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Pelli Tower in Sevilla: A new concept in the building architecture

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ABSTRACT:

Pelli Tower is being built in the City of Sevilla. A new concept of building Architecture is born. Singularities are being described in the article: structural typology, materials, loads considered in the calculations (seism and wind tunnel Test), and construction methods used in the execution.

A list of the main quantities used in the Pelli Tower is included to emphasize the importance of the execution.

Keywords: Tower, slabs, metallic roof, wind tunnel test, seismic study

1. INTRODUCTION

This article describes the main characteristics of the structure of the Pelli Tower that was erected in the City of Seville, in the Autonomous Community of Andalusia, Southern Spain.

This article deals with the architectural project currently being carried out, the structure of which now completely finished.

The text includes a brief description of the project to help familiarise the reader and also details the main issues of interest relevant to the project of the tower's structure.

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2. GENERAL DATA

The Pelli Tower is part of the project being carried out by the “Puerto Triana” Tertiary Services Centre, in a plot measuring approximately 350 x 110 m2, on the Island of the Cartuja, to the West of the historic centre of Seville.

Figure 1: *Map of the city of Sevilla with the Project location*

The project is situated on the old stream of the river, which was modified in a series of works in order to protect the city from floods.

Figure 2: *Comparison between the different streams of the river*

In 2006 the Owner held a competition in which six internationally renowned teams of architects participated. The proposal presented by the Pelli Clarke Pelli Architects Studio won the competition, with the architect César Pelli as project leader.

The project includes a high-rise building, whose ground floor occupies an area of approximately 1500 m2. The rest of the building works included in the project occupy around 36,000 m2 in ground floor space and have a maximum height of 3 floors in a limited area.

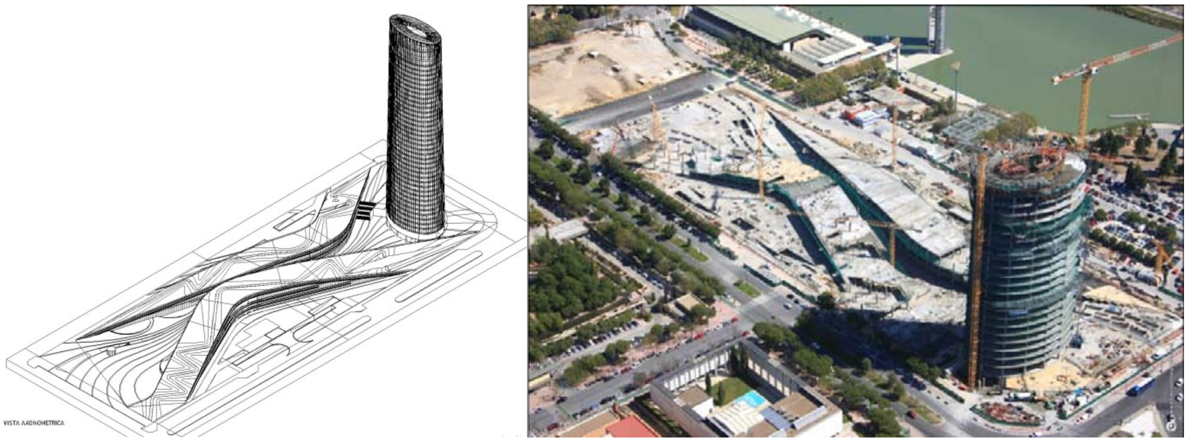


Figure 3: *General view of the construction. Panoramic view.*

Regarding the structures, the area of the floor slabs (foundations not included) measures approximately:

- Tower: 53,000 m2.
- Rest: 152,000 m2.

The project deals with a tower 180 m above ground, with four basements that add around 17 m. To date, it is the highest building to be erected in Andalusia.

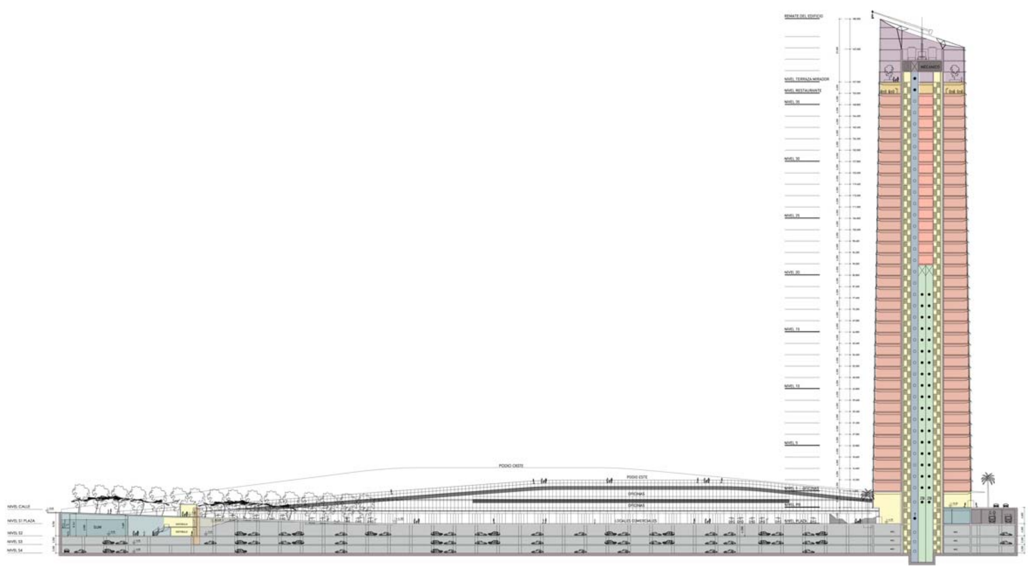


Figure 4: *Longitudinal section of the whole Project.*

3. GEOMETRY

The perimeter of each floor of the building is oval shaped (two curved radii), each floor slab at an equidistance (6 cm) from the lower slab, so that the building tapers as its height increases.

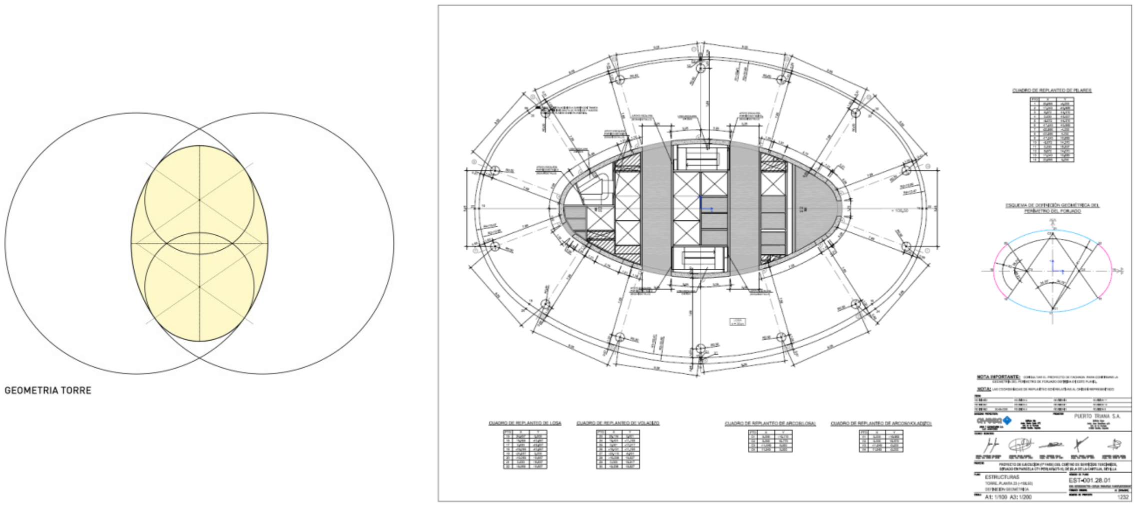
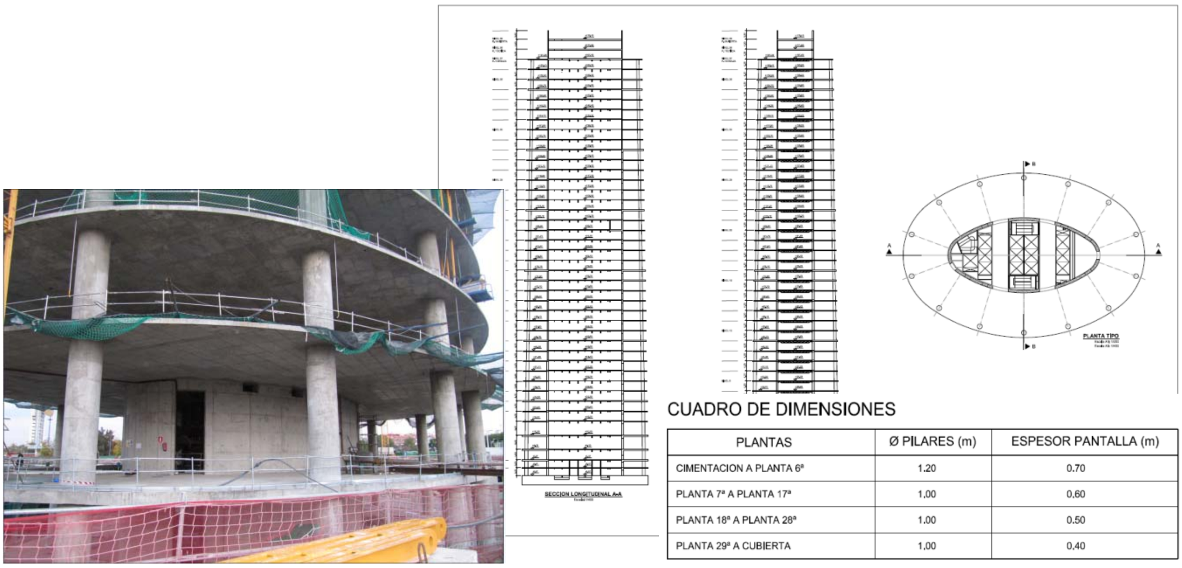


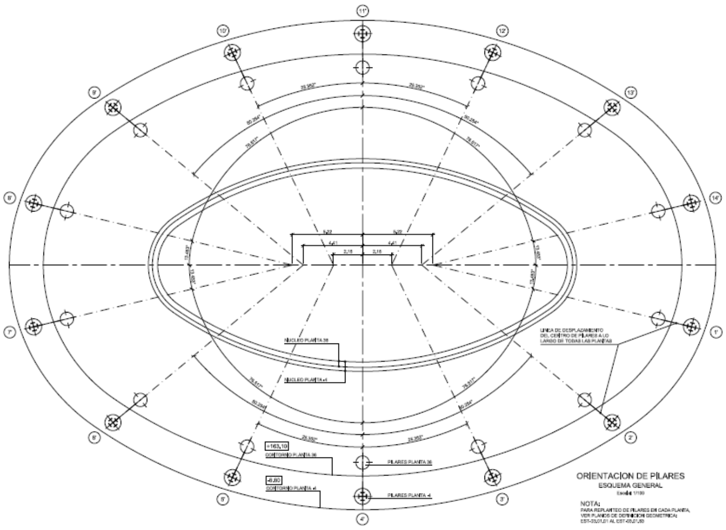
Figure 5: *Example of a geometrically.*

The vertical elements that the floor slabs support are a central interior core and 14 perimetral columns:



PLANTAS	Ø PILARES (m)	ESPESOR PANTALLA (m)
CIMENTACION A PLANTA 6ª	1.20	0.70
PLANTA 7ª A PLANTA 17ª	1.00	0.60
PLANTA 18ª A PLANTA 28ª	1.00	0.50
PLANTA 29ª A CUBIERTA	1.00	0.40

Figure 6: *Column´s geometry.*



The columns are "dual sloped" in order to adapt to the geometry of the façade:

The tower's foundations are deep, consisting of 4 m high pile caps supported by two concentric rings of screens measuring 28 m deep (equivalent to the height of a conventional building of over ten floors) achieving a total hinged in the resistant marlstone layer, typical of Seville's substratum.

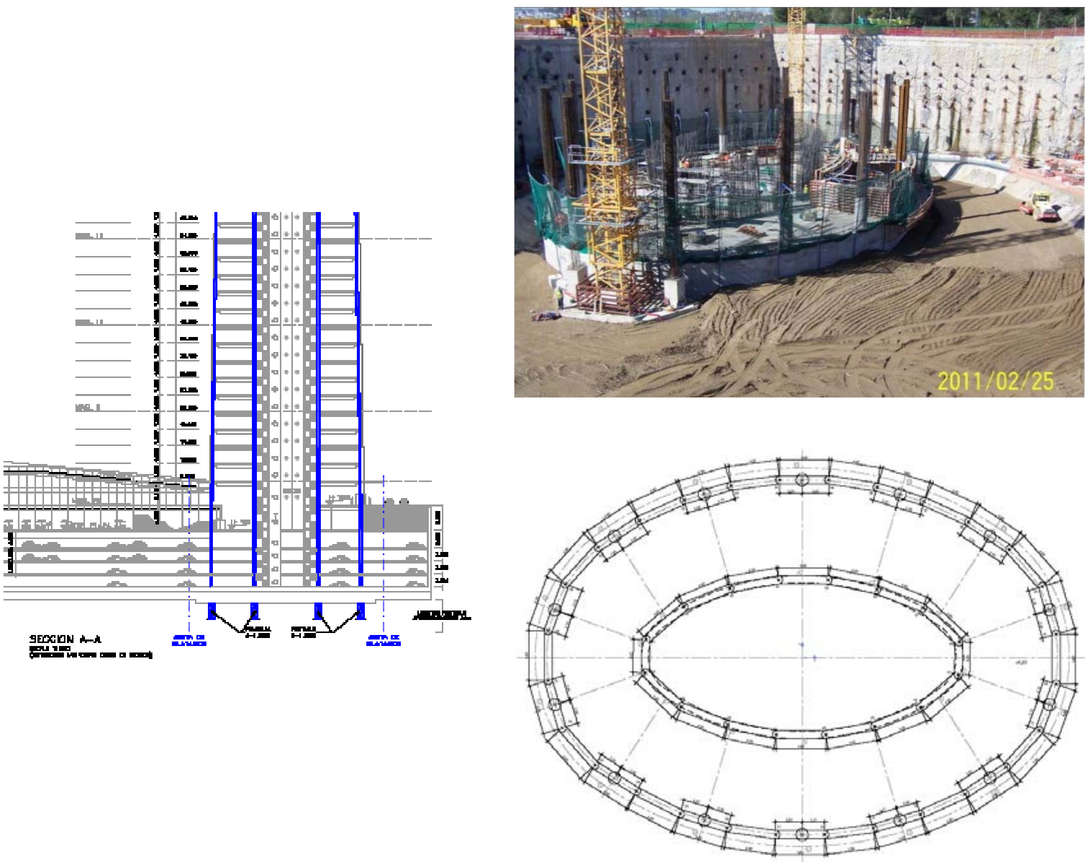


Figure 7: *Tower´s foundations drawing.*

The tower will have a sloped roof, solved with a metallic structure.

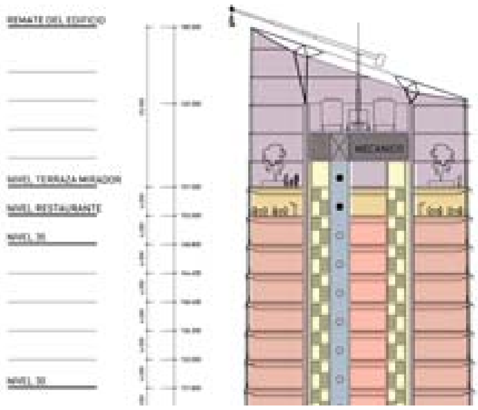


Figure 8: *Sloped roof.*

4. STRUCTURAL TYPOLOGY AND MATERIALS

The structural framework described is good for this structure type, displaying two interesting characteristics:

- Interior core that provides strong resistance from horizontal wind and seismic forces (important in this kind of building), situated at the symmetrical centre.
- Laid out vertical elements (columns and core) to avoid imbalanced span and excessive inclination in relation to the vertical slope.

The main material used is reinforced concrete. A metal structure is employed in the interior slabs of the core and in the upper roof.

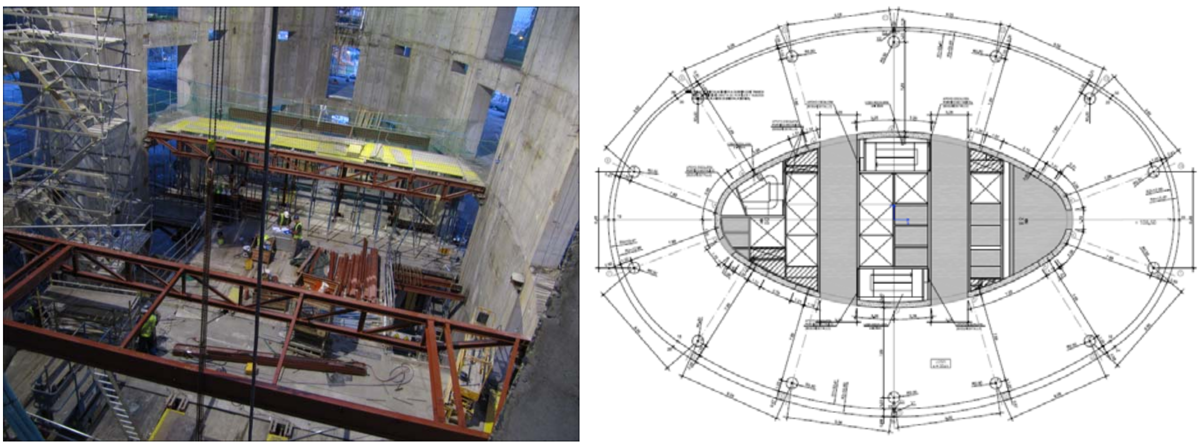


Figure 9: *Detail of the interior slabs.*

At the Preliminary Design Stage several structural solutions were considered. Indeed, for the slabs on core's exterior, the option of a metallic structure was suggested and then ruled out because of the following disadvantages it implied for this specific case:

- Need for more thickness on the slabs in order to resolve the structure because of the difficult design of the real architectural heights and the spatial requirements for the facilities;
- The reduction of the perimeter because of the slabs due to the height and the "dual sloped" of the columns meant that it would be impossible to apply type details, due to the variability of the lengths and the union angles with the core,

On the other hand, some of the known advantages of reinforced concrete are:

- Better behaviour when exposed to fire
- Better behaviour when exposed to terrorist attacks
- It requires less maintenance

However, the use of this material requires a heavier structure. For this reason, in order for the structure itself to weigh less and to maintain the dimensions of the columns to a desirable degree, two special kinds of concrete are employed in the project:

High resistance concrete (RC-65) in the columns on the lower floors, which allows to get a higher degree of resistance in case of equal section;

Lightweight aggregate concrete (LAC-35) floor slabs which allows for a reduction of the structure's weight, thus reducing the strain on the columns, core and foundations.

5. HORIZONTAL ACTIONS

5.1. Wind

Given that we are dealing with a high- rise building, a study was carried out on wind forces. To achieve this, wind tunnel tests were conducted by the University of Ontario (Canada).

Tests were carried out on two models:

- Tower complex – surroundings, to the scale of 1: 400
- Roof tower plus five floors, to the scale of 1: 65

Varied information was obtained from these tests:

- Pressures on the façade and wind loads to apply to the structure
- Comfort study on higher floors (maximum acceleration)
- Comfort and pedestrian safety study in the surroundings
- Wind loads on the metallic roof

Pressure was measured in a total of 243 points of which 110 were distributed in the podiums (low-rise buildings).

Figure 10: *Wind tunnel test.*

The entire project includes a pedestrian street between the low-rise buildings (podiums), with a similar configuration to the commercial streets in the centre of Seville. This street, of variable width, has some of its endpoints located at the base of the tower. The wind tunnel tests allowed for a comfort and pedestrian safety test of this zone's users to take place, based on wind velocity and its period of re-occurrence.

To do so, velocity measures were taken at 26 points in total.

Table 1. Criteria that establish Levels of Comfort and Pedestrian Safety based on the probability of the occurrence of determined wind velocities (Kapoor et al. 1990).[1]

CRITERIA	DESCRIPTION	AVERAGE VELOCITY EXCEEDED 5% OF THE TIME
Comfort Level 4	Recreation, reading, leisure	4 m/ s
Comfort Level 3	Short recreational use	6 m/ s
Comfort Level 2	Walks	8 m/ s
Comfort Level 1	Transit	10 m/ s
CRITERIA	**DESCRIPTION**	**AVERAGE VELOCITY EXCEEDED ONCE A YEAR**
Safety Level 2	Safe all the time	15 m/ s
Safety Level 1	Safe only in good weather	20 m/ s

The results were satisfactory and did not involve the need to change the initial architectural designs.

The acceleration experienced by users of the tower, as a consequence of wind forces, was also studied. The findings indicate that highest acceleration, 7.8 thousandth of gravity, occurred at the points corresponding to the semi-major axis of the higher floors. This maximum acceleration, below 10 thousandth of gravity, with a return period of ten years, is below the usual limits applied to this kind of building, even for residential use:

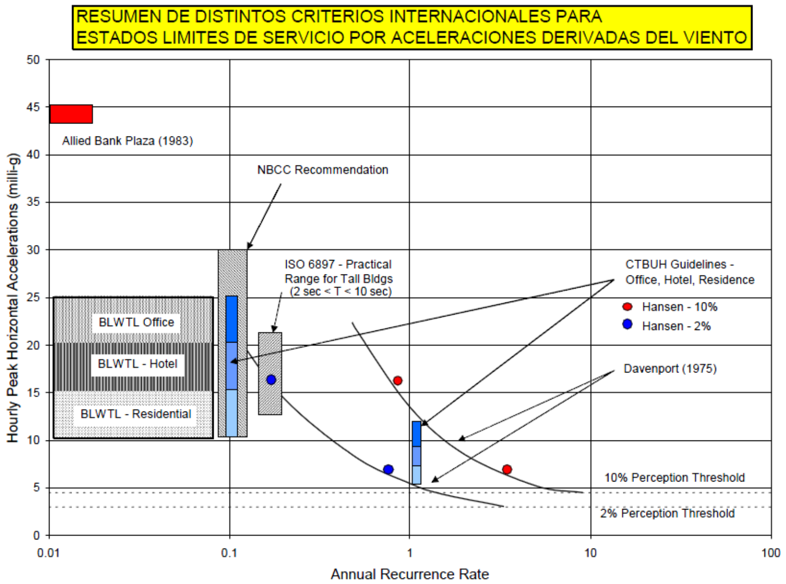


Figure 11: *Various wind-induced Acceleration Criteria (J. Kilpatrick).*

Special attention was also paid to the wind action on the roof of the tower, being an open, lightweight structure, situated in the highest part of the building.

Pressures were applied to more than 170 points of the higher, lower, rising etc. areas. The estimation of the forces and moments was made based on the integration of the temporary series of local forces in each one of the tributary areas in which these areas are divided. Based on the obtained results, the most unfavorable loads are estimated to be (maximum and minimum peak values):

- Total moments around six axes, three in each direction
- Support loads (vertical) and dragging (horizontal) more unfavorable

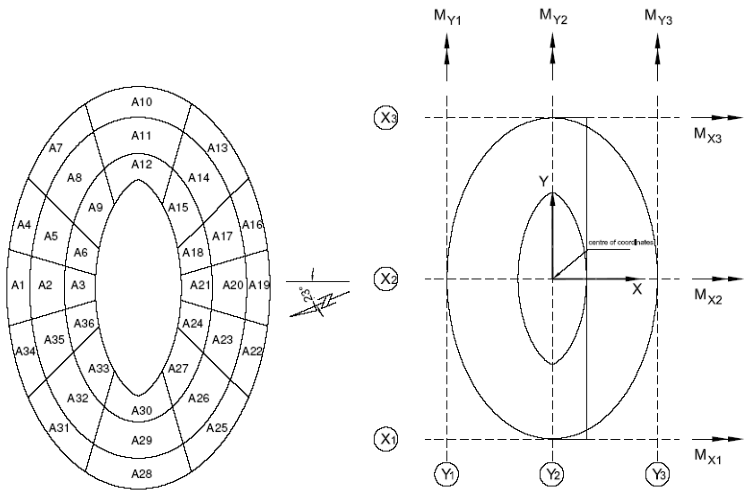


Figure 12: *Estimated Loads.*

5.2. Seism

Regarding seismic action, a modal spectrum analysis was conducted, recording seismic forces, consequently reinforcing them.

The results of the calculation demonstrate that the preferred structural system (rigid core situated at the centre of symmetry) is more than sufficient to support the relevant seismic action in Seville. It should nevertheless be pointed out that seismic action in Seville is of low intensity, not being in anyway comparable to the seismic action in other parts of the world, such as Japan, Mexico City or the West coast of the United States.

6. CALCULATION MODELS EMPLOYED IN THE PROJECT

Different calculation **software packages** were employed mainly based on the **finite elements** theory [2], in order to obtain a complete, detailed and reliable modelling of the behaviour of the **structure**, its **foundations** and the **land** supporting it.

For the **pre-dimensioning** of the structure, simplified models and manual calculations were made which allowed for approximate knowledge of the behaviour of the structure complex and the necessary dimensions for the different structural elements.

In the first calculations, some simplifications were made, such as simulating the central core, using a simple bar with the relevant geometrical and mechanical characteristics.[3][4][5]

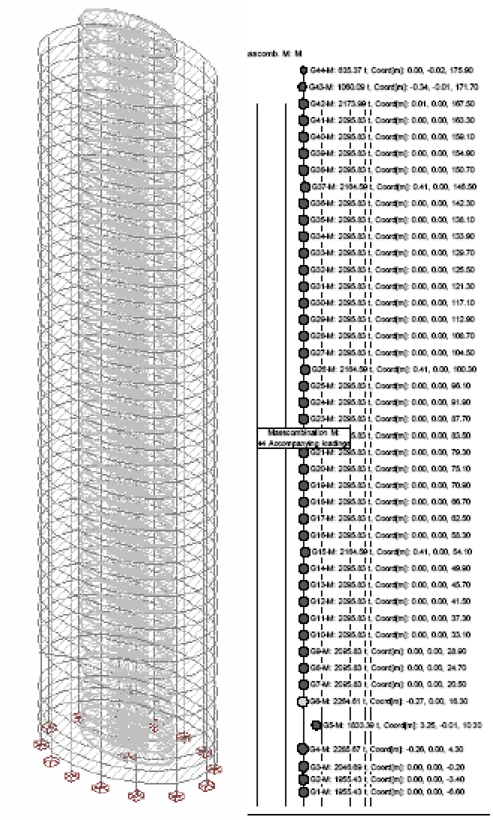


Figure 13: *Global model for pre-dimensioning*

For the calculation of the structure, a complete modelling of the tower was carried out using the calculation programme Ansys.

Various calculations were made on this model: subjected it to gravity loads, seisms, wind (from the results of the wind tunnel test). [6][7][8]

The forces in the core were obtained from the main model, that involved macro post-processing using a calculation sheet to define the needs of the reinforcing needs of the areas and to identify the areas with the most needs, in order to study them separately and in more detail, as is the case of the lintel over the doors:

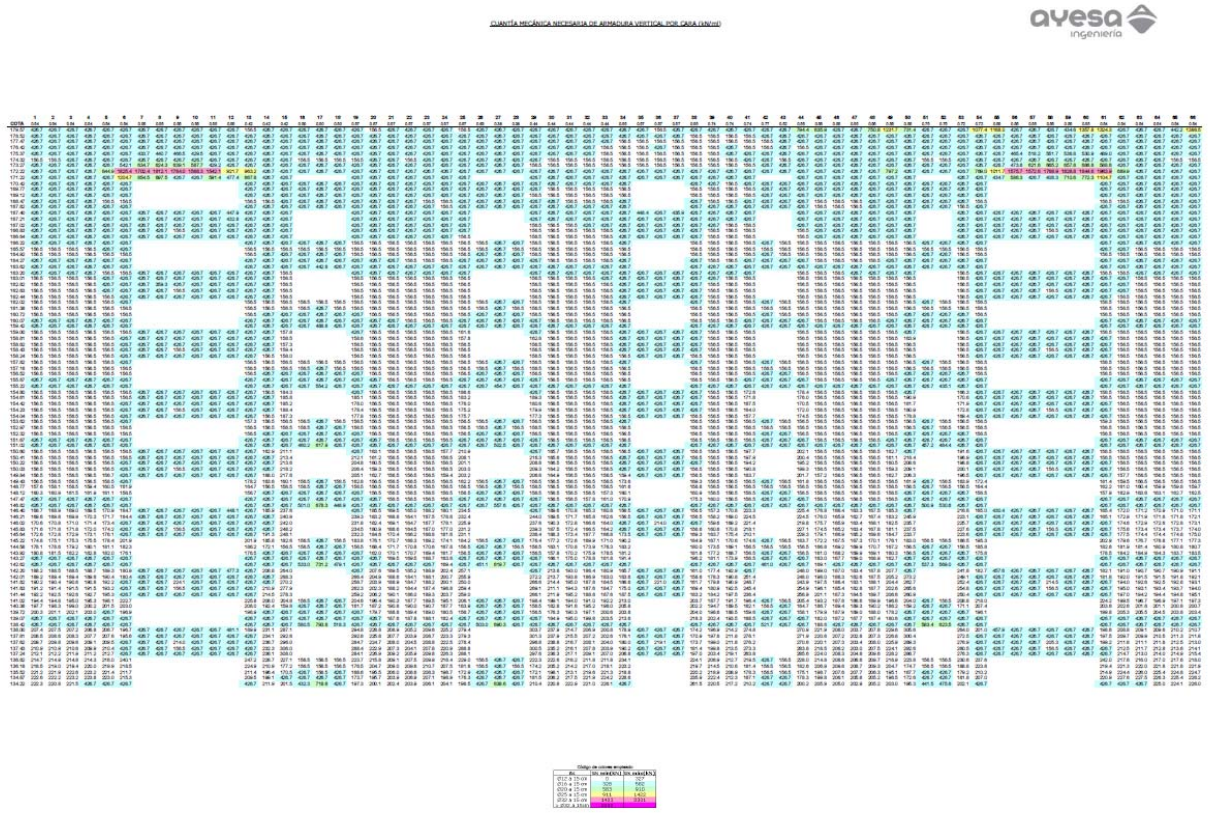


Figure 14: *Design of the lintels over the doors.*

In addition to the main model, local models were also made, for example those employed to analyses the force received by the floor slabs, by means of the finite element programme SAP2000 or those models used for the calculation of the roof.

A specific calculation model was also made to analyses the foundation and the soil-structure interaction.

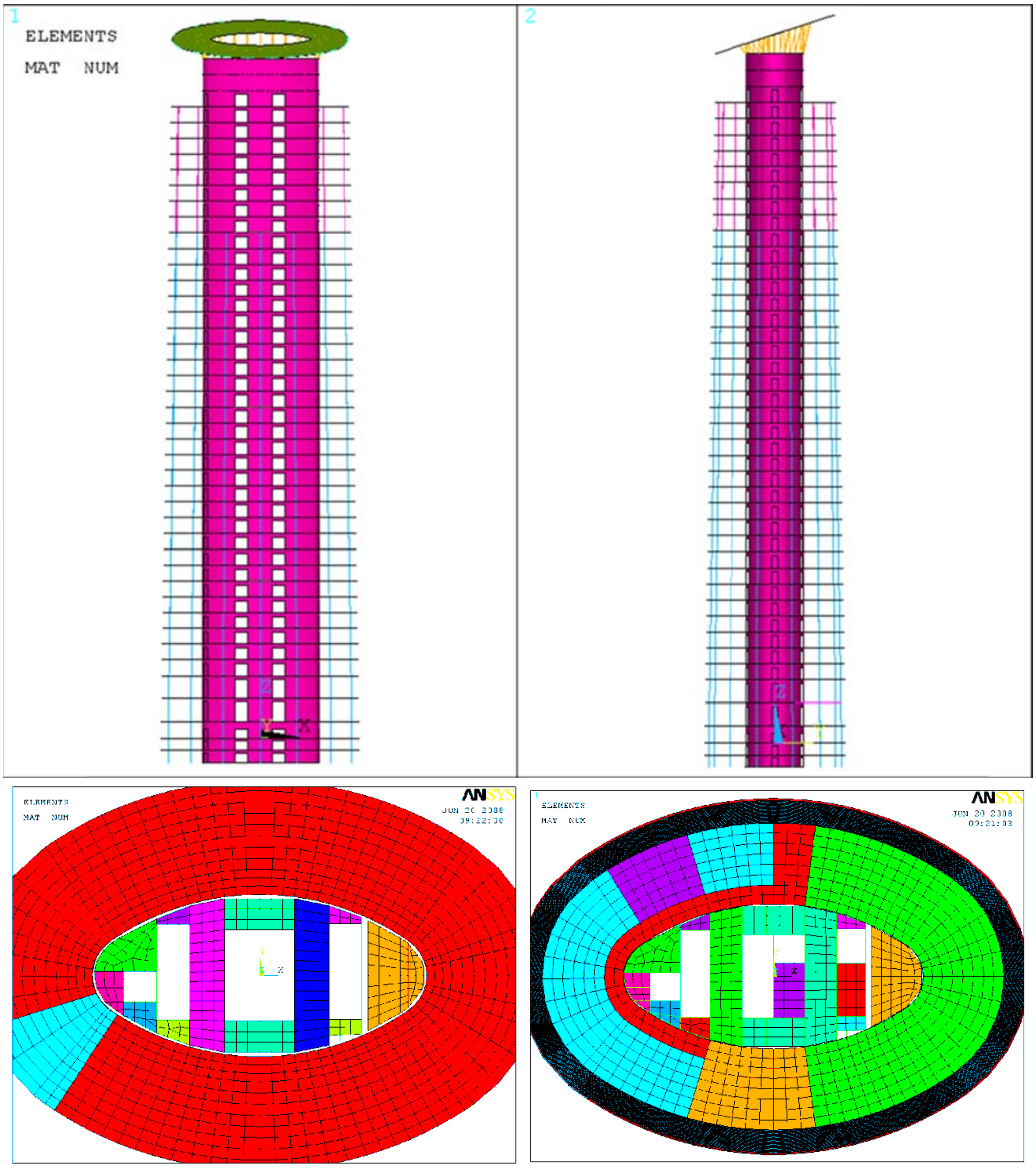


Figure 15: *Global model (distribution of gravity loads to the floor slabs).*

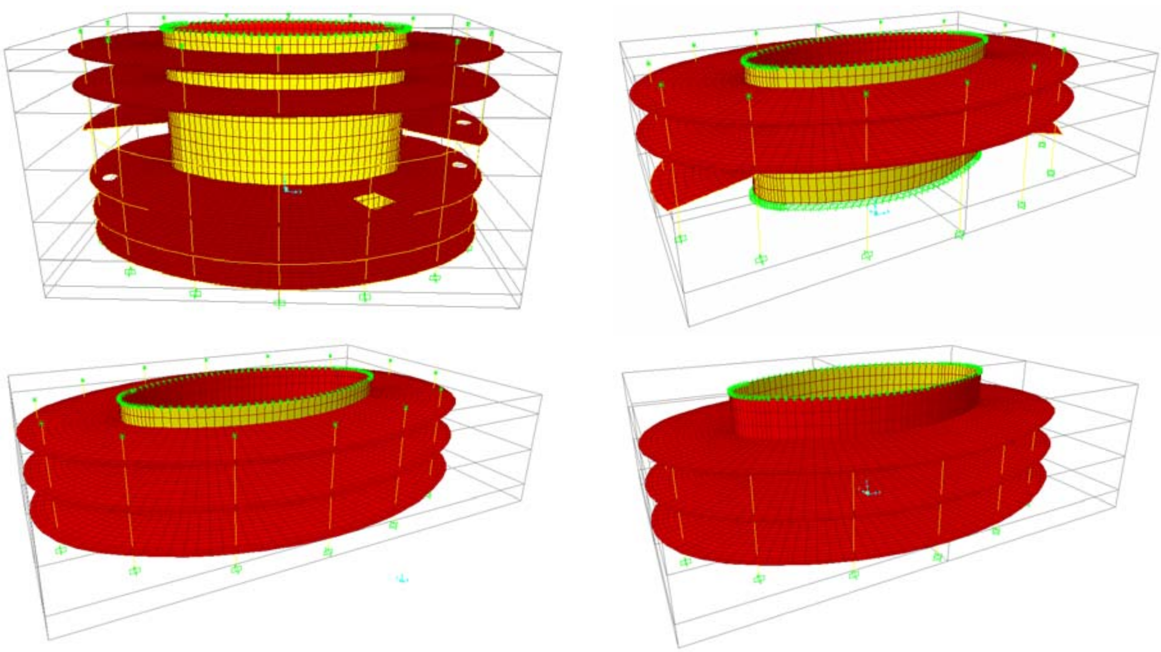


Figure 16: *Local models for the calculation of floor slabs*

The calculation of the foundations was performed in parallel to the calculations of the tower structure, so that the interaction of both elements (transmission of loads and compatibilisation of deformities) was updated in the two calculation process at every moment.

For the calculation of the foundations, various models were made using the programme FLAC 3D, allowing the simulation of the structure and the adjoining ground in one single model, thus permitting the simulation of behaviour as a whole (interaction) of the two parts.

This software is based on the finite differences method, which makes it possible to take into account issues such as the nonlinear behaviour of the material and the construction process.

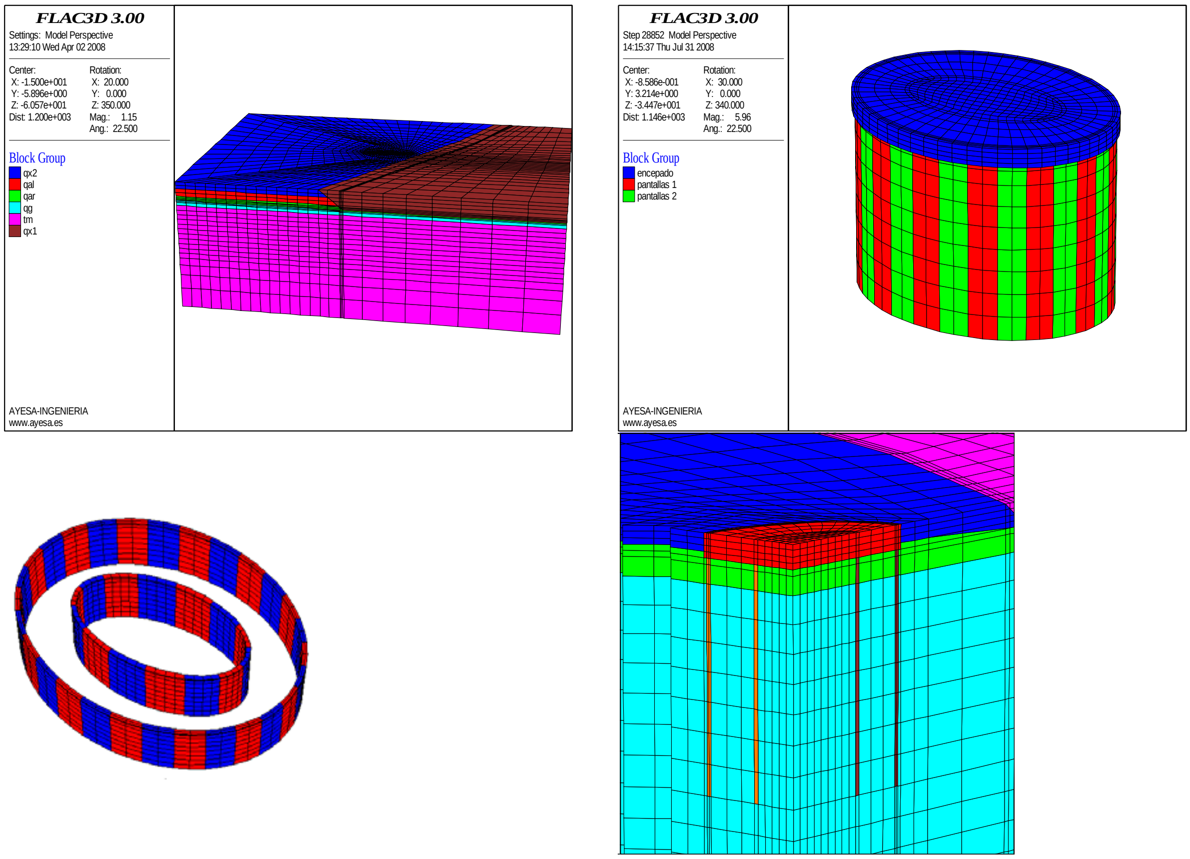


Figure 17: *Simulation of the structure and the adjoining ground in the single model in FLAC 3D.*

7. OTHER CONSIDERATIONS TAKEN FROM THE CALCULATION

7.1. Relative shortening columns- core

Additional calculations were made on the models, such as the study of the relative shortening between the columns and the central core. In this case, this relative shortening is cushioned, eliminating its effects, by:

– Keeping the column section in the upper third of the tower so that tensions from working on the columns are relatively low.
– Employing mixed columns (metal profiles embedded in concrete) on the lower floors, which in addition to increasing the resistance of the columns; reduce the shortening of the latter.
– Correcting deviations during the execution of the tower thanks to the construction process.

7.2. Column- slab nodes

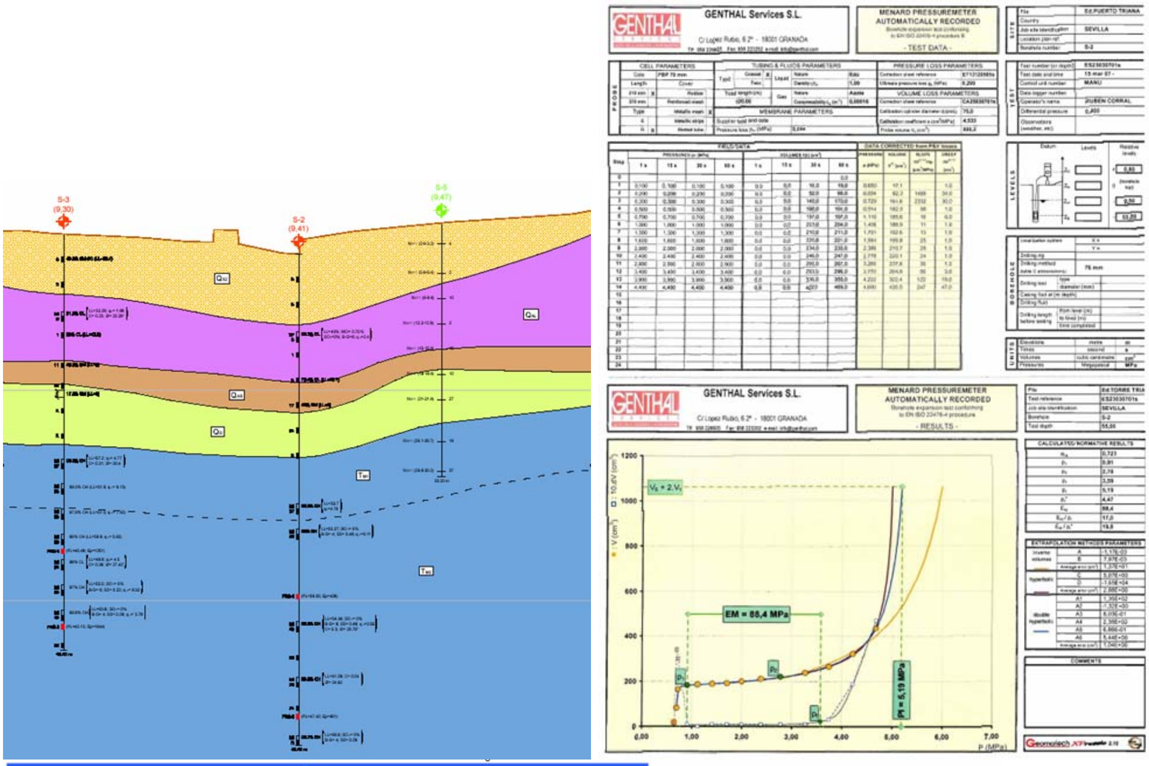
Due to the employment of high resistance concrete with fck= 65 MPa in the columns of the lower floors, and lightweight concrete with fck=35 MPa of the floor slabs, a detail was defined in the Project in which the section of slabs that define the intersection column- slab node is encased in concrete first, using concrete with similar characteristics to those of the concrete columns.

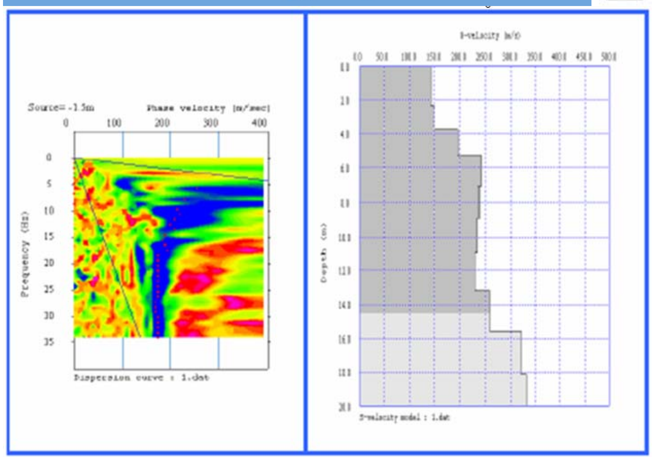
On the other hand, to guarantee complete concrete- steel behaviour in the columns of the mixed section, wielded connectors were employed in the wings of the profiles.

7.3. Geotechnical campaign

For the correct simulation of the properties of the terrain, a wide- reaching, geotechnical campaign was carried out, including surveys that reached around 60 m deep.

Special studies were performed, such as seismic studies of surface waves through passive and active waves, that allowed for the confirmation of the module values of dynamic deformation for the calculation of the foundations exposed to the action of horizontal weights.





METRO	d	Vs	G
0-4	2,0	150	0,04
4-5.5	2,0	195	0,07
5.5-15.5	2,0	245	0,12
15.5-20	2,0	330	0,21

d: densidad (g/cm³) ; Vs: Velocidad Ondas S (m/s) ; G: Módulo de Rigidez (Gpa)

Figure 18: *Results of the seismic study with superficial waves*

7.4. Behaviour when exposed to terrorist acts

The Owner considered it pertinent to perform a global study on terrorist attacks. The study was carried out by a British Engineer specialising in the field, who in his investigations included an analysis of the possible consequences of the impact of an aeroplane coming into contact with the tower.

In this part of the study, calculations were made by means of simulation, using computerised models to obtain conclusions on the behaviour of the structure upon impact with an aeroplane in several possible configurations.

For security reasons, images of these studies are not shown but it may be said that the results were satisfactory, making it clear that the employment of reinforced concrete columns over a wide section, also provide advantages from this point of view.

8. SOME COMMENTS ON THE EXECUTION

The pile cap was encased in concrete in six stages, with some points receiving reinforcement of eight layers of ϕ 32 mm bars:

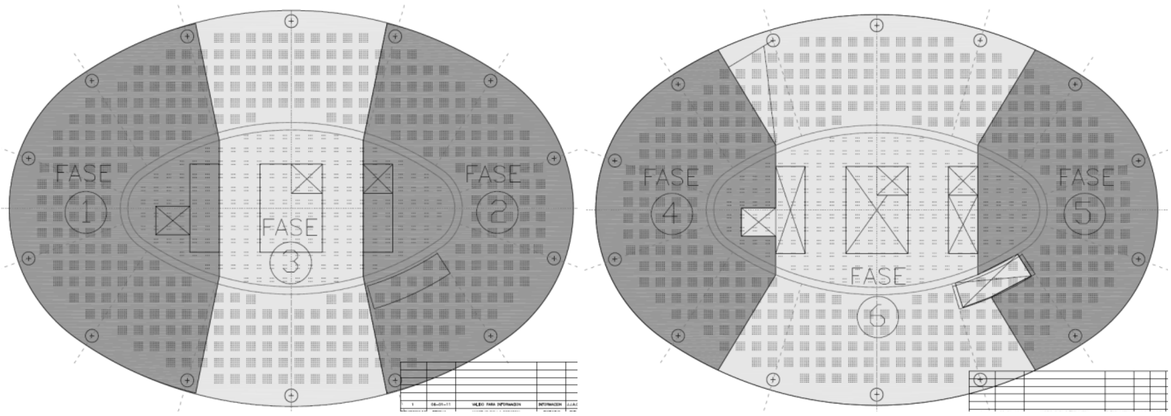


Figure 19: *Stages of pilecap excetion.*

The core was constructed using self-climbing formwork on the interior face, compatible with the project's design for the interior floor slab- core union, that was defined as rigid, following the conventional framework in the order of execution: wall- slab- wall.

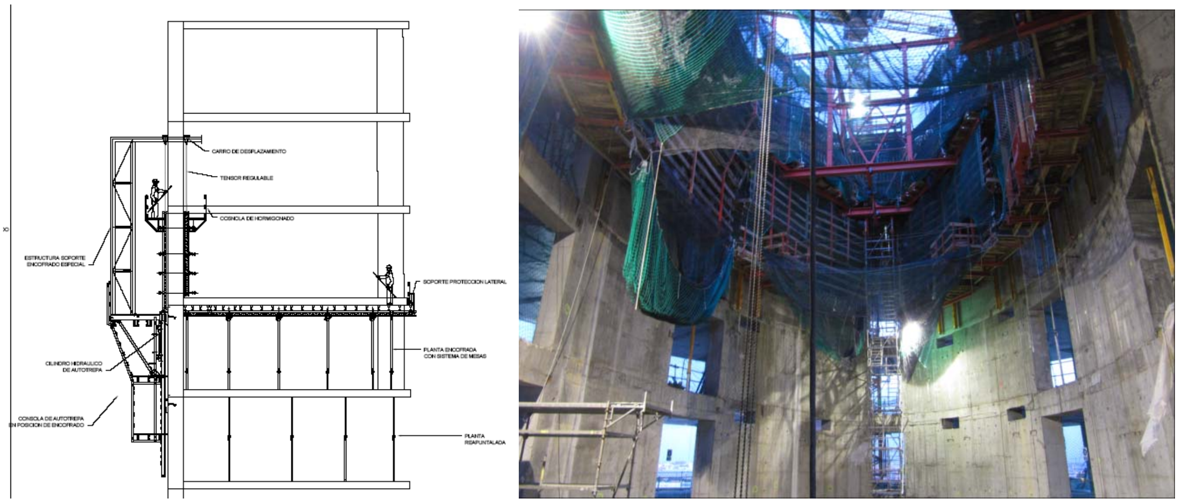


Figure 20: *Self-climbing formwork used in the core execution.*

The climbing formwork system employed in the works for the floor slabs consisted of reusable tables with adjustable legs. A compatibility study of the stripping times, evolution of resistance in time, and work and project loads, was carried out prior to their use.

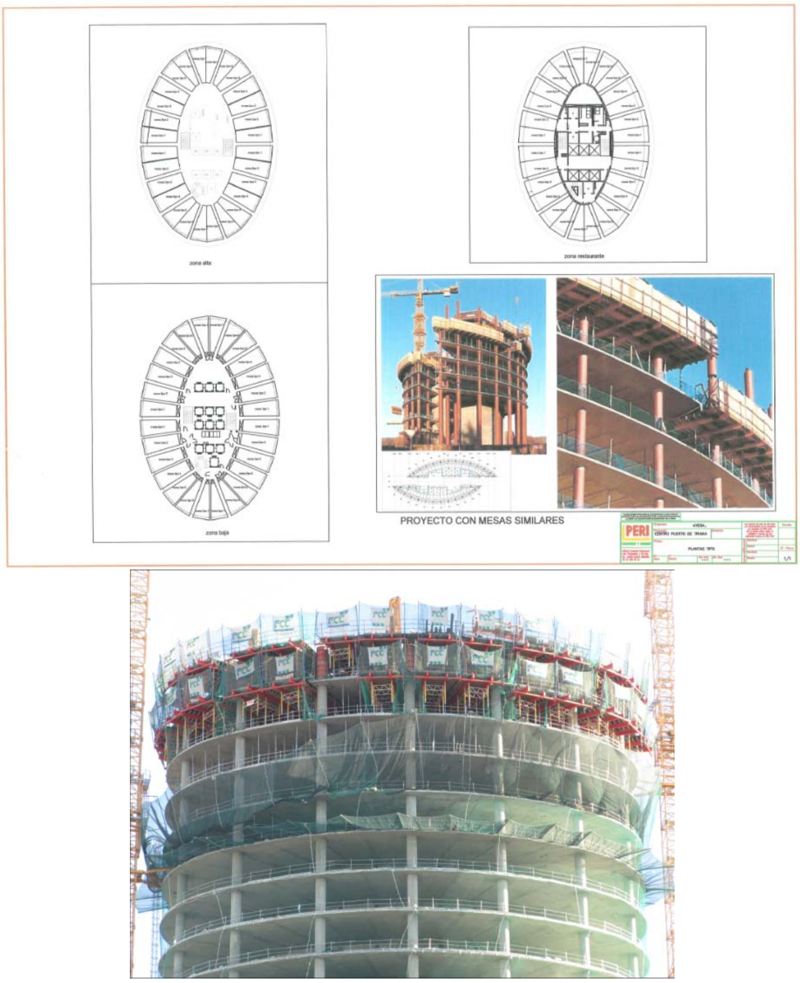


Figure 21: *Reusable tables with adjustable legs.*

Another aspect of the project that also received special attention, both during the Project and execution stages, was the reinforcement of the lintels on door gaps in the core, being heavily reinforced areas as a result of the concentration of forces mostly caused by horizontal actions.

Figure 22: *Reinforcement of the lintels on door gaps in the core.*

The metallic roof consists on a light triangular cover, defined with a ball and rod system working at axial tow compression. This roof tower includes a series of metallic oval slats, in keeping with the slats of the façade of the last complete floor of the building.

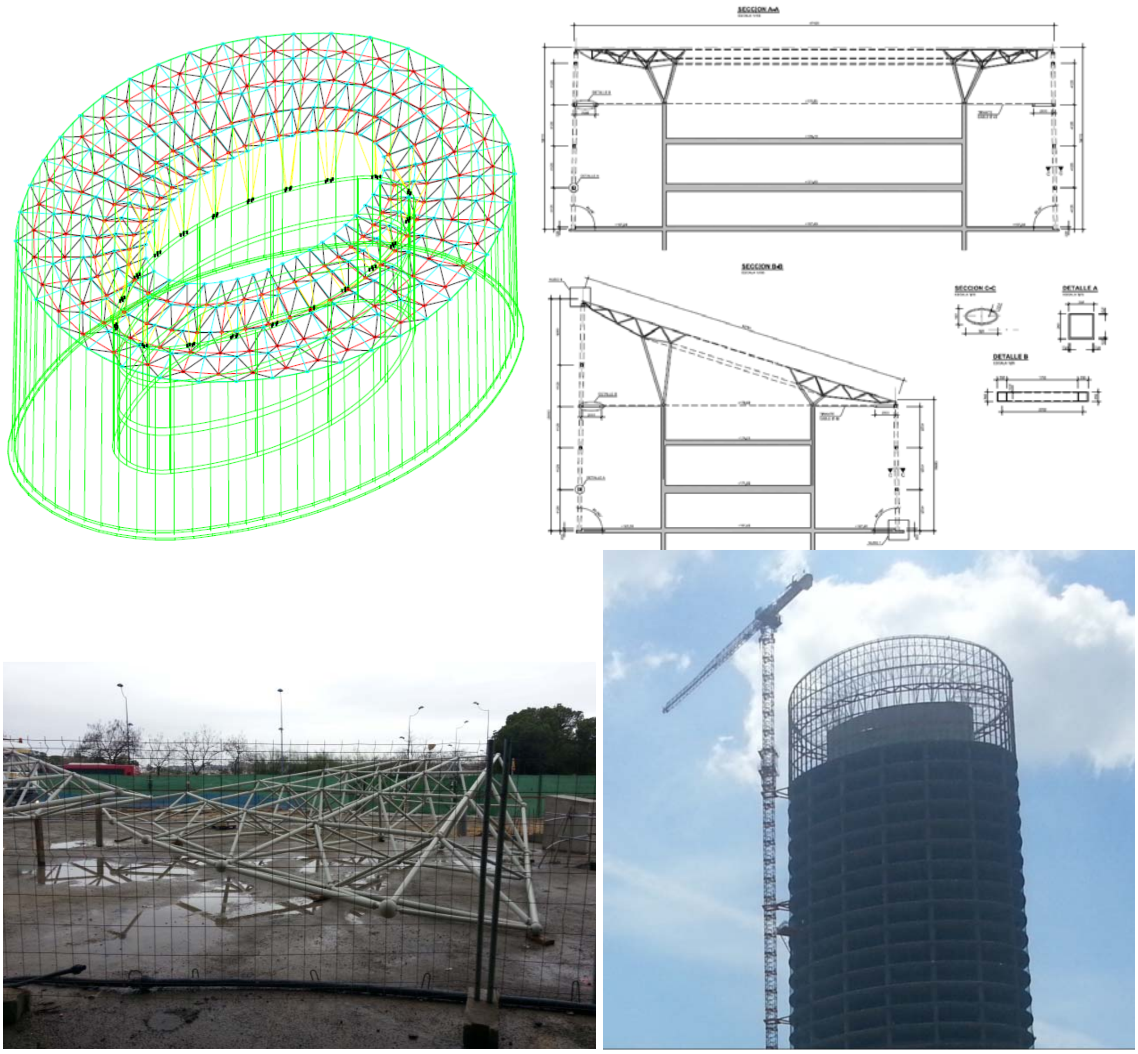


Figure 23: *Metallic oval slats used in the roof tower*

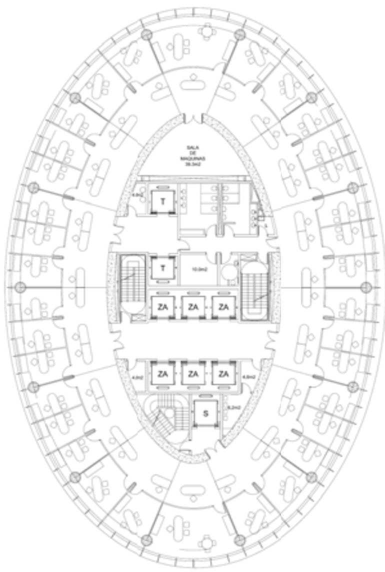
9. QUANTITIES

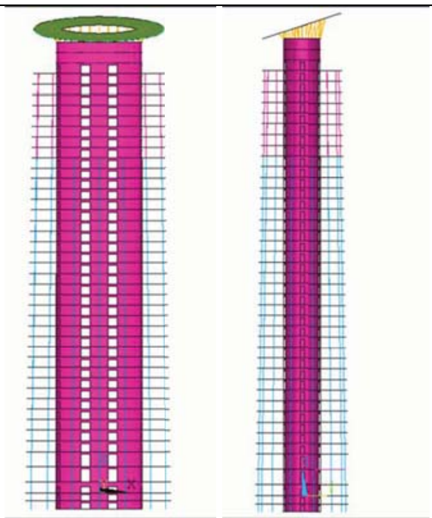
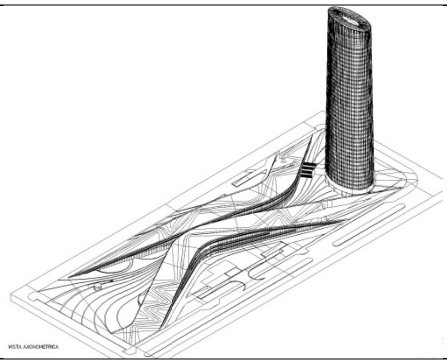
Some of the quantities used in the project are detailed below:

•Area of slab foundations:	1,537.05 m2
•Volume of concrete:	5,822.57 m2
•Weight of passive steel reinforcement (kg):	1,383,681.41 Kg
•Unit weight of shear columns:	496,38 Kg (425 columns)
•Ground floor dimensions of the columns:	1.5 m x 1.5 m
•Slab cement type:	CEM IV/B (V) 32.5 N
•Slab additive type:	Superplasticiser
•Screen cement type:	CEM-II/A-M 42.5R
•Slab additive type:	Superplasticiser
•Concreting phases:	Two 2 m deep layers
	Three fractions per layer 62.5 m3/hour
	Provided by two floors

Table 2. Characteristics and specifications table EHE

CHARACTERISTICS AND SPECIFICATIONS TABLE EHE			
STRUCTURAL ELEMENT		LOCALISATION	
		PILE CAP	SCREENS
REINFORCED CONCRETE	CLASSIFICATION (Art.39.2)	HA-35/B20/IIa	HA-30/F/20/IIa+Qa
	COATING (MIN,+MARG) (Art. 37)	45+5=50 mm	70+5= 75 mm
(Art. 30)	COEF, PARC, Seg (ELU) (Art. 15.3)	1.50	1.50
	CONTROL OF CONCRETE (Art 88.4)	STATISTIC	STATISTIC
REINFORCING OF STEEL	DESIGNATION (Art. 31.2)	B 500 SD	B 500 SD
	COEF, PARC, Seg (ELU) (Art. 15.3)	1.15	1.15
(Art. 31)	CONTROL OF OF STEEL	NORMAL LEVEL	NORMAL LEVEL

PICTURE(S)	**PROJECT DESCRIPTION**
	Type / occupancy: Offices Storeys/height: 38 storeys (180,50 m) Frame Cost: 23.388.824,02 euros Construction period: 2007 – 2012
	**PROJECT TEAM** CLIENT: CaixaBank ARCHITECT: Pelli, Clarke, Pelli Architects & AYESA STRUCTURAL ENGINEER - Basic Project and Construction project: Ayesa - Technical consultant in Concept Design and Basic project: Fhecor Ingenieros, Consultores. M&E ENGINEER: Ayesa MAIN CONTRACTOR : UTE FCC-INABENSA Project Manager: Aynova Works and construction supervision: AYESA

	**STRUCTURAL SOLUTION** Stability system: Elliptical reinforced concrete core (32.00 x 16.00) Foundation: Deep foundation with two rings of diaphragm concrete walls. Columns: Sloping composite columns with 1.2 – 1.0 diameter. HA-65 to HA-30. Core: Thickness between 0.70 and 0.40 m and concrete grade HA-40. Floor slabs: Light weight concrete slab with 350 mm depth and maximum span of 9.60 m.
	**OTHER INFORMATION** The Pelli Tower is an office skyscraper in the south of Seville, built under the masterplan of Puerto Triana. It is situated in La Cartuja, former zone of the Universial Exposition of 1992 (Expo'92). The whole construction comprises over 200.000 m^2 of singular structure in an built-up area of 110m * 350m.

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