MASTER'S THESIS

Structural rehabilitation of the RAI Steel building (Skyscraper) in Turin

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Supervisor: **Candidate:**

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ABSTRACT

In modern times high-rise buildings or “sky-scrapers” are an optimal solution for saving space by occupying space vertically. However, this solution has existed in the developed world for over a century. The same is known for Italy, which is known for its historic infrastructure. Many structures that stand today were constructed with old design standards and codes. Which makes them prone to Lateral loads such as wind and Earthquakes due to insufficient detailing, deterioration of material with time etc. To avoid such a catastrophe, an intervention becomes inevitable, where an evaluation of structural capacity and required retrofitting interventions are done. This Thesis studies a High-rise building in Torino called ‘RAI SKYSCRAPER’, an 18-floor high building near porta-Susa, where we investigate its structural drawings to draw and analyze structural modal, for its evaluation and verification of structural safety. Autodesk Robot Structural Analysis FEM software was used for modelling and analyzing the building. Since Turin is a low seismic zone, the analysis emphasized wind forces. Two models were analyzed, one with modelled foundation and the other with rigid supports. The results that were obtained were compared and a prototype experiment was conducted for checking the outcome of a possible intervention on the core walls of the building. The ‘RAI SKYSCRAPER’ which is unfortunately close due to its use of ASBESTOS- a Fire-resistant that is now known for health hazards- stands perfectly well during its reclamation issues. With all the information provided, despite its detailed and meticulous structural drawings, many missing Members were assumed during the modelling. The level of knowledge lacks proper and clear information and understanding of the connections of beam and column in many places. A comprehensive survey would reveal more details that would be required to precisely assess the building to possibly intervene if necessary to Retrofit one of the iconic buildings of the city of Turin.

In the memory of Ami.

And thanks to Professor Ferro Giuseppe Andrea for being patient with me and letting me grow on my own in this spectacular field of structural engineering.

“What floor, please?” said the elevator man.

“Any floor,” said Mr In.

“Top floor,” said Mr Out.

“This is the top floor,” said the elevator man.

“Have another floor put on,” said Mr Out.

“Higher,” said Mr In.

“Heaven,” said Mr Out.

—F. Scott Fitzgerald, “MayDay”

High-rise, A Brief History

Skyscrapers or High-rise buildings are the epitome of human skills and are an engineering marvel. Skyscrapers portray countries' development or their desire to reach that goal. It not only provides a clever solution to ever-decreasing spaces in a city but in an impactful tells an impactful story of development and prosperity. In all of human existence, there has been an innate human drive to build upward. The Qutub Minar in India, the Mayan temples in Tikal, Guatemala, and the ancient pyramids of Giza in Egypt are just a few examples that forever attest to this tendency. Modern skyscrapers first appeared over a century ago, but it wasn't until after World War II that the necessity for large structures emerged due to fast urbanization and population increase.

Figure 1Home Insurance Building 'wikipedia'

In 1852 the Introduction of the safety elevator by Elisha Otis, which was an improvement from an earlier industrial elevator that was unsafe for passengers, made the construction of taller buildings safer and feasible for residential and official use. The first buildings to be called "skyscrapers" were buildings of steel-framed buildings of at least 10 floors. Such buildings were constructed in the late 19th century in different cities in the United States. Such as New York City, Chicago, Detroit and Philadelphia. The first true skyscraper as we understand it by modern standards was the home insurance building in Chicago. The start of construction started in 1885 when engineer William LeBron Jenney pioneered the design of a 42 meters tall building 1885 for the Home Insurance Building. Some other skyscrapers of that era were 10-storey Jayne Building (1849–50) and New York's seven-floor Equitable Life Assurance Building, which was constructed in 1870.

Figure 2 new York skyline

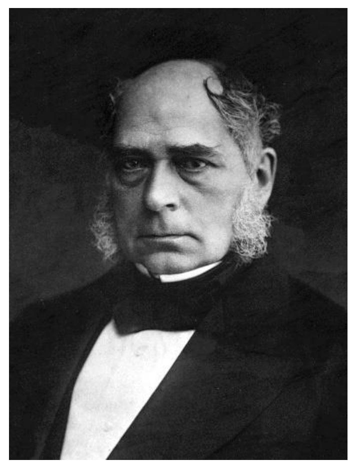


Figure 3 henry bessemer

In 1885 an Englishman Henry Bessemer invented the first process to mass-produce steel inexpensively, which made the construction of skyscrapers was made possible on a large scale. This innovation in the large-scale production of steel allowed builders to make it taller. Modern steel today is still made using technology based on Bessemer's process.

Although the cheaper mass production of steel was the most essential part that paved the way for taller buildings, George A. Fuller was the person who discovered the construction technique that allowed buildings to get taller. He used Bessemer steel beams for the building to act as a load-bearing skeleton. Thus in 1889, Fuller constructed the Tacoma Building, which is the successor of the Home Insurance Building, as it was the First building where walls of the building did not carry its loads.

The Sears Tower, a 110-story, 1450-foot-tall structure in Chicago, was completed in 1974, capping the second wave of tall buildings, which had started in 1956 and were based on new structural design principles and building technologies. The Sears Tower marked the end of the second generation of supertall structures, and only "mixed" construction, which combines steel and reinforced concrete, has been used since. Two examples include the 1667-foot Taipei 101 building, which surpassed Malaysia's Towers as the highest structure on October 17, 2003, and the 1476-foot Petronas Towers, which were constructed in Kuala Lumpur, Malaysia, in 1997.

Figure 4 Burj al Khalifa. Tallest Building in the world

General Description

Grattacielo Rai or RAI SKYSCRAPER is in Turin, Italy. It is located between Via Cernaia and Piazza XVII Decembre, adjacent to Porta-Susa. It was designed by two architects, Aldo Morbelli and Domenico Morelli. The Construction was completed from 1962-1968.

Figure 5 google map view of the Rai Building

When the construction took place, the material that was used for strength and fireproofing ability**,** including concrete, bricks, fireplace cement, pipes and insulation was Asbestos. As we know now that this material is associated with many health hazards.

Breathing asbestos can cause tiny asbestos fibers to get stuck in the lungs and irritate lung tissues. Breathing in asbestos fibers can cause asbestosis, lung cancer and mesothelioma. The risk of contraction of diseases increases with the number of fibers. People who get health problems from inhaling asbestos have usually been exposed to high levels of asbestos for a long time. The symptoms of these diseases do not usually appear until about 20 to 30 years after the first exposure to asbestos.

At the time of construction, the health hazards associated with the inhalation of Asbestos fibers were not yet known, thus an extensive use of asbestos-based materials was done throughout the building. In 2009 an executive died due to an illness related to the inhaling of asbestos material. This led to the beginning of the systematic shifting of the workforce out of the building and in 2016 the building was completely evacuated and sealed for this reason.

50 m x 13.6 m in size, the structure has a rectangular layout with 11 rows of columns on the long side and 4 on the short side. There is a stairway leading up to the main building close to the south-east facade of the structure.

There are few smaller buildings adjacent to the main sky-scrapper. With those building together makes the complex that is of rai building. However, for this thesis we will only Analyze the main rai building.

Table 1 Building Elevation

FLOOR	HIEGHT
ROOF /SHELTER	71.31m
18th	65.310 m
17th	61.310 m
16th	57.310 m
15th	53.810 m
14th	50.310 m
13th	46.810 m
12th	43.310 m
11th	39.810 m
10th	36.310 m
9th	32.810 m
8th	29.310 m
7th	25.810 m
6th	22.310 m
5th	18,810 m
4th	15.310 m
3rd	11.810 m
2nd	8,310 m
1st	4.550 m
1st underground	- 0.90 m
2nd underground	- 4.40 m
foundation	-12.15

METHODOLOGY

EVALUATION OF STRUCTURAL DRAWINGS

The most important step in structurally analyzing was to evaluate the knowledge that was in hand. For this thesis, it was the structural drawings that are the only source of knowledge provided. With this limited knowledge. It was decided to make to limit the thesis to preliminary structural analysis to pave the way for future interventions in order to increase the precision of the knowledge and any structural faults that may in the building for providing any proper retrofitting if required for the building.

From dozens of drawings that were provided, SOP no. 'Tav_35958' was the one that I considered to be the most important as it provided a comprehensive view from all sides of the building and provided every structural member labelled with the name of the sop drawing that member. The name of the drawings that showcases the detail structural components for example beams, columns and bracings were provided in this sop drawing.

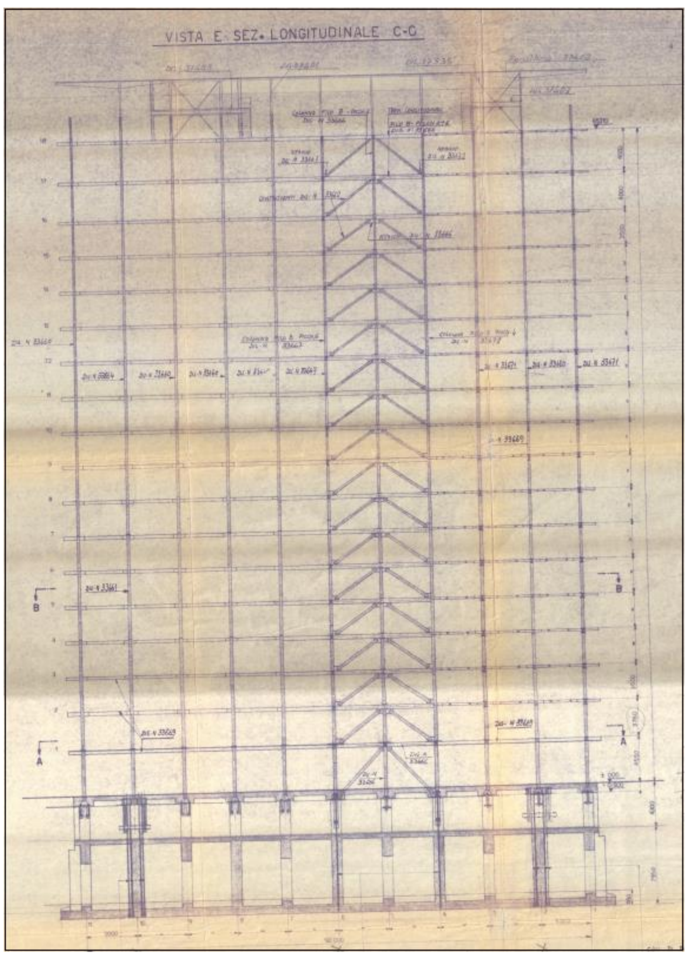


Figure 6 Main building front view

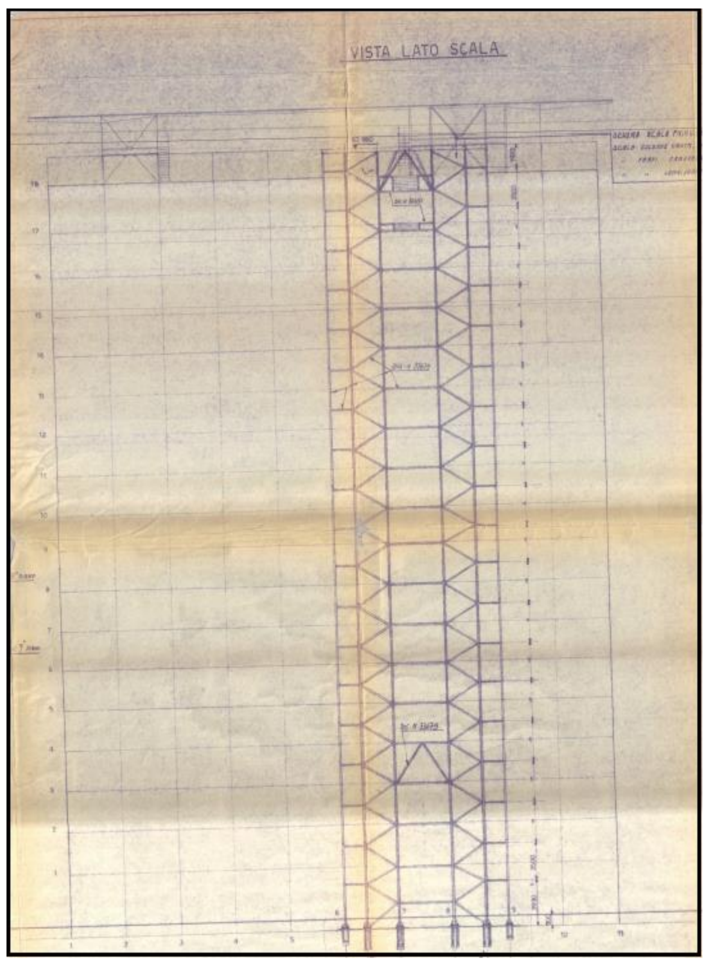


Figure 7 Main building back view

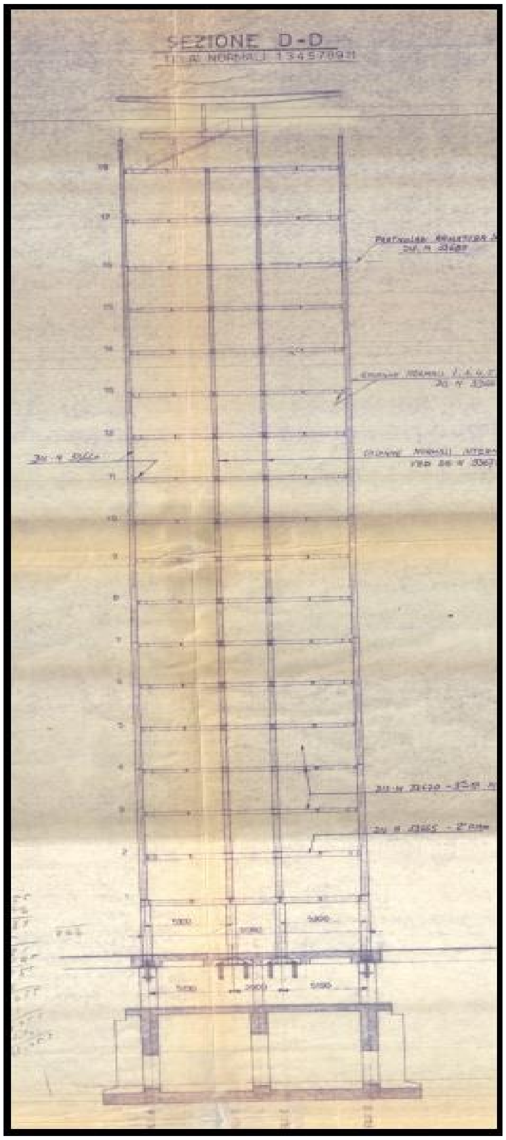


Figure 8 Main Building Side view

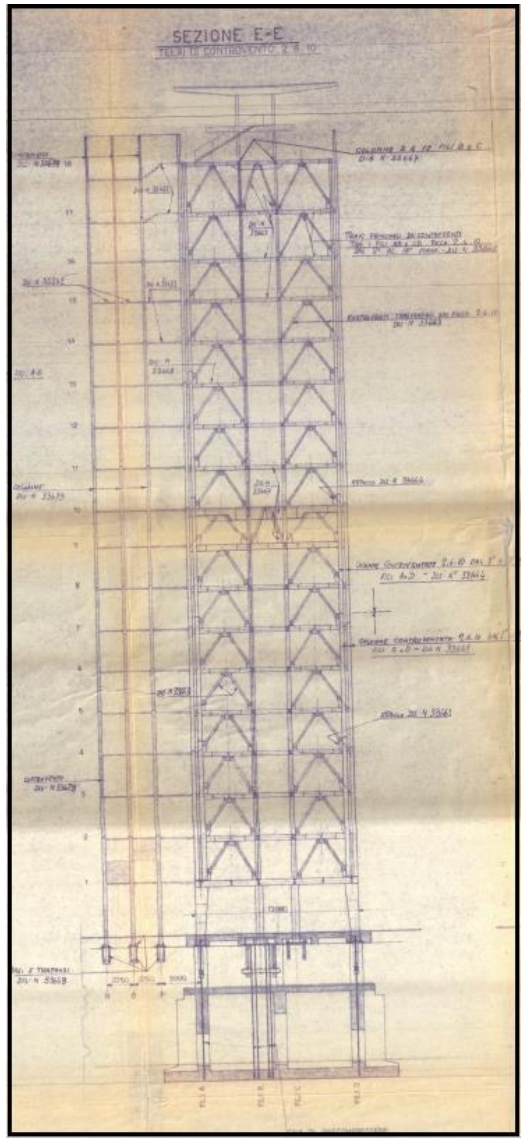


Figure 5 Main Building side view

Taking this drawing as the guideline it was much easier to navigate through all the information that was provided. One needs to take note of the fact that all the possible structural members that are labeled in Tav_35958 were not in reality present or those drawings were in such a bad conditions that it was impossible to comprehend its contents.

COLUMNS

In order to start investigating the drawings for modeling the structure, by using Tav_35958 as the guideline I started investigation columns. All the columns are rectangular hollow with certain thickness.

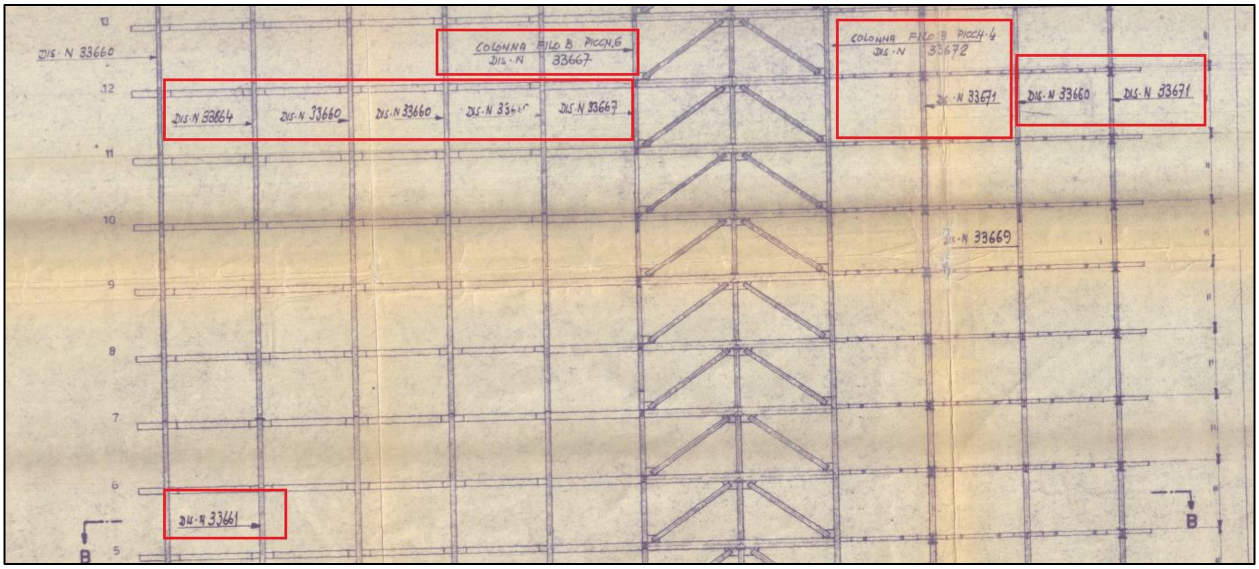


Figure 9 Tav 35958 view sheet

The structural drawing that was labelled for different columns are:

Tav_33661

Tav_33664

Tav_33660

Tav_33667

Tav_33671

Tav_33672

Among above-mentioned drawings Tav_33664 Tav_33667 are not available.

In the present structural drawings, the location of any columns is located by top view and sectional view/side view of the building. With exact mark where the columns are located. One more expects of the building is that the dimensions any columns change according to the story of the building. Which is also properly marked in the drawing.

The following figures are from tav_33661 they show double-rectangle columns at the 'filo' A and D, for the column number 2,6 and 10.

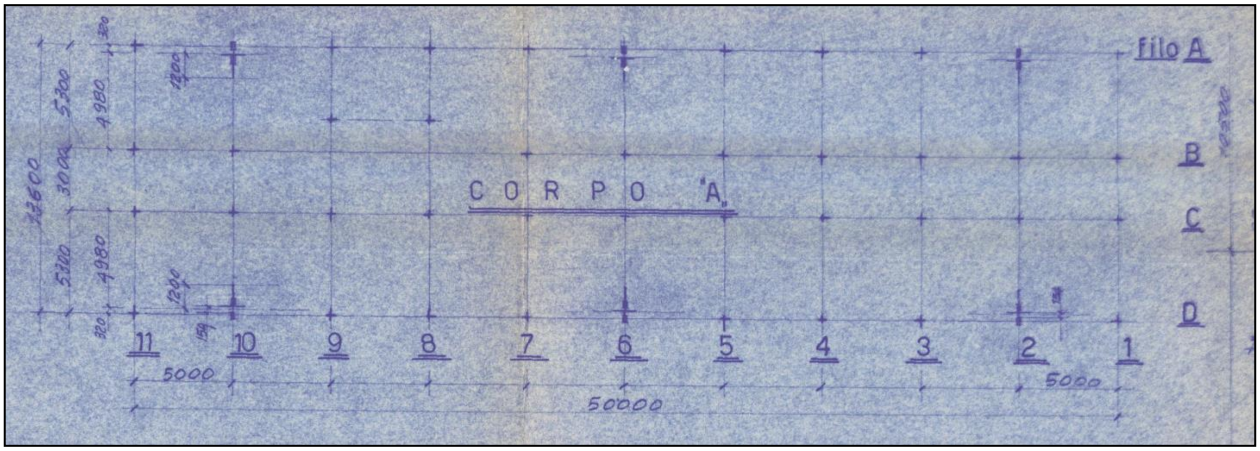


Figure 10 tav 33661

Table 2 Dimension of Columns

Story	Breadth (cm)	width (cm)	thickness(cm)
1	38.0	26.6	1.8
2	38.0	26.6	1.8
3	38.0	26.6	1.8
4	36.0	25.2	1.2
5	36.0	25.2	1.2
6	36.0	25.2	1.2
7	32.0	23.0	1.0
8	32.0	23.0	1.0
9	32.0	23.0	1.0
10	30.0	22.4	0.8
11	30.0	22.4	0.8
12	30.0	22.4	0.8
13	30.0	21.0	0.6
14	30.0	21.0	0.6
15	30.0	21.0	0.6
16	28.0	19.6	0.6
17	28.0	19.6	0.6
18	38.0	26.6	1.8

Tav_33671

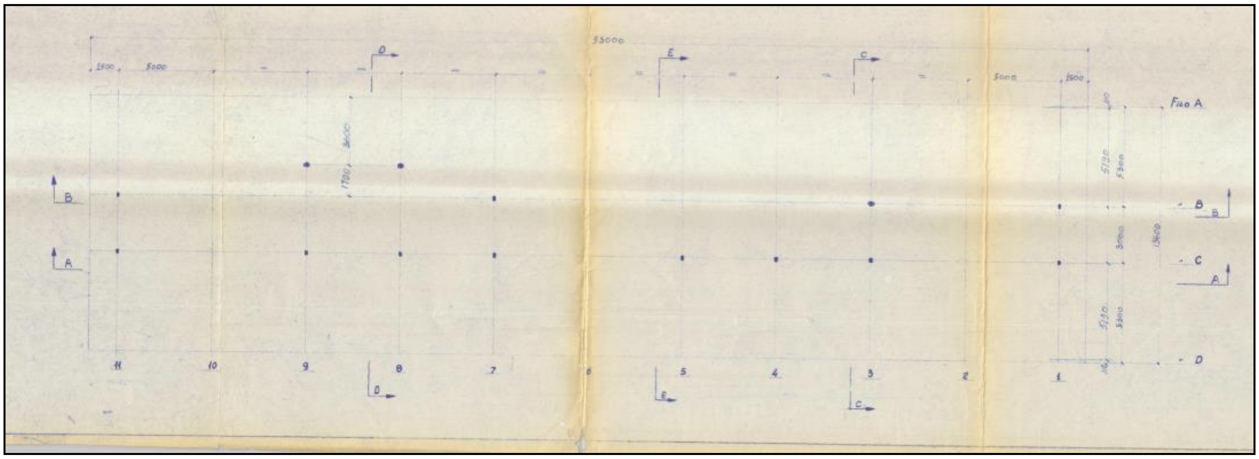


Figure 11 tav_33671

Table 3 dimensions of interior columns

Story	Breadth (cm)	width (cm)	thickness(cm)
1	38.0	26.6	1.2
2	38.0	26.6	1.2
3	38.0	26.6	1.2
4	36.0	25.2	1.0
5	36.0	25.2	1.0
6	36.0	25.2	1.0
7	34.0	23.8	1.0
8	34.0	23.8	1.0
9	34.0	23.8	1.0
10	34.0	22.4	0.8
11	34.0	22.4	0.8
12	34.0	22.4	0.8
13	34.0	22.4	0.8
14	30.0	21.0	0.6
15	30.0	21.0	0.6
16	30.0	21.0	0.6
17	28.0	19.0	0.6
18	28.0	19.0	0.6

Tav_33672

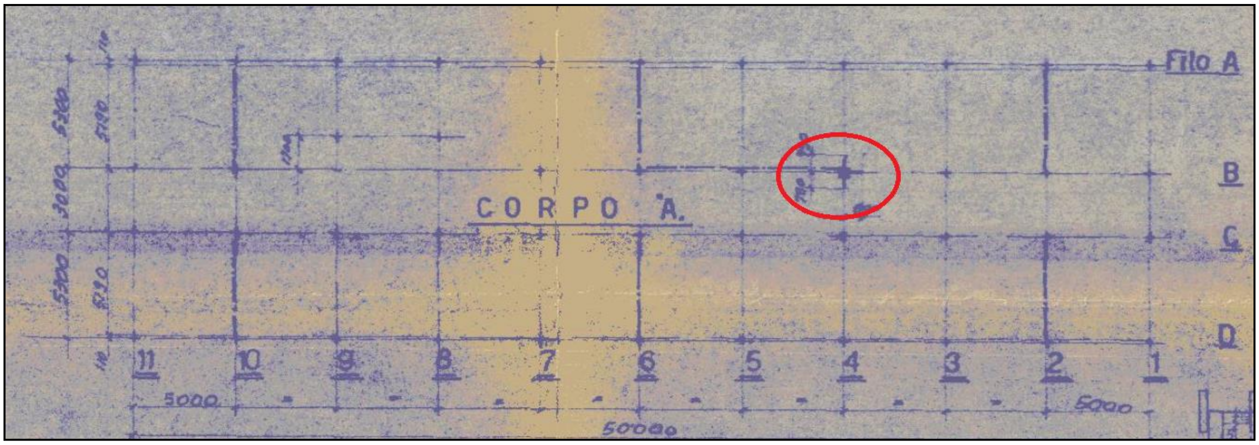


Figure 12 tav_33672

Table 4 Interior columns

Story	Breadth (cm)	width (cm)	thickness(cm)
1	38.0	25.0	3.4
2	38.0	25.0	3.4
3	38.0	25.0	3.4
4	38.0	25.0	3.4
5	36.0	25.2	3.0
6	36.0	25.2	3.0
7	36.0	25.2	3.0
8	34.0	29.8	2.4
9	34.0	29.8	2.4
10	34.0	29.8	2.4
11	32.0	22.4	1.8
12	32.0	22.4	1.8
13	32.0	22.4	1.8
14	30.0	21.0	1.2
15	30.0	21.0	1.2
16	30.0	21.0	1.2
17	30.0	21.0	1.2
18	30.0	21.0	1.2

Tav_33660

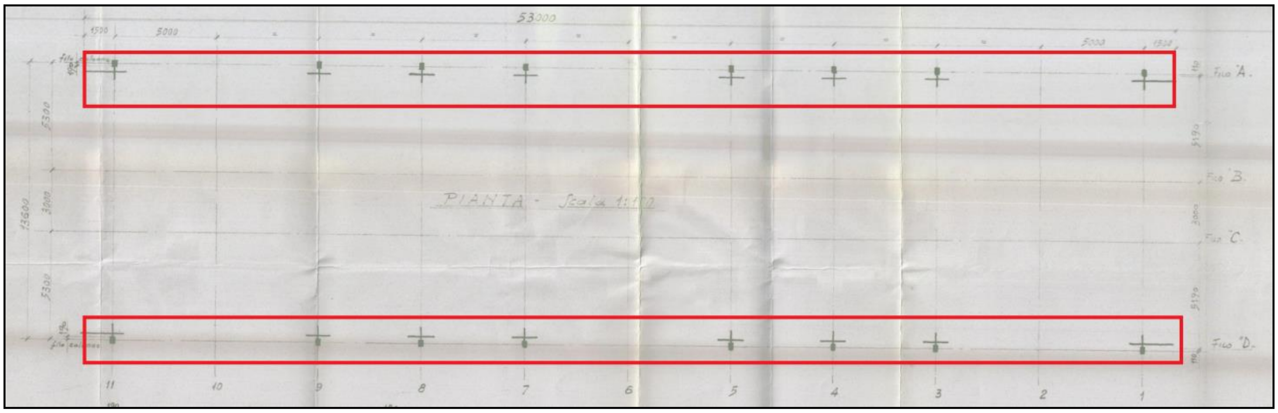


Figure 13 Tav 33660

Table 5 Exterior columns

Story	Breadth (cm)	width (cm)	thickness(cm)
1	38.0	26.6	1.6
2	38.0	26.6	1.6
3	38.0	26.6	1.6
4	38.0	26.6	1.6
5	36.0	25.2	1.4
6	36.0	25.2	1.4
7	36.0	25.2	1.4
8	34.0	23.8	1.4
9	34.0	23.8	1.4
10	34.0	23.8	1.4
11	32.0	22.4	1.2
12	32.0	22.4	1.2
13	32.0	22.4	1.2
14	30.0	21.0	1.0
15	30.0	21.0	1.0
16	28.0	19.6	1.0
17	28.0	19.6	1.0
18	28.0	19.6	1.0

The remaining columns were properly assumed as there was no information. As shown below:

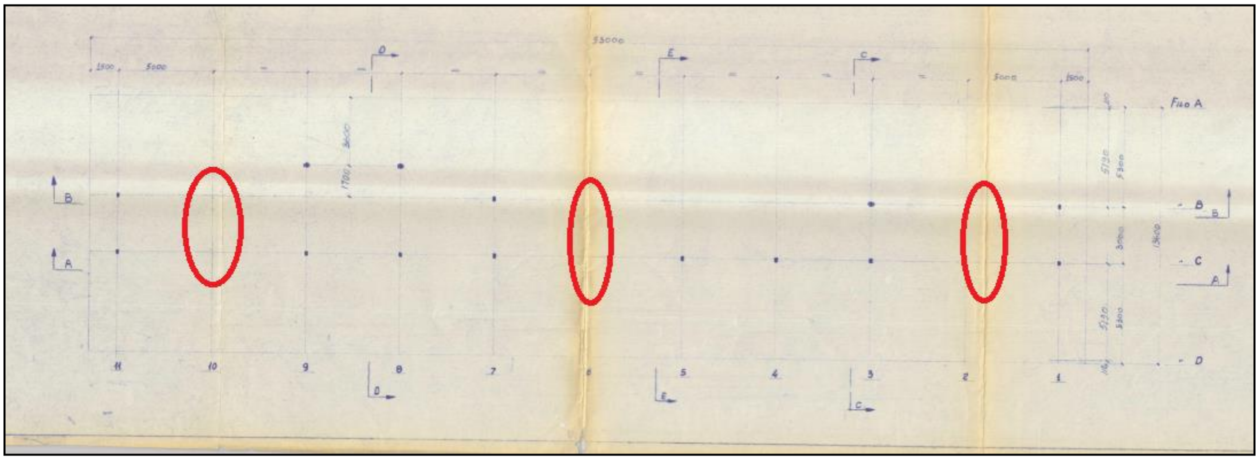


Figure 14 Missing Column

Table 6 Assumed Interior Column Dimension

Story	Breadth (cm)	width (cm)	thickness(cm)
1	33.0	26.6	1.5
2	33.0	26.6	1.5
3	33.0	26.6	1.5
4	33.0	26.6	1.5
5	33.0	26.6	1.5
6	33.0	26.6	1.5
7	33.0	26.6	1.5
8	33.0	26.6	1.5
9	33.0	26.6	1.5
10	33.0	26.6	1.5
11	33.0	26.6	1.5
12	33.0	26.6	1.5
13	33.0	26.6	1.5
14	33.0	26.6	1.5
15	33.0	26.6	1.5
16	33.0	26.6	1.5
17	33.0	26.6	1.5
18	33.0	26.6	1.5

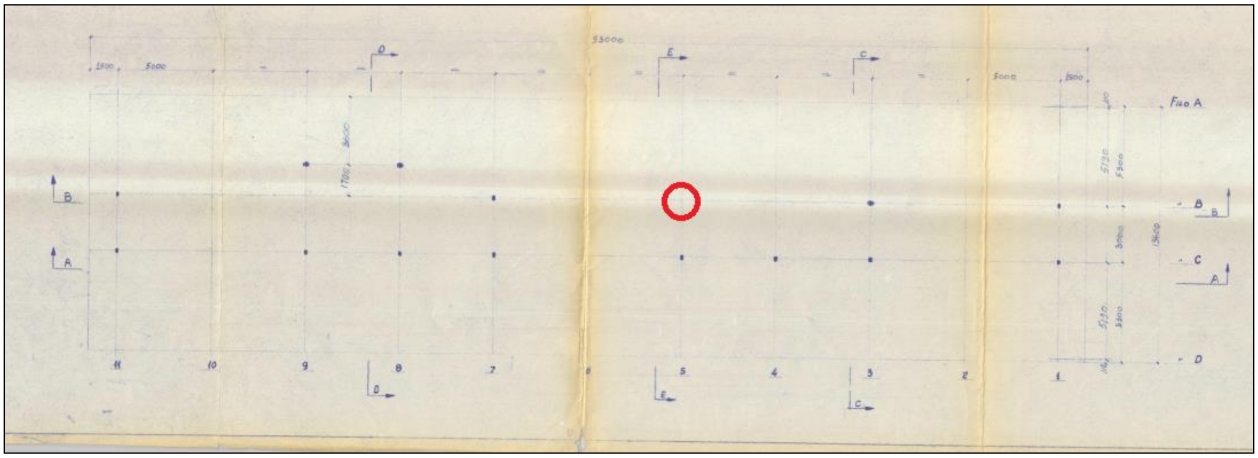


Figure 15 Missing Column

Table 7 Interior Column Dimension

Story	Breadth (cm)	width (cm)	thickness(cm)
1	38.0	25.0	3.4
2	38.0	26.6	1.2
3	38.0	26.6	1.2
4	38.0	26.6	1.2
5	36.0	25.2	1.0
6	36.0	25.2	1.0
7	36.0	25.2	1.0
8	34.0	23.8	1.0
9	34.0	23.8	1.0
10	34.0	23.8	1.0
11	32.0	22.4	0.8
12	32.0	22.4	0.8
13	32.0	22.4	0.8
14	30.0	21.0	0.6
15	30.0	21.0	0.6
16	30.0	21.0	0.6
17	30.0	19.6	0.6
18	30.0	19.6	0.6

BEAMS

The same methodology was used to evaluate and extract information of the beam.

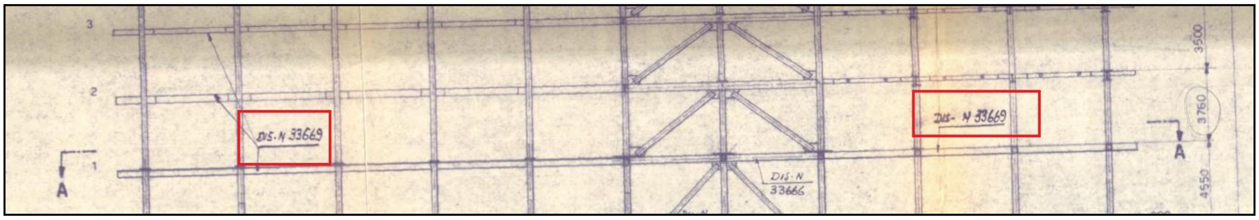


Figure 16 Main structural sheet

Tav_33669

Longitudinal beams for the buildings were provided in the following tav_33669

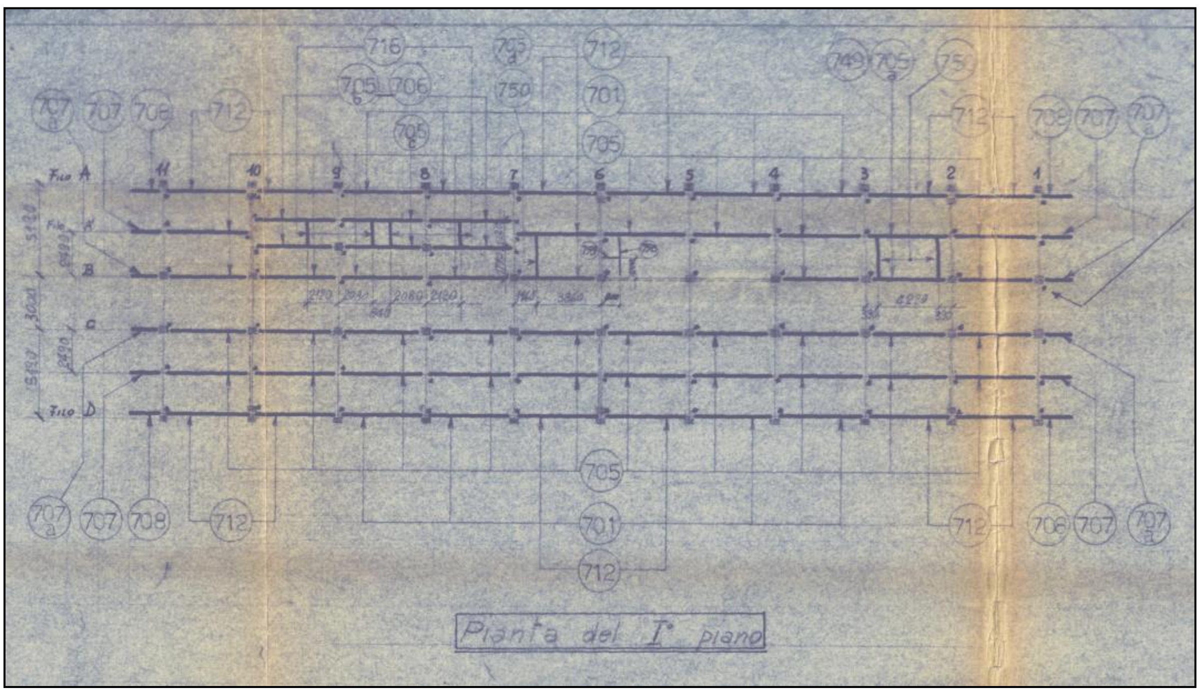


Figure 17 Tav 33669

for 2nd floor:

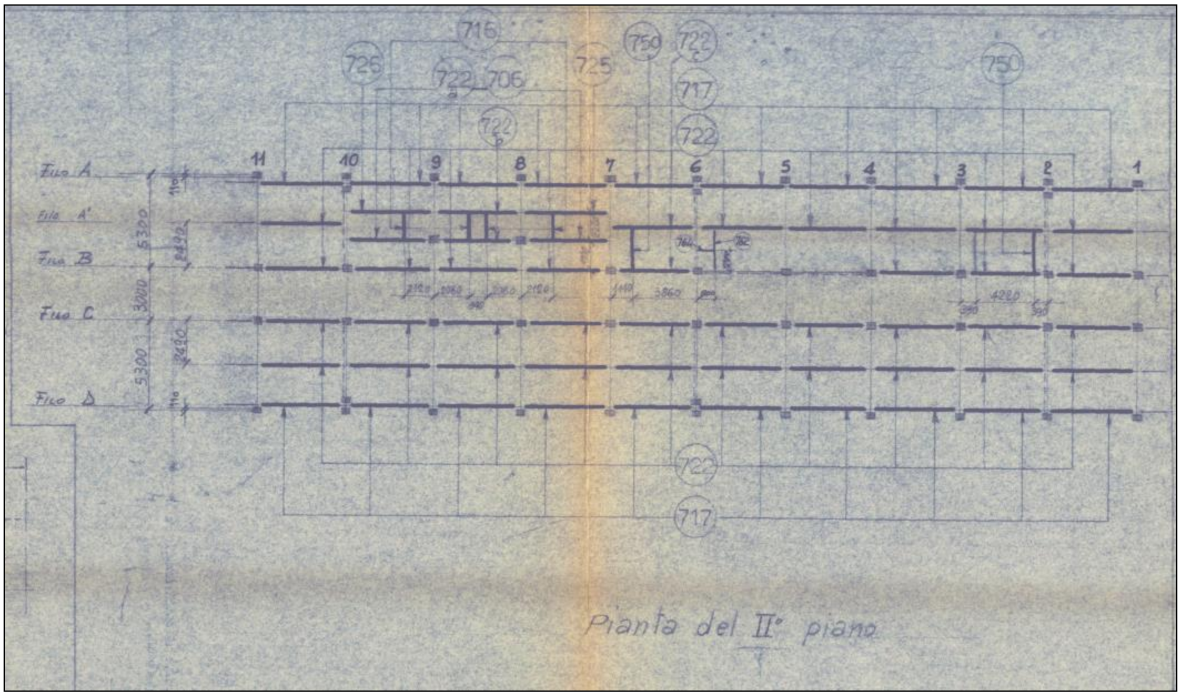


Figure 18 Tav 33669 for 2nd floor

from 3 to 18th floor:

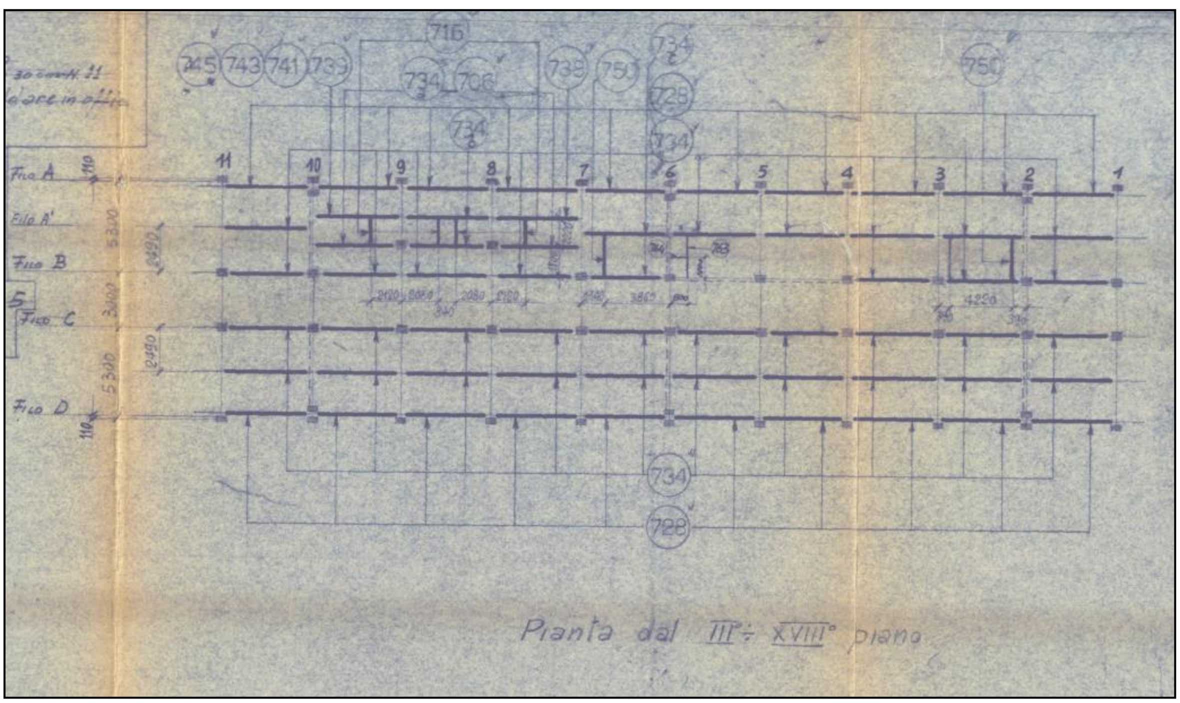


Figure 19 Tav 33669 3rd to 18th floor

Table 8 Dimensions for the beams

story	type of beam	b(cm)	hw(cm)	tw(cm)	tf(cm)
1	C (708)	10	36	1.4	2
	C (712)	10	36	1.4	2
	C(700)	10	36	1.4	2
	I (IPN 280)				
	I (IPN 200)				
	I (IPN 180)				
2	C(728)	10	28.8	1	1.6
	C(708)	10	36	1.4	2
	I (IPN 220)				
	I (IPN 280)				
	I (IPN 425)				
	I (IPN 180)				
3 to 18	C(728)	10	28.8	1	1.6
	C(708)	10	36	1.4	2
	I (IPN 220)				
	I (IPN 280)				
	I (IPN 425)				
	I (IPN 180)				

tav_33670

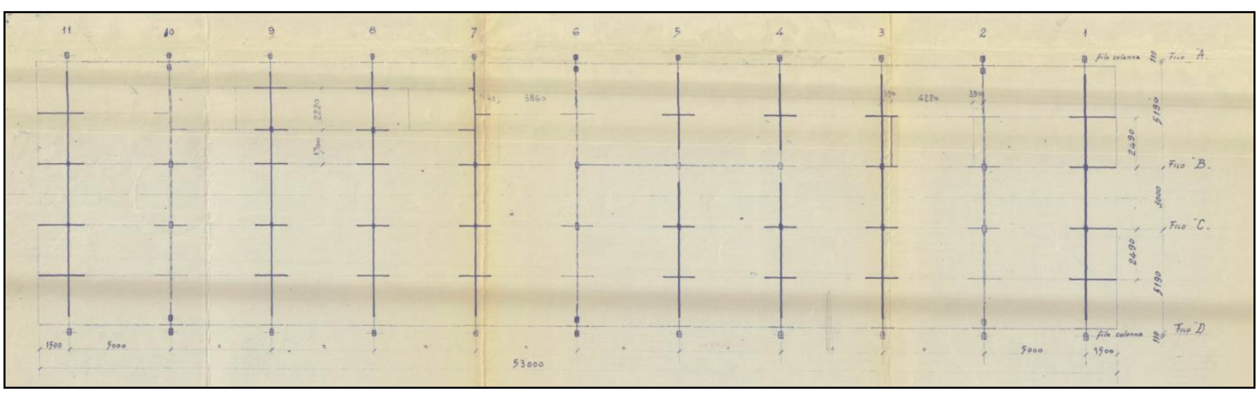


Figure 20 Tav 33670

This drawing shows the beams that are normal in direction to the longitudinal drawings that we saw in the previous drawing.

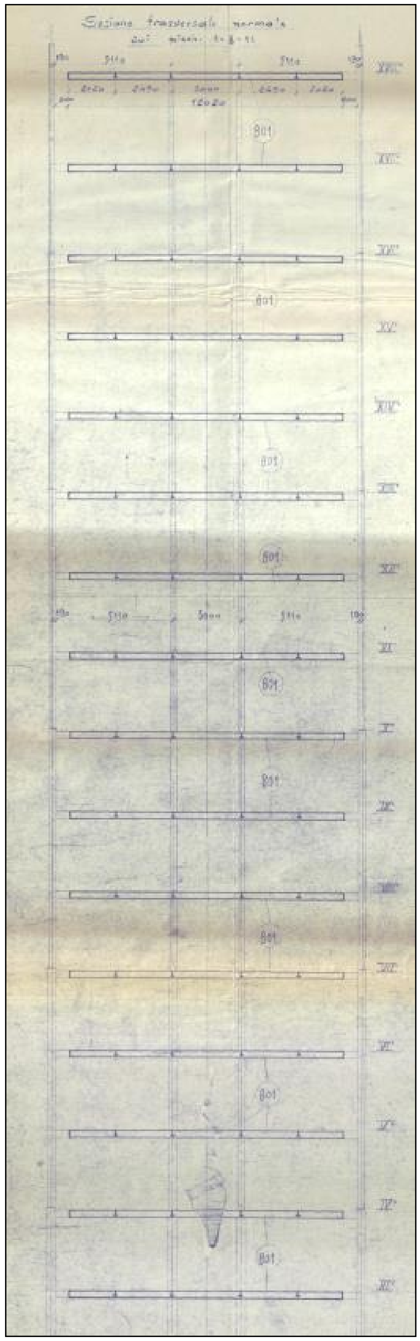


Figure 21 longitudinal beams

Table 9 longitudinal Beam Dimension

story	name of beam	type of beam
1st -18th	801	IPN 320

Transverse beam shown in the figure shown are similar except for sections at “picch”-4,5,7,8 and 9 shown below:

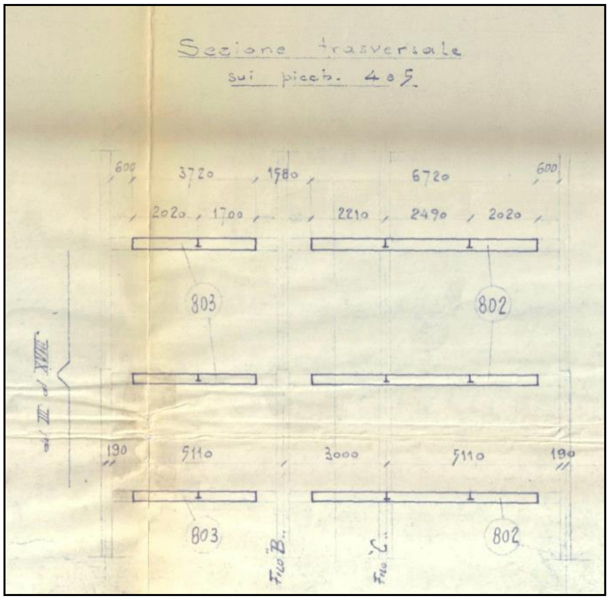


Figure 22 transverse sections picch 4-5-7-8-9

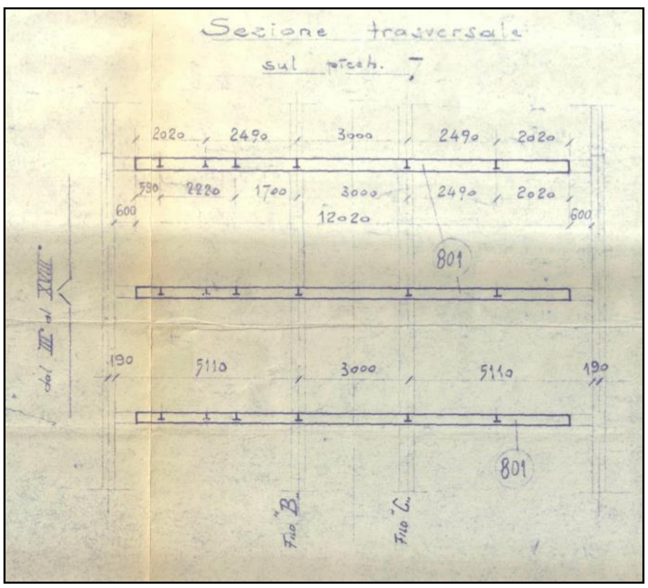


Figure 23 transverse sections

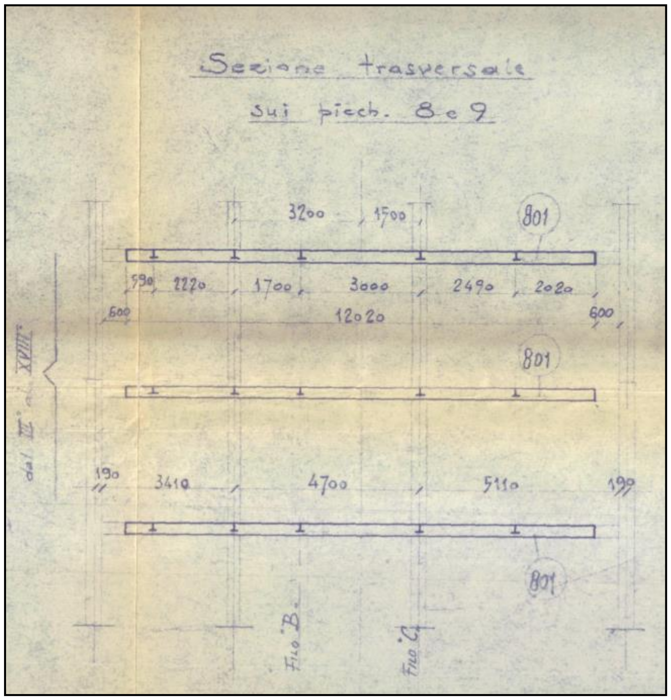
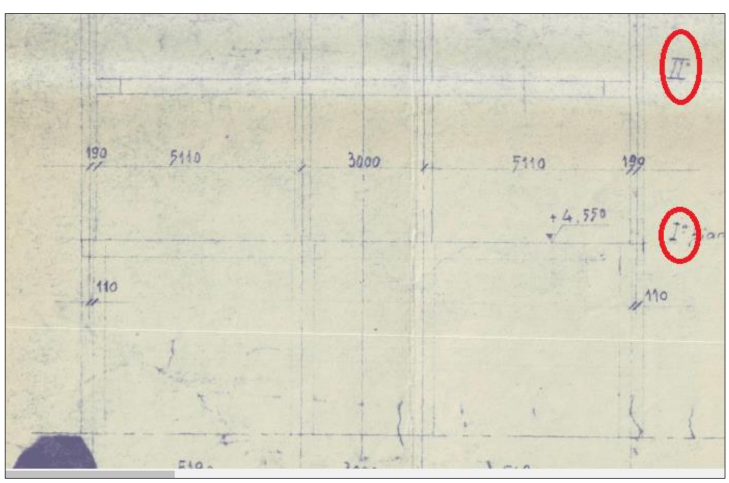


Figure 24 section picch 8-9

Table 10 transverse beam type

story	name of beam	type of beam
3rd -18th	802	IPN 320
3rd -18th	803	IPN 320
3rd -18th	801	IPN 320

One thing to note is that the beams start from the 3rd from that means that transverse beams for the 1st three floor were missing which were assumed after accordingly.



For the missing transverse beams in 1st and 2nd floors, I assumed IPN 340 considering the structural pattern of the building, larger sections are used in the lower section and as we observe the building towards the top.

One of the most important beams that are missing are the one spotted below:

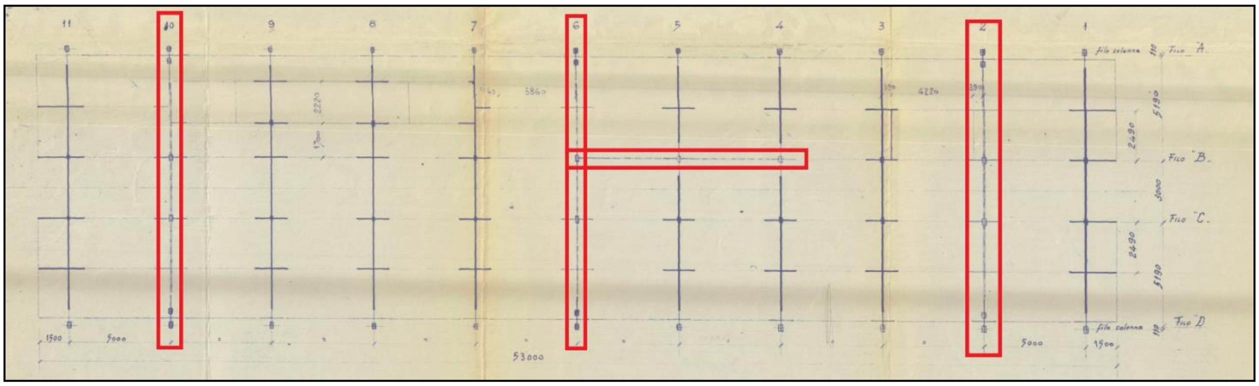


Figure 25 Transverse beam of bracing Frame

Table 11 Beams of bracing Frame

story	type of beam
1st-2nd	IPN 380
3rd -18th	IPN 340

From the “picch” 2,6,10 where we have the double hollow rectangular columns, the beams were larger in section then other transversal beams because as there bracing element present over them.

For the longitudinal beam highlighted above from 1st story to the last I assumed IPN 425.

BRACING

These diagonal elements were provided in three places in transverse direction and at one in longitudinal direction.

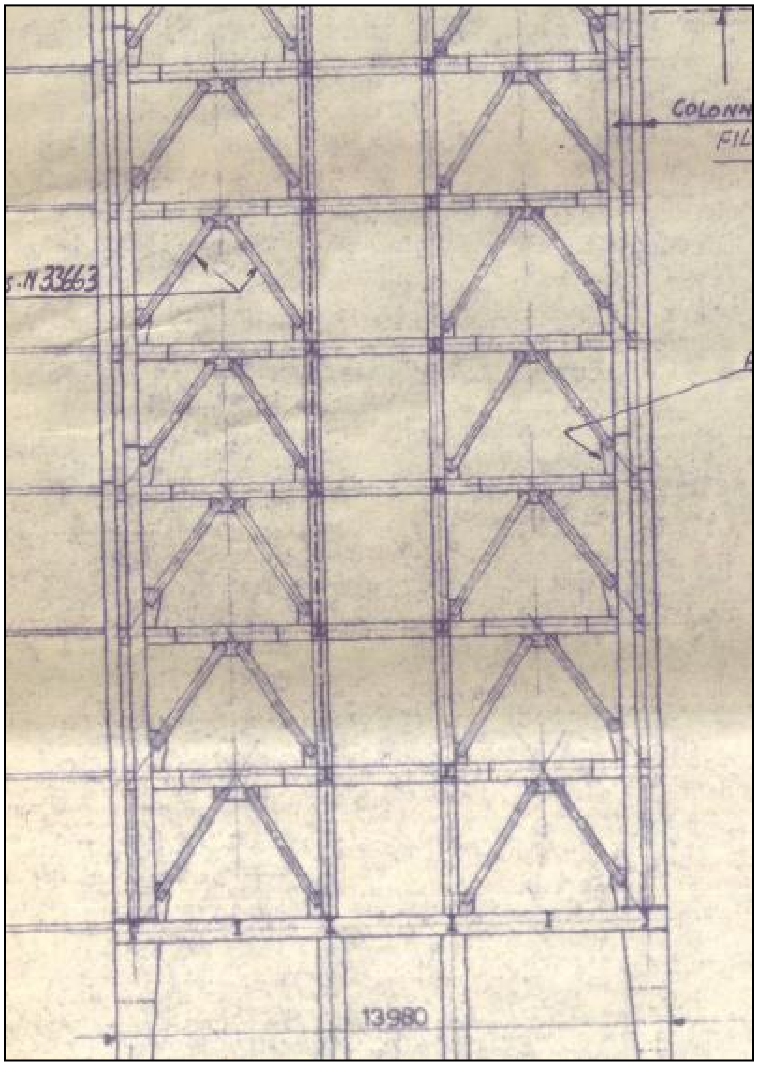


Figure 26 Bracing from the Main Structural sheet

All the drawings for bracing elements were not available except for the longitudinal bracings.

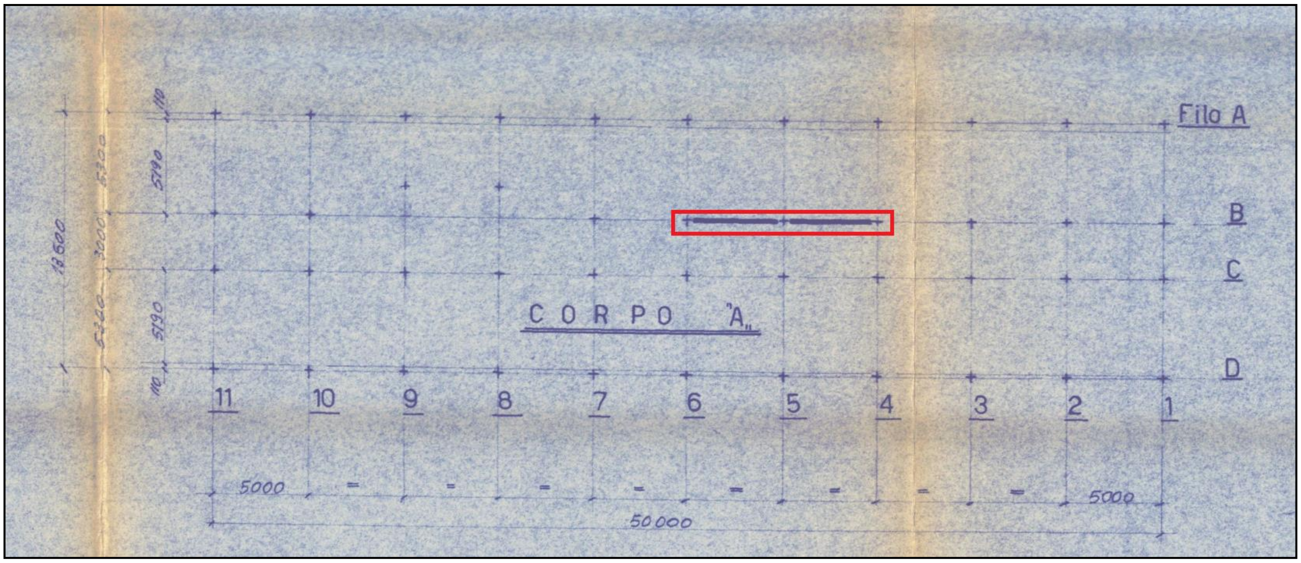


Figure 27 Beam of longitudinal bracing Frame

Table 12 Dimension of Beam for longitudinal Frame

story	type of beam	diameter(cm)	thickness(cm)
1	circle	29.2	1.2
2	circle	29.2	1
3	circle	29.2	1
4	circle	29.2	1
5	circle	29.2	0.8
6	circle	29.2	0.8
7	circle	29.2	0.8
8	circle	26.7	0.75
9	circle	26.7	0.75
10	circle	26.7	0.75
11	circle	24.1	0.75
12	circle	24.1	0.75
13	circle	24.1	0.75
14	circle	24.1	0.6
15	circle	24.1	0.6
16	circle	24.1	0.6
17	circle	21.6	0.55
18	circle	21.6	0.55

However transverse bracings structural drawings were missing. Therefore, I approximated the transverse bracings same with the longitudinal bracings. These bracings are in yellow circles below.

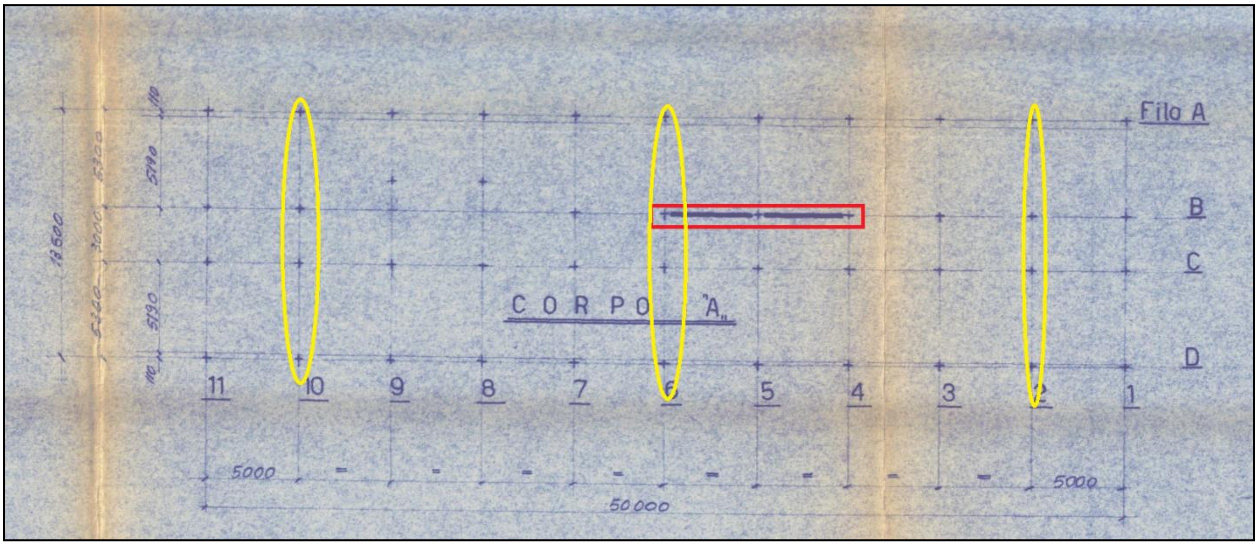


Figure 28 Missing Bracings

Table 13 Assuming Bracings Dimension

story	type of beam	diameter(cm)	thickness(cm)
1	circle	29.2	1.2
2	circle	29.2	1
3	circle	29.2	1
4	circle	29.2	1
5	circle	29.2	0.8
6	circle	29.2	0.8
7	circle	29.2	0.8
8	circle	26.7	0.75
9	circle	26.7	0.75
10	circle	26.7	0.75
11	circle	24.1	0.75
12	circle	24.1	0.75
13	circle	24.1	0.75
14	circle	24.1	0.6
15	circle	24.1	0.6
16	circle	24.1	0.6
17	circle	21.6	0.55
18	circle	21.6	0.55

STAIRCASE BUILDING

The documentations for are not fully available so the geometric elements and their dimensions are assumed at certain places and accurate.

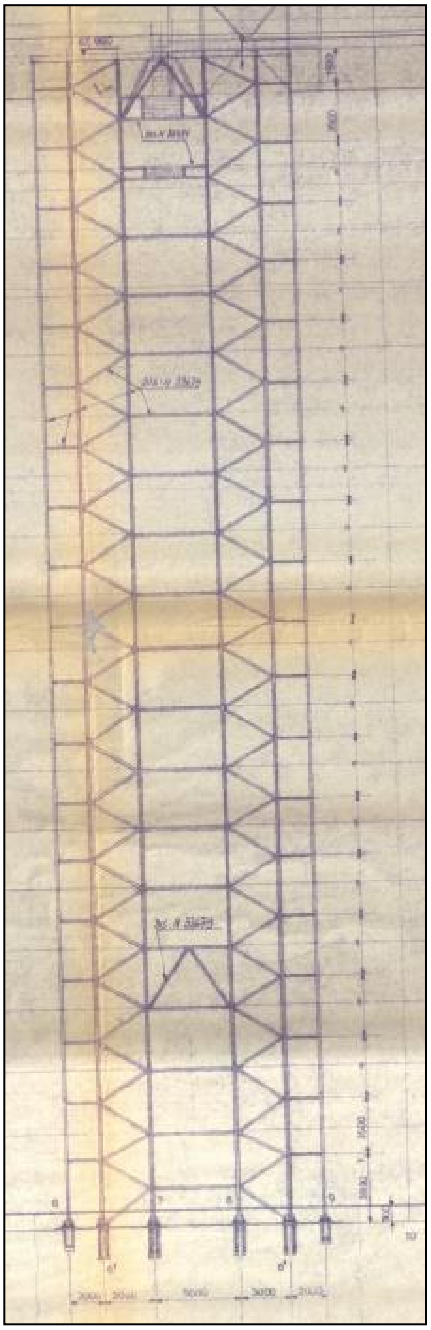


Figure 29 Main Stair Building view

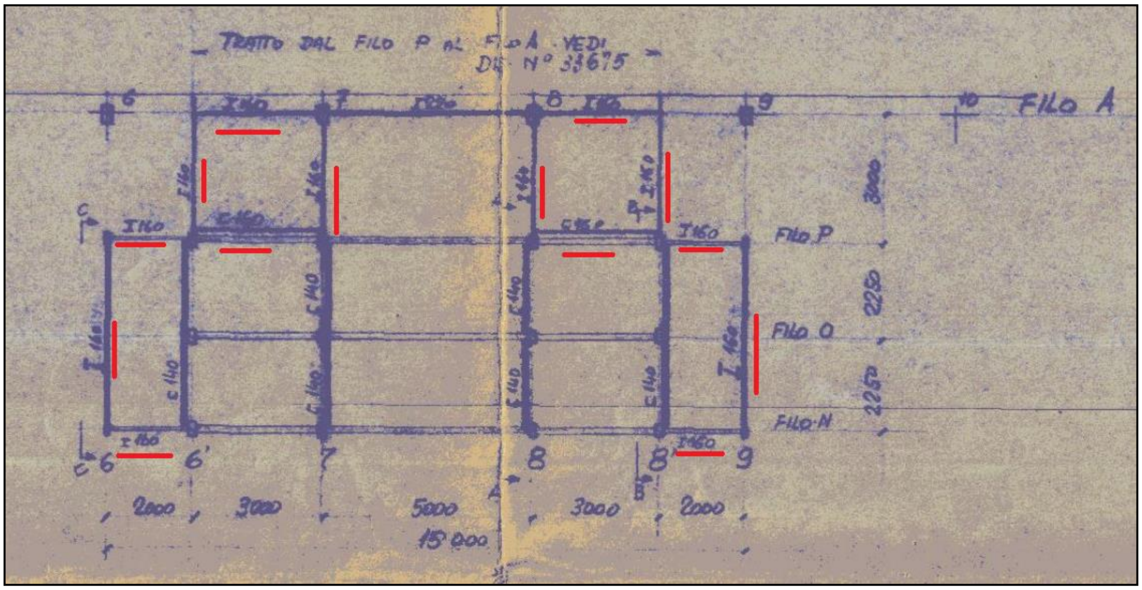


Figure 30 Tav-35242 Exterior Beam

Table 14 Exterior Beam Dimension

story	type of beam
1	IPN 160
2	IPN 160
3	IPN 160
4	IPN 160
5	IPN 160
6	IPN 160
7	IPN 160
8	IPN 160
9	IPN 160
10	IPN 160
11	IPN 160
12	IPN 160
13	IPN 160
14	IPN 160
15	IPN 160
16	IPN 160
17	IPN 160
18	IPN 160

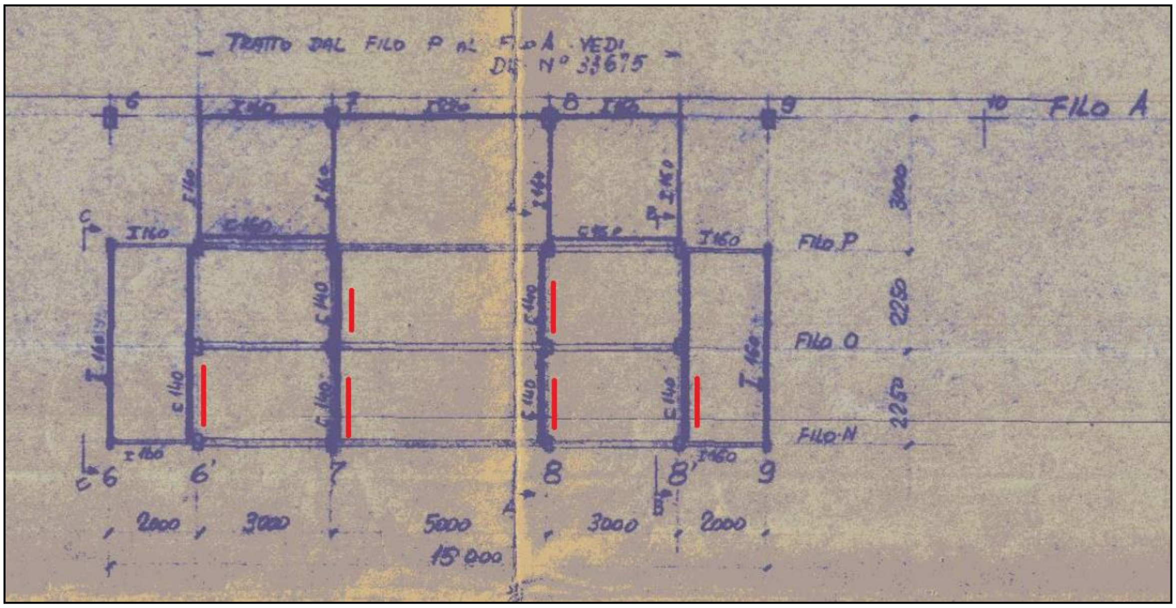


Figure 31 Tav-35242 Interior Beam

Table 15 Dimensions of stair Interior Beam

story	type of beam
1	UPN 140
2	UPN 140
3	UPN 140
4	UPN 140
5	UPN 140
6	UPN 140
7	UPN 140
8	UPN 140
9	UPN 140
10	UPN 140
11	UPN 140
12	UPN 140
13	UPN 140
14	UPN 140
15	UPN 140
16	UPN 140
17	UPN 140
18	UPN 140

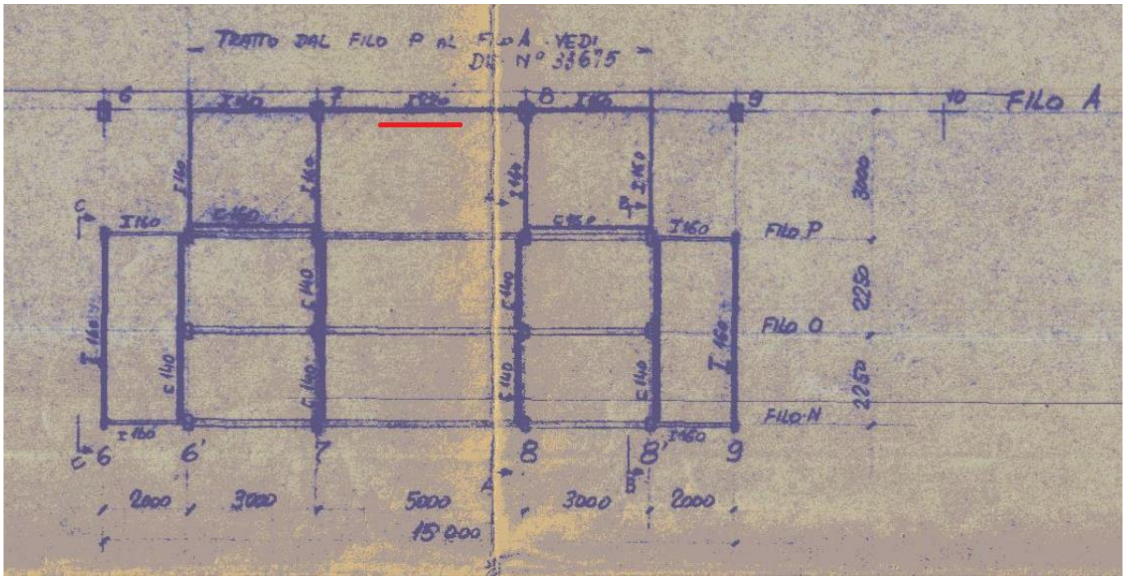


Figure 32 Tav-35242 out-line Beam

Table 16 out-line Beam

story	type of beam
1	IPN 220
2	IPN 220
3	IPN 220
4	IPN 220
5	IPN 220
6	IPN 220
7	IPN 220
8	IPN 220
9	IPN 220
10	IPN 220
11	IPN 220
12	IPN 220
13	IPN 220
14	IPN 220
15	IPN 220
16	IPN 220
17	IPN 220
18	IPN 220

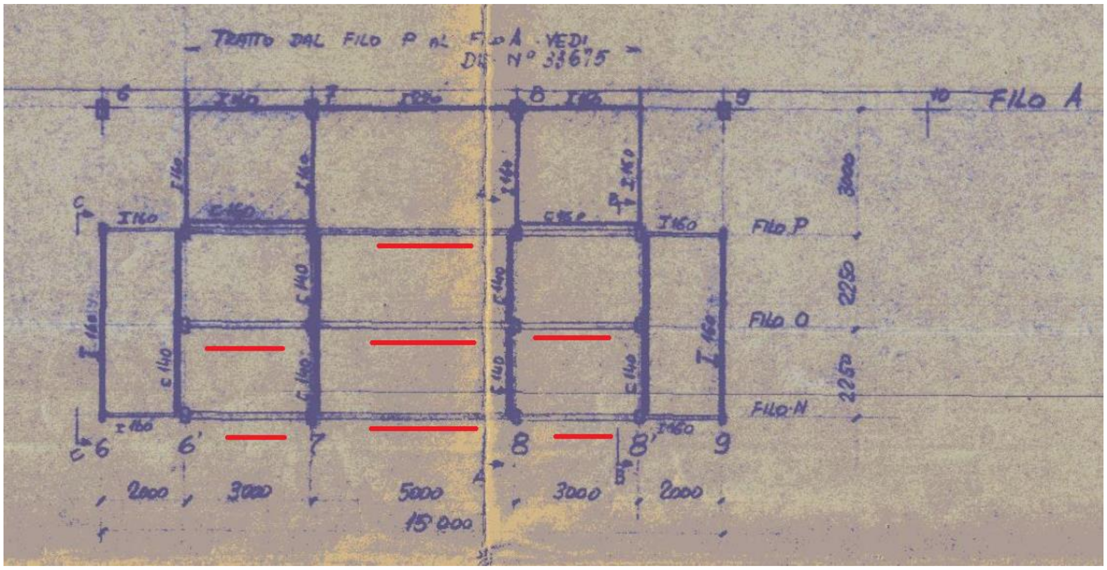


Figure 33 Tav-35242 Interior Beam

Table 17 Interior Beam

story	type of beam
1	IPN 200
2	IPN 200
3	IPN 200
4	IPN 200
5	IPN 200
6	IPN 200
7	IPN 200
8	IPN 200
9	IPN 200
10	IPN 200
11	IPN 200
12	IPN 200
13	IPN 200
14	IPN 200
15	IPN 200
16	IPN 200
17	IPN 200
18	IPN 200

FOUNDATION

Analyzing foundation for the building was the most challenging aspect of the thesis. There were two kinds of foundations provided in the documents. During investigating of the structural drawings, I found 3 pile foundation patterns. After thorough analysis I realize that these were a possible foundation solution that the engineers may be contemplating. However, in order to check properly, a thorough investigation of the site can tell us about the exact nature of the foundation of the building.

The 2nd and most likely foundation for the building is a Rigid 2 story R.C.C walls. The foundation when observed looks like a strip foundation with load bearing Reinforced wall with different thickness and openings. The foundation is 12.15 m deep and the whole building is to its foundation is divided in “LOTTO A” and “LOTTO D”. where lotto A comprises the main building and lotto D has to do with the staircase of the building that also has deep foundation. For simplicity the foundation beam/strip are divided in Parete A,R,S,D for the main building and for the stair case Parete N,P. In transverse direction the whole building to its foundation has axis definition:

- The Lotte A has 11 divisions
- Lotto D has 12 to 17.

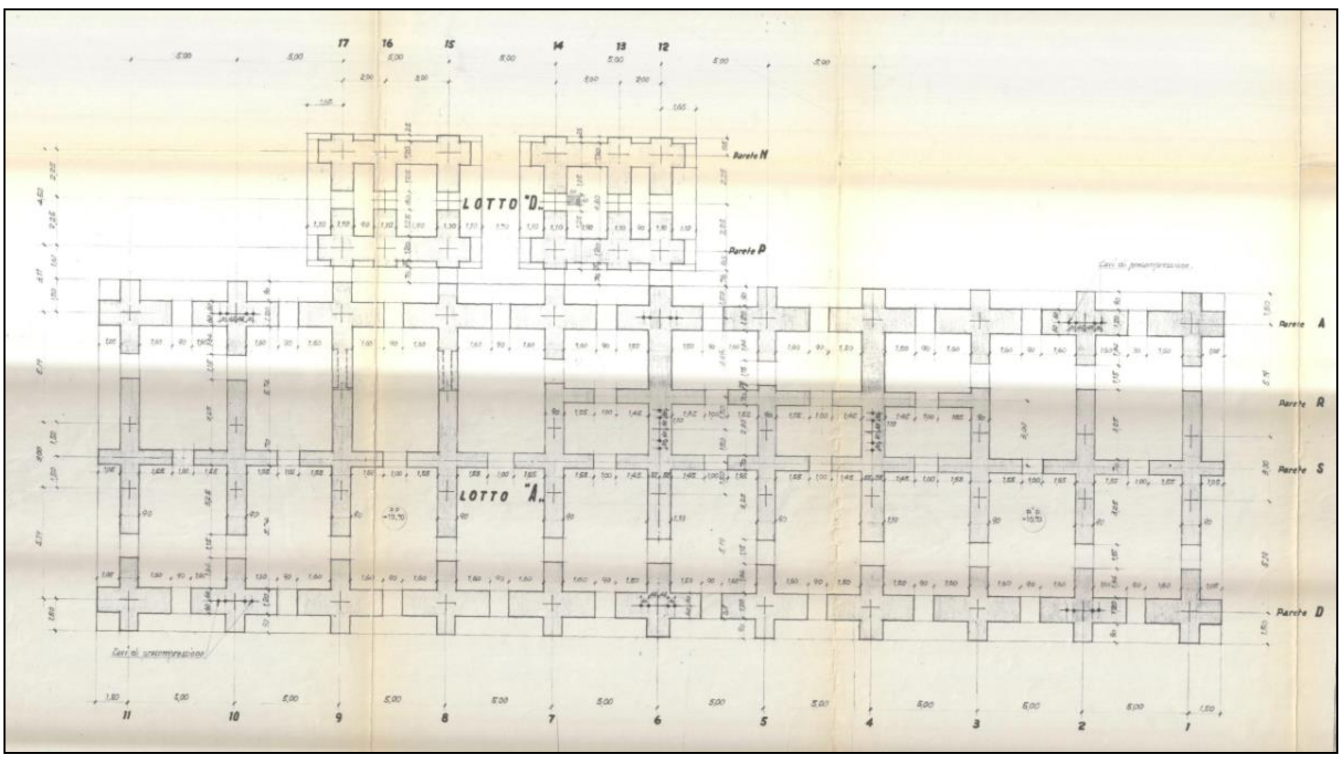


Figure 34 Top view of the foundation at -12.15 m

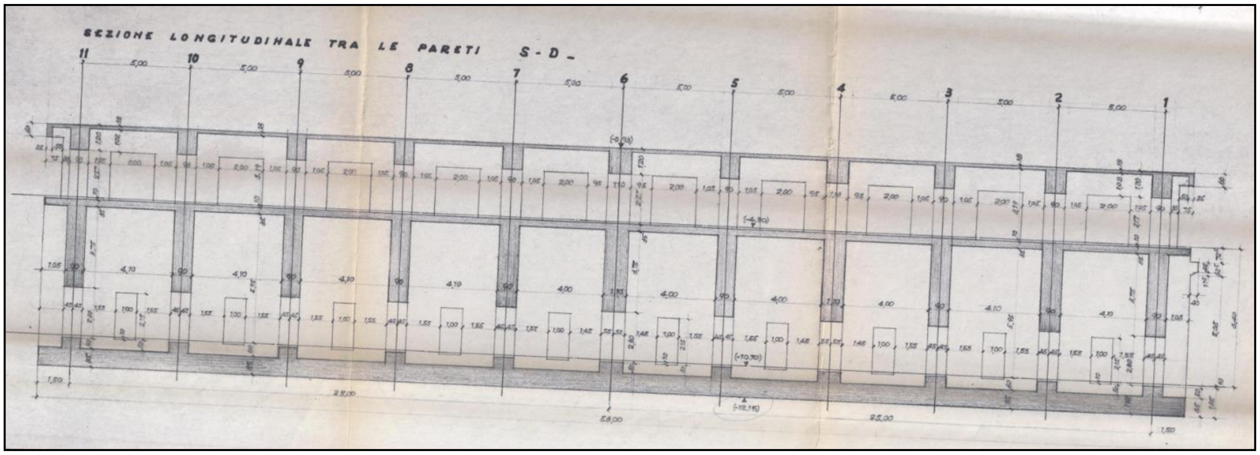


Figure 36 Side View of the 2 story foundation

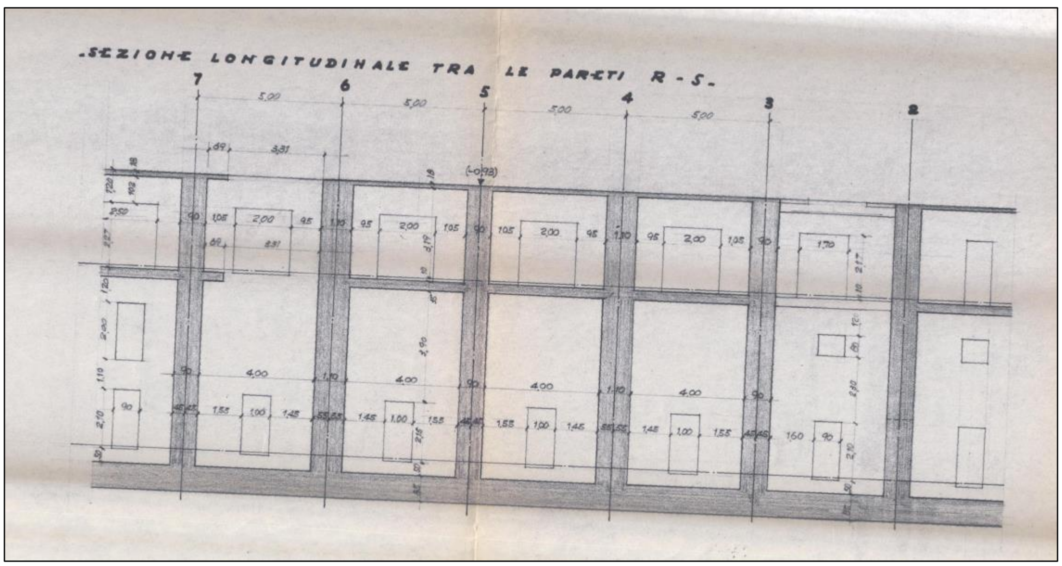


Figure 35 Side View of the 2 story foundation

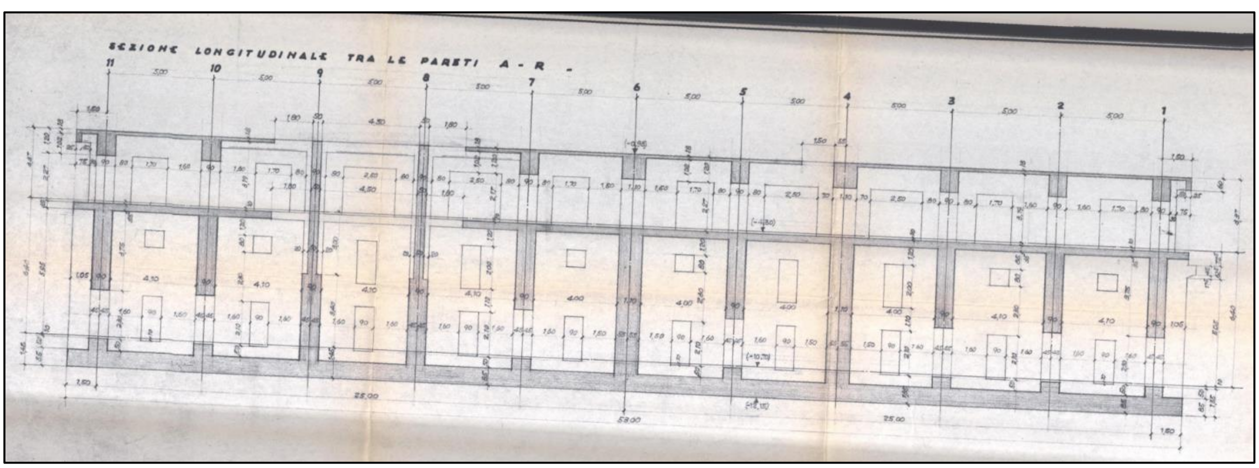


Figure 37 Side View of the 2-story foundation

Above 3 figures show the dimensions and placements of the openings. It also provides a rough idea of the thickness of the slabs provided in the foundation.

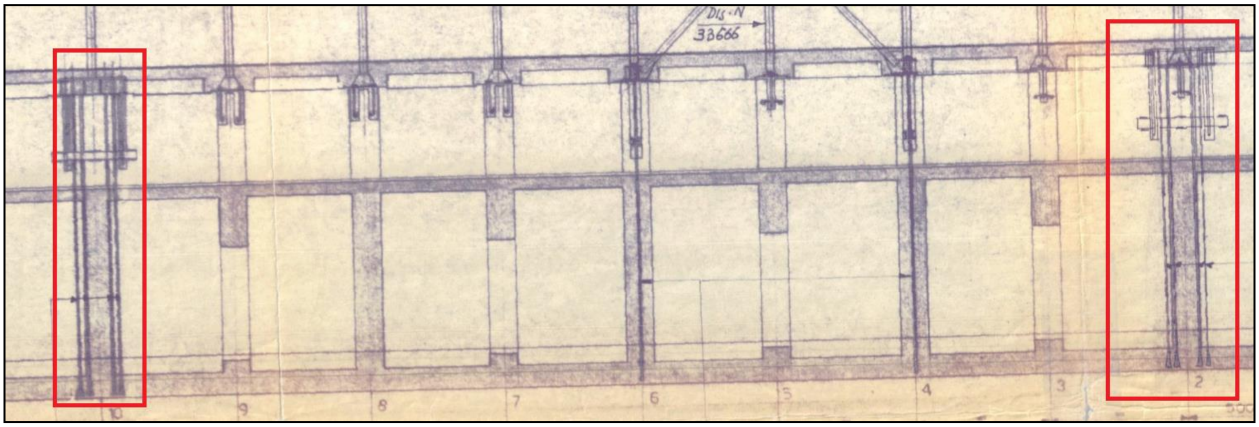


Figure 38 pre-stressed foundation

Other thing to note in the foundation is the connections of the steel super-structures to the foundation. As it can be observed the bolts looks to be pre-stressed into the rigid foundation. Providing proper connection to the foundation.

The width of the foundations are as follows:

FOR LOTTE A:

- The beam/load bearing wall at Parete D, A is 120 cm
- The beam/load bearing wall at Parete S, R is 70 cm
- The beam/load bearing wall at Axis definitions from 1 to 11 is 90 cm except 4 and 6
- The beam/load bearing wall at Axis definitions at 4 and 6 are 110 cm

FOR LOTTE D:

- For Parete P and N beams are 120 cm
- For Axis definitions at 12 to 17 beams are 110 cm.

RAI BUILDING MODEL IN FEM SOFTWARE

For analysis I made two models, one with Reinforced foundation, other with rigid supports:

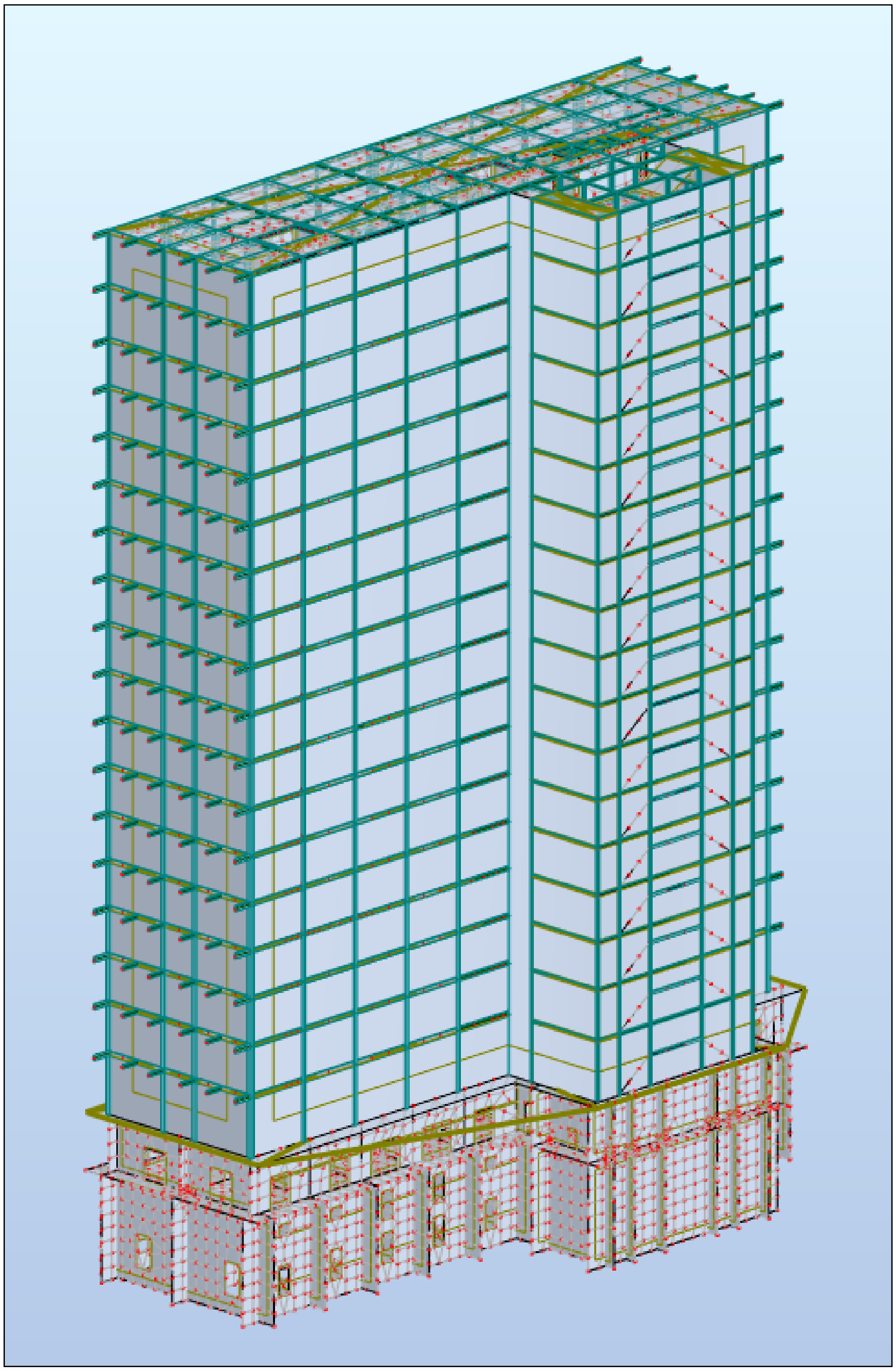


Figure 39 Clamped RAI building with foundation

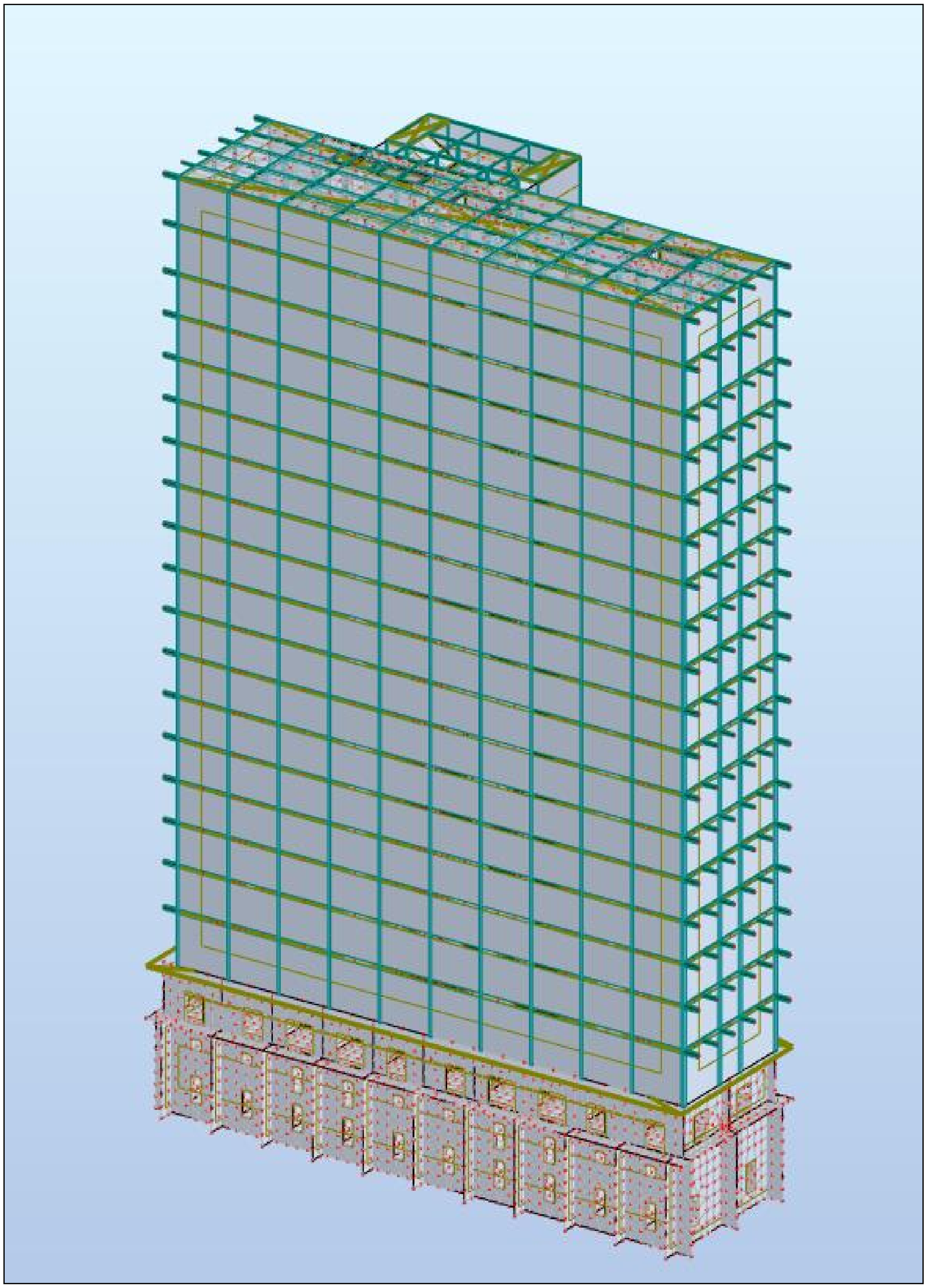


Figure 40 Clamped Building with Foundation

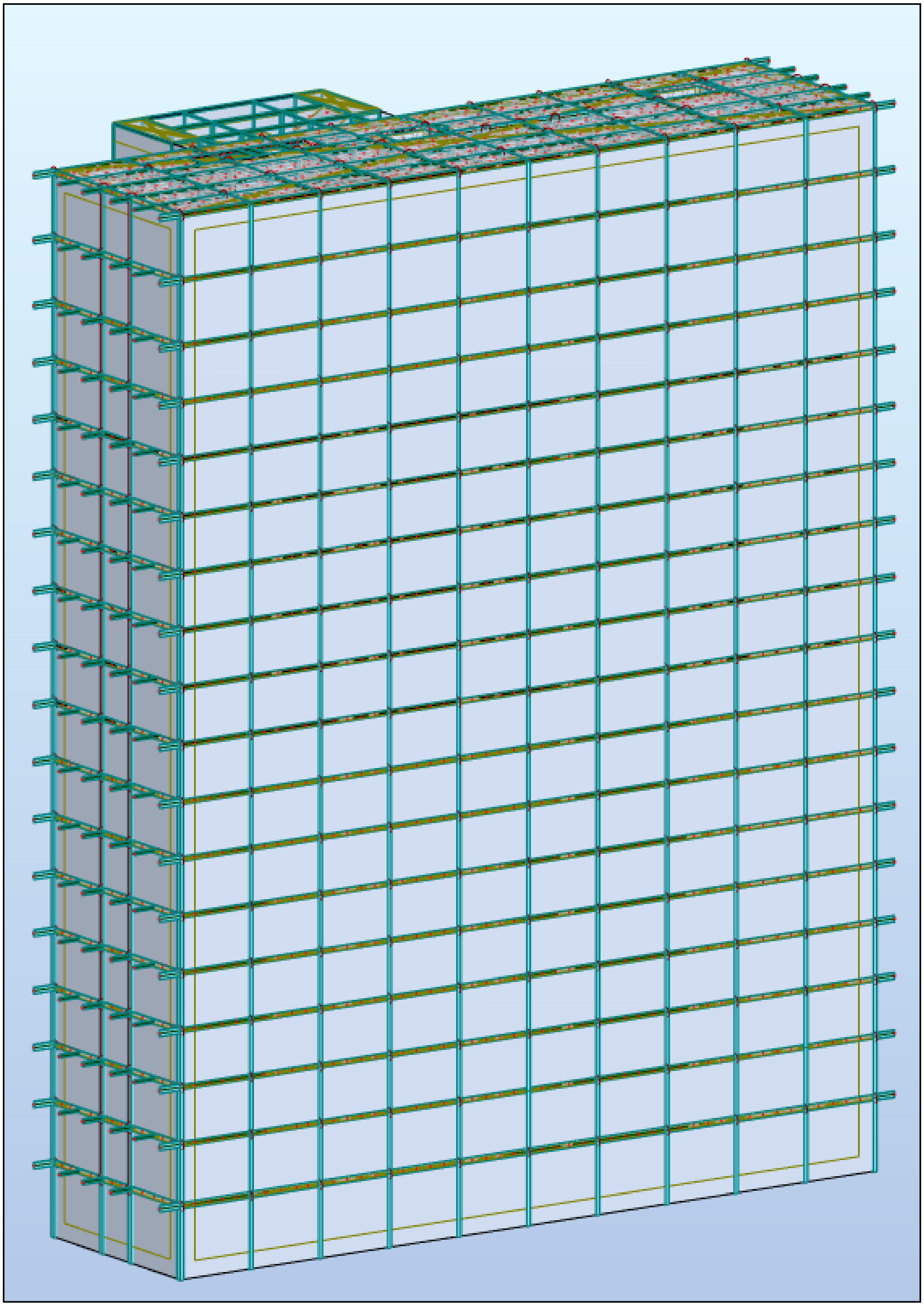


Figure 41 Clamped Building without Foundation

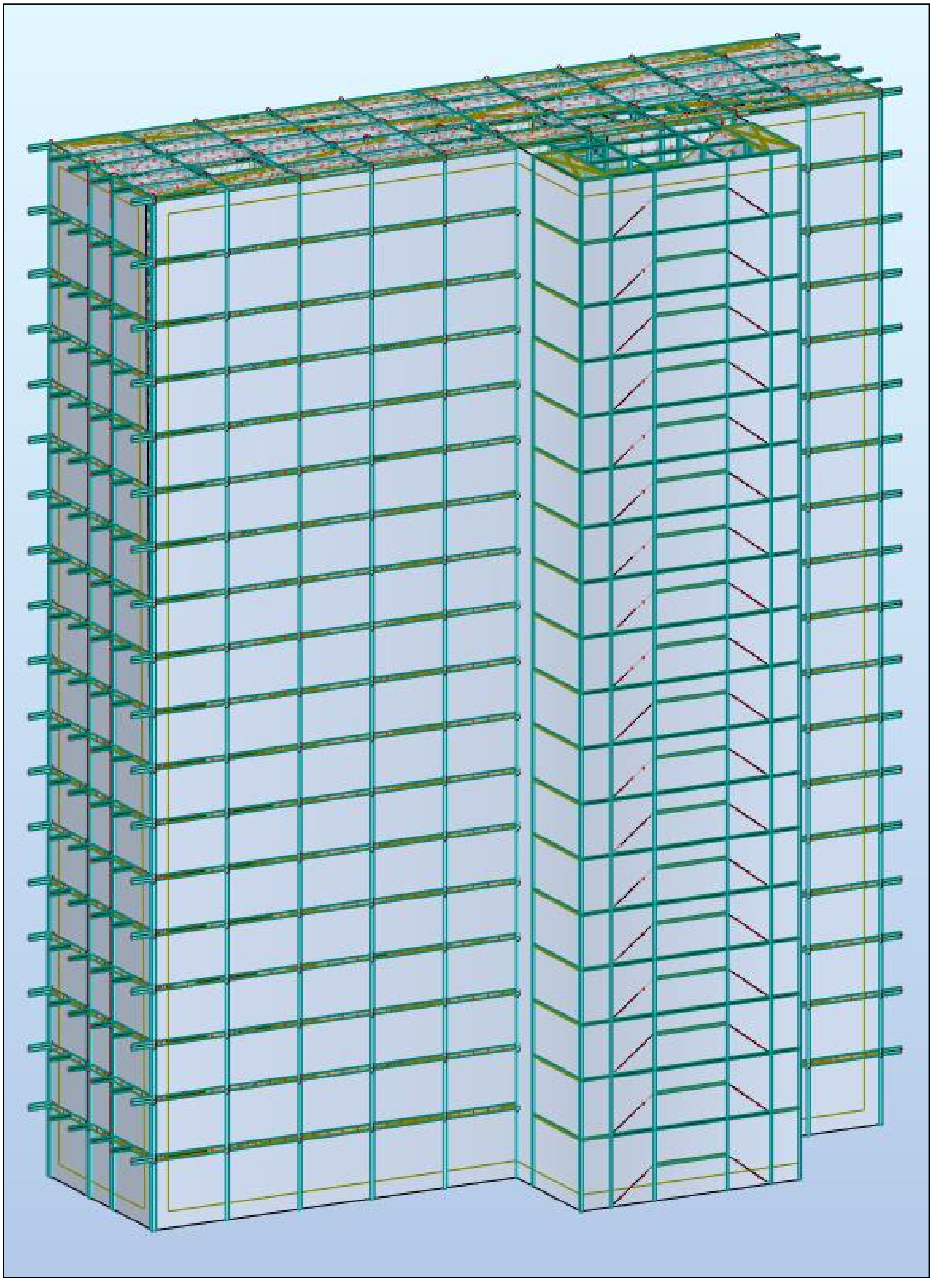


Figure 42 Clamped Building without Foundation

After investigating documents and structural drawings and extracting the all the relevant structural geometry, modelling for structural analysis was done of Autodesk Revit 2023 software. The Idea for using this FEM software to use the BIM methodology for exporting the model from REVIT to ROBOT.

I started making model in REVIT by starting from the definition of Levels and Grids. I started the model by modeling the foundation. Modeling of foundation was extremely difficult as I reinforcement was extremely hard to put. There were many irregular shape rebars that needed to be design and placed accordingly.

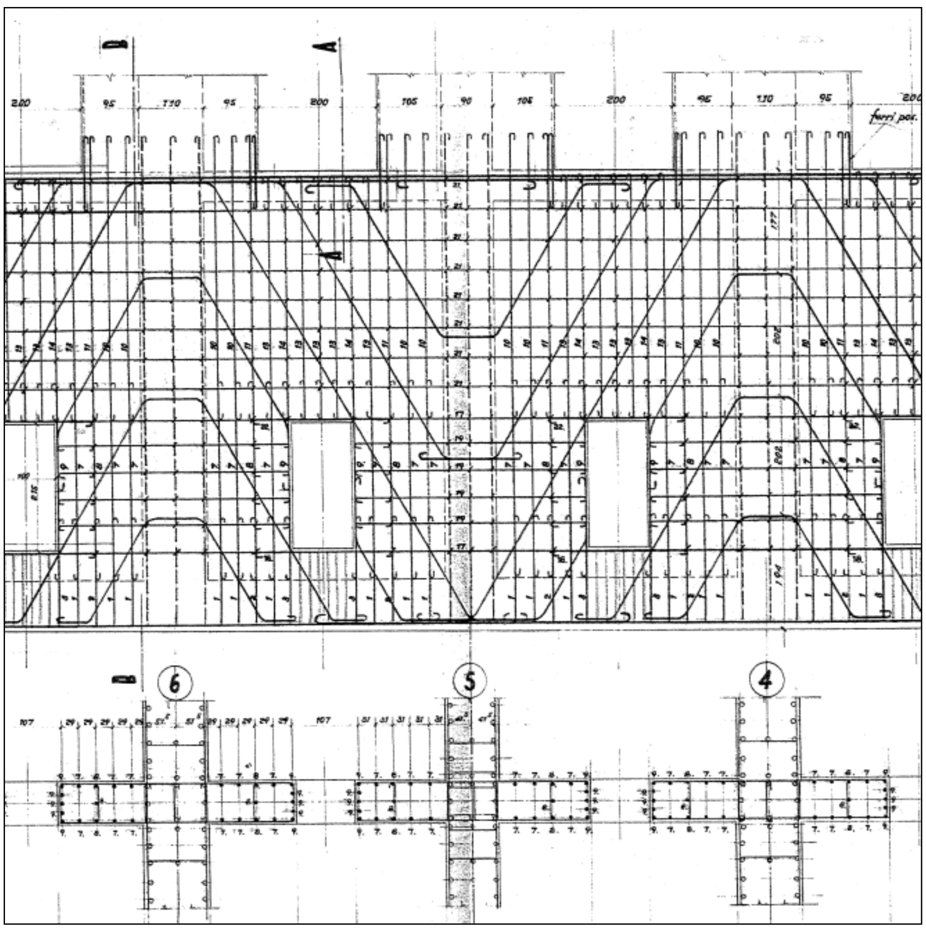


Figure 43 Foundation 2 story wall Reinforcement

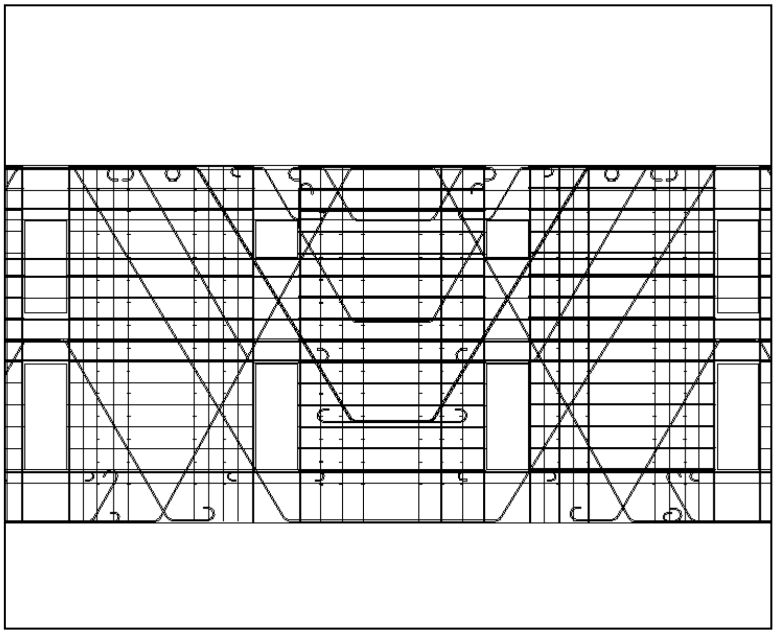


Figure 44 Foundation wall reinforcement

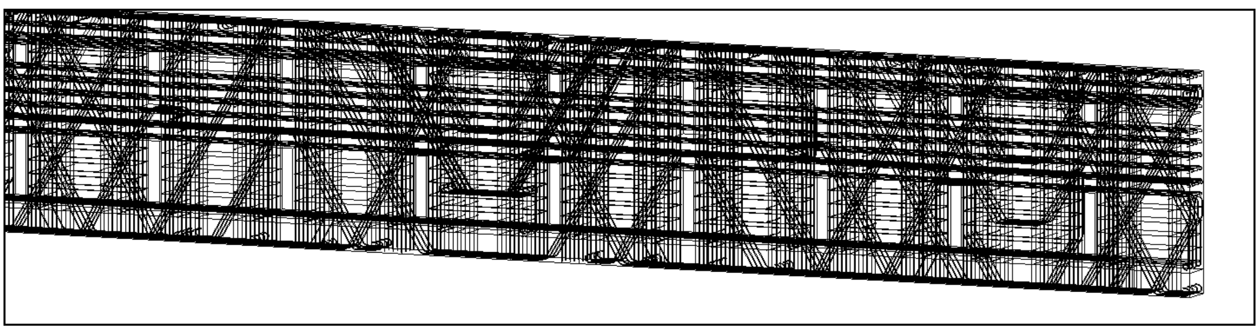


Figure 45 Reinforcement model in Revit

As it can be seen in the figures above extremely arduous and meticulous process of placing and modelling every single wall of the foundation was done in the Revit as it allows to make rebars that are not available in different rebar families.

After making every single wall of the foundation with their openings and reinforcement. They were compiled together to make the complex as shown below.

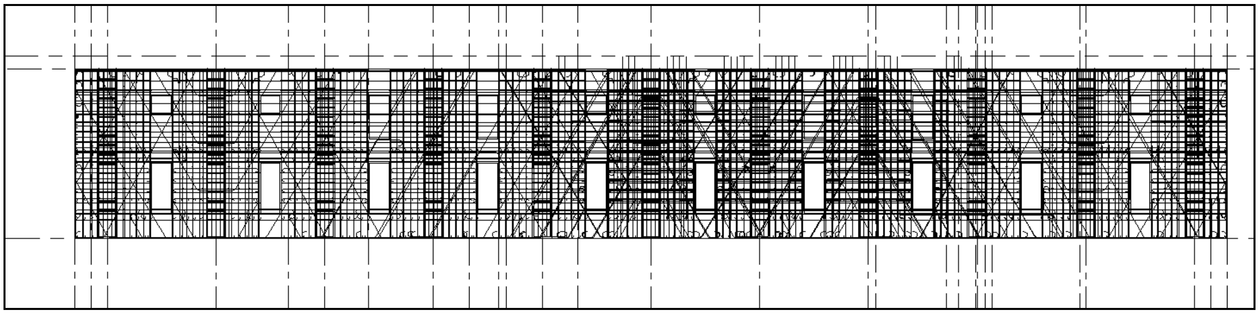


Figure 47 Revit foundation Reinforcement

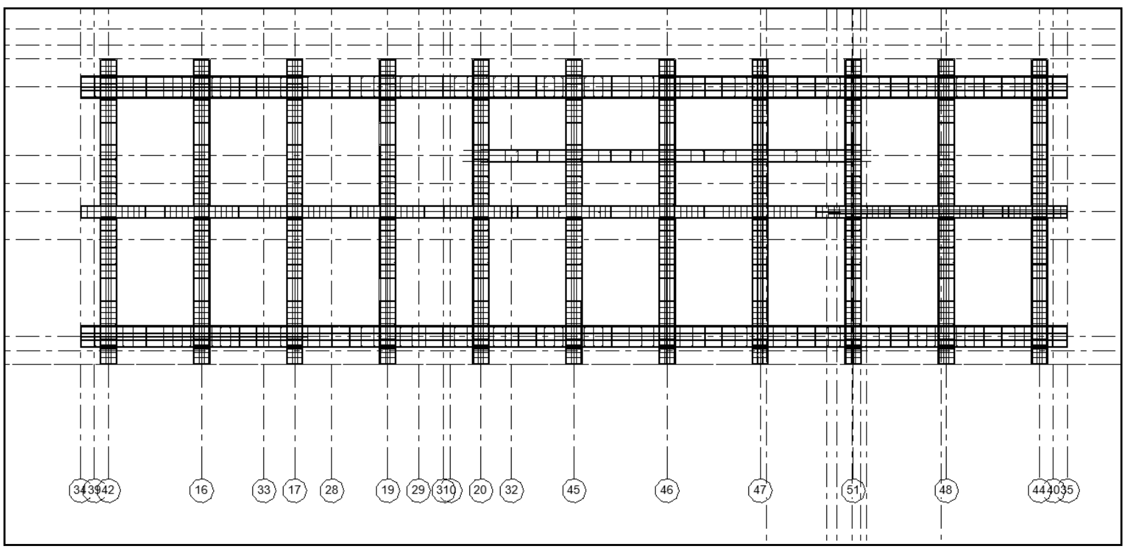


Figure 46 Top view Revit foundation

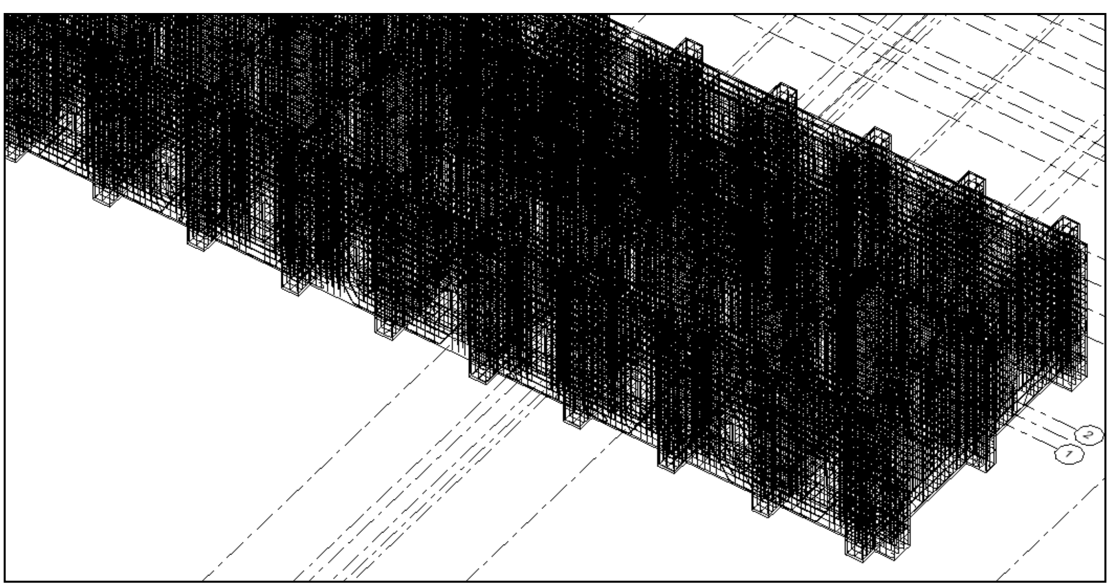


Figure 48 Dense Revit Foundation Reinforcement

Unfortunately, after working for weeks on the modeling the interoperability between Robot and Revit is not perfect. The node-to-node connections that is needed for structural analysis didn't manifest.

Thus, I discarded the foundation model at Revit and started making the model of the building again on Robot.

The most essential parts for the conducting FEM modeling are not only the dimensions of the structural elements but to provide the Material properties. As there was no information provided in the structural drawings. I assumed the steel properties of the beams and columns as S235.

Additionally, the slabs were considered rigid diaphragm,

"Unless specific assessments are made and provided that the openings present do not significantly reduce their stiffness, flat horizontals can be considered infinitely rigid in their middle plane provided that they are made of reinforced concrete, or of brick-cement with a reinforced concrete slab of at least 40 mm thick, or in a mixed structure with reinforced concrete slab at least 50 mm thick connected to the structural elements in steel or wood by appropriately sized connectors."

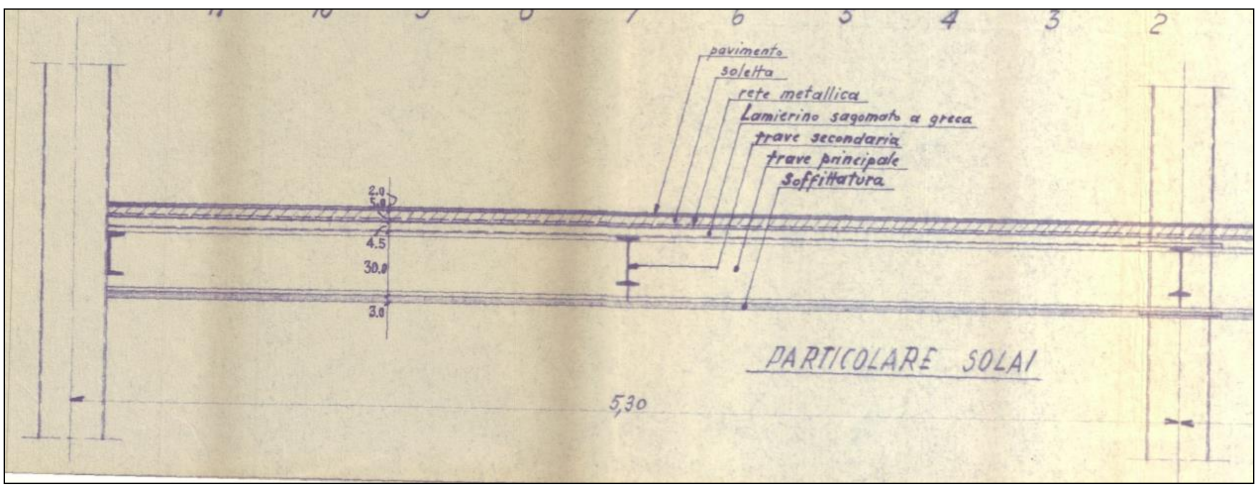


Figure 49 Slab Detailing

The slabs are 44,5 mm with different non-structural layers as shown in the figure above.

LOADS

STRUCTURAL LOADS

ROBOT Fem software automatically provides self-loads of the structural material. The non-structural permanent loads for an office building according to NTC 2018 is 3 KN/m^3 and for the Staircase, it is 4.00 KN/m^2.

WIND LOADS

A tall building's primary structure and cladding must be built to securely resist the strong winds that it will encounter over its anticipated lifespan. It is crucial to ascertain the wind load and associated uncertainty for mean recurrence intervals. The mathematical techniques outlined in building regulations are frequently used to specify the wind load, suitable load factors that account for uncertainty in typical buildings. However, given the significance of wind loads to the cost and safety of tall buildings, these analytical approaches frequently fall short of the required level of precision. Additionally, they do not adequately consider crucial wind phenomena like crosswind excitation, aerodynamic interactions between neighboring structures, and aerodynamic instability, all of which can have an impact on loads as well as result in excessive building motions that occupants find uncomfortable. Due to these factors, wind tunnel studies using scale models of the structure and its surroundings are often used to assess the wind loads and movements of tall buildings, providing more accurate, project-specific information.

Autodesk Robot allows the simulation of wind loads. The information needed for wind simulations is the wind speed of the city that is available in NTC 2018.

Tabella 3.3.I - *Valori dei parametri* $v_{b,0}$, a_0, k_s

Zona	Descrizione	$v_{b,0}$ [m/s]	a_0 [m]	k_s [1/s]
1	Valle d'Aosta, Piemonte, Lombardia, Trentino Alto Adige, Veneto, Friuli Venezia Giulia (con l'eccezione della provincia di Trieste)	25	1000	0,010
2	Emilia Romagna	25	750	0,015
3	Toscana, Marche, Umbria, Lazio, Abruzzo, Molise, Puglia, Campania, Basilicata, Calabria (esclusa la provincia di Reggio Calabria)	27	500	0,020
4	Sicilia e provincia di Reggio Calabria	28	500	0,020
5	Sardegna (zona a oriente della retta congiungente Capo Teulada con l'Isola di Maddalena)	28	750	0,015
6	Sardegna (zona a occidente della retta congiungente Capo Teulada con l'Isola di Maddalena)	28	500	0,020
7	Liguria	28	1000	0,015
8	Provincia di Trieste	30	1500	0,010
9	Isole (con l'eccezione di Sicilia e Sardegna) e mare aperto	31	500	0,020

Other data needed is Exposure coefficient. Which can be calculated again by using the NTC 2018:

The height z of the point under consideration, the topography of the land, and the exposure category of the site where the construction is placed all affect the exposure coefficient. For heights on the ground not exceeding z = 200 m, the formula is presented in the absence of precise analyses that account for the wind's direction of origin and the real roughness and topography of the terrain surrounding the building:

$$C_e(z) = k_r^2 \cdot C_t \cdot \ln\left(\frac{z}{z_0}\right) \cdot \left[7 + C_t \cdot \ln\left(\frac{z}{z_0}\right)\right] \text{ per } z > z_{min}$$

$$C_e(z) = C_e(z_{min}) \text{ per } z < z_{min}$$

Where is it:

The construction category of the site where it is placed determines the values for kr, z0, and zmin in table 3.3.II in NTC 2018.

Ct is the topographical coefficient, which is often believed to be equal to 1. It was envisaged for the proposal under consideration that the building will rise in Turin in an urban area where at least 15% of the structures had an average height greater than 15 m:

Tabella 3.3.III - *Classi di rugosità del terreno*

Classe di rugosità del terreno	Descrizione
A	Aree urbane in cui almeno il 15% della superficie sia coperto da edifici la cui altezza media superi i 15m
B	Aree urbane (non di classe A), suburbane, industriali e boschive
C	Aree con ostacoli diffusi (alberi, case, muri, recinzioni,....); aree con rugosità non riconducibile alle classi A, B, D
D	Aree prive di ostacoli (aperta campagna, aeroporti, aree agricole, pascoli, zone paludose o sabbiose, superfici innevate o ghiacciate, mare, laghi,....)
L'assegnazione della classe di rugosità non dipende dalla conformazione orografica e topografica del terreno. Affinché una costruzione possa dirsi ubicata in classe A o B è necessario che la situazione che contraddistingue la classe permanga intorno alla costruzione per non meno di 1 km e comunque non meno di 20 volte l'altezza della costruzione. Laddove sussistano dubbi sulla scelta della classe di rugosità, a meno di analisi dettagliate, verrà assegnata la classe più sfavorevole.	

Tabella 3.3.II – *Parametri per la definizione del coefficiente di esposizione*

Categoria di esposizione del sito	k_r	z_0 [m]	z_{min} [m]
I	0,17	0,01	2
II	0,19	0,05	4
III	0,20	0,10	5
IV	0,22	0,30	8
V	0,23	0,70	12

The coefficient factor which the ROBOT calls velocity factor was calculated as below for with and without foundation:

Table 18 Velocity factor with and without foundation respectively

Velocity factor	Height
0.65	4.55
0.939	8.31
1.125	11.81
1.27	15.31
1.391	18.81
1.494	22.31
1.585	25.81
1.666	29.31
1.739	32.81
1.806	36.31
1.868	39.81
1.925	43.31
1.979	46.81
2.029	50.31
2.076	53.81
2.121	57.31
2.164	60.81
2.21	64.81
2.254	68.81

Velocity factor	Height
0	7.95
0	12.25
1.48	16.8
1.48	20.56
1.52	24.06
1.69	27.56
1.83	31.06
1.95	34.56
2.05	38.06
2.14	41.56
2.23	45.06
2.31	48.56
2.38	52.06
2.44	55.56
2.51	59.06
2.56	62.56
2.62	66.06
2.67	69.56
2.73	73.56
2.78	77.56
2.85	77.56

The data was transferred into ROBOT files to get the graph shown below:

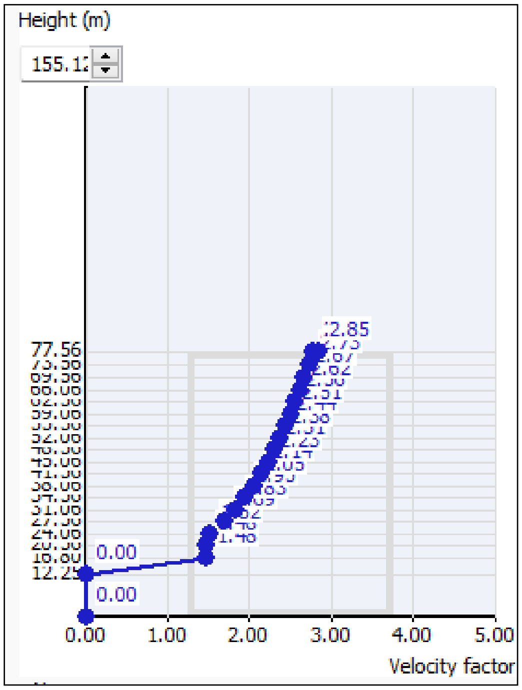


Figure 51 velocity factor graph in robot with Foundation

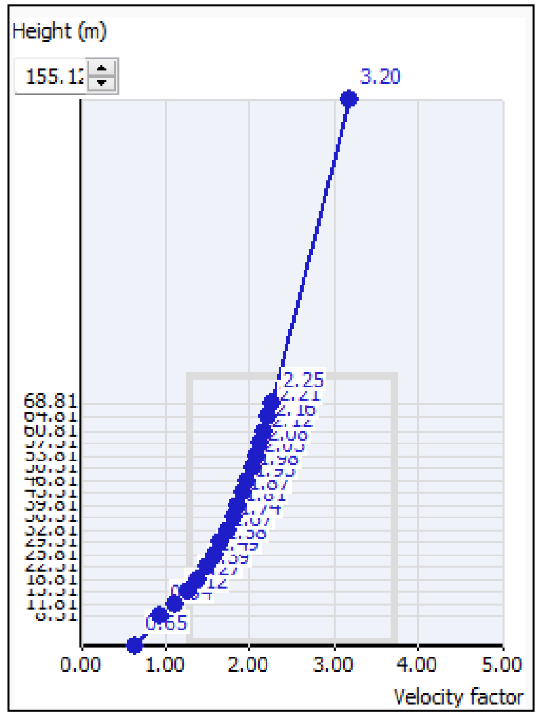


Figure 50 velocity factor graph in robot without Foundation

After defining the wind profile, the wind direction can be set as shown below with wind velocity:

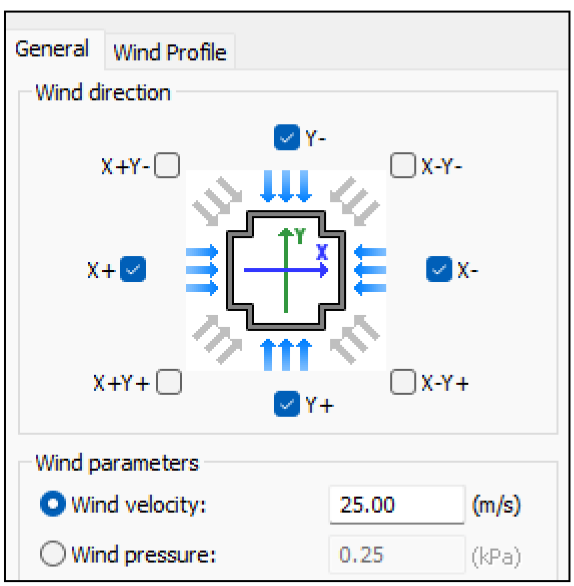


Figure 52 wind Directions

The software runs the wind tunnel simulations in all directions assigned and presents the results at the end:

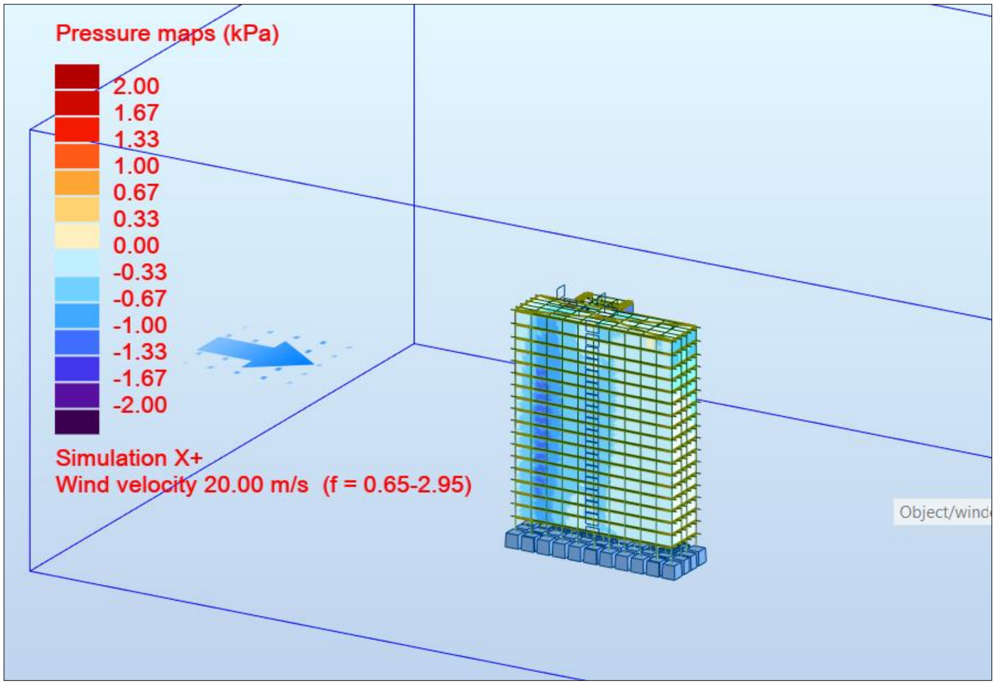


Figure 53 Simulation in X+ direction

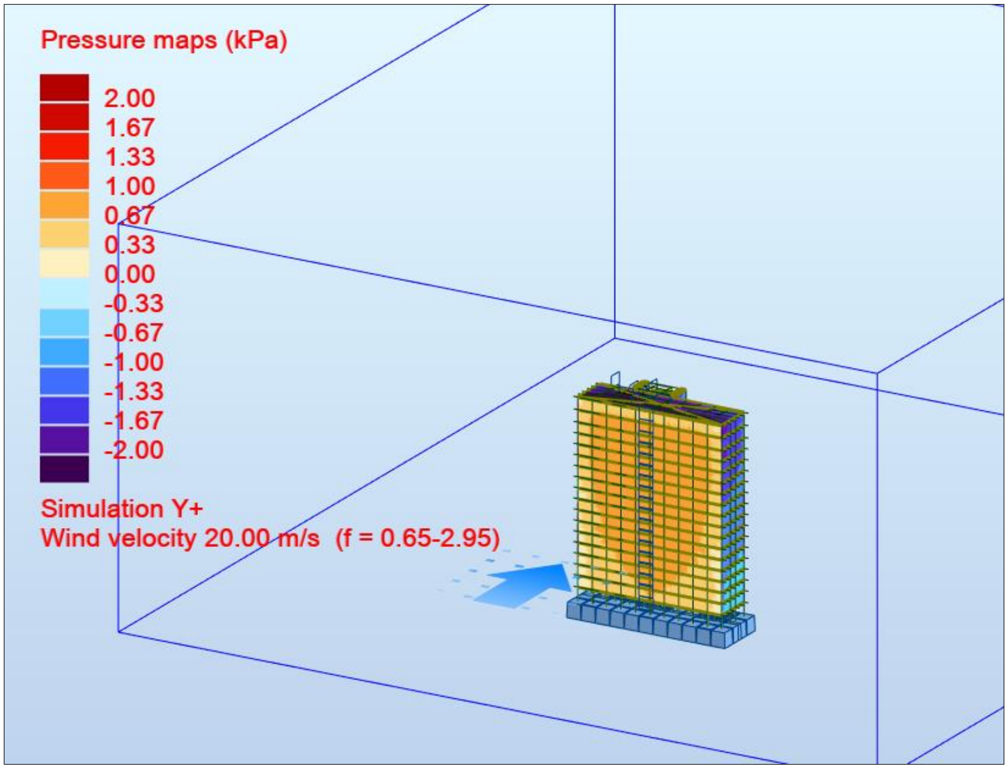


Figure 54 Simulation in Y+ direction

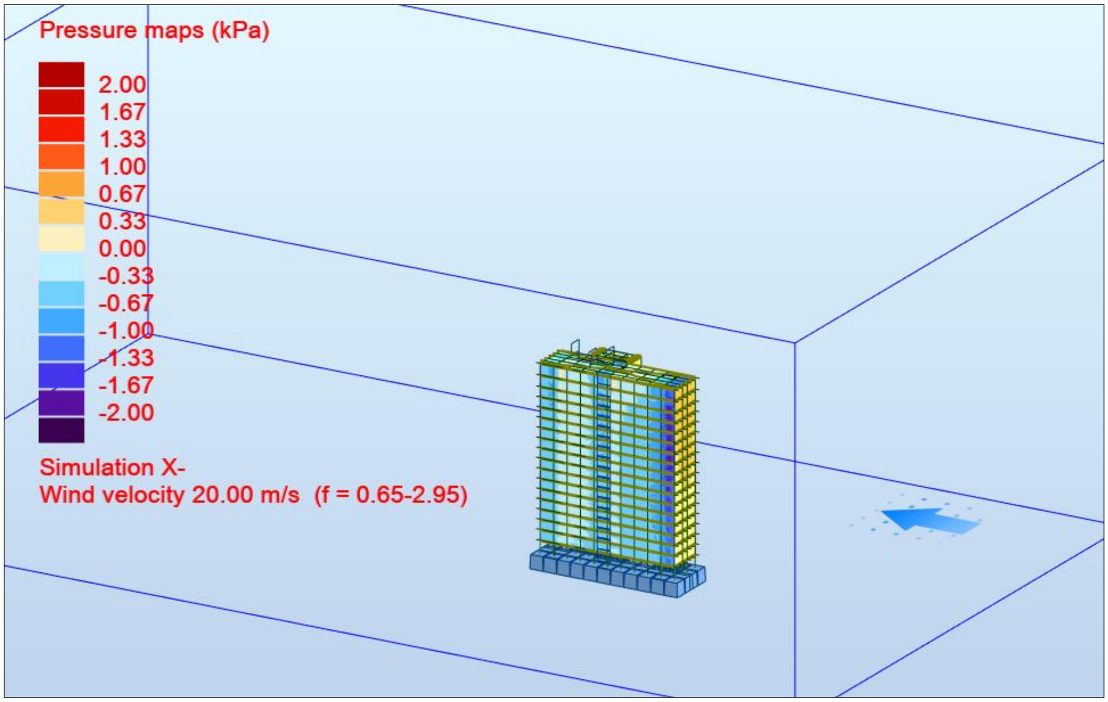


Figure 55 Simulation in X- Direction

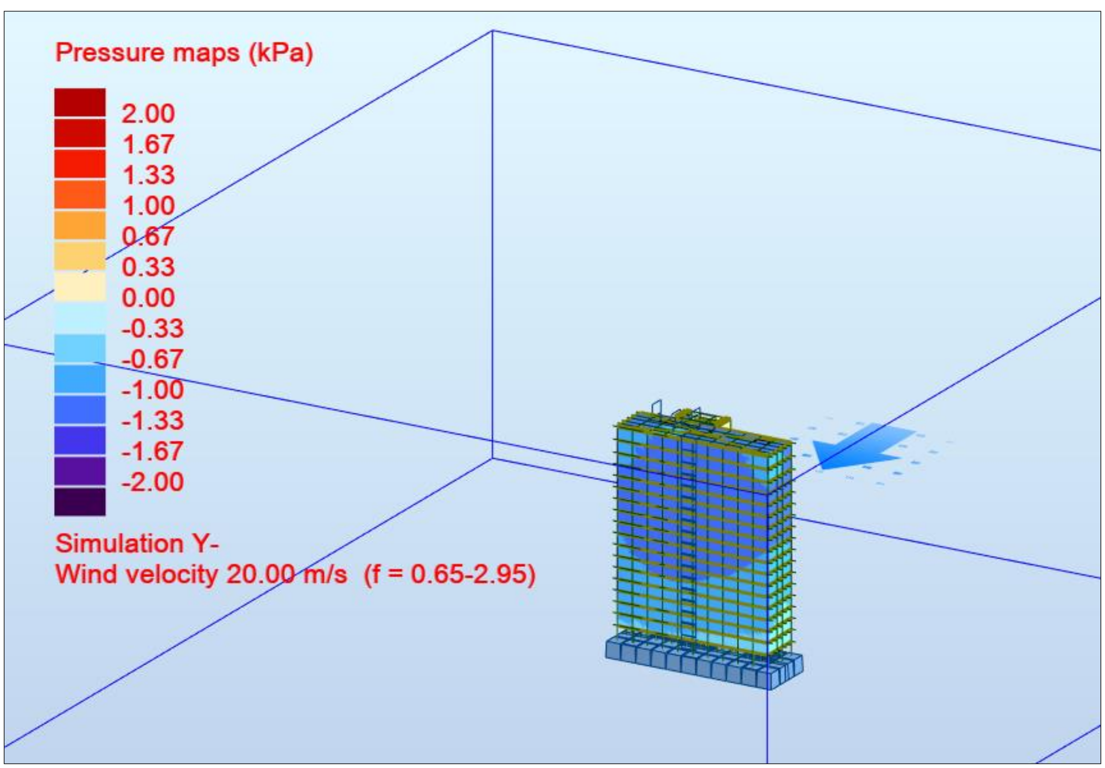


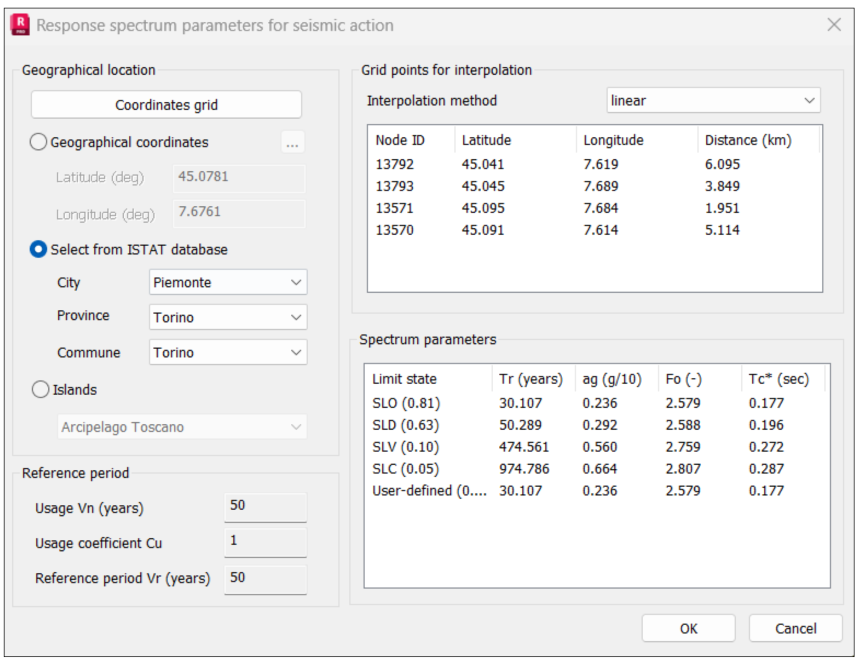
Figure 56 Simulation in Y- Direction

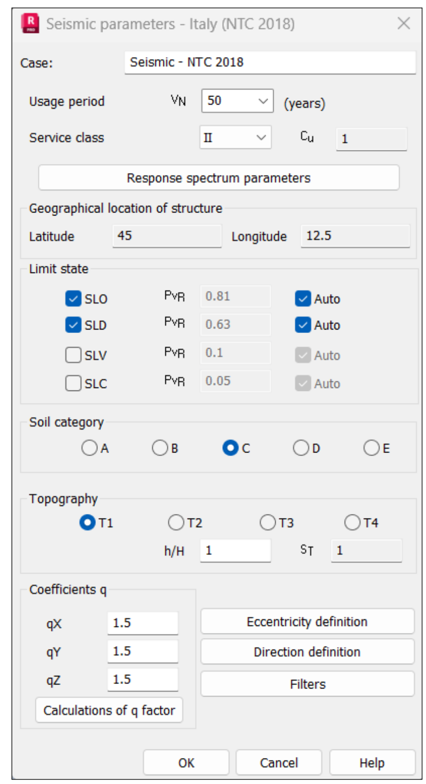
For Seismic actions, Service limit states (SLS) or Stati limite di esercizio (SLE) was used.
in SLE I used:

Operational Limit State (SLO): After the earthquake, For the complete Building, including the structural, non-structural elements and other important components, must not get damage and interruptions.

Damage Limit State (SLD): After the Earthquake, structural, non-structural elements and other important component should not damage and be at risk.

Robot structural Analysis software automatically allows us to use seismic analysis as shown below:





However, Turin is a low Seismic Zone so the Primary Analysis would be considered for the wind Analysis.

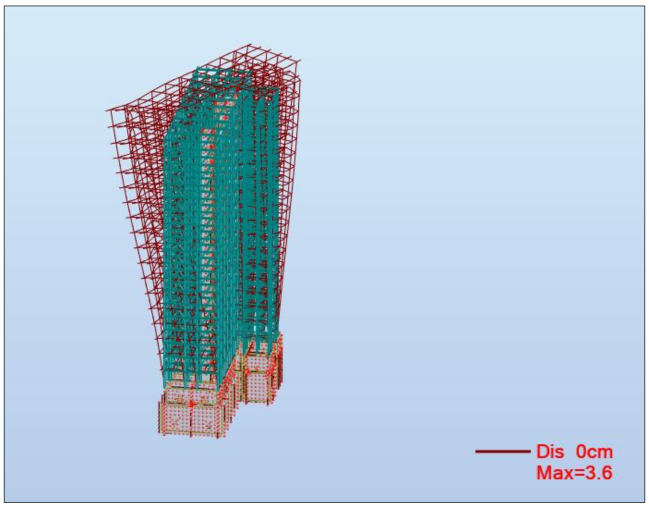
RESULTS

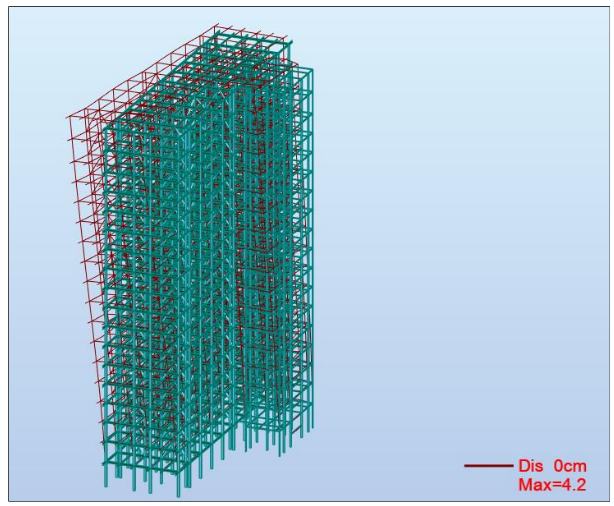
Structural analysis was done by Robot Structural Analysis Professional. The results are summarized as a comparison of the model with and without the foundation.

The results comprise the displacements due to a combination of wind:

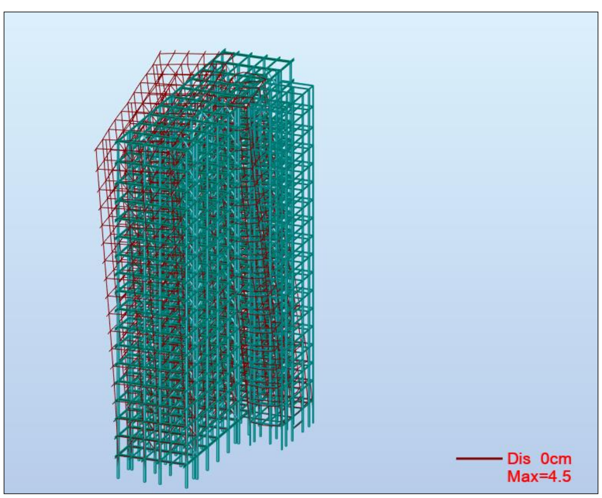
Displacement due to wind:

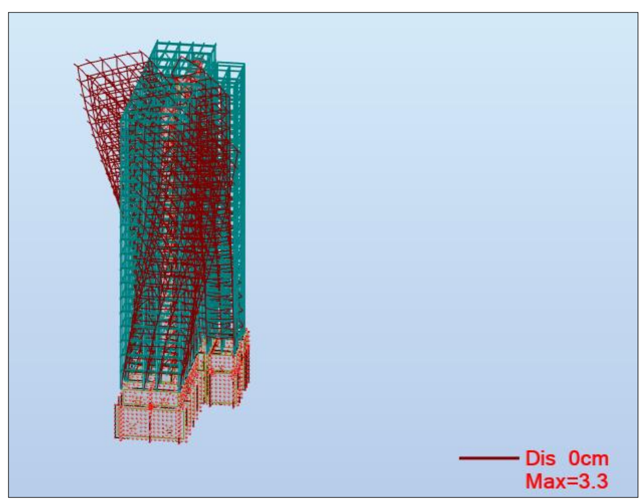
Direction X-:



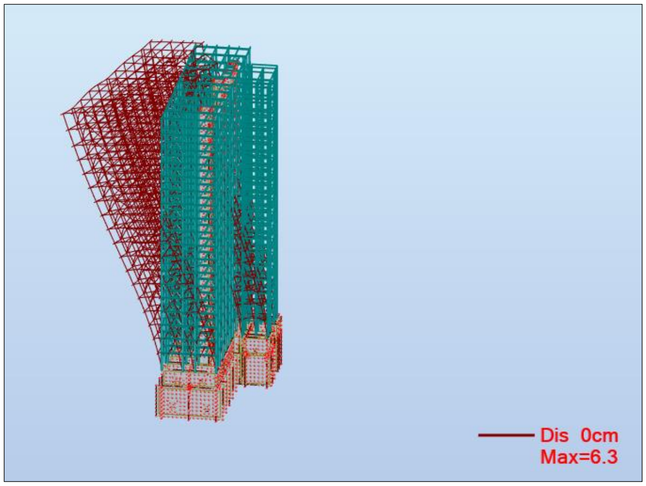


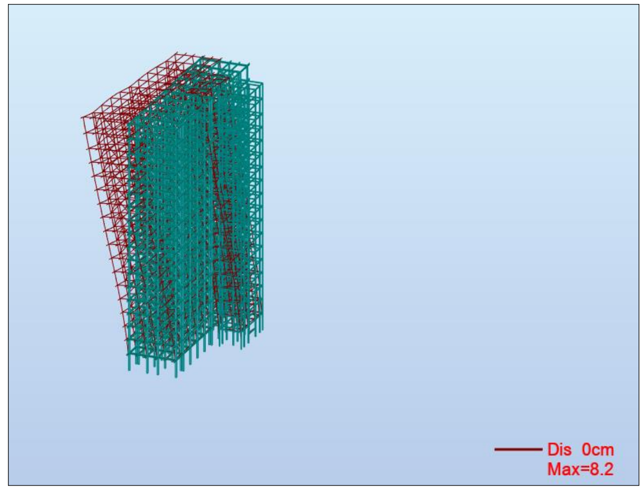
Direction X+:



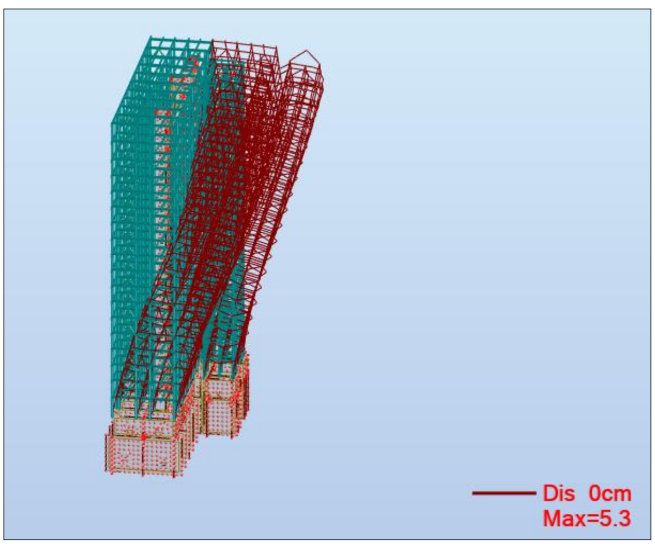


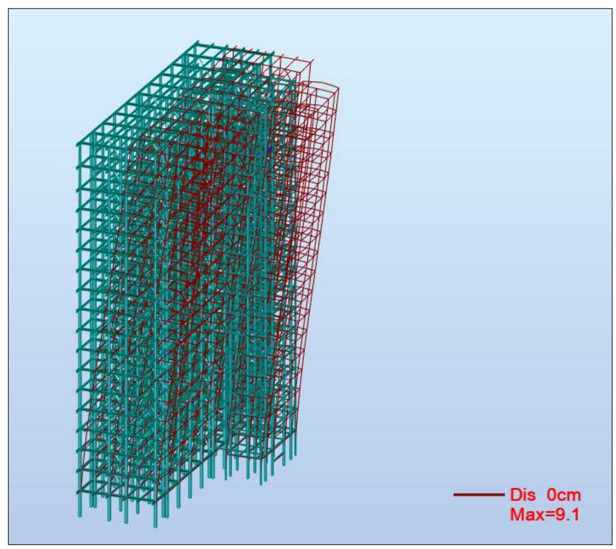
Direction Y-:





Direction Y+:

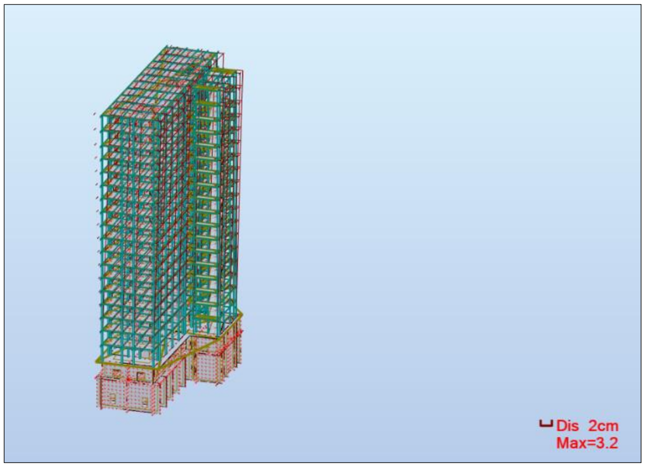


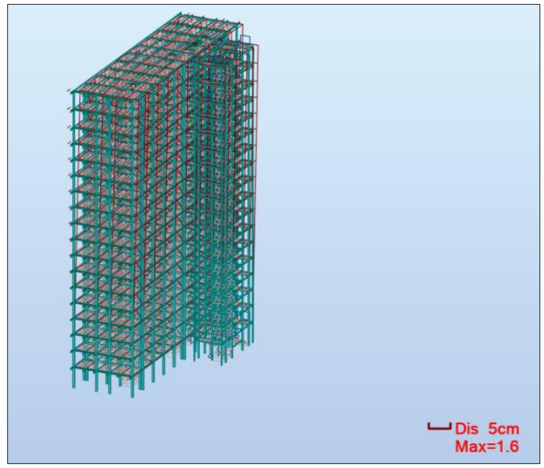


DISPLACEMENTS DUE TO SEISMIC ANAYLYSIS

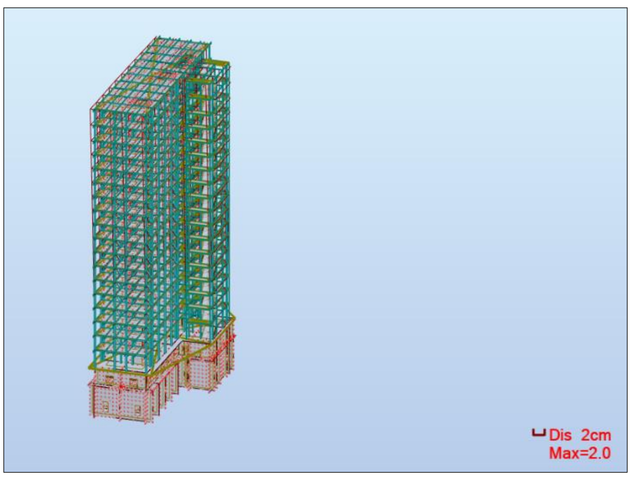
Sld :

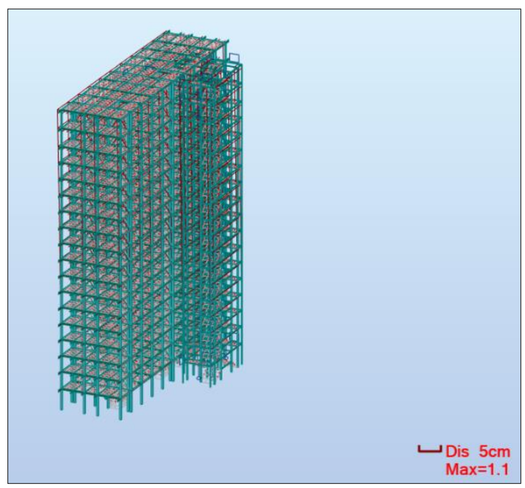
1x *0.3y



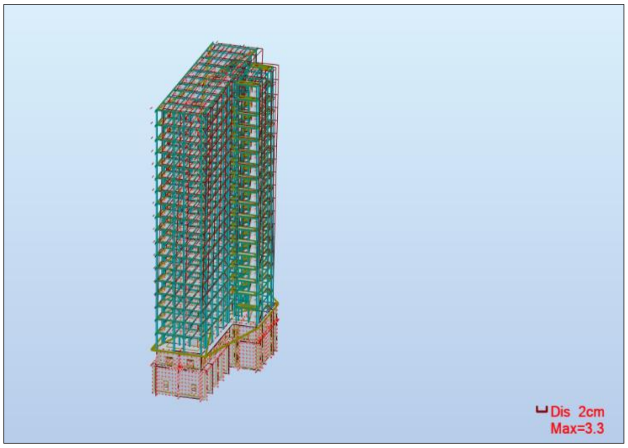


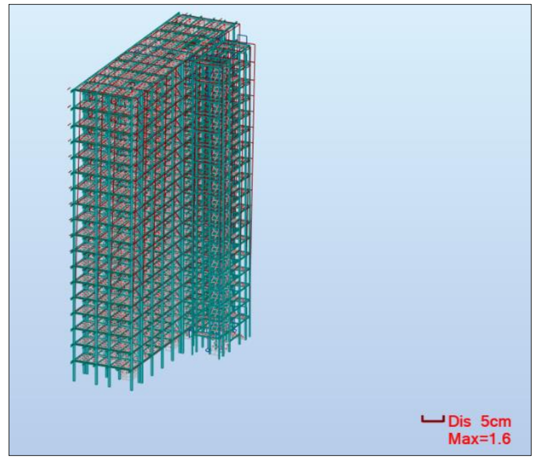
0.3x *-1y



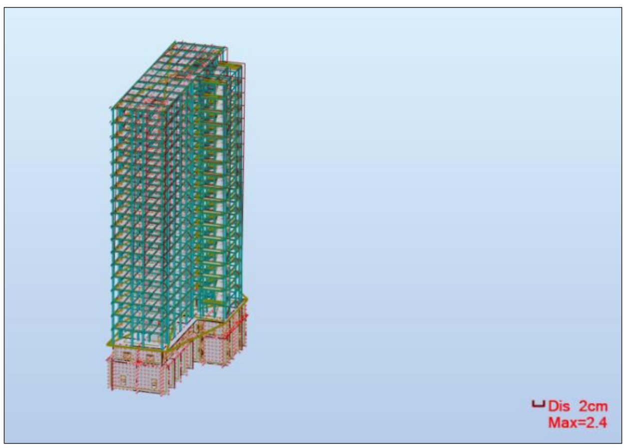


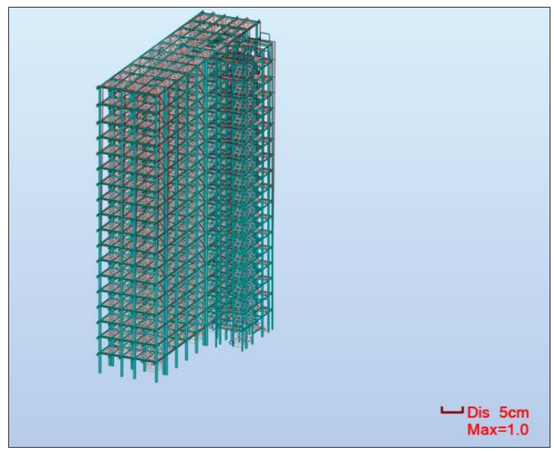
1x *0.3y





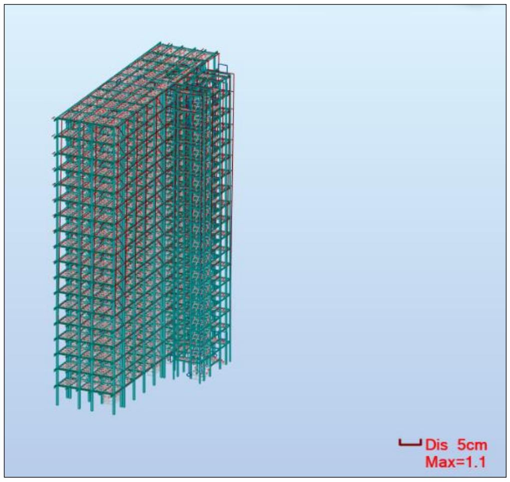
1x *-0.3y



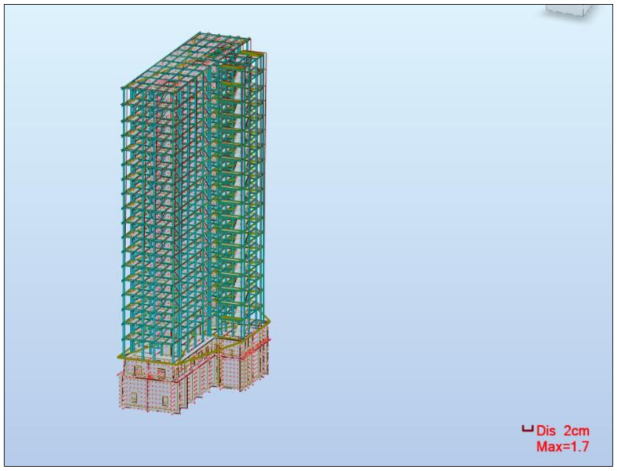


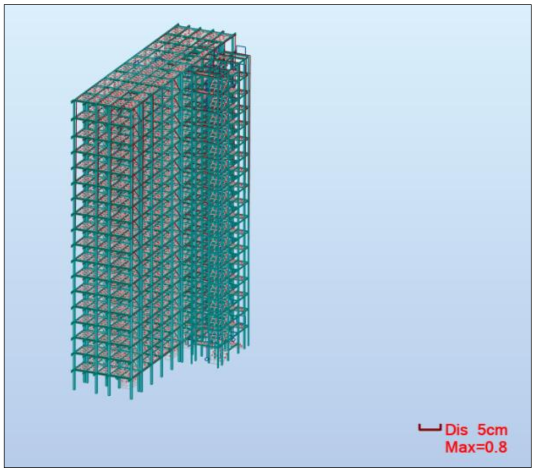
SLO

1x 0.3y

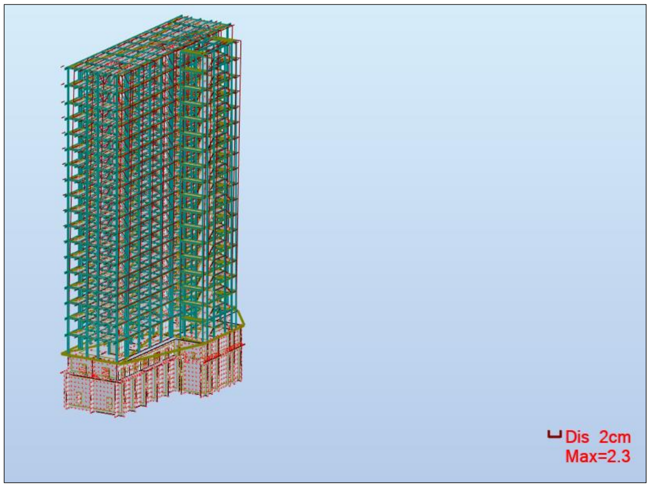


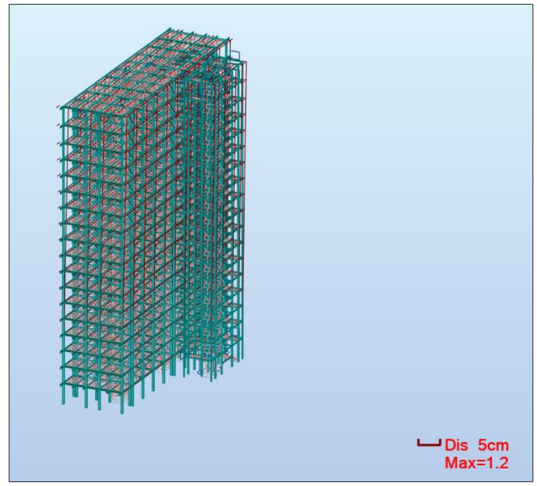
1x -0.3y



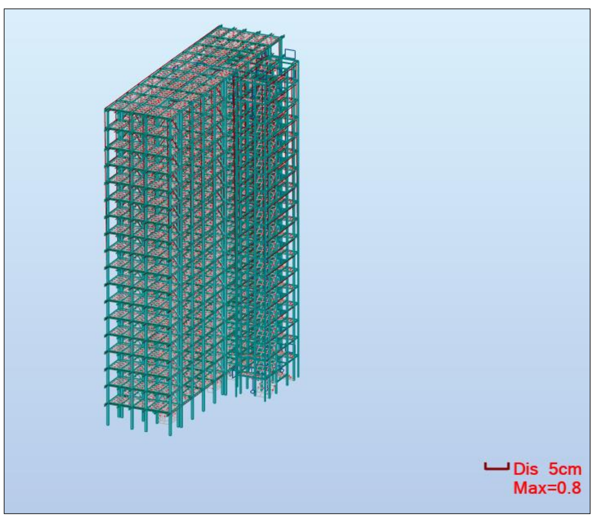


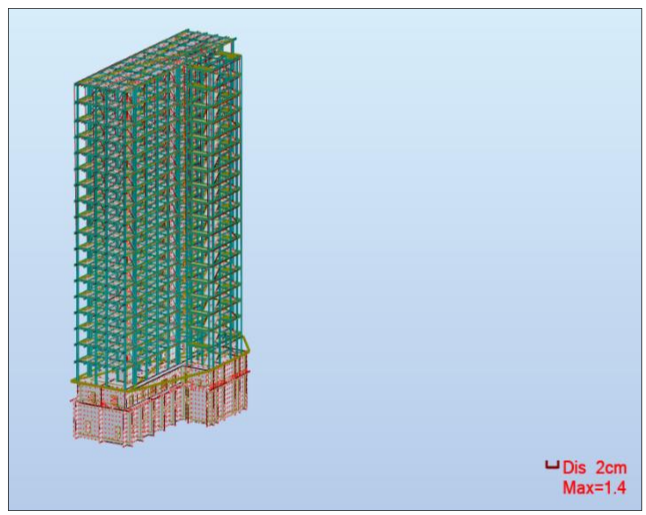
0.3x 1y





0.3x -1y





	without foundation			with foundation		
	Ux (cm)	Uy (cm)	Uz (cm)	Ux (cm)	Uy (cm)	Uz (cm)
SLO 1 * X 0.3 * Y	0.8	1	0.1	1.8	2	0.2
SLO 1 * X -0.3 * Y	0.7	0.5	0	1.7	1	0.1
SLO 0.3 * X 1 * Y	0.3	1.1	0.1	0.7	2.2	0.3
SLO 0.3 * X -1 * Y	0.2	0	0	0.4	0	0
SLD 1 * X 0.3 * Y	1.1	1.3	0.1	2.4	2.7	0.3
SLD 1 * X -0.3 * Y	1	0.6	0.1	2.3	1.4	0.2
SLD 0.3 * X 1 * Y	0.4	1.6	0.2	1	3	0.3
SLD 0.3 * X -1 * Y	0.2	0	0	0.6	0	0
Wind X+ 25 m/s	1.7	0	0.3	2.5	2.1	0.3
Wind Y+ 25 m/s	0.4	9.1	1	0.5	5.3	0.6
Wind X- 25 m/s	0	0	0.3	0	1.5	0.3
Wind Y- 25 m/s	0.5	0	0.6	0.7	0	0.4

Table19 Max Displacements

The displacement diagram and the table above show the relative displacements that occur in both models. It can be observes that the rigid foundation restrict any displacement in the foundation and the only significant displacement occurs is at the top of the models.

Another observation of the models is the is the difference of displacement at the same direction and force however the pattern is more similar. That showcases the similar pattern of resistance of the both models.

MODAL ANALYSIS

MODAL ANALYSIS WITH FOUNDATION:

Mode	freq (Hz)	Time (s)	Mass participation ratio		
			Ux	Uy	Uz
1	0.35	2.87	2.49	56.39	0
2	0.37	2.69	15.32	66.96	0
3	0.5	2	70.69	66.96	0
4	1.19	0.84	72.9	71.03	0
5	1.24	0.8	73.44	84.39	0
6	1.7	0.59	84.4	84.39	0
7	2.34	0.43	85.45	84.57	0
8	2.52	0.4	85.47	90.28	0
9	3.4	0.29	89.58	90.28	0
10	3.67	0.27	90.2	90.29	0

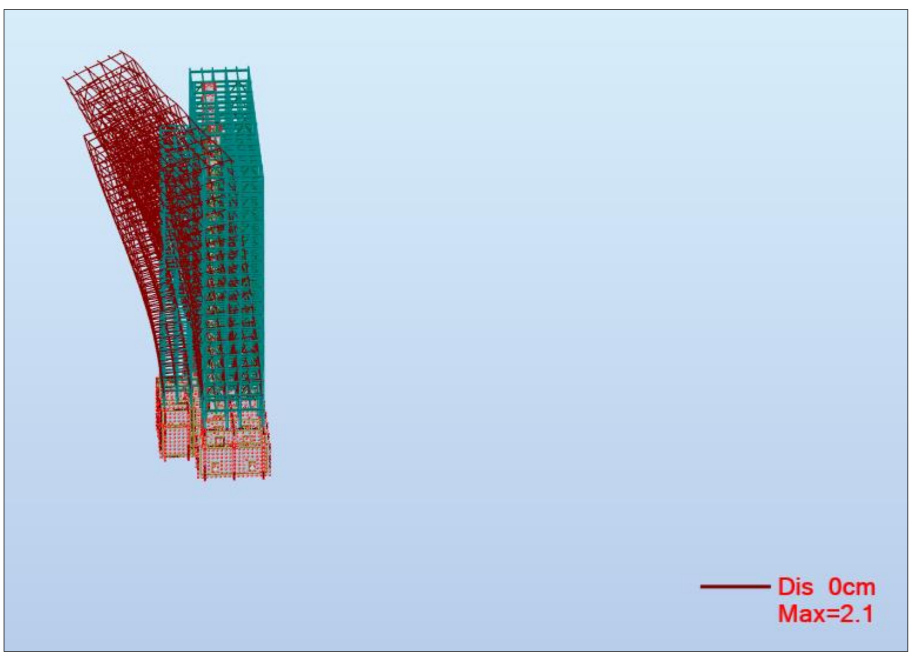


Figure 57 mode 1

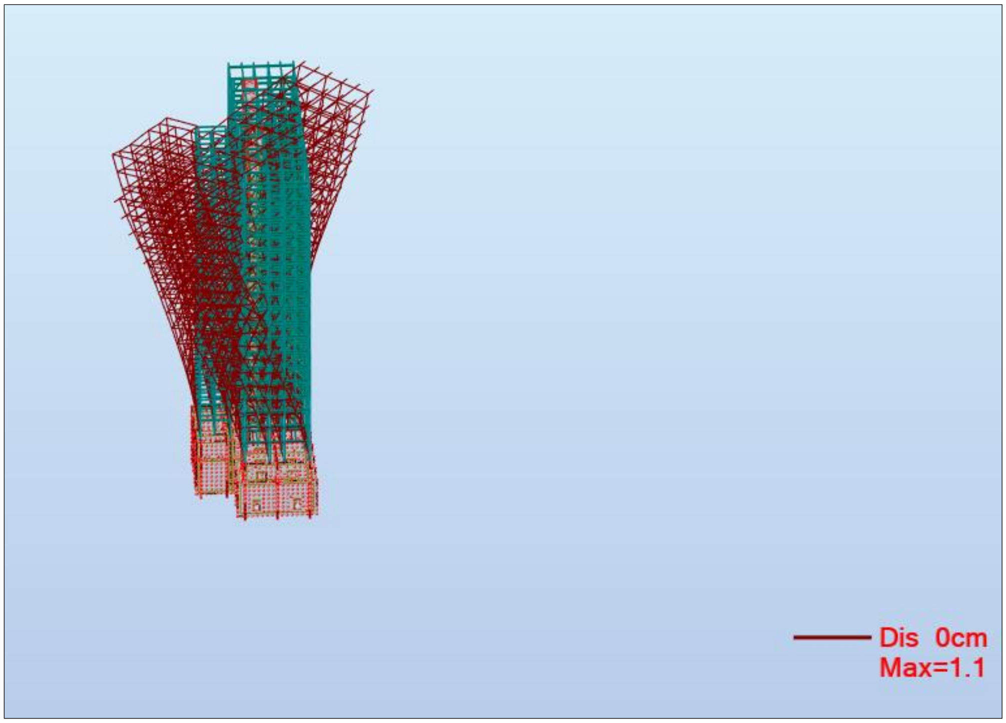


Figure 58 mode 2

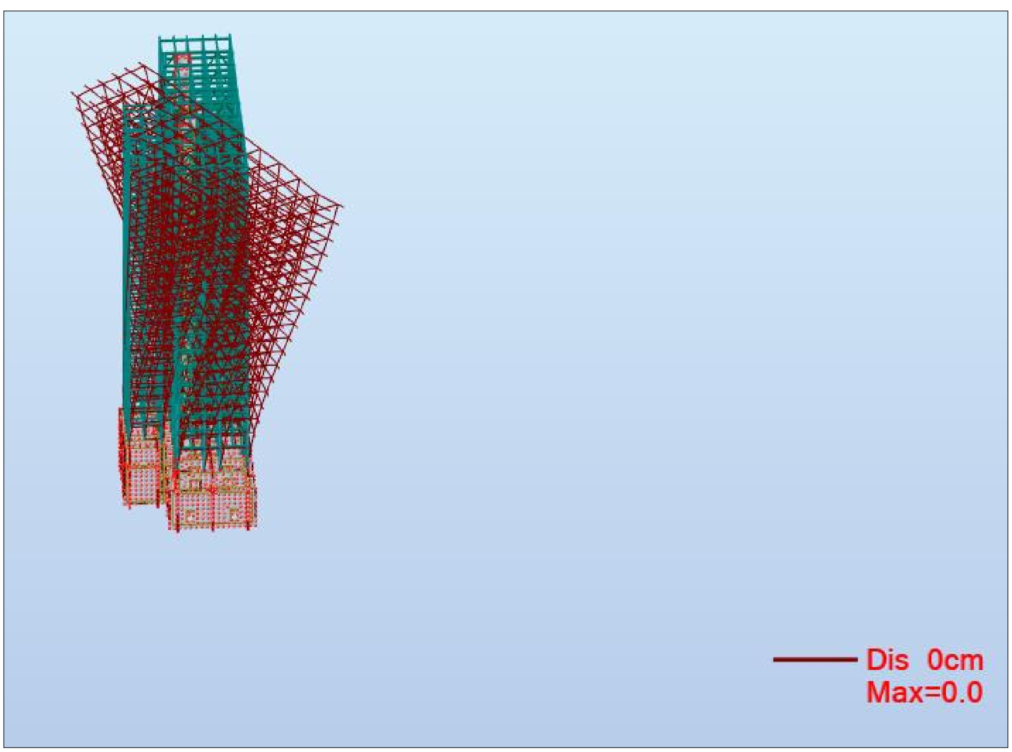


Figure 59 mode 3

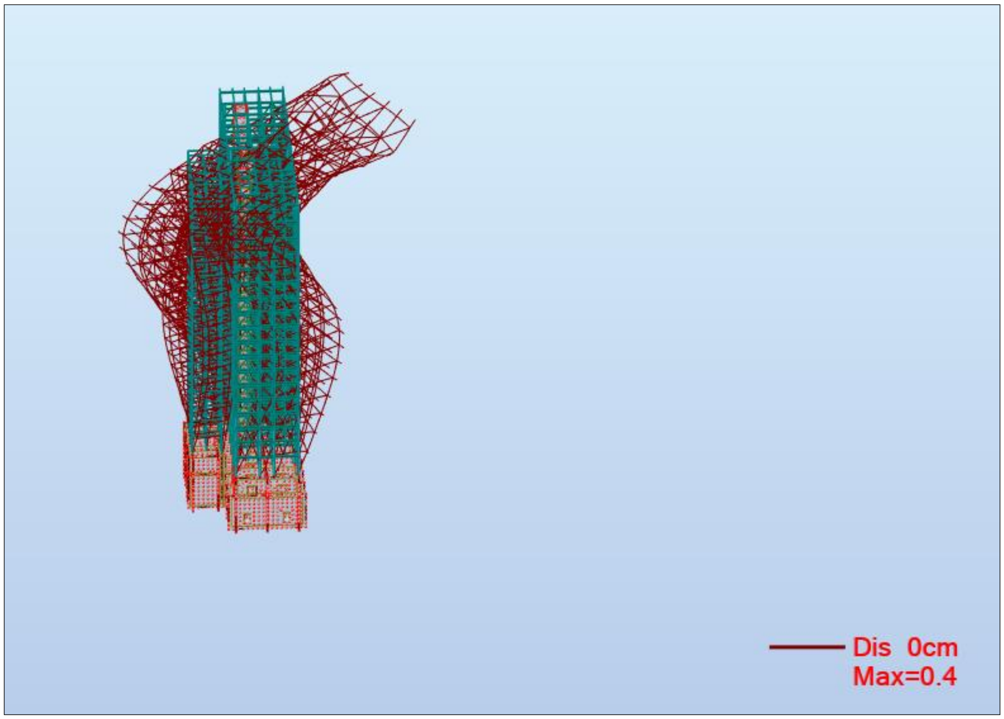


Figure 60 mode 4

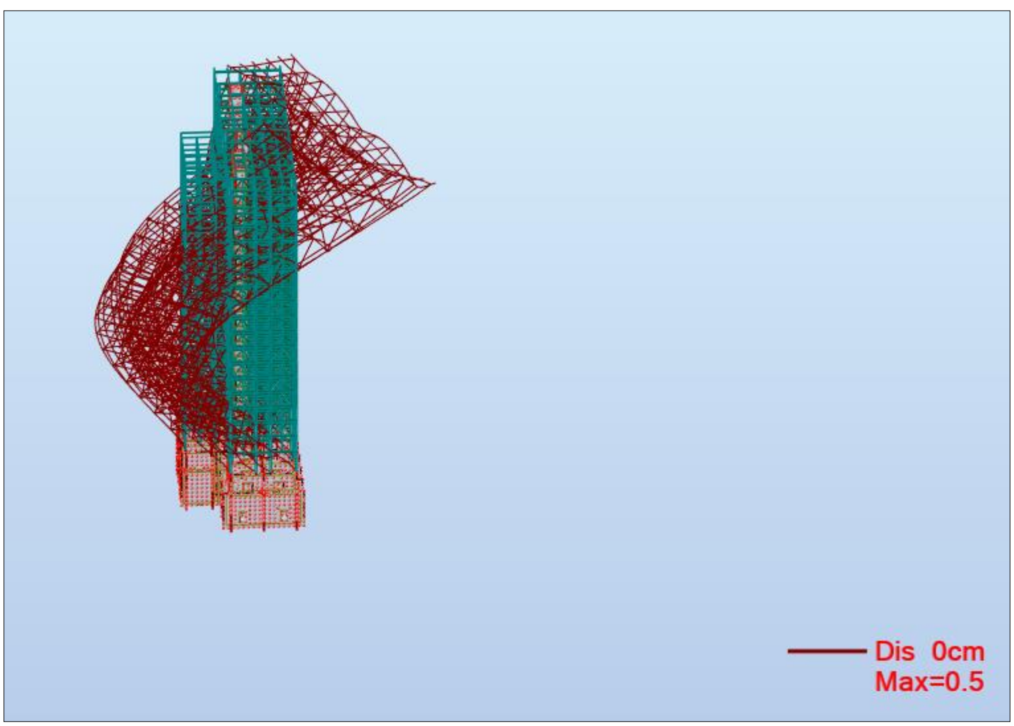


Figure 61 mode 5

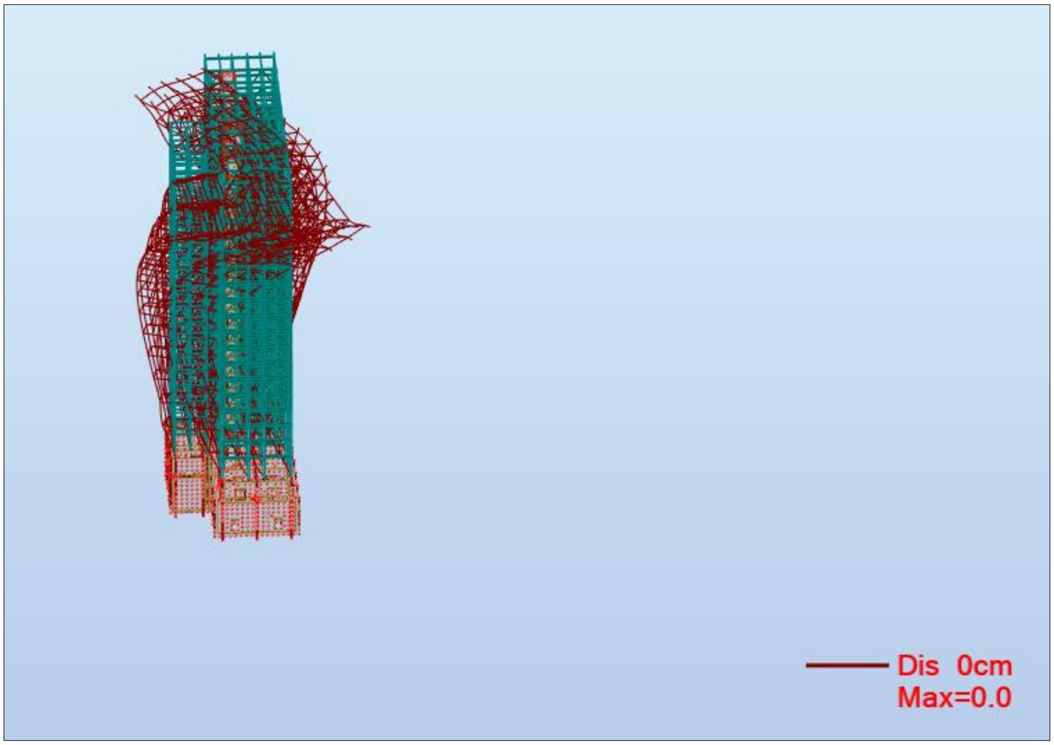


Figure 62 mode 6

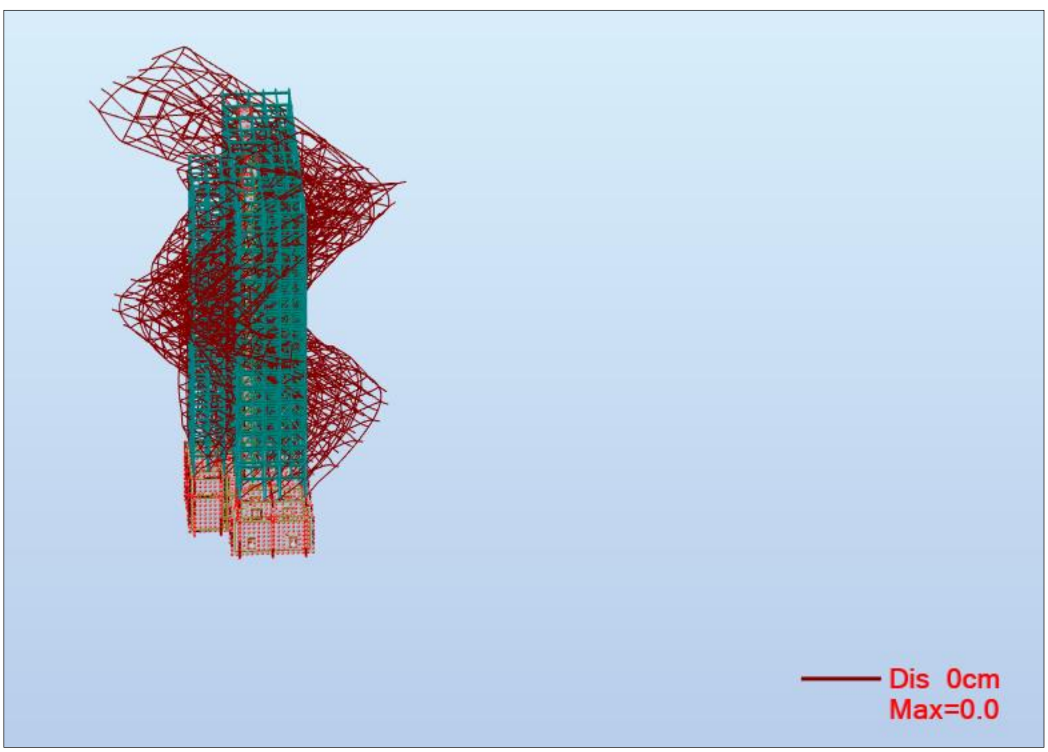


Figure 63 mode 7

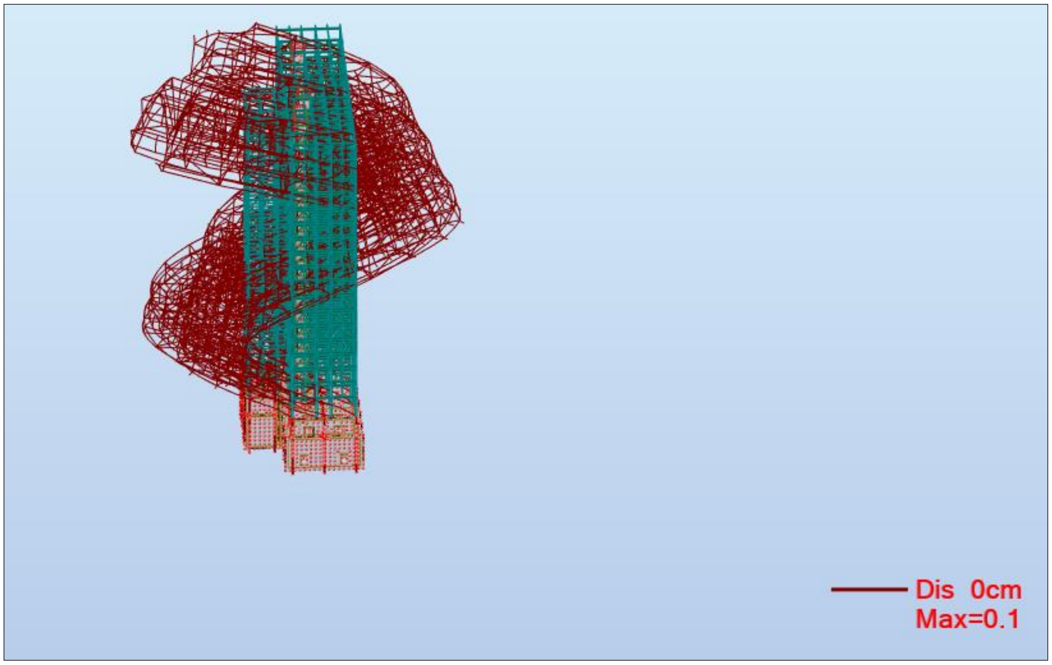


Figure 64 mode 8

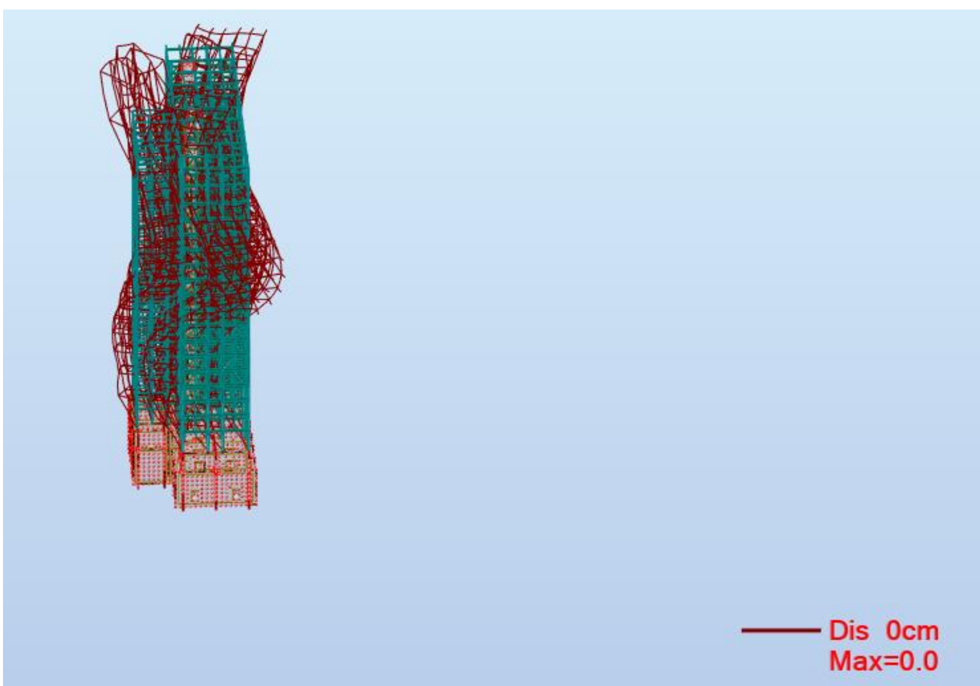


Figure 65 mode 9

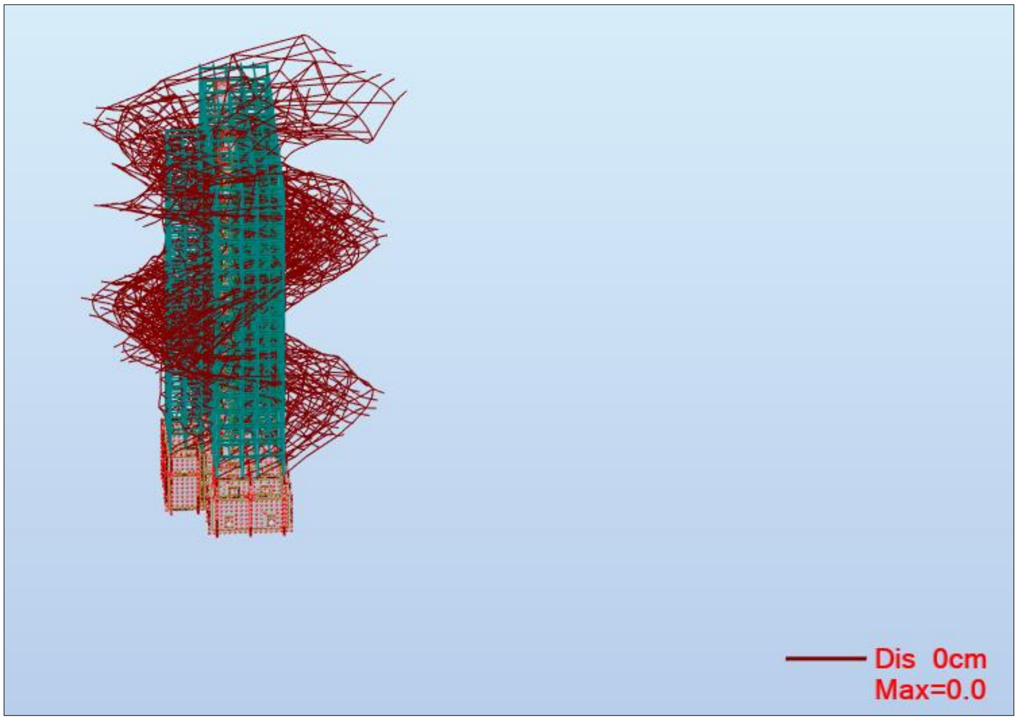


Figure 66 mode 10

MODAL ANALYSIS WITHOUT FOUNDATION:

			Mass participation ratio		
mode	freq (Hz)	Time (s)	Ux	Uy	Uz
1	0.51	1.96	0.68	64.6	0
2	0.56	1.78	13.14	67.42	0
3	0.75	1.33	70.19	67.44	0
4	1.86	0.54	71.03	79.57	0
5	1.89	0.53	72.36	85.29	0
6	2.71	0.37	85.66	85.29	0
7	3.8	0.26	86.42	85.36	0
8	3.99	0.25	86.44	91.56	0
9	4.65	0.21	86.46	91.71	0
10	4.81	0.21	86.6	91.73	0
11	5.25	0.19	86.62	91.73	0
12	5.67	0.18	90.65	91.73	0

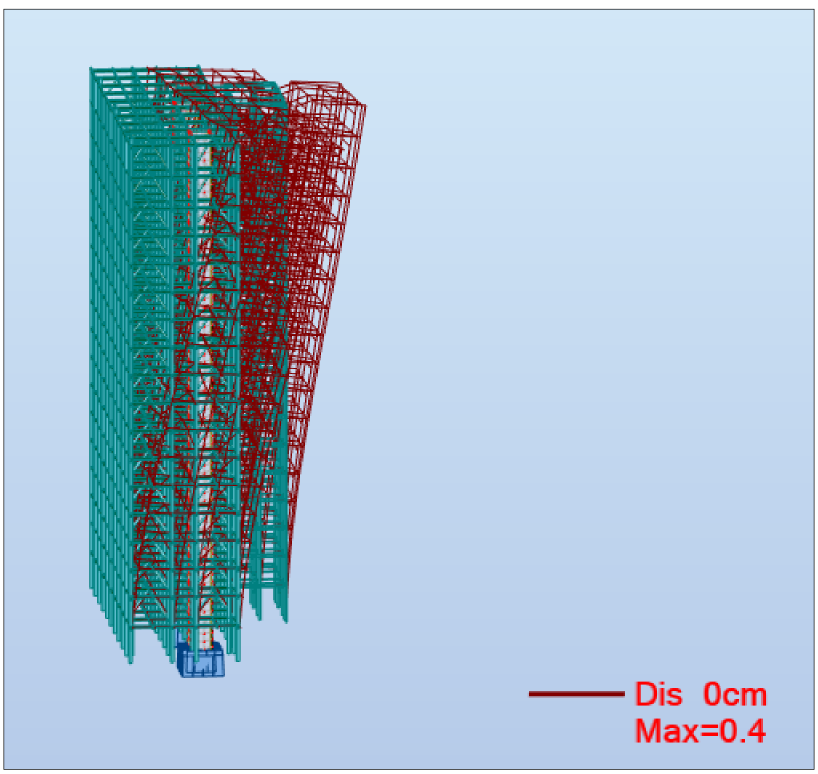


Figure 67 mode 1

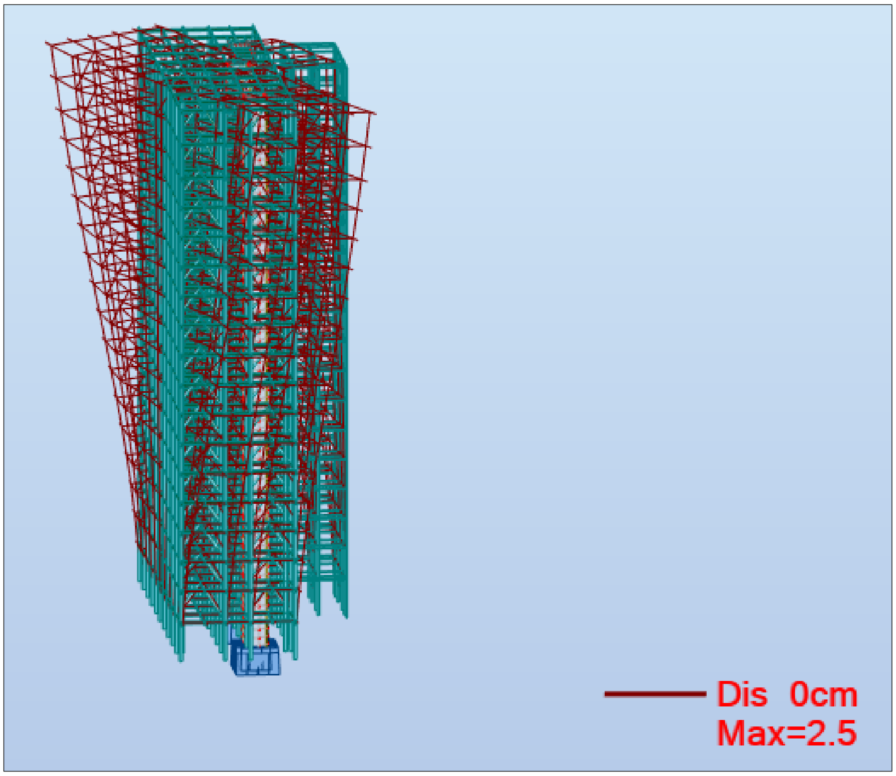


Figure 68 mode 2

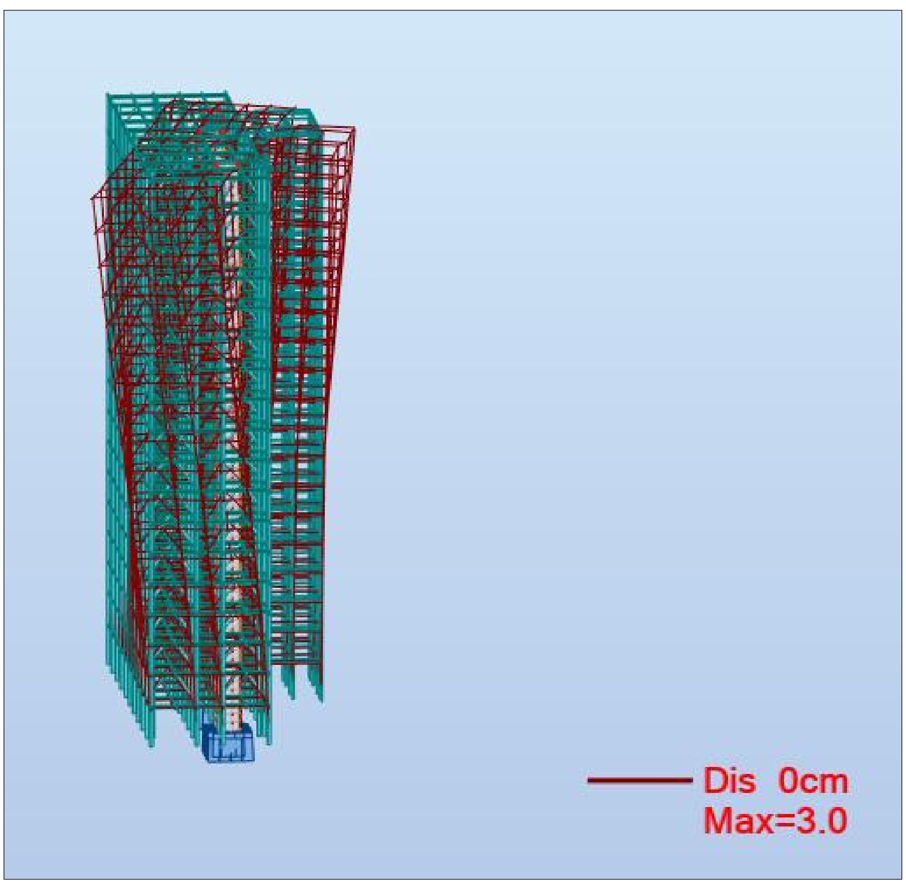


Figure 69 mode 3

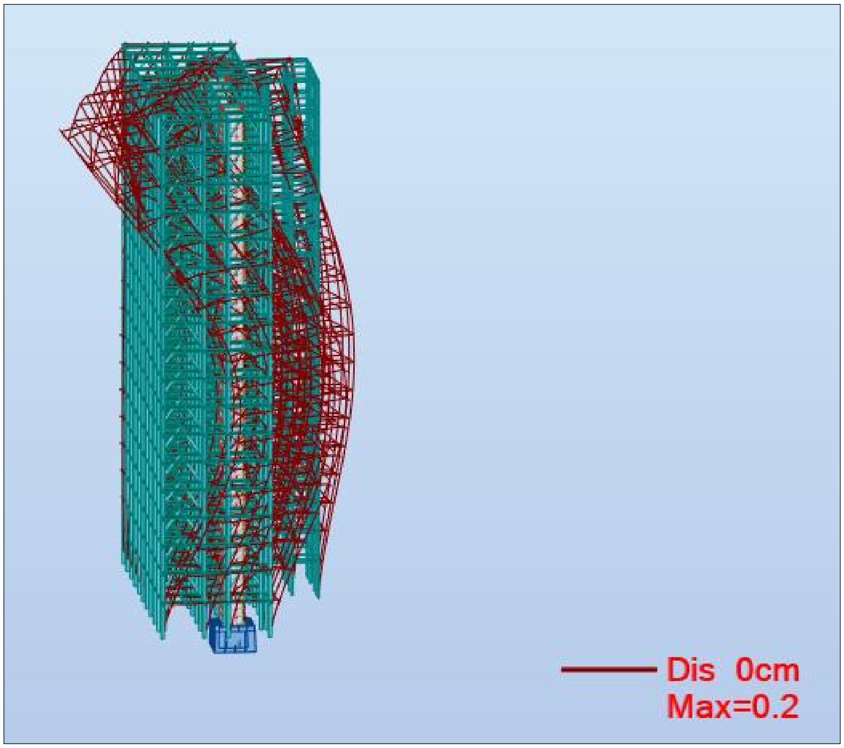


Figure 70 mode 04

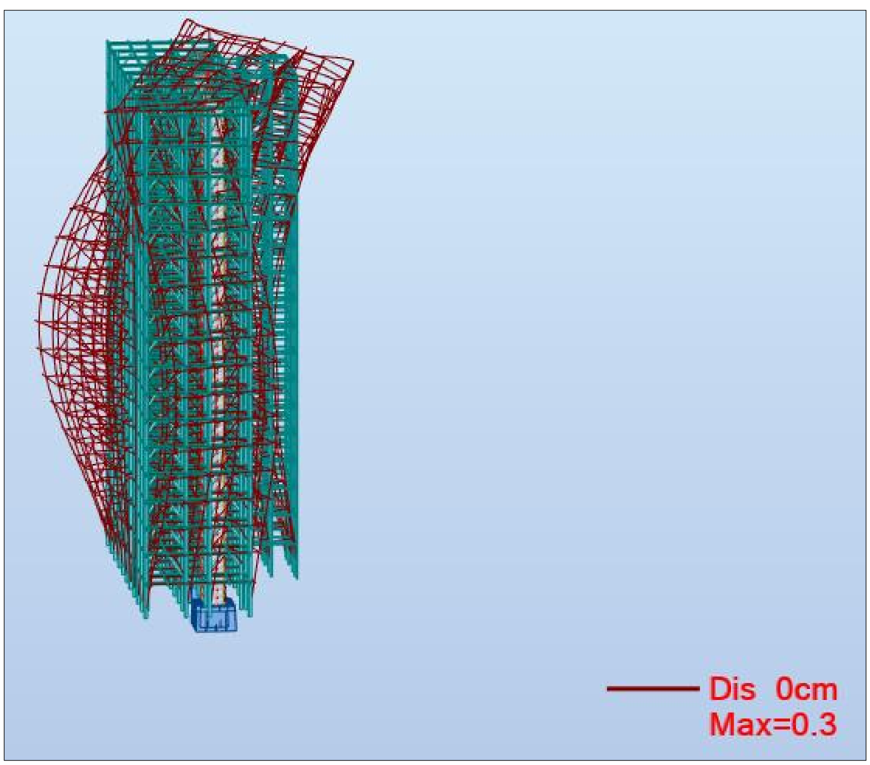


Figure 71 mode 05

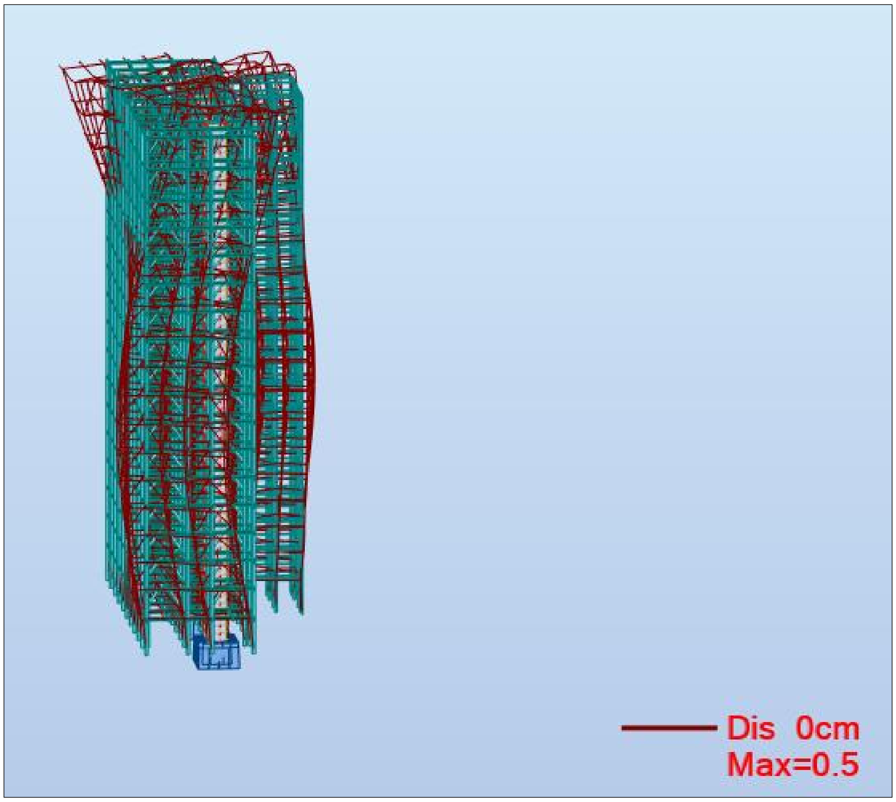


Figure 72 mode 06

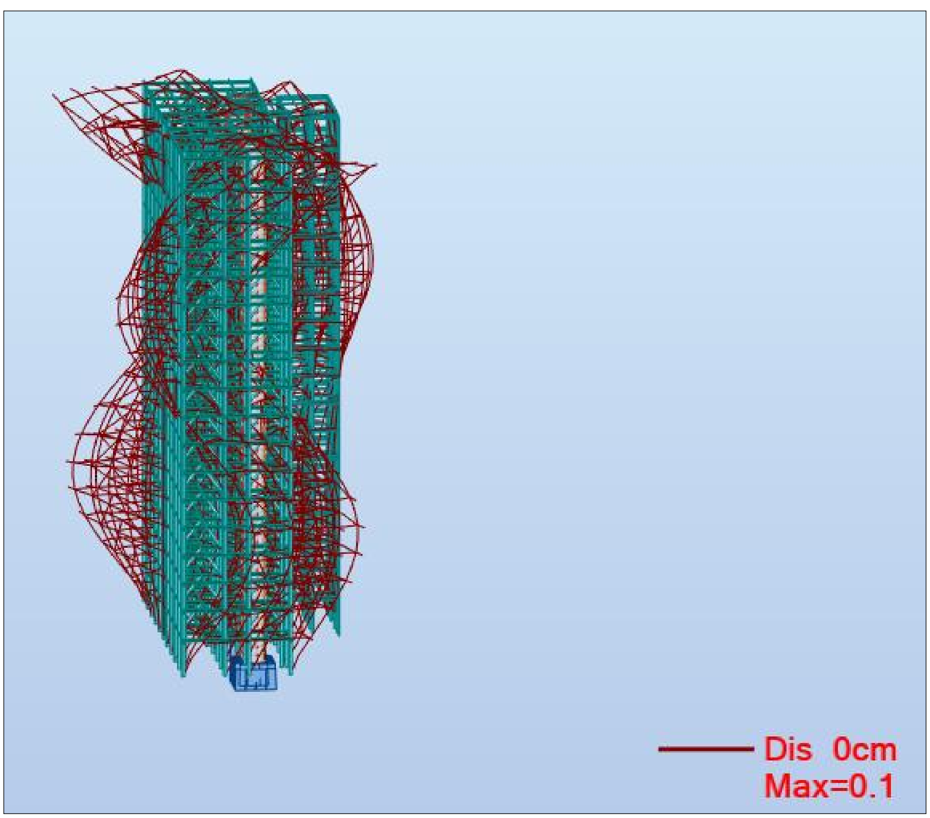


Figure 73 mode 07

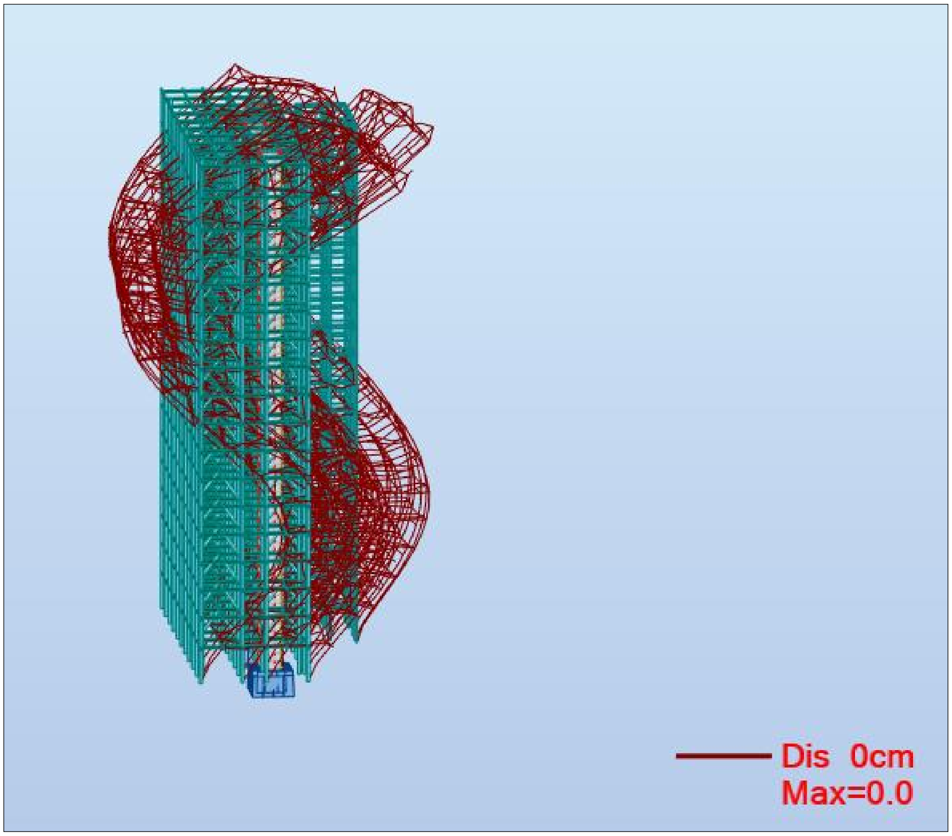


Figure 74 mode 08

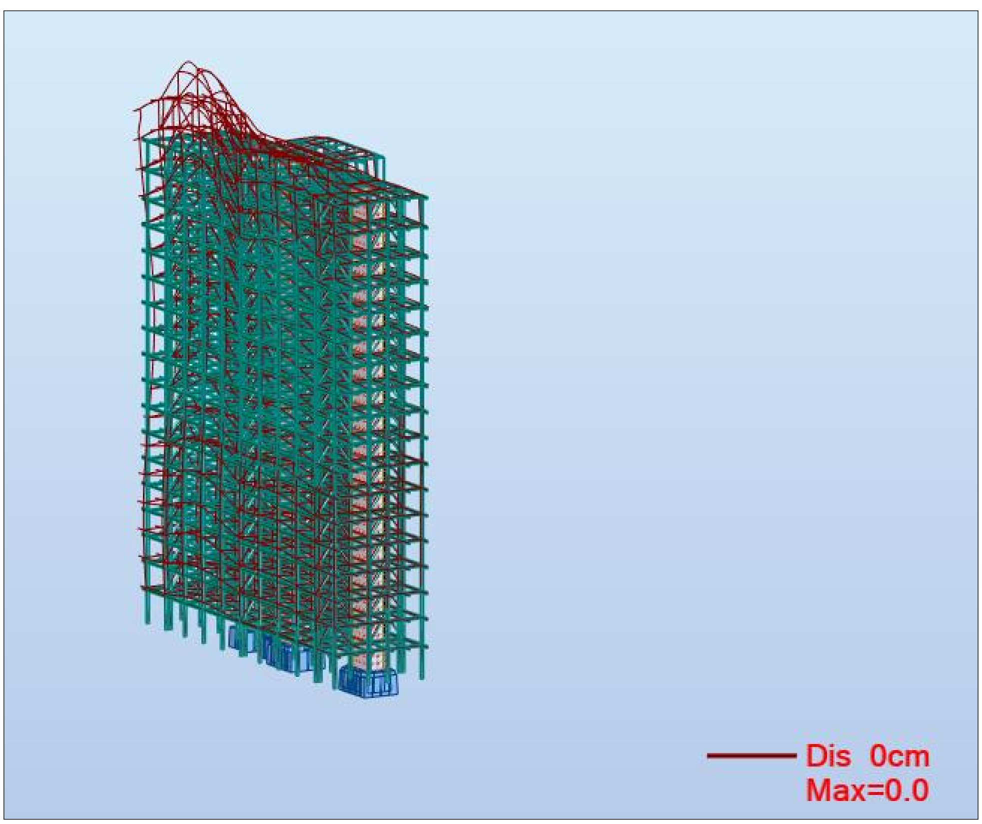


Figure 75 mode 09

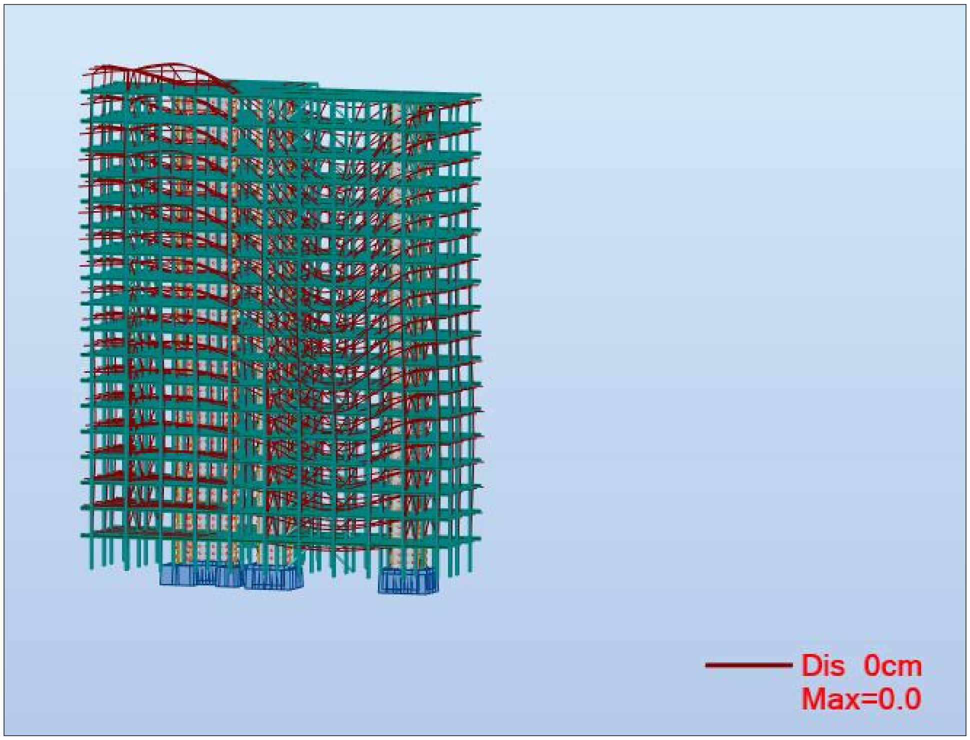


Figure 76 mode 10

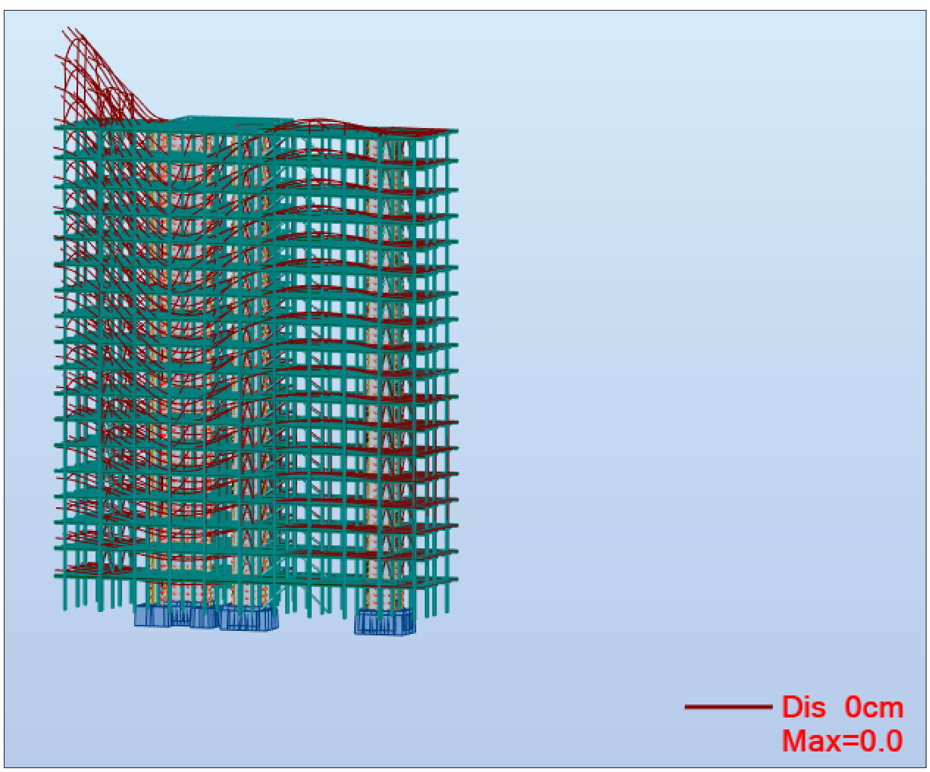


Figure 77 mode 11

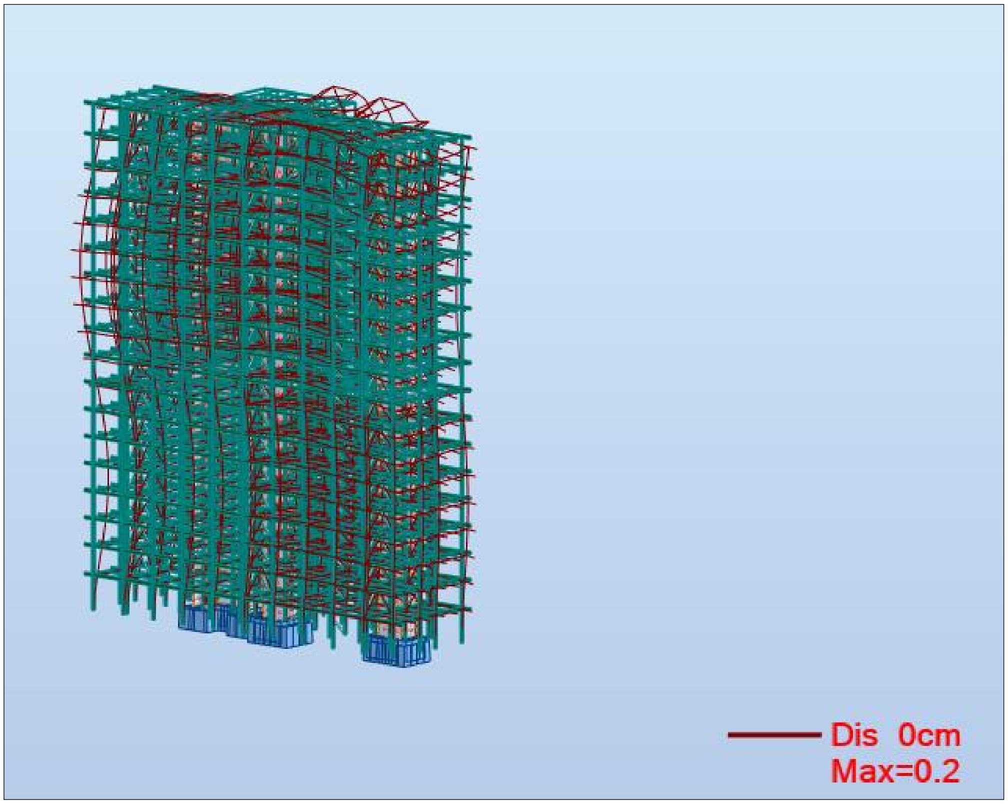
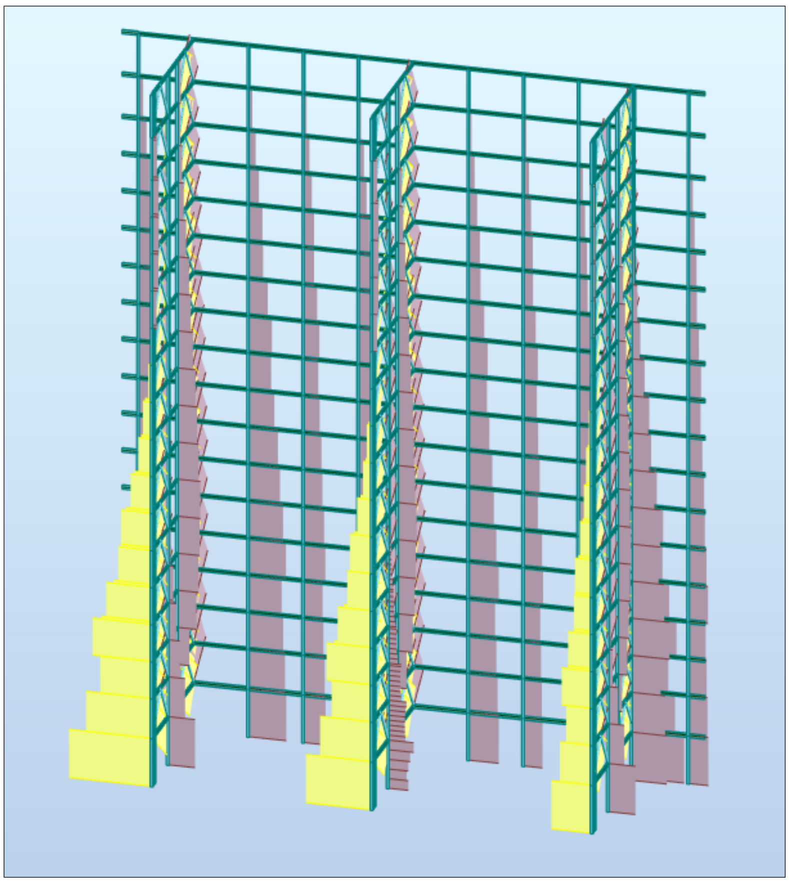


Figure 78 mode 12

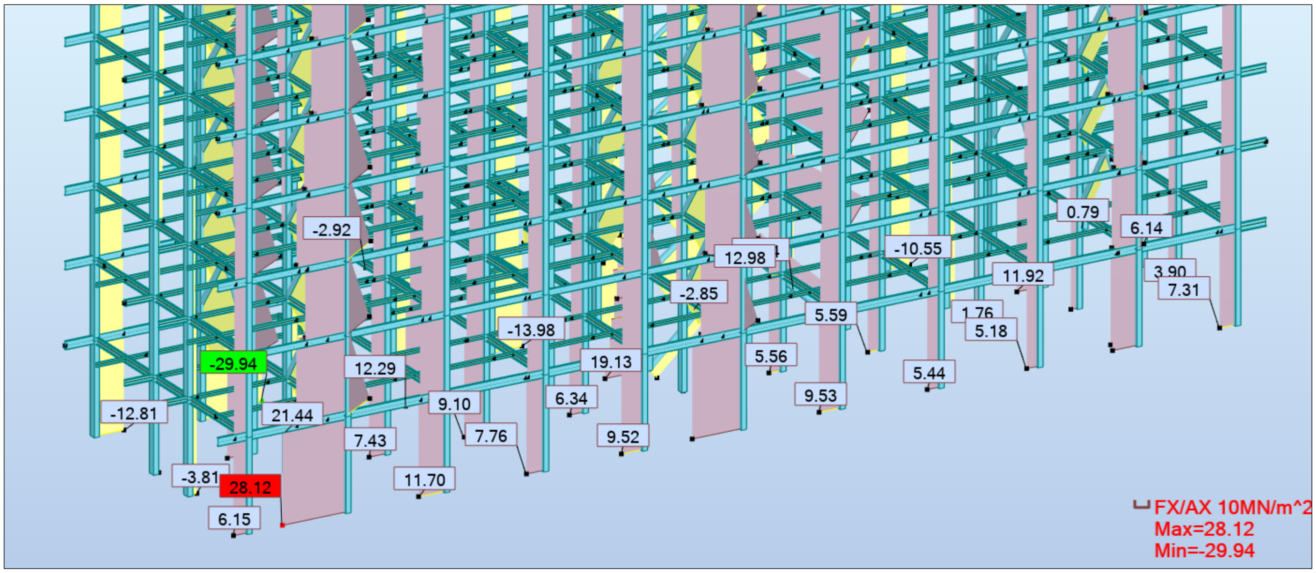
AXIAL STRESS

As the wind is the predominant force that affects the building, an important aspect of the building was to be evaluated. That is at the frames of the braces, more axial stresses were found to occur as seen in

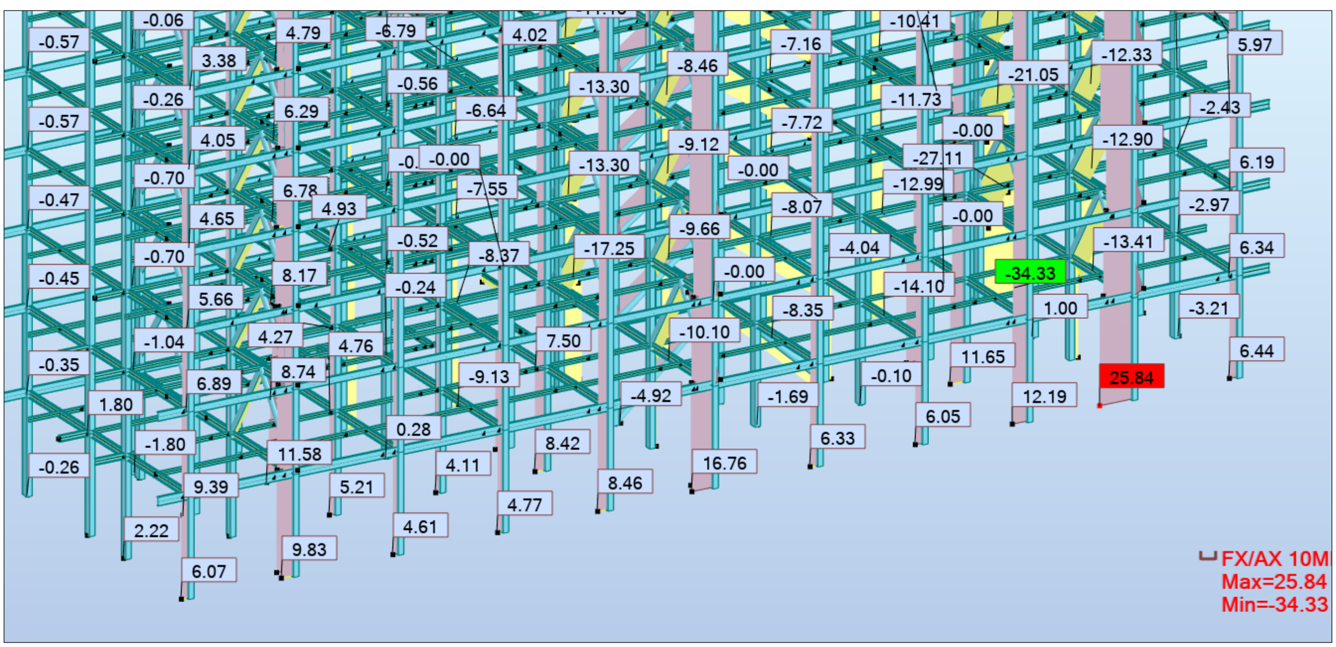
Wind Y- direction:



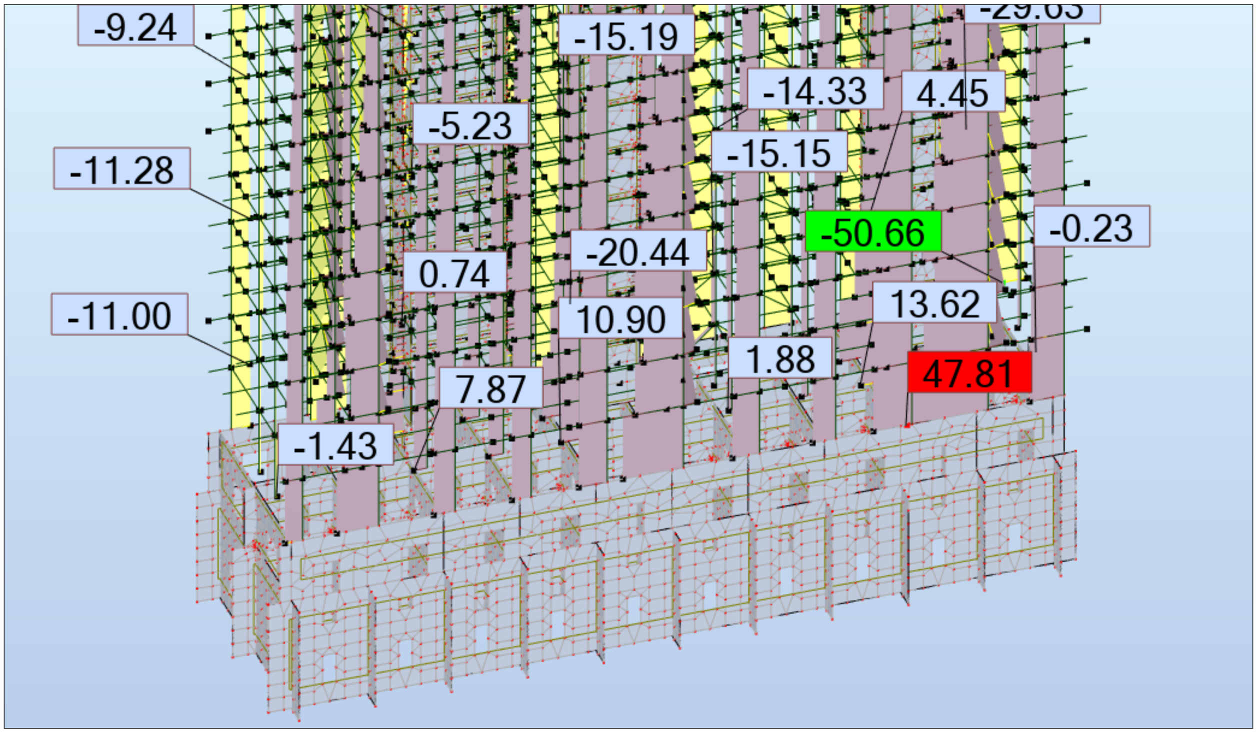
Wind X+ Direction:



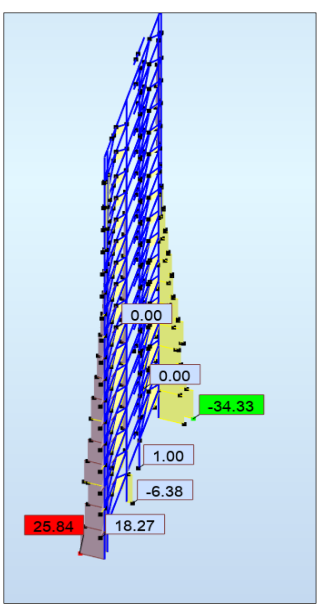
Wind X- Direction:

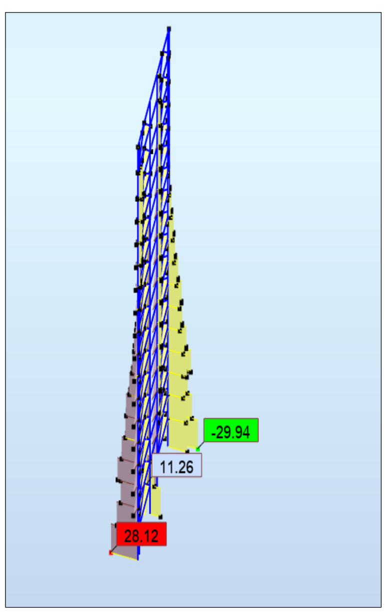


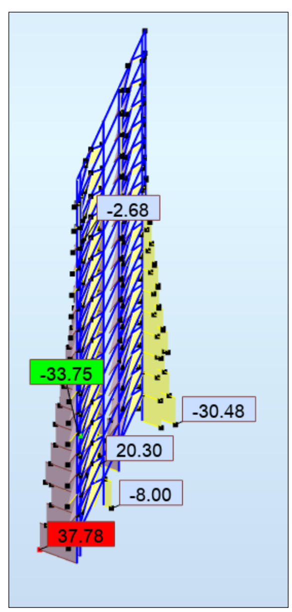
Wind Y- direction:

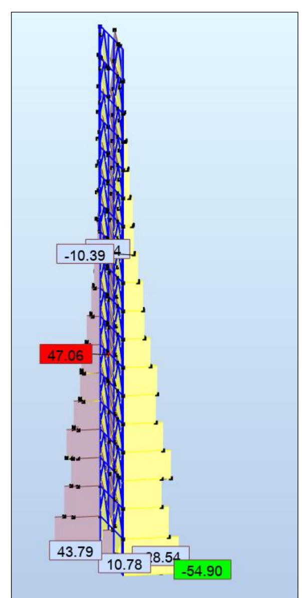


For individual Frames with bracing showcasing axial stresses in all 4 different wind simulation:









As it can be seen from the diagrams above, there are considerable axial forces in the base of the columns of the building especially the frame where bracings are present.

Thus, in order to counter the traction, there is considerable prestressing done at the base of the building. as shown below:

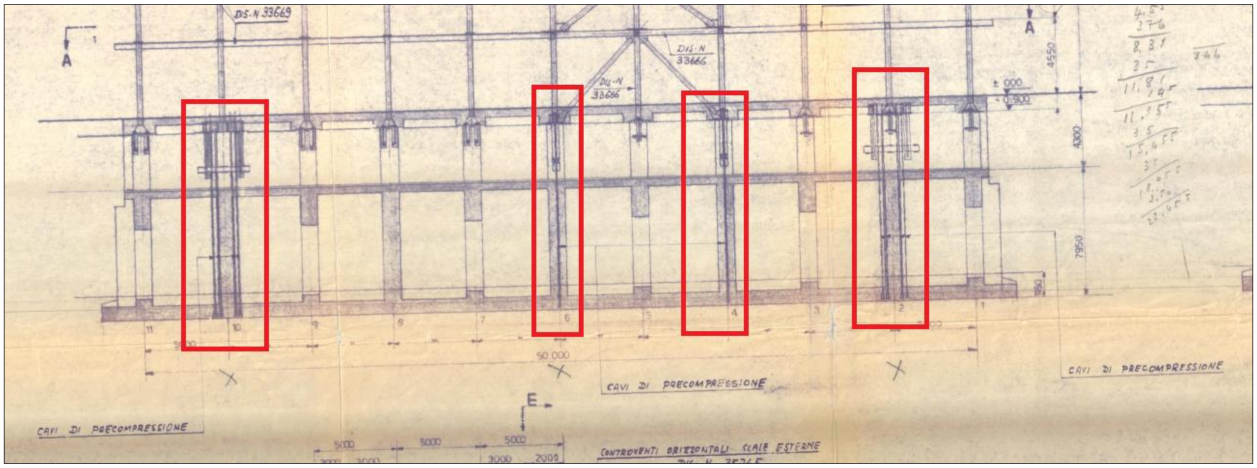


Figure 79 prestressing at the foundation

CONCLUSION

In conclusion, in order to carry out comprehensive retrofitting more information is required however the models that was analyzed do provide a good preliminary structural analysis of the building.

The structural sheets and other documents provide ample information. This also provide an pin point location to do further investigation needed to do in order to get the complete structural information needed for retrofitting intervention.

For the scope of this thesis, it was not possible to do inspection on site and enter the building due to legal activities for reclamation of the building.

Once this is done a proper investigation can be recommended in order to understand and determine the proper scale of deterioration of the structure at this moment.

Few recommendations:

- Complete survey of all the building especially the structural elements that are missing in the structural drawing to come complete the structural knowledge of the building.

- Going through the building and intervening with visual and destructive or non-destructive test in critical areas in order to understand the state of the building

- Destructive test in order to see the structural viability and the contents of the R.C.C slabs. In order to confirm the information of the sheets and provide more precision in the knowledge.

- Visual inspection of the steel column used in order to check the type of steel used.

- Surveying and conduction in-situ investigation on the foundation especially pre-stressed parts in order to see if any intervention is needed there.

- Welded elements across the building can be investigated for knowledge and for possible intervention at critical places where elements may be highly stressed.

All of the above mentioned can help in understanding the RAI Skyscraper better and help us determine the future of this Iconic building in the heart of the city of Turin.

References:

- https://en.wikipedia.org/wiki/Skyscraper
- https://www.thoughtco.com/how-skyscrapers-became-possible-1991649
- *D.M. 14.01.2018 – Aggiornamento delle "Norme tecniche per le costruzioni"*
- *Google maps*
- SEISMIC RETROFITING OF AN EXISTING STEEL STRUCTURE
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- Seismic analysis and retrofitting of an existing multi-storey building in Stockholm CELINE HAIKAL & MATILDA MUCA