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MOVING A LISTED HOUSE IN MEXICO CITY FOR PRESERVATION

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Abstract. *In 2009 in order to build the foundation a for the Torre Reforma project it was necessary to move a Historical House built on the 1930's and listed in 1982 by the National Institute of Fine Arts (INBA). The two story house was made of unreinforced masonry; therefore it is very sensitive to ground settlements. The location of the house in the site interfered with the construction of some of the slurry walls that are part of the foundation of a tower of 244 meters high, and its nine underground levels. In order to move the house, a waffle slab was built at the same level of the existing foundation. The slab would transfer loads coming from masonry walls of the house to two sliding lines spaced 18.7m apart from each other. Three hydraulic jacks were placed along each of the sliding rails to elevate and slide the house 18m. In order to reduce costs, the moving project used some structural elements that would be part of the definitive tower structure and foundation. This paper describes the main phases of the project: the construction of the slab, the excavation beneath the house to place jacks and rails, the lifting maneuver and separating movement, the construction of the foundation elements under the area occupied by the house, the returning maneuver, the temporary supports to remove the jacks, and finally the tying of the slab to the tower´s foundation. Likewise, a brief summary of the different mathematical models used to capture the behavior of the house under the different support conditions and the likely forces that can be induced onto the house´s fabric is presented. Finally, issues such material properties, structural non homogeneity, structural design of elements, selection of hydraulic jacks; as well as, the expected response parameters that were monitored during the entire moving process required to ensure the safety of the structure will be also addressed.*

1. INTRODUCTION

The twentieth century marked a significant development in the construction industry worldwide, being this an essential factor of the cultures and responds to the growing need for infrastructure and housing products as a result among others of the anthropogenic phenomena of migration to large cities. Consequently, much of the existing infrastructure and especially those with high cultural value are now seriously threatened. Therefore, its protection and preservation has become a pressing need and task for many countries. Thus, the movement of historical structures as a preservation strategy has become more frequent. However, this approach for preservation is not a new practice, in fact, there are documents that testify that structures have been moved since about 300 years ago [1]. Nevertheless, modern society lacks of the appropriate technical literature for its practical application and the description of past experiences.

It has recently been found in many countries that the movement of structures represents a feasible and valid solution to avoid the terrible loss of tangible historical heritage. As a matter of fact, records have been found that in countries like: The U.S.A., China, England, Australia, Egypt, Spain, and China, depicting hundreds of successful repositioning of historical structures weighting up to 10,000T.

On the other hand, Mexico, a nation with a highly dynamic economy and where its capital Mexico City, perhaps the largest and most populated city in the world, demands for a huge amount of infrastructure and vital modernization. Nonetheless, due to its character of the oldest and most important city of the New World, it also has a lot of buildings not only with high historical and cultural, but also archaeological value. As a matter of fact, it possesses many buildings and archaeological sites declared cultural heritage of humanity by UNESCO. Even so, in Mexico, the movement of historical structures as a preservation strategy has been used in a small measure. Some cases of its implementation have allowed the preservation of several historical structures with high aesthetic value such as: The Arrow Thrower of the North Star fountain - “La Fuente de la Diana Cazadora”, The Monument of Cuauhtemoc – “El Monumento a Cuauhtemoc”, The Horse Sculpture – “El Monumento del Caballito”, etc.

Worth mentioning is that the structural movement of heritage structures must be employed as a last resort and only until all other possible solutions have been thoroughly studied and discarded. Venice Charter [2] states that monuments are inseparable witnesses of history and the settings where they belong. It also establishes that the total or partial movement of a historic building or monument cannot be allowed, unless its integrity is threatened or there is a large international or national interest that justifies it [3].

Within techniques used to move structures as preservation strategy, we can find the three most important: *Monolithic movement:* This procedure involves the movement of structures as units. This provides the most desirable results since structures retain their authenticity, structural integrity is guaranteed and its implementation is relatively quick. Nevertheless, this method involves the highest associated costs, since fairly complex analytical procedures are required, heavy duty equipment is often required, temporary structures are used and the need for many disciplines involved, and other factors. *Movement by parts*: This method is relatively similar to the previous, though it is used when structures are too large, heavy or their geometry does not allow them to be moved as units. It consists of the fragmentation of structures into more maneuverable sections and generally when space restrictions govern the moving procedure. *Movement by complete dismantling*: This technique has possibly been the most common to implement throughout history, due to its ease of understanding and implementation. As its name suggests, it involves the complete disassembly of structures into their minimal components, making it the most undesirable from the conservationist point of view.

Regardless the solution adopted, the moving method must enhance and/or at least safeguard the valuable historical resource; thus, extending the commercial, economic and historical benefits to the society to which they belong [2]. Therefore, the project for the movement shall always be the result of the contribution of various individual efforts and should be carefully reviewed and approved by experts in the subject matter.

The project subject to study comprised the construction of a 57 story tower of for a mixed use i.e. offices and retail, with an approximate area of 76,000m^2. The project also required the construction of 9 underground levels for parking that will accommodate roughly 10,000 cars. Thus, the structural concept includes slurry walls built along the edge of the lot to retain the ground and provide support to the tall building. However, within the small lot intended for the construction, a historical house lay in one corner and which was recently listed by the National Institute of Fine Arts (INBA) due to its high artistic and aesthetic value, representative of the time in which it was built Figure 1.

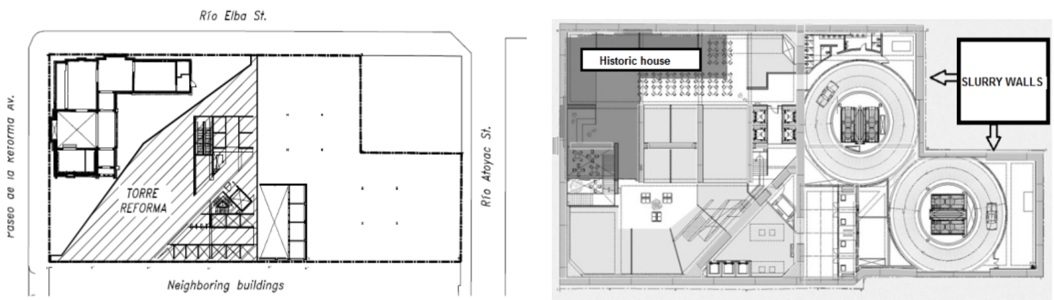

Figure 1 General Layout and overlapping Reforma Tower Project [4]

Due to economic and commercial motivations, the undersized piece of land had to be used; therefore, a solution that would allow the construction of the new and important skyscraper meanwhile assure the coexistence and preservation of the heritage structure had to be found. Subsequently, the group of structural engineers commissioned for the project, faced the necessity of moving the historical house built in 1929 because it hindered the construction of the slurry walls at the front of the land of the project.

In order to solve this problem, the engineering team made several proposals to temporarily move the structure; this approach would allow the construction of the skyscraper´s foundation while the historical house is preserved. The high intrinsic and aesthetic values of the historical house allowed it to be integrated into the master project of the architect Benjamin Romano[4] as shown in Figure 2.

Figure 2 Integrated project Reforma Tower – Historical house [4]

[4] CEO, L. Benjamin Romano & Associates (LBR&A); website: www.lbr.com.mx

2. MOVING METHODS STUDIED

In the pursuit of appropriate methods to move the historic house which would allow the construction of the skyscraper's deep foundation and simultaneously preserving the historical house, a group of engineers and experts in the field made a set of proposals described below.

The three main moving strategies studied were: the complete dismantling of the construction, the monolithic movement of the structure with heavy duty cranes, and finally the monolithic movement of the structure via sliding. The main features of each method are presented as follows:

2.1. Total dismantling

This method proposed the complete dismantling of the house down to its smallest components to re-assemble after the deep foundation of the Reforma tower would be completed. That is, the building would have been dismantled piece by piece removing the binding mortar; the pieces would have been carefully stored and numbered. Nevertheless, this method would have taken a fair amount of time to be completed, it would have implied fairly high associated costs; likewise, this method possessed the most invasive characteristics which represented a serious threat to the authenticity and artistic-aesthetic features of the building. As a result, the institution responsible of safeguarding the integrity of heritage structures in Mexico (INBA) discarded the proposal.

2.2. Movement as monolith with cranes

This method on the other hand, suggested moving the entire structure via the construction of a lightened concrete slab (waffle slab) underneath the weak historical construction. The slab would work as a rigid matrix strong enough to carry and lift the house to then be moved by using powerful lattice boom crawler cranes. Thus, the construction of the foundation of the tower could have been made. Subsequently, the historical house would be relocated back to the original position and tied to the new foundation. This method however had the inconvenience of having to use rather large equipment that neither is available in Mexico, nor the poor soil shear capacity would have been strong enough to support the reactions; thus jeopardizing the entire project. Likewise, equipment's dimensions would have made the maneuvers rather difficult due to the existence of adjacent buildings. The estimated weight of the historical house is approximately 1,500T and the new concrete waffle slab about 1,000T.

2.3. Movement as monolith via sliding

This method was based on the previous one and also implied the construction of a concrete lightened slab (Type "waffle"), which would ensure an adequate stiffness/weight ratio to support the weight of the existing brittle structure. The slab would have been built at the same level of the existing shallow foundation made of stones. The slab would allow the historical building to be lifted a few inches by hydraulic jacks placed on a system of special metal rails that would serve to slide the structure about 18m to the back of the lot. The house would remain there until completion of construction works and then slide back to its original position. The process of lifting and sliding would be carried out by a specialized company and using cutting edge equipment called skidshoes resting on skidrails. After the construction of the foundation of the tower, the house would be relocated to its original position using the same slip method [5].

2.4. Decision making

The solution adopted was not selected until after conducting a thorough scrutiny of pros and cons of each of the options and their characteristics such as: total associated costs, adherence to conservationist recommendations, acceptance of the relevant authorities, and previous experience carrying out the work, among others. The option that proved to be the most suitable and ultimately that would be implemented was the one suggesting the movement of the house as monolith via sliding it. The waffle slab would possess the sufficient stiffness to resist and transfer the weight of the slab-house system to a horizontal dual-axis and vertical hydraulic jacks adapted on two lines of special sliding rails spaced 18.7m apart.

The house would be smoothly moved roughly 18m away from its original location and remain about 12 weeks on temporary supports, while the construction of the tower's foundation would be completed.

3. MATHEMATICAL MODELING

In order to evaluate the various solutions several analyses were conducted to determine which would imply the least risks to the structural integrity of the construction. Thus, in order to evaluate the response of the structure to all possible load case scenarios (e.g. gravitational, accidental and construction stages), several models were created. Moreover, such models took into account the different boundary conditions that the structure would be subjected to during movement. Mathematical models were made in advanced software based on the theory of finite element (FE). Such complex models provided many advantages due to its versatility, for instance, the possibility of refining the type of analysis, iterative analysis, carry out changes that would improve results with relatively low effort and investment. In turn this could represent savings to the overall cost of the project.

For the appropriate construction of such models, a thorough historical research was conducted in order to collect original data for the design and construction of the heritage building. It also was also required a detailed in site inspection and diagnosis of the structure. The later with the aim of getting to know the current conditions of the building, so, as to gather the necessary information to construct the most accurate models of the structure. For instance: geometry, identification of structural systems, construction materials and their current status, likely existing structural damages and/or repairs, alterations throughout its lifetime, differential soil settlements and any other site constrains that could influence and affect the development of the movement of the historical house.

3.1. Description of the structure

The information collected that served for the creation of the numerical models is summarized as following:

General dimensions: The two-story structure has an approximate footprint of 23X26m with an L shape and interstory height of 4.5m. The house has an internal patio and there are adjacent buildings in two of the four sides of the lot. Small differential settlements and some cracks on walls were identified and instrumented for monitoring purposes. All non structural protruding elements were carefully disassembled for their protections and to ease the maneuvers. Windows, doors and vaults were temporarily shored in order to provide additional stiffness to the overall system.

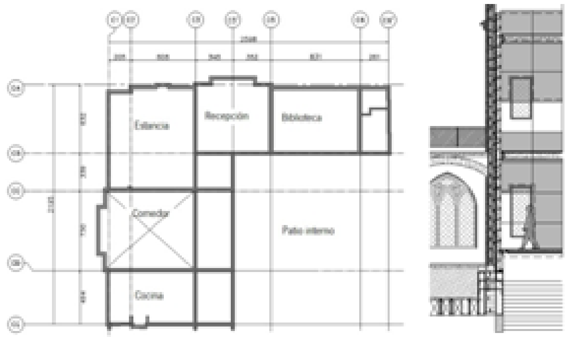

Figure 3 Plan view Historical House Reforma [4]

The structure of the house consists of solid concrete floor slabs supported by unreinforced masonry walls 30cm thick made of two different materials: clay bricks and brown tuff stone blocks. These elements in turn could resist lateral forces induced during earthquakes, likewise the walls transfer loads to the foundation. The foundation consisted of strip footings made of tough volcanic rock commonly found in quarries around Mexico City and bonded with cement-sand mortar. Due to a high aesthetic and historical value, the house possesses sublime architectural features such as: arches and Neo-Gothic ribbed vaults, as shown in Figure 4.

Figure 4 Neo-Gothic architecture features of the historical house [4]

3.2. Materials and mechanical properties

As a result of a comprehensive historical research, as well as various site inspections the materials of the house were figured out. Table 1 describes the properties of the constitutive materials of the historical house, which were used for the construction of FEA models.

Table 1 Mechanical properties of construction materials of historical house [6]

Material	γ (Kg/m^3)	Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)	Shear Strength (N/mm^2)	Young's Modulus (N/mm^2)	Poisson's Ratio
Tuff Masonry	2,034	3.10	0.10	0.76	1,961	0.21
Clay Brick Masonry	1,580	3.90	0.30	0.34	1,177	0.30

Noteworthy is that the values used were the result of a combined effort of an exhaustive historical research and the invaluable experience provided by Dr Roberto Meli Piralla[5].

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Minor Destructive Tests were unfeasible due the lack of available equipment and the haste with which works had to be done. Therefore, values were provided by experts in the field.

On the other hand, materials used to reinforce the house and build the concrete waffle slab are shown in Table 2. This selection took into account materials that would be available, possess a good weight/resistance ratio, are economical, durable and as far as possible compatible with the constituent materials of the house.

Table 2 Construction materials of waffle slab [4]

Material	γ (Kg/m^3)	Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)	Shear Strength (N/mm^2)	Young's Modulus (N/mm^2)	Poisson's Ratio
Concrete	2,400	24.50	2.90	-	21,707	0.20
Concrete 70	2,400	68.60	8.20	-	32,841	0.20
Pebble stone	2,000	-	-	-	1,961	0.25
Filling mat.	1,800	-	-	-	1,000	0.30

3.3. Load assesment

The assessment of loads to be used for structural analysis purposes was made based on the current Building Regulations for the Federal District (RCDF) and its Complementary Technical Norms (NTC) - Design Criteria and Actions. Furthermore, loads which would act onto the structure during the entire moving process and which the house would need to sustain once reinstalled in its original and final position were determined. Table 3 contains the main loads considered.

Table 3 Load assessment for structural analysis of Historical House [7], [4]

Material	Permanent G_k (KN/m^2)	Variable Max. Q_k (KN/m^2)	Variable Instant. Q_k (KN/m^2)	Construction (KN/m^2)
Ground floor	5.15	3.43	1.47	0.98
First floor	6.66	2.45	1.76	0.98
Roof	7.35	0.98	0.68	0.98

Note that the weights of the structural elements of the house were calculated taking into account the dimensions measured in site and volumetric weight values found during the historical research. Loads described in Table 3 were used during the construction of mathematical models during the evaluation of the moving strategies, as well for final models used to study the different stages of the movement of the house and at its final position.

3.4. Soil Properties

According to the zoning proposed by the Building Code of the Federal District (RCDF) and its Complementary Technical Norms (NTC) - Design of Foundations, the Reforma Tower is located in Zone II (Transition soil), but very close to the Zone I (Stiff soil) [8]. This zone is characterized by the presence of silty layers interspersed with sandy alluvial strata. Besides, as a result of in situ soil mechanics studies, it was found that the soil at the site under study is composed of alluvial deposits with inhomogeneous load capacity. Resistant strata were detected up to 50m deep and a variable water level was detected. Likewise, regional subsidence was identified due to the continuous groundwater pumping with a 4cm/year subsidence rate.

Therefore, the geotechnical report recommended building a deep foundation consisting of slurry walls ("Milan" walls) supported at 55m deep. As for the movement of the historical house, the use of a combination of the permanent elements of the tower and some temporary foundations that would allow the displacement of the structure were recommended [9].

3.5. Models and types of analysis

Two types of models based on finite element theory were made. The first model included a concrete waffle slab that would support the entire weight of the house and which would transfer loads to 6 points supported onto mobile hydraulic jacks. On the other hand, the second model consisted of finite solid elements emulating the stone blocks, masonry bricks, arches and slabs that form the house. Such model also included the structural elements of the concrete waffle slab used to support the house for its movement.

The main purpose of creating two mathematical models was to compare results from the two different approaches, likewise with the aim of having simple models that are easy to understand and modify if necessary. Based on the premise of preserving the structure intact, both mathematical models must ensure that principal stresses induced to the structure during all the stages of the movement would remain within the elastic range. The nonlinear behavior of the historical structure was not desired, and on the contrary, deflections (sagging and hogging) of the concrete waffle slab were limited, so, as to avoid damages on the house´s fabric [7].

In order to carry out the seismic assessment of the historical house linear elastic theory was used Earthquake Resistant Design of RCDF. To this end, a spectrum of pseudo-acceleration Vs time with the appropriate mean of recurrence of the corresponding to the seismic zone in which the project site recommended in the NTC is built. Modal spectral analysis was used to determine the dynamic response of the structure.

3.6. Load Combinations

The load combinations used for the analysis of the different load scenarios and analyses were obtained in accordance with the Complementary Technical Standards for Design of Criteria and Actions (NTCC&A-RCDF) [10]. Table 4 contains two main types of load combinations: temporary and permanent.

Table 4 Combinations loads used for structural analysis [7]

Combination	Self Weight	Permanent G_k	Variable Max.$Q_{kmax.}$	Variable Instant. $Q_{ki.}$	Accidental EQ. X +/-	Accidental EQ. Y +/-	Construction
Temporary 1	1.0	0.0	0.0	0	0.0	0.0	1.0
Temporary 2	1.0	0.0	0.0	0	1.0	0.3	1.0
Temporary 3	1.0	0.0	0.0	0	0.3	1.0	1.0
Permanent 1	1.0	1.0	1.0	0	0.0	0.0	0.0
Permanent 2	1.0	1.0	0.0	1.0	1.0	0.3	0.0
Permanent 3	1.0	1.0	0.0	1.0	0.3	1.0	0.0

3.7. Finite element model using bars

Perhaps the most challenging engineering problem the project presented was the analysis and design of a waffle slab that would support historical house that weight about 1,500T itself. This slab must not only withstand the loads from the walls and transfer them to the supports, but also must have sufficient bending stiffness to limit the maximum deflection of the slab, as even small vertical distortions would be reflected in shear forces transmitted to the unreinforced masonry walls. Its adequate design signified a great achievement as there were several constraints for the design and construction of the slab.

For instance, a 19m clear span save between supports had to be saved; the maximum depth of the waffle slab must match with the depth of the original foundation of the house and contain it. To make this possible, Engineers Rodolfo Valles and Ismael Vazquez proposed and designed a waffle slab made of high strength concrete i.e. f'c = 700kg/cm^2 of 1.75m depth and ribs of various widths within a range between 0.75m 0.35m. The use of the waffle slab provided the following advantages: proper weight-capacity sufficient bidirectional stiffness, relative lightness, ease of construction, robustness, excellent vibration control, fire resistance, inexpensive compared to other materials such as steel and high degree of durability. The model used to simulate the waffle slab with loads from the walls of the house was created using the commercial structural analysis and design software SAP2000.

This software allowed the modeling of ribs, slabs, capitals, the existing foundation, the steel brackets which will serve to lift the system slab-historical house and all the different loading scenarios

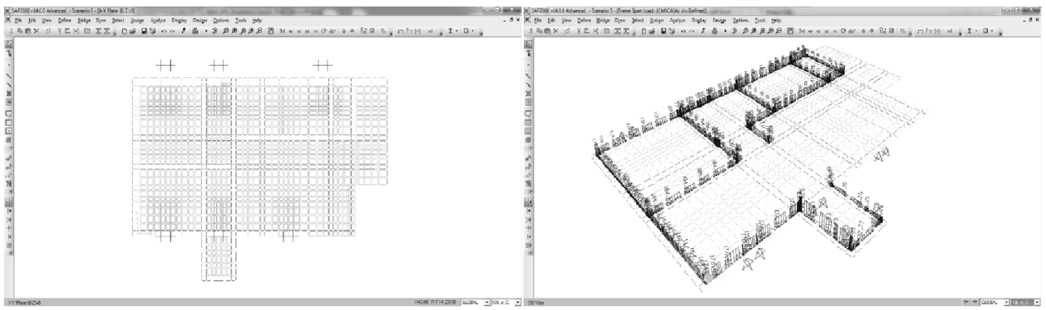

Figure 5 Bar element model of waffle slab and uniform distributed loads [7]

For the structural design of structural elements of the slab, SAP2000 post-processor in conjunction with hand calculations in accordance with the NTC - Concrete Design RCDF were used. In order to estimate the stresses in the concrete and steel beams under service loads, the elastic theory was used; this theory states that if the cracking moment (Mag) of a beam is larger than the acting moment (M_{max}), the inertia of the entire section can be used for the calculation of inertia without taking into account the steel. However, if the Mag is smaller than the M_{max}, the cracked section has to be considered for deflection calculation purposes. The following equations were used to calculate the cracked section:

The equations are as follows:

$$I_e = \left(\frac{M_{ag}}{M_{máx}}\right)^3 I_g + \left[1 - \left(\frac{M_{ag}}{M_{máx}}\right)^3\right] I_{ag} \qquad (1)$$

Where,

$$M_{ag} = \frac{\overline{f_f}\, I_g}{h_2}; \quad \text{is the cracking moment} \qquad (2)$$

Then, M_{max}, is the maximum flexural bending moment corresponding to the loads for which the deflections are being calculated;
h_2, is the distance from the neutral axis and the extreme fiber in tension;

$f_f = 0.7\,(f'c)^{0.5}$, the tensile strength due to flexure (3)

$$I_g = \frac{b * h^3}{12}$$, is the moment of inertia of the gross section (4)

Angular distortions were calculated based on recommendations provided in NTC-Design criteria and actions (NTC-C&A). The design code states that the allowed deflections in beams subjected to positive moment and wherein angular deflections may lead distortions that could damage structural elements shall be in the order of the free span/240 +0.3 mm, where L is in mm clear. Two types of deflections were of special attention due to the particular arrangement of the supports for the stage of the historical house movement. The first and the most critical was the one led by the 19m clear span approximately; while the second type was the deflection caused in the slab due to negative bending moment on the cantilever beams.

Furthermore, the NTC - Design of foundations (NTC - DC) provides that differential settlement of structures with very sensitive finishes as flattened, carved stone and others; must have a maximum angular distortion smaller than 1/1000. This value must be respected for cases that present both positive moment (Sagging) and negative moment (Hogging), ensuring not structural damage to the fabric of the house will be caused.

3.8. Solid finite element model

In order to further investigate the response of the house's fabric to the stresses that might be led by angular distortions, a model of solid elements was created with the help of commercial software SAP2000. The program is based on the finite element theory, which proposes an approximate method for calculating the response of real structures. The program performs the solution of algebraic operations of equations that represent the structure. To this end, 8-node finite elements were used and it is based on the isoparametric formulation including 9 flexural modes. The software uses numerical integration 2x2x2 and local stresses on elements are evaluated at the integration points and extrapolated to the nodes of the elements. An approximate error in efforts can be estimated from the difference between the calculated values of the various elements connected to a common node values.

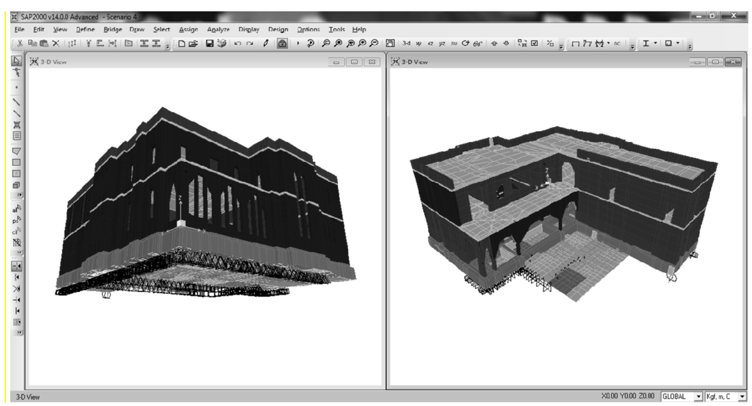

Figure 6 Finite element model of the historical house [7]

The model included all the structural elements identified during historical research and different surveys on the site´s project (e.g. masonry walls, quarry stone walls, concrete slabs and foundations made of volcanic stones). Live and dead loads were applied as surface loads on both slabs (mezzanine and roof). The mass that was used in the spectral modal analysis was obtained from both the self weight as heavy overload and dead loads calculated for the new use of the building.

3.9. Response of the structure

Four main load case scenarios were considered. Scenario 1 studied the house at its original position without any intervention. Scenario 2 considered the historical house supported on the concrete waffle slab and transferring the loads on six points to skidshoes, emulating the moving process. Scenario 3 considered the waffle slab supported on temporary piers to partially relieve weight to hydraulic equipment. Finally, scenario 4 emulated the house supported on its new foundation. The results were related to revision of the structure under different load combinations and their resulting principal stresses [7]. A thorough review of mathematical models was carried out to ensure no overstresses would be induced causing cracks and / or crushing of its fabric.

4. MOVING THE HISTORICAL HOUSE

4.1. Monitoring the structure

For purposes of control and ensure the integrity of the historical building, three types of monitoring means were carried out. The first consisted of monitoring the pressure of the hydraulic system used to raise the house; the second involved the measurement of existing cracks in the house´s fabric and finally measuring deflections at different midspans of the slab and locations where the waffle slab could show large deflection values. To this end, a specialized team of surveyors and equipment such as total stations were used to daily monitor the structure. The structure showed and appropriate behavior at all times and deflections remained within allowable limits.

4.2. Strengthening the historical house

For the process of building the ribbed slab support was necessary to expose the original foundation of the house and demolish interior floors. Necessary Earthworks to have free access to existing foundation were made. Then, the construction of the concrete waffle slab was made ensuring the existing foundation would be embedded within the new structure.

Due to the new architectural layout and an as a result of the structural analysis of the house some walls needed to be reinforcement, especially where walls would work as cantilevers. Likewise, some inner walls that did not feature special features and were mainly intended to support slabs were reinforced to provide an additional resistance against shear forces that may be induced. Additionally, steel ties surrounding the house were used to confine the fabric and enhance its global resistance.

4.3. Lifting and sliding the house

In order to select the most appropriate equipment to use to move the system concrete slab-house the reactions obtained from mathematical models. The locations of supports were strategically selected so as to ensure reactions at supports were fairly similar to use similar hydraulic equipment. To this end, the specialized company ALE Lift[6] provided expert technical support.

[6] www.ale-heavylift.com

4.4. Moving the historical house

The first stage of the movement took place with very gentle and slow movements of 80cm at the time of the temporary reinforced house. The movement was carried out with the house resting on the sliding rails. The historical house was moved a total of 18m northwest within the property with a total duration of 10 hours to complete. The house was kept out of its position for twelve weeks onto a temporary shoring system while the construction of the deep foundation of the Tower Reforma was completed. After the construction of the foundation, the house was moved back with the similar process for the first movement.

4.5. Repositioning movement and tying

For purposes of repositioning of the historical house, some structural elements such as steel trusses were embedded in the foundation elements. Once the house was back on its original position, hydraulic equipment was dismounted and the edges of the slab tied to slurry walls. The new supports would provide sufficient resistance and stiffness to withstand all static and dynamic forces that the system slab-house system could be subjected to in the future.

4.6. Additional Repairs

As a complement to the structural moving project, a restoration project of non structural elements of the house was undertaken, i.e. cleaning façades, desalination, minor repairs on carved stones, grouting cracks and fissures by means of stabilizing materials such as epoxies.

5. CONCLUSION

The moving project of the historical house Reforma has signified a great achievement not only for the Mexican Structural Engineering, but also for the preservation movement all over the world. This successful project may even impulse the protection of many other endangered historical structures throughout the country and worldwide via their temporary or permanent movement. One more time, as long as it would be the last resort and all other options had been thoroughly studied, discarded and such project even ensures an enlargement in the lifetime of the historical resource.

Worth mentioning that the solutions used were taken from rather simple principles, such as the tray precept used to move the entire volume of the house. Structural Engineering is an evolving science where today´s engineers can still learn from proven engineering principles in combination with the state of the art in structural analysis tools. Undoubtedly, engineers of modern times are not only called to resolve issues related to the design of the new structures; conversely, every day they are required to look after and when possible enhance the invaluable cultural heritage inherited from our ancestors.

On the other hand, through the decomposition of the whole process of moving the historical house, it was possible to learn the systematic procedure followed. Likewise, it was possible to note the importance of timely and reliable data collection relating to the historical structure through different means. For instance, the exhaustive historical research allowed avoid Minor Destructive Testing that could have threatened the authenticity of the heritage building and could have hindered the entire project. Similarly, the detailed description of the moving process allowed to realize the great importance of the construction of numerical models as an important tool for engineers during the decision making stage.

As for the solution adopted for this project, it is believed that the particular characteristics of the project as a whole played a fundamental role for the selection of the moving strategy. Structural designers acknowledge the necessity of the collaboration of specialized and experienced structural movers required to carry out this kind of projects in a timely fashion.

Finally, the successful implementation of this project may represent a breakthrough within the field of preservation as a viable and reliable strategy. This project might encourage structural engineers from all around the world to notice that there is always a solution that can allow the harmonious coexistence of the invaluable ancient heritage with the fast paced and modern infrastructure required in major importance cities.

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