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CABLE BRACING

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ABSTRACT

This retrofitting system takes advantage of the original structures resistance and the addition of the postensioned cables enables the structure to withstand earthquakes. Both systems work together which allows for the saving of money and construction time.

KEYWORDS

Cable Bracing; Retrofitting Structural System;

CABLE BRACING

Mexico City, Earthquakes-September 19 and 20, 1985.

On September 19 and 20, 1985, two strong earthquakes shook Mexico City. They had a magnitude of 8.1 and 7.6 respectively. The first earthquake lasted 2 minutes with the epicentre being located 400 Km near the Pacific coast.

Mexico City has wide areas of poor high compressibility soil characteristics. This amplified the effects and caused a large number of buildings to collapse, others had to be reinforced or rebuilt. A large number of buildings lacked the necessary strength to sustain these kind of earthquakes; so they have to be retrofitted.

Mexico City Construction Building Code (1987).

The Mexico City Construction Building Code was revised based on the information obtained from these earthquakes and new restrictive specifications were established.

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. A number of buildings which fall under this new regulation must be reinforced within a short period of time. This process was to guarantee adequate safety levels and to improved their stiffening. This is required to avoid noteworthy displacements during strong seismic conditions.

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

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

A System for Retrofitting Buildings Structures by Means of Postensioned Cables Diagonals.

According to the new Construction Code Building Regulation, a number of buildings located in Mexico City had to be modified to resist strong seismic forces.

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

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

In 1986 a new and very efficient system for reinforcing and stiffening structures was developed in Mexico City. It consists of bracing the original structure using postensioning cables (placed like diagonals) to increase the original lateral structure capacity (Fig 1). This enables the structure to withstand seismic forces and to restraint lateral displacements.

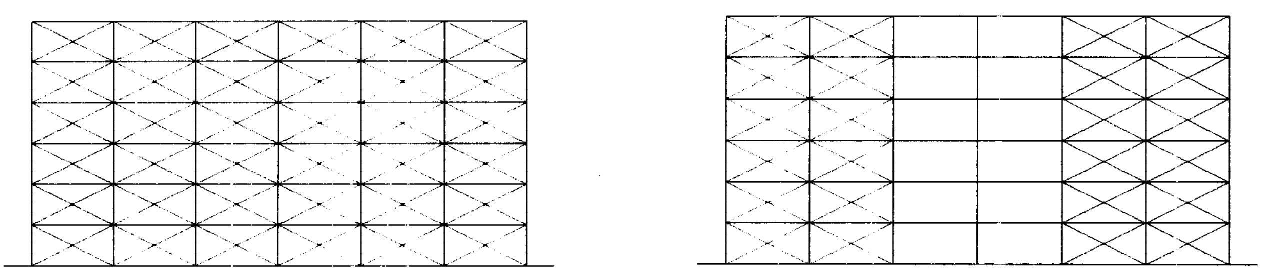


Fig. 1. Two diagonals lay outs options, employing cables bracing.

The system offered many advantages to reinforce buildings because its degree of strengthening and stiffening can be calibrated according to the rigidity of the original structure thus taking full advantage of its seismic capacity. This allows the moment and force distribution in the original structure. This process requires the installation of a reduced number of connections and the procedure is also economical. There is minimum interference with the functioning of the building.

This reinforcing structure system proposes the use of postensioning strains (firs = 270 Kpsi or similar) for bracing the original structure instead of rolled steel shapes elements. They can reach higher stress and strain levels permitting the postensioned cables to work together with the original existing structure.

One of the most important characteristics of the system is the possibility of using postensioned cables in one, two or more bays of the structure and/or in one, two or more levels. The system provides the possibility of regulating the stiffness and strength to retrofit the structure. (Fig 2)

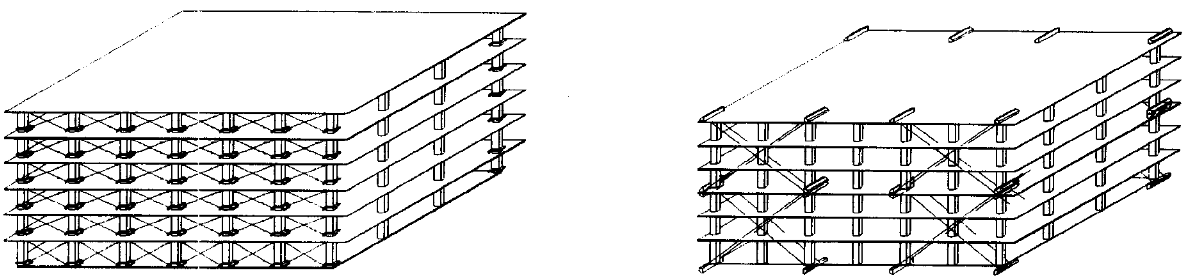


Fig. 2. Two retrofitting systems employing diagonals based on cables bracing.

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

An important point is that the use of postensioned cables for bracing structures instead of using steel shapes diagonals, reduces a great deal of the interference with activities inside the buildings during construction.

This reinforcing system also profits from the existing original structure capacity when resisting horizontal forces.

The postensioned cables are made up with the adequate number of strands and wires. The characteristics of the cables depends on the structural properties of the building to be reinforced and on the amount of reinforcing required. The cables are carefully protected to avoid corrosion by means of a covering protection mixture. (Fig 3, 4, 5 & 6).

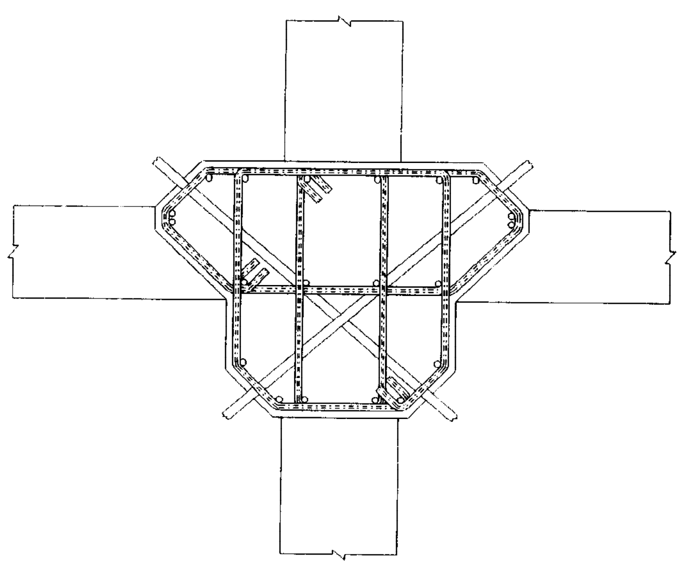
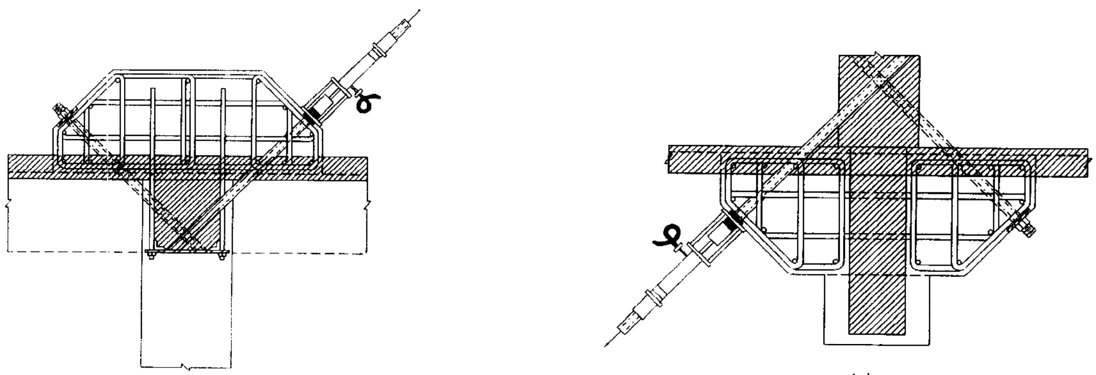


Fig. 3. Interior column postensioned cables joint

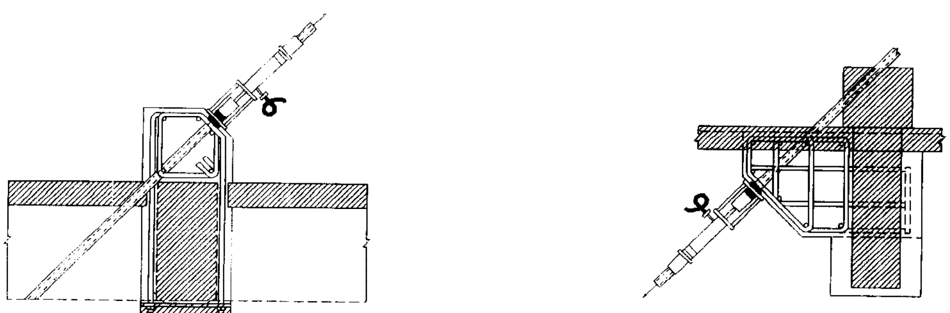
(a) (b)

Fig. 4. Bottom and middle column length cables joints



(a) (b)

Fig. 5. Upper and bottom column length cables joints



(a) (b)

Fig. 6. Upper and bottom column length cables joints

The postensioned cable diagonals are attached on its extremes to the original structures, 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. (fig. 5 & 6)

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 depends on the prestressed forces coming from the cables. This is a function of the strength required by 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 guarantees the correct attachment of the anchor. These anchors are set on the original structure by anchor rods made of common reinforcing bars. These anchor rods sometimes have a stirrup shaped surrounding columns or beams. The upper and bottom anchors can have one or two cables.

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 cables. The accessories are the ones used for postensioning system.

When the bracing is extremely long, a steel plate or a concrete block is placed at the intersection of the cables. This block allows for the longitudinal movements of the cables, but avoids any transverse moments or vibrations.

After the cables are installed, the system is ready to work long with the original structure to resist seismic or wind forces. Because the amount of steel required to reinforce the structure is considerable less than what is needed for other systems, this new invented system represents an important money saving component.

This system constitutes a stiffening and reinforcing technique for framed structures which is very efficient, particularly for low and medium height buildings. It is a very economical technique contrary to traditional solutions. It takes advantage of the original structure'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 these techniques can be done with a minimum of interference with the building daily activities.

A structure reinforced with this system has the possibility to demonstrate it's flexibility, which permits the dissipation of energy produced during an earthquake by means of deformation. The displacement will be controlled so it will never exceed code limits. This system profits from the strength 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 requires the following activities:

* Determining the strength capacity and stiffens of the original structure.

* Determining the strength and stiffness required by the structure according to the new construction codes.

* Evaluation of the differences between the strength and stiffness required and the strength capacity and stiffness of the original structure.

* Determining the layout of the diagonals 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 stiffness required and with the ones of the original structure.

* Determining the anchorage elements, either reinforced cast concrete or prefabricated steel plates.

* Setting the postensioning cables up according to the reinforcing design.

* Construction or setting up of the anchorage elements which are attached to the original structure by anchor rods made of reinforcing bars.

* Attaching postensioning cables to anchorage element by applying a postensioning force to prestressed cables to provide a dynamic reinforced action to increase the ability of the structure and 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 or by pouring concrete or any other materials which will protect the cables against corrosion.

* Inspection of the structure behaviour.

Comparing 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 (270 Kpsi, fyp = 18900 Kg/cm^2), it is nevertheless 100% larger than the yield point of the common structural steel (A-36, fy = 2530 Kg/cm^2). This means that contrary to the system 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. This must be accomplished without 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 system has these advantages:

* The seismic resistance capacity of the original structure is enhanced.

* 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 behaviour.

* The cables do not interfere with the functioning of the buildings.

* A large number of the modifications are outside the building.

* The cables avoid the reinforcing of beams and columns in the original structure.

* A noteworthy reduction of cost for reinforcing the structure.

* A noteworthy reduction of time for reinforcing the structure.

* The cables do not produce direct shear strength on original structural elements.

* The cables do not restress the buildings foundation.

Earthquake simulation test of a six story retrofitted 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 a ductile moment resisting frame structure (before the retrofit), and a second one a retrofitted 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 retrofitting technique is coastwise very competitive, since it uses very little steel material, and require 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 indicate that this technique of using postensioned steel cables to reinforce structures has tremendous potential for improving earthquake resisting construction and therefore mitigating earthquake hazards.

This is a new engineering technique. 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 the U.S.A. this technique was submitted for patent in 1987. It is still in the processing stage.

The System for Strengthening and Stiffening structures by means of using prestressed cables constitutes a stiffening and reinforcing technique for framed structures. It is very efficient particularly for medium height buildings that are exposed to serious earthquakes and that are actually being occupied. The systems main characteristics are: it is a very economical technique and contrary to traditional solutions, it takes advantage of the original structure's seismic capacity and also doubles its resistance and capacity for deformation without having to reinforce its structural elements. In most cases, the construction is limited to the placement of the cables and other modifications.

This engineering technique has been used mainly for school and hospital buildings. These building have been shaked by several earthquakes, after theirs retrofitting; the strongest one was the September 14, 1995 earthquake which had a magnitude of 7.2 and lasted for one minute. Their behaviour were very good.