ASEISMIC DESIGN IN MEXICO

by Emilio Rosenblueth*

Aseismic design practice in the Republic of Mexico is still in a rudimentary stage, although the country is awakening rapidly at present, and there is promise of stupendous developments in the near future. The main reason for its slow development is to be found in the present concentration of tall buildings, important dams and bridges, and delicate industrial installations in regions of nill or moderate seismic activity.

It is true that the State of Oaxaca and part of Guerrero in the South West of the country are seismically very active. The State of Veracruz, in the east coast, has also suffered violent, though less frequent, seismic disturbances. (The 1920 Veracruz earthquake was one of the strongest ever recorded in Mexico; entire villages were covered by mud and sand rivers, and many churches and one-story houses were completely destroyed.) But few buildings over four stories tall are found outside Mexico City, and practically none over six stories in height, and seismic activity in the Federal District is quite moderate.

Delicate industrial installations are located principally in the Federal District and nearby San Bartolo Naucálpam, State of Mexico. The only other industrially important cities are Guadalajara, Jalisco, where earthquake shocks have been felt mildly in recent years despite intense seismic activity of the past, and Monterrey, Nuevo León, whose inhabitants do not remember ever having felt a temblor. Cities whose industries are developing rapidly, such as Irolo, Hidalgo, and León, Guanajuato, have also suffered only mild shocks in recent times. (See Fig. 1.)

The seaport and tourist resort of Acapulco has acquired great importance in the last few years. Although located in the State of Guerrero, it is sufficiently west of the main epicenters, and sufficiently isolated from them by mountain ranges, that its strngest earthquakes are far milder than in other regions of the country. Nevertheless, it is more exposed than Mexico City. And the number of relatively tall hotel and apartment buildings (up to about fifteen stories), which are now being built, have awakened a greater interest in aseismic design.

The recent (7 Jan. 1956) earthquake of Guerrero was responsible for the collapse of one three-story house and the severe damage of three hotel buildings and one nearly finished four-story hospital, all in Acapulco. These failures were quite obviously attributable to poor workmanship in a city practically devoid of building tradition. Also to the poor quality of the weathered granite that is used as aggregate in most of the concrete which is manufactured in Acapulco, rather than to defective design. Still, the Acapulco failures have spurred the interest in aseismic design.

Other factors have contributed in the recent awakening. Thus, the Ministry of Hydraulic Resources contemplates construction of the Marqués earth dam in the State of Oaxaca. It has become interested in the aseismic design of dams, not being content with computing water pressures by

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the Westergaard theory(1) nor with computing the inertia forces in the dam with a constant seismic coefficient.

The Ministry of Communications and Public Works contemplates construction of several bridges, which are to have a 138-ft intermediate support that will be less than six feet wide at its base and less than four feet wide at its top; this has called for elaborate dynamic analyses.

In Mexico City, there are only five buildings over 18 stories in height, two of them under construction, one of them 43 stories tall. Previous to 1948 there were none. And the design of their structures, the cracks and alarmingly large oscillations that one of these buildings suffered during the 5 Jan. 1951 earthquake, and the partial collapse of one 18-story building about nine years ago, when it was still under construction, have been partly responsible for the concern of Mexican engineers with aseismic design.

One must make a sharp distinction between building codes and the practice of the more advanced group of engineers. Only the Federal District possesses a building code with provisions for aseismic design. And even there the code is rarely respected. Tall buildings are designed according to the judgment of individual consultants.

The Federal District code was issued in 1942(2). Its most recent amendments and additions (15 Dec. 1951) have not altered the requirements on aseismic design. At the time it was first published, the code was up to date in what concerned aseismic design of buildings. It did not differ radically from the building codes of other large cities of the world in force at that time; witness the following translation taken from Chapter 41.1.

> <u>Article 9</u>. The following rules shall be complied with to prevent earthquake damage as far as possible. They shall hold until special studies permit additions or modifications thereof.
>
> <u>Article 10. Joints</u>. Joints between different structural elements must be designed in such a manner that they resist at least as much as the elements they join.
>
> <u>Article 11. Unity</u>. Each structure shall be designed and built so that it oscillates as a single unit. Structures provided with wings (T-, L-, or H-shaped in plant) shall have these rigidly fixed to the rest of the building, so they oscillate together with it.
>
> <u>Article 12. Classification</u>. When requesting a building license, the structure shall be classified in one of the following types, for purposes of this chapter. The Department of Public Works will reclassify it if necessary.
>
> Type I. In this group are included all structures whose permanence is indispensable when all other structures have been destroyed by an earthquake. This includes, for example, all those upon which depends the life itself of the city's inhabitants, such as pumping stations, water deposits, fire stations, electric plants, and sewage

treatment plants. Also, those monuments it is intended to preserve.

Type II. This group covers all buildings intended for the gathering of large numbers of people, as well as those upon whose stability depend the lives of many people. It covers schools, theaters, and similar buildings.

Type III. To this group belong all buildings intended for public use, but where large numbers of people are not gathered. Also, those structures whose failure would endanger these buildings. To it belong hotels, apartment-, office-, and industrial-buildings, etc.

Type IV. Here are included buildings destined to enclose costly or important goods and equipment. Examples: warehouses, bins. Also included are those structures whose failure would endanger these.

Type V. Buildings of small value whose failure would endanger the lives of only a few people. Example: comparatively expensive private homes.

Type VI. Any building used to accomodate a small number of persons.

Type VII. Any structure where a small number of people may occasionally congregate, but not habitually used to accomodate them.

Type VIII. Any isolated structure whose failure would not normally endanger human lives or other structures.

Article 13. Seismic coefficient. Seismic coefficients (ratio of assumed earthquake acceleration to acceleration of gravity) to be used in the design of each of the foregoing types shall be as follows.

Type I,	0.10
Type II,	0.05
Type III-VI,	0.025
Type VII,	0.01
Type VIII,	0.00.

Article 14. Definitions. "Seismic force" is equal to the seismic coefficient times the entire weight of the building above the horizontal plane considered. The entire weight includes dead and live loads.

The "seismic shear" equals the seismic force corresponding to the same horizontal plane.

Article 15. Foundations. Foundations shall be designed and built in such a manner that, when the building is fully loaded, including dead, live, and earthquake loads, they satisfy the following conditions under the most unfavorable combination.

a) The structure will not slide.

b) Joints between piles and foundation girders or slab will not fail.

c) No pile will be overstressed by more than 33 percent.

d) No point of the bearing area of the ground will be overstressed by more than 33 percent. (Maximum stresses usually occur at corners, when seismic forces act diagonally.)

e) The structure will not topple over.

f) Foundation elements, their joints, and joints between superstructure and foundation, will not be overstressed by more than 33 percent.

Article 16. Walls. Structural walls, when taken as a unit, shall resist without failure the seismic shear in horizontal planes. Nonstructural walls shall be built in such a way that permissible stresses are not exceeded during an earthquake. (By structural wall is meant one built so it may receive seismic shears from other structural elements.)

Article 17. Buildings designed against wind pressure need not be designed against simultaneous action of wind and earthquake. Only those effects shall be taken in consideration which produce the greatest stresses. For increase in permissible stresses see Chapter 41.2*.

Article 18. Presentation of computations. Buildings requiring the presentation of aseismic design computations are those whose height exceeds 16 meters, those whose height exceeds twice the least dimension of the base, and all those intended for the gathering of large numbers of persons.

The specification in Art. 14, concerning consideration of full live load, may seem excessively conservative. Yet, design live loads specified in the Mexico City building code are somewhat smaller than is usual. For instance, office live load is 41-51 psf and most designers assume the lower figure. Dead loads, too, are somewhat smaller than may be expected: the unit weights specified for masonry walls, for example, do not include weight of mortar. Moreover, it may be justified to increase the factor of safety as the live load increases.

One point is certainly criticizable: There are no special provisions to increase seismic coefficients in the design of the brittle constituents of buildings, such as parapet and curtain walls and protruding brick elements.

The Inst. of Eng. will soon be engaged in a complete revision of the building code. It is intended that the sections on soil mechanics and engineering seismology receive special attention.

* It requires taking the greater section: the one obtained with static load and no increase in permissible stresses, or with static plus wind or earthquake forces, allowing a 33 percent increase in permissible stresses.

Prior to 1942 the Federal District building code (1920), which only applied to Mexico City proper, had no more than general recommendations on types of building materials. Also available were the recommendations of the Bulletins, Parargones, and Folletos de Divulgación, Instituto Geológico de México (1903-1922), Secretaría de Fomento, which advocated careful workmanship, the use of high-quality construction materials and methods, and the rebuilding of villages affected by strong-motion earthquakes and by mud rivers, away from the regions where they were most vulnerable.

The practice of consulting engineers in Mexico has rarely coincided with recommendations in the building code. Thus, in the 1940's they were concerned, as were most engineers in other parts of the world[3], with the natural periods of ground vibration and the ensuing resonance phenomena in building vibrations. Structures with fundamental period in the neighborhood of 1.0 sec were deemed unsafe, independently of their strength or rigidity. The tendency was to make those structures much more rigid, thus decreasing their natural periods. It was not until several years had elapsed since Housner's definitive work[4] on the randomness of strong-motion earthquake waves, that the concept of dominating ground periods was slowly abandoned.

The tendency of the engineer engaged as consultant for the elaboration of the aseismic-design section in the building code had been to use much higher seismic coefficients than were finally adopted, and specify limit design with load factors close to unity. But he refrained from it because he did not consider most designers ready to abandon classical methods of structural analysis[5]. In his own jobs he has advocated seismic coefficients as high as 0.15 in buildings for which the code requires 0.05, together with a limit design criterion and a load factor equal to unity [6]. Certainly, this practice leads to a more rational utilization of the structural capacity if seismic coefficients are adequately chosen.

Awareness about the dynamic behavior of structures subjected to earthquakes has been nearly fully established. Several papers [7,8] have helped in this direction. Indeed, Westergaard's method of stress analysis in buildings idealized as shear-beams[9] exerted appreciable influence. It has produced designs characterized by considerably greater shear capacity and rigidity in the upper stories than is usual in conventional constant-seismic-coefficient design, effecting at times some economy with respect to the latter in the lower stories[8]. Even if one does not agree with the assumed shapes of seismic waves in those analyses, there is little doubt as to the significance of improvements attained thereby over conventional methods.

As is common in the rest of the world, few engineers have been conscious of the consequences of using ordinary reinforced-concrete slabs in floor systems. Too often each frame of a building is designed as though it behaved independently of the rest of its frames, with little concern for the extreme rigidity of the slab in its plane, and no concern at all for torsion and associated phenomena. In recent years a number of dissertations presented in partial fulfillment of the requirements for the degree of Civil Engineer, as well as more serious works[8,10], have contributed to clarifying these concepts.

The tendency toward probabilistic methods in aseismic design (11) has also exerted some influence in recent years, These methods have already been applied in the design of some of Mexico City's tallest buildings(12,13).

Mexican designs are at present characterized by rather rigid structures. Thus, diagonal bracing is common in Mexico City and Acapulco, even for reinforced-concrete structures. The tendency springs in part from experience, since the main seismic damage observed in modern buildings has been wall and plaster cracking. This situation is attributable to the tendency toward glass façades, justified by the benign weather of Mexico City and the boldness of its architects. Also to the use of flimsy and brittle interior partitions, which in most cases are mandatory for economic reasons in the strive for lighter construction, less apt to settle excessively in the soft lacustrine deposits of Mexico City.

Few structures have themselves presented earthquake damage. Being particularly aware of possible damage to partitions, most engineers in Mexico cast aside the corollary derived from dynamic analyses of elastic systems(14), which leads toward more flexible construction. Certainly, theoretically computed stresses are greater in the more rigid structures, but the tendency toward increased rigidity has been reinforced by studies which leave little doubt as to its advantages in structures made of ductile materials.(15)

Some research was carried in past years at the Inst. of Geophysics, U. of Mexico, and some at Ingenieros Civiles Asociados, S.A. de C.V., a private construction firm. It is now primarily concentrated at the Inst. of Engineering, U. of Mexico. The chief present preoccupations of research workers in aseismic design concern probabilistic methods, damping, effects of soft layers in the sub-soil, foundation compliance, and simplification of design methods, with emphasis on approximate dynamic influence lines. Most of the work is at present analytical and numerical.

The awakening of Mexico in aseismic design has been slow indeed. But the country has at last begun to produce serious work and holds promises for the near future.

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Locations of Earthquakes in Mexico.

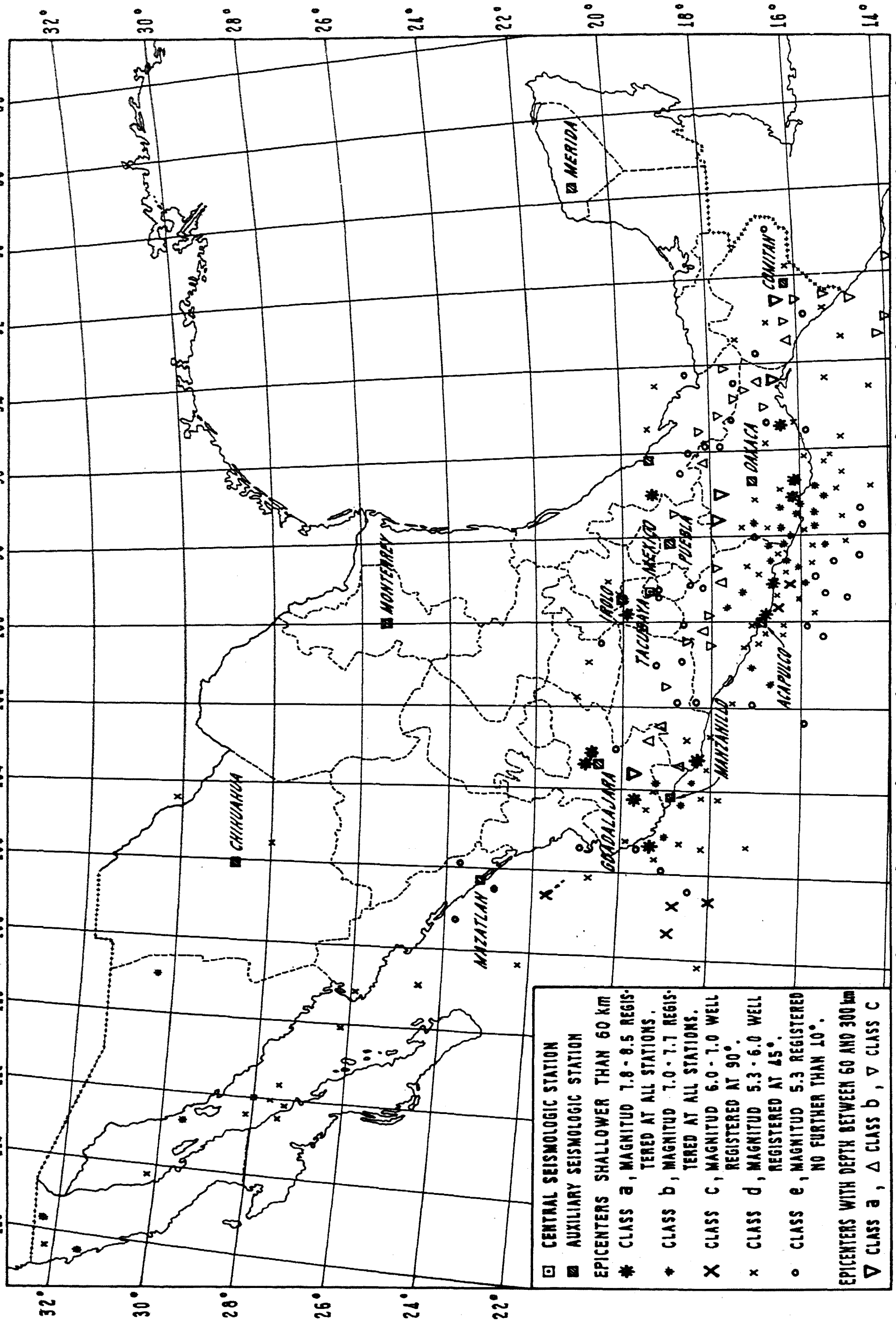

FIG. 1