ASEISMIC DESIGN OF LATINO AMERICANA TOWER IN MEXICO CITY

L. Zeevaert* and N. M. Newmark**

The 43-story building of "Latino Americana" Seguros de Vida, S. A., is nearly twice as tall as any other building in Mexico. Because of the foundation conditions in Mexico City, it was necessary in the design of the building to conserve weight as much as possible. Consequently, in planning the building, detailed consideration was given to earthquake forces.

A view of the structure is shown in Fig. 1. The building is not yet completed, although the frame has been erected and all of the floors cast. The covering and the windows are being erected now and Fig. 1 shows the structure in its present state of completion. On top of the building, there is a tall mast holding the television transmitting antennae. A line diagram showing the columns of the building and the shapes of several cross-sections is shown in Fig. 2. The building is very nearly of constant cross-section over its entire height, with the part from the fourteenth to the thirty-eighth floor differing from story to story only in the stiffness of the columns and girders. Changes in the plans of the building during the period of the design, including increases in height and the addition of the television tower, brought up special problems which had to be considered in the final review of the design features for earthquake resistance.

In Mexico City, the specified shear coefficient for the aseismic design of office buildings, apartment houses, hotels and industrial buildings of any number of stories is taken as 2.5 per cent. The code specifies that the horizontal shearing force at any elevation may be computed by the product of this shear coefficient by the total dead and reduced live load applied to the structure above the elevation. Essentially, this involves a constant seismic factor for the full height of the building.

Buildings designed on this basis apparently have resisted satisfactorily, with only occasional minor damage, earthquakes up to

* Consulting Engineer, Mexico City

** University of Illinois, Urbana, Illinois

intensities VII on the modified Mercalli scale.* Records of earthquakes in Mexico City are kept at the seismological station at Tacubaya, D. F. This station is situated on firm alluvial deposits, and has recordings dating from 1900. A tabulation of the recorded earthquakes of intensity III or greater is shown in Table 1, in which is also given the acceleration ascribed to the various intensities by the seismological station.

It appears that occasional earthquakes of intensity VIII may be expected, and that buildings should be designed to resist earthquakes of this intensity, occurring infrequently, or earthquakes of intensity VII , occurring every 10 to 20 years.

The seismological station in Tacubaya estimates periods of vibration between 0.5 and 1.0 sec. However, because this station is situated on a firm soil and Mexico City is located on lacustrine clay deposits which are quite deep, it may be expected that the period of vibrations for strong earthquakes in the city area may be longer, between 1.5 and 2.5 sec. Therefore, the maximum ground velocity which may be expected in Mexico City is of the order of 8 cm. per sec. for an earthquake of intensity VII and about twice as great for the maximum earthquake which might be expected.

If it is assumed that the basement of the building follows the ground motion, the maximum shear in the structure will occur in the first story. If the building is assumed to be very tall and if the foundation motion is assumed to be a constant velocity pulse, then the shear in the first story can be computed from the spring constant of the first story and the mass of the first floor, by the following relation:

$$V = \sqrt{mk}\,\dot{x} \tag{1}$$

in which

m = mass of first floor,

k = spring constant of first story,

V = base shear,

and $\dot{x}$ = maximum ground velocity,

The shear given by Equation (1) is only a conventional value. Because of the actual way in which the ground motion is applied, and because of reflections and transmission of shock pulses through the building, the actual maximum shear may differ considerably from this value.

* See Table 1 for a definition of these intensities.

The maximum intensity of stress anywhere in the building may be considered to be a function of the probability of the stresses arising from different pulses reinforcing each other in various levels in the building. In order to arrive at a reasonable basis for design, an analysis was made of the building, considering the first four modes of vibration. The shears were computed for each mode and the probable shear at any height was determined as the square root of the sums of the squares of the shears for each of the four modes considered. On this basis, and with the base shear determined from Equation (1), both the relative shears and the design shears throughout the height of the building were obtained.

The modes of vibration of the building are shown in Fig. 3. The periods of vibration of the various modes were calculated as 3.66 sec. for the first mode, 1.54 sec. for the second mode, 0.98 sec. for the third mode, and 0.71 sec. for the fourth mode. The analysis for period and for mode shape was made with a modified shear stiffness, taking into account the rotations of the ends of the columns in each story corresponding to the relative stiffness of the floor and girders compared with the columns. A limited moment distribution analysis of sections of the building was made to determine the effective shear stiffness of the various stories.

The results shown in Fig. 3, and the periods of vibration reported, are for the final configuration of the building with the added stiffness of the joints to take account of the television tower.

The dynamic shears for each mode are shown in Fig. 4. These are plotted in such a way that the base shear for mode 1 is taken as 380 metric tons, or 2.5 per cent of the total weight. The values of the base shears for the other modes were computed in accordance with the relative proportions of these modes entering into the static deflection of the building for a load corresponding to the weight of the building, and adjusted also for the period of the mode considered.

There is also shown in Fig. 4 a curve labelled as

$$\sqrt{\Sigma V_n^2}$$

in which V_n is the shear for any mode n, and the summation includes the first four modes. This curve is also drawn so as to have a base shear corresponding to 380 metric tons, which corresponds to the 2.5 per cent seismic factor of the Mexico City code. The relation used above is explained in Reference (1).

In the preliminary design of the building, the first estimate of the seismic shears for the design was made on the basis of a uniform seismic coefficient of 5 per cent. This figure was arrived at on the basis that the building was proposed to be approximately twice as tall, at that time, as the previous tallest building in Mexico City. Since the previous buildings had successfully withstood earthquakes and were designed for shears corresponding to a 2.5 per cent uniform seismic coefficient, it was felt that owing to the increased height of the building the shearing stresses might be increased roughly in proportion to the height. The base shear was based on preliminary estimates of the weight of the building. The building at that time was to be only 40 stories in height. A rough preliminary design of the building was made and the fabrication of the steel was begun. However, at this time it was decided to add three stories to the structure as well as a television antennae. The increase in height and weight of the tower made it necessary to consider the design of the building again. It was at this stage of the problem that the first dynamic analyses were made.

The results of the various bases for the design of the building are shown in Fig. 5. In this figure, the curve marked "A" is the shearing capacity of the various stories for the original forty-story building. The curve marked "B" shows the shears computed on the basis of a seismic coefficient applied uniformly, of 5 per cent, considering the same structure as "A" but with the increased height and taking into account the weight of the television tower. The curve marked "C" is the result of the dynamic analysis based on the most probable dynamic shears, for a base shear coefficient of 2.5 per cent. It can be seen by comparisons of curves A, B, and C that the upper part of the building would be overstressed and the lower part understressed, under dynamic conditions. The shearing strength for the final design of the building is shown by curve D. Only the upper part of the building was strengthened, from the twenty-eighth floor to the top. This strengthening was done so as to provide the resistance indicated by the requirements of the dynamic analysis, with a slightly greater resistance provided in the region just below the television tower. Because the steel was already fabricated, the building has an increased strength below the twenty-eighth floor, compared with the indicated design values from the dynamic analysis. The final strength of the building, shown by curve D, is the same as that indicated by curve A below Floor 28.

The procedure outlined was, of course, carried out in stages. The analysis was made at least twice to correspond to the different stages in the design calculations. The final curves shown in Fig. 5 are for the final configuration of the building.

It is therefore apparent from Fig. 5 that the structure above the twenty-eighth floor is actually designed for a dynamic shearing condition corresponding to a base shear of 2.5 per cent of the total weight of the building. However, the lower part of the building is actually designed for a shear coefficient of approximately 4.0 per cent.

The effective shear coefficient for the base of the tower is about 19 per cent, for the forty-first story 14 per cent, for the thirty-ninth story 10.5 per cent, for the thirty-fifth story 7 per cent, and for the twenty-seventh story slightly more than 4 per cent. For the upper part of the structure these shears are at least 40 to 75 per cent greater than those required by the Uniform Building Code, and somewhat greater even than this factor in relation to the provisions of the Joint Committee(2). For the lower part of the building the design is conservative by any standards, the base shear being about twice that specified by the Joint Committee Code.

With the use of Equation (1), the base shear for a maximum velocity of the ground of 8 cm. per sec. is 207 metric tons, and for a maximum ground velocity of 16 cm. per sec., 413 metric tons. Consequently, it appears that the structure is adequately safe for the maximum probable earthquake in Mexico City and has a factor of safety of about two for the maximum earthquake which has occurred in the period from 1900 to 1956, based on working stresses. The actual factor of safety is, of course, considerably greater.

To add stiffness to the superstructure, and thus to reduce the deflections during earthquakes, the steel frame was stiffened at the connections, and the floors were stiffened by providing composite action between the girders and the concrete floor slab by means of shear connectors. A view of the shear connectors attached to the top flange of one of the floor girders is shown in Fig. 6. The floor slab is 3.5 in. thick, and was cast monolithically with reinforcement to provide resistance against diagonal tension in the plane of the floor.

Before the building was completed, instruments were devised to measure the relative motions in various parts of the buildings during earthquakes, windstorms, or other influences. The device shown in Fig. 7 was constructed and mounted in several floors of the building. The device consists essentially of a long rod mounted on a pivot at one end and arranged so that changes in length of the diagonal in the panel of the building are recorded. The rod is supported along its length by wires, and is attached to a lever which actuates a recording pencil. The length of the linkage is made adjustable so as to set the recording diagram on a zero datum. A close-up view of the recording mechanism in its initial stages is shown in Fig. 8. Here, the pivot of the short lever is shown at about the center of the figure. The recording chart is a circular chart mounted on a simple clock which turns it at a uniform rate. The pencil mechanism draws a line as the chart turns. When winds or earthquakes strike the building, a short radial line is drawn on the chart. The time scale is so short that the deflection-time curve cannot be obtained from the chart, but the maximum amplitude of deflection is easily determinable. The deflection of the bay can be determined from half the total amplitude, if the motion is elastic, because in general the excursions on each side of the base line are about equal. The multiplication of the lever is of the order of about five.

A later modification of the device puts the recording on a drum so that the lines are drawn circumferentially on the drum rather than on the circular chart as shown in Fig. 8.

Since the completion of the structure, and the installation of the devices, several earthquakes have been recorded. The devices were installed only in Stories 1, 25, and 39. For two earthquakes of intensity IV and one of intensity V, according to the Tacubaya Seismological Station, the records are summarized in Table 2. The relative motions indicated in the table are half the total amplitude of deformation. It may be pointed out that most of these motions are of about the same order of magnitude as the motions which occur daily from the effect of the sun shining on part of the building. Motions due to wind forces are too small to make any effective record.

The shears computed for the relative motions in Table 2 are also shown. These were determined from the shear stiffnesses of the stories in which the instruments were mounted. These shears ranged from about 6 to as much as 36 metric tons.

The data have been studied in two ways. The first study was to determine whether the data would lend themselves to a determination of the mode in which the earthquake occurred. The second study involved an estimate of the probable base shears from an actual strong earthquake of the order of intensity VIII.

The relative shears in the various modes of vibration of the building are recorded in Table 3 for the first, twenty-fifth, and thirty-ninth story of the building. There are also recorded the shears determined by the dynamic analysis, as the square root of the sums of the squares of the shears in the first four modes. By comparison of Table 2 and Table 3, it can be seen that very roughly the "measured" shears are in about the same proportion as the probable maximum shears. The relative values of the measured shears generally agree more closely with mode 2 than with any of the other modes. However, it cannot be concluded definitely that the building responds in mode 2 to the earthquakes which have occurred. Probably all of the modes are excited to some extent with perhaps mode 2 predominating in the earthquakes which have been recorded.

There is finally given in Table 4 a comparison of the base shears determined in various ways. The base shears computed from the maximum accelerations for the different intensities of earthquakes are shown in the second column. These are based on the fact that a base shear of 380 metric tons corresponds to a base shear coefficient of 2.5 per cent, which corresponds to the maximum acceleration of an earthquake of intensity VII. The other values can easily be obtained by direct proportion.

The values given in column 3 are computed from the maximum velocities corresponding to the maximum acceleration values (assumed as sine pulses of period 2 sec.), with the use of Equation (1). These values are considerably smaller than those computed from the maximum accelerations, and the intensity of base shear for the maximum expected earthquake of intensity VIII is about 400 metric tons.

The last column in Table 4 shows a comparison of the observed base shears from Table 2. For the two earthquakes of intensity IV, the observed values are fairly close to the value of 21 metric tons computed from the maximum velocity. For the observed earthquake of intensity V, the observed shear is fairly close to the value of 41 metric tons computed from the maximum velocity. Although the inference may not be too sound from these limited data, it appears that one might expect that an earthquake of intensity VIII might produce shears which would not be too greatly different from those for which the building is designed.

Acknowledgment is due to Latino Americana for releasing for publication the information concerning their building. The authors want especially to acknowledge the help of the engineering staff of the company and particularly of Mr. Adolfo Zeevaert, Chief Engineer, for cooperation and suggestions both in the conduct of the studies and in the interpretation of the results.

BIBLIOGRAPHY

1. "Aseismic Design of Firmly Founded Elastic Structures," by L. E. Goodman, E. Rosenblueth, and N. M. Newmark, Transactions ASCE, Vol. 120, 1955, pp. 782-802.

2. Report of a Joint Committee on Lateral Forces, "Lateral Forces of Earthquake and Wind," Transactions ASCE, Vol. 117, 1952, pp. 717-754.

TABLE 1

EARTHQUAKES RECORDED IN MEXICO CITY

Intensity Mod. Mercalli Scale	Acceleration cm/sec^2	Recorded Quakes 1900 to Feb. 1956
III	0.5 - 1.0	307
IV	1.0 - 2.5	114
V	2.5 - 5.0	24
VI	5.0 - 10.0	12
VII	10.0 - 25.0	3
VIII	25.0 - 50.0	0

TABLE 2

OBSERVED EARTHQUAKE MOTIONS

Date	Story	Relative Motion cm.	Computed Shears metric tons
May 13, 1954	1	0.028	22.1
	25	0.039	14.0
	39	0.034	6.5
June 4, 1954	1	0.021	16.6
	25	0.030	10.8
	39	0.032	6.1
Jan. 8, 1956	1	0.046	36.2
	25	0.048	17.3
	39	0.072	13.7

TABLE 3

RELATIVE SHEARS IN VARIOUS MODES

Story	$\sqrt{\Sigma V_n^2}$ metric tons	Relative Story Shears			
		Mode 1	Mode 2	Mode 3	Mode 4
1	380	380	335	180	65
25	185	230	121	40	40
39	70	25	55	55	42

TABLE 4

COMPARISON OF BASE SHEARS

Intensity	Base Shears in Metric Tons		
	Comp. from Max. Accel.	Comp. from Max. Veloc.	Observed (Table 2)
IV	38	21	16.6, 22.1
V	76	41	36.2
VI	152	83	
VII	380	207	
VIII	760	413	

1. View of Latino Americana Tower

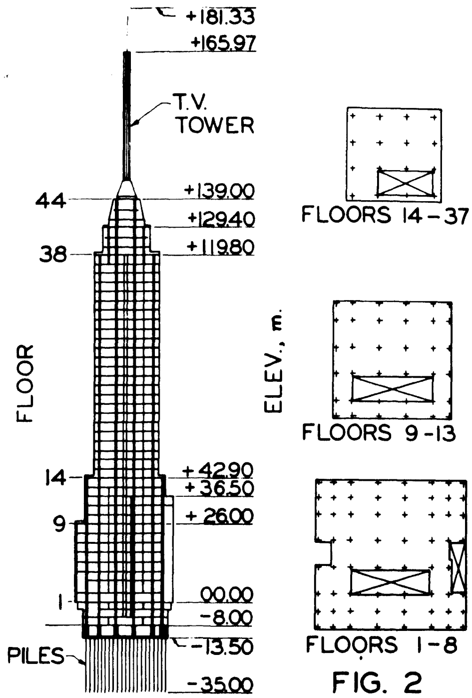
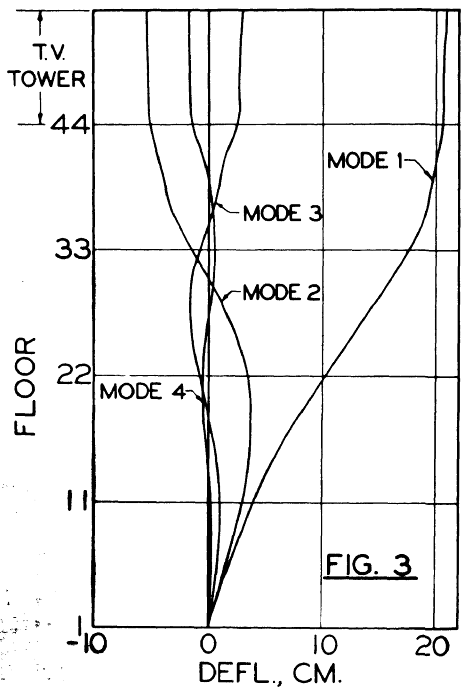
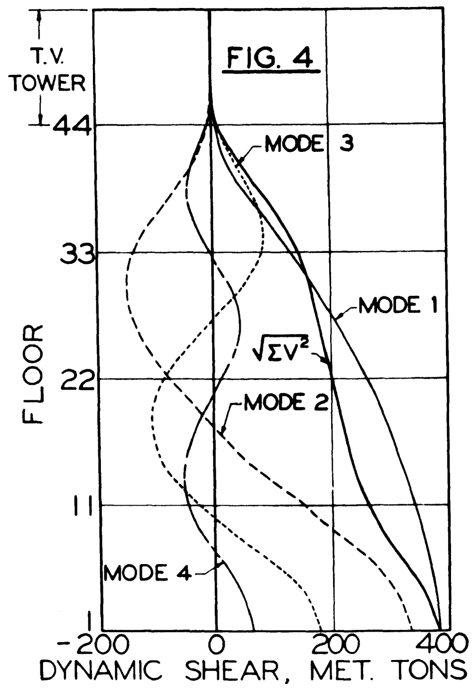


FIG. 2

2. Elevation and Cross-Sections of Latino Americana Tower



3. Deflections in Various Modes of Vibration



4. Dynamic Shears in Various Modes of Vibration

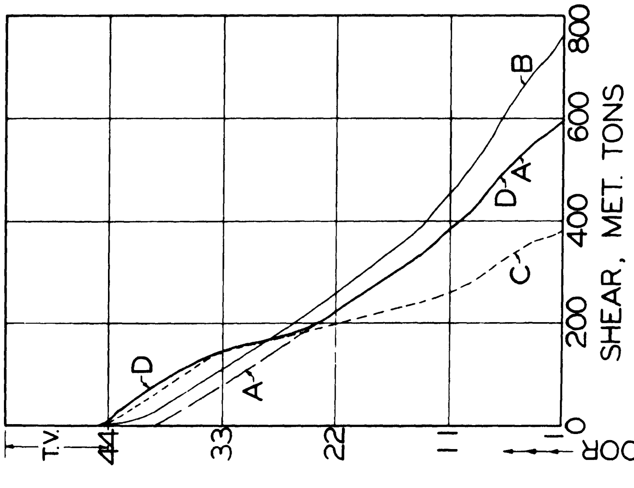
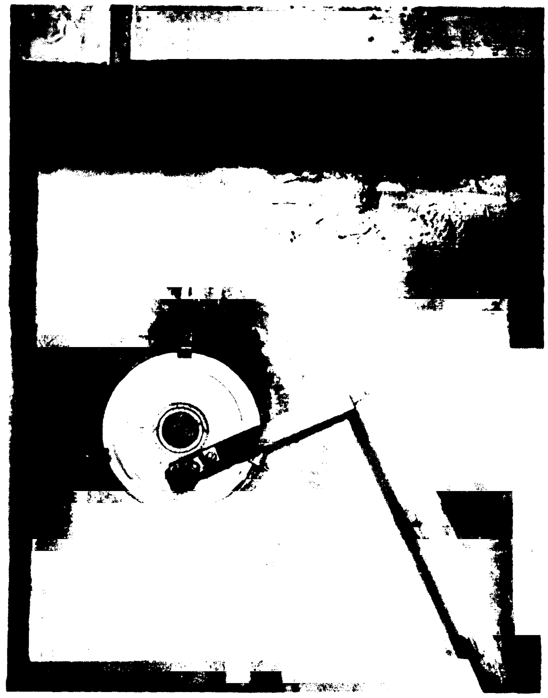


FIG. 5

Aseismic Design Curves and Shearing Strength at Various Floor Levels

6. View of Shear Connectors on Girders

7. Relative Deflection Device



8. Close-Up of Recording Mechanism for Deflection Device