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MILLENARY OCCURRENCE OF SEISMIC INTENSITY : ITS EVALUATION BY A MATHEMATICAL MODEL OF MEAN SEISMIC ACTIVITY

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SUMMARY

The determination of the mean time of millenary seismic intensity occurrence in a rock site is shown from the evaluation of the effect produced by the geographic distribution of the mean regional seismic activity defined by appropiate mathematical relations. The relation adopted to describe this mean seismic activity in each elemental volume of earth crust is:

$$\text{Log } N = A - B.M_s - C(M_s/M_{ss})^{30}$$

Where: N is the number of annual seismic events the magnitudes of which are equal to or larger than the magnitude M_s ; A, B, C and M_{ss} are values which are functions of latitude, longitude and depth. These are estimated from the statistical analysis of the instrumental and historical seismological information and its correlation with the results of the geological and tectonic studies of the region.

The spectral acceleration corresponding to the Wilmot seismoscope (0.7 sec. period, 10% damping) is adopted as the value to measure the seismic intensity at the rock site. It is calculated by the appropiate relationship between magnitude, distance and spectral acceleration in a rock site.

INTRODUCTION

In order to estimate the probable seismic intensity which could shake a given location, it is necessary to collect and to analyze information provided not only by the seismological stations but also by the history and the geological and tectonic studies. If this probable seismic intensity were applied to the design of important constructions, such as large dams and nuclear power plants, it would be necessary to estimate the values corresponding to very low risk. This evaluation requires the collection of information dating from long time ago, preferably thousands of years. So ancient information is not obtainable from instrumental data which come only from the present century and moreover is very uncommonly found on the historical accounts. This fact is more critical when the area has a medium seismic activity and its actual population is still sparse and not too old, such as to the west of the central-southern area of the Argentine Republic, near the border with Chile, where several dams and hydroelectric plants have been projected and built along the Limay River, Fig. 1.-

To provide a solution to the problem brought about by the lack of seismic information about these dam sites, the mean seismic activity of a more extended surrounding area, referred to as the "region seismically associated to the site", is evaluated, Fig. 1, and then its distribution according to latitude, longitude and depth in the region is estimated to obtain the density of seismic activity. These density values are the mean number of seismic events of different magnitudes whose foci are located in each element of earth crust of the selected region. The occurrence of each one of them will produce on the rock foundation of a dam site tremors and earthquakes the intensity of which could be evaluated by means of one appropiate relationship between magnitude, distance and intensity. By considering the effects produced on the site by the total number of seismic events occurring in the region, the mean number of earthquakes whose intensity is equal or larger than a given value may be determined and, as a consequence, the mean time of different seismic intensity occurrences or mean return periods, through which it is possible to describe the seismicity of the dam site.

GEOGRAPHICAL DISTRIBUTION OF THE SEISMIC ACTIVITY

To estimate the probable seismic intensities which could occur on the dam sites of the Limay River, Fig.1, we have selected as the "region seismically associated to the site" that which lies between 36° and 44° of south latitude and 67° and 78° of west longitude. The International Information Network of Seismic Data, Ref 1, 2, and 3, has reported about an important amount of seismic events that have occcurred in the corresponding earth crust of the region from the early years of this century up to date. Of these, the most important is the extremely-large-magnitude event dated May 22, 1960 with a sequence of aftershocks included in a disturbed area located mainly on the ocean floor near and parallel to the Chilean coast along several hundreds of kilometers, Ref.5. The area more strongly shaken by this event was that lying around the City of Valdivia, approximately 400 km. away from the dam sites of the Limay River. These and the rest of the events recorded in the area up to date rapidly decrease in number from the coast line towards the east. Simultaneously, their focal depth increase up to 150 km below the dam sites tracing the Benioff line, which is assumed by the modern Global Tectonic Theory as the colision front between the South American and Nazca Plates, Ref.5. In addition to this seismic activity, there are other shallow events, such as the Chillan earthquake of January 24, 1939, located in the Central Valley of Chile and in the Los Andes Mountains, not far from some of the dam sites studied, whose number and magnitude decrease from the Central Valley towards the east. Both volumes of seismic activity, namely Benioff and Central Valley, constitute the two principal sources where the seismic events that could produce a certain effect on the dam sites of the Limay River are located.

In the past centuries, the sparce population in the area studied, Fig. 1, was mainly situated on the coastal line and, as a consequence, the historical accounts known nowadays about earthquakes that occurred a few hundreds of years ago, are only about those destructive ones in large areas the magnitudes of which have been generally greater than 7 or 7.5. On the other hand, the instrumental data show the coast as the most active seismic area of the region. Therefore, these historical seismic references are appropiate to estimate how the great events are distributed in time and space. Ref. 4 shows that on the past four centuries there has been a very uniform distribution of greater events along the coastal line of the area studied.

The remaining source of information available used in the present work are the results of geological and tectonic studies about the region, which will be correlated with some of the seismological particularities already mentioned. Since the Global Tectonic Theory assumes that the actual interaction between the earth crust plates are evidenced by the distribution of seismic activity and that the Chilean Trench is the shallow trace of the colision front between Sud American and Nazca Plates, it is concluded that near the coastal line of Chile and along it, after thousands of years, a uniform seismic activity must be located and this should be the most important of the region, as shown by the great earthquake of May 1960 and the others similar to it that have occurred during the past four centuries. According to this Theory, the seismic activity must decrease towards the east of the Trench, which agree with the number of events instrumentally recorded. In addition to these conclusions, the regional geological studies carried out in the region, Ref. 6, show a minor influence of tertiary-age uplifts on the areas located to the east of highest mountains of the Andes chain, which also agree with the low number and magnitude of the shallow seismic events recorded, furthermore, it has not been found that there are in the vicinity of the dam sites evidences of neotectonic disturbances in the superficial faulting.

The main characteristics of the seismic activity distribution outlined are the bases to quantify the density of seismic activity in the region.

DISTRIBUTION OF SEISMIC EVENTS ACCORDING TO MAGNITUDE

In the whole region selected, Fig. 1, the annual mean number of seismic events has a certain distribution according to their magnitude which could be expressed by the well known relation given by Gutenberg - Richter with a third term, so that it becomes:

$$\text{Log } N = A - B.M_S - C(M_S/M_{SS})^{30} \qquad (1)$$

Where: N is the number of annual seismic events the magnitudes of which are equal to or larger than the magnitude M_S ; A, B constants. This third term shows that the large magnitude events are much more scarce than the other ones, since the state of large energy acumulated in the earth crust is more unstable and so, the release of that energy through an earthquake occurs.

The values of the constants A, B, C and Mss can be calculated from the amount of events reported up to date by the International Information Network of Seismic Data, Ref. 1 and 2, revised by the influence of the variation in the number of seismological stations in operation and the types of instruments existing there during the successive decades of the present century. However, as was pointed out before, this recording interval alone is insufficient to determine the mean number of large magnitude events and, therefore, historical reference studies about the great earthquakes given in Ref. 4, must be taken into account. To this purpose, the set of the largest magnitude event each 50 years has been analyzed by means of the statistics of extreme values and from this the mean return period of 250 years for the magnitude M = 8.5 event were obtained. With this result in mind, the adjustment of the values of Eq(1) coefficients can be archieved, thus becoming, Fig. 2:

$$\text{Log } N = 5{,}312 - 0{,}847\, M_S - 0{,}06(M_S/8)^{30} \qquad (2)$$

This activity must be distributed on the region according to latitude, longitude and depth to obtain the mean number of seismic events per year in each elemental volume of earth crust of the region, a value that is referred to as "density of seismic activity" D_S and which must verify the condition:

$$N\ (\text{Eq } 2) = \int_{\text{region}} D_S\ .dV \qquad (3)$$

To evaluate D_S, an equation similar to Eq(1) is adopted, but the new coefficients A, B, C and M_{SS} vary according to latitude, longitude and depth, and are obtained from the correlation with the characteristics of the geographical distribution of seismic activity afore mentioned, adopting to this purpose the form:

$$D_S = F_0\,(\mathrm{lat}) \,.\, F_1\,(\mathrm{long}) \,.\, F_2\,(\mathrm{depth}) \,.\, N(\mathrm{Eq}(2)) \qquad (4)$$

where F_0, F_1 and F_2 are functions depending on latitude, longitude and depth, respectively. In Fig. 3a and 3b, the resulting mean number of seismic events in ten thousand years with magnitudes larger than 6 and 8, respectively, that correspond to each degree of longitude on 40° of south latitude are shown, whereas Fig. 4 shows the interval selected of depths in which the 80% of these events are included.

MEAN TIME OF SEISMIC INTENSITY OCCURRENCE

The principal object of this work is to estimate the probable seismic intensity which corresponds to very low risk on the dam sites of the Limay River.

The Wilmot Seismocope is a simple, low-cost, reliable and easy to maintain instrument to record the strong earthquake motions, of which more than 200 have been installed in the western part of Argentine. With these instruments whose characteristics are 0,7 sec period and 10% of damping, records have been obtained whose amplitudes are better correlated with the Mercalli Intensity values assigned to field observation than the correlation between these latter values with the maximum ground aceleration, thus showing that the amplitude of seismoscope records is a good value to be used as an instrumental measurement of seismic shaking. On the other hand, to estimate the corresponding relation between the Wilmot response with the magnitude of a seismic event and its distance to the focus, the available information about the Wood Anderson Torsion Seismograph in relation to the Richter Magnitude Scale could be used, due to the fact that its 0,8 second period is very close to the Seismocope Wilmot period, Ref. 7. From this information and from the results of records obtained in the near field of strong earthquake, Ref. 8 and 9, the spectrum acceleration response attenuation mean curves of Fig. 5 for the Wilmot Seismoscope on rock sites have been derived, changing the distance to the focus by that to the baricenter of seismic energy release by the event.

Finally, it is possible to estimate the mean values of return periods of seismic intensity from the estimation of the number of earthquake produced on the dam sites by the mean number of events located in the region of Fig. 1, whose spectral acceleration in seismocope are larger than one selected value:

$$NE\,(\,I,\,U\,) = \int_M \int_V e(M,D).\ D_S.\ dV.\ dM \qquad (5)$$

Where:

NE(I,U) = mean number of earthquakes occurred in the site U with intensity equal or larger than the value I.

I = seismic intensity in U measured by the spectrum acceleration in Wilmot Seismocope produced by the seismic event with magnitude M at distance D

D_S = seismic density given by Eq (4).

V = earth crust volume of the region of Fig. 1.

dV = elemental volume of earth crust.

e(M,D) = 1 , if the earthquake has an intensity in U equal or larger than I.

= 0 , if the earthquake has an intensity in U lesser than I.

From NE(I,U) the mean return periods of seismic intensities I are obtained:

$$TI_m = 1/NE(I,U) \qquad (6)$$

CONCLUDING REMARKS

The values of TI_m resulting for the dam sites of the Limay River are shown in Fig. 6. These curves show differences between the mean times corresponding to the dam sites of the Limay River studied. These differences can be understood if they are correlated with the differences in situation, geology and seismic evidences among the sites, thus giving enough confidence to use this methodology for estimating the millenary seismic intensity on dam sites in order to meet very low risk requirements.

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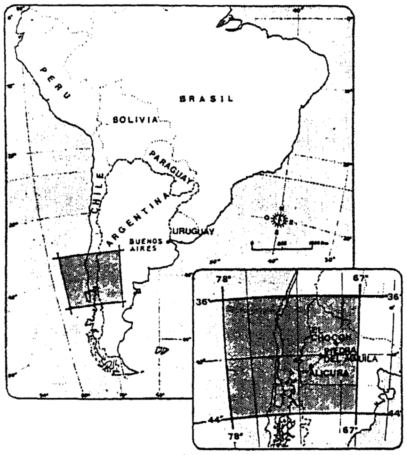

Fig. 1
Dam sites estudied

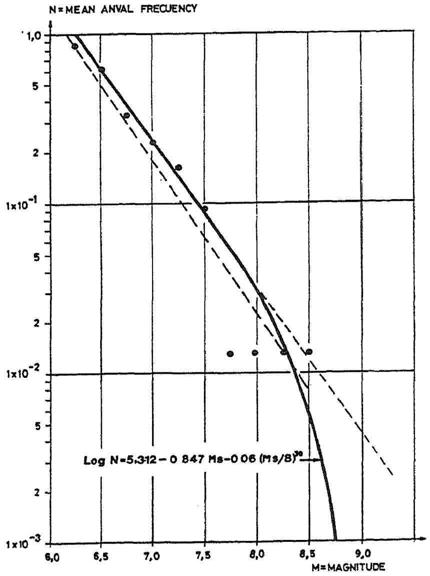

Fig. 2 Gutenberg Richter Law
estudied region-1906-87

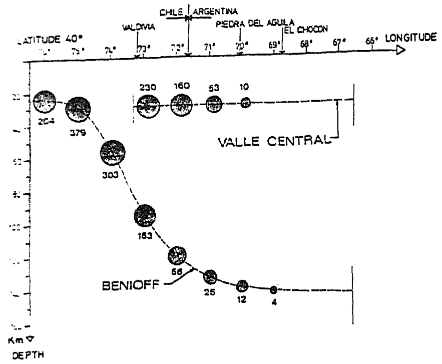

Fig. 3a Mean number seismic events.
Thousand years; M=6

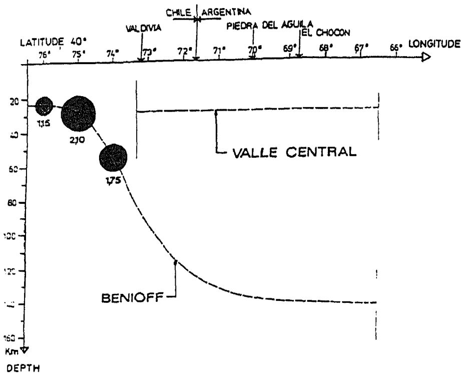

Fig. 3b Mean number seismic events.
Ten thousand years; M=8

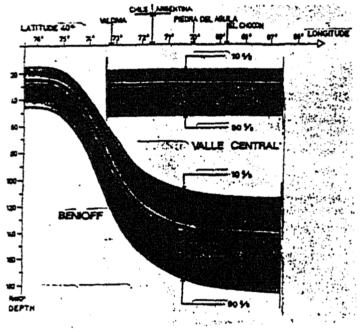

Fig. 4 Depth limit curves.
10% and 90%

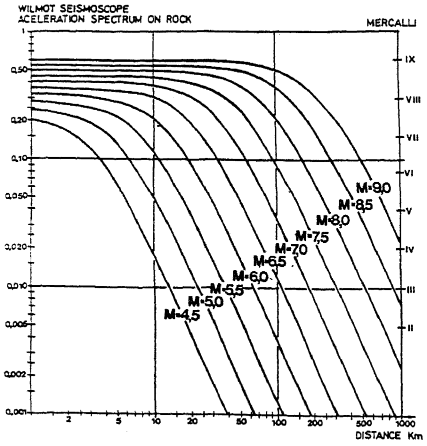

Fig. 5 Wilmot seismoscope
attenuation curves.

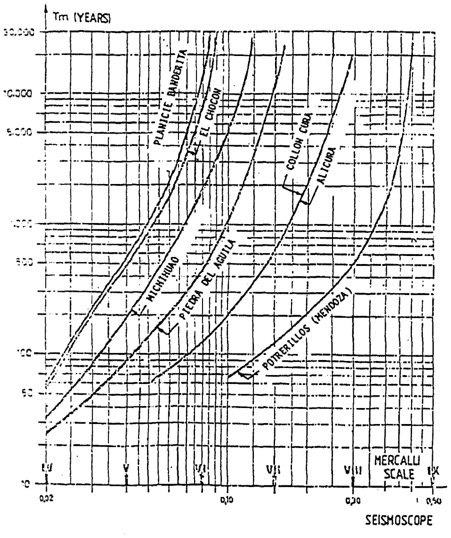

Fig. 6 Seismic intensities
mean return periods.