

GROUND MOTIONS AS A FUNCTION OF SEISMICITY

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Synopsis

Statistical relations are presented to assess ground motion as a function of seismicity.

Symbols and abbreviations

a_{max} = maximum horizontal ground acceleration (g)
 a_v = maximum vertical ground acceleration (g)
D = distance to the fault or equivalent (km)
d = maximum horizontal ground displacement (cm)
I = Modified Mercalli intensity scale
M = magnitude
n = number of cycles of acceleration $\geq 3\%$ g
S.E. = standard error of a prediction of a further observation
T = average period (s)
T' = period corresponding to the maximum of the acceleration spectrum (s)
 T_v = average period corresponding to the vertical acceleration record (s)
t = duration (s)
 t_v = duration of vertical motion (s)
 v_{max} = maximum horizontal ground velocity (cm/s)

Introduction

Seismic probability studies and maps must be based in a large amount of data extending to historical times. So, seismic intensity, and for more recent times magnitude, epicentral distance and focal depth must be used in them.

On the other hand, modern studies of response of structures are based upon spectra or records. An acceleration diagram is of a random nature, so that it will never be possible to predict it mathematically. Notwithstanding certain similar properties emerge from records corresponding to similar conditions. In order to study these effects it is necessary to define a diagram by only a few parameters: maximum ground acceleration, duration, average period, etc...(1).

Acceleration diagrams have only been recorded from 1933, and in most places there are no strong motion accelerographs. So, it is very important to relate these values with the ones that emerge from earthquake probability studies and ground conditions.

Definitions

"Duration" of an earthquake is defined as the time that includes all the pulses equal to or greater than 3% g (II) (3)

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(II) This definition is sustained by the fact that there is only a 7% probability that an earthquake with intensity V or VI will have a maximum ground acceleration larger than 3% g

The "average period" is defined as the duration of the earthquake divided by the number of cycles during it. The convenience of this definition is sustained by the close correlation existing between the average period and the period corresponding to the maximum of the acceleration spectrum (v. eq. 8 and table II).

The records included in the statistics correspond to focal depths not deeper than 160 km.

Frequency distributions

The arithmetic mean and the standard error when this mean is used as a prediction of a further observation are shown in table I for several frequency distributions. When the distribution of the logarithms is considered, this particular is indicated in the arithmetic mean.

Regressions

Some linear regressions and the standard error of a prediction are indicated below:

$$a_{\max} = 0,140 + 0,059 M - 0,210 \log_{10} D \quad (1)$$

valid for $a_{\max} \geq 10^{-3} g$

$$S.E. = 0,097 \sqrt{1,008 + 0,010(M-6,2)^2 + 0,028(\log_{10} D - 1,73)^2 - 0,018(M-6,2)(\log_{10} D - 1,73)}$$

If $D < 2$ km, $D=2$ must be introduced in the above equations.

$$a_{\max} = 0,121 + 0,0051 (v_{\max} - 20,6) \quad (2)$$

$$S.E. = 0,118 \sqrt{1,030 + 0,00009 (v_{\max} - 20,6)^2}$$

$$\log_{10} t = -1,546 + 0,348 M + 0,999 a_{\max} \quad (3)$$

$$S.E. = 0,333 \sqrt{1,013 + 0,016(M-6,2)^2 + 0,52(a_{\max} - 0,215)^2 + 0,026(M-6,2)(a_{\max} - 0,22)}$$

For rock:

$$\log_{10} T = -1,452 + 0,085M + 0,091 \log_{10} D \quad (4)$$

$$S.E. = 0,021 + 0,0009(M-6,05)^2 + 0,0016(\log_{10} D - 1,564)^2 - 0,0005(M-6,05)(\log_{10} D - 1,56)$$

For Pleistocene & firm soil:

$$\log_{10} T = -0,787 + 0,112 \log_{10} D \quad (5)$$

$$S.E. = \sqrt{0,02 + 0,0017 (\log_{10} D - 1,826)^2}$$

For alluvium and medium soil:

$$\log_{10} T = -0,591 + 0,112 \log_{10} D \quad (6)$$

$$S.E. = \sqrt{0,04 + 0,0017 (\log_{10} D - 1,454)^2}$$

For very soft soil:

$$\log_{10} T = -0,288 + 0,112 \log_{10} D \quad (7)$$

$$S.E. = \sqrt{0,057 + 0,0017 (\log_{10} D - 2,095)^2}$$

If $D < 0,08$ km, $D=0,08$ must be introduced in eq. (4) to (7) and in the corresponding standard error expressions

$$\log_{10} T' = -0,047 + 0,918 \log_{10} T \quad (8)$$

$$S.E. = 0,137 \sqrt{1,018 + 0,337 (\log_{10} T + 0,600)^2}$$

The results of Seed et al. (1), based in a much smaller number of records, seriously underestimate a_{max} , and overestimate T and t by a factor of the order of 2.

Confidence limits

The confidence limits corresponding to the centre of gravity of the distribution for some of the previous estimates are shown in table II.

The following comments may be made to table II:

As already stated by Newmark (2), the maximum ground velocity is much better related to intensity than the maximum ground acceleration (and better than displacement).

The estimate of T is better than the estimate of a_{max} . The estimate of t has the largest dispersion.

Acknowledgements

This research is supported by the Fundación Juan March. The help of C. Funes and D. Moyano is acknowledged.

Bibliography

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Table I

Arithmetic mean and standard error of a prediction of a further observation for several frequency distributions

Frequency distribution	Mean	S.E.
$\log_{10} a_{\max}$ for I = IV	$\log_{10} 0,03$	-
$\log_{10} a_{\max}$ for I=V & VI	$\log_{10} 0,13$	0,41
$\log_{10} a_{\max}$ for I= VII	$\log_{10} 0,18$	0,29
$\log_{10} a_{\max}$ for I= VIII	$\log_{10} 0,29$	0,28
v_{\max} for I = V	8,4	-
v_{\max} for I = VI	9,6	6,7
v_{\max} for I = VII	26,8	18,7
v_{\max} for I = VIII	35,6	27,5
d for I = IV	0,75	
d for I = V	3	
d for I = VI	4,8	
d for I = VII & VIII	18,5	
d for I = IX	50	
$\frac{a_v}{a_{\max}}$	48%	
$\frac{t_v}{t}$	70%	
$\log_{10} T$	$\log_{10} 0,28$	0,28
$\frac{T_v}{T}$	74%	
n for I \geq VI	63	

Table II

Confidence limits for some of the estimates

Estimate	Upper limit for 90% confidence	Limits for 80% confidence
<u>Frequency distributions</u>		
a_{\max} for I = V & VI	$\log_{10} 0,13 \pm \log_{10} 3,5$	
a_{\max} for I = VII	$\log_{10} 0,18 \pm \log_{10} 2,4$	
a_{\max} for I = VIII	$\log_{10} 0,29 \pm \log_{10} 2,5$	
T		$\log_{10} 0,28 \pm \log_{10} 2,3$
v_{\max} for I = VI	9,6 + 9,9	
v_{\max} for I = VII	26,8 + 25,1	
v_{\max} for I = VIII	35,6 + 40,6	
<u>Regressions</u>		
a_{\max} (eq. 1)	0,14 + 0,13	
a_{\max} (eq. 2)	0,23 + 0,16	
t (eq. 3)	$\log_{10} 6,8 \pm \log_{10} 2,7$	
T (eq. 4)		$\log_{10} 0,16 \pm \log_{10} 1,6$
T (eq. 5)		$\log_{10} 0,26 \pm \log_{10} 1,5$
T (eq. 6)		$\log_{10} 0,37 \pm \log_{10} 1,8$
T (eq. 7)		$\log_{10} 0,89 \pm \log_{10} 2,2$
T' (eq. 6)		$\log_{10} 0,25 \pm \log_{10} 1,5$