*Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5*

# Retrofitting techniques used in telephone buildings in Mexico

M.D.Canales, R.Briseño de la Vega
*Consultoría Integral en Ingeniería S.A., México D.F., México*

ABSTRACT: Several rehabilitation techniques have been used to upgrade telephone buildings in Mexico City. These structures are characterized by having heavy live loads, large story heights, and long spans. The seismic response of the building is computed by means of an elastic structural analysis. The periods of vibration of the structure are evaluated by ambient vibration tests. The building behavior is compared against the requirements specified in the Construction Code. In most cases, a retrofitting scheme has to be used to upgrade the structure to the force levels specified. The strengthening elements that have been used vary in terms of material and location on the building plan. The foundation must be modified to be able to transmit the loads generated by the new lateral force resisting system into the supporting soil.

## 1. INTRODUCTION

After the earthquake in September 1985, the Mexico City Building Code was substantially modified: higher seismic force levels were specified and allowable lateral displacements were reduced. It was also established that important buildings, like those housing special equipment or a large number of people, those which have to remain operating in an emergency situation (hospitals, schools, etc.), electric stations and telephone buildings , for example; should fulfill the new strength and serviceability requirements of the Code, even if they were already built and did not experience serious damage in the 1985 earthquake. Under these conditions many telephone buildings have been retrofitted in order to upgrade them in compliance with the new Building Code and increase their structural reliability.

This type of buildings have very special characteristics due to the equipment they house: very heavy live loads (650 $kg/m^2$, 130 psf), large story heights (5.40 m, 17.7 ft), and long beam spans (11.3 m, 37 ft). Most of these constructions have a concrete structure, but some have steel structure. A very important aspect that must be considered is that all these buildings are already in operation and it can not be interrupted. The distribution of equipment inside the buildings, reduces the available space to position strengthening elements and they can not be located easily. In most cases the equipments are already installed before the retrofitting works are done and they cannot be moved. These particular conditions make complicate the study of these buildings.

## 2. STRUCTURAL ANALYSIS

The first step for the study of these buildings is to perform the structural analysis of the existing structure. A model of it should be proposed, trying to consider all the elements that modify the structural behavior. The seismic response of the building is determined by means of an elastic structural analysis program and the forces that are generated on the existing elements, are obtained. After the analysis is performed, the general behavior of the building is checked, the lateral displacements of the building are compared with the allowable displacements and, the forces on the members are compared with their capacities.

At the same time, the periods of vibration of the structure are measured by ambient vibration tests. These results are compared with the calculated periods and the parameters of the structural model are modified in order to match the measured results. This step is very important because in this way the model can be adjusted to match the real structural response; for example, the real contribution of walls can be estimated.

Most of times the structure does not satisfy the Code requirements; if this happens, a retrofitting scheme must be used in order to upgrade the structure to the new lateral force levels specified. This retrofitting scheme has to be proposed considering the particular characteristics and limitations of the building under study. The analysis of the strengthened structure has to be performed and, again, its general behavior must be checked. Several systems should be tried until a satisfactory behavior is reached, torsions in plan and excessive force concentrations have to be avoided.

The strengthening elements that have been used vary in terms of materials and location on the building plan. Among these are: strengthening of masonry walls, added concrete structural walls, added braced steel frames and steel braces added to the existing structure.

## 3. *DIFFERENT RETROFITTING SYSTEMS*

The retrofitting system that should be applied in a particular case depends on the characteristics of the structure and the problems of the original structure (insufficient structural capacity, low stiffness, inadecuate ductility, etc.). In this chapter, a description of the different retrofitting systems, usually applied in telephone buildings in Mexico City, will be given. In each case the advantages of the system will be pointed out.

### 3.1. Strengthening of masonry walls

This retrofitting scheme consists in increasing the masonry wall section with concrete reinforced with a welded wire fabric. The surface of the wall is prepared by peeling off the finish. The wire fabric is positioned and fastened with bent rods inserted in drilled holes made in the wall, see Fig. 1. These holes must be filled with epoxy resin to prevent rod pull-out from the wall. The holes can have about 30 to 50 cm (1 to 1.5 ft) spacings. Concrete can be cast in place or shotcrete can also be used. The thicknesses usually specified lie between 5 to 10 cm (2 to 4 in).

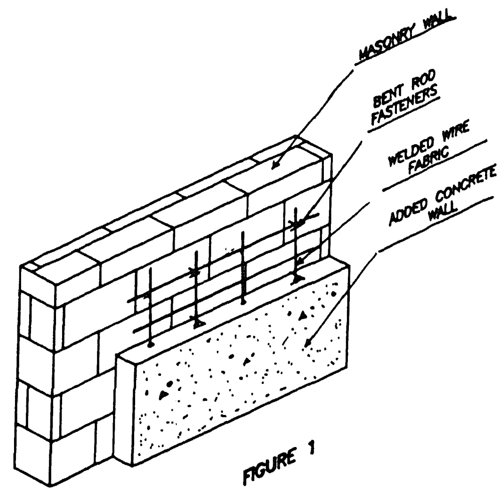



FIGURE 1

This system can be used in bulidings of low or medium height with many masonry walls in plan. The walls to be reinforced have to continue throughout the building height so the retrofitting scheme is continous and symmetry must be taken in account to avoid torsions. This scheme is very economic and its construction is quite simple. For the case of telephone buildings it can be helpful to work on the outside face of the walls in order to keep the interior clean from dust. This system can not be used when a large increase in the lateral capacity is needed. The stiffness of the original structure is not significantly incresed either. The weight added to the building is negligible.

### 3.2. Concrete walls

This system consists in the addition of concrete walls to the existing structure, see Fig. 2(a). In order to have a good flexural strength in the wall, the longitudinal reinforcement must be placed at the ends of the wall and run continously through the entire height; for this, the reiforcement has to be passed through holes in slabs and around the beams, to avoid interference. To achieve both conditions, boundary elements can be used, see Fig. 2(b). It is also convenient to have continous shear reinforcement; if that is not possible, the wall must be adequately connected to the beams, slabs and columns to insure proper shear transfer. Different shear connectors can be specified; generating a friction connection with rods placed in holes in the existing structure is usually very efficient. Wall thicknesses vary from 15 to 20 cm (6 to 8 in).

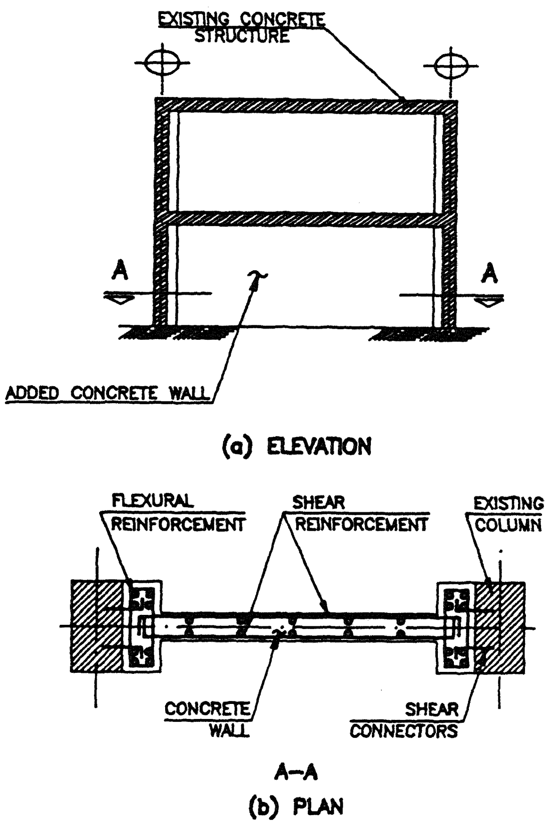



FIGURE 2

This retrofitting system is only adequate for concrete structures, and a big increase in lateral capacity and stiffness can be obtained with it. A reasonable structure ductility can be reached if the wall is properly designed, good detailing of it is very important. The connections to the existing structure have to be carefully designed to guarantee shear transfer. The additional weight added to the building is a negative aspect of this system, if the building is tall, the weight increase might affect the foundation making it work under critical conditions. Since these walls take most of the seismic shear, the load concentrations generated also affect the foundation.

3.3. Braced steel frames

This system gives an alternative strengthening scheme to the concrete walls in retroffiting concrete structures, with many advantages.

The system consists in the addition of braced steel frames to the existing structure. This frames work as vertical trusses and can be placed in the interior of the building as well as at the exterior, see Fig. 3(a). Columns must run continously in all the height; for the interior frames some holes have to be opened in the slabs for this purpose, existing beams must be avoided. A great lateral strength capacity can be given to these frames and very good ductilities can be reached. The stiffness of the structure can also be considerably increased. A very important advantage of this system is the negligible increase of the structure weight, which is critical for the foundation.

An elastic design must be given to the braced frames in order to have the needed strength and guarantee good ductilities avoiding elastic instability of its members. Also, an adequate stiffness is necessary to insure load transfer from the existing structure to the frames and to control lateral displacement of it . Sometimes the design of the frames is determined by the stiffness requirements, the frames should be stiff enough to take a large percentage of the lateral loads.

Many tests have to be made before the final design of the frame is reached. The geometric configuration of the frame, and the distribution of braces is of fundamental importance on their behavior. Many times special configurations must be used in order to satisfy the design requirements, in Fig. 3(b) a macroframe configuration is shown. The location of frames in plan must be as symmetrical as possible to avoid undesirable torsions. The number of frames depends on the magnitudes of the loads applied. Load concentrations can be generated in the foundation, the number and configuration of frames must be adjusted to reduce this problem.

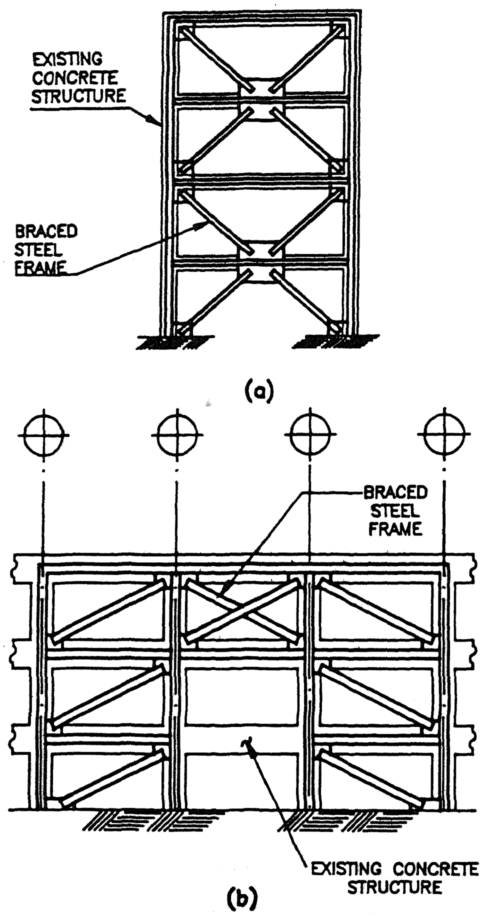



FIGURE 3

Connections from the braced steel frames to the concrete existing structure are very important, they must be well designed so shear transfer is guaranteed. Fig. 4 presents two cases of these connections. In Fig. 4(a) a steel plate is welded to the beam of the strengthening frame and it is connected to the beam of the existing structure by anchor bolts and another plate. The space between the fist plate and the concrete beam is filled with reinforced concrete forming a bracket type connection. The flexural moment generated in this connection is taken by the concrete and anchor bolts, the shear is transmitted using the concrete bracket and by a friction type connection between the bracket and the existing beam. Rods are used to generate the friction strength needed on the surfaces in contact. In Fig. 4(b), a similar case is shown but a steel bracket is specified, the shear is transmited by bearing using steel angles placed in boxes made in the beam.

Other important conections are those to the foundation. The good performance of the retrofitting system depends on them also.

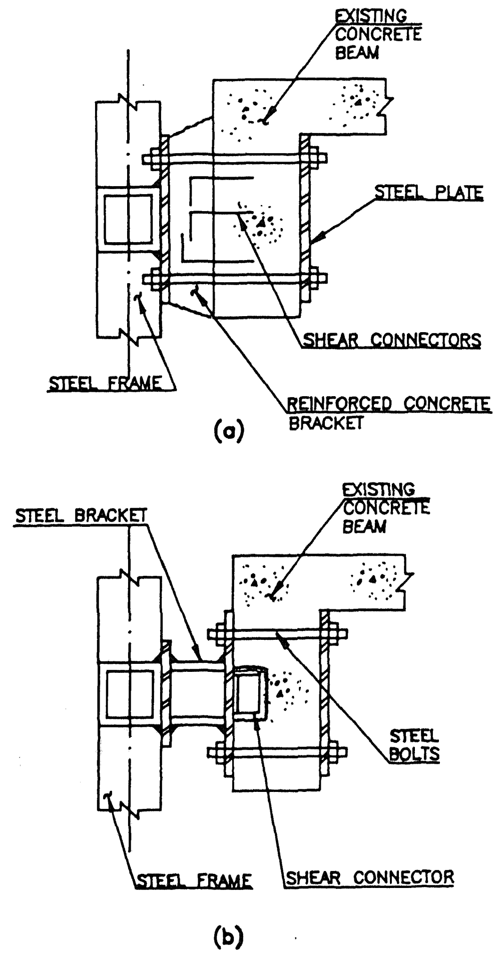
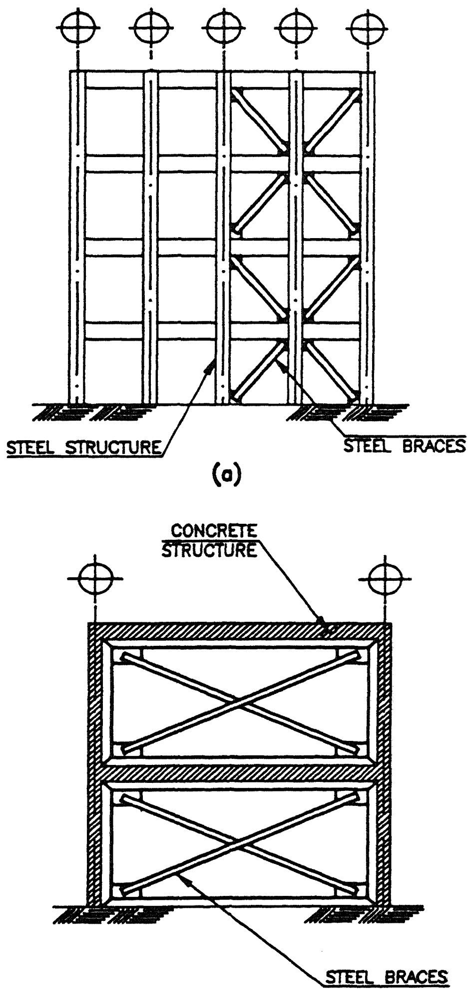



FIGURE 4

3.4. Steel braces

This retrofitting system is equivalent to the described above and it can be used in steel structures, Fig. 5(a). Braces can be added to the structure to improve its behavior. Local reinforcement of columns may be needed to take the load increases generated on them. This system can be applied to concrete structures also, Fig 5(b); steel elements placed along columns and beams can be used to connect the braces. Also, special connections to the concrete structure at the brace ends can be designed.




(a)

(b)

FIGURE 5

## 4. STRENGTHENING OF FOUNDATION

When a retrofitting system, like those described above, is specified to improve the dynamic behavior of a building, the strengthening elements are designed to take most of the seismic forces and, the way the structure resists the loads is changed; this may generate important local load concentrations in the foundation. Many times, the foundation has to be modified to be able to transmit the loads generated by the new lateral force resisting system into the supporting soil. On the other hand, the Code requirements for foundations have been modified also, and the foundation must be upgraded in order to satisfy these requirements.

The final design of the foundation depends on the chacarcteristics of the existing foundation and the magnitude of the new loads. Increase of contact areas, addition of precast piles and strengthening of existing foundation beams and slabs are works that may be needed to upgrade the foundation.

## 5. CONCLUSIONS

a) The seismic behavior of telephone buildings has been improved with adequate retrofitting techniques.
b) The earthquake forces on the existing elements and the lateral displacements of the structure have been reduced satisfactorily with the addition of new lataral force resisting systems.
c) The results of ambient vibration tests are useful to determine whether the structural model is adequate or not.
d) Connections of strengthening elements, to the existing structure and to the foundation have to be carefully designed to insure proper shear transfer.
e) Foundation work has to be performed depending on the strengthening scheme adopted.

## REFERENCES

Arnold, C., Reitherman, R., 1985. Building configuration and seismic design. John Wiley and Sons, Inc.

D.D.F., 1987. Reglamento de construcciones para el Distrito Federal. México D.F. México.

D.D.F., 1987. Normas técnicas complementarias para diseño por sismo. México D.F., México.

Del Valle, E., 1980. Some lessons learned from the March 14 earthquake in Mexico City. Proceedings of Seven World Conference on Earthquake Engineering. Istambul, Turkey.

Meli, R., Bazán,E., 1985. Manual de diseño sísmico de edificios. Ed. Limusa. México.

Teléfonos de México, 1988. Reto sísmico. Ed. IDH. México.