# ENGINEERING COMPANY OF CENTRAL AMERICA

Consulting – Engineering – Supervision
Industrial Plants – Buildings – Infrastructure

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# NEWSLETTER

## Torre Futura – World Trade Center III, San Salvador – Structural Aspects

### 1. INTRODUCTION

World Trade Center III "Torre Futura" has been built on the slopes of the volcano of San Salvador, one of the most beautiful locations of the Salvadorian capital, joining an existing facilities complex that combines offices, a hotel and a convention center.

The structural design and supervision of this important project was developed by EC in strict compliance with national seismic design legislation, the design code for concrete construction of the American Concrete Institute "ACI-318" and the American Uniform Building Code (UBC), which is an international design standard widely recognized for its thoroughness and technical consistency.

The World Trade Center III project, "Torre Futura" in San Salvador, has a 20 level tower with a total height of over 90 m. Annex to the Tower, as part of this development, the project includes a parking building of 6 levels, on which stands a square with gardens and commercial premises. Both buildings form an architectural functional unit, but are designed to act as two independent structural bodies. The complex has a total area of 65.000 m$^2$ of construction, achieved with a volume of approximately 30,000 m$^3$ of concrete and 5000 tons of reinforcing steel. The average area of each office floor exceeds 1300 m$^2$. The casting of the foundations of the tower began in early December 2007, the casting of roof slab ended in November 2008. The opening event of the facilities was held on December 1, 2009.

This success reflects undoubtedly the effort of a multidisciplinary team that includes companies and professionals committed to quality and excellence, all guided and inspired by the clear vision of Agrisal Group to make this project an architectural icon with unprecedented engineering standards in El Salvador.

***Fig. 1*** *Digital Editing Views (top),* ***Fig. 2:*** *Photos during construction (center) and* ***Fig. 3:*** *Final photos (bottom) of Torre Futura, WTC III, San Salvador, El Salvador.*

### 2. ON SITE STUDIES

A widespread campaign of standard penetration tests and rotary drilling on natural terrain was conducted. Because of its proximity to the volcano, heavy rocks at surface level were detected in the project area.

In addition to the standard drilling tests, geophysical surveys were performed to confirm the foundation levels and general characteristics of the soil. As a result of the on-site studies, the rock strata on which the foundations of the tower are based was accurately characterized. Seismic refraction trials were conducted as well as Multichannel Analysis of Surface Waves (MASW). The shear wave velocities measured at foundation levels reached 840 m/s, a value that indicates suitable rock for shallow foundations.

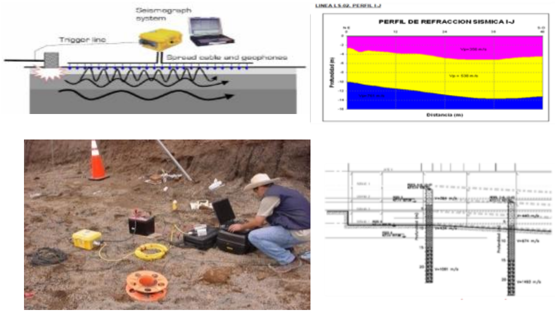

***Fig. 4:*** Geophysical testing (seismic refraction and MASW) at the project site during planning and design phases.

## 3. FOUNDATIONS SYSTEM IN “TORRE FUTURA”

The soil characteristics determined the chosen foundation type. The existence of a relatively hard soil layer (located at the foundation base), enabled the design of shallow foundation using a bearing capacity of 28 tons per square meter. The maximum axial load in columns exceeded 3500 tons and overturning moments under seismic conditions are over 2 million tons-meters. As consequence of the fact that all high-rise buildings have relatively few vertical elements (columns and walls), the foundations receive large magnitude loads concentrated in small areas.

The above leads to the selection of foundation systems that control the punching shear forces (two-way shear) and differential settlement. For Torre Futura, several options were investigated, such as large diameter piles and foundation beams combined with isolated footings. The final choice consisted in a 1m thick slab system (mat foundation) combined with square concrete caps at the base of the vertical members (total thickness up to 2 m).

This system allows a uniform distribution of the pressures caused by high seismic overturning moments and an optimal control of the high vertical two-way shear forces (punching effect); in addition, it reduces the volume of concrete by 15%, compared to the other systems which were considered.

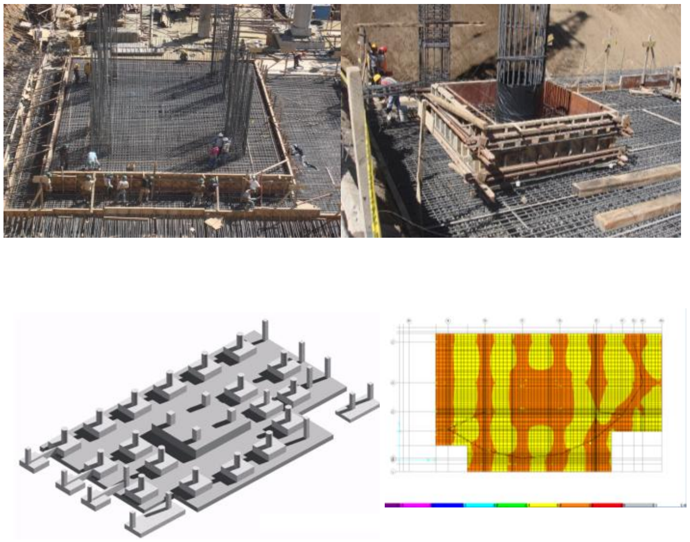

***Fig. 5:*** Construction of foundations. Top: slab with square caps in the structural core area and a main tower column. Bottom: schematic overview model of the main columns at foundation level.

## 4. MAIN STRUCTURE OPTIONS FOR HIGH-RISE BUILDINGS

### 4.1 SEISMIC DESIGN STRATEGIES

There are two general strategies for the seismic design of building structures in seismic zones:

I. Behavior within the elastic range:

Using this approach, structures are designed to resist the earthquake actions elastically. This is achieved by the use of unreduced seismic forces which necessarily conducts to the use of either massive structural systems or the introduction of base isolation devices. The aim of base isolation systems is to increase natural period of the structure. Therefore, this latter method has shown to be effective when applied to low-rise buildings.

II. Behavior within the post-elastic range:

This approach allows elastic behavior for frequent earthquakes (low to moderate intensities) and requires the use of post-elastic (plastic) deformations to dissipate the energy induced by strong, non-frequent earthquakes (such as the design earthquakes prescribed by norms). When considering the occurrence of large earthquakes, it is permitted to apply reduced seismic forces in combination with the controlled occurrence of post-elastic deformations. The local and overall stability of the structural system must be granted in any case.

### 4.2 STRUCTURAL SYSTEMS FOR HIGH-RISE BUILDINGS

In terms of structural engineering, a building is considered as being tall when its design is ruled by the lateral displacements and vibrations (acceleration) caused by wind and earthquakes actions. Therefore, as the buildings grow in height, the main challenge for the structural designer consists in controlling lateral displacements whilst granting comfort to the users by keeping acceleration (vibration) in the building at acceptable levels.

It is a common international practice to use wind tunnels to predict the behavior of buildings over 40 levels or those with particular slenderness. In some cases of slender structural systems, the only way to control vibrations or large lateral displacements is through the use of damping systems, placed at strategic locations of the structure. The design of a tall building requires a close interaction between the architect and the structural designer from the early stages of the project. Both disciplines are critical for achieving an optimal solution (in terms of cost, safety, functionality and building aesthetics). Figure 6 summarizes the typical structuring systems for tall buildings.

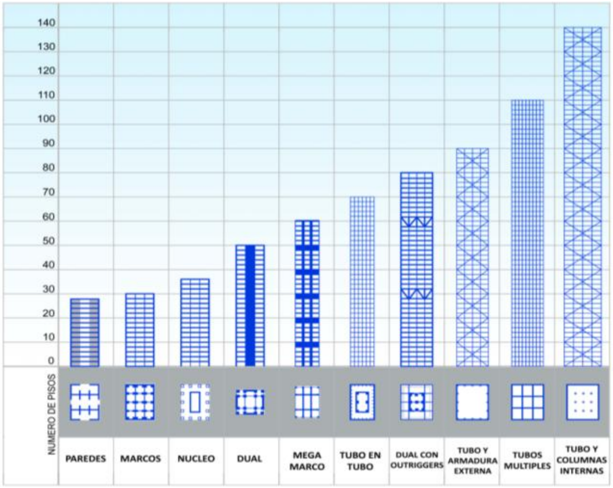

***Fig. 6:*** *Common structural systems for tall buildings.*

As shown in figure 6, there are different options for structuring a tall building. Selecting the most appropriate is case-specific and is achieved through both interactive and iterative processes that combine functionality with technological and economic feasibility. It should be noted that the enormous forces developed in the structures of this type (for example: for a column in a building of 40 levels the axial load can be 5000 ton on the lower levels), require to use high strength materials (concrete with a compression resistance above 700 kg/cm$^2$) and special construction details for shortening control in vertical members (columns and walls). This accounts especially for the case when composed systems (e.g. metal and concrete) are used.

### *4.2.1 Structure for buildings up to 20 levels.*

From the standpoint of structural performance, buildings with less than 20 levels (up to approximately 60m in height) can be efficiently solved with the use of reinforced concrete shear walls or central rigid core as the only lateral resistance systems. In some particular cases it may also be feasible to use reinforced concrete frames in spatial arrangement. The biggest constraint for the use of shear wall systems is their impact on the building's functionality. The use of shear walls requires numerous permanent walls that start from the foundation of the building. This creates serious conflicts with the parking lot and vehicular circulation on the lower floors and open spaces on the upper floors. The solely use of rigid core systems may lead to loss of comfort due to high vibrations at heights greater than 50m. The space frame system alone usually does not comply with the limits of lateral drift required by norms for earthquake prone regions, particularly for steel frames.

### *4.2.2 "Dual system" Structures*

The structural system known as the dual system is appropriate for most cases of buildings of up to 50 levels. This requires the use of shear walls (structural walls prepared to withstand high forces in its horizontal plane) combined with spatial frames (columns rigidly connected with beams arranged in a three-dimensional arrangements).

In high seismic risk zones, special provisions for the detailing of connections and critical areas of the structure are required by applicable norms. Dual systems combined with outriggers (6m high) strategically located at different heights of the building allow efficient solutions for structures around 80 levels, controlling lateral drift and absorbing external tensions.

## 5. EARTHQUAKE-RESISTANT DESIGN OF WTC III (TORRE FUTURA)

The structural solution applied for WTC III is of the "Dual system" type, consisting of combined structural shear walls with reinforced concrete frames, each with special detailing. The special detailing for shear walls, interconnection beams, columns, main beams and connections, was performed in strict compliance with the special seismic design provisions of the ACI-318 (American Concrete Institute) chapter 21. The aforementioned chapter contains proved guidelines to achieve ductile behavior under the actions of severe earthquakes. The implemented ductile design for WTCIII implies that even under the occurrence of seismic events greater than the design earthquake, the structural system must remain stable and able to dissipate the seismic energy through controlled plastic deformations.

**Fig. 7:** *Views of different stages of construction*.

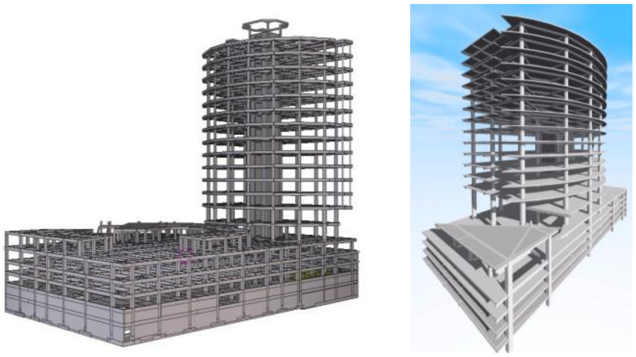

***Fig. 8:*** Isometric view of the WTCIII structural system. It consists of structural walls, combined with reinforced concrete frames, (dual system) with special ductile details in critical member zones.

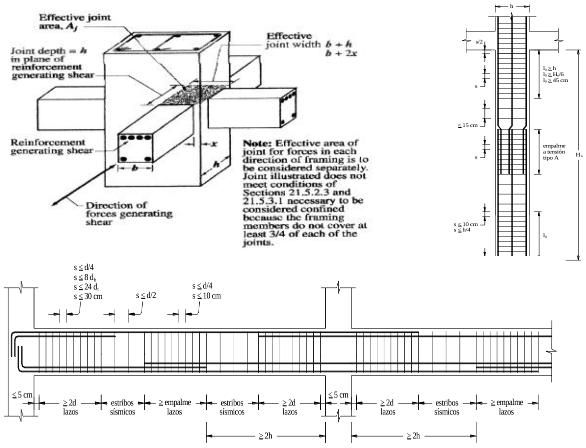

***Fig. 9:*** *Special ductile detailing for main members and connections.*

To obtain the design's seismic forces (according to local regulations), acceleration on rock of 0.40g multiplied by an amplification factor of 2.5 was used. The applied seismic coefficient was 0.04, which means that 4% of the seismic weight (self-weight of the building, facilities and expected occupancy during an earthquake) was applied as a static horizontal force to simulate the effect of inertial forces generated by earthquakes. The seismic weight of the tower resulted in approx. 38.500 tons and the static force at the base are approx. 1.500 ton. In addition, a linear dynamic analysis was carried out (modal spectral) to evaluate the dynamic behavior of the system. The results obtained from the dynamic analysis were the base for the design, after the application of safety factors obtained from its relation to the static method as required by the local standard. The computed structural elastic natural period was 3.6s and the natural period in a stage of resistance resulted in 4.1s (considering cracked sections according to the norms). According to the local code, the natural vibration period for calculating the seismic forces is limited to 1.8 s, which implies the inclusion of additional safety factors compared to other regional standards.

The maximum amplified relative displacement (drift) under the action of combined seismic and gravity loads was 3.7 cm, a value that is lower than the permissible limit of 6.7 cm. High strength concrete was used for both, structural shear walls and columns. At lower levels, concrete strength of shear walls is above 550 kg/cm$^2$ with a thickness of 60 cm. In the columns strength is 450 kg/cm$^2$ with a diameter of 130 cm. At higher levels the concrete strength of shear walls and columns were gradually reduced to 280 kg/cm$^2$. For these upper levels, the thickness of the walls was gradually decreased with height from 40 cm to 30 cm, and diameters of the columns from 110 cm to 90 cm respectively. The slab system's concrete has a compressive strength of 280 kg/cm$^2$ and a thickness of 18 cm.

## 6. VERIFICATION AND PROJECT CONTROL

As an additional design control tool, the "Push-Over" analysis method was used to simulate the conditions of collapse against incremental horizontal loads; this in order to evaluate the local capacity to dissipate seismic energy in the critical areas and overall performance of the building to severe seismic loads. This analysis allowed the evaluation of the seismic performance of different alternatives for the definition of the structural system during the pre-design stage.

The aforementioned method was also used to verify the impact on the structural behavior due to changes originated during the construction process. For the quality assessment of structural concrete, in addition to standard laboratory tests, a systematic monitoring of Non-Destructive Tests (NTD) was implemented. By means of NDT Testing the consistency and strength of the main members of the structural system was confirmed during the construction stage. More than 1500 NDT distributed throughout the entire structure were performed.

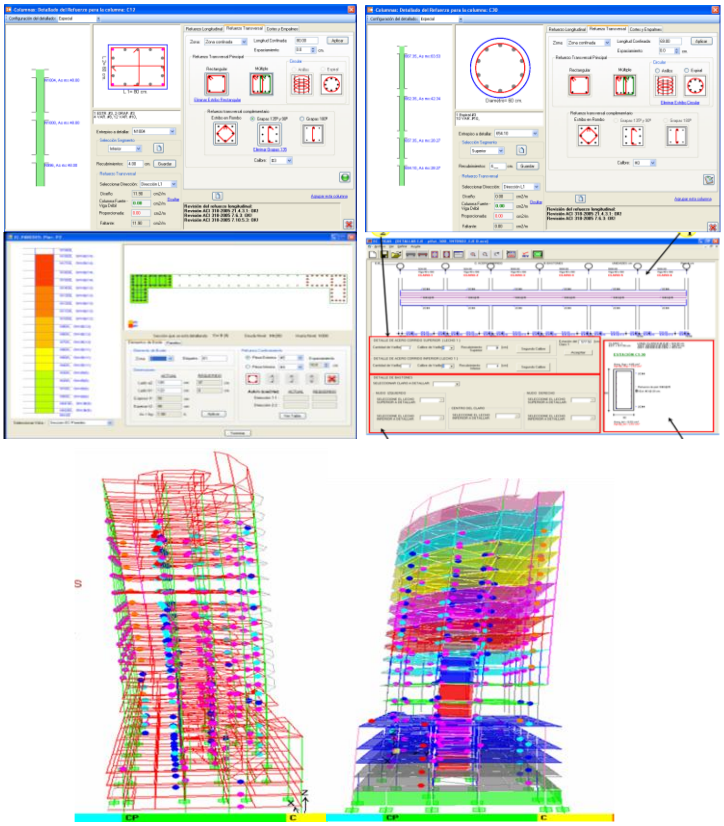

***Fig. 10:*** *Software tools developed by EC for special detailed ductile structural elements of tall buildings and views of the models used to simulate violent earthquakes.*

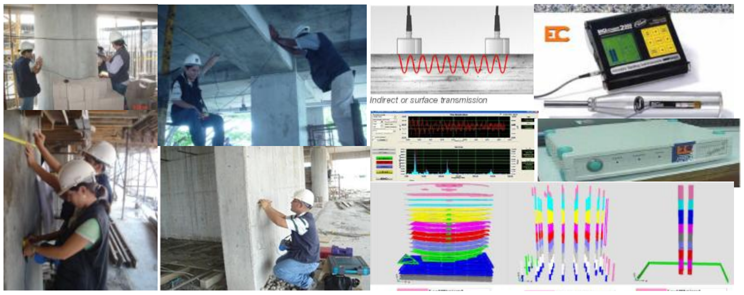

***Fig.** 11Views conducting non-destructive testing during construction.*

***Fig. 12****Views of EC's technical team members who participated in WTCIII*