard is controlled by local sources in both frequencies (1 and 10Hz) but for the 1Hz (T=1sec) case the difference between the two sets is significantly smaller. Thus we decided to include in our synthetics the case of a big earthquake from a far epicentral distance. The peak horizontal acceleration with a 50% probability of non exceedence, for the next 50 years, as proposed by the new Building Code, was also computed and found to be 0.24g for the area of Pyrgos.



(a) (b)

Figure 2: a) Regional seismic sources b) Local seismic sources around Pyrgos. Sources correspond to the seismotectonics of the area as described by Melis et al[8].



(a) (b)

Figure 3: a) Contribution to the hazard by source for T=0.1sec b) Contribution to the hazard by source for T=1sec

4 Synthesis of seismic motions at the bedrock

After computing several synthetic seismograms for the region, three seismic motions were adopted to be used in the site's response analysis.

The first seismic motion chosen (EQ1) was the (T) component of the Pyrgos 1993 earthquake recorded in the city of Pyrgos with a peak acceleration of 0.45g. The second (EQ2) was the (T) component of a recording, at the National Observatory of Athens (N.O.A.), Kalogeras & Stavrakakis[3], Amaliada station, close to Pyrgos, of an earthquake occurred in the seismic zone 4, which is very active and has maximum magnitude M_{max}=6.8. Finally the recording of a large magnitude earthquake at long epicentral distance (>100km), was chosen as the third seismic motion (EQ3) and it was used to simulate big earthquakes from zones 5 or 6. The accelerograms and the response spectra of the three recordings are presented at Figs.5 and 6.

The recordings were scaled to a maximum acceleration compatible with the one computed in the previous PSHA step.

5 Site investigations

Five exploratory boreholes were drilled during the geotechnical investigation of the area. Insitu standard penetration tests (SPT) were carried out at all the boreholes and soil samples were taken. The soil samples were subjected to classification tests and undisturbed sample tests were also carried out for the determination of the wet bulk density. Unfortunately, all the boreholes ended at 25m depth, without reaching the bedrock. Thus a geophysical survey was planed in order to understand better the bedrock depth and the seismic wave velocities in the area.

Two shallow seismic reflection lines were contacted using a 24 channel, digital seismograph and a Buffalo gun as a seismic source. Based on the seismic reflection results (Fig.4a), the bedrock was found at 50m depth. The results from the Pyrgos microzonation study, indicate a shallower depth for the bedrock, in the city centre, but the area of our investigation is almost 1km NE of the city outskirts and also the sediments are displaced towards NE by neotectonic faults.

6 Seismic response analysis

Based on the model proposed by the boreholes and the geophysical investigation, (Fig.4b) we computed the site's 1-D response to the three synthetic motion we derived in a previous step. The distribution of shear wave velocities with depth was derived using two empirical formulas - one for cohesive soils (PI>7%) (eq.1) and one for cohesionless soils (PI<7%) (eq.2)- between Standard Penetration Test (SPT) counts and shear wave velocity. The formulas were recently proposed by Bouckovalas[1] for the area of Pyrgos.

$$V_s=110N_{spt}^{0.33}\ \text{(m/s)} \tag{1}$$

$$V_s=76\ N_{spt}^{0.40}\ \text{(m/s)} \tag{2}$$

The above equations were derived after correlation of SPT data, with data from Cross-Hole measurements, executed during the microzonation study of the city of Pyrgos.

In the response analysis the program SHAKE91 was used, Schnabel et al[11]. SHAKE is using the equivalent linear method to compute the response of a set of layers overlying a halfspace. In Fig.5a we present the computed seismic motions at the surface of the site and in Fig.5b the corresponding spectra. An amplification ratio is computed, Fig.6, dividing the motion spectra at the bedrock with the motion spectra at the surface.

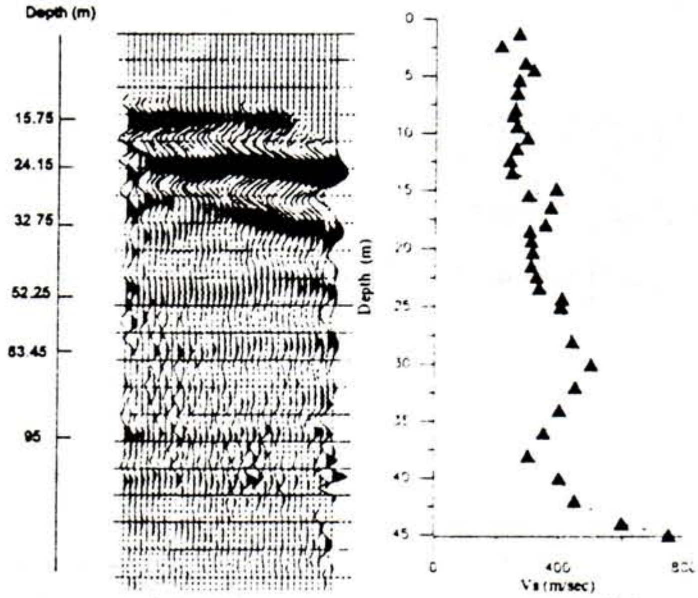


Figure 4: a) Results from the seismic reflection survey, b) variation of shear wave velocity with depth, used in the seismic response analysis.

The results of the response analysis are summarised in the Table 1, for the three earthquakes used as excitation motions at the bedrock. The peak acceleration for every earthquake is given, at the bedrock and at the surface. Also the predominant period (T) and the amplification ratio (A) are given. The mean amplification ratio is found 1.6 and is used in the computation of the design spectra.

	Bedrock	Surface	A	T (sec)
EQ 1	0.45g	0.64g	1.43	0.4-0.9
EQ 2	0.29g	0.4g	1.38	0.4-0.8
EQ 3	0.29g	0.6g	2.0	0.4-1.0
		Mean	1.6	

Table 1: Peak accelerations at the bedrock and at the surface of the site, amplification ratio and period of maximum amplification for the three studied earthquakes.

In order to check the validity of our computations, after the seismic response analysis, a study of microtremors at the construction site was performed. The standard technique of spectral ratios relative to a bedrock site and the technique of the ratio of horizontal to vertical component (Nakamura[9]) were used. The results were in good agreement with the results taken from the theoretical computations, both in the amplification factors and the amplification period.

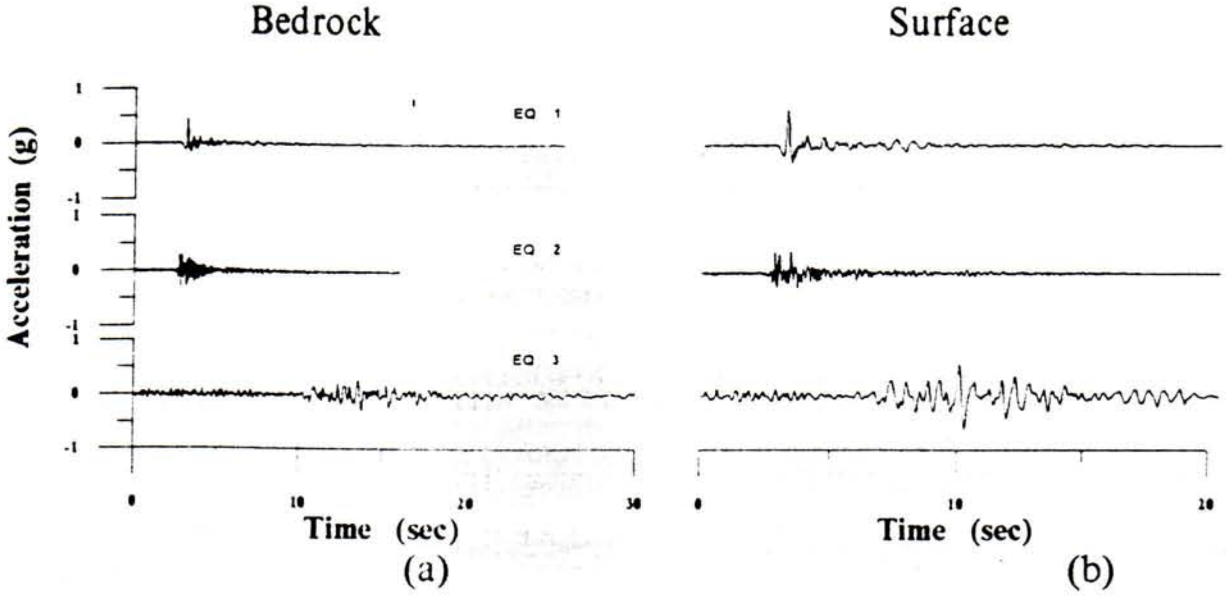


Figure 5: a) Accelerograms at the bedrock and b) at the surface for the three earthquakes used in the analysis.

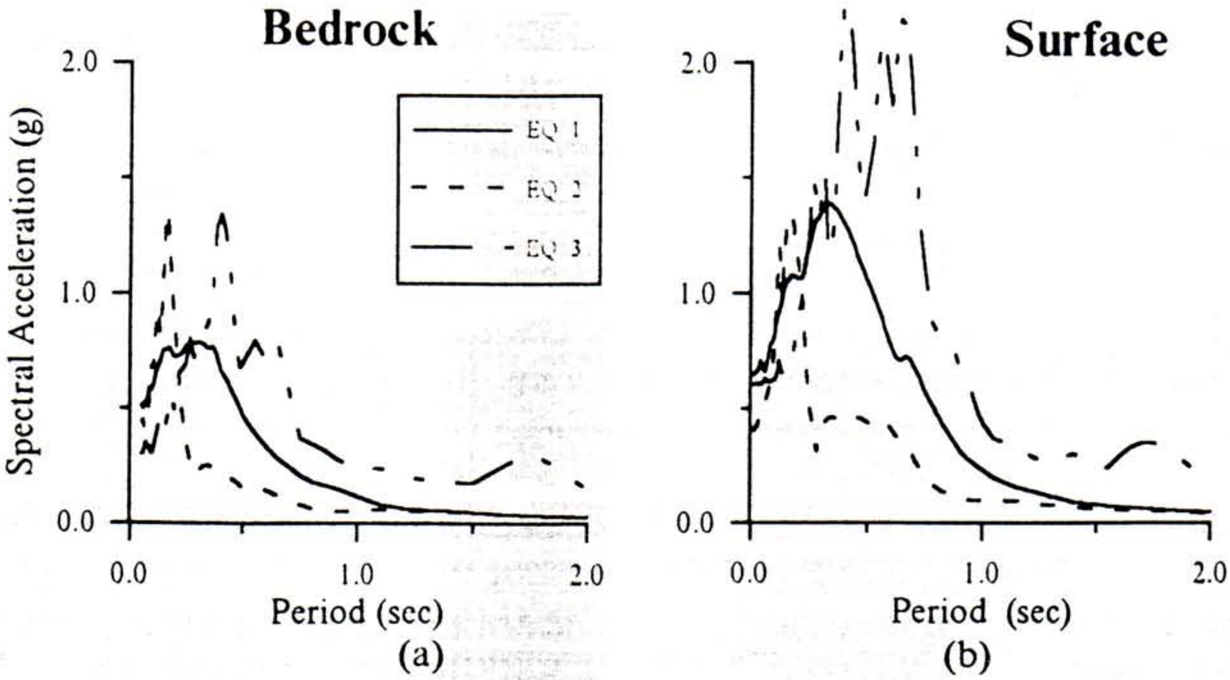


Figure 6: Response spectrum for the three earthquakes at a) the bedrock and b) the surface.

7 Design spectra according to new Building Code of Greece

According to the new Building Code of Greece the elastic design spectrum is given by the following equation

$$A\beta_d(T) = \begin{vmatrix} A\beta_o & for \quad T < T_2 \\ A\beta_o(T_2 / T)^{2/3} & for \quad T_2 < T \end{vmatrix} \tag{3}$$

where A is the acceleration at the surface, β_o is an amplification coefficient, T_2 is the characteristic period of the spectrum, β_d is the modified elastic spectrum and T the period. From our previous analysis, multiplying the 0.24g at the bedrock by 1.6 amplification ratio, an acceleration A of 0.38g is produced. The value used in the design of the spectrum is the RMS (80%) value according to the Building Code (0.3g). The period T_2 is been given by the Building Code according to the soil conditions and in our case equals 0.7sec. Finally, β_o is also given by the Building Code and is equal to 2.54. This value was also modified to correspond to the local site conditions and according to the response analysis it had to be increased by 20%. The design spectrum produced by these computations is shown in Fig.7a.

Following the computation of the design spectrum, the corresponding accelerogram was derived following the method by Gasparini & Vanmarcke[2]. The produced accelerogram is shown in Fig.7b.

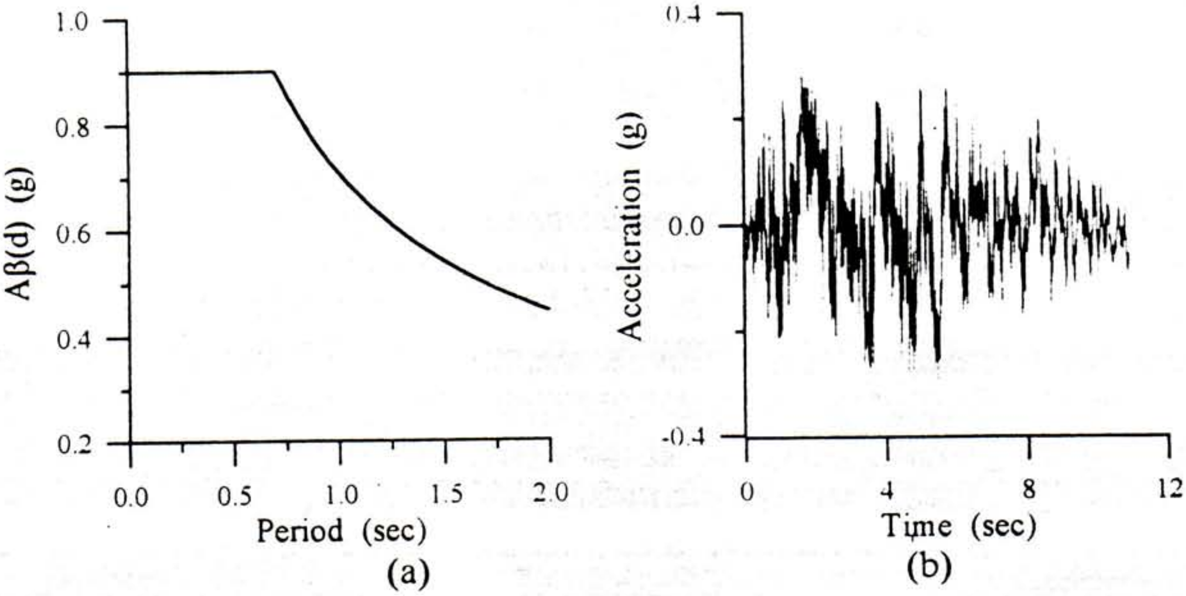


Figure 7: a) Proposed design spectra and b) corresponding accelerogram.

Acknowledgements

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