

# CAE CONFERENCE 2013

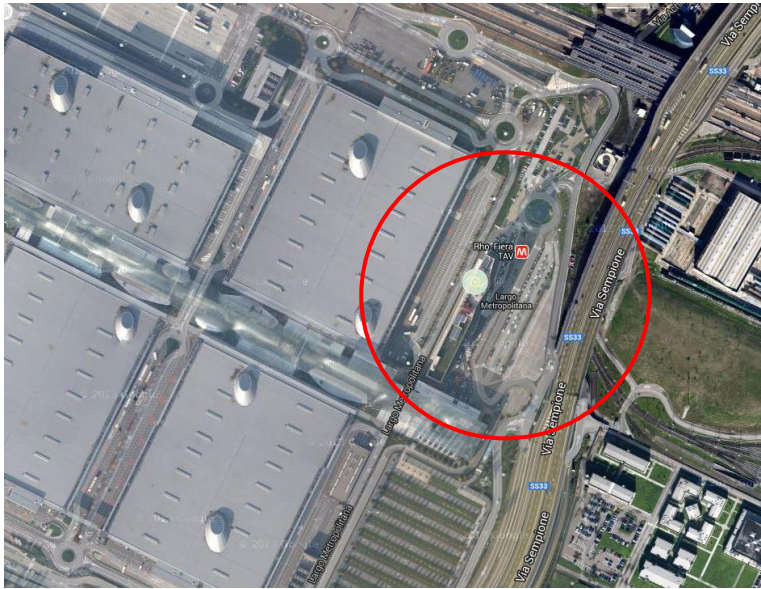
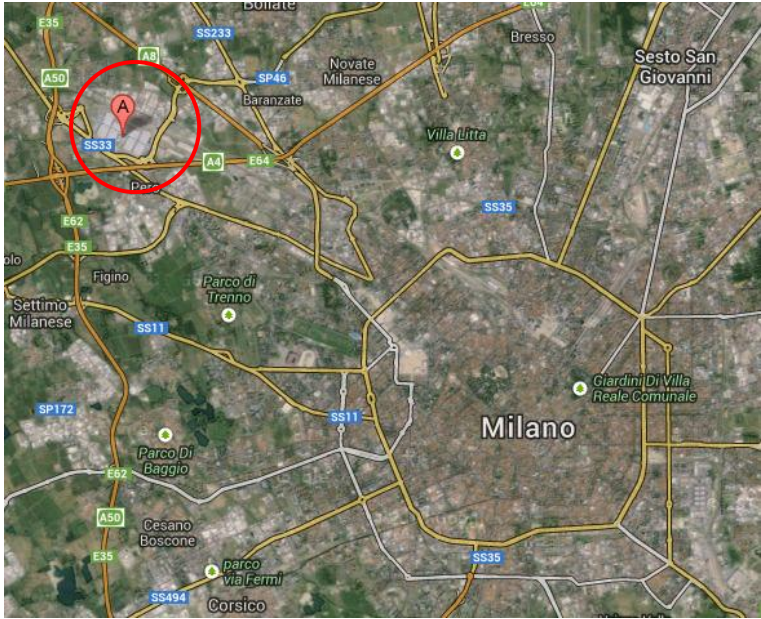
Lazise (VR) 21÷22 october 2013

## DESIGN AND CONSTRUCTION OF THE “FIERA MILANO BUILDING”

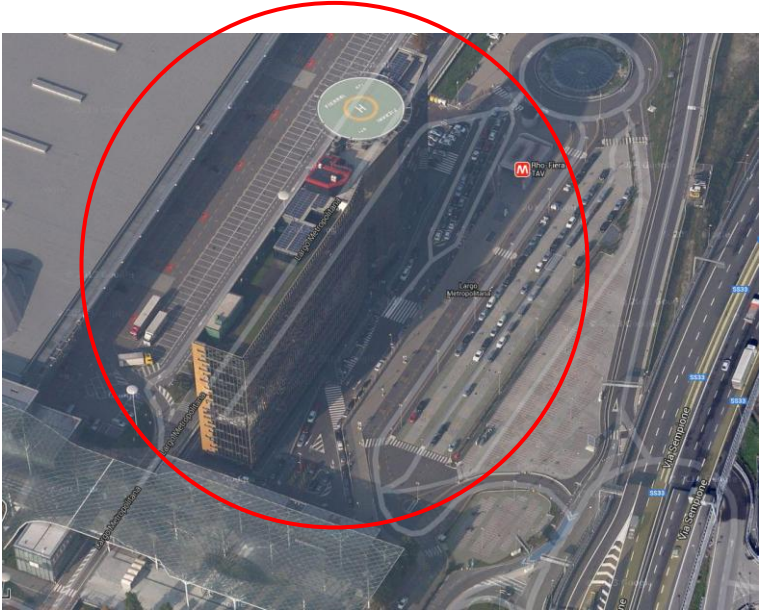
Ing. Luca ROMANO – I QUADRO INGEGNERIA – GENOVA



LOCATION OF THE “FIERA MILANO BUILDING”



PLAN VIEW



AERIAL VIEW

## INTERNATIONAL TENDER

The design of this building followed from an international tender, in which different groups of architects, engineers and construction-companies proposed their ideas for the new offices of the “Fiera Milano building”.

The winning proposal was conceived as a golden, horizontal tower at the east entrance of the “Fiera di Milano”.

Here you can see some early images of the winning idea for the tender:



## DESCRIPTION OF THE BUILDING

During the competition phase various solutions were studied in order to match construction time and costs. This resulted in a mixed steel-concrete structure that allowed to complete the building in less than two years and to respect tender costs.

Design consists of a 132.5 m long building of 15.60 m depth and about 60 m height.

The Building is divided in two by a joint: building “A” is composed by 12 floors while building “B” is composed by 13 floors.

They are separated but connected by the foyer with staircases and footbridges.

In order to provide an helicopter landing pad, an important cantilever steel structure was built on the roof of building “B”.

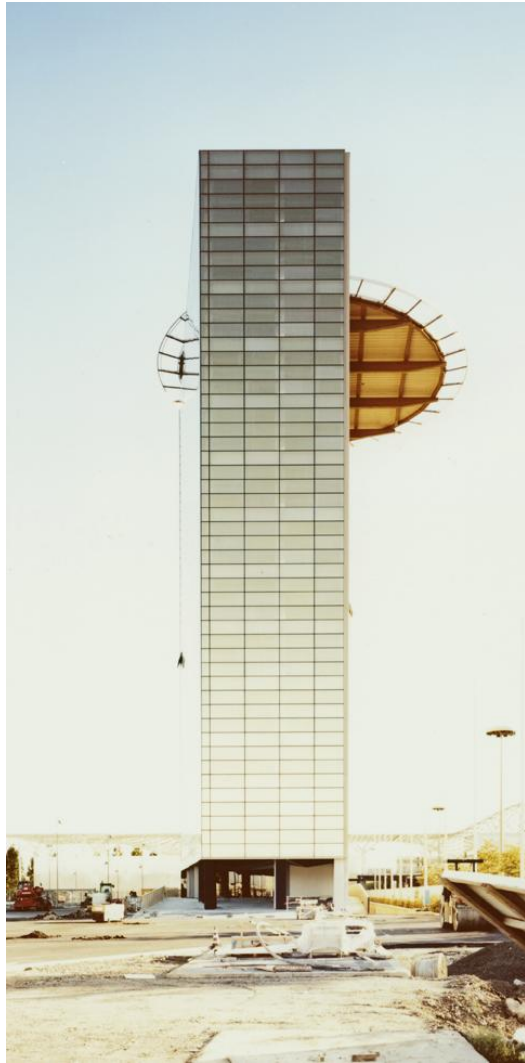


Side of the building in the actual destination



Rear of the building with view of the landing pad

Here are some views of the finished building:

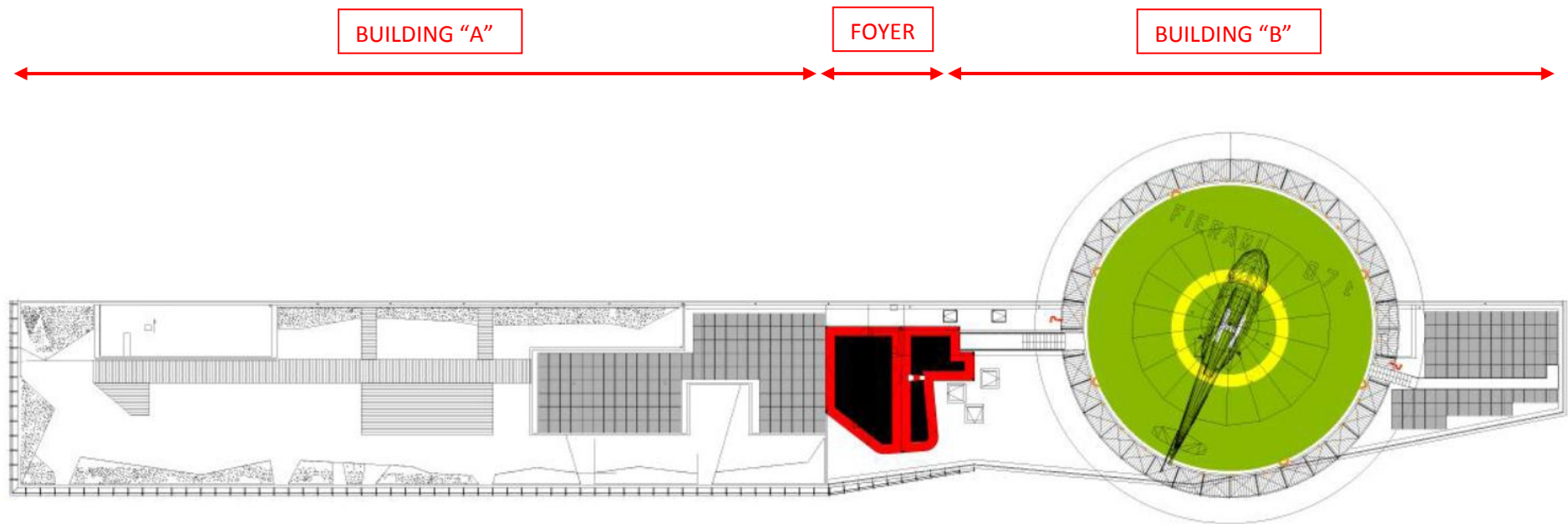


Side of the building with view of the cantilever landing pad



View of the rear of the building

The building is composed by two parts connected by a foyer and footbridges at different floors.

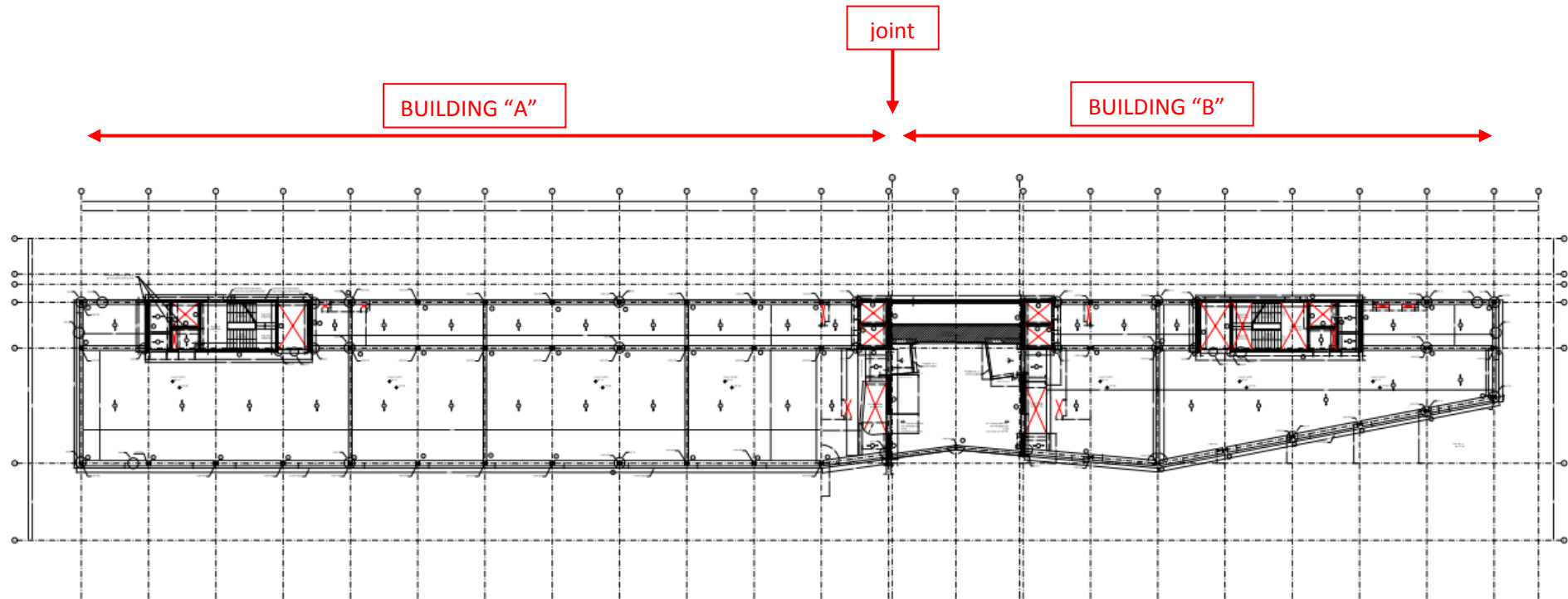


Plan view of the building, with the landing pad on the right

# STRUCTURE

## Structural Strategy And Description

The structure was very long, so it was divided in two structures separated by a joint. Here you can see the typical floor plan:



plan view of the typical floor

Longitudinally the structure is a repetition of 6.25 m spaced columns; they are aligned along the perimeter and on an internal position. Transversely two precast, prestressed slabs - 4.25 m and 10.7 m long - connect the longitudinal steel beams. These beams are made with welded plates, to reduce thickness.

## STRUCTURE

Each building is a core supported structure, with shear walls, to resist lateral forces from wind and earthquakes. In this way steel columns are pinned at the base and resist only to vertical loads.

This classical strategy was adopted to realize the structure in few months, with respect of tender costs: steel structures was produced on workshop, while on construction site we realized reinforced concrete core structures.



Core structures of the two buildings - floors in construction

Concrete core structures were realized with climbing form-works.

In the picture you can see also the steel boxes provided in the walls for the connection of steel beams:



Climbing form-works for the shear walls of stair cases

In this way the steel structure was a simple assembly of pinned columns and hinged beams:

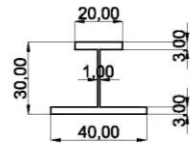


Pinned connections of the steel columns

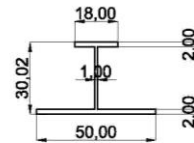
Steel beams were composed with welded plates, hinged and dimensioned to support precast slabs:

To reduce thickness, slabs were supported on bottom flange:

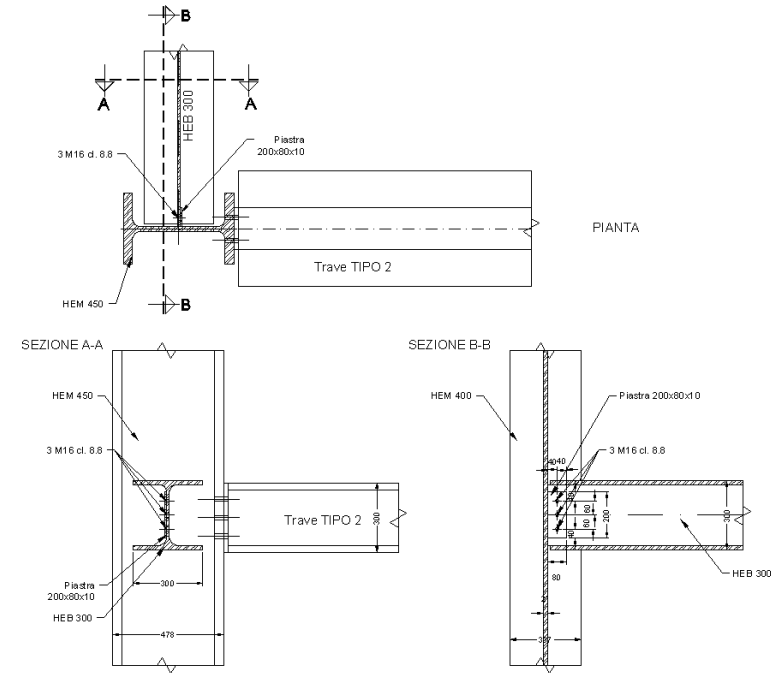
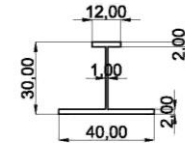
TRAVE TIPO 1



TRAVE TIPO 2



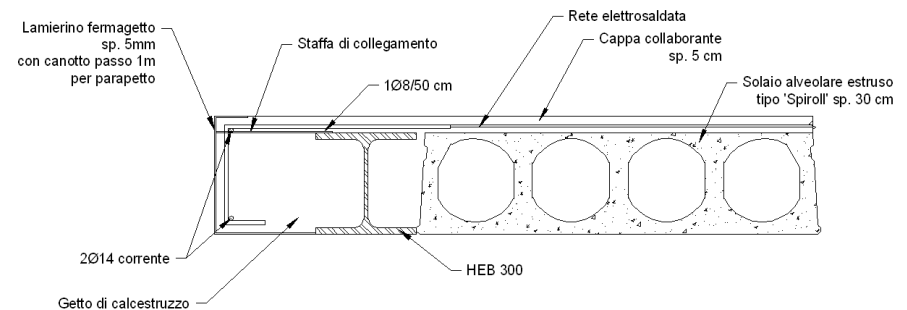
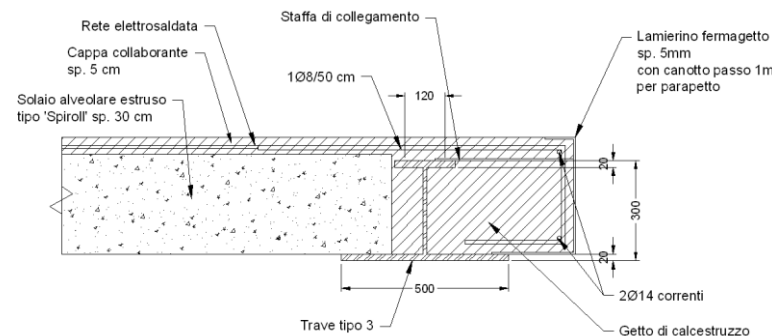
TRAVE TIPO 3



Prestressed slabs are placed on the wide bottom flanges of the steel beams and casted in situ.

Slabs were 30 cm thick, 10.25 metres long, with a layer of 5 cm of concrete cast in situ.

In the following details you can see the intersection beam-slab:



Here are some pictures of the construction phases of the floors:



Positioning of precast slab of floors



Detail of the intersection between slab and steel beams (view from above and from below)

## FOOTBRIDGES

The connecting foyer has footbridges 12 metres long, at various floors. These structures are free to move to absorb lateral movements due to wind, earthquakes and thermal effects.

They are composed by IPE 500 steel beams with a composite slab on cold-formed steel decking.



Main steel beams of the two footbridges connecting the two buildings: fixed on one side and free to move on the other.

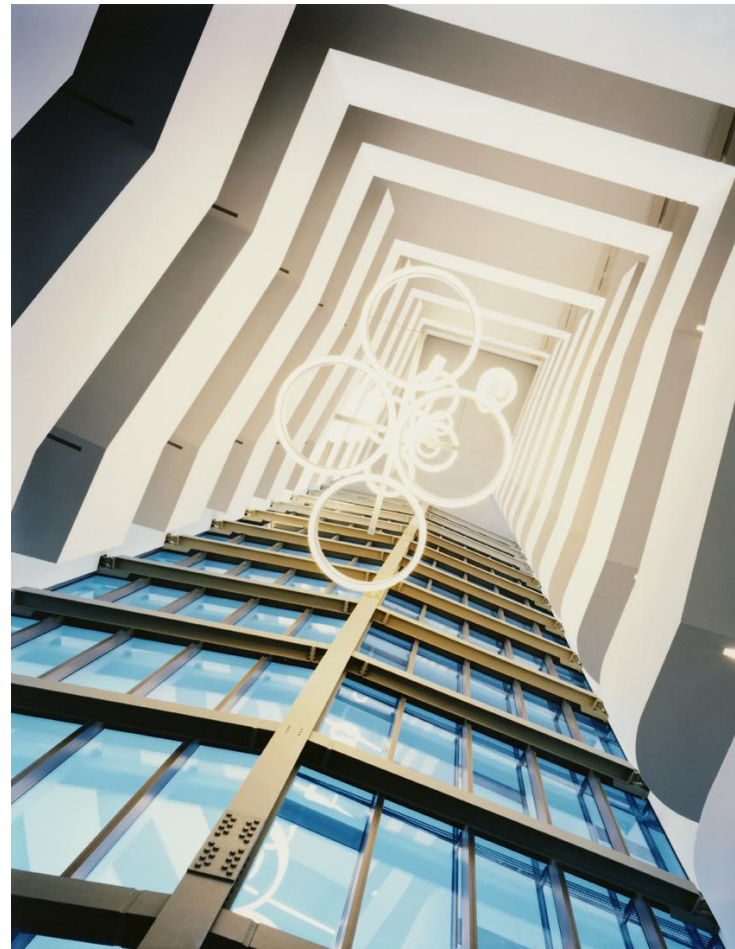
## FOYER

The foyer is an hollow structure with staircases and footbridges connecting people at each floor.

Windows in front of the foyer have a complicate pinned systems that permits movements of translation and rotation of the two buildings. These windows are linked to a steel tree-structure, pinned to building “B” and free to move in the connection of building “A”. Cinematic was important to prevent window crashes and all calculated displacements were given to the facade developers to take care of relative movements.



view of the foyer connecting the two buildings



view of the finished foyer from below, in the entrance

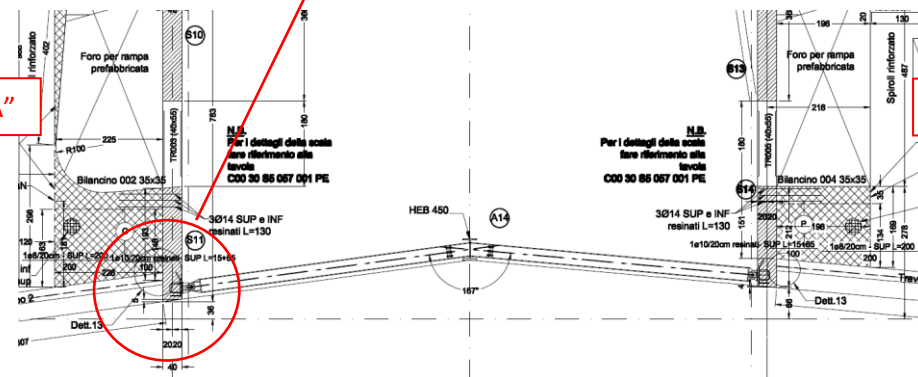
Here you can see the structural detail of the hinges of the tree-structure of the foyer:



General and detailed view of the Pinned and slipping connections of the facade of the foyer



STRUCTURE "A"



STRUCTURE "B"

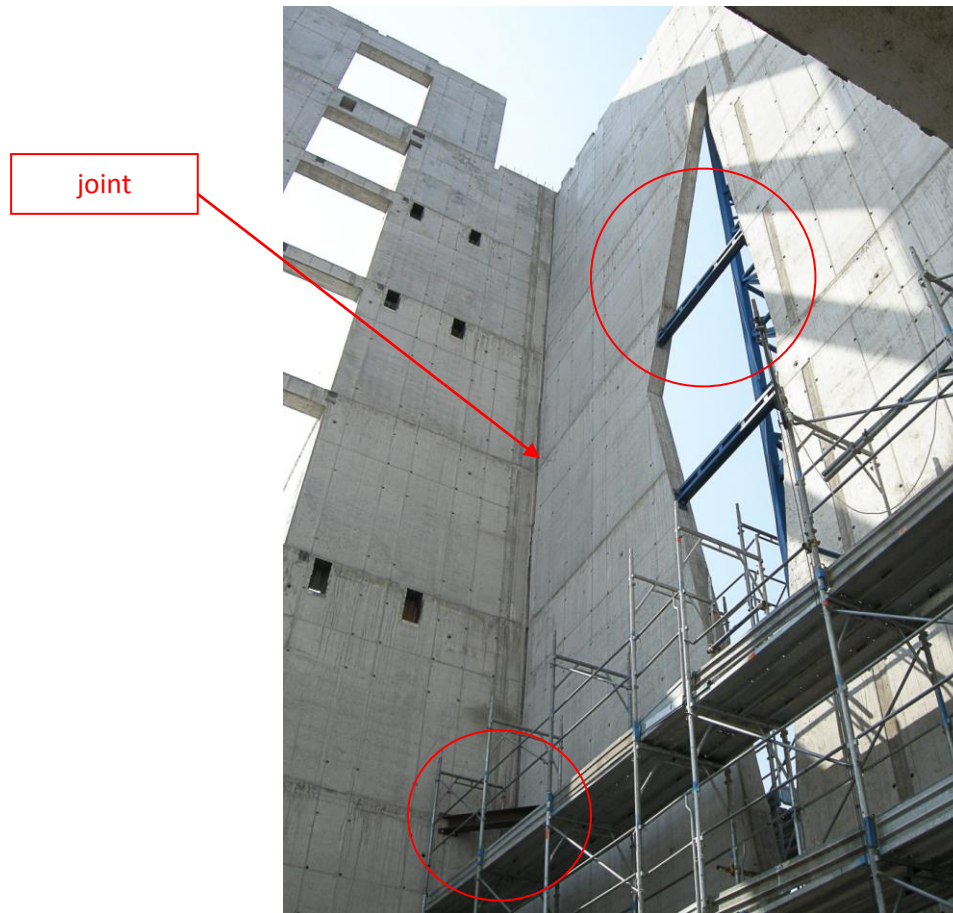
Plan view detail of the foyer

Construction phases were important.

Before finishing the roof, the wall at the rear of the foyer was 54 metres high, 40 cm thick, separated by joint and free at the top.

Because of stability check, you can see some provisional beams positioned.

You can also see the joint which separates the two structures.



## HELICOPTER LANDING PAD:

On the roof of building “B” an helicopter landing pad was realized.

The structure is made with cantilever “I” beams, 10 metres apart from the facade, connected by damping supports to the steel columns of the building, not to transmit vibrations.

The deck was formed by aluminium box section supported by the beams.

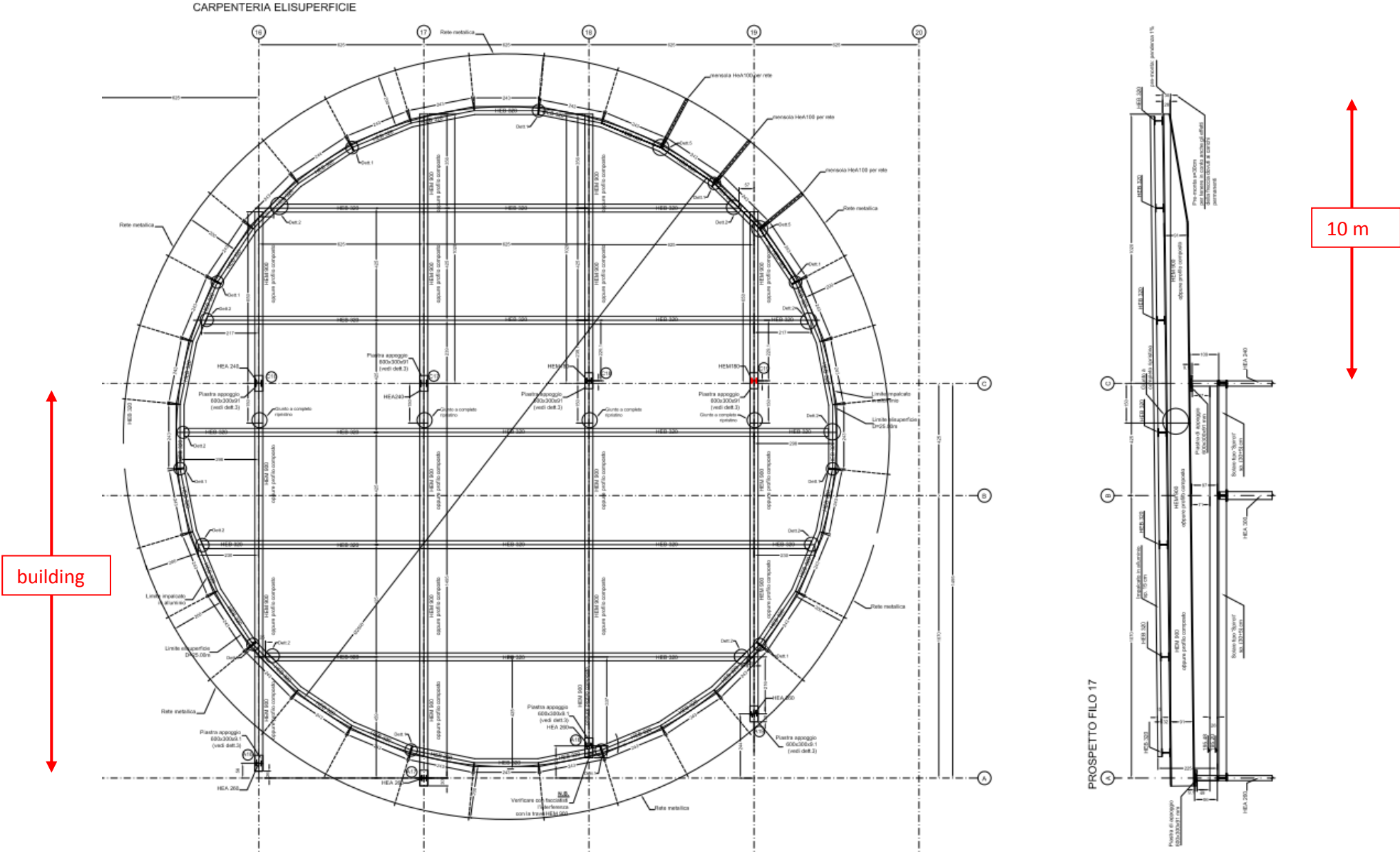


General view of the structure of the landing pad



detail of the structure extremity

Here you can see the design of the steel structure: the plan view on the left and the cross section of the cantilever on the right. Only extremity columns were used as support, to prevent traction.



## FOUNDATIONS

In order to prevent ground displacements and subsidence, we realized a steel sheet-pile bulkhead, 10 metres long, installed by vibratory hammer.

In the picture one can see this earth retaining wall without dead space near existing buildings:



Positioning of steel sheet piles before digging

Another problem was the presence of the Underground of Milan, that didn't accept any pressure against its existing walls. That's why we had to dig till the bottom of the tube, realize a joint and replace the ground with casting concrete, able to resist to the pressure of the new building transmitting forces only to the bottom of the foundation.



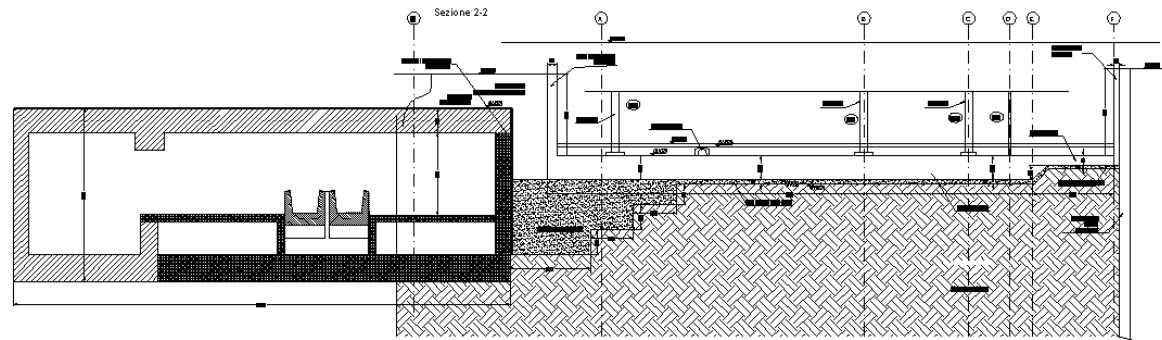
Steel sheet piles and base of the mat foundation. On the left the existing Underground



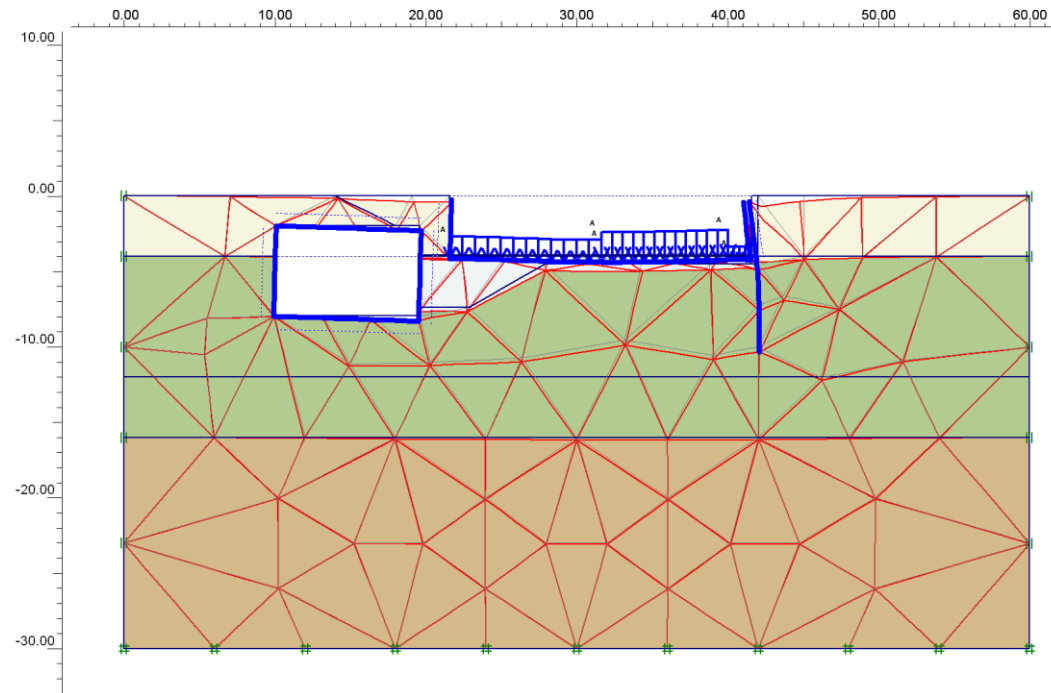
Concrete casting near the Underground, to prevent earth pressure against existing walls

Underground of Milan asked the simulation of the construction phases.

Here you can see the vertical section, with the Tube on the left, the mat foundations on the right and the concrete layer in the middle:



The simulation analysis was performed in 5 steps with a bi-dimensional model, to answer the Underground of Milan in terms of subsidence:



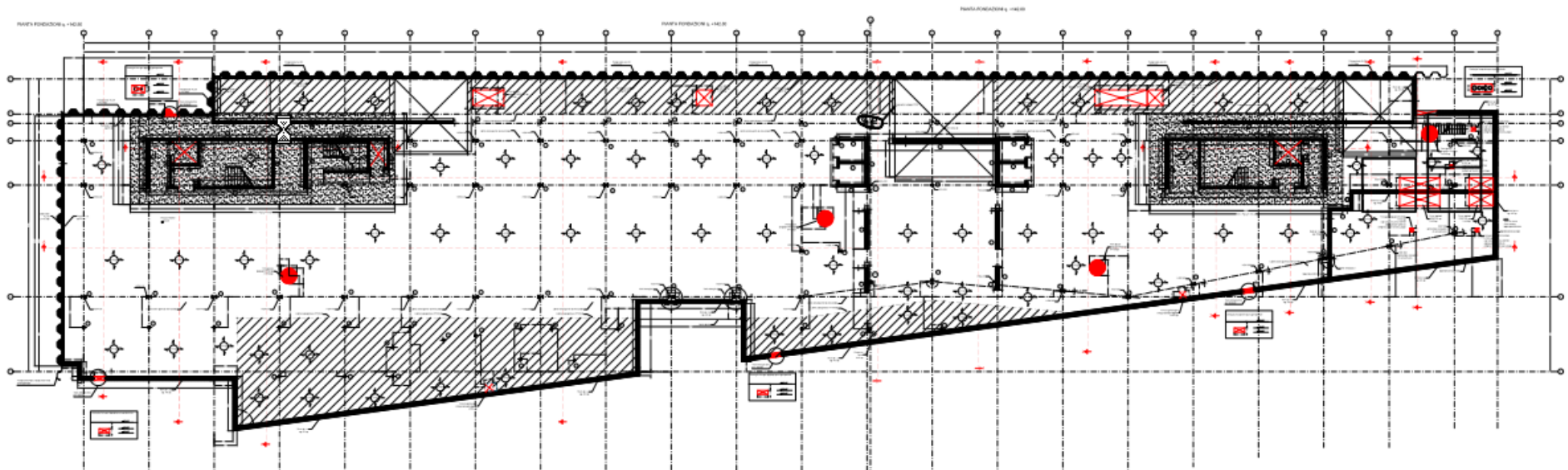
## Mat Foundation

Due to the good soil characteristic, we designed a mat foundation, continuous under the entire building.

Instead, the building itself was divided in two structures, which were separated by a joint.

The thickness of the mat was 1 metre under the steel columns and 1.5 metres under the core structures. It was reduced to 40 cm near the steel sheet piles, in order to reduce the cantilever.

In the following plan view you can see the foundation: 137 metres long and 30 metres wide:



In the next picture you can see the positioning of reinforcement in the mat:



Reinforcement of the mat foundation before casting

## ANALYSIS

The structure had many particularities, but it was not so unusual.

So we decided to realize models for design purpose, easy to handle and to understand.

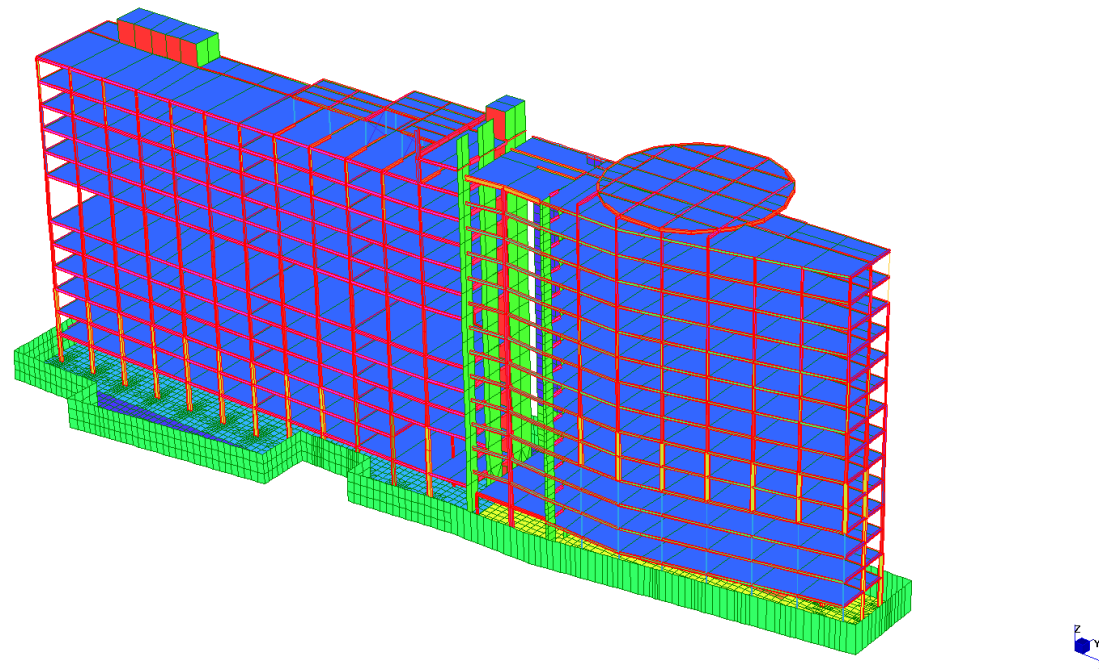
Here you can see the finite element model of the structure, performed with Straus 7.

The model simulates the exact structural stiffness by means of:

2084 element beam

12427 element plate

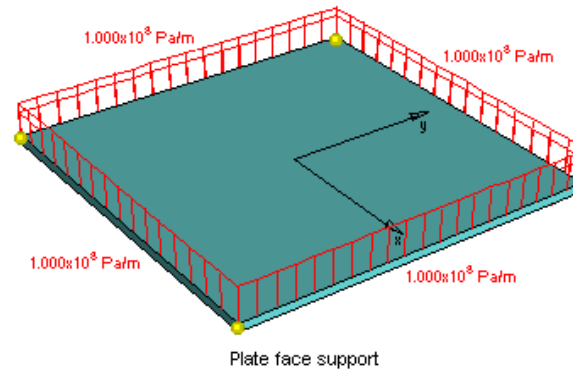
for a total of 46994 degrees of freedom



View of the model

Mat foundations are modelled with plate elements on ground support: Modulus of Subgrade Reaction

These plates have either membrane or bending properties, calculated through their thickness.



Earth retaining walls are modelled with plate elements.

Columns and beams are modelled with beam elements, hinged at the end.

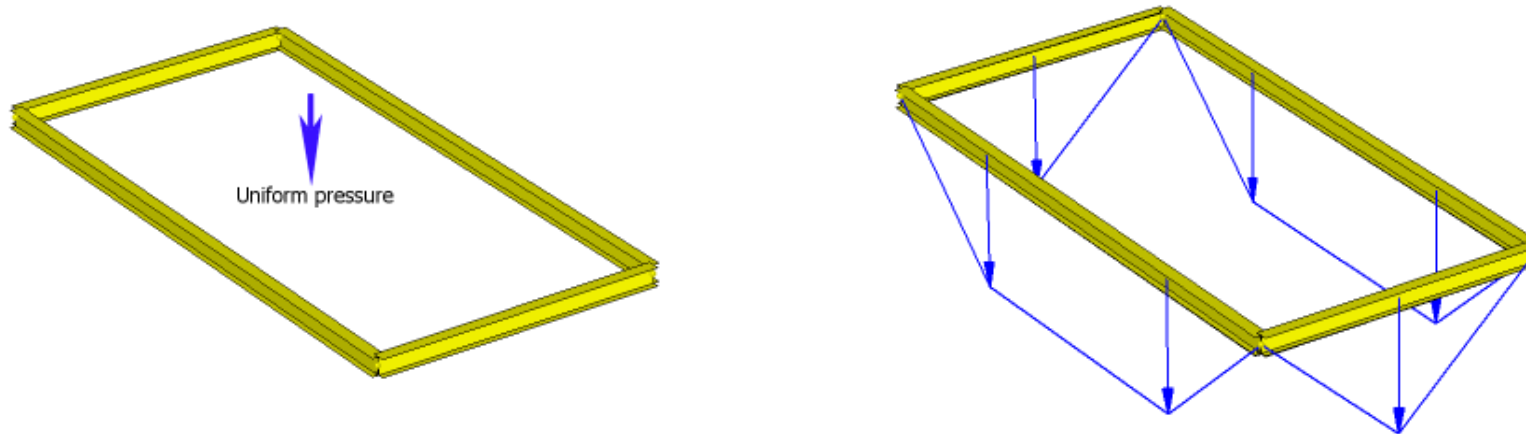
shear walls forming the box shaped cores around stairs and elevators, are modelled with plate elements, which have either membrane or bending properties, calculated through their thickness.

This is a spatial system capable of resisting all types of loads: vertical forces, shear forces and bending moments in all directions, as well as torsion.

In this way we realized an efficient lateral load resistance structure for the two buildings.

Slabs are modelled with load patch elements and rigid floor links.

This plate element does not have any property attributes. It is used solely as a way of transferring distributed area loads and non-structural mass to beams that may be connected around the perimeter of the plate:



In this way you don't influence the stiffness of beams and you consider the rigid link of each floor.

The software Straus 7 allows the definition of different non structural mass for various load condition and to any of them one can associate a dynamic factor that define the mass to be considered in dynamic analysis. In this way you have the maximum of possibilities of simulating seismic conditions.

Analysis performed during design were of three types:

- Static: load conditions – SLS and ULS combinations - envelopes
- Dynamic: natural frequencies – mode shapes
- Spectral response: seismic base excitation

During construction phases we performed also various static analysis on partial models, to help the construction company to reduce construction time.

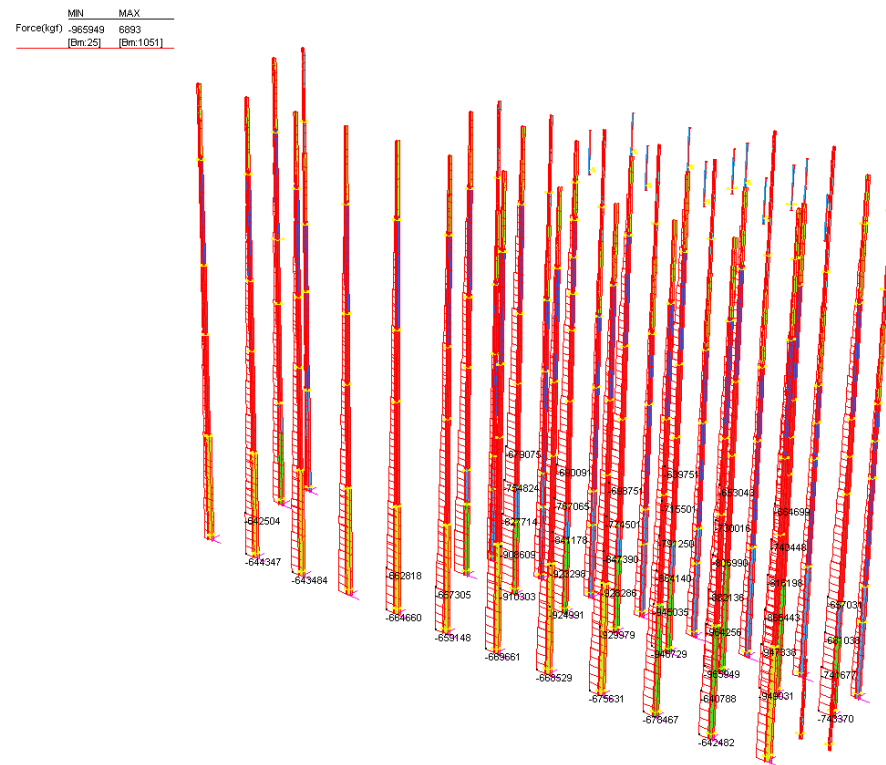
Static analysis are performed considering various load conditions:

- Self weight is automatically determined by Straus 7
- Either permanent or live loads were introduced through non structural mass in different load cases
- Wind was introduced through forces acting on facade load patch elements. These forces change of intensity with height

Solutions were combined to maximize effects on beams and columns.

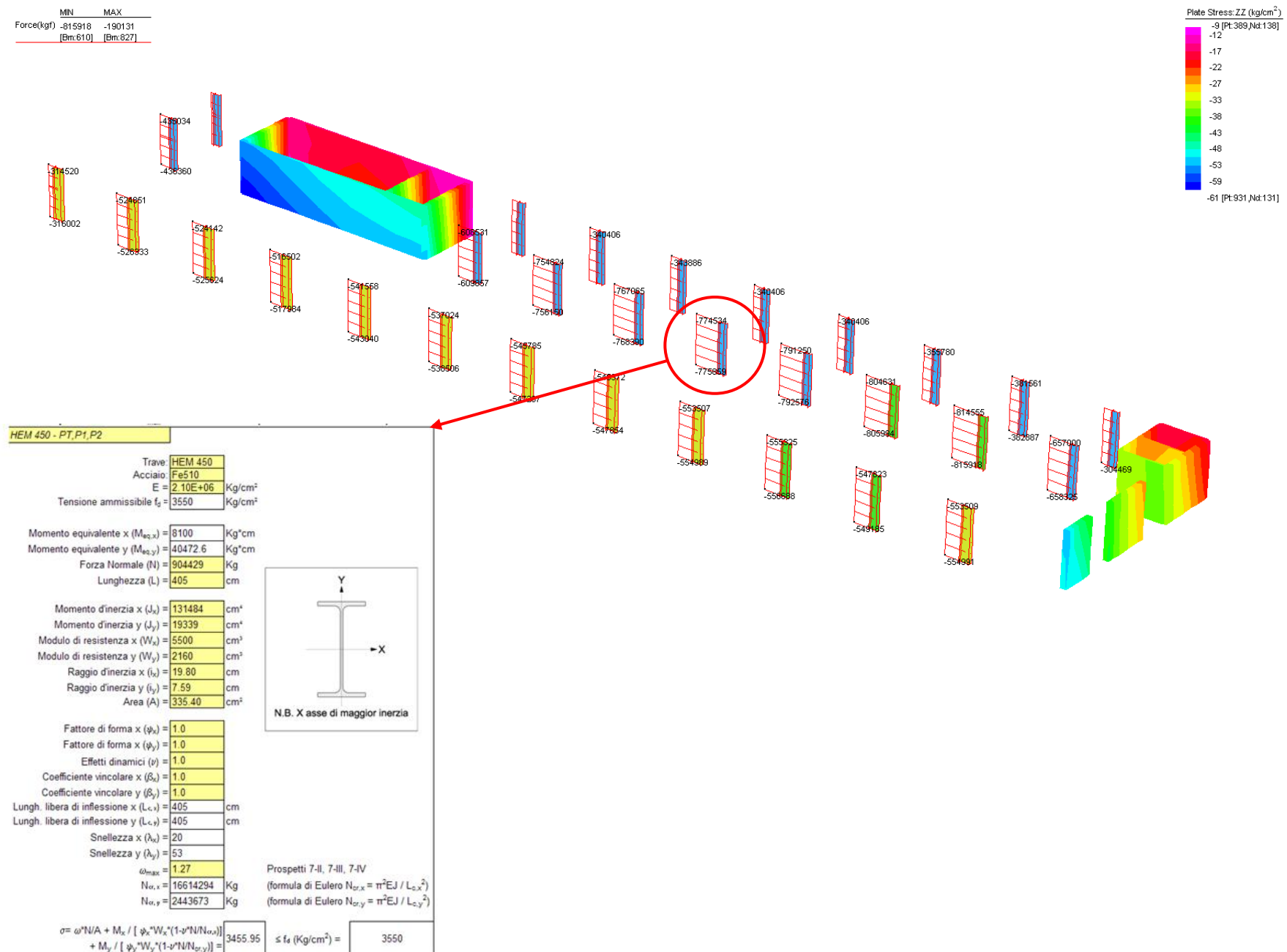
Various combinations were performed, in order to obtain Service and Ultimate Limit State conditions.

For example next figure represent maxima axial forces at ULS for the columns:



In next image we see the values of axial forces in columns and stresses in shear walls of a single floor.

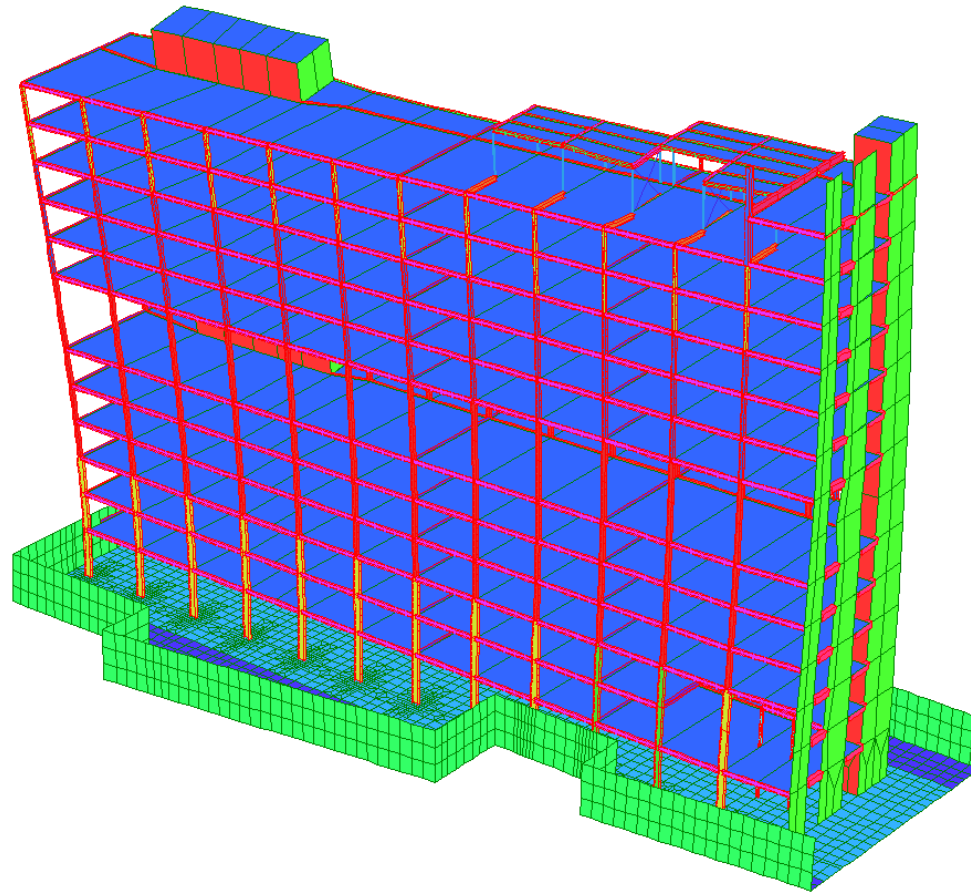
They are used for resistance and stability check required by Code:



The natural frequency solver was used to calculate free vibration frequencies and corresponding mode shapes of the undamped structure.

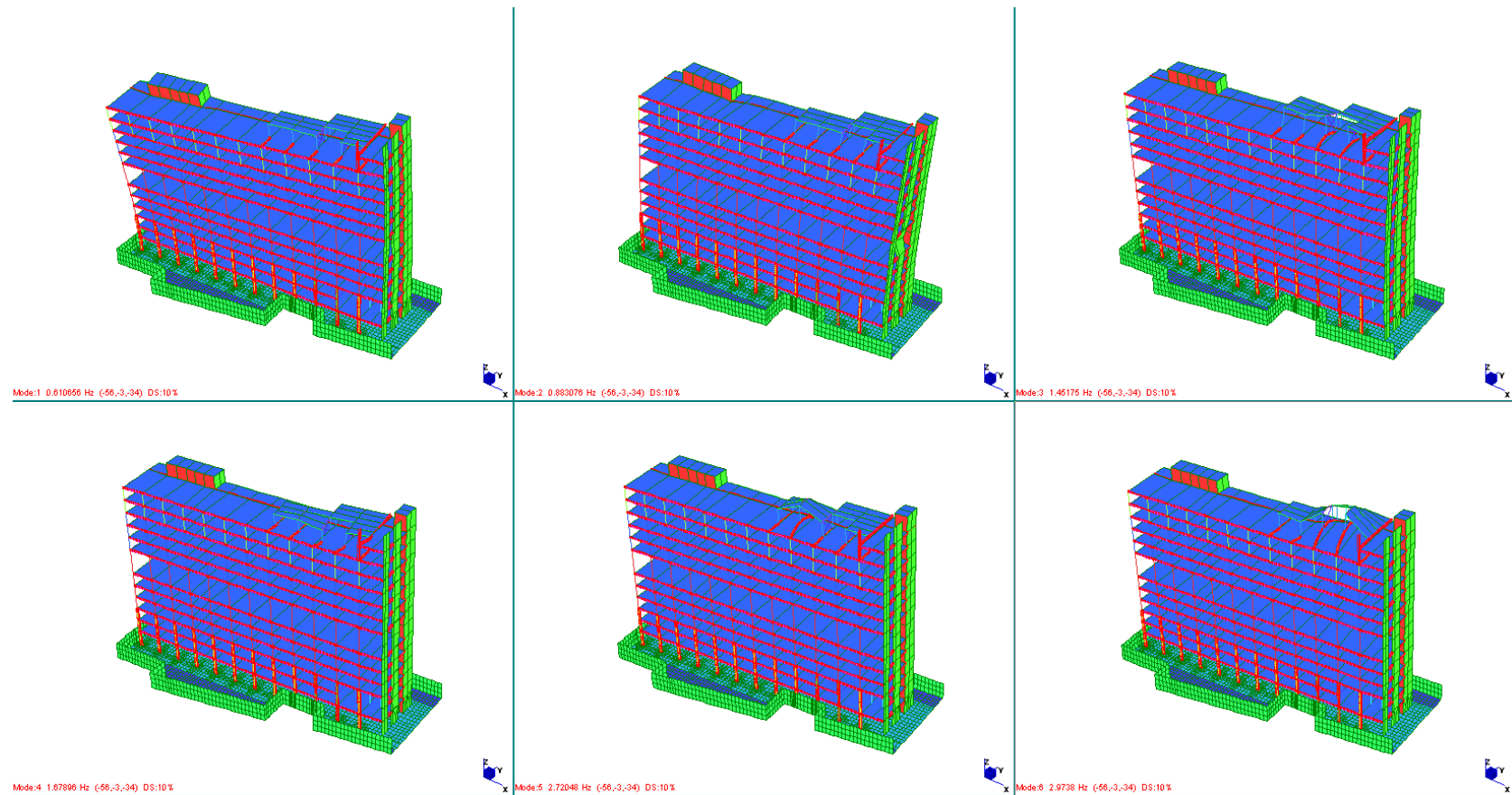
It is possible to determine the participation factors for all directions to be sure to involve more than 85% of the global mass of the structure: 100 mode shapes were necessary.

In next figure you see the first mode shape of structure “A”:



first bending mode shape in the transverse direction: 0.61 Hz of frequency

In next figure you see the first six mode shapes of structure “A”:



First six mode shapes of structure “A”

## Seismic design

The Spectral Response solver calculates the response of a structure subjected to a random dynamic loading.

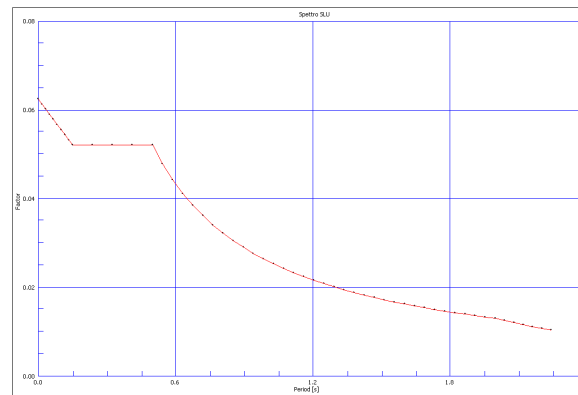
In this spectral response analysis, the random dynamic loads applied are base excitation (earthquake)

The spectrum input used is Response Spectrum, defined by seismic Italian code: a spectral curve as a function of period.

The site is considered as low seismic and Code provide a ground acceleration of 0.05 g

Considering the building braced by concrete core structures, irregular and low ductile, a structural factor of 1.68 was adopted.

In this way we can calculate spectral acceleration for SLD and SLV conditions, to be used in spectral analysis:

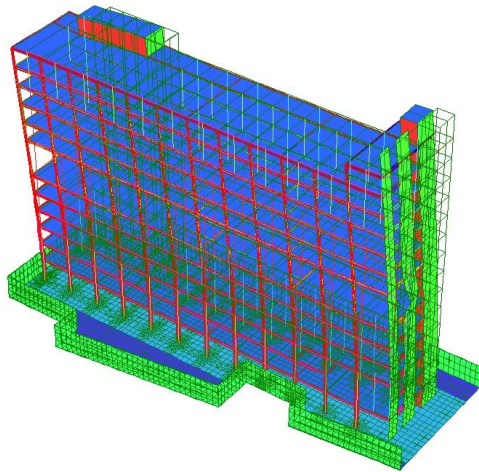
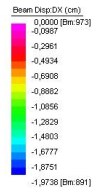


SLV spectral curve

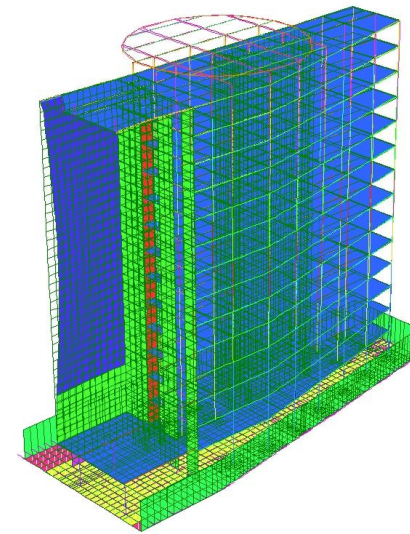
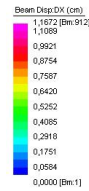
Seismic forces were combined with vertical and gravity forces as in Code requirements:

$$\gamma_E E + \gamma_G G_k + \gamma_P P_k + \sum i (\psi_{2i} \gamma_Q Q_{ki})$$

Control of seismic displacement for the two structures and dimension of joint:



Displacement in x direction of structure "A"



Displacement in x direction of structure "B"

To determine the entity of the joint we adopted a safety factor  $\gamma_F = 1.4$  for the displacements calculated (sum of displacements of building "A" plus "B"):

wind:  $\Delta x = (0.41 + 0.12) \cdot \gamma_F = 0.53 \cdot 1.4 = 0.75 \text{ cm}$

seismic displacements:  $\Delta x = (3.75 + 3.22) \cdot \gamma_F = 6.97 \cdot 1.4 = 9.76 \text{ cm}$

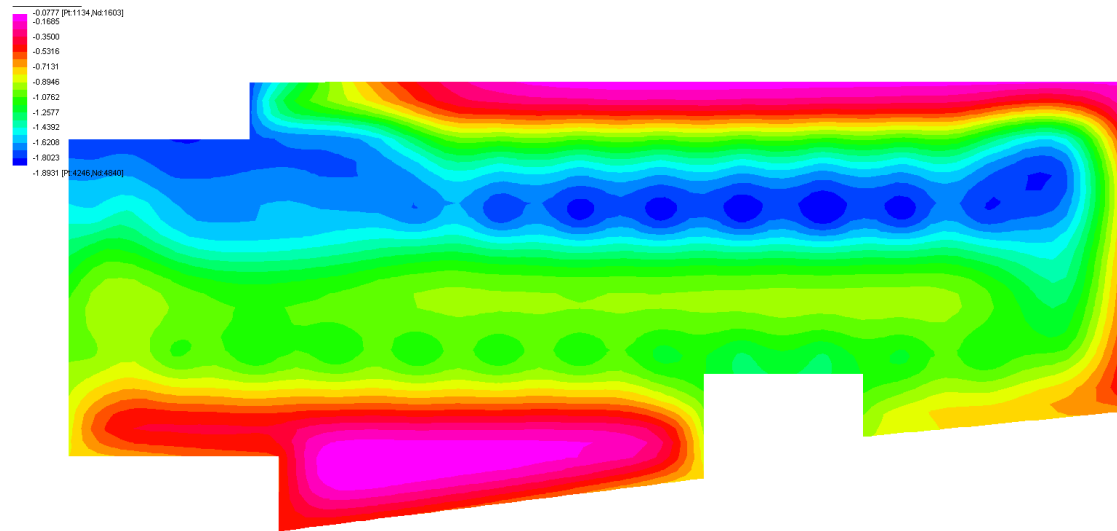
A joint of 10 cm was realized between the two buildings.

## Foundations

The model was supported by plates on ground support, of thickness corresponding to the mat foundation.

In this way you can have a response on the soil and structure interaction, calculating subsidence and pressure on ground.

In the following image you can see the example of pressure calculated under building “A”:



Max pressure on ground for building “A” ( $\text{kg/cm}^2$ )

In the same way you can obtain the envelope of the maximum Bending moment in the x and y direction, to dimension reinforcement and check Service and Ultimate limit states:

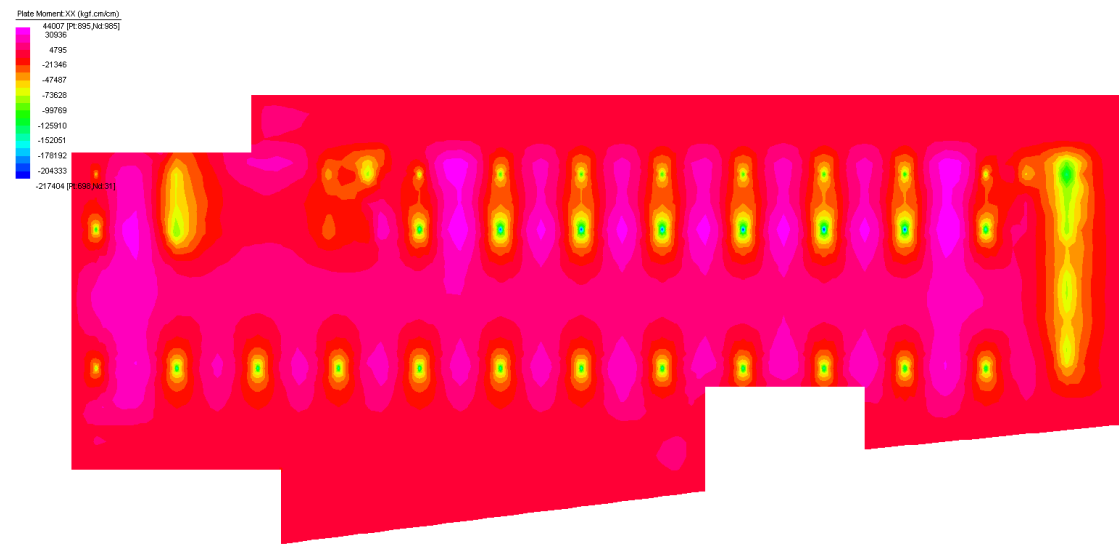
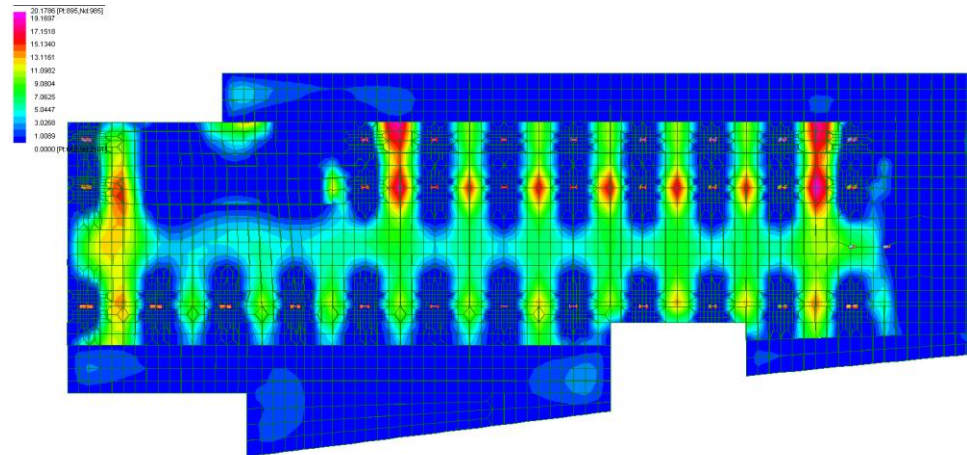


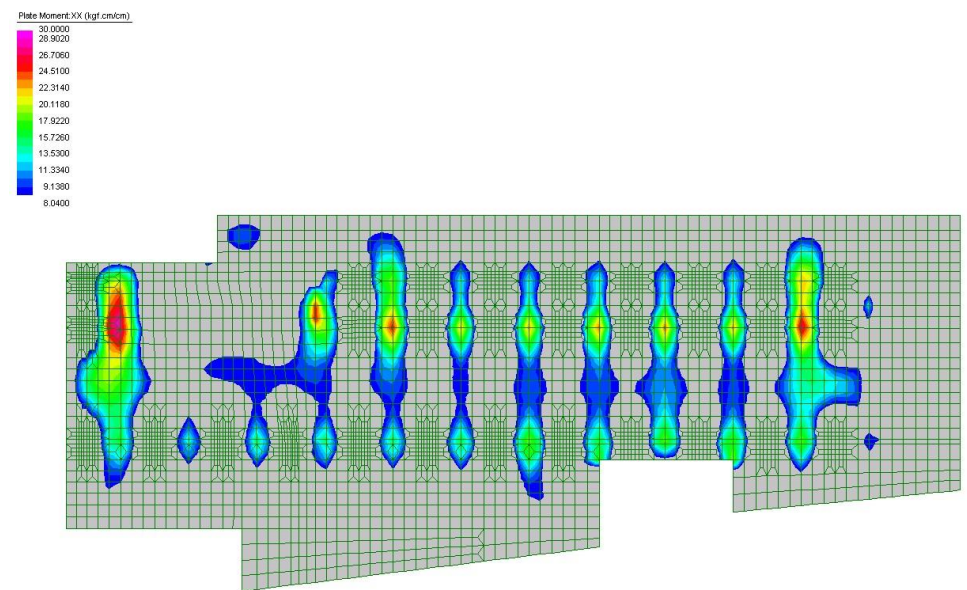
Plate moment  $M_{xx}$  max envelope in x direction

It is possible to create an envelope combined to obtain the percentage of rebars to be positioned every metre.

In the following image it is possible to see the maximum envelope, produced to estimate the percentage of top rebar in the mat foundation, for x direction:



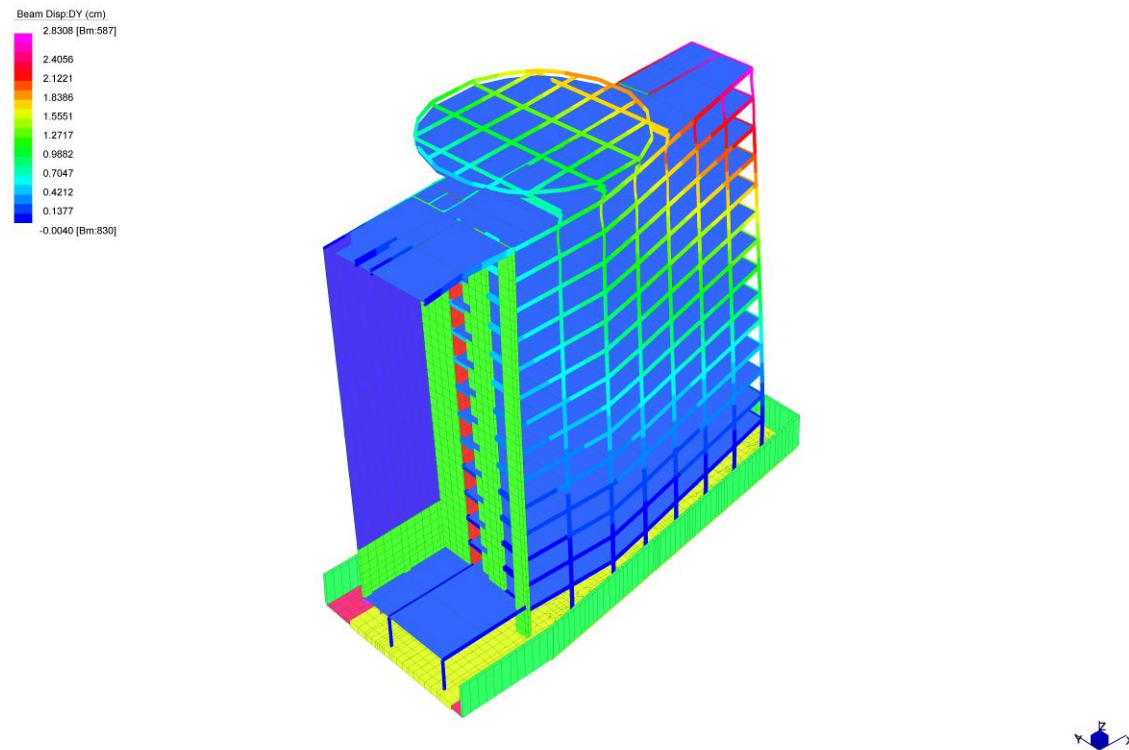
We decided to position a net of  $\varnothing 20\text{mm}$  rebars every 20 cm either on the bottom or on the top of the mat, so you can obtain an image of the place where we have to integrate rebars in the x direction:



## Serviceability Limit State: deflection control

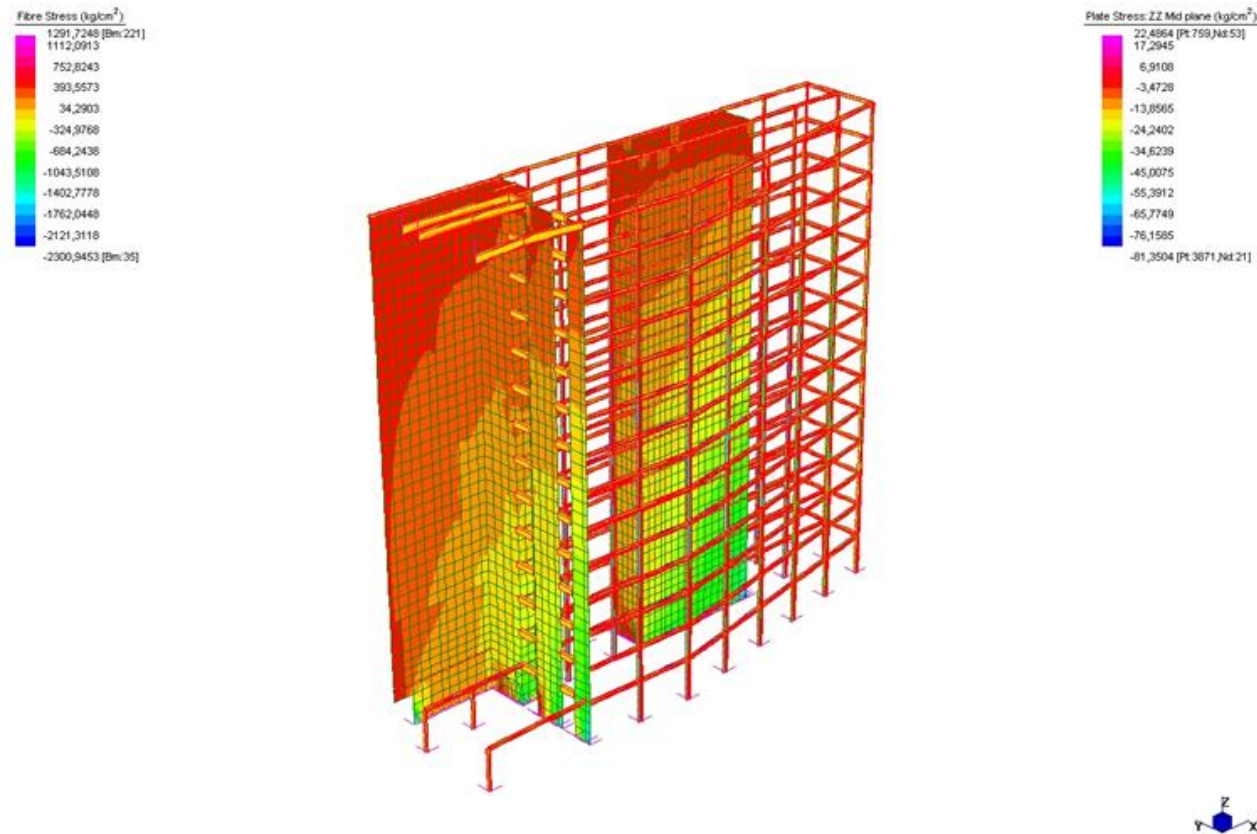
Calculation of deformations under SLS combinations were used to control limitations given by Code. Deflection of the building under wind loads were useful to dimension facades and window elements.

In the following figure the displacements due to wind on the long direction:



## Serviceability Limit State: stress control

Calculation of stress under SLS combinations were used to control limitations given by Code.

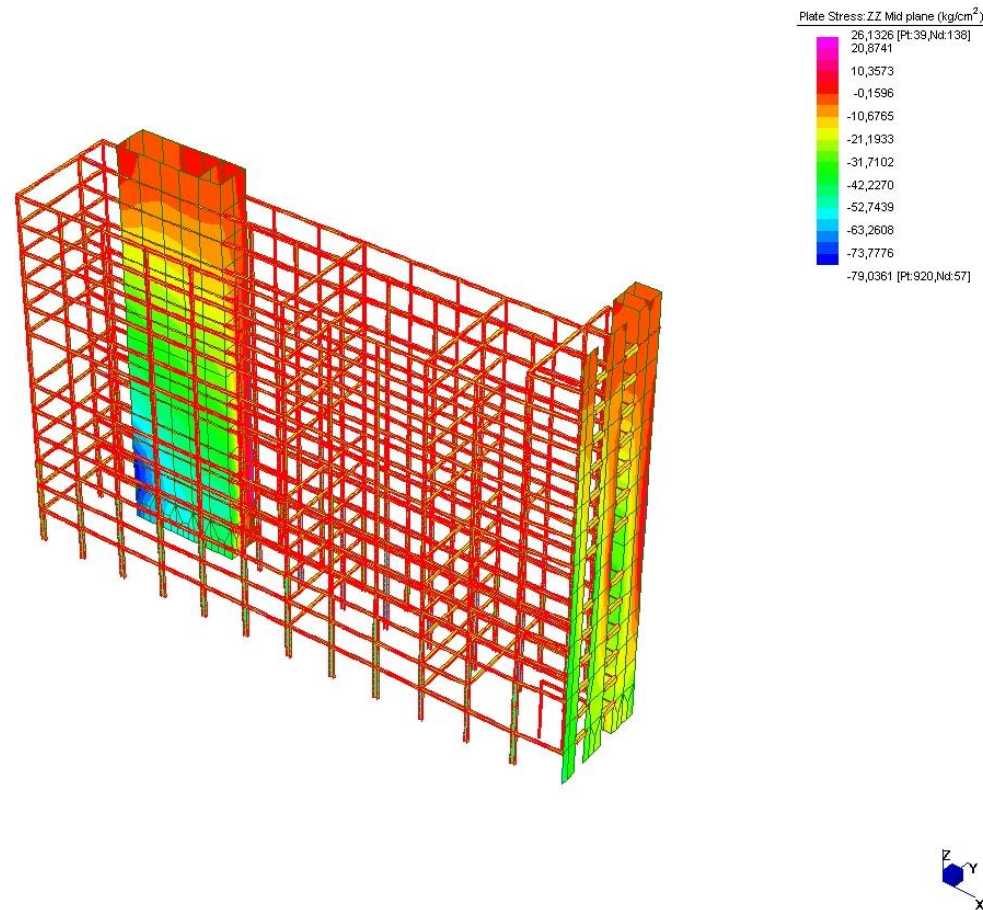


Serviceability limit states: envelope stress in all members

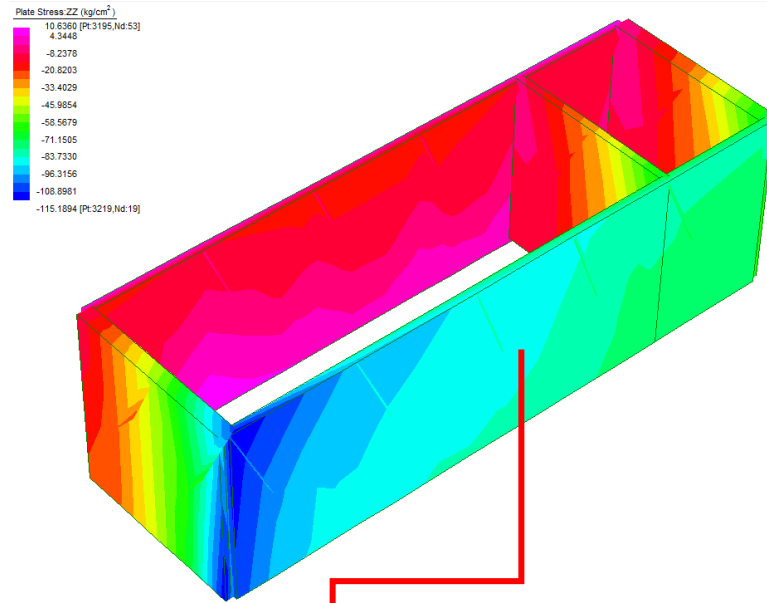
## Lateral bracing system

Calculation of stress under ULS combinations were used to check resistance

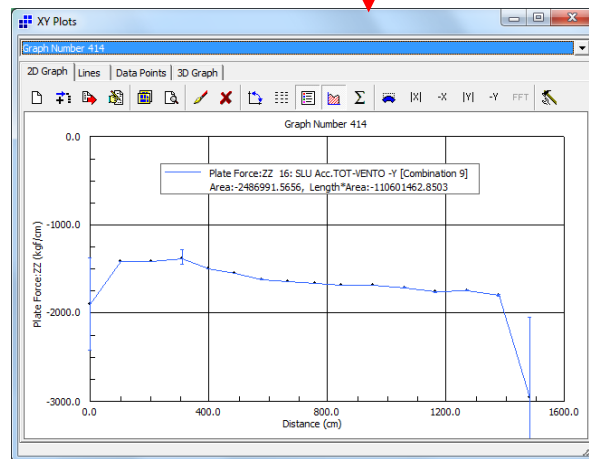
Here we can see the vertical stress in shear walls forming the box shaped cores around stairs and elevators, modelled with plate elements.



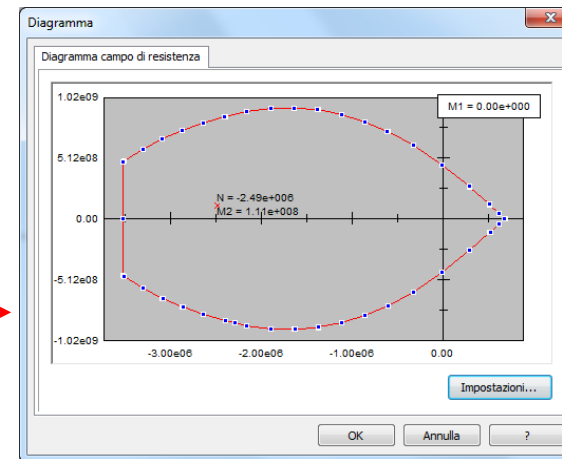
We can see the stress distribution on all the core and the integration of stresses on a wall, to obtain the forces needed to evaluate Ultimate Limit State Resistance:



distribution of stresses in the core



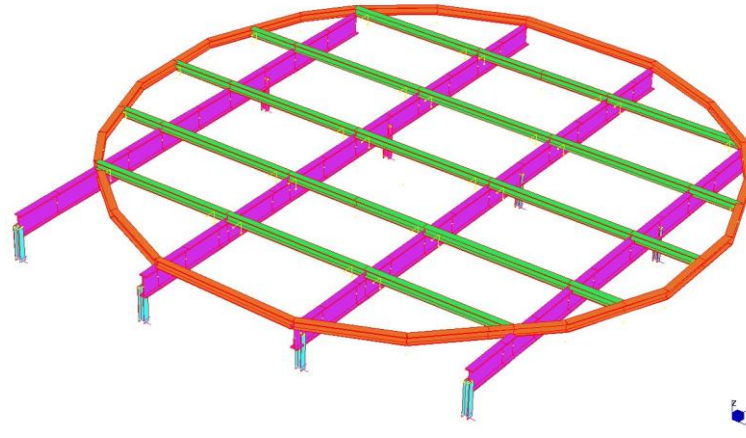
Integration of stresses in the shear wall



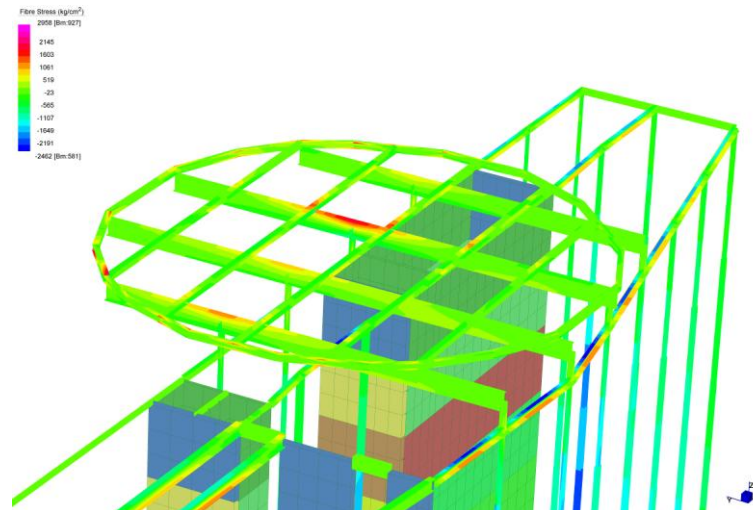
Ultimate Limit State Resistance

## Helicopter landing pad

Live load were given for the helicopter with dynamic action in landing and emergency conditions.  
We can see the cantilever landing pad from the global model:

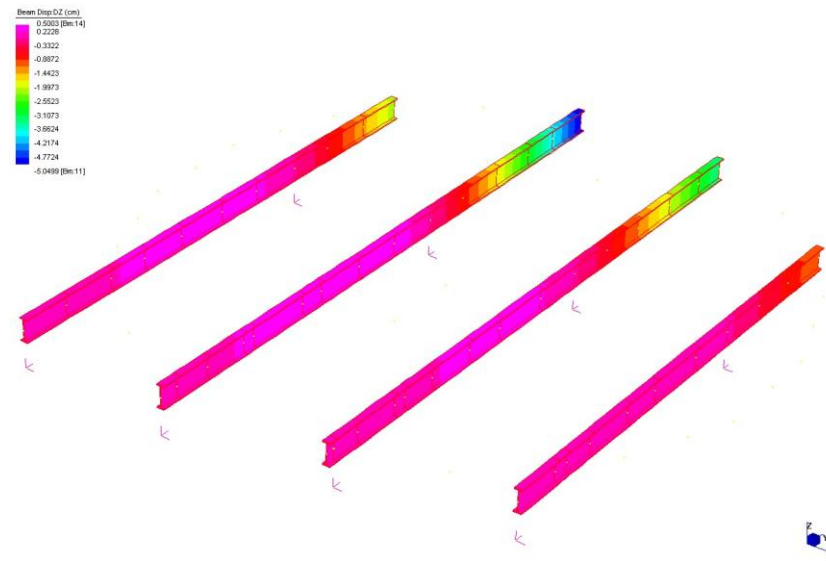


And a global view of the results in terms of stress in ULS conditions:



Cantilever landing pad: envelope stresses in members

In next image there is the simulation of vertical displacements of the cantilever beams, calculated for testing of the structures: they were compared with experimental results.



Vertical displacements

## CONCLUSIONS

The simulations here performed are design-oriented.

They were necessary to give a quick response to structural problems either for the final solutions or for construction problems.

In fact it was usual to be on yard with various models and take decision analysing the partial model in construction phases.

This is a correct way to optimize construction time safely.

With simulation analysis for such a particular structure we could check:

- displacements to correctly dimension window-facades and guaranty serviceability for the whole structure
- resistance and stability for all members



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