Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

8-3-2

DESIGN SPECTRA FOR MEXICO'S FEDERAL DISTRICT

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SUMMARY

We describe the methods used to obtain seismic design spectra adopted for different zones of Mexico's Federal District in 1987 Building Code. Paper discusses the two approaches followed in the study, deterministic and probabilistic. The assumptions adopted are exposed and justified. Several aspects that require detailed scrutiny are pointed out.

INTRODUCTION

Mexico's Federal District is exposed to four different types of earthquakes. In the deterministic approach one representative earthquake of each type was selected under the assumption that it was the most dangerous of that type one can reasonably expect during the next 150 years. Fourier acceleration spectra (FAS) at the University City (CU) were estimated for the four earthquakes from semiempirical formulas or a calibrated source spectrum theory. FAS at different representative sites were obtained by multiplying the transfer functions (computed using one dimensional theory) and FAS at CU. Finally, the expected acceleration response spectra for 5% of critical damping were calculated from FAS and estimations of strong ground motion duration at each site by applying random vibration theory. These results and computed spectra for the September 19, 1985 Michoacán earthquake, allowed construction of the design spectra proposed for inclusion in the 1987 Building Code. These are simple shape envelopes of computed response spectra with modifications to account for the expected duration of ground shaking at each site, and for inelastic behavior of structures.

In the probabilistic approach, the information from the catalogs was combined with that from tectonically similar regions in order to increase the data base. The non Poisson nature of the generating processes was accounted for when that assumption was significant. Design spectra were computed for the combination of all relevant events in such a way that, for each site, the spectrum was associated with a fixed expectation of the present value of the losses. It was found that, in general, the adopted spectra were consistent with the probabilistic computations.

SPECIFIC EARTHQUAKES

Based on earthquake catalogs of last and present century and studies on source parameters, the events which may affect the Federal District were divided in four groups (Fig. 1). These groups along with specific event chosen in each (see Ref. 1 for criteria) are:

1. Local earthquakes (L): Representative event is a shallow, M_L=4.7 originating in or very close to the valley at a focal distance of 11 km.

2. Continental plate earthquakes (A): An Acambay type earthquake originated in the graben (Ref. 2) with M_W = 7.0 and focal distance of 80 km is taken as the representative event.

3. Intermediate depth earthquakes (N): As a representative earthquake of normal faulting in the subducted Cocos plate an event with M_W = 6.5 and focal distance of 65 km (and same focal depth) was considered.

4. Subduction zone earthquakes (G): Subduction earthquakes have historically generated the most severe consequences in Mexico City. The most violent shock that one can reasonably expect in the Guerrero seismic gap, West of Acapulco, will have M_W = 8.2. Probabilities of 0.25, 0.5 and 0.25 were assigned to R = 130, 248 and 280, respectively, where R is the closest distance to the rupture area.

FOURIER ACCELERATION SPECTRA (FAS) ON FIRM GROUND AT CU

Expected FAS on firm ground at CU for all nonsubduction earthquakes were obtained from the ω^{-2} model (Ref. 3). The model produces Fourier acceleration amplitudes in terms of source and path characteristics. The application of model and assessment of necesary parameters is described in Ref. 1.

Semiempirical relationships were used to represent the subduction type earthquake (Ref. 4). These expressions predict expected FAS at CU in terms of magnitude and distance. Results are displayed in Fig. 2.

FOURIER SPECTRA FOR OTHER LOCATIONS

Using available information (Refs. 2, 5, 6) stratigraphic profiles were determined for sites of the transition and soft zones in the valley. For each site the transfer functions that relate incoming motion at the basement with the surface response were computed using the Thompson-Haskell matrix method (Ref. 7) of wave propagation in viscoelastic layered media. Only vertically incident SH waves were considered. Fig. 3 shows the transfer functions computed for three sites. Results do not take into account the effects of oblique incidence, surface wave propagation, and nonlinear behavior. Their influence has been qualitatively considered in the proposed design spectra.

RESPONSE SPECTRA

Acceleration response spectra for 5% of critical damping were computed using random vibration theory (RVT) (Refs. 3,8). This requires FAS and the equivalent duration of ground motion. The duration assessment was done on the basis of the observed values for earthquakes recorded at CU. Computed response spectra are displayed in Figs. 4-7. They include a reduction factor of 0.4 that was assigned by the Subcommittee responsible, for the code to account for structural ductility which for the narrow band earthquakes, typical of the lake-bed zone, produces significant reductions (Ref. 9), more drastic than which could be expected for wide band events (Ref. 10). This reduction factor takes also into account the fact that ordinary structures, particularly the most common short-period ones, have great reserves over their capacity computed in a conventional way. To consider systems that undergo deterioration in strength after a great number of load cycles, the new building code establishes specially conservative strength reduction factors for such structures.

RVT response spectra were calibrated through direct comparisons (Ref. 11). The agreement was satisfactory showing that RVT generates accurate estimates of response spectra.

In a short range of structural periods of practical interest the spectrum obtained for local earthquakes is slightly above that adopted for design, which are also shown in Figs. 4-7. This apparent error on the unsafe side is justified in terms of exceedance rates, as we will see. Moreover, the apparent strength of very rigid structures under very short duration earthquakes is much larger than the strength predicted by conventional analyses (Ref. 12). This is supported by experience on zone I of the Federal District, where the short period, rigid, old Colonial buildings subsist.

DAMAGE DISTRIBUTION AND ITS IMPLICATIONS

It was concluded after considering damage distribution of past events (see Ref. 1) that the seismic microzonation originally proposed in the 1976 Building Code was satisfactory, except in two areas where the damage level is much higher than that of the surrounding zones. Various sources of information confirm this situation. In fact, greater effects of surface waves are expected in these places, and such waves were not considered in calculating response spectra. It has been argued that higher design base shear coefficients should be used in these areas (Ref. 13). This was accepted by the Subcommittee for a small portion in the transition zone, but not for the rest, which is included in the lake-bed zone. This was decided in the light of the various conservative provisions already contained in the code for this zone. However, a less conservative level of dynamic analysis was introduced into the code for the lake-bed zone. It recognizes the effects of local prevailing ground period and allows reductions of spectral ordinates if this period is known and only if soil structure interaction is taken into account. Figure 8 shows the maximum spectral ordinate as a function of dominant ground period. Also, the code permits the use of a sharper design spectrum when both ground period and soil structure interaction are included into the analysis. These reduced second-level design spectra are depicted in Figs. 4-7. Detailed 2D and 3D soil dynamic analysis, still pending, should lead to a more precise microzonation.

PROBABILISTIC ANALYSIS

For all nonsubduction earthquakes, it was assumed that, due to the many potentially seismogenic faults, the generating process was Poisson type. The exceedance rate-magnitude relation proposed in Ref. 14 was adopted. A Bayesian approach (Refs. 15,16) was used to compute the appropriate parameters.

Subduction earthquakes are responsible of a great portion of the damage to the valley of Mexico, particularly those that occur along the coast of Guerrero and Michoacán. The large and great earthquakes of this kind are generated in a few well-delimited zones, so a Poisson idealization is not justified. Therefore, we assigned a gamma distribution to the inter occurrence times of events with $M \geq 7$. For $M < 7$ we adopted the Poisson hypothesis. We treated events with greater magnitudes as characteristic (Ref. 17). To this end, the Mexican subduction zone was divided into twelve regions (Ref. 18).

EXCEEDANCE RATES OF STRUCTURAL RESPONSES

Consider earthquakes generated by a Poisson process. Let $a = a(T, M_i)$ be the spectral ordinate at a given site for natural period T due to an event of magnitude M_i originated in the *i*-th seismogenic source. Let $\lambda_i = \lambda(M_i)$ be the exceedance rate of magnitude M_i for earthquakes from source *i*. Then, the exceedance rate of a due to *i*-th seismogenic source is also λ_i. The combination of Poisson processes is also a Poisson process (Ref. 19) with exccedance rate $\nu(a) = \Sigma \lambda_i$. Expected present value of the number of events producing exceeddances of a, assuming only one limit state exists, is $\nu(a)/\gamma$, where γ is the discount rate. This ratio is the quantity which has to be multiplied by the expected losses in one event to obtain the expected present value of the losses (Ref. 20). For non-Poisson events, expected present value of the number of ocurrences considered the inter ocurrence times probability density function. Summation of such quantities for each region gives EN(a), the expected present value of the total number of events that would produce ordinates higher than a. We define equivalent exceedance rate as $\eta = \gamma$ EN(a). This quantity, like the exceedance rate, measures the expected present value of the total losses.

For code purposes we selected the equivalent exceedance rate associated with a maximum spectral ordinate of 0.4 g -the selected design ordinate- at a site with predominant ground period of 2.08 s. The rate turned out to be 7×10^{-3}/year. This is the constant equivalent exceedance rate associated with the spectra in Figs. 4-7, where they are compared with deterministic and design spectra. Although the local deterministic earthquake predicts higher spectral ordinates than the code provisions for a range of structural periods, this ordinate corresponds to an extremely low equivalent exceedance rate.

CONCLUSIONS

Adopted seismic design spectra for different zones in the 1987 Mexico's Federal District Building Code were obtained using both deterministic and probabilistic approaches. Results from the two approaches are consistent. The working assumptions are made explicit from where becomes clear that the assessment of maximum magnitudes, the assumption of inter ocurrence times distributions, more detailed studies of the seismic source, of wave propagation in the earth, and on site effects, as well as studies of the nonlinear response of structures and their interaction with the soil are all topics that require additional research. In the light of the present state of the art in earthquake engineering, the design spectra adopted are reasonably conservative. They reflect the consensus of a number of experts in various fields.

AKNOWLEDGEMENTS

Thanks are given to F Mooser and G Suárez for their valuable cooperation. F J Chávez-García, E Reinoso, L E Pérez-Rocha, M Suárez, E Mena, and M A Bravo colaborated in different parts of the study. Their help is greatly appreciated. This work was supported by Departamento del Distrito Federal and Mexico's National Council for Science and Technology (CONACYT).

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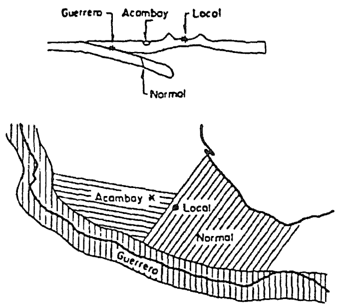

Fig. 1 Earthquake groups and their possible occurrence regions.

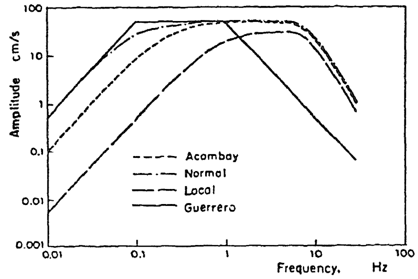

Fig. 2 Fourier amplitude spectra of ground acceleration for selected events.

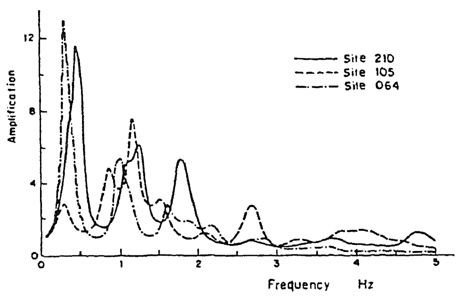

Fig. 3 Transfer functions for three typical sites.

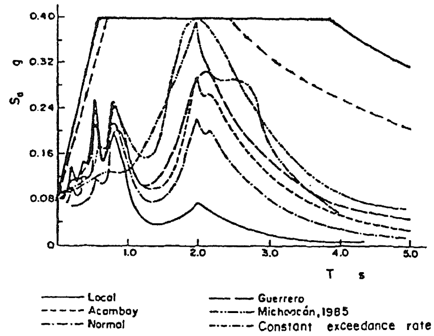

Fig. 4 Response and design spectra; lake bed zone, T_s= 2.08 sec.

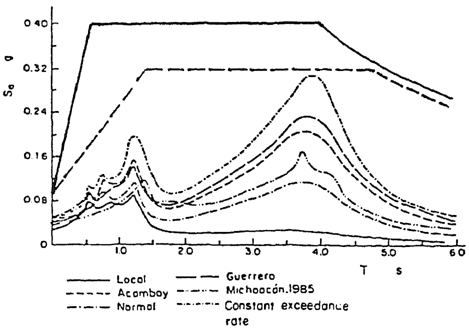

Fig. 5 Response and design spectra; lake bed zone, T_s= 3.97 sec.

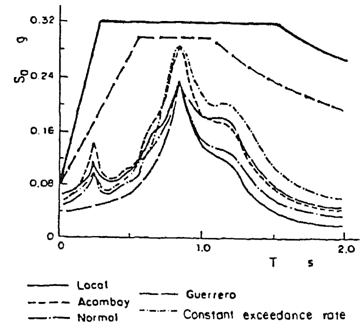

Fig. 6 Response and design spectra; transition zone, T_s= 0.87 sec.

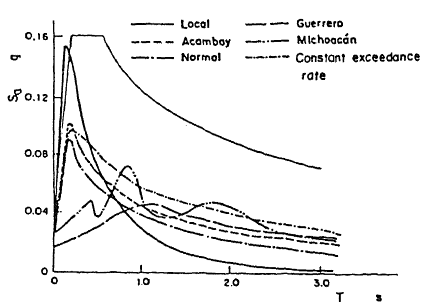

Fig. 7 Response and design spectra; firm ground.

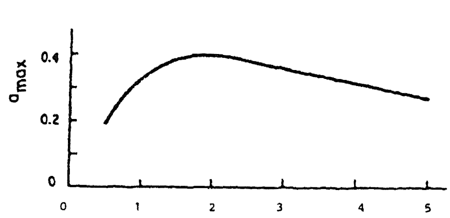

Fig. 8 Maximum spectral ordinate as a function of prevailing ground period.