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SEISMIC - RESISTANT CENTERS FOR PRECAST CONCRETE BUILDINGS AND BRIDGES

J. RIOBOO.

Rioboo Group
Prado Sur 664, Lomas de Chapultepec, 11000
Mexico City

ABSTRACT

A rather new construction technique has been developed in Mexico City, it takes into account its high seismic activity and poor soil conditions, it is based on seismic-resistant centers which also withstand vertical loads. Two totally precast - prestressed concrete middle height buildings and more than twenty precast- prestressed concrete bridges, spanning up to 200 ft and covering more than 1.5 million square feet, have been built with this structural system.

KEYWORDS

Seismic-Resistant Centers: Seismic Structural Desing.

SEISMIC - RESISTANT CENTERS FOR PRECAST CONCRETE BUILDINGS AND BRIDGES

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

On September 19 and 20, 1985; two outstanding earthquakes shook Mexico City, they had a magnitude of 8.1 and 7.6 respectively; the first earthquake lasted 2 minutes. Earthquakes epicenter was located 250 miles in the Pacific coast.

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

Mexico City Construction Building Code (1987).

Mexico City Construction Building Code was revised and adequated to the information obtained from the 1985 earthquakes, and new and more restricted specifications were set down.

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).

New Structural Option for Precast Concrete Buildings and Bridges.

A new structural solution for precast- prestressed buildings and bridges (that can be use also in cast in place concrete and steel structures) was developed, in Mexico City; it defines seismic-resistant centers to withstand both vertical and lateral forces of strong magnitude; allowing a rather well behaviour of the structures.

BUILDINGS

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.

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

During the last 10 years, technical systems and equipment for precasting, prestressing, transportation and erection of concrete elements have been upgraded, a great deal, in Mexico City and more sophisticated and efficient ones are in use today; so larger, wider, more depth and weigher concrete elements are used now.

The new structural criteria described here, consists basically to define in each structure some strength or seismic- resistance centers, which efficiently withstand, both the vertical loads, and the seismic forces, and transfer them, from every floor slab, to the foundation of the building.

These seismic-resistance centers were also proposed due new code regulations, regarding seismic design, compelled to increase seismic forces, in a big proportion, comparing with the original 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 first floors, where arquitectural design do not allow them, also span needed are considerable long, to improve the functionality of these buildings, among others aspects, so these concentration of resistance strength in nucleus or centers which allow to have both; longers clear spans and noteworthy resistance to withstand seismic forces.

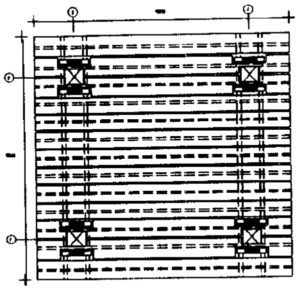
Two middle height building will be briefly described here; in one of them, the seismic-resistance centers are located in small areas; while in the other one, the seismic-resistance centers are located in some of the axis of the structure.

Banamex Computer Center.

In the southern part of Mexico City, closed to the University , this building was built four years ago; it is owned by one of the most important banking firms of Mexico. This building is the newest computer center of this company and also one of the most updated building of its type in Mexico.

The most outstanding features of this building are: the concrete structure was totally precast, the innovative structural solution employed, based on seismic-resistant centers, the dimensions of the precast columns, the construction procedure used and the tight schedule required to build it.

This five story building is 89.83 ft high, its square size area is 128.08 x 128.08 ft. One side is adjacent to another building the same bank and the other three sides are facades. (Fig. 1).



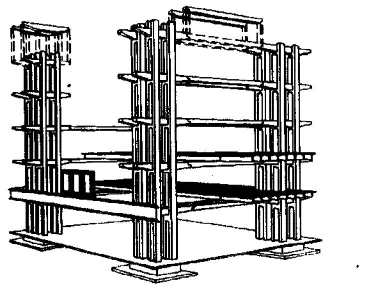


Fig. 1. Plan of building showing principal structural elements. Fig. 2. Perspective view of structural system

The structure of this building was resolved with four seismic-resistance nucleus or centers, integrated each one, by four columns; these columns allowed to pass through them, main continuos beams, which are formed by two support elements and one central supported elements, 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. 2 & 3).

The building is located in geological zone one (1), its 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 big frames. These frames are formed by four columns and at every level by the support elements which are portions of the continuos main beam. East-West seismic forces are withstand by eight small slender frames, consisting each one, of two columns before mention, and five partially precast short span beams (located at every level of the building).

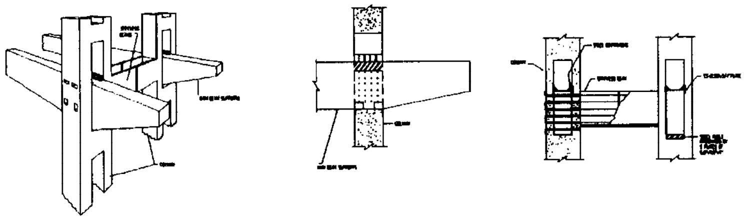


Fig. 3. Connection between column and main beam support elements.

New Building for Mexico City Civil Engineers Association.

A new building for the Mexico City Civil Engineers Association was built in Mexico City. It has six floors; the two first floors are for parking garage while the other four are for the offices of the association.

This building has a rectangular size surface; first floor is 165.7 x 181.3 ft, with an area of 13,978.2 square feet; the other five floors are 72.3 x 181.3 ft with area of 13,978.2 square feet. (Fig. 4).

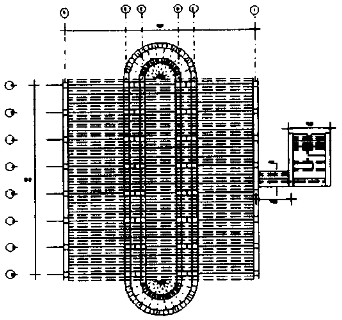


Fig. 4. Plan of building showing principal structural elements.

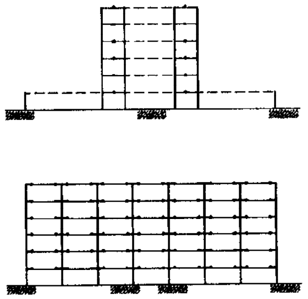


Fig. 5. Structural frames

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

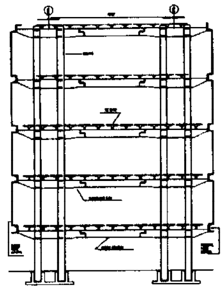


Fig. 6. North-south elevation of building.

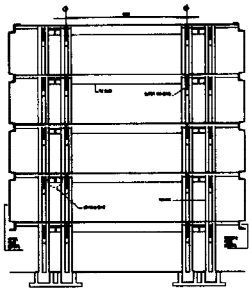


Fig. 7. East-west elevation of building.

Columns are reinforced concrete, they were fabricated on in a precasting plant, and later on they were transported and mounted at site. They are a single piece columns, covering the six floors high. Their height are 72.35 ft . They have at each floor level, a portion of the support main beams, which were cast also at the precasting plant, simplifying the connection to support main beams. Also at each floor level they had cast a portion of the stiffening beam, which are part of the frames which will resist seismic forces. (Fig. 5, 6, & 7).

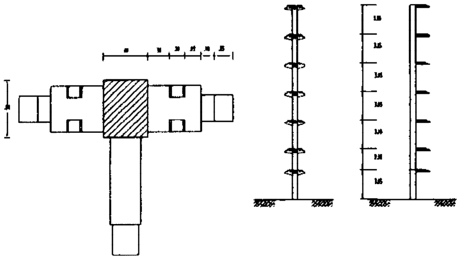


Fig. 8. Column.

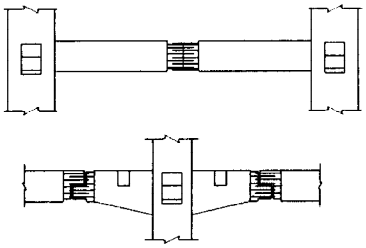


Fig. 9. Connection between precast elements.

Seismic forces in this building are 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 which were precast in plant; while 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. (Fig. 8 & 9).

BRIDGES

Mexico City 1987 Construction Code compelled structural designer to achieve new criteria's on bridge design, and instead of using simple support beam solutions, which seismic forces are resisted, in both directions, by means of cantilevered columns, in recent years other structural option were developed; in one of them, vertical loads are resisted by continuos but issostatical beams; and earthquakes forces are resisted by **seismic-resistant centers,** defined by frames in both directions. (Fig. 10).

This structural system employing seismic-resistant centers was used for the first time in 1989 on an elevated section of Mexico City's rapid transportation system. Since the beginning of 1992, more than 20 middle range bridges, totaling now, five miles, they have been built using continuos but issostatical beams, which were 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 200 ft, avoiding traffic interferences on main avenues (during their construction), and obtaining a high quality standards. (Fig. 11 & 12).

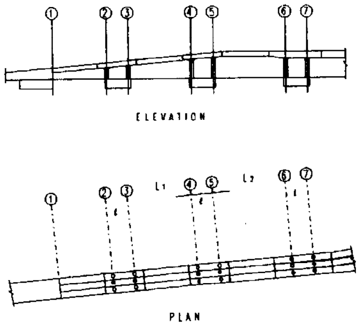


Fig. 10. Bridges General Outline

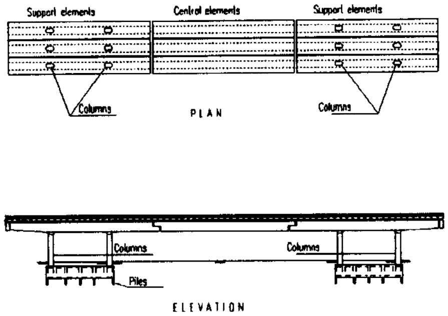


Fig. 11. Longitudinal Structural System

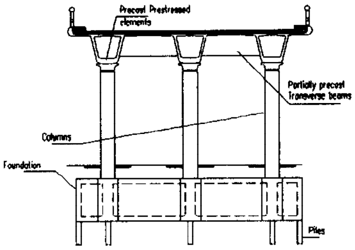


Fig. 12. Transversal Structural System

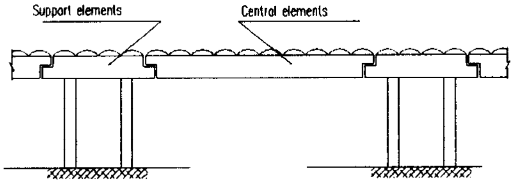


Fig. 13. Vertical Loads Structural Design

This new system has proven to be very efficient, because it takes into account the special conditions and requirements of Mexico City, such as the unbelievably high density of traffic. Traffic major transportation corridors cannot be stopped for long periods of time to build bridges, and most of the bridges need to be built in the areas of heaviest use. In addition, the soil in major portions of Mexico City does not possess what we could call "top strength properties" necessary for supporting great amounts of weight and heavy loads. Consequently, foundations must be designed in such a way that differential settlement due to ground consistency problems can be minimized. In addition to of all the previously mentioned factors, budget constraints add additional pressure to the construction of bridges. Perhaps the most important factor to keep in mind, however, is that all of these bridges are built in a city that is renowned for heavy seismic activity; therefore, the structure and foundation need to be designed in accordance with the requirements established in the rigorous Mexican construction regulations.

Several other technical aspects were considered in the design of these new bridges: the efficient support of vertical loads; the need to allow for large spans between columns, do not affect the structural behavior of nearby buildings; and the necessity to create a structure in aesthetic accordance with its surroundings.

The aesthetic appearance of the structure is outstanding. The well-designed connection between the hollow box girders sections conceal 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.

Vertical loads structural design.

The girders which integrate the superstructure of these bridges were designed as a continuos, but issostatical 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; it means, that the support elements have only negative bending moments, while the central elements have only positive bending moments. This structural solution offers many advantages, compared with a simple support solution.

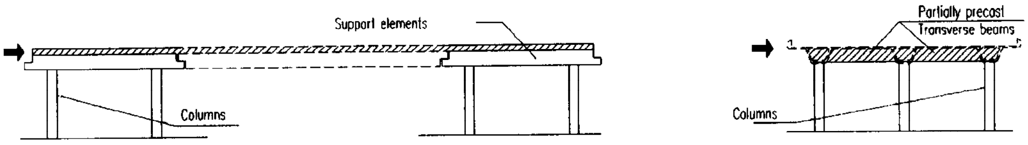
To achieve the highly efficient structural solution for supporting vertical loads , needed for these bridges, it was not possible to use common simple supported beams. Moreover, it is almost impossible to think of efficient and economical simple supported precast concrete beams, to span 200 ft. Therefore, continuity had to be achieved in the structural solution, for these bridges. (Fig. 13).

These bridges have been designed to support an AASHTO HS20-44 highway load, a paving surface dead load of 4 in. of concrete, a sidewalk live load of 85 psf, and an additional dead load (including fence, sings, poles and other accessories) of 67 lb per linear ft.

The double cantilever support beams carry the central beams by means of a hinged connection that transmits shear, vertical loads and deflection without transmitting bending moments and rotation. Thus, the vertical loads are supported efficiently with a significant reduction of positive bending moments. Beam deflection is reduced and the capacity to withstand differential settlement of the columms is enhanced. In addition, the sizes of the precast concrete beams are more suited to handling conditions

Seismic structural design.

These bridges were designed, considering that seismic forces were resisted by seismic resistant centers, defined, in the longitudinal direction of the bridges, by a system of structural frames, integrated each one by two columms and one support element; and in the transversal direction, by a system of frames formed by two, three or more columms 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 columms. (Fig. 14).



LONGITUDINAL FRAMES

TRANSVERSAL FRAMES

Fig. 14. Seismic Structural Design

The Mexican Building Code contains rigorous seismic design requirements. For most of the city (Geological Zone III), a 0.6g seismic coefficient, the most restrictive in the Mexican Code, is assigned. For a precast concrete structure, a seismic behavior factor of 2 is required. Thus, it was necessary to meet very strict requirements in the design of these new bridges.

Superstructure.

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

Attached to the support elements, there are partially precast concrete transversal beams forms, located at column axis. These beam forms, are made of precast 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.

The superstructure is finally fulfilled by steel diaphragms, which are located at the mid span of central precast elements and at ends of both central and support precast elements.

Support Elements. The support elements are notched at each end to receive the central elements. Also, the support elements have channel-shaped, precast units attached to one or both sides to serve as forms for the partially precast transverse beams. (Fig. 15).

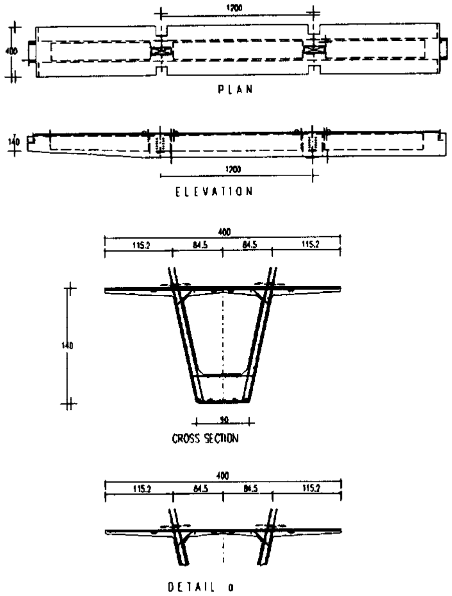


Fig. 15. Support Element

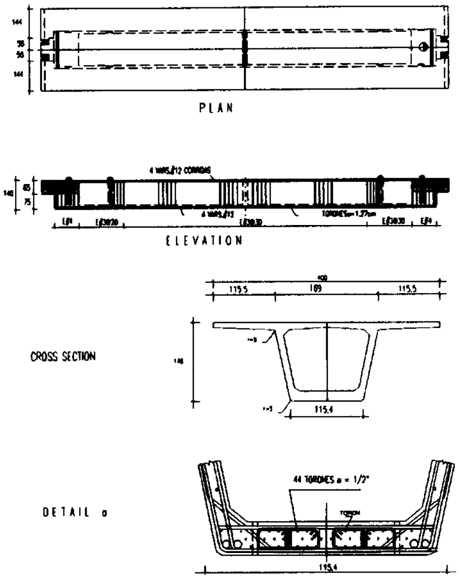


Fig. 16. Central Element

Central Elements. The central elements have a constant hollow box cross section having two upper flanges. The depth, width, and exterior shape are the same as the support elements. These elements are notched at their ends to rest on the support elements. (Fig. 16).

Partially Precast Transverse Beams. Transverse partially precast concrete beams are located at each transverse column axis. They are cast in a precast, reinforced concrete form attached to the main support elements at these locations before they are erected. Reinforcing steel and concrete are added at the site to complete the transverse concrete beams. Since the forms are cast in the plant, they are assured of matching the main support elements in finish, quality, and color . Using these precast, pre-attached forms makes it unnecessary to build and support form work above ground at the site. (Fig. 17).

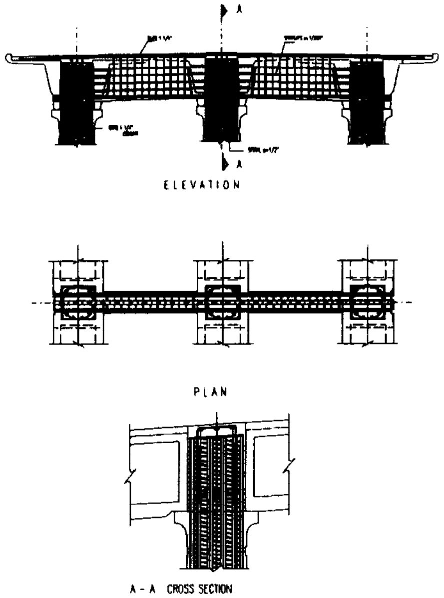


Fig. 17. Partially Precast Transversal Beams

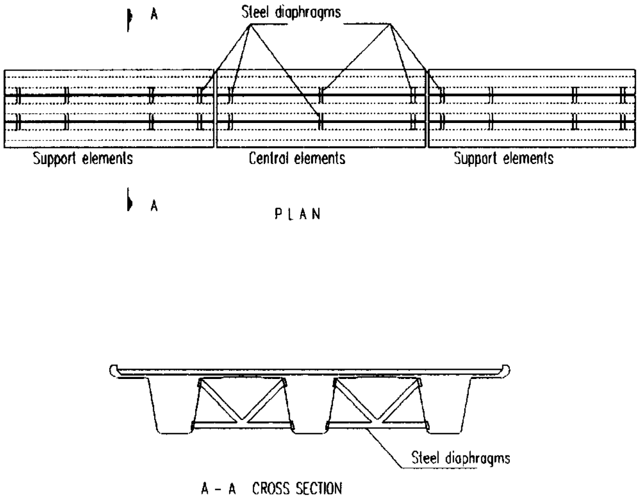


Fig. 18. Steel Diaphragms

Steel Diaphragms. To meet AASHTO specification requirements, diaphragms are incorporated at each end of both types of pretension elements and at the mid span of central elements. Prefabricated diaphragms made of 4 inch diameter structural steel tubing are welded to precisely positioned embedments in the precast concrete girders. This system provides another opportunity to avoid building forms high above the street. (Fig. 18).

Topping. Above the longitudinal girders and the transverse concrete beams, a 3.15 inch thick concrete topping was reinforced with 1/2 in steel mesh.

Connections Between Support Elements and Columns. To make seismic resistant frames in the longitudinal direction, it was necessary to provide an opening in the bottom slab of the support elements where they go over the columns. This permitted the vertical steel in the column to run through the support element up to the concrete topping, establishing a monolithic connection between columns and support elements. Reinforcing steel, including shear reinforcement, was set in place for the transverse beams before concrete was poured to complete the connection. (Fig. 17).

Connections Between Support and Central Elements. Neoprene bearings are provided where the central main elements rest on the support elements. The neoprene is encased in steel boxes to protect it from environmental pollution which is an ongoing problem in Mexico City. The steel boxes allow a controlled longitudinal temperature displacement, and they are restrained by vertical bolts to avoid element run out during earthquakes. (Fig. 19).

Both support and central elements are designed to allow access to the bearings. In addition, the steel boxes are designed to be readily removed so they can be replaced during one working night without any traffic interference

Substructure.

Substructure is made of (cast in place) reinforced concrete columns, some of them with oval cross section, and some others with circular cross section. There are also two concrete retaining walls located at the approaches of the bridges.

Foundation.

Foundation is resolved with independent caissons, each one supporting a group of 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. (Fig. 20).

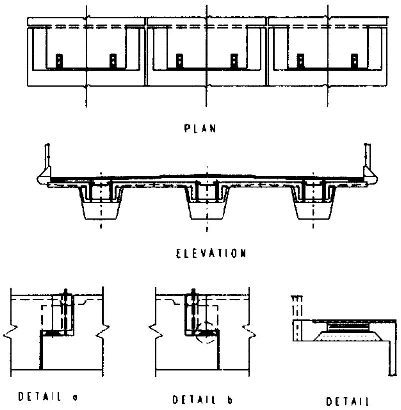


Fig. 19. Connections Between Support and Central Elements

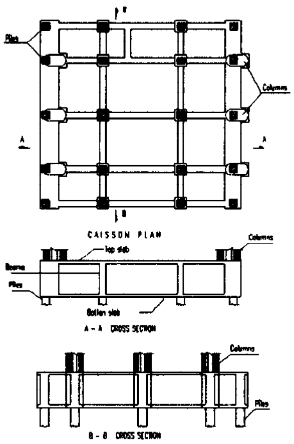


Fig. 20. Foundation

Structural Options

According to its span, width, traffic loads, and locations, each bridge has its own characteristics and different seismic and soil conditions. Hence, it is possible to say that each bridge is different from the others, and each requires a different structural option. The most interesting structural options encountered in the process of building are briefly described below.

Cross Sections. The length of span defines the depth and cross section required; three cross sections have been used, corresponding to 4.6, 6.6 and 7.5 ft. depth. (Fig. 21).

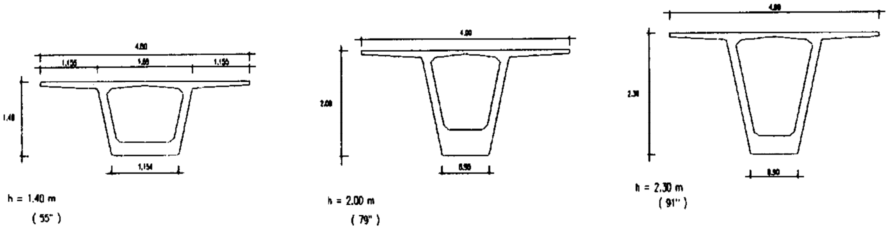


Fig. 21. Precast-Prestessed Elements Cross Sections

Skewed Bridges. Due to the fact that a large percentage of sloped bridges and passage ways built in urban zones are skewed, a variation of this same structural system was developed for these bridges in which .the prefabricated, pretensioned concrete elements present an obliqueness of great magnitude in the supports. (Fig. 22).

Curved Bridges. In order to deal with the problem of bridges with curved at their base as well as in the elevation, a solution was arrived at in which the curved beams were resolved through the use of small upright segments. That is to say that they employ prefabricated, prestressed upright elements which present transverse inclined faces with respect to the longitudinal axis of the beam. (Fig. 23).

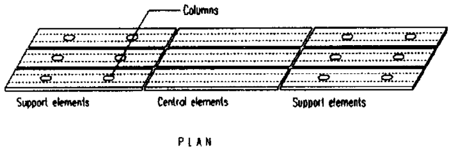


Fig. 22. Skew Bridges

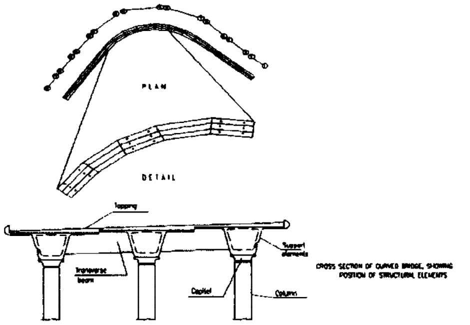


Fig. 23. Curved Bridges

Longitudinal Structural System. Seeking to optimize the structural solution for each bridge in accordance with its specific conditions and characteristics, the structural solution has been modified in the longitudinal direction in various manners, as is shown in Fig. 24.

Figure 24a shows the longitudinal structural option in which the support elements are a constant. In Fig. 24b and 24c, these elements have variable depth and variable transverse sections. Figure 24d shows a structural option in which all of the elements that integrate the continuous beams are support elements.

Transversal Structural System. Similar to the previous case, variations in transversal direction of the bridges are shown; figure 25 demonstrates some of them. Figure 25a shows the original solution which presented it self in which each of the support elements rests directly on the columns. Figure 25b shows a case in which the support elements are supported on prefabricated, transverse beams. In figure 25c, a case is shown in which the support elements provisionally rest on a false support. Later, the transverse support beam is positioned, and, having acquired strength and resistance, the longitudinal support elements are placed onto them and the temporary support is removed. Finally, in figure 25d an option is shown in which part of the support elements rest directly on the columns and part of them on transverse beams. In other words, it is a combination of the two options demonstrated in figures 25a and 25c.

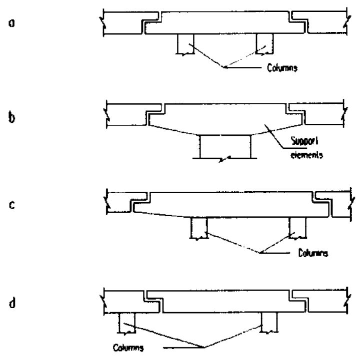


Fig. 24. Longitudinal Structural System Options

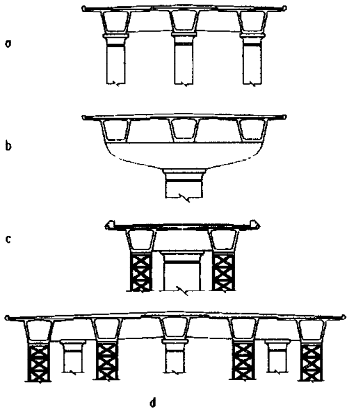


Fig. 25. Transversal Structural System Options

CONCLUDING REMARKS

In February 1991, PCI presented a special award to the Mexico City authorities and to the Design, Consulting & Project Management Engineers in recognition of the innovative use of precast and prestressed concrete in the design and construction of the bridges located at the Tlalpan freeway crossing with Emiliano Zapata and Municipio Libre Avenues (see July-August 1991 PCI JOURNAL, p. 108). These bridges were the first ones built employing this innovative new structural system. Later on, some other PCI awards were presented to the design Group, relating to Apatlaco bridge and Division del Norte and Tlalpan freeway bridges.

Since the 1985 earthquakes, Mexico City has been shook by several other quakes, of different magnitudes, but the biggest one was presented September 14, 1995; it had a magnitude of 7.2 and it lasted for one minute, besides that no damage and injured people were known and the behaviour of this structures were proved.

It is important to point out that the experience obtained with the design and construction of 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 magnitude of seismic forces that, from time to time, shake this city.