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AN APPLICATION OF CORNELL'S CLASSICAL APPROACH TO SEISMIC HAZARD ANALYSIS OF VOLOS, CENTRAL GREECE

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ABSTRACT

The estimation of seismic hazard of an area is of primary importance in earthquake engineering. This paper deals with the application of Cornell's classical model for the evaluation of the future seismic loading in the city of Volos, central Greece.

The model is based on the combination of the main seismotectonic features of small seismic sources with the recurrence model of each source. The assessment of seismic hazard involves four stages: (i) delineation of potential seismic sources around the site of interest, (ii) determination of the recurrence model of earthquakes in each source, (iii) attenuation model and (iv) estimation of the contribution of all sources to the site.

Two attenuation models are used in the application, giving similar hazard values. A close inspection of the detailed numerical results reveals the level of the contribution of each source to the estimated hazard: Source 1, south to the city of Volos, contributes about 70% of the total hazard to the city.

The sensitivity of the model to a certain number of input parameters is further investigated using alternative values and repeating the calculations.

INTRODUCTION

The probabilistic method of seismic hazard analysis developed by Cornell (1968) is mainly based on the delineation of the potential seismic sources distributed around the site of interest and the seismicity parameters (b-value, mean activity rate, maximum expected earthquake magnitude) of each source.

The delineation of seismic sources is attained considering the geographical distribution of epicenters. Generally, the correlation of seismicity with tectonic structures is not a simple task, requiring detailed knowledge and evaluation of all available information. Most commonly, the general geotectonic characteristics of the area are subjectively incorporated in the model contributing, mainly, to the estimation of geometry and depth of source. Three types of seismic sources are used by the model identified as "point", "linear" and "areal" sources. Seismicity in each source is considered homogeneous and an earthquake is equally likely to occur at any place over the whole length/area of source (Cornell, 1968).

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In the present model the occurrence of earthquakes is thought to be a Poissonian process. This assumption practically introduces no limitation in engineering studies and implies that earthquakes follow the exponential distribution regarding their magnitude and are randomly distributed with regards to time.

Past earthquake occurrence information is summarized by means of a recurrence relationship. The parameter b of the Gutenberg-Richter (1956) law is so estimated. A high b-value implies a small fraction of the total earthquakes at the higher magnitudes, whereas a lower b-value implies a larger such fraction. It is therefore obvious that, since the higher levels of ground motion at a site are dominated by occurrences of major earthquakes, the accurate estimation of b is of great importance in seismic hazard analysis. Moreover, there is a statistical uncertainty about the mean rate of occurrence of earthquakes, reduced however as the data increases, indicating that the volume of data has a significant effect on the quality of estimations.

A most critical point in seismic hazard analysis is the choice of the attenuation model. Usually, attenuation laws are empirical derived from regressions of observed motions against earthquake magnitude and distance from the causative fault. It is evident that the reliability of these laws is critically dependent upon the data volume. The variation of the tectonic regime, even in local scale, suggests the regionalization of such laws when enough data are available.

The estimation of the maximum magnitude expected from a source is most difficult to be assessed among all seismic hazard parameters. This is correlated with the tectonic regime, the accumulation of stress and energy release, as well as the mechanical properties of the fault plane. There have been proposed scaling laws correlating earthquake magnitude with the above mentioned parameters (Kiratzi et al., 1985), however associated with large uncertainties, since they are based on relatively small number of measurements and valid only for a predetermined magnitude range.

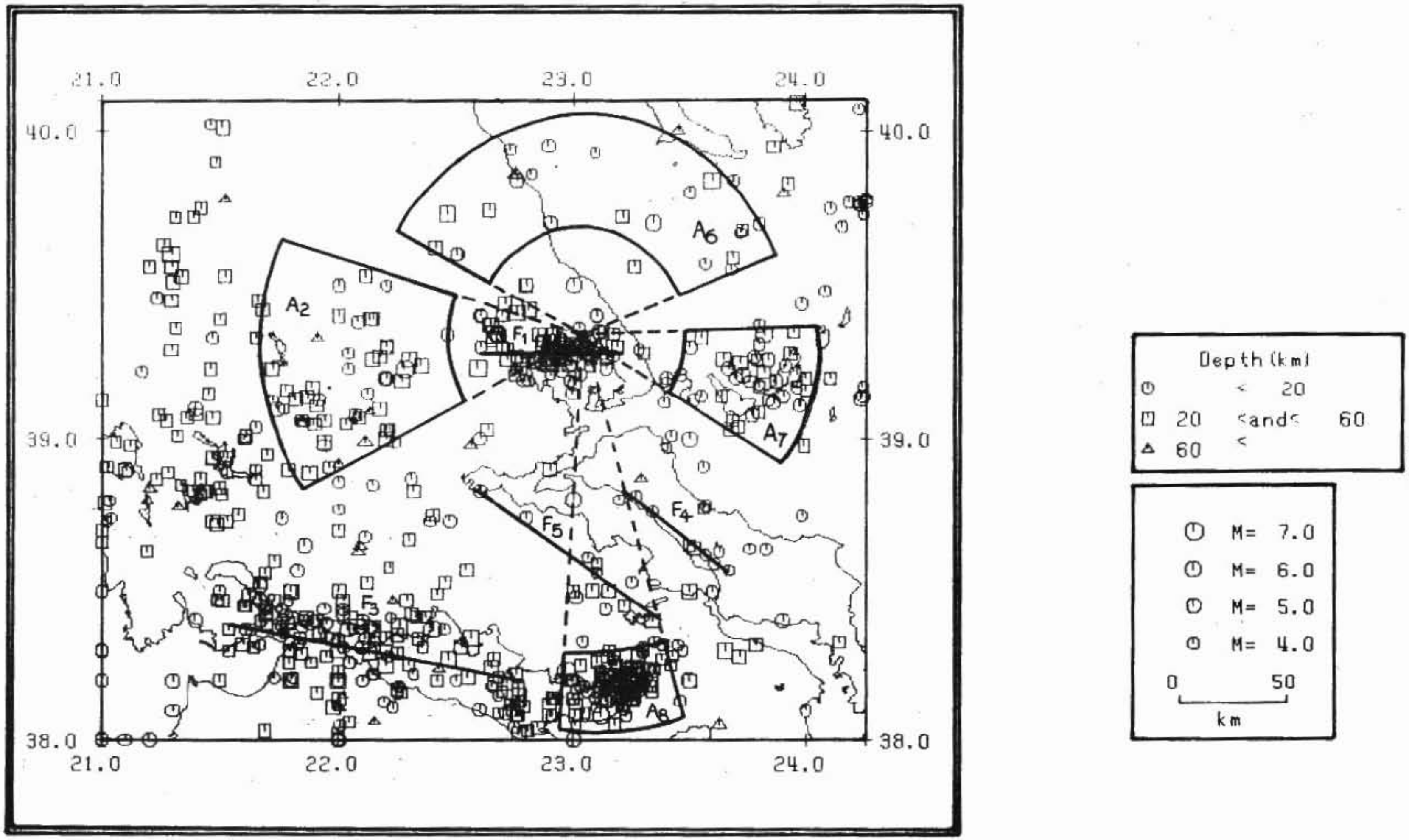
The most common method of estimating the largest possible earthquake magnitude is the theory of extreme values which has been fully exploited by many investigators (Drakopoulos and Makropoulos, 1983; Makropoulos and Burton, 1984b). This method is adopted in the present study.

The mathematical formulation of the model is analyzed in detail in previous studies (Cornell, 1968; Cornell and Merz, 1974).

SEISMIC SOURCE MODEL

In the central part of Greece there are some zones of repeated historical seismicity among which is the area around the city of Volos. However, the primary source of interest with respect to the strong motion in Volos is the area immediately south of the city. This very area is the host of the epicenters of the destructive earthquakes of the periods 1954-1957 and 1980-1985.

[illegible] distribution and the proposed seismic source model for the city of Volos. The delineation of seismic sources has been attained considering the



• VOLOS

680 Events

Scale 1: 2500000

Figure 1: Seismic Source Model

regional tectonics and the main seismic fracture zones for shallow earthquakes in Aegean and surrounding region (Papazachos et al., 1985).

Source F_1 is delineated very close to the south of Volos in an almost E-W direction. This area is seismically very active, as already mentioned above, characterized by shallow earthquakes. A series of shocks with magnitudes up to 7.0 occurred here during the period 1954-1957 and later, in the period 1980-1985. However no earthquake with magnitude larger than 6.5 had occurred in this source for more than two hundred years before 1954. Fault plane solutions of the latest earthquake sequence of July 9 1980 show a N-S extension, in agreement with the expansion of the Aegean plate in the same direction (Papazachos et al., 1983). Faults are normal with a slight sinistral slip component.

The epicenter distribution in south Thessalia (source A_2) is rather random, while the tectonic regime of this area is complicated with no dominating fault direction. This source is thus characterized areal.

The tectonic evolution of the gulf of Corinth (source F_3) is mainly characterized by normal faults, many of which are still active today (Mariolakos et al., 1985). The correlation of epicenters with the well defined fault zone of the gulf justifies the linear identification of the source.

A small seismic source with low activity is oriented in northwestern Evia (source F_4). This source is characterized linear due to the approximate correlation of epicenters with a tectonic line of NW-SE direction representing a small part of a larger fault zone of the broader area.

Source F_5 represents the well defined fault zone of Atalanti. It is remarkable to notice that large magnitude events in this zone have a very long return period. The most destructive known earthquake in Atalanti occurred in 1894.

The area of Theba-Platees (source A_8) presents high seismicity. The randomness in epicentral distribution and the weakness of any correlation with known tectonic structures lead to the use of the areal model. However, the large distance of this source from the city of Volos (about 90 km) compared with its small dimension could as well justify the point source model, since the distance may be assumed the same everywhere within the source.

Finally, because of the random epicentral distribution and the complicated tectonic regime in the areas east and north to Volos, sources A_7 and A_6 are considered areal.

INPUT

The model requires as input the parameter b of the exponential distribution of the recurrence model of earthquakes estimated by regression analysis of the data of each source, the mean annual number (rate) of events above a minimum magnitude in each source, mean focal depth, minimum and maximum considered magnitude and geometrical characteristics (F_1) of each source (Cornell, 1968). All characteristic parameters of the seismic sources of the proposed model are summarized in Table I.

The attenuation law for peak ground acceleration adopted in the present study is the one proposed by Makropoulos (1978). For

TABLE I

Characteristic parameters of the seismic sources of the model

Seismic Source	b	v rate	Depth (km)	Mmin	F_1* (km)	F_2* (km)	F_3* (°)	F_4* (°)	Mmax
F_1	0.665	1.305	10	4.0	2	−30	35	–	7.0
A_2	0.743	0.736	10	4.0	50	120	240	276	6.6
F_3	0.703	1.137	10	4.0	80	−40	100	–	6.8
F_4	0.600	0.333	10	4.0	67	−4	−120	–	5.6
F_5	0.811	0.089	10	4.0	26	−56	−100	–	7.0
A_6	0.859	0.946	10	4.0	40	98	83	126	6.0
A_7	0.390	0.002	10	4.0	26	80	66	305	6.8
A_8	0.651	0.846	10	4.0	110	150	150	180	7.0

* see Cornell (1968)

reasons of comparison a relationship proposed by Papoulia (1988) is also used. Both relationships are general and the results derived in this study are those at a base rock level. Soil effects, if they exist, must be introduced to derive expected risk on the ground.

RESULTS

On the basis of the recurrence model of earthquakes, seismicity, geometry of sources and the attenuation law, the return period for different levels of maximum expected acceleration in the city of Volos is estimated. The results of the analysis are illustrated in figure 2. Specifically, the return period for acceleration 0.2g is 24 and 21 years, using the Makropoulos (1978) and Papoulia (1988) relationships, respectively.

Both attenuation relationships used in the application are average and the obtained values represent a mean estimate of the return period. This estimation probably encloses some uncertainty. Incorporation of local attenuation laws could lead to more realistic hazard values, but these must await for more strong motion data, not available at present.

A close inspection of the detailed numerical results reveals the level of the contribution of each source to the total expected seismic hazard. Specifically, about 70% of total hazard is contributed by source 1, south and relatively close to Volos. Source 7 contributes about 15%, while sources 2 and 3 contribute about 5% and 2% each.

UNCERTAINTIES ANALYSIS

Because of the inherent uncertainty in several of t parameters in such an analysis, alternative parameter values a used and the analysis repeated to define their influence to t estimated hazard.

First, the sensitivity of the model to the physic relationship describing the attenuation of seismic waves investigated. The use of two different attenuation laws in t present application does not seem to strongly effect the resul (figure 2). However, both laws are average, as mentioned befor Previous studies for the area of Greece for the seismic intensi distribution (Papoulia and Stavrakakis, 1990) have emphasized t importance of use of local attenuation laws.

The dependance of hazard on the seismicity parameter b then examined. To represent statistical uncertainty in b, a me value of 0.7 was chosen with alternate values of ± 0.2 units. is shown (figure 3) that this small variation in b significant differentiates the obtained hazard values. The parameter b may estimated from historical seismicity and uncertainty could reduced if an infinite data set was available. However, be estimates of seismic hazard can be obtained using a mean b- valu as demonstrated here, overcoming the difficulty of its mo reliable estimation.

The model seems to be very sensitive to the estimation of t mean focal depth. Thus, a 5km increase in focal depth results

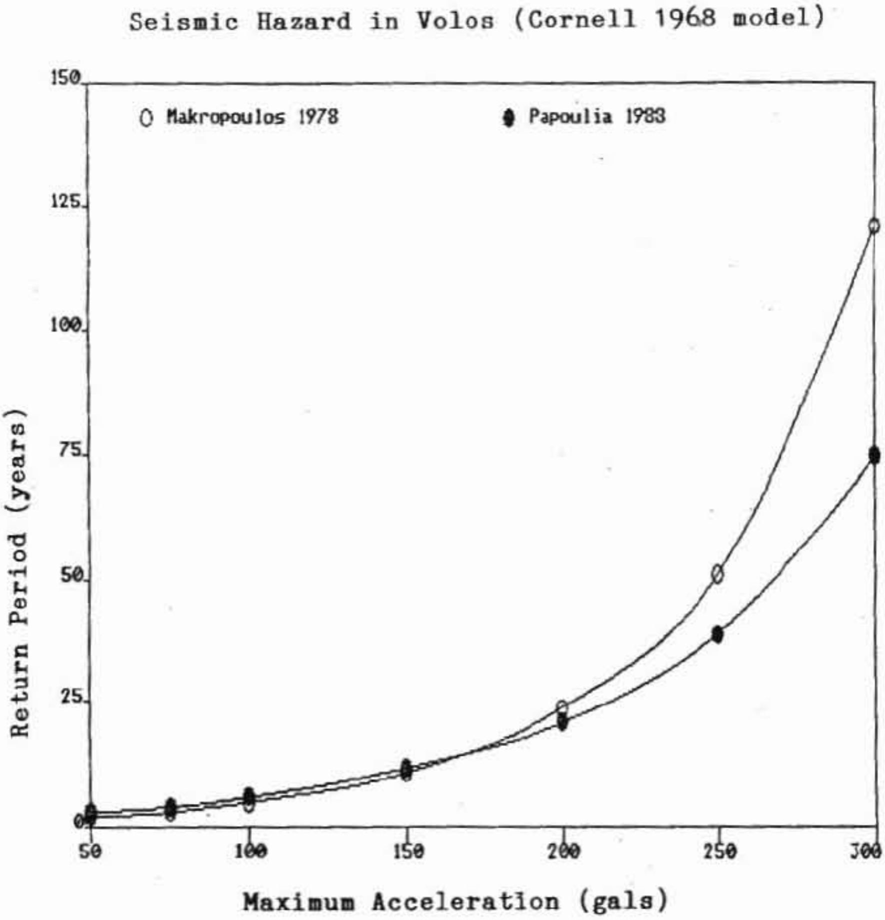


Figure 2: Maximum acceleration in the city of Volos using different attenuation relationships

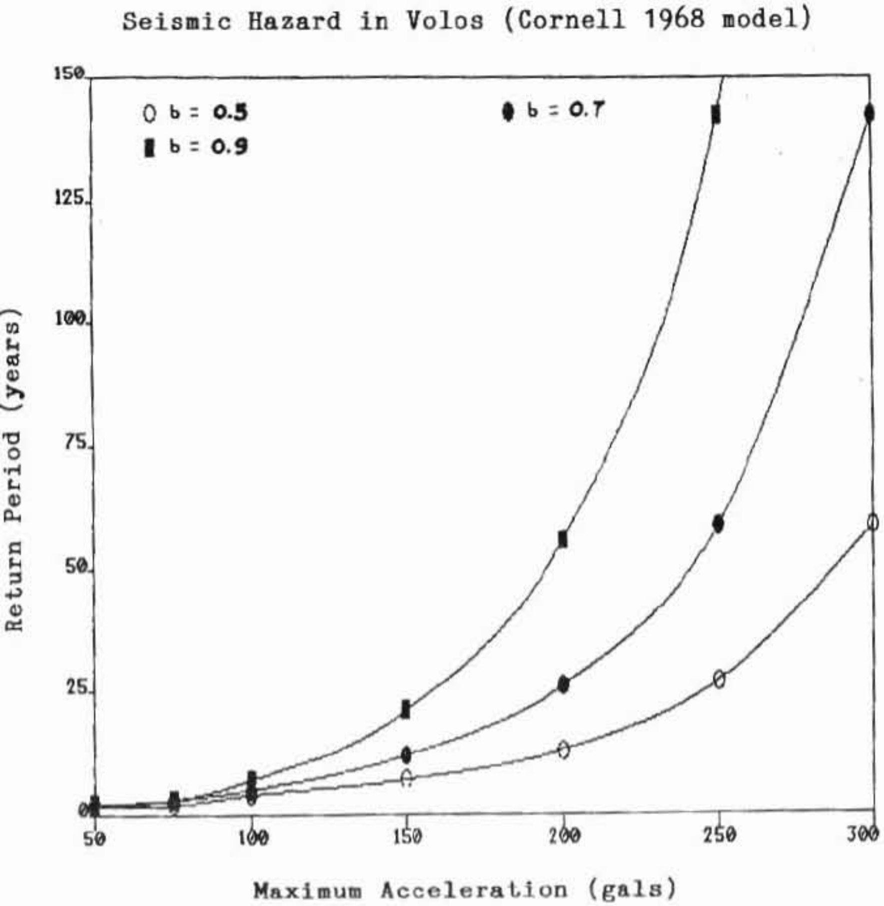


Figure 3: Maximum acceleration in the city of Volos for different b-values

high variations in the calculated hazard, especially at the higher levels of ground motion (figure 4).

Finally, the influence of the maximum possible earthquake magnitude expected from a source is investigated. It is remarkable to notice that a 0.2 increase in magnitude leads to large uncertainties in the expected acceleration, these increasing at higher levels (figure 5). This fact emphasizes the need to consider all available information, based on both seismological and geological data, for a most accurate estimation of the upper bound magnitude.

CONCLUSIONS

In the present study, Cornell' s classical model for seismic hazard analysis is applied in the city of Volos, central Greece, for an estimation of the maximum acceleration on rock, expected over a certain time period.

The results of the analysis show a good correlation to those obtained from previous studies (Makropoulos and Burton, 1984b).

The necessary seismicity parameter assumptions and their influences are discussed through an uncertainties analysis, emphasizing the model' s sensitivity to these parameters. Significant improvement of the seismic hazard estimates requires increase of the time duration of the seismological data, derivation of local attenuation laws and good knowledge of the seismotectonic characteristics of the investigated region.

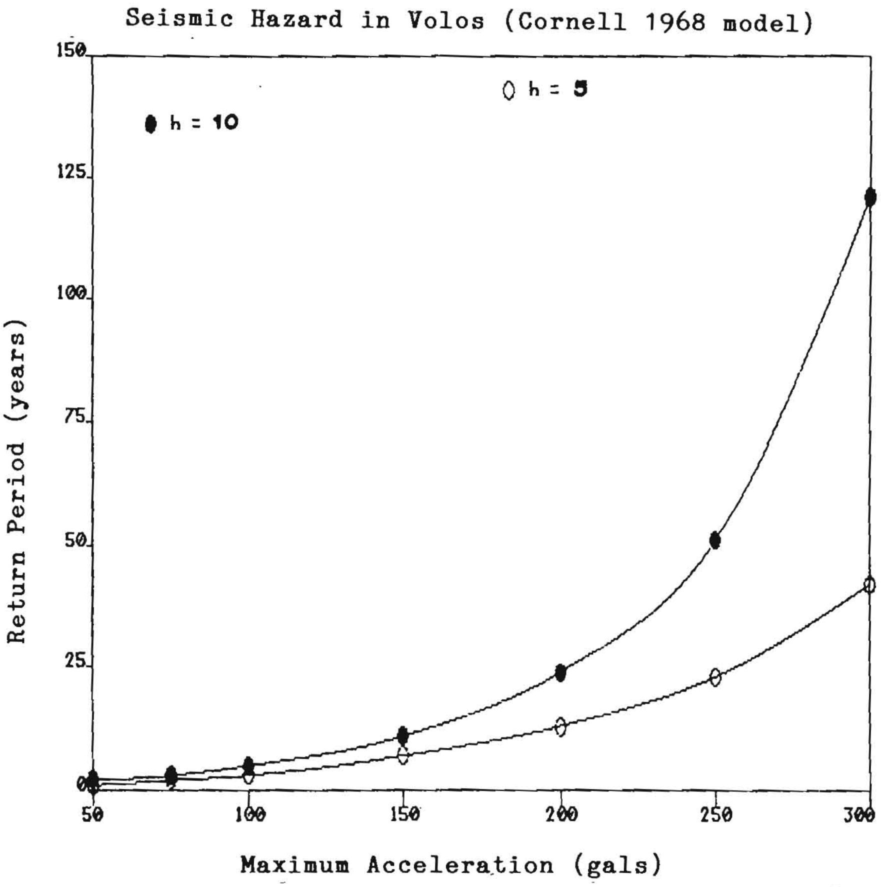


Figure 4: Maximum acceleration in the city of Volos for different focal depths

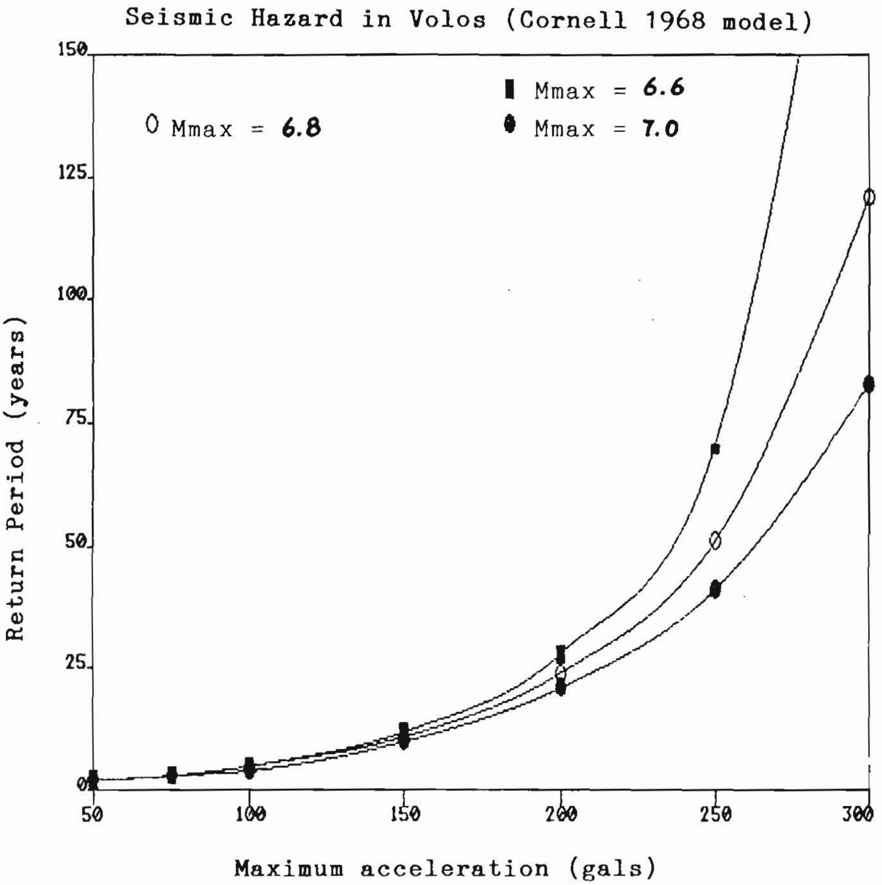


Figure 5: Maximum acceleration in the city of Volos for different expected maximum magnitudes

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