SOME EXPERIENCES IN STRUCTURAL DESIGN* IN HIGH SEISMIC ZONES (BRIDGES & BUILDINGS)

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ABSTRACT

Taking into account the changes introduced in the 1987 version of Mexico City Construction Code, several structural solutions recently proposed and applied in Mexico City are discussed. Particular emphasis is given to the user of precast-pretensioned concrete elements for bridges and medium height buildings. Also, the utilization of postensioned cable for the retroffiting of buildings is proposed. Finally, the convenience of revising the values of the seismic behaviour factor, Q, of the 1987 code is suggested.

RESUMEN

Se discuten varias soluciones estructurales que recientemente fueron propuestas y aplicadas en la Ciudad de México, dichas soluciones toman en cuenta los cambios incorporados en la versión de 1987 del Reglamento de Construcciones de la Ciudad de México. Se enfatiza la utilización de elementos de concreto prefabricado y pretensionado para puentes y edificios de mediana altura. También se propone el uso de cables postensionados para el reforzamiento/rehabilitación de edificios. Finalmente se se sugiere revisar los valores del factor de comportamiento sísmico Q incluídos en el reglamento de 1987.

1. MEXICO CITY, EARTHQUAKES-SEPTEMBER 19 AND 20, 1985

On September 19 and 20, 1985, two outstanding earthquakes shaked Mexico City, they had a magnitude of 8.1 and 7.6 respectively; the first earthquake lasted 2 minutes, and had a period of two seconds (in some parts of the city, situated where it used to be the bed of the old lake). Earthquakes epicenter was located 400 Km in the Pacific coast.

Poor high compressibility soil characteristics, of a wide area of Mexico City, was the reason for amplified effects; a large number of buildings were collapsed and also a lot of them had to be reinforced or rebuilt. It was observed, that the lack of strength or stiffening was one of the main causes of the inadequate structural behaviour of the buildings that presented structural problems.

2. MEXICO CITY CONSTRUCTION BUILDING CODE (1987)

Mexico City Construction Building Code was revised and adequated to the information obtained from the earthquakes already mentioned and new and more restricted specifications were set down.

* Trabajo invitado a la 61st Anual Convention de la Structural Engineers Association of California (SEAOC) celebrada en Ixtapa, Gro. del 30 de septiembre al 2 de octubre de 1992.

The new building code specifies that the most important structures located in Mexico City, the so called Group "A", have to be revised according to new and stronger seismic requirements; so a lot of buildings which fall under the new regulation, must be reinforced in a short period of time, to guarantee an adequate safety level and to improve its stiffening, in order to avoid noteworthy displacements during strong seismic conditions.

This new code regulations, double design seismic forces, for almost all the structures of group "A", located in the so called lake Zone of Mexico City (Zone III).

Also, in this code, two kind of structural frames were clearly defined (both for reinforced concrete or steel); they were "common frames" and "ductile frames". For ductile reinforced concrete frames, it was allowed to use a Q (seismic behaviour factor) of 4.

3. BRIDGES

Mexico City 1987 Construction Code compeled structural designer to achieve new criteria on bridge design, and instead of using the simple support beam solution, where seismic forces are resisted, in both directions, by means of cantilevered columns, other structural options were developed and tested in recent years; in one of them, vertical loads are resisted by continuos but isostatical beams and seismic forces are resisted by structural frames.

In Mexico City, recently, following the above-mentioned criteria several new middle range bridges have been built. In these bridges, continuos but isostatical beams have been designed using precast-pretensioned elements, obtaining with this structural solution, a noteworthy reduction in construction time and cost, compared with other common structural options, and allowing to reach spans up to 151 ft (52 m), avoiding traffic interferences on main avenues (during their construction), and obtaining high quality standards.

These continuos beams are defined by several support elements and some central elements, the first ones are bearing on columns, while the second ones are bearing on support elements, so that support elements, have only negative bending moments and central elements have only possitive bending moments.

In these bridges seismic forces are resisted by means of two structural frame systems, in the longitudinal direction these frames are integrated by two columns and one support element, while in the transversal direction, the frames are integrated by two or three columns and one transversal partially precast reinforced concrete beam.

3.1. TLALPAN FREEWAY BRIDGES (E. ZAPATA & M. LIBRE)

A twin precast-pretensioned concrete bridges, 1539 ft (469 m) long, were recently built over one of the most important freeways in Mexico City; they were designed for a central clear span of 171 ft (52 m).

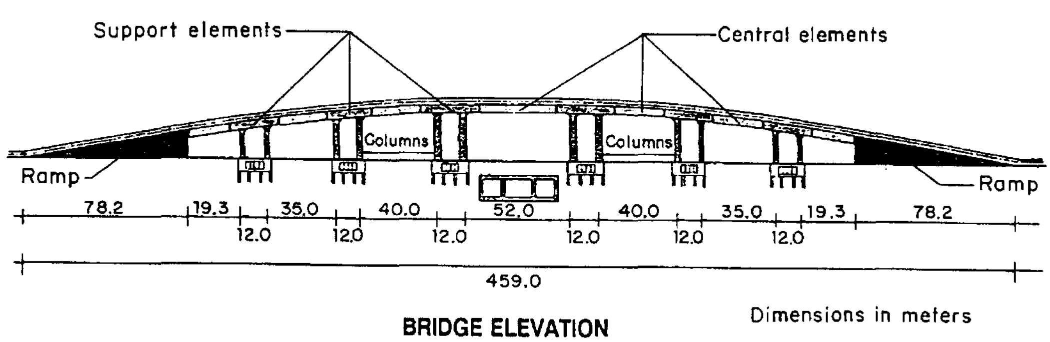

Fig. 1 Bridges Elevation

This structural solution brings a new dimension to bridges located in heavy traffic urban areas, with poor soil characteristics and severe seismic conditions. These bridges were built in a short period of time, with minimum cost, maintaining freeway's traffic (both highway vehicles and Metro trains) during construction.

Each of these twin bridges consists (transversally) of three longitudinal girders, they have a total length of 1539 ft (469 m). Each girder comprises 13 pretensioned elements, of hollow box section with two upper flanges (Fig 1).

High magnitude seismic forces acting on these bridges are resisted by longitudinal frames integrated by two columns and one main precast-pretensioned support element, and by transversal frames, consisting of three columns and a transverse partially precast reinforced concrete beam.

To achieve the highly efficient structural solution for supporting vertical loads, needed for these bridges, it was not possible to use common simple supported beams. Moreover, it is almost impossible to think of efficient and economical simple supported precast concrete beams, to span 171 ft (52 m). Therefore, continuity had to be achieved in the structural solution, for these bridges. (fig 2).

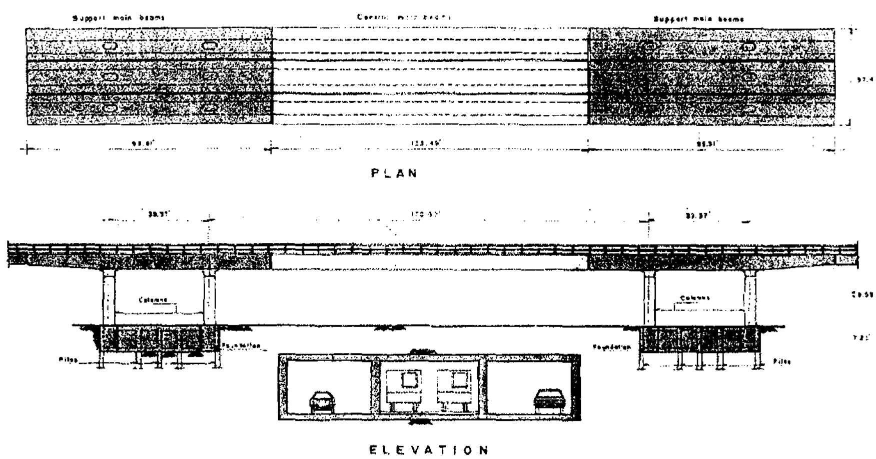

Fig. 2 Plan and longitudinal elevation of central part of the bridges.

The aesthetic appearance of the structure is outstanding. The well designed connection between the hollow girders sections conceals the real joints and show only a single vertical line. Use of plant-fabricated precast concrete forms for the cast-in-place transverse beams, provided a smooth, uniform appearance that would lack with conventionally formed beams.

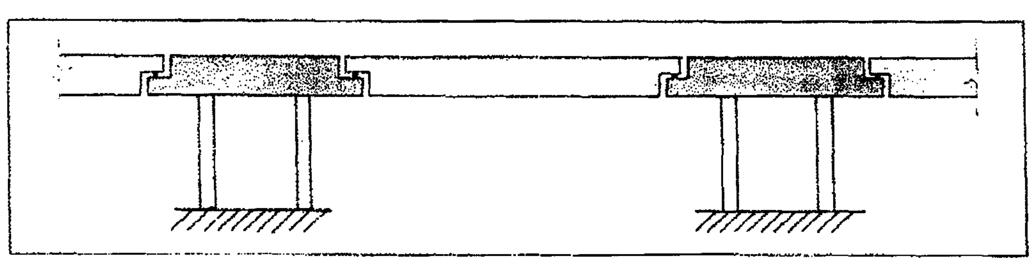

Fig. 3 Vertical loads design

Vertical loads design

The three girders which integrate the superstructure of these bridges were designed as a continuos, but isostatical beam (Gerber type), each one of them are integrated by several support elements and several central elements, the last ones are simple supported by the first ones while the first ones are supported by pairs of columns. This means that the support elements have only negative bending moments, while the central elements have only possitive bending moments. These elements, both support and central elements are precast-pretensioned concrete. This structural solution offers many advantages, compared with a simple support solution (fig. 3 & 4).

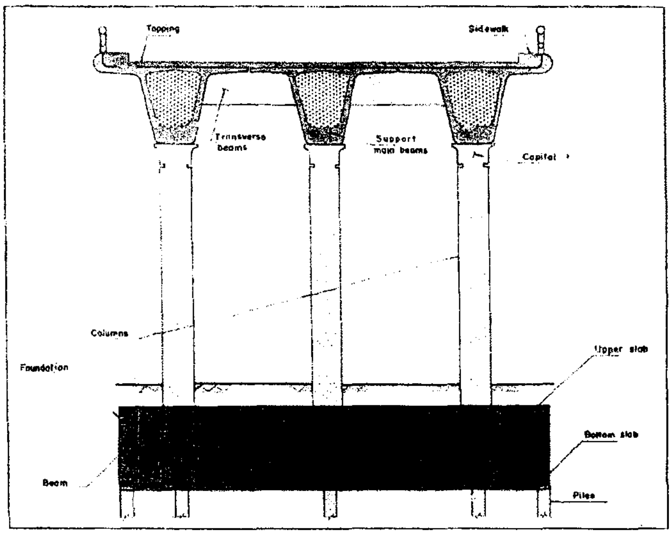

Fig. 4 Vertical loads design

Seismic forces design

These bridges were designed, considering that seismic forces were resisted in the longitudinal direction of the bridge, by a system of structural frames, integrated each one by two columns and one support element; and, in the transversal direction, by a system of frames formed by three columns and one transversal partially precast reinforced concrete beam. These structural solution is rather more efficient than the common employed solution, which consists in resisting seismic forces in both directions, by means of cantilevered columns (fig. 5).

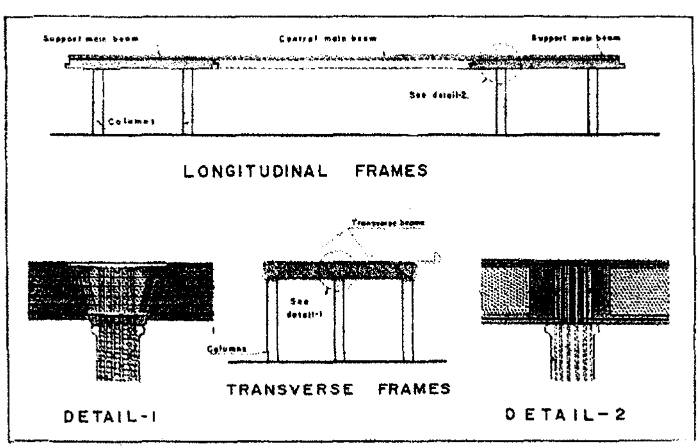

Fig. 5 Structural frames

Regarding seismic design a 0.6 g force and a seismic behaviour factor of two were employed in the structural design of these bridges.

Superstructure

The superstructure of these bridges is defined by means of three main gerber type beams (continuos isostatically), joined together with a structure cast in place topping, concrete transverse partially precast beams and steel diaphragms.

Its total lenght is 1539 ft (469 m), the width is 36 ft (11 m) which allows three traffic lanes and one sidewalk. These bridges are located, at midspan, at 30 ft (9 m) above street level.

Each one of the gerber type beams is integrated by 13 precast pretensioned elements, made out of a hollow box section and two upper flanges. Six of the precast pretensioned elements, called support elements, are bearing on columns; the other seven ones, called central elements, are bearing on the support elements.

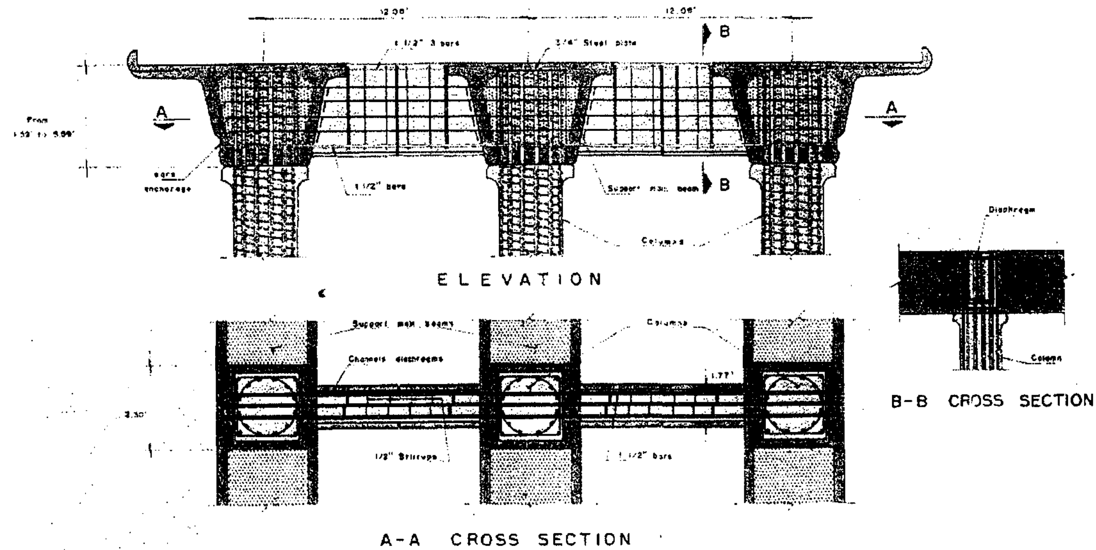

Fig. 6 Transversal beams

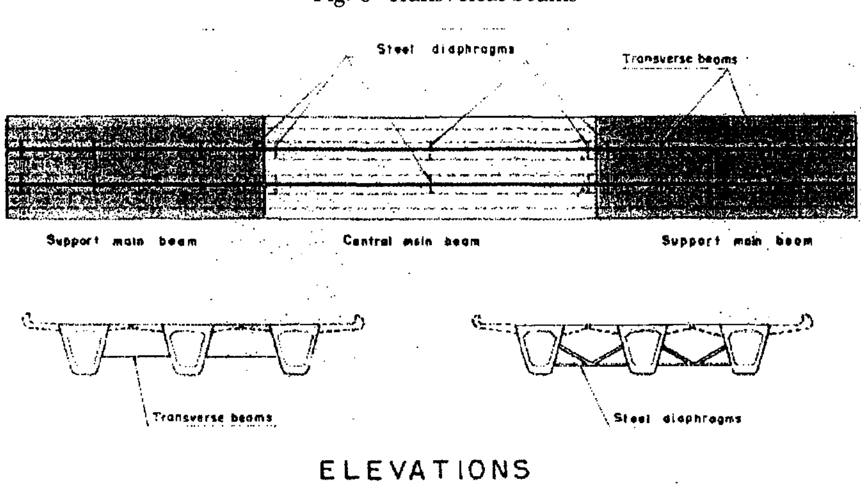

Fig. 7 Steel diaphragms

Attached to the support elements, there are partially precast concrete transversal beam forms, located at column axis. These beam forms are made of precasted reinforced concrete and they are attached to the support elements, from the plant. Steel reinforcement is added, and finally concrete for these transversal beams is poured at job site (fig. 6).

The superstructure is finally fulfilled by steel diaphragms, which are located at the midspan of central precast elements and at ends of both central and support precast elements (fig 7).

Substructure

Substructure is made of (cast in place) reinforced concrete columns, some of them with oval cross sections, and some others with circular cross sections. There are also two concrete retaining walls located at the approaches of the bridges. The columns location define the spans of the bridges as follows; six spans of 39.37 ft. (12 m), two spans of 63.26 ft (19.18 m), two spans of 114.83 ft. (35 m), two spans of 131.23 ft. (40 m), and one more span, of 171 ft. (52 m) (figs. 8 & 9).

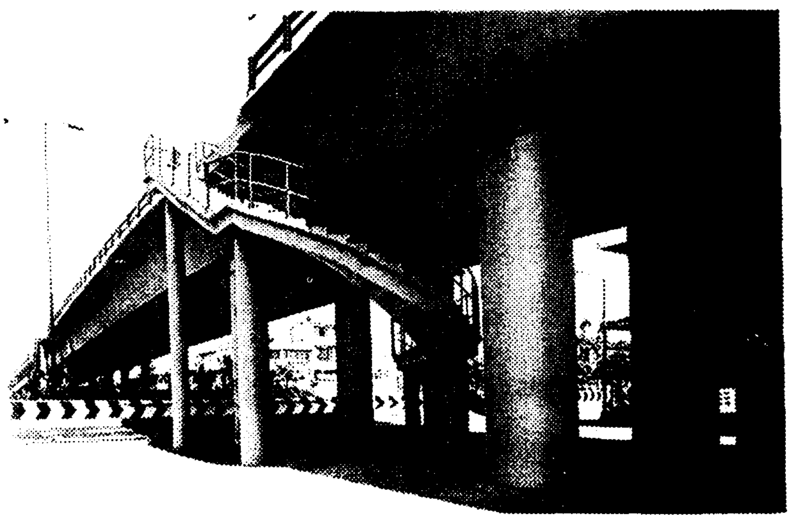

Fig. 8 Bridge spans

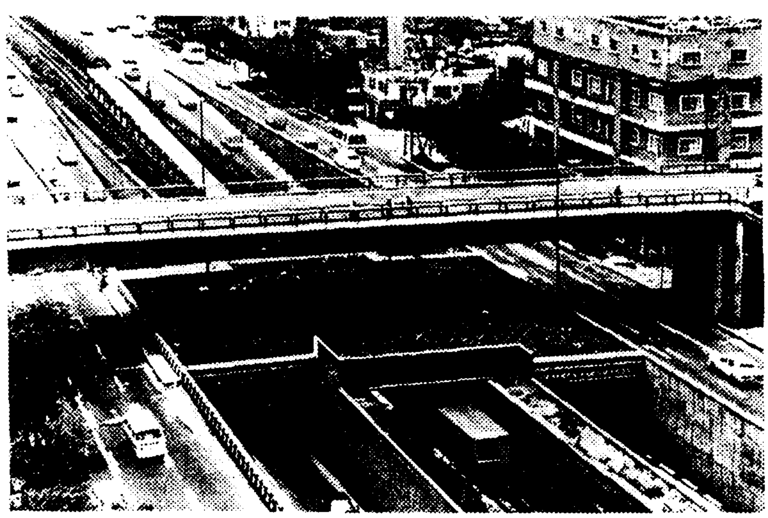

Fig. 9 Bridge spans

Foundation

Foundation is resolved with six independent caissons, each one supporting a group of six columns. The foundation is semi-compensated type, consisting of horizontal hollow cages formed by a grid of foundation beams and slabs, working together with precast reinforced concrete, square section friction piles.

3.2. TLALPAN FREEWAY & DIVISION DEL NORTE BRIDGES

Today in the intersection of Tlalpan freeway and Division del Norte Avenue, two new similar bridges 1889 ft. and 1450 ft. respectively (576 m. and 442 m.) are being built; the same structural design criteria were employed for them. However, they have some slight differences (compared with the bridges already mentioned); they present a curve configuration, both in its horizontal plane and in its vertical one; in its central spans, the substructure had to be changed for a one or two columns system, to resolve the rather conflictive crossing point between both important avenues; where additionally, a suburb train pass along Tlalpan Freeway, and a very old but rather big and important water supply pipe is located under Division del Norte Avenue; the other spans of these bridges were resolved with the same three columns system substructure, mentioned before (figs. 10, 11, 12 & 13).

Fig. 10 Columns system

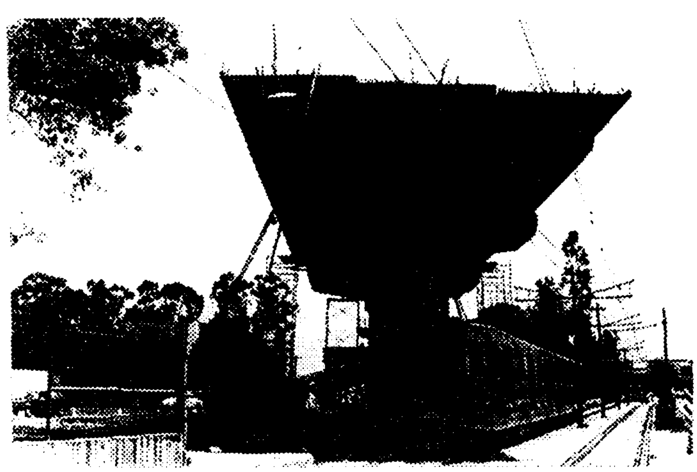

Fig. 11 Columns system

Fig. 12 Columns system

Fig. 13 Columns system

4. BUILDINGS

Building design and construction procedures are being changed after 1987 code regulations were set down, and new criteria have been developed, always looking for more efficient and economical structural solutions.

One structural criterion employed in two buildings recently built in the southern part of Mexico City, is the one that uses precast concrete elements. It must be said that these buildings are almost totally precast concrete structures but, anyway, this structural criterion can be used for both, precast structures and cast in place concrete buildings.

This criterion consists basically in defining in each structure some strenght or resistance nucleus, wich, efficiently, withstand, both the vertical loads and the seismic forces, and transfer them from every floor slab to the foundation of the building.

This resistance nucleus was defined because the new code regulation, regarding seismic design, compeled to increase the seismic forces in a large proportion, comparing them with the old code. And to resist them, it is not always possible to have shear walls, because they must be located in all the floors of the buildings, even in the first floors, where architectural design do not allow them. Also among other aspects, span needed are considerable long to improve the functionality of these buildings, so these concentrations of resistance strenght in nucleus allow to have both, longer clear spans and noteworthy resistance to withstand seismic forces.

In one of these buildings, the resistance nuclei are concentrated in small areas; while in the other one, the resistance nucleus is located in some of the axis located on the plan (horizontal) of their structures.

4.1. BANAMEX COMPUTER CENTER

In the southern part of Mexico City, close to the University City, a new building was recently built; it belongs to one of the most important banking firms of Mexico. This building is the newest computer center for this bank and also one of the most updated buildings of its type in Mexico.

The most outstanding features of this building are: the structure was totally precast (not too common in Mexico City), the innovative structural solution employed, the dimensions of the precast columns, the construction procedure used and the tight schedule required to build it.

During the last 30 years, a lot of buildings employing precast-prestressed concrete elements have been built in Mexico City, but most of them, have used precast elements only for slabs and main beams; whereas columns, stiffness beams and walls are cast in place. This practice is due to the wrong but common idea that it is not suitable to use totally precast elements structures in Mexico City, due to the very poor soil conditions and the magnitude of the seismic forces that frequently shake this city.

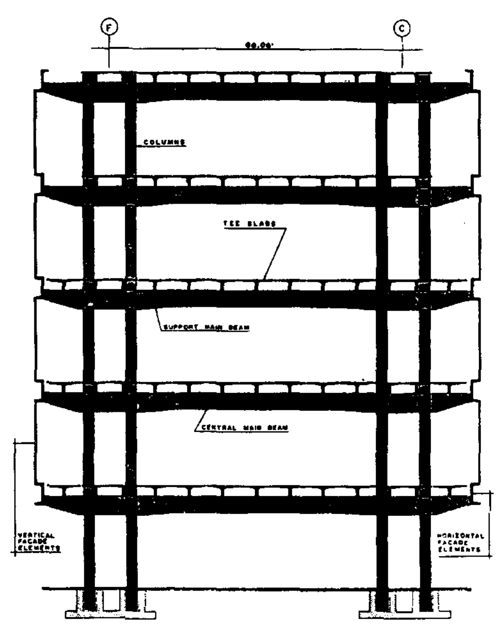

Fig. 14 North-South elevation of building

Partially precast structures do not offer the full advantages of a totally precast solution; and perhaps it is one of the reasons to explain why Precast and Prestressing Industries have not developed in this country, as well as they could.

This five story building is 27.38 m (89.83 ft) high, its square size area is 39.04 x 39.04 m (128.08 x 128.08 ft). One side is adjacent to another building of the same bank an the other three sides are facades. (figs. 14, 15 & 16).

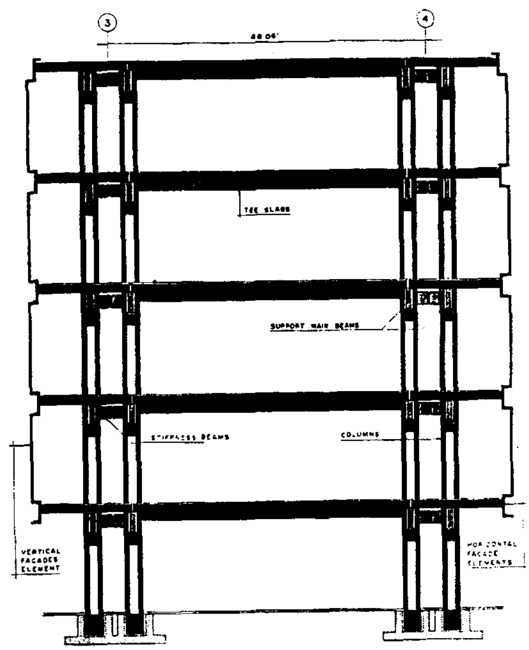

Fig. 15 East-west elevation of building

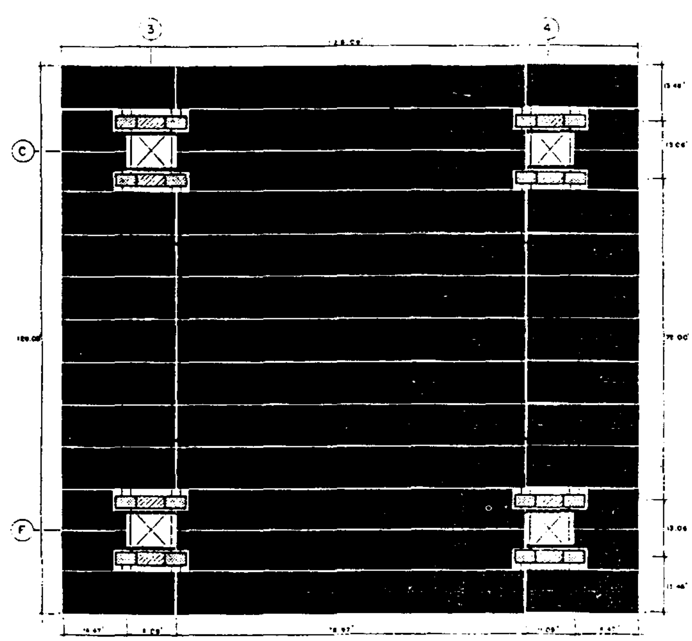

Fig. 16 Plan of building

The structure of this building was resolved with four resistance nuclei, integrated each one by four columns; these columns allowed to pass through them, main continuous beams, wich are formed by two support beams and one central supported beam, so that support elements resist only negative bending moments, while central elements have only positive bending moments; this structural solution allows to reduce positive bending moments, obtaining a noteworthy reduction of the beam depth and beam cross section. Slabs are solved with precast-pretensioned "Tee beams" (fig 17).

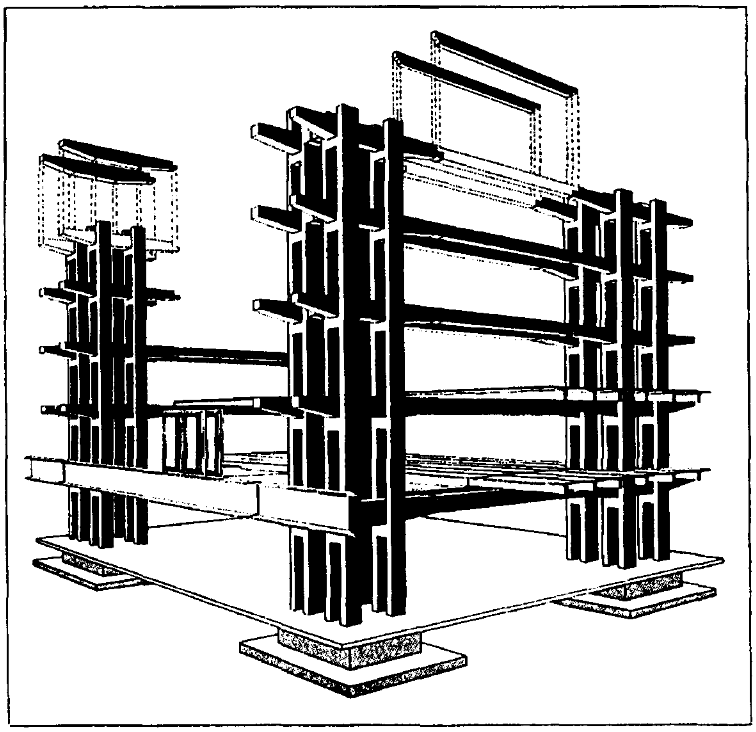

Fig. 17 Precast-pretensioned "Tee beams"

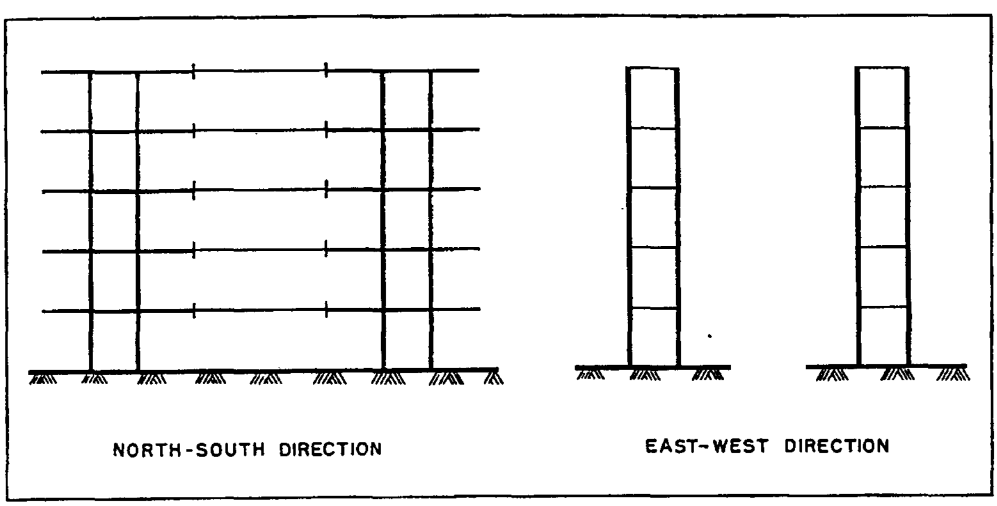

Fig. 18 Precast short span beams

The building is located in geological zone one and it is typed as Group "A", thus complying with mexican codes, a 0.24 seismic coefficient was employed. Being the structure formed by precast elements, a seismic coefficient behaviour factor of "two" was considered for both directions.

This structure was designed to resist seismic forces in North-South direction, by four large frames. These frames are formed by four columns and at every level, by the support elements, wich are portions of the continuous main beam. East-West seismic forces are withstanded by eight small slender frames, consisting each one of two columns already mentioned, and five partially precast short span beams (located at every level of the building) (fig. 18 & 19).

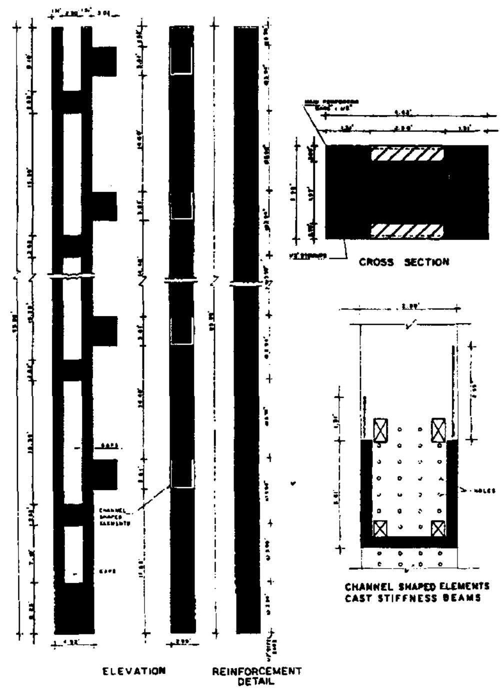

Fig. 19 Precast short span beams

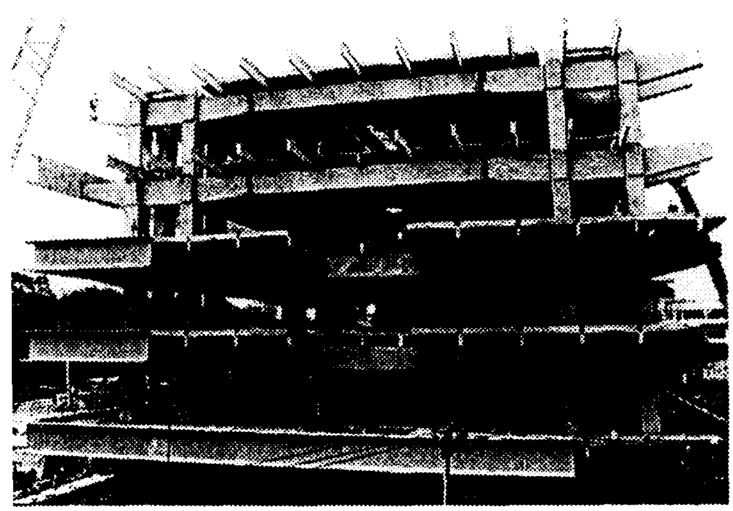

Fig. 20 Building under construction

It is important to point out that the experience obtained with the design and construction of this building has shown that totally precast concrete structures are feasible, economically competitive and can be a fast construction for buildings located in Mexico City; despite of the poor conditions of the city subsoil and the magnitude of seismic forces that, from time to time, shake this metropoli.

It is interesting to mention that for larger areas this structural solution can grow on either direction (fig 20 & 21).

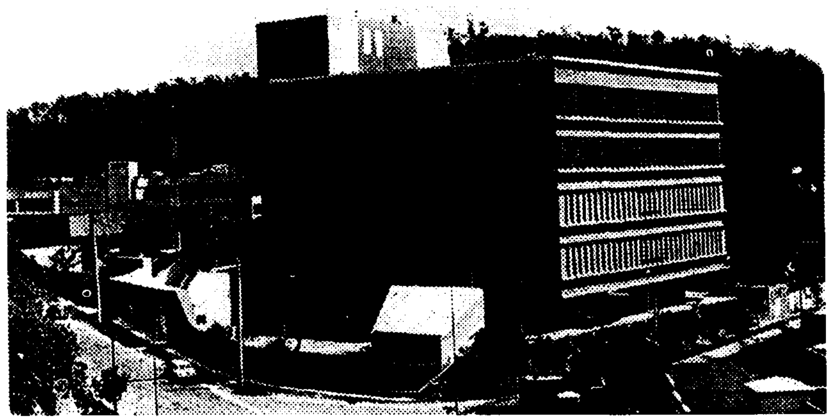

Fig. 21 View of the building after construction

4.2. NEW BUILDING FOR MEXICO CITY CIVIL ENGINEERS ASSOCIATION

A new building for the Mexico City Civil Engineers Association is being built now, and it is located close to the Pedregal Park. It has six floors, the two first floors are going to be for parking, while the other four will be for the offices of the association.

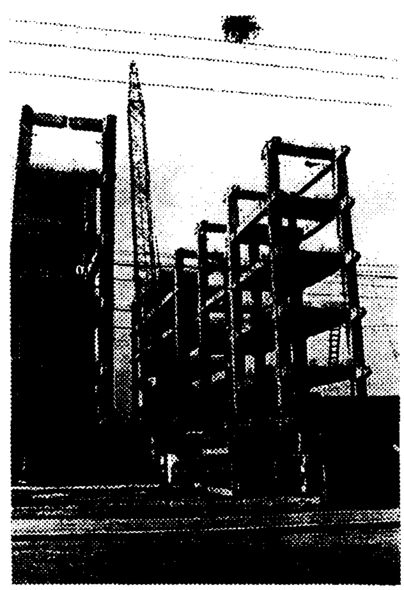

Fig. 22 Double Tee beams solution

This building has a rectangular size surface; first floor is 165.7 x 181.3 ft., with an area of 30, 041.4 square feet; the other five floors are 72.3 x 181.3 ft. with an area of 13, 978.2 square feet.

The structural nucleus of this building consists of four axial resistance nucleus, located, two at the outer axis of the structural horizontal plan, and the other two located at the thirds of the horizontal plan of the structure, coinciding with the outers frames of the five floors.

Columns are reinforced concrete, they were precasted in a plant, and later on transported and mounted at site. They are a single piece columns, covering the six floors. Their hight is 72.35 ft. they have, at each floor level, a portion of the support main beams, which were casted also at the precast plant, simplifying the connection to support main beams. Also at each floor level they had casted a portion of the stiffening beam, which are part of the frames which will resist seismic forces.

Seismic forces in this building will be resisted by two system of frames. In one direction these resistance frames are integrated by the columns already mentioned and the portion of the support elements wich were precasted in plant; in the other direction the resistance frames are integrated by the same columns and by the beams which are formed when they are joined together at site. Floors were defined by means of precast-pretensioned Double Tee beams (figs. 22 &23).

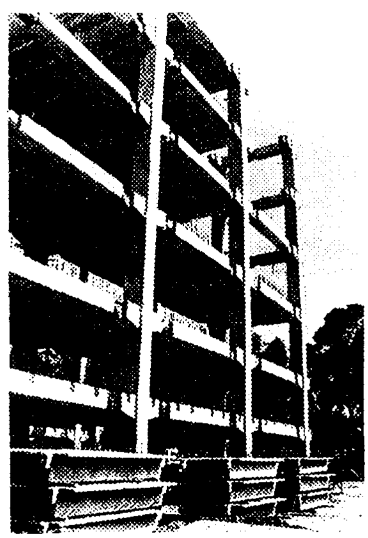

Fig. 23 Double Tee beam solution

5. NEW SYSTEM FOR RETROFFITING BUILDING STRUCTURES BY MEANS OF POSTENSIONED CABLE DIAGONALS

According to the new Construction Code Building Regulation, a lot of buildings located in Mexico City had to be revised.

Most of the modern available techniques for strength and stiffening structures, depends on the addition of new structural elements, whose strength and stiffness are so large that they absorb, practically, all the lateral forces, thereby, not using or profiting of the seismic capacity of the original structure. Besides, these structural options involve very complicated and expensive construction procedures, forcing, in most cases, to rebuild the whole foundation.

Some of the systems used to reinforce structures are the following: reinforcement of the seismic resistance elements of the original structure (mainly beams and columns); to increase their strength and stiffening with the addition of shear walls; addition of steel shaped diagonals (mostly plates or angle elements); addition of buttress or exterior stiffener elements; and finally addition of seismic resistance macroframes.

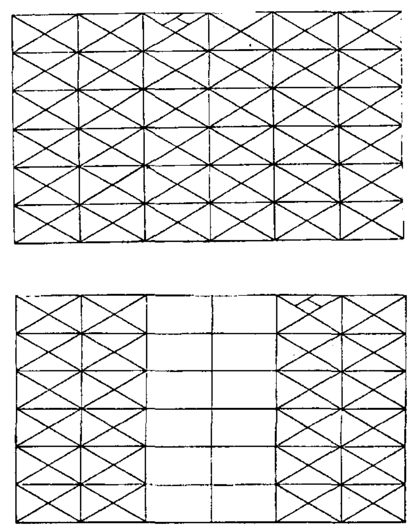

Fig. 24 Postensioned cable diagonals solution (elevation)

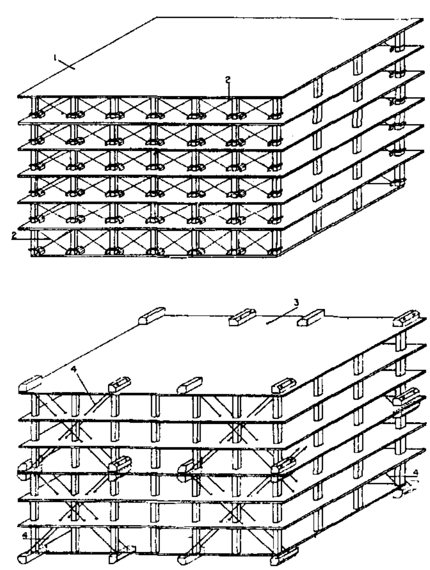

Fig. 25 Postensioned cable diagonal solution (perspective)

A new and very efficient system for reinforcing and stiffening structures was developed in Mexico. It consists to brace the original structure by using postensioning cables, placed like diagonals, to increase the original lateral structure capacity to withstand seismic forces and to restraint lateral displacements.

The system offers many advantages to reinforce buildings: Since its degree of strengthening and stiffening can be calibrated to be according with the rigidity of the original structure, taking full advantage of its seismic capacity, and allowing that the moment and force distribution which results in the original structure makes its behaviour even more economical, requiring only the installation of a reduced number of connections, with a minimum of interferences with the functioning of the buildin (fig. 24).

This reinforcing structure system proposes the use of postensioning strands (fsr = 270 kpsi or similar) for bracing the original structure (instead of rolled steel shapes elements); so they can reach higher stress and strain levels, permitting the postensioned cables, bracing to work together with the original existing structure.

One of the most important characteristics of the system is the possibility of using postenssioned cable in one, two or more bays of the structure and/or in one, two or more levels of them. The system, provides the possibility of regulating the stiffness and strength to retrofit the structure (fig. 25).

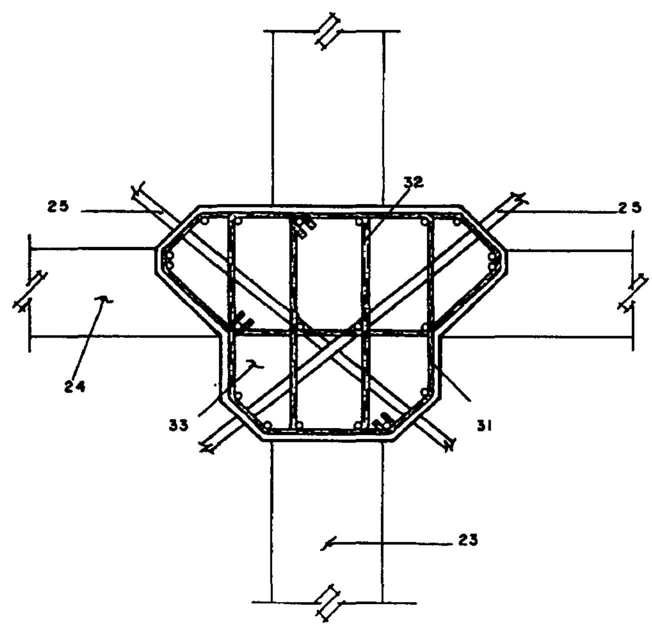

Fig. 26 Covering protection of cables

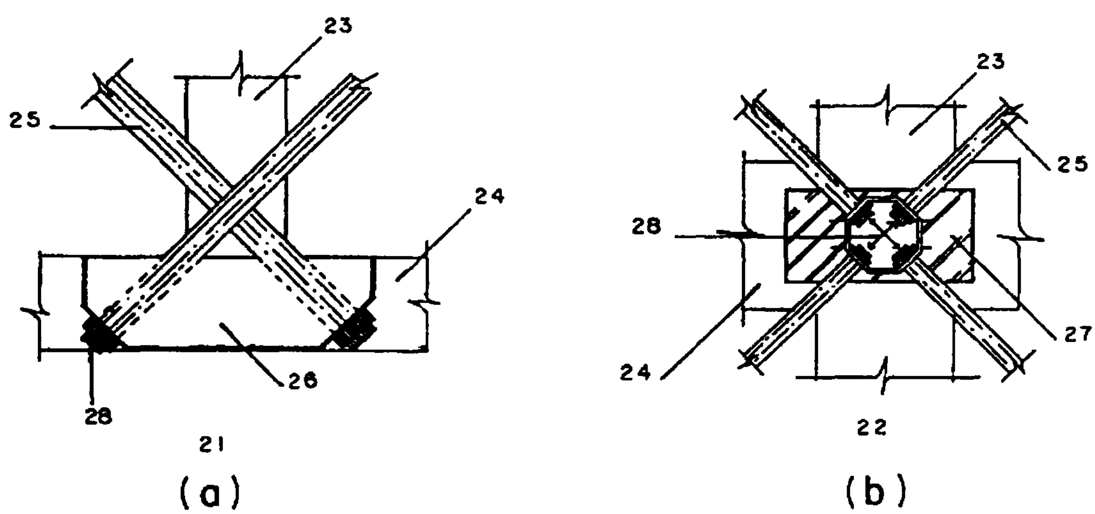

Fig. 27 Covering protection of cables

In the system based on diagonal postensioning cables, the bracing layout is designed to have a compatible stiffness level with the original structure, as a result, they work like one whole unit or system.

It is needed to say, that the use of postensioned cables for bracing structures instead of using steel shapes diagonals reduce a great deal of the interferences of the activities in the buildings, during construction time. This reinforcing system also profits from the existing original structure capacity, to resist horizontal forces.

The postensioned cables are made up with the adequate number of strands and wires. The characteristics of the cables depend on the structural properties of the building to be reinforced, and on the amount or reinforcing required. The cables are carefully protected to avoid corrosion by means of a covering protection mixture. (fig 26,27,28 & 29).

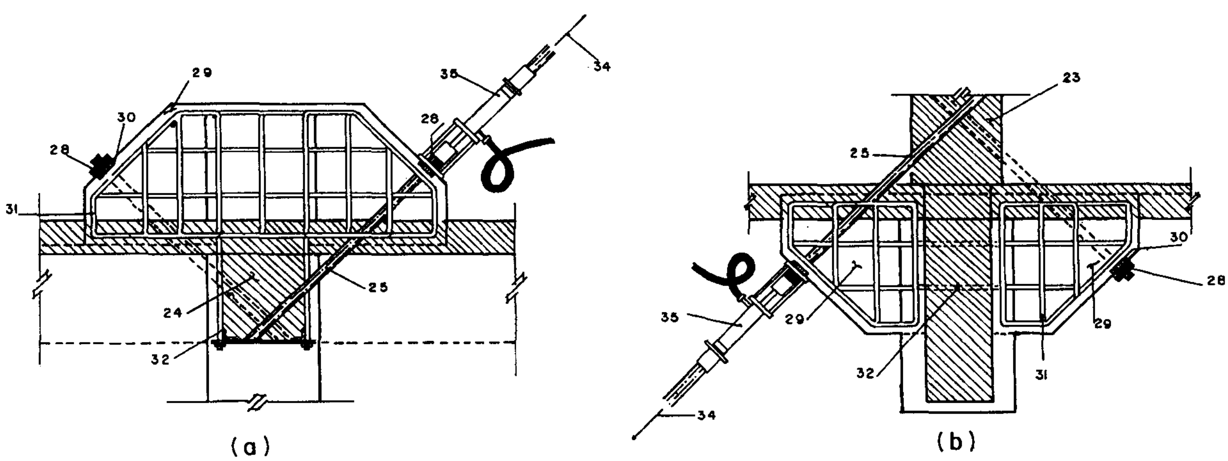

Fig. 28 Covering protection of cables

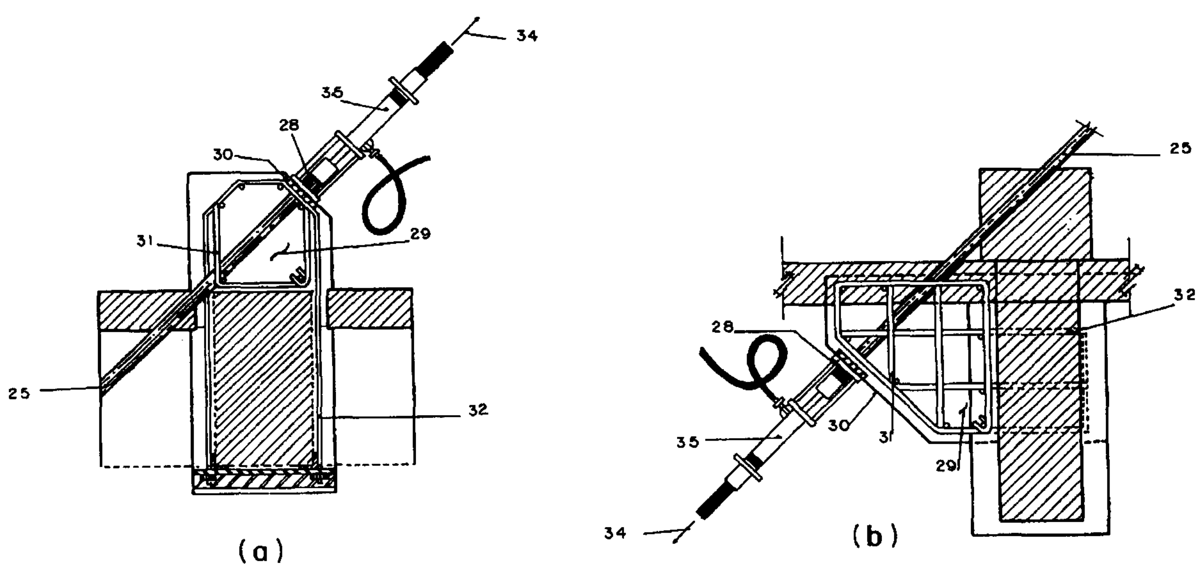

Fig. 29 Covering protection of cables

The postensioned cable diagonals are attached on its extremes to the original structure, at the exterior geometric vertex of the beam column joint and out of the bay level unit that the cable is reinforcing. With this last provision direct shear stresses does not exist and only shear friction stresses are acting.

The diagonals are slightly eccentric to the frame plane, however; when large tension forces are predicted to occur, diagonals are set on both sides of the frame in a symmetrical shape. The cable anchorage can be achieved in several different ways.

The anchorage size and geometry depend on the prestressed forces coming from the cables, which are a function of the strenght required for the original structure.

Normally the anchors have a regular trapezoid geometric shape one of its side faces is normal to the postension cable axis, which guarantee the correct attachment of the anchor. These anchors are set on to the original structure by anchor rods made of common reinforcing bars. These anchor rods sometimes have a stirrup shape surrounding columns or beams. For the case of upper anchors, for two cables; bottom anchors, for two cables, upper anchors, for one cable and bottom anchors, for one cable.

Once the diagonals layout is defined as well as the geometry and size for the anchors, the cables are tensioned with a hydraulic jack as the ones employed in postensioning system. The tensile force is determined at the design step. After the cable is tensioned the jack adjust and set the anchor accessories for the cable. The accessories are the ones used for postensioning systems.

When the bracing are extremely long, a steel plate or a concrete block is cast in place at intersection of the cables. These blocks allow the longitudinal movements of the cables, but avoid any transverse movements or, vibration of them.

After the cables are installed, attending the details mentioned here after, its system is ready to work long with the original structure to resist seismic or wind forces. Because the amount of steel required to reinforce and retrofit the structure is considerable less than the needed for the frequently used systems, this new invented system represents an important money saving, if we refer to the normal cost of reinforcing and strengthening of buildings using the traditional procedures.

This system constitutes a stiffening and reinforcing technique for framed structures which is very efficient, particulary for low and medium height buildings. It is a very economical technique since, contrary to traditional solutions, it takes advantage of the original structures's seismic capacity. In most cases, the construction is limited to the placement of the connections in the original structure, setting the postensioned cables and tensioning with the hydraulic jacks, all of them with a minimum of interferences with the building activities.

A structure reinforced with the presented system has the possibility to adequate its flexibility, which permits to dissipate the energy produced during an earthquake by means of deformation. The displacement will be controlled, so they will never exceed code limits. This system permits to profit from the strenght and stiffness of the original structure.

Procedure for strengthening and stiffening structures using postensioned cables.

The method for reinforcing and stiffening new and existing structures, by means of diagonals based on postensioned cables comprises the following activities:

- Determining the strength capacity and stiffness of the original structures.
- Determining the strength and stiffness required by the structure according with the new construction's codes.
- Evaluation of the differences between the strenght and stiffeness required, and the strenght capacity and stiffeness of the original structure.
- Evaluation of the differences between the strength and stiffeness required, and the strength capacity and stiffeness of the original structure.

- Determining the layout of the diagonal postensioning cables in one or both directions of the original structure; covering one or more levels and one or more bays, according to the differences between strength and stiffeness required, and the ones of the original structure.
- Determining the anchorage elements, said cast in place reinforced concrete or prefabricated made of roller steel plates.
- Setting the postensioning cables up, according to the reinforcing design.
- Construction or setting up of the anchorage elements, attached to the original structure, by anchor rods made of reinforcing bars.
- Attaching postensioning cables to anchorage elements; applying a postensioning force to prestressed cables to provide a dynamic reinforced action, to increase the ability of the structure to resist seismic forces. These forces are applied by means of conventional postensioning hydraulic jacks.
- Anchoring the cables by means of traditionally employed postensioning accessories.
- Protection of postensioning cables and its anchors with an epoxy resin, pouring concrete or any other materials, which cover the required specifications to fully protect the cables against corrosion, etc.
- Inspection of the structure behaviour.

Compared Postensioned cables system vs. steel shaped diagonals system.

Comparison with steel profiles, the stresses that would appear in steel braces of any type are determined as a function of those lateral deformations that allow the development of ultimate strength in typical framed structures (def.=0.006h). Although the resulting stresses are under 30% of the prestress steel ultimate strength (270Kpsi, fyp=18900 kg/cm2), it is nevertheless 100% larger then the yield point of the common structural steel (A-36, fy=2530 Kg/cm2). This means that contrary to the systems of cables, the bracing solution using structural profiles requires a great deal of stiffening to reduce the structure's displacements to obtain allowable stress levels in the profiles, at the cost of not taking advantage of the capacity of the original structure.

To compare the system of diagonals postensioned cables with conventional system (steel shaped diagonal system), the first one has these advantages:

- Profit the seismic resistance capacity of the original structure.
- Postensioned cable diagonals work together with the original structure.
- Noteworthy reduction in the use of structural materials.
- Allow move away the structures vibration period of the one, of the subsoil.
- Even for high magnitude earthquakes, postensioned cables remain in elastic range behaviour.
- Do not interfere with the functioning of the buildings.
- Mostly all the works are outside the building.
- Avoid the reinforcing of beams and columns of the original structure.
- A noteworthy reduction of cost for reinforcing of structures.
- A noteworthy reduction of time for reinforcing of structures.
- Do not produce direct shear strength on original structure elements.
- Mostly do not overstress the buildings foundations.

Earthquake simulation test of a six story retroffited postensioned steel frame.

In october 1988, in the Earthquake Engineering Research Center of the University of California, at Berkeley, this system for strengthening and stiffening structures, by means of diagonals of postensioned cables, was tested in two models of a six stories steel frame. Two tests were done, one on a ductile moment resisting frame structure (before the retrofit), and a second one on a retroffited post tensioned frame structure. So the second structure could be evaluated against the results obtained of the first one.

Conclusions obtained after the test indicates among other aspects the following: that this retroffiting technique is costwise very competitive, since it uses very little steel material, and requires no special construction technique or equipment (other than the hydraulic postensioning jack), the high strength postensioned steel cables greatly enhance the structure stiffening, this system gives the designer a lot of freedom in laying out openings on the buildings facades, because the postensioned cables are very small and practically does not interfere with lighting and views.

Finally, the report of these tests said that this technique of using postensioned steel cables to reinforce structures has a tremendous potential for improving earthquake resisting construction, and therefore for mitigating earthquake hazards.

Due to the novelty of the present system, it was patented from "Dirección General de Desarrollo Tecnológico" de la Secretaria de Comercio y Fomento Industrial (Patent Office in Mexico City), on May 7, 1987 with expedient number 160318 and title "Sistema y método para rigidizar y reforzar, a base de contraventeos, estructuras nuevas o existentes, empleando cables o torones de acero de presfuerzo"; in U.S.A. this patent is in tramit since 1987.

The System for Strengthen and Stiffening structures, by means of prestressed cables constitutes a stiffening and reinforcing techniques for framed structures, which is very efficient particulary for medium hight buildings without serious earthquake and actually being occupied. Its main characteristics are: It is a very economical technique since, contrary to traditional solutions, it takes advantage of the original structure's seismic capacity, more than doubling its resistance and its capacity for deformation almost without having to reinforce its structural elements. In most cases, the construction is limited to the placement of the connection in the original structures, with a minimum of interference with its functioning (fig 30, 31, 32 & 33).

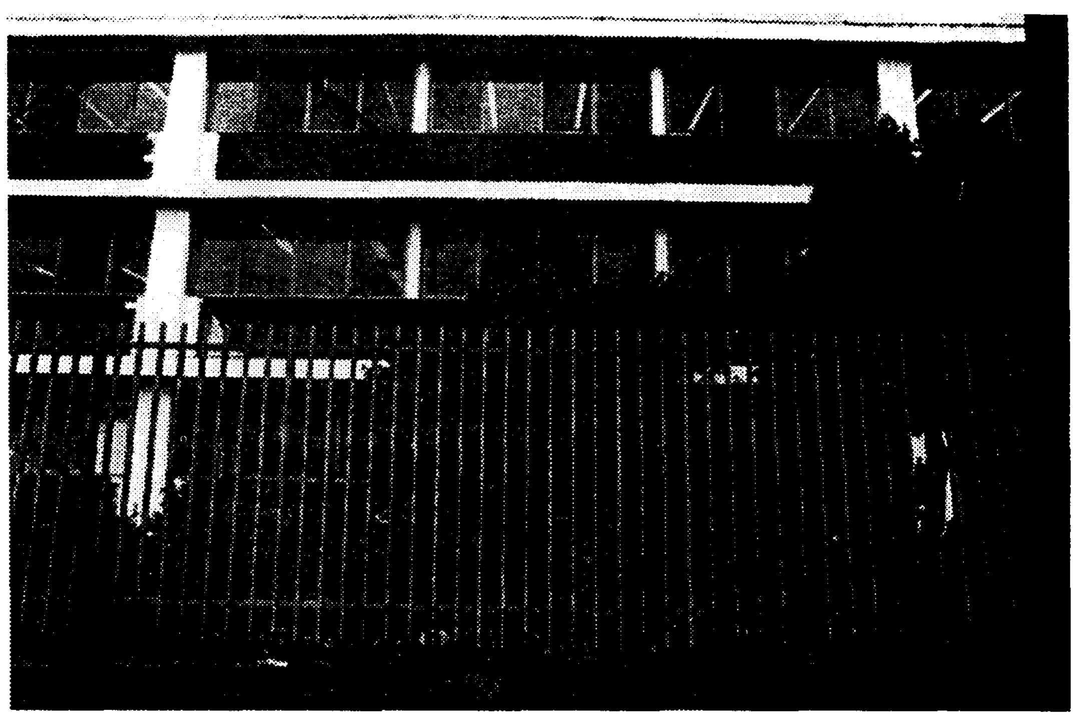

Fig. 30 Building view after retrofitting

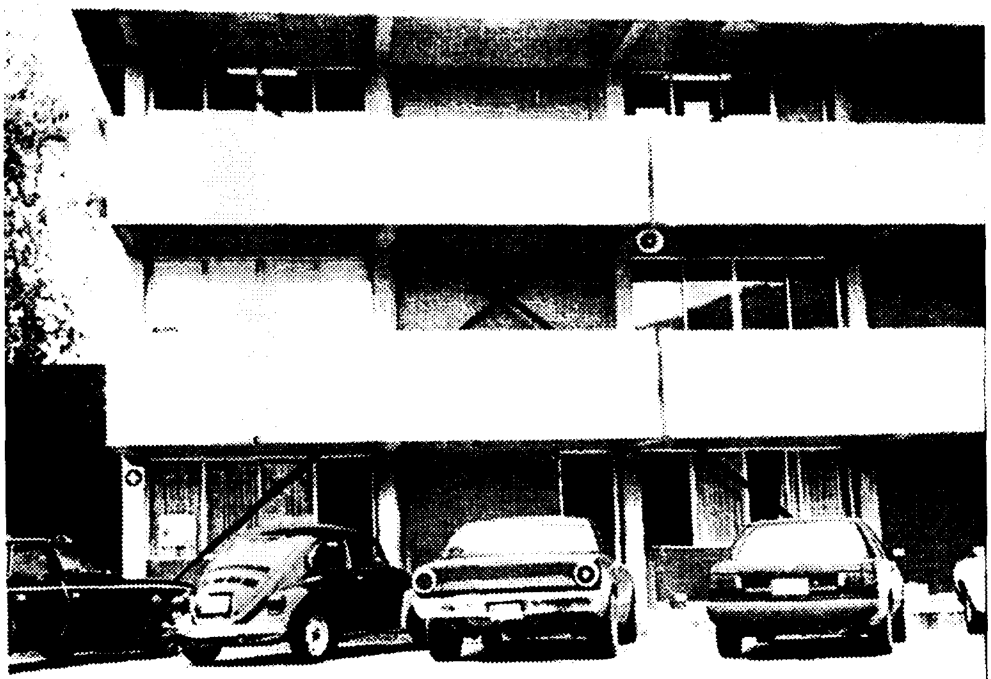

Fig. 31 Building view after retrofitting

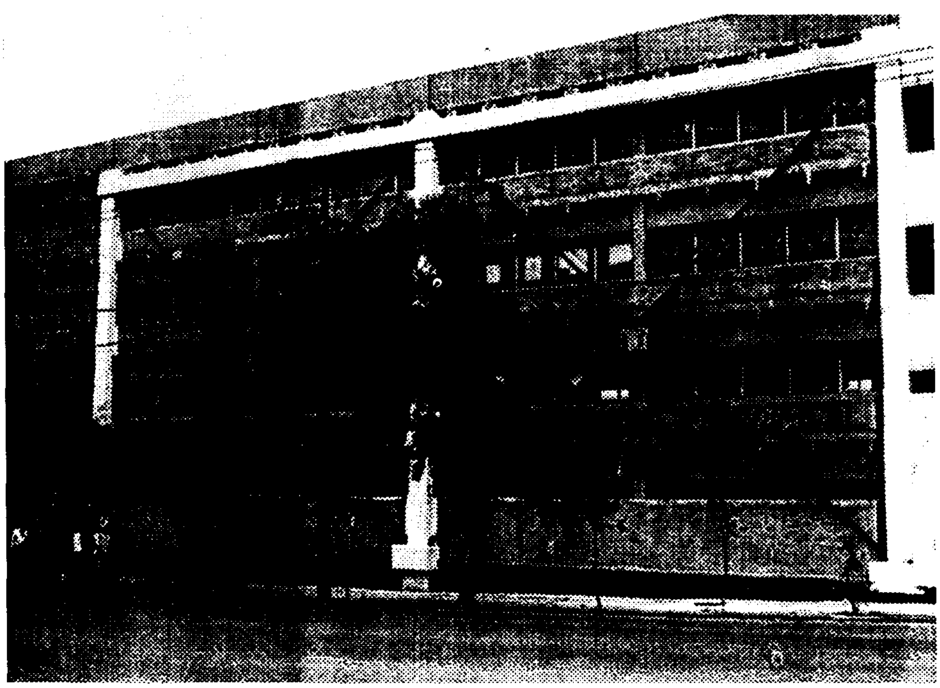

Fig. 33 Building view after retrofitting

Fig. 33 Building view after retrofitting

6. FINAL COMMENTS

It is important to point out that the procedure and the aspects and factors which are part of the structural design, must be revised and adequated from time to time, as the only way to achieve efficient and economical results in the construction of bridges and buildings.

In 1987 as a result of the high magnitude earthquakes that shaked a wide part of this country, a new construction code was defined, and new criteria to design and to built buildings and bridges were settled down.

It must be said that in Mexico City, after its Construction Building Code on 1987 was set down, several rather important results has ben achieved, regarding design improvement and construction quality among others; there are now, two kinds of concrete, named Class 1 and class 2, nowadays it is possible to obtain with the first one of them, a rather high quality material, which allows to reduce shrink and a better well behaviour concrete.

Regarding this code, it must be said that after applying these new construction regulations in a wide range of designs both in bridges and buildings, it was observed that some specifications are rather restrictive and perhaps, should be revised taking in to account of the results obtained from the practice, of the last five years, and later on. If it is considered adecuated, to propose some changes in this construction code.

It would convenient to revise:

1) The possibility to allow that the Q (seismic behaviour factor) could be interpolated from 4 to 3 for Ductile Concrete frames which work together with concrete or brick walls, instead of having Q= 4 or Q= 3; it means that would be possible to have, for instance, a Q= 3.4, according to some equation which takes into account all the factors or aspects which participate in seismic design.
2) The possibility for structures integrated by precast concrete elements, which now defined Q= 2 to allow to use a value of Q= 3, or perhaps even Q=4, if the connections between precast elements are located in places of the beams not too critical, but compeling to them accomplish certain specifications. It must be said that there are a wide range of different type of connections between precast concrete elements and applying, for all the precasts cases a value of Q= 2 is perhaps too conservative, for some specific structures, and this increasing its cost.