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TWO STRUCTURAL SOLUTIONS FOR THE FIRST SKYSCRAPER IN MEXICO: "LA NACIONAL" BUILDING, 1932-2013

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Abstract. *This document developes a comparison between two different structural solutions for the same building, "La Nacional". The first one considers the engineering methods used in the 1930's whereas the second is according to the current practice in engineering. Built in 1932, "La Nacional" was the first skyscraper in Mexico, a prelude to the modernity in architecture that occurred in the post-revolution period in Mexico. This building represents the triumph of Mexican engineering ability in a construction designed by Mexican architects and built with steel and concrete provided by two Mexican companies. With its construction, the rising of higher structures became ordinary to the eyes of the population in this city, and diverse fields of study began to be developed.*

1 INTRODUCTION

Since times before the Spanish domination, the local population in the Valley of Mexico has fought against challenging subsoil conditions. The Aztec civilization established their capital city in the middle of *Texcoco Lake*, where artificial islands called *chinampas* were fabricated in order to gain land to build temples, houses and for agriculture. The main temples were made up of stone and the soil properties were improved with wood piles that compressed the ground. The *Templo Mayor* was built with this procedure. But heavy structures constantly sank, and new constructions were built over the old ones in a constant determination to correct differential settlements. The Spanish conquerors decided to establish the New Spain capital over the old city of Mexico-Tenochtitlan, facing the problems of a difficult subsoil, regular floods and occasional earthquakes. During the three centuries of Spanish domination, the main structure built in the city was the *Metropolitan Cathedra*l, which construction took almost the same three centuries; and whose towers, completed in 1792, were the highest man-constructed structure with 60 m high in the sky of Mexico City [1].

After the fight for Independence and throughout the eighteenth century, not many constructions were built in the city, but at the very end of eighteenth and the beginning of nineteenth centuries, with the dictatorship of Porfirio Díaz and to commemorate the century of the Independence, several government buildings and some other private were raised, changing the appearance of the city. Inequality and unconformity among the population derived in the Mexican Revolution of 1910, which led to the end of the dictatorship and the establishment of constitutional governments in the early 20’s and a new era of development and welfare arrived to the country. The adoption of the *Art deco* as the modern style and the popularization of the use of concrete as a new building material contributed to the expansion of the city.

A few decades before, the model of the modern western city was created in Chicago and New York. The *Great Chicago Fire* of 1871 brought conditions for the development of the new way of construction called *Skyscraper*. The city had a prosper progress due to the iron and steel industries, and the fire left spaces for new constructions that were built with the conviction of making them fire proof. The growing of business and the concentration of commercial activities in an increasingly exclusive and expensive urban area were some of the causes of vertical development. Technical advances just as the building materials (iron to steel), and the safe elevator were other of the causes. The main constructions in the cities were not temples and churches, or government buildings anymore but the skyscraper which symbolizes the strength and wellness of a company. The diversity of applications of *Art deco* as a cultural style found in the architecture, especially in the skyscraper constructions, a good field of development. In the case of Mexico, the skyscraper arrived not for the saturation of the urban area, but to adopt a modernity inspired by North American buildings. The first attempt to build a skyscraper was the 1927 project of José Luis Cuevas, with a 12 story building in a set-back mass concept. This project was not built, but three years later, the insurance company “La Nacional Compañía de Seguros Sobre la Vida” announced and began the construction of *La Nacional* building, named the first skyscraper in Mexico [2].

From 1925 to 1930, the use of concrete in structures in Mexico was promoted by some producers who published a small magazine in which the advantages and benefits of concrete were encouraged. Some of the architects involved in that promotion participated in the project of *La Nacional*, and the successful implementation of concrete in the building was used in advertisements in which it was pointed out that although more expensive, concrete results more economic.

La Nacional building is a 13 story structure made of steel and concrete. The form of the building remembers the shape of a pyramid. This skyscraper is a symbol of the economic progress after the Revolution. It represents acceptance of *Art Deco* as the modern style of living, and it shows the success of building technology in a design of Mexican architects, with steel and concrete provided by two Mexican companies, who managed to control the difficult conditions of the soil bellow the city.

Figure 1: Construction of *La Nacional* building. Photo by Guillermo Kahlo. Courtesy of Parque Fundidora de Monterrey.

2 LA NACIONAL BUILDING

The building is located in the corner of two main streets in the city: Avenida Juárez and Eje Central. *La Nacional* is a 13 story building with a regular rectangular floor plan until the 9th floor, where its corners are cut off forming a cross section. At the 11th floor it has another cut that forms a rectangular section and finally, the top of the building is a small tower that enhances the complete height of the structure, rising 55 m above the city streets. The floor plant is inscribed in a rectangle that measures 29 m in the longitudinal dimension and 24 m in the lateral. The area of its typical story is 698 m² and the total construction area is 8,860 m².

The structure of the building is formed by rigid frames in orthogonal directions and concrete walls in the perimeter. The floor system is made of rigid slabs with a thickness of 0.2 m supported in its perimeter. Columns and beams are made with structural steel shapes covered with concrete.

The typical floor has 42 columns distributed in the intersection of the slightly symmetrical grid axis. The cross sections of columns are square of 0.44 m in each side. The beams are in every axis joining the columns with 73 elements per story. They are formed by steel beams covered with concrete with 0.22 m wide and 0.32 m in height. The walls in the perimeter vary in width from 0.2 m to 1 m in the main façade in order to achieve the architectonic style.

According to information from the inaugural ceremony of the building [3], the total weight of the structure is 981,000 kN. The foundation consists of a rigid slab that rests on 373 wood piles which reach the hard stratum of the subsoil at a total depth of 31.5 m below the level of the street. Other constructions in the city with wooden piles have shown that the wet environment in the subsoil preserve wood in good conditions.

The structure has shown a good behavior throughout its history, standing almost intact after three hard earthquakes that had shocked the city in the twentieth century: 1957, 1979 and 1985, this last being perhaps the one with the more damages in the history of the city. The only problem that is evident in the construction nowadays is an important settlement that has tilted the building in the west direction, being the main reason why it is now partially uninhabited.

Figure 2: *La Nacional* building, left, leaned in the west direction. OMG 2013.

3 ANALYTICAL STUDIES

Not much information was found related to the building. Books about the history of architecture in Mexico barely mention that the building was the first skyscraper in the country and that its foundation was the first that reached the hard stratum. Alternative sources of information were consulted for this work such as the *Manual* published by the Compañía de Fierro y Acero de Monterrey of 1930 (*CFyAM manual*) [4] and a thesis from 1935 in which computing methods for steel and concrete structures are described [5].

A first structural design and analysis from the 30's was made based on those documents for a structure with the same characteristics as *La Nacional*. A second design was made with the considerations of a contemporary project and according to the provisions of the construction code of the city (Reglamento de Construcciones para el Distrito Federal 2004 [RCDF-04]) and its complementary technical norms. Both designs were done respecting the architecture of the original project.

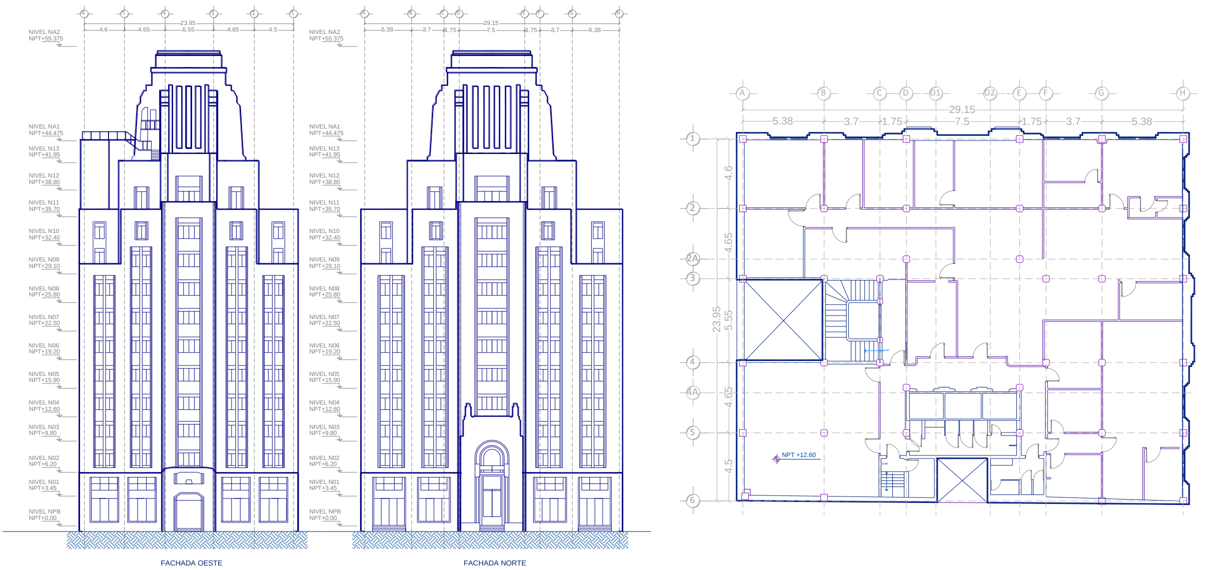


Figure 3: Façades and a typical floor plan of *La Nacional* building

Both structures were modeled in the software ETABS version 9.7.3 with the material properties, geometrical configuration and corresponding loads to obtain mechanical elements in order to proceed with the revision.

3.1 First design, 1930

This structure is formed by rigid frames in orthogonal directions following the pattern of the original project; and by walls of different thickness in the perimeter. The floor system is formed by a two directions rigid slab of constant thickness. The sections used were taken from the CFyAM manual: I sections for beams and two channel sections joined with plates for columns. Walls were modeled with three different thicknesses according to a discretization of the multiple thicknesses of the real walls: 0.8 m, 0.4 m, and 0.2 m.

The materials properties used in steel and concrete are shown in table 1.

Table 1: Material Properties for the first design 1930 [MPa].

Steel ASTM A-7		Concrete	
Ultimate stress	$f_u = 380$	Compression Stress	$f'_c = 21$
Yielding stress	$f_y = 207$	Modulus of elasticity	E = 20,700
Modulus of elasticity	E = 200,000	-	-

The total live load used was 2,452 Pa, typical consideration for office buildings in the 30’s.

To evaluate the forces due to seismic activity, in those days it was common to take the maximum acceleration recorded of 0.3 m/s², which means a seismic coefficient of c = 0.030 g.

In the case of wind forces, the maximum recorded wind velocity in the city was 24 m/s. Considering that the wind acts perpendicular to the surface of the building and that the weight of air is 11.7 N/m^3, results in a pressure due to wind of P = 691.2 Pa.

The process for the design began with the distribution of loads from the upper stories to the lower ones, with trapezoidal distribution for beams and rectangular for columns. A reduction in the live load was made according to number of stories above, reducing 5% per story with a maximum reduction of 50%.

This design was checked with Allowable Stresses Design criteria, common in early years of nineteenth century. The allowable stress in steel for flexure was 124 MPa according to the CFyAM manual. For members in compression, the allowable stress was computed as follows:

$$1125 - 5 \times \frac{l}{r} \tag{1}$$

with a maximum value of 96.5 MPa.

3.2 Second design, 2013

This design is solved with rigid frames of beams and columns made with standard W shapes. The floor system is solved with steel deck. The façade was chosen as attached to the main structure but with no structural work, just considering the corresponding loads, in order to reduce the weight of the structure. Due to the location of the building, the corresponding seismic loads are large, causing high levels of displacements and drifts, thus, to meet the requirements of the code, an eccentrically bracing system was chosen to stiffen the structure.

The materials properties used in steel and concrete are shown in table 2.

Table 2: Material Properties for the second design, 2013 [MPa].

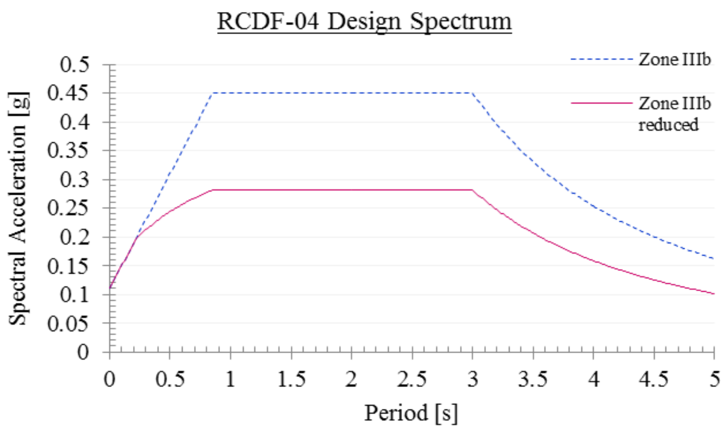
Steel ASTM A-992 GR-50		Concrete	
Ultimate stress	fu = 400	Compression Stress	f'c = 24.5
Yielding stress	fy = 344.7	Modulus of elasticity	E = 21,708
Modulus of elasticity	E = 206000	-	-

The loads for the different uses of the building are given in table 3.

Table 3: Loads for the second design, 2013 [Pa].

		Stores	Offices	Roofs	Hallways and stairs
Dead Load	CM =	1128	1030	451	1177
Medium Live Load	W =	2746	981	147	392
Instantaneous Live Load	W_a =	3089	1765	686	1471
Maximum Live Load	W_m =	3432	2452	981	3432

The local code (RCDF-04) specifies for this type of buildings and with this location that a modal spectral analysis has to be done to evaluate the seismic forces with parameters shown in fig. 4.



Spectrum Parameters
c = 0.45
a_0 = 0.11
T_a = 0.85 s
T_b = 3.00 s
r = 2

Figure 4: Design Spectrum from the code RCDF-04 used in *La Nacional* models.

The ductility factor considered is Q = 2, reduced to Q'= 1.6 to take into account the regularity of the structure, so, the spectrum used in the design is reduced for this factor Q'.

This design was checked with the provisions of the RCDF-04 code with the load combinations shown in table 4.

Table 4: Load combinations for steel design, second design 2013.

$C1 = 1.07\,(CM + CV_{máx})$	$C6 = 0.75\,(CM + CV_{ins} + Sx_{din} - 0.30\,Sy_{din})$
$C2 = 0.75\,(CM + CV_{ins} + Sx_{din} + 0.30\,Sy_{din})$	$C7 = 0.75\,(CM + CV_{ins} + 0.30\,Sx_{din} - Sy_{din})$
$C3 = 0.75\,(CM + CV_{ins} + 0.30\,Sx_{din} + Sy_{din})$	$C8 = 0.75\,(CM + CV_{ins} - Sx_{din} + 0.30\,Sy_{din})$
$C4 = 0.75\,(CM + CV_{ins} - Sx_{din} - 0.30\,Sy_{din})$	$C9 = 0.75\,(CM + CV_{ins} - 0.30\,Sx_{din} + Sy_{din})$
$C5 = 0.75\,(CM + CV_{ins} - 0.30\,Sx_{din} - Sy_{din})$	

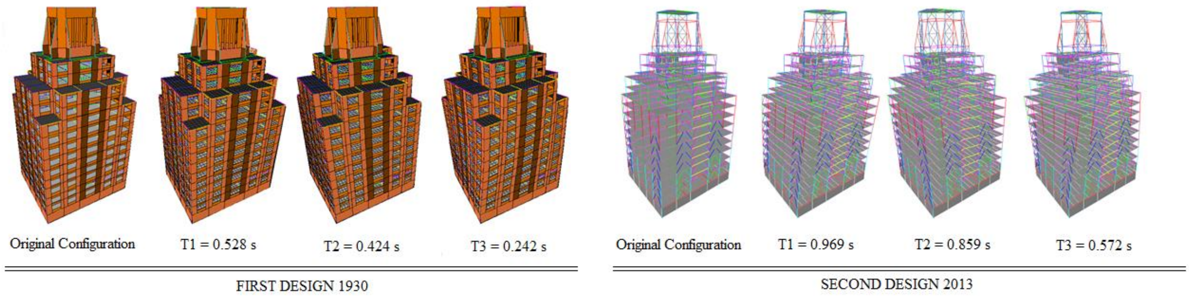


Figure 5: View of the analytical models with the first three vibration modes.

4 RESULTS

The following results were taken from the analytical models.

Figure 7.a shows the total weight distribution of the different elements in both structures. The total self-weight load for the 1930 design is 84,300 kN, 240% more than the 2013 design, which is 34,300 kN, The main difference between the two models are the heavy walls of the 1930 model, which in the second design were considered as additional loads not shown in the figure. Another difference is the change from concrete slab compared with the steel deck including the secondary beams system, which is lighter.

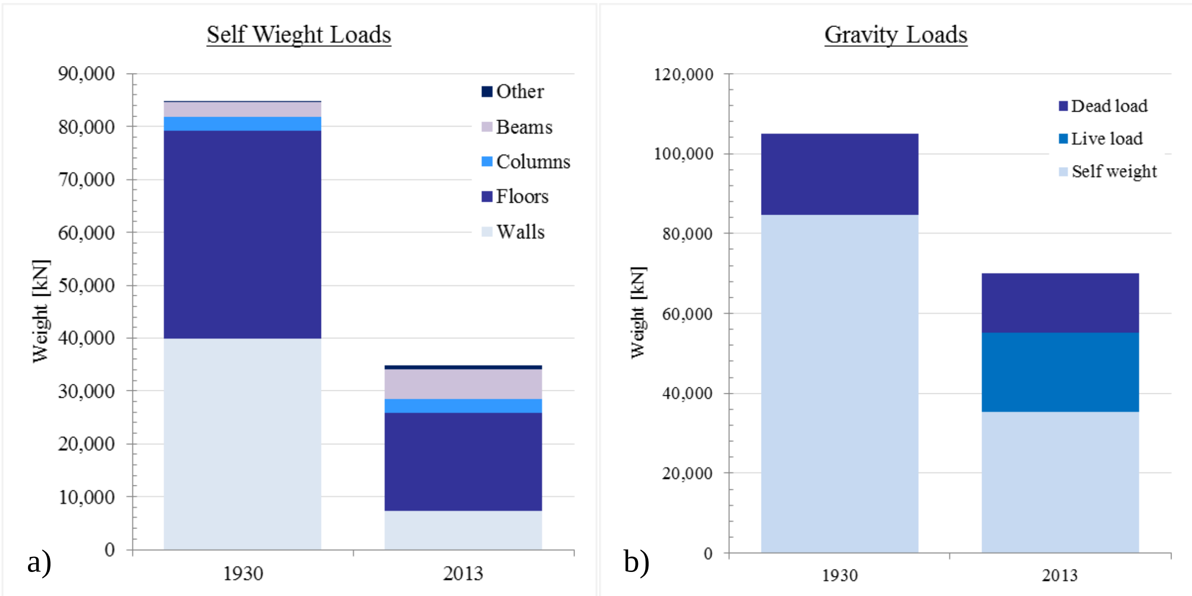


Figure 7: Comparison between self-weight loads in both structures analyzed.

In figure 7.b, the total gravity loads are shown. The difference given in figure 5.a is reduced considering the weight of the walls. Hence, the 1930 design gives 105,075 kN, that is 150% greater than the 2013 design (70,050 kN).

Table 5 shows the first three periods of vibration in both models. It can be seen from the values that the period is almost the half in the 1930 model than that of the 2013 structure, this due to the considerations of walls in the perimeter that add a considerable amount of stiffnes to the structure.

Table 5: Periods of vibration in the structures analyzed [s].

	T_1	T_2	T_3
1930	0.529	0.425	0.242
2013	0.969	0.859	0.573

If the weight and the period of each structure are considered, the outcome is that the 1930 structure is 5 times stiffer than the 2013 structure.

$$\frac{k_2}{k_1} = \left(\frac{T_{n1}}{T_{n2}}\right)^2 \times \frac{m_2}{m_1} = \left(\frac{0.969\ s}{0.529\ s}\right)^2 \times \frac{105{,}074\ kN}{70{,}049\ kN} = 5.03 \tag{2}$$

The displacements obtained from the models are shown in figure 8. It is evident that the second structure is more flexible than the first one. Again, the walls in the perimeter play an important role for displacements control because of their stiffness. The second model is lighter and the bracing system is intended to control the displacements to acceptable values given by the code.

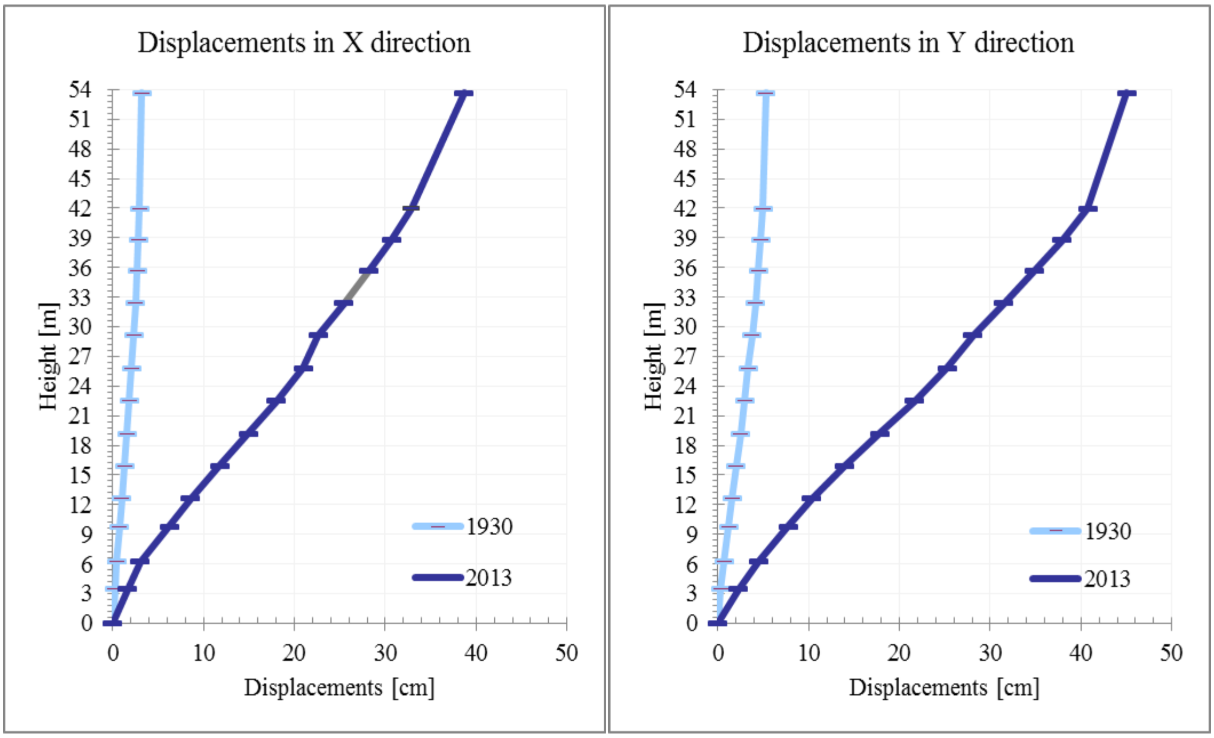


Figure 8: Comparison of displacements in between the structures analyzed.

The design of the connections was not made for this work, but it deserves to be mentioned because is one of the major changes in steel construction. During the nineteenth and the first half of the twentieth centuries it was common the use of rivets for connections. The typical diameter was 7/8 in and the distance between rivets had to be computed, considering that the failure could be for shear in the rivet, tearing in the plate or crushing of rivet. The actual code of construction mentions the importance of this type of connections but unfortunately it just states that specialized old bibliography shall be consulted for the revision of rivets.

5 CONCLUSIONS

- In this work, a comparison between two schemes of structuration for the same building was performed. The first design is a building with frames formed by sections used in 1930. The different loads were computed in a regular distribution from the upper levels to the foundation and so, columns and beams were dimensioned with the guide of the CFyAM manual. Walls made of reinforced concrete were considered in the perimeter of the building. For the design of the second structure, steel frames were chosen to resist the total loads of the structure and a system of eccentrically bracing was used to control the displacements due to seismic forces. The walls were considered attached to the structure.
- From the results, the first structure is 150% heavier than the second one; this is due basically to the consideration of the concrete walls of the perimeter as structural, which make the first structure more rigid, 5 times more rigid than the second.
- The second structure is more flexible, so, its displacements are greater. The braces make the structure satisfy the requirements of the corresponding code.
- From these results, it can be seen that in a location like Mexico City, specifically in the lake zone, a rigid structure will resist accidental loads with a good behavior, as it is the case of the original building. But the problem of a heavy construction is that it is more expensive, besides that a special focus on the foundation has to be done in order to control the typical settlements of a compressible clayey soil.
- The second structure is lighter, thus cheaper, and less rigid. This means that in the case of the design seismic event, the building will present a considerable amount of damage which derives in additional costs for reparation, restructuration or reconstruction depending of the magnitude of the damage. New high structures in the city are being designed with the specifications for special frames, which have shown benefits in locations with considerable seismic activity. These frames release energy through deformations, consequently, special specifications in the connections have to be done in order to achieve that level of ductility without collapse, but these types of structures are not necessarily more economic for the reason mentioned above, and project developers in conjunction with owners must evaluate the life cycle of the structure considering not only the initial costs.
- *La National* building is currently partially uninhabited mainly because a leaning problem, which is probably caused by modifications of the subsoil in the surroundings and not a problem of the structure. This situation does not seem to represent a risk, but can be solved with a scheme of re-foundation or sub-excavation, which presents more difficulties because it requires a stricter monitoring of the nearby constructions to avoid affectations in them.
- Important changes have been developed in order to design seismic resistant structures in the past century. In 1930, the equivalent seismic coefficient was 0.03 g, while for this type of projects the current code specifies a coefficient of 0.45 g, 15 times greater. The maximum recorded acceleration in 1985 reached 1 g in the lake zone, in an area that was not even part of the city in 1930. This tells about better safety factors, but accidental forces are not predictable, and maybe in the future the current coefficients will have to be adjusted. One of the ways to achieve changes and improvements can be done by studying and instrumenting buildings, especially in a location like Mexico City where the conditions are extremely peculiar.

- To perform the analysis of old structures and establish whether they fulfill the code requirements or not is a job of structural engineers. Sometimes there is not much information about them and it becomes necessary to find other sources. The thesis found for this work was helpful to know about how engineering was done then. Comparing the methods used then with the methods that are used now as well as understanding what was on the mind who designed a structure can contribute to establish the actual state of a building, and if the case, to plan solutions to guarantee a good behavior.
- Engineering is a subject with solid basics but in constant transformation due to improvements in technology, research and criteria. Structures like the one analyzed in this paper has proven that the work of engineers is not much different through time, but methods are. Even though in the first decades of the twentieth century the computation of structures implied several simplifications, the understanding that the designers had of the structure seems to be clearer. Nowadays, it is possible to model any complex structure and to consider several variables in such a way that we do not know if the structure will present the behavior we expect. The fact is that this building designed in 1930 is still standing there, whether we do not know if the buildings designed today will remain 80 years. The most possible answer to this question is no, they will not last 80 years because they are not being designed for that, they are not that rigid.
- Structures have a certain life time. Respecting the life time of a structure is indeed a good practice because this way it is ensured that they will remain in constant update, guaranteeing the safety for the users. But what happen with the cultural heritage that a building can give to a civilization? A structure like *La Nacional* tell us about the men who made it, their traditions and their habits, the available technology and even the way they conceived the world; it is a success in Mexican construction and it had become cultural heritage, this is a reason for the building to be preserved. Mexico has a vast number of archaeological zones in which the greatness of ancient civilizations is shown, and constructions like *La Nacional* shall remain with the same intention for the next generations.

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