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SEISMIC ZONATION OF MEXICAN CITIES

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ABSTRACT

This paper describes the project of seismic zonation of several cities in Mexico, where the main technical problem is the lack of local information. An important part of this effort is the way in which local scientists and engineers have been involved in the work, making it easier to incorporate the results into building codes and professional practice.

KEYWORDS

Zonation; microzonation; cities; Mexico; period; evaluation; damage; intensity; code; risk.

INTRODUCTION

The first seismic zonation of an urban center in Mexico was included in the emergency building code for Mexico City, enacted after the 1957 Acapulco earthquake. This zonation recognized three different zones, defined on the basis of the observed damage distribution throughout the city. The correspondent seismic coefficients were obtained from the calculation of the maximum shear force in the base of the tallest building then: La Torre Latinoamericana. The seismic zonation of the capital city remained the same with only few changes until 1987 when, after the 1985 Michoacan earthquake, the new building code included two new zones of high seismicity, associated to the lateral interaction of topographical and geotechnical irregularities. This time, the seismic coefficients were product of the expertise of the people in charge of the new code (DDF, 1987).

In 1989, the government of the State of Guerrero asked a scientific institution in Mexico City to elaborate the seismic zonation of Acapulco, but even though the proposal was finished by 1990 it was enacted into a building code for all the State of Guerrero until 1994 (GEG, 1994).

This short description of the history of seismic zonation in Mexico emphasizes the fact that despite the existence of many important urban complexes subjected to seismic hazard, some of them with several million inhabitants, most of the attention had been only focused in the capital city. Even the seismic zonation of Acapulco was made by an institution from the capital, without intervention of local scientists and professionals, which explains the lack of interest for including the proposal into the building code. Paradoxically, this centralism is based on the belief that the only way to achieve reliable results is through very sofisticated mathematical earthquake risk analysis models, that require scientific personal and technical information not available outside Mexico City; despite the fact that in the past, all previous zonations of the capital were made on the basis of the observed building damage and professional expertise.

With the experience obtained from the seismic zonation of the 1987 Mexico City code, which was mainly defined through the study of the damaged buildings done at the Universidad Autónoma Metropolitana (UAM), this institution began in 1990 a research project for the seismic zonation of the most important cities in the country subjected to seismic hazard. The main challenges to overcome were the lack of local technical information, as to approach the seismic zonation in an orthodox way, and the need to involve in the project local scientists and engineers whose expertise and enthusiasm were judged to be indispensable to introduce the results in a new building code and, finally, to the common practice.

TECTONICS AND SEISMICITY

The first step for the seismic zonation of a city is the knowledge of the tectonics mechanisms that affect the region under study. In general terms, this information is available for all of Mexico, and it is even possible to identify seismogenic regions of similar seismicity and model them with a probabilistic approach, using the seismographical data available (Fig. 1). On the other hand, there is a lack of knowledge of the existence and behavior of active faults that could be of local importance. Even worse is the lack of accelerographic information about local ground motion. Accelerographs are concentrated mainly in Mexico City and in the Pacific coast, and even in these places the number of instruments was very small before the 1985 earthquake; thus the information available is very limited.

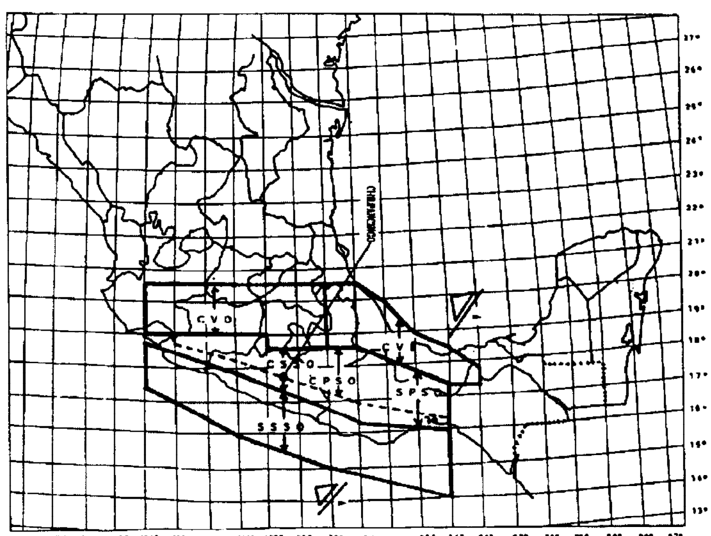

Fig. 1. Seismogenic regions of interest for Chilpancingo city.

GEODYNAMICS

For the study of local characteristics, geological, topographical and urban maps are available for most important cities, but this is not the case for geotechnical information which is usually very scarce. Generally, it is possible to find a limited number of soil borings that give enough information as to calculate the fundamental period analytically, through elastic theory; but this information tends to be concentrated in downtown and main avenues, where the most important buildings are located.

As a way to increase the knowledge of soil dynamic characteristics, ambient vibration measurements are used for this project. This has been done with a digital recorder Kinemetrics SSR-1 and WR-1 sensors.

Beginning in the boring points for calibration purposes, the spectral analysis of the records from other points allows to estimate fundamental periods, thus covering all parts of the city (Fig. 2). It must be emphasized that this approach is a first step toward a rational seismic zonation, and that there will always be need to obtain more boring information in order to improve the soil characterization.

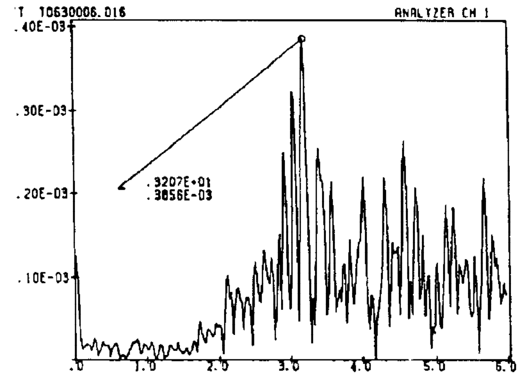

Fig. 2. Fourier spectrum from Toluca firm soil.

Based on the estimate of the fundamental periods, it is possible to elaborate a map of equal period curves (Fig. 3), and from this, a seismic zonation map for the city under study. Curves for periods less or equal than 0.40 seg used to be related with the topography, so this type of information is also very useful. The final objective is to distinguish the possible existence of a firm soil zone with periods less than 0.40 seg, an intermediate zone with periods between 0.40 and 1 seg, and a soft soil zone with periods greater than 1 seg. The criteria of looking for three different zones only is based on the Mexico City code.

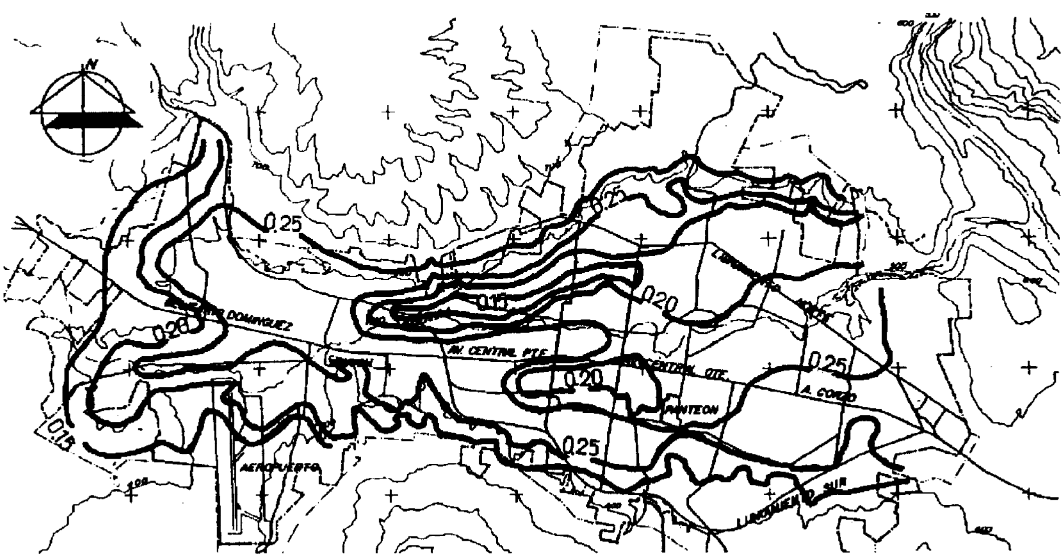

Fig. 3. Equal period curves for Tuxtla Gutiérrez city.

For the definition of limits between different zones, a preliminary proposal is subjected to review from local geothecnical engineers whose contribution greatly enhance the results, and even lead to the reanalysis of some of the fundamental period estimates. Finally, it is important to adapt the limits to streets to facilitate their use in practice.

EARTHQUAKE INTENSITIES

Due to the lack of local instrumentation, the main source for the study of ground motion is the estimate of seismic intensities from the damage caused by earthquakes in the past. For this purpose, it is necessary to compile damage information through the available historical documents, and even oral tradition. Fortunately for Mexico, professor Jesús Figueroa spent most of his career recovering historical data and producing isoseismal maps for the main earthquakes of the past 150 years; this constitutes an invaluable material available through several publications (Figueroa, 1972; 1974).

For more recent earthquakes, it is sometimes possible to find damaged buildings and to evaluate their seismic capacity through the calculation of their base shear resistance coefficient; in this way, a more precise estimate of the intensity may be obtained. In the absence of enough accelerographic information, it was through a map of intensities derived from the damaged buildings evaluation that the present seismic zonation of Mexico City was done after the 1985 event (Iglesias, 1991). The Mexico City experience allowed us to establish a correlation between Modified Mercalli intensity and the base shear resistance coefficient of damaged buildings (Jara *et al.*, 1992), that permits to relate historical intensities data with damaged evaluation results and, finally, to use both in the definition of design parameters.

RISK ANALYSIS

An orthodox probabilistic approach to earthquake risk analysis confronts such a lack of local information that it is very difficult to obtain reliable results for most Mexican cities. The absence of ground motion records prevents the definition of local attenuation curves, and recent works have shown great differences between local curves and conventional attenuation relationships, at least for earthquakes from the most important Pacific subduction zone (Carballo, 1994). There is also a general lack of knowledge of the urban infrastructure characteristics outside Mexico City that makes it impossible to define reliable loss functions. However, the risk analysis done for many cities using general attenuation and loss relationships provides important elements for the decision-making process (Esteva and Ordaz, 1988; Trigos, 1988).

The definition of design parameters in terms of seismic coefficients and even design spectra has been successfully done in this project by considering actual practice, the intensity of the most important earthquakes in the past and the results of existent risk analysis, if any. The procedure has been to define the seismic coefficient for each zone of the zonation map, by covering the maximum shear resistance coefficient derived from the intensities of past earthquakes and the values proposed for existing risk analysis in a conservative way. Usually, seismic coefficients define the maximum spectral values, while fundamental ground periods are derived from the geodynamical definition of the zone limits, with conservative criteria. Final decision is taken after consulting with local structural engineers, who provide economical and practical considerations to the process; this has sometimes led to the acceptance of parameters that do not cover the most extreme scenarios.

PROJECT ORGANIZATION

Great emphasis has been given to the importance of involving the local scientific and professional community. In this way, the role of the UAM has been to promote the integration of local research teams to carry on most of the work, and to provide them with permanent technical support and guidance.

In a first instance, the scope of the project has been limited to the study of capital cities in those states most affected by earthquake hazards; another reason for this is the existence of state universities with engineering schools in almost all the state capitals in Mexico. So, the first step is to contact the local university, through the civil engineering faculty, to discuss the project and to invite them to a joint venture. In some cases there is local research experience, but even when that is not the case, the relevance of the work has been attractive enough to the integration of a research team with academic personal. The decision to colaborate is made official by an agreement contract between the two institutions.

The work begins with the local team compiling information in the form of urban, geological and topographical maps. Geothecnical boring information is more difficult to obtain and it implies to contact the local engineering firms which may provide it. This contacts are very useful later on to incorporate the professional expertise into the project.

Based on a first characterization of the city, the local and the UAM research groups work together in the measurements of ambient vibration, in an interactive process that analyze the results, confront them with geotechnical and geological information through the local professional expertise, and then define the need of new measurements, until an equal period curves map is finally obtained. From it, a first proposal for the zonation map is defined and then submitted for review to the geotechnical engineers in order to reach a final version. In parallel, the local team compiles the historical data on earthquake intensities, and proceeds to evaluate the shear resistance coefficient of damaged buildings, if any. This information, together with that from the available risk analysis, is studied to elaborate a first proposal of seismic coefficients and design spectra, which is submitted for review also to structural engineers before a final seismic zonation is integrated.

Until now, this process has been carried out in five capital cities: Chilpancingo , by the Universidad Autónoma de Guerrero (Gama *et al.*, 1994); Puebla, by the Universidad Autónoma del Estado de Puebla (Ruiz *et al.*, 1994); Morelia, by the Universidad Michoacana de San Nicolás de Hidalgo (Jara *et al.*, 1994); Toluca, by the Universidad Autónoma del Estado de México (Ramírez *et al.*, 1994) and Tuxtla Gutiérrez, by the Universidad Autónoma de Chiapas (Alonso *et al.*, 1995) (Fig. 4).

Figures 5 to 9 show the seismic zonation maps proposed for the five studied cities. It is interesting to observe the different criteria on limits definition followed by each work team.

BUILDING CODE

The work done by the research group of the local university with the technical support of the UAM leads to a seismic zonation proposal which has been elaborated with the intervention of several local engineering firms and professionals, who, in this way, become the most interested part in its inclusion into the local building code. As members of the state engineering association they submit the proposal for discussion inside the association, where it may suffer some modifications and, finally, it is through the engineering association, with the support of the local university, that it reaches the authorities for the final approval.

In April of 1994, the seismic zonation of Puebla, capital city of the state of the same name, was enacted together with a complete new building code for the city (AMP, 1994). The proposal for Chilpancingo, capital of the State of Guerrero, is now under discussion in the local civil engineering association before its submission to the authorities as part of a new building code.

The Puebla building code is the first one in the country that includes a local study of the city, and that is not a mere copy of the Mexico City code. It is clear that the impact of this project into the building codes that are under way is mainly due to the protagonic role of the local scientists and engineers, that makes a significant difference with past experiences of seismic zonation of cities in Mexico.

FURTHER WORK

The success of the project has stimulated the consolidation of local research groups. The first consequence of this has been the birth of an earthquake engineering interuniversitary association: Grupo Interuniversitario de

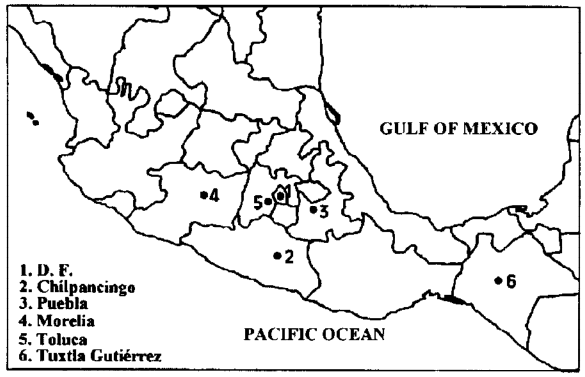

Fig. 4. Capital cities studied.

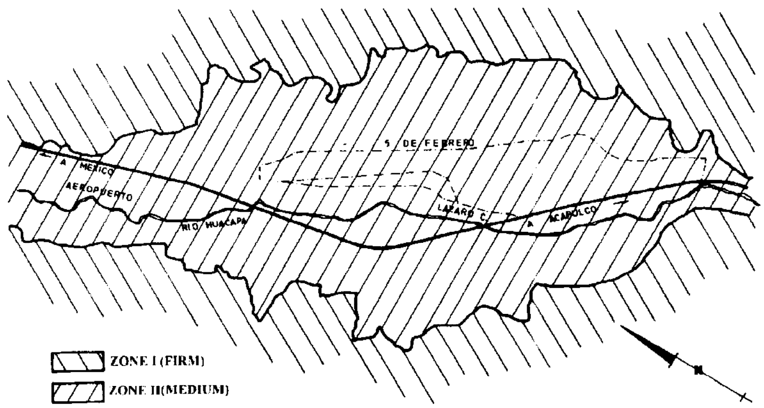

Fig. 5. Seismic zonation map for Chilpancingo city.

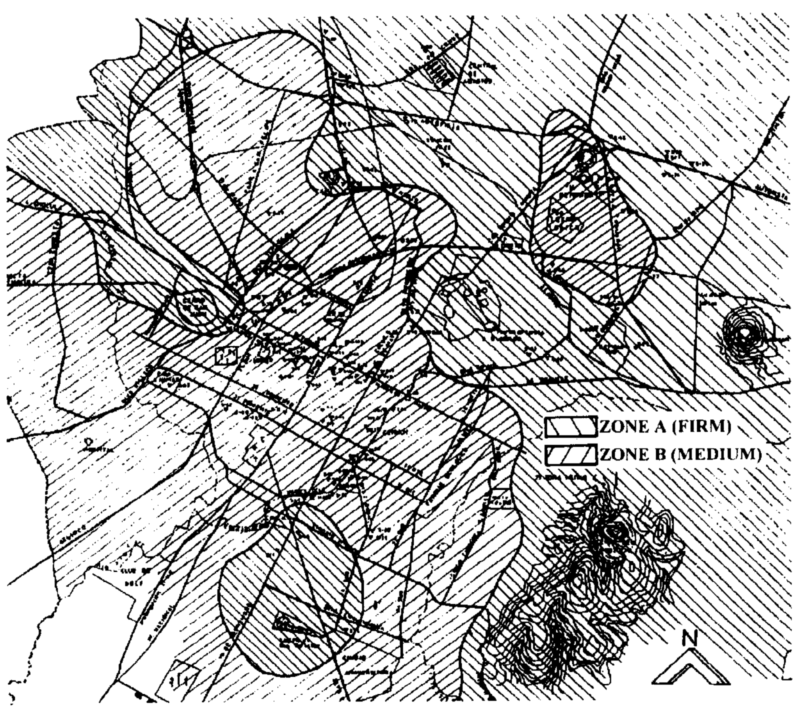

Fig. 6. Seismic zonation map for Puebla city.

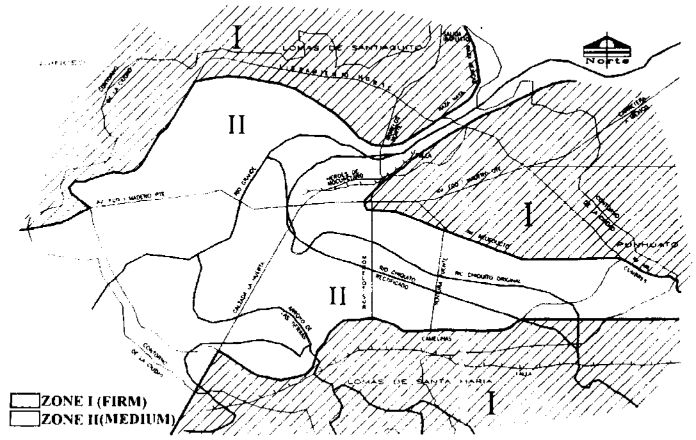

Fig. 7. Seismic zonation map for Morelia city.

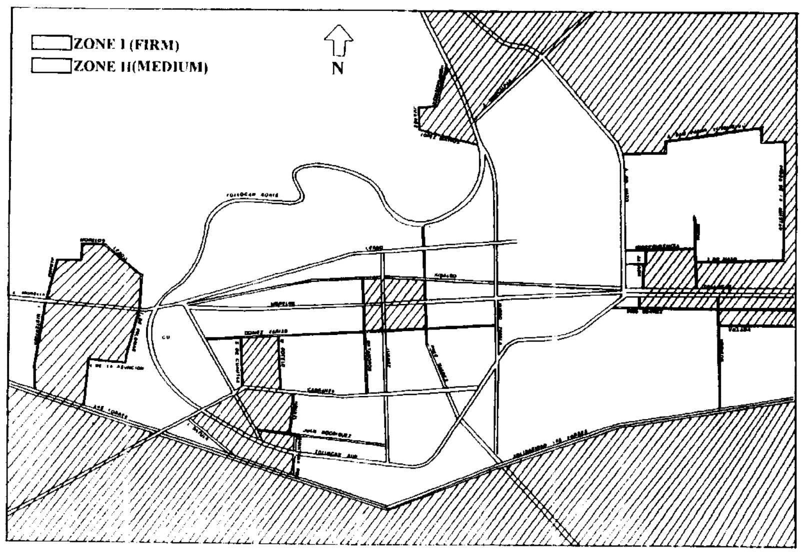

Fig. 8. Seismic zonation map for Toluca city.

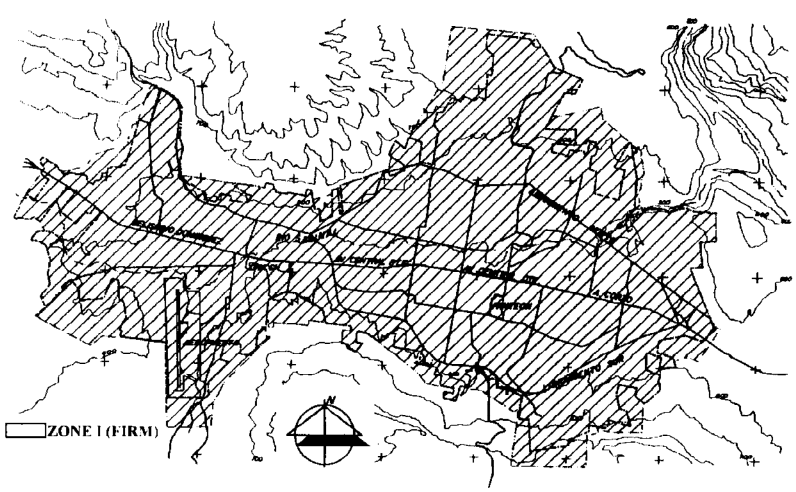

Fig. 9. Seismic zonation map for Tuxtla Gutiérrez city.

Ingeniería Sísmica (GIIS), integrated by the six institutions involved to date. This association has been working since 1994 in the integration and operation of an accelerometric network, with the purpose of obtaining strong ground motion records in the five studied cities. At present, the network has in operation two accelerographs Kinemetrics SSA-2 in each city, one on firm soil and the other on the soft soil zone. In other directions, local risk analysis and local amplification studies are now under development by the association in the cities already studied. Finally, the local research groups are beginning to use the experience gained from the capital cities for the seismic zonation of other important cities in their corresponding states.

CONCLUSIONS

The project described in this paper shows the possibility of preparing the seismic zonation of cities, despite the lack of local information, using all available data and complementing it through alternative sources, such as ambient vibration measurements and the estimate of past earthquakes intensities. In this effort, local participation, both, in the integration of the main research team and through the consulting of geotechnical and structural engineers, proves to be of capital importance for the good quality of the results, their inclusion in building codes, and their adoption by professional practice. As a complementary result to the seismic zonation of the studied cities, the consolidation of local research groups in close contact with engineering associations has resulted in a multi-institutional cooperation that has began to make deeper studies and to extend the experience to other important urban centers besides the capital cities in each state.

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