A central core tall slender building in Mexico

By Luis M. Bozzo

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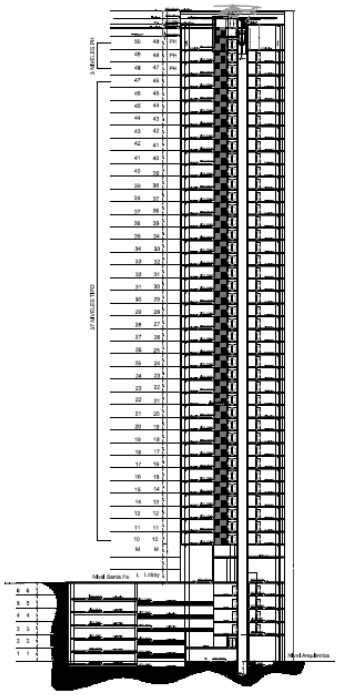


Abstract

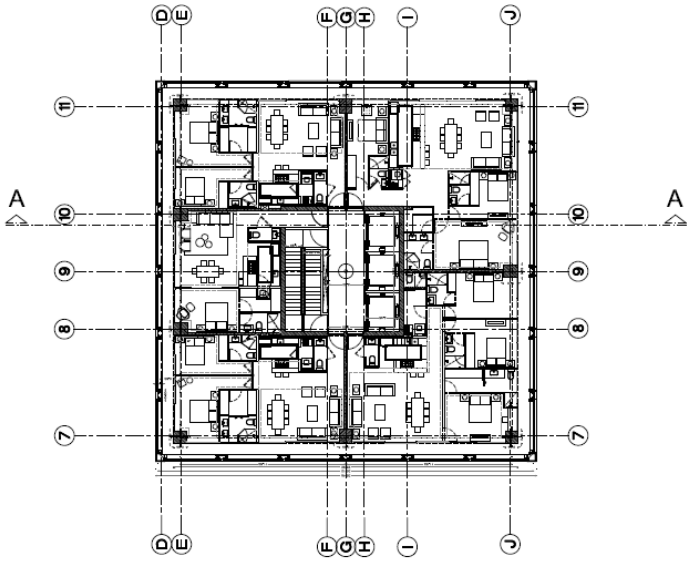
The Santa Fe II tower is a 52 stories residential building 167m total height including a heliport on top. There are eigth levels on the base for parking on a 60m by 30m base area. The concrete tower is slender because it has only 26,5mx26,5m for the 44 stories above the base area. The lateral load is transferred by a central core and a border beam connected by a flat lightened postensioned 250mm slab. A good structure should have a relationship between the structural system and the overall shape. Certainly in this case the tower looks slender because of the rigidity of the central core. Besides the core there are only 9 columns located at the perimeter (one column at each corner and one intermediate except in one border where there are two intermediate columns). The dramatic exterior view of many discontinuous white columns is achieved by architectonical non-structural elements. The core has a 9mx8,5m dimension with a variable thickness from 50cm to 30cm. The lightened postensioned slabs avoid all intermediate beams or supports with the advantages of a flat slab system. The construction time was less than 6 days per level. Regarding number of stories is the third largest building in Mexico.

Introduction

The building consists of 52 levels for residential housing including eight base levels for parking. In the parking levels the structure includes the totality of the land (60x30m), whereas, from the first level of apartments, the building is conceived like a 26,5m x 26,5m square with a concrete central core that contains all the vertical circulations. The architectonic project contemplates a very particular space disposition of the facade with many discontinuous white columns without any structural function. Behind the “Torre Mayor” and the “Torre ejecutiva Pemex” and with respect to number of stories the Santa Fe II tower is the third largest building in Mexico. Regarding residential buildings is the largest in Mexico and probably the largest in South America indicating a trend change in user’s preferences.



Architectural section of the tower



Architectural plan view of Santa Fe II for a typical level showing central core, 9 columns on the perimeter and the facade elements.

The structure is symmetric except for one side where there are two border columns instead one column at the middle. The lightened PT slab allows 9m x 13m spans using 250mm thickness with a self weight of only 3,5kN/m2 (a full slab would weight 6kN/m2 with a significant effect for 52 levels).

The parking area has a different vertical support elements distribution than the upper levels. The parking is inclined so there is an optimization of space without missing parking slots due to a ramp. The structure in this area is formed by 3D girders and also lightened PT slabs (see photograph 1).



Photograph 1. Parking zone using 3D girders and PT slabs

In the previous figures the singularity exterior architectonical appearance of the building is appraised. The central core of reinforced concrete, the nine perimetral columns and the lightened PT slab is shown next for the first level in July 2012.

Structural scheme

Symmetry, scheme of transmission of loads, spans, self-weights and materials significantly define the total cost for a building. Good conceptual design is the basis for an efficient structure particularly today when computers allow fast and apparently efficient structural analysis. A bad conceptual design cannot be replaced by a good or even excellent structural analysis while the contrary was possible for many years before the massive use of computers. In general, a building will be economic if his mechanisms of transmission of loads are clear and well defined. This is because the analysis model will be more precise and effective resulting in an optimisation of sections and members. On the other hand, the correct selection of the material and structural system influence the final cost. Today there are many structural systems available for the engineer and its correct selection will define the total cost for a building.

The proposed building is evidently singular regarding it architectonical exterior view and as far as its total height is concerned but it presents well defined load transmission mechanisms. Lateral loads are transferred mainly by the central core which frees the remaining structural elements for transferring seismic loads allowing eliminating all interior columns. In fact there are just 9 columns per level, one at each corner, and one at the centre, except in one border where we have two columns. The reason to have two columns instead on one column in one side was simply cost and view requirements. The cost is reduced if we use two columns instead of one column at the border because the axial load is very high requiring large sections and high strength concretes. In the other hand the view is more diaphanous as fewer columns we include so the final design includes two columns in the border where the exterior view is less important.

The foundation is resolved using one macro-piles per column and 9 macro-piles for the central core base slab. Each pile has 150cm diameter and a total length of 33m. The underground layer that transfer a significant part of the loads are “blue-clays” which allows a cost-efficient foundation that had almost no settlement in the whole construction process.



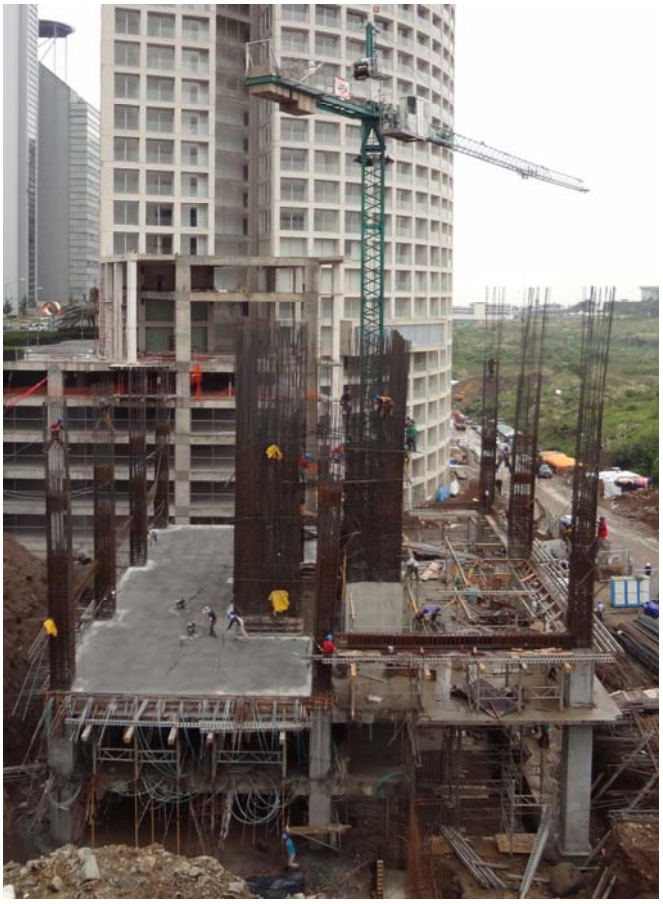
Photograph 2. Foundation based on Macro-piles, one per column besides 9 piles for the central core (in total 18 macro-piles).

The slabs are bi-directional elements with thickness equal to L/35 ratio. The slab depth is 250mm with interior ribs each 120cm in both directions. The border beam is only 600mm depth with 300m width. Theoretically this structural system allows a complete flat slab without any border beam. However this border beam has various important structural advantages such as stabilizing the whole structure against structural overturn. In fact during lateral loads analysis their shear forces are low but the axial tension/compression are as significant as 7000kN (about 30% of the service axial force in the column). Consequently in my opinion am optimal structural system is a central core one combined with a border beam and columns, as this building.

The central core and lateral walls have a 2,5% ratio compared to the total floor area in the basement, although on top is has only 1,5%. In South America high seismic regions it is usual to have a 2% ratio while in the US this ratio decreases to about 0,5%. However the stiffness of a central core cannot be compared in terms of plan area to the stiffness of individual walls because certainly its shape provides more stiffness.



Photograph 3. Central core and first level PT lightened slab at July 2012.



Photograph 4. Central core and second level PT lightened slab at August 2012.

As it may be appreciated in photos 3 and 4 at the beginning the construction process was slow. However after that period a whole level was constructed in less than one week as it may be appreciated in the following photo.



Photograph 5. Structure in April 2013 showing the construction process for the architectonical exterior white precast elements.

The building has the following structural subsystems :

- Foundations using macro piles 150mm diameter and 33m length. In total there are only 18 piles for the tower.

- Central core walls in a 2,0% total average area ratio.

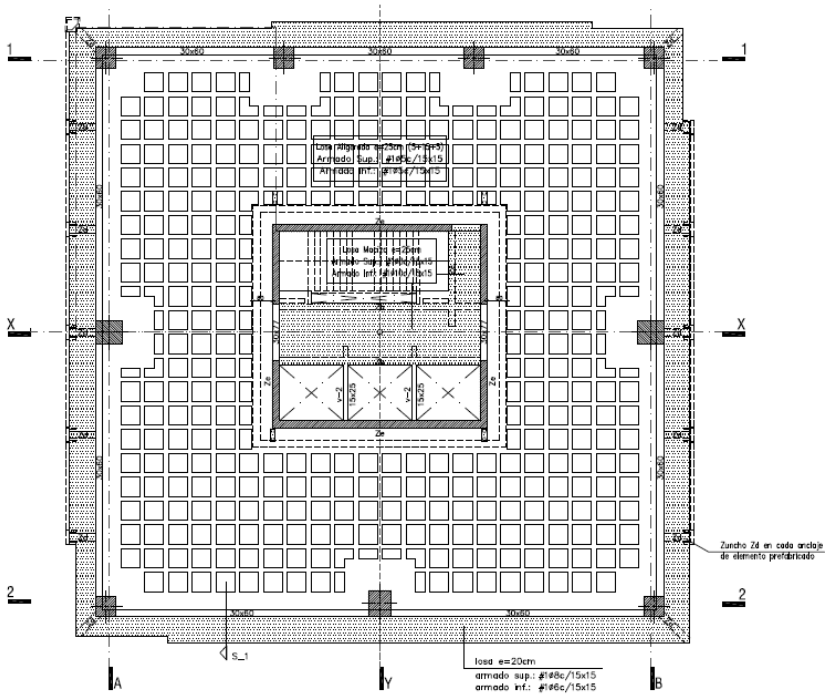
- A border or perimetral frame including 9 supports and a beam with only 600mm depth and 300mm width allowing a diaphanous interior flat space.

- By-directional postensioning lightened 250mm thickness slabs supported on the border beams and central core.

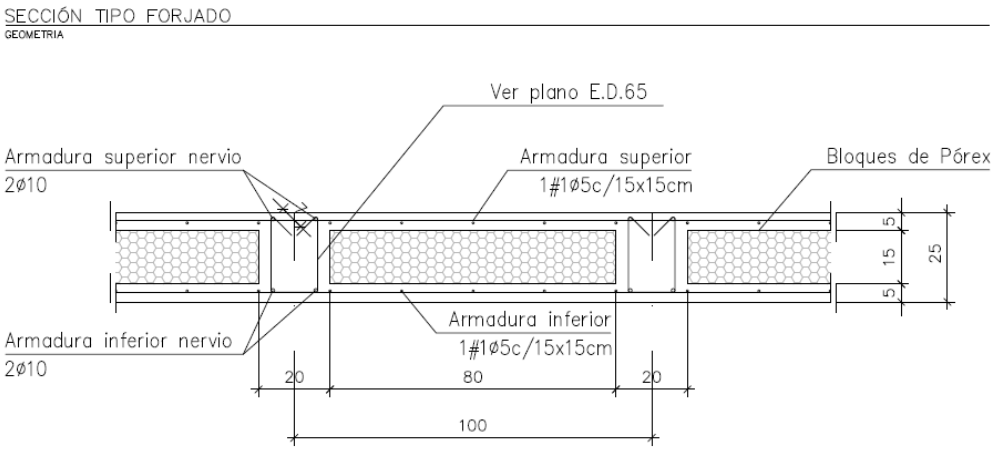
The scheme of transmission of loads is simple and clear: each plan is supported on the border beams, which are supported on the columns and the central core. Most of the seismic load is transferred by the central core which is quite stiff.

The vertical settlement during construction varies between the central core and the border columns requiring special analysis for each slab level. For example in the 51 roof level the service maximum vertical displacement in the central core is about 51mm while in the border columns is 78mm. The difference (27mm) originates negative bending moments in the slabs which vary at each level.

For the parking the average span is 15m x 9m and the structure is a 3d girders and bi-directional 250mm depth postensioned slab. The girder have a maximum 800m depth and in some cases they required a light postensioning.



(a) bi-directional postensioned slabs supported on border beam and central core.



(b) bi-directional postensioned slab section

Figure 1. Structural drawings for the Santa Fe II tower.

Another interesting aspect of the tower is the comfort criteria or human response to building motion. Certainly all tall buildings move during wind loading and for a slender building such as this one the comfort criteria analysis is required. The acceleration level for which majority of people will perceive motion is between 0,1 and 0,25 m/sec^2. The level for which just sensitive people would perceive motion is between 0,05 and 0,1m/sec^2. Consequently a minimum acceleration of 0,1m/sec^2 is a good maximum target. Considering a very strong wind motion event the maximum displacement on top is 15cm and assuming a first mode response a maximum acceleration of 0,1m/sec^2 is obtained. This value may look apparently a limit value but we must take into account all the facade elements that contribute in two ways to reduce maximum potential acceleration. First of all the diagonal and additional facade elements stiffened significantly the structure. Second a complex facade as this one avoids regularity in the wind swirls so the dynamic loading is less than in a clean homogeneous facade. Consequently even though the acceleration of a 0,1m/sec^2 for a very strong wind even may look high considering the real structure final configuration and considering the analysis limitations the result is clearly correct. Certainly the human comfort for this tower may be felt by the end users.

A special note is for the dynamic analysis of the tower which is located in Mexico seismic zone 1. In this zone the seismic coefficient is 0,16g and the minimum coefficient regardless any reduction factor is 0,04g, resulting in significant lateral loads. Using a mass concentrated model the number of modes required to satisfy the minimum 90% mass participation requirement only 27. In this sense there is a significant advantage of the central core system compared to a conventional frame structure or even the dual system regarding dynamic structural analysis precision. For this structure the first mode in each direction has about 50% of the total modal mass resulting in requiring a few modes to precisely (and safely) analyse the structure. In a more conventional 3D frame the number of modes is certainly larger and their mass participation is more divided resulting in uncertainties at combining the modes for obtaining stresses. The fundamental period in X was 6,8s and in X was 6,6s indicating a quite symmetric structure. The height from the street level up to the main roof, without considering the heliport, is 163m. Consequently the building height versus period ratio is about 25 which seem quite small. However looking into the interstory drift and for

the spectra without any reduction as defined in the local code, the maximum drift is about 0,0043 and 0,004 for X and Y directions respectively. These values are clearly below the 0,007 maximum values mostly accepted in international modern codes.

The macro pile construction began April 2012 and the structure was completed July 2013 in a 1 year and 4 month period. Approximately 4 months was required for the piles and basement and one year for the 52 stories (less than one week per level). Also take into account that each level is similar in geometry but steel reinforcement is different due to different vertical settlement for axial deformation in the supports. At the end of the construction the theoretical vertical movement due to self weight was negligible and the sensitivity to any lateral movement is also negligible even before adding the additional large lateral stiffness provided by the facade diagonal precast elements. Finally, the construction was completed without a single construction accident and

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Basic project: 2012
Executive project: 2012
Building area: 31.500m2
Parking area: 13.500m2

Project credits: Structural project: Luis Bozzo Structures and Projects S.L.
Architectonic project: Teodoro González de León.
Builder: Anteus
Owner: Citicapital