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Facing the issues of design, construction and management of Zagreb Airport Terminal - a case study

Jure Radić, Nina Dražin Lovrec, Branko Kincl, Velimir Neidhardt

Facing the issues of: design, construction and management of Zagreb Airport Terminal - a case study

Zagreb Airport Terminal

- Start of the project
- Evaluations for the new terminal
- Surrounding area and landscaping
- Architectural and structural form
- Functionality and flexibility
- Concrete foundations and inner structure
- Steel space truss roof construction
- Conclusion


AIRPORT FRANJO TUĐMAN

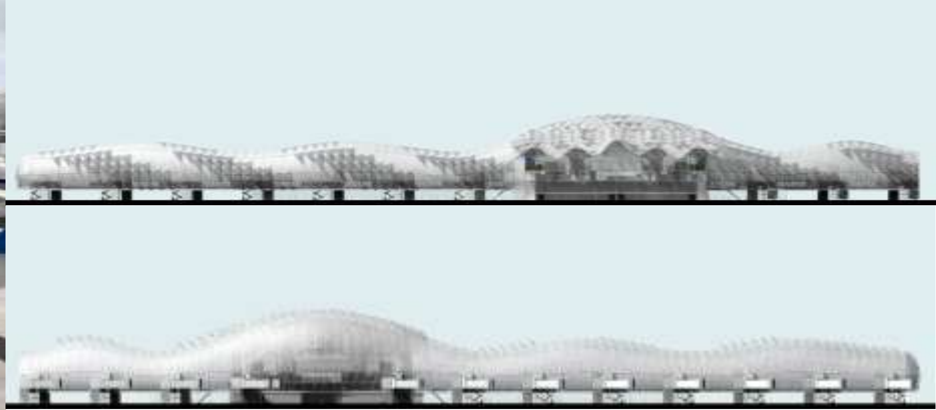
First prize on an international competition for the design

In 2008 a first prize on an international competition for the design of the New Airport Terminal was awarded to the project by

Branko Kincl,

Velimir Neidhardt and

Jure Radić



Second prize was awarded to the project by Shigeru Ban and Taro Okabe, and the third prize to the project by Norman Foster. From other 14 entries, two were awarded fourth and fifth prize, and four others were buyouts. And this is the

2nd prize: Shigeru Ban and Taro Okabe

3rd prize: Norman Foster

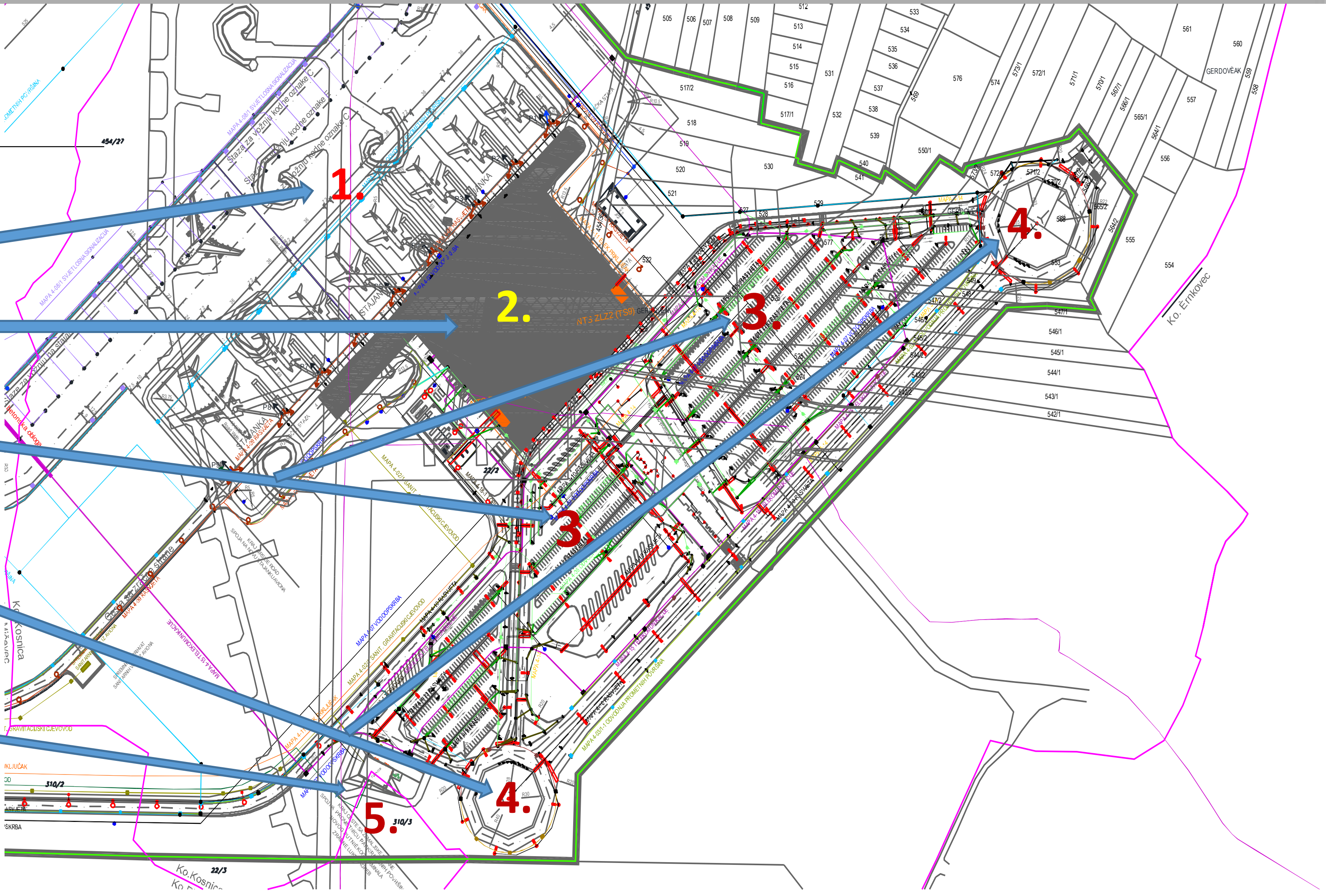
1. Aprons for 8 passenger boarding bridges for direct boarding, extensible in the second phase

2. Elevated ramp construction and Departures level viaduct

3. Parking lots

4. The surroundings of the airport building are divided into the eastern Arrivals section and the western Departures section, both ending in roundabouts, and equipped with aprons and parking lots

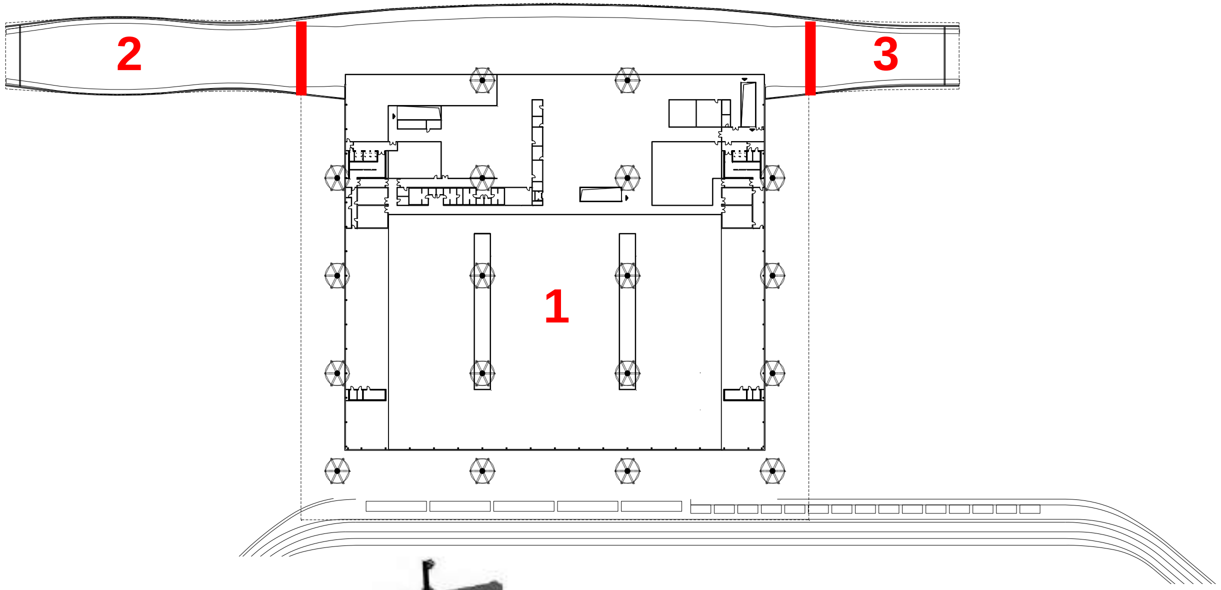
5. Boiler room



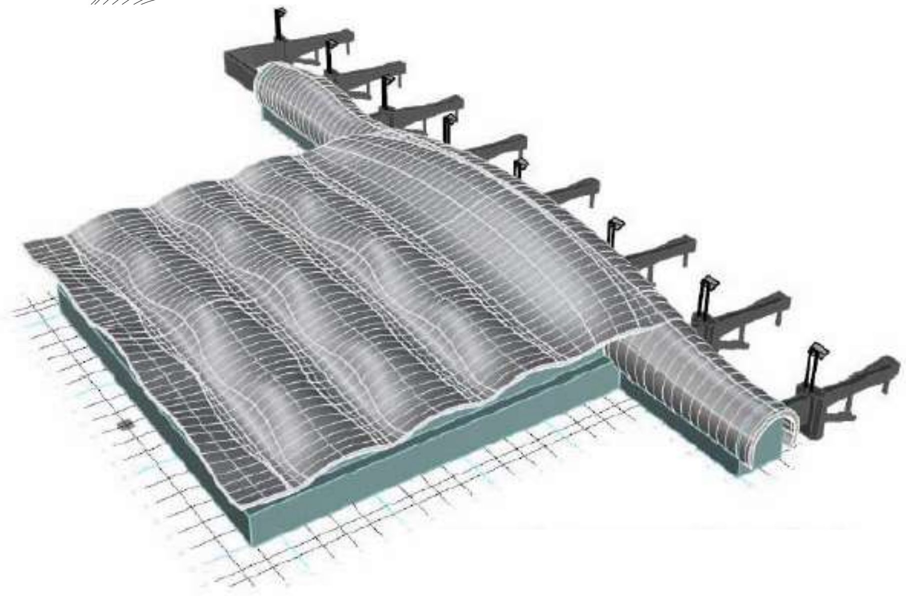
- In 2011 a concessionary agreement was signed with French company Bouygues for the erection of terminal according to the winning design
- The Authors and the Concessioner both agreed for changes to be made in order to optimize the cost of the New Terminal:

	Competition winning design	Main design (as being built)
Passengers / year	from 5 million (phase 1) up to 8 million (phase 2)	
Layout area (Main building)	155 x 165 m	129.6 x 136.8 m
Pier lenghts	353 m (left), 151 m (right)	83 m (left), 40 m (right)
Gross construction area	73.320 m^2	65.883 m^2
Number of Levels	Basement, 0, 1-4	0, 1-3
Concrete construction	Monolithic, RC	Monolithic, RC, Prestressed
Steel roof construction	Three-directional Plane Truss	Triangular grid Space Truss
Cost	280 – 300 mil €	236 mil €

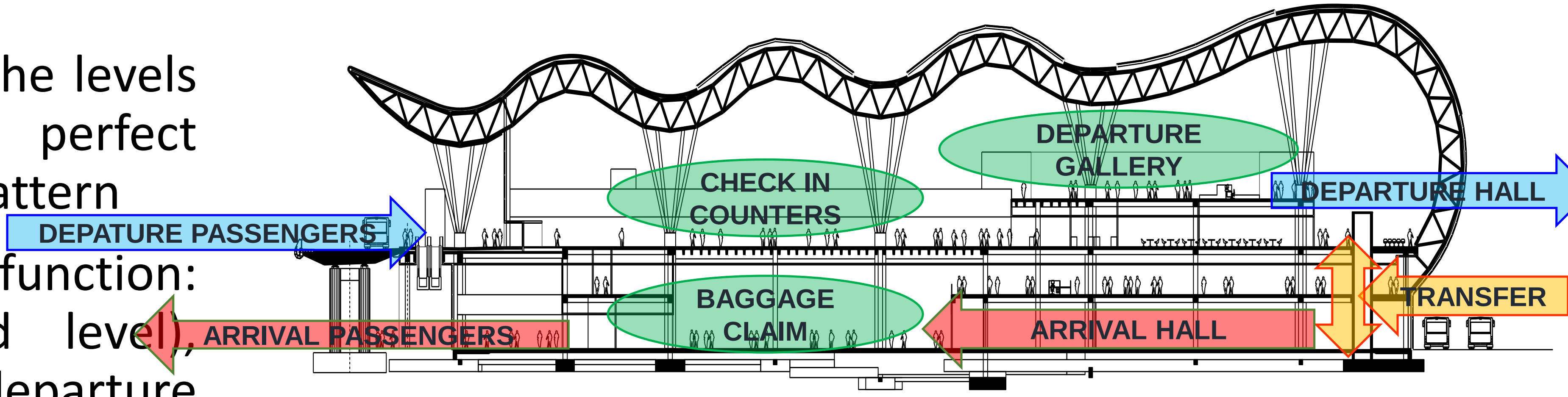
Visualization according to the new project (AS BEING BUILT)

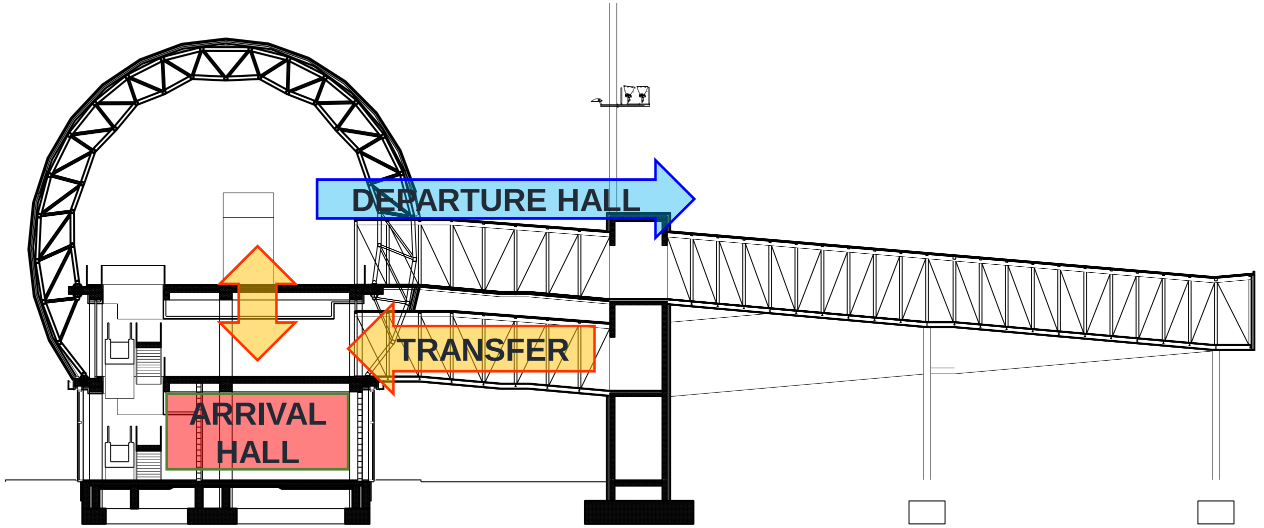


- 2 discrete geometrical and structural forms, which divide the terminal into 3 dilatation parts:
  1. **Main building (First dilatation)**
  2. **Linear structures of the piers left and right (Second and Third dilatation)**
- These functionally different parts are also structurally divided with dilatations in concrete floors and roof steel space truss.

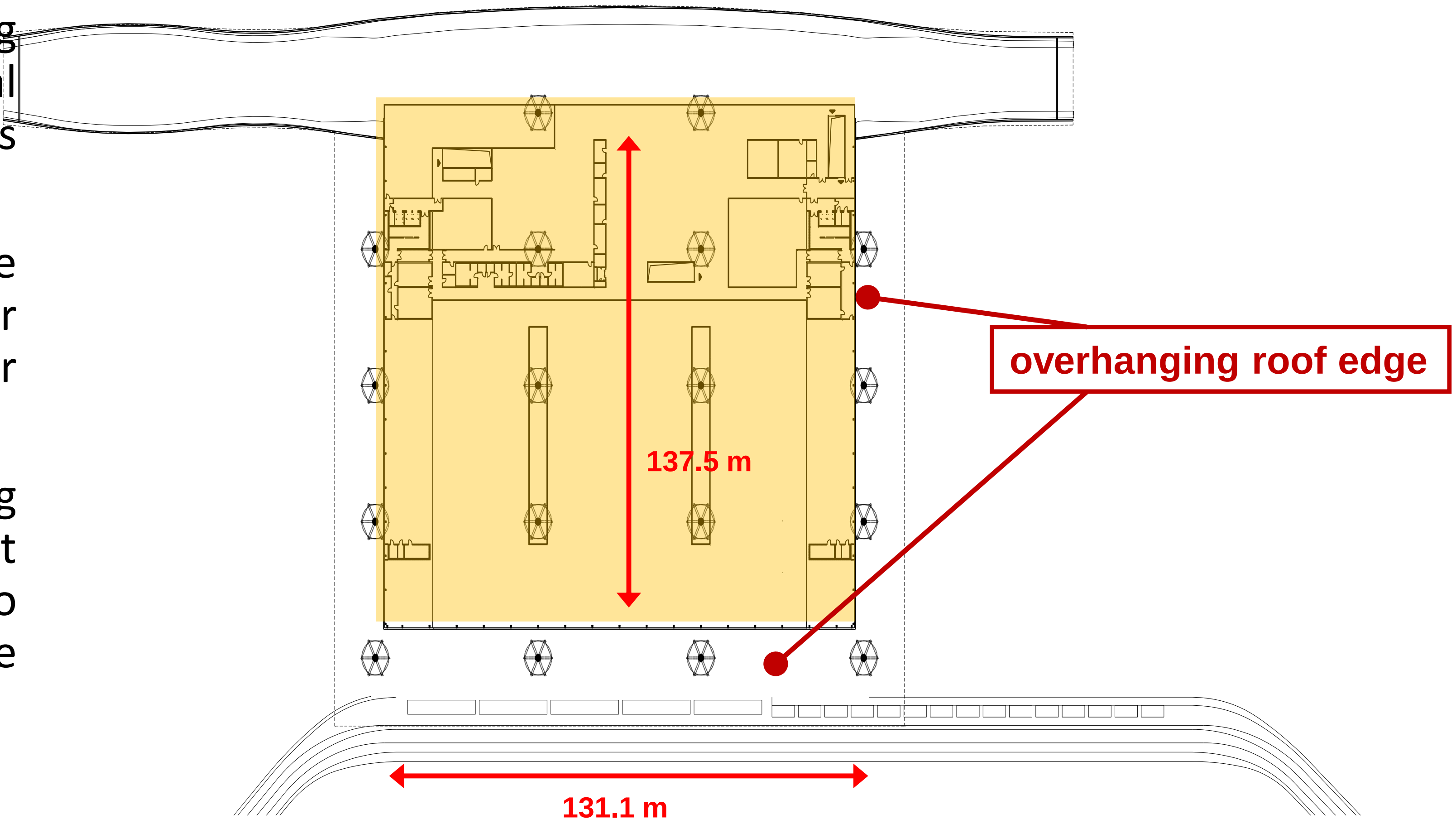


- Number and layout of the levels are designed for a perfect passenger orientation pattern
- Each level has a distinct function: arriving level (ground level), transfer level (+5.4 m), departure level (+10.2 m) and departure gallery (+15.0 m).
- They are connected by stairways and escalators which are enclosed with walls that serve as main seismic shear walls.

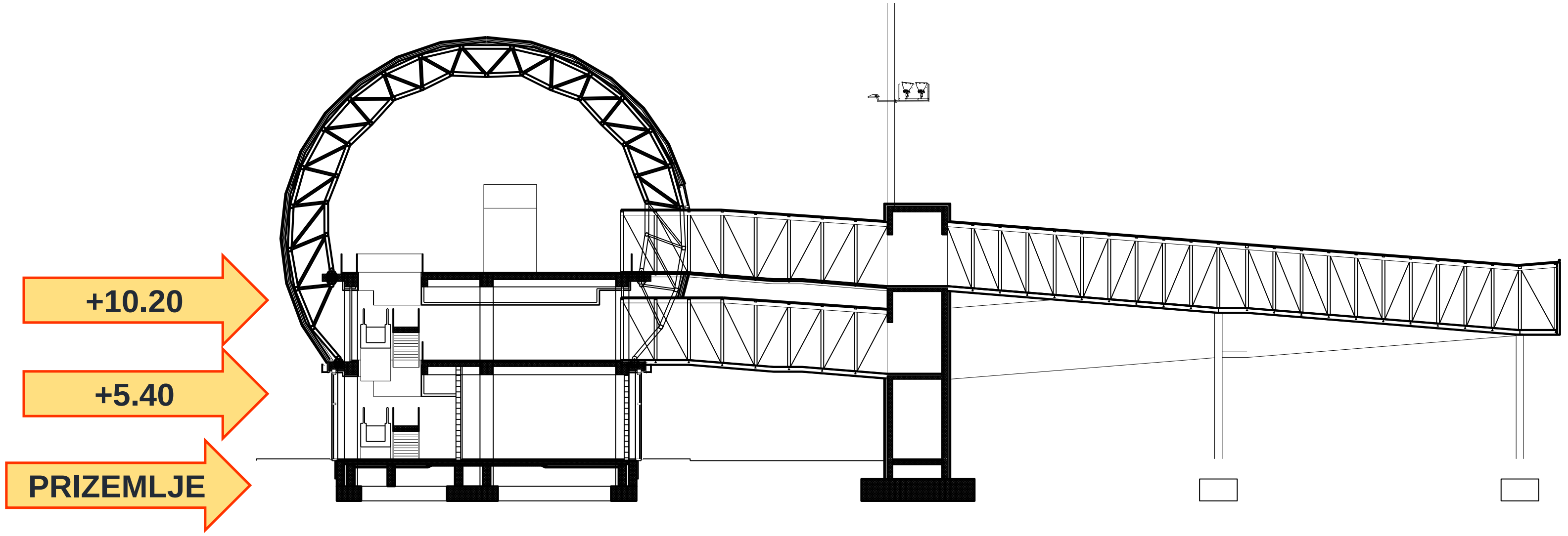




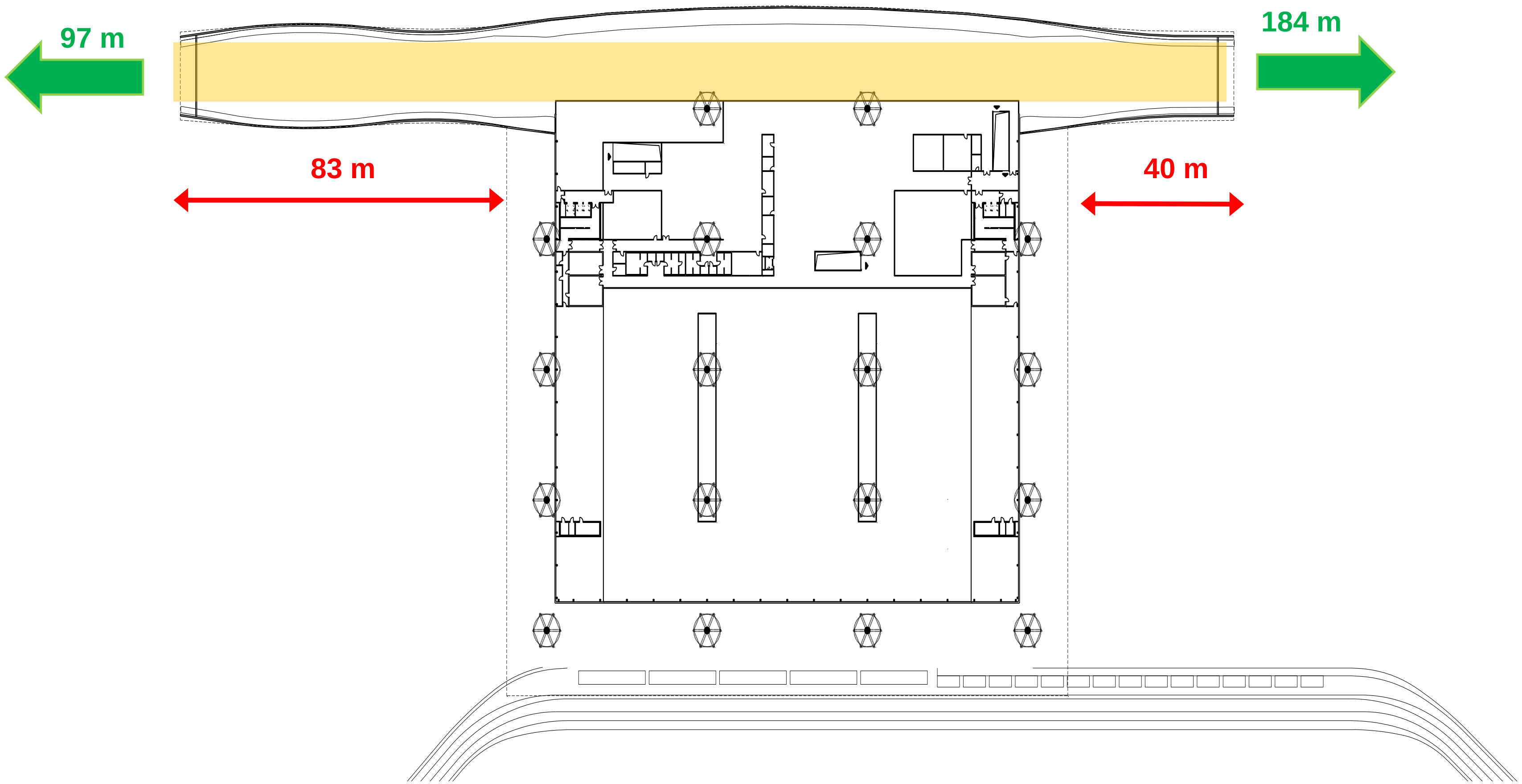
- The inner layout of the main building measures 137.5 x 131.1 m. The total layout of roof structure (roof shadow) is 151.2 m in width by 152.3 m in length.
- Main building is concrete structure which comprises 4 levels: ground floor 0.00 m, first floor +5.40 m, second floor +10.20 m and third floor 15.00 m.
- The roof is variable in height ranging from minimum 20 m in the lowest part (near the building entrance) to maximum 34 m at the middle on the airstrip side.



- Pier comprises ground floor and two upper floors (elevation +5.40 and +10.20 m)
- Pier roof height is also variable following the descending form of the main building.
- Pier roof is a vault with circular cross section, so with the change of its height it also changes horizontally. This causes a variable width of pier upper floor at level +10.2 m and a curvy edge of concrete slab at that level.
- Therefore, the width of the floors in the pier area varies from 16.2 m to 17.4 m.
- Left pier is 83.50 m long and right pier is 40.25 m long

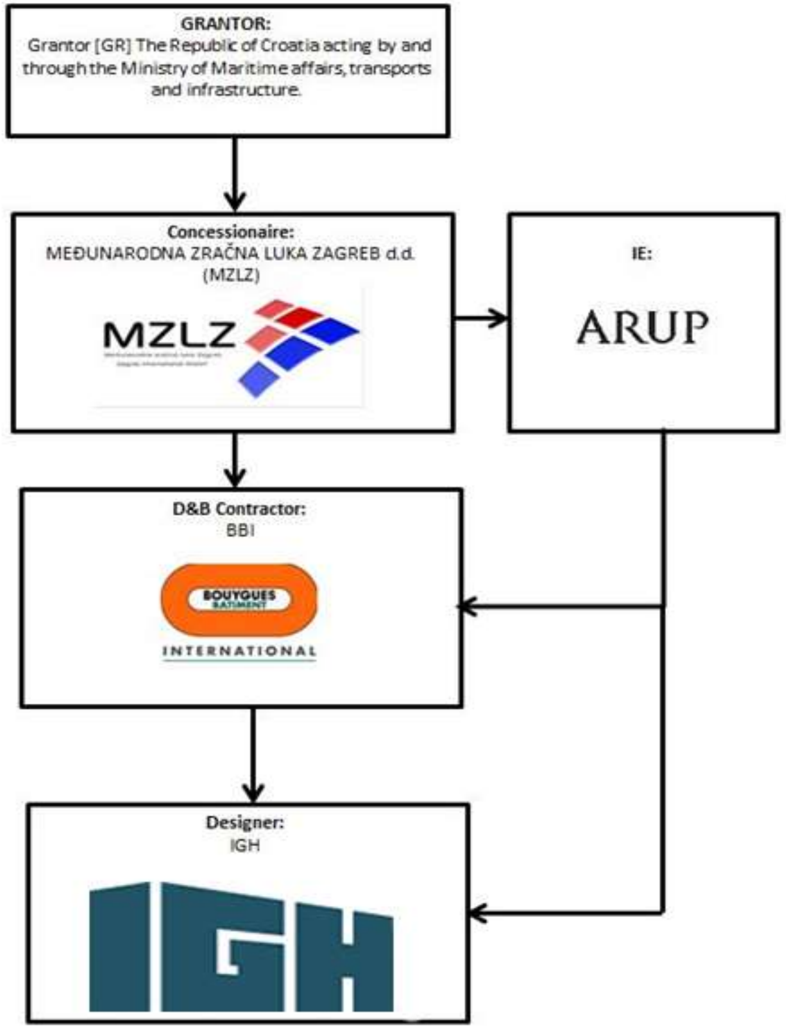


Linearity of the piers allows the adaptability towards the developing or changeable needs and optimal functional performance of the terminal.




ZRAČNA LUKA FRANJO TUĐMAN

Design organization structure



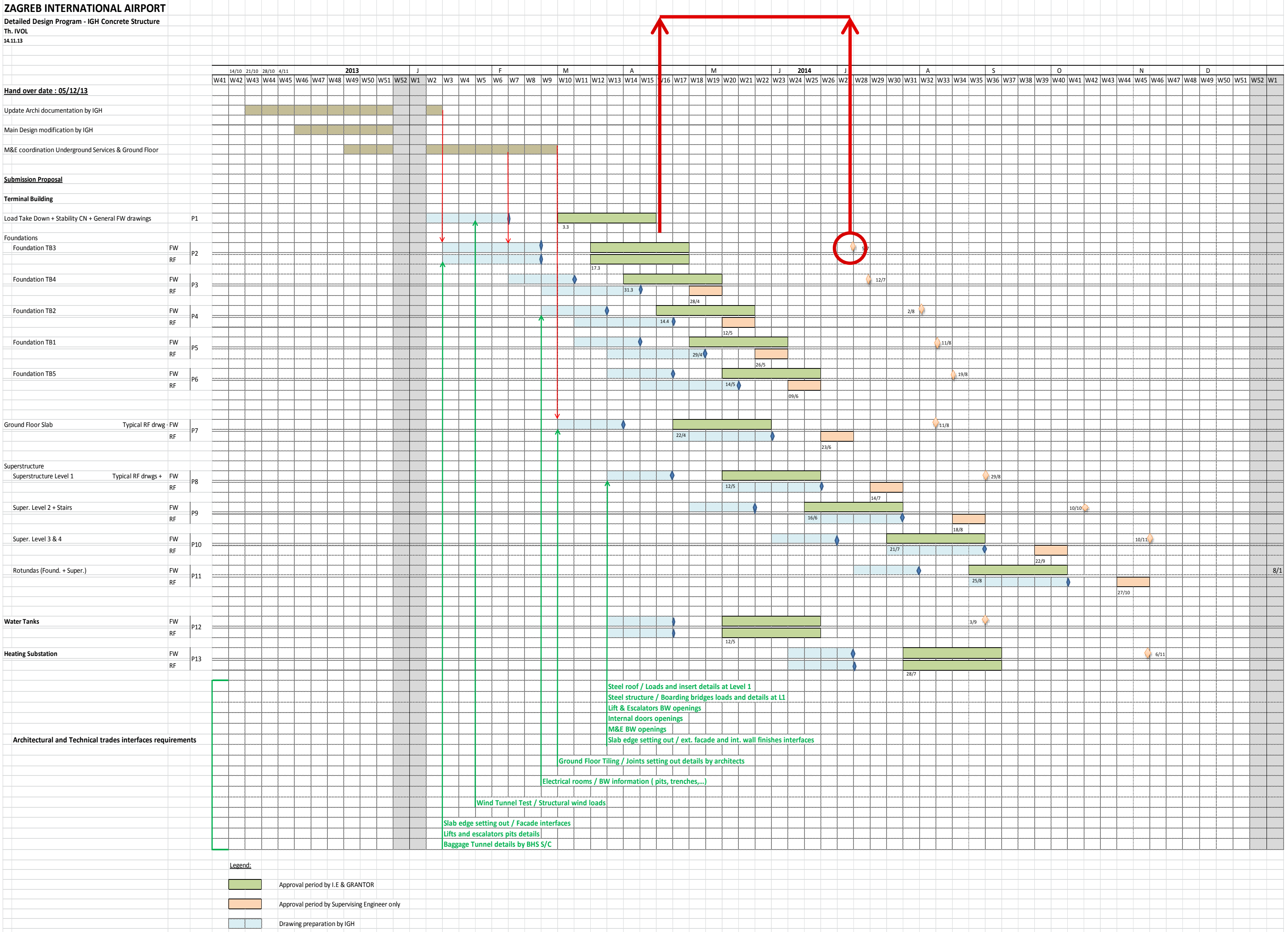
Medium level impact risk

1. Concessioner’s decission to alter the main concrete construction design in October 2014 (from precast RC construction to monolithic post-tensioned RC construction)
2. Concessioner’s decision to change the beginning of construction works (from middle od July 2014 to middle of April 2014)

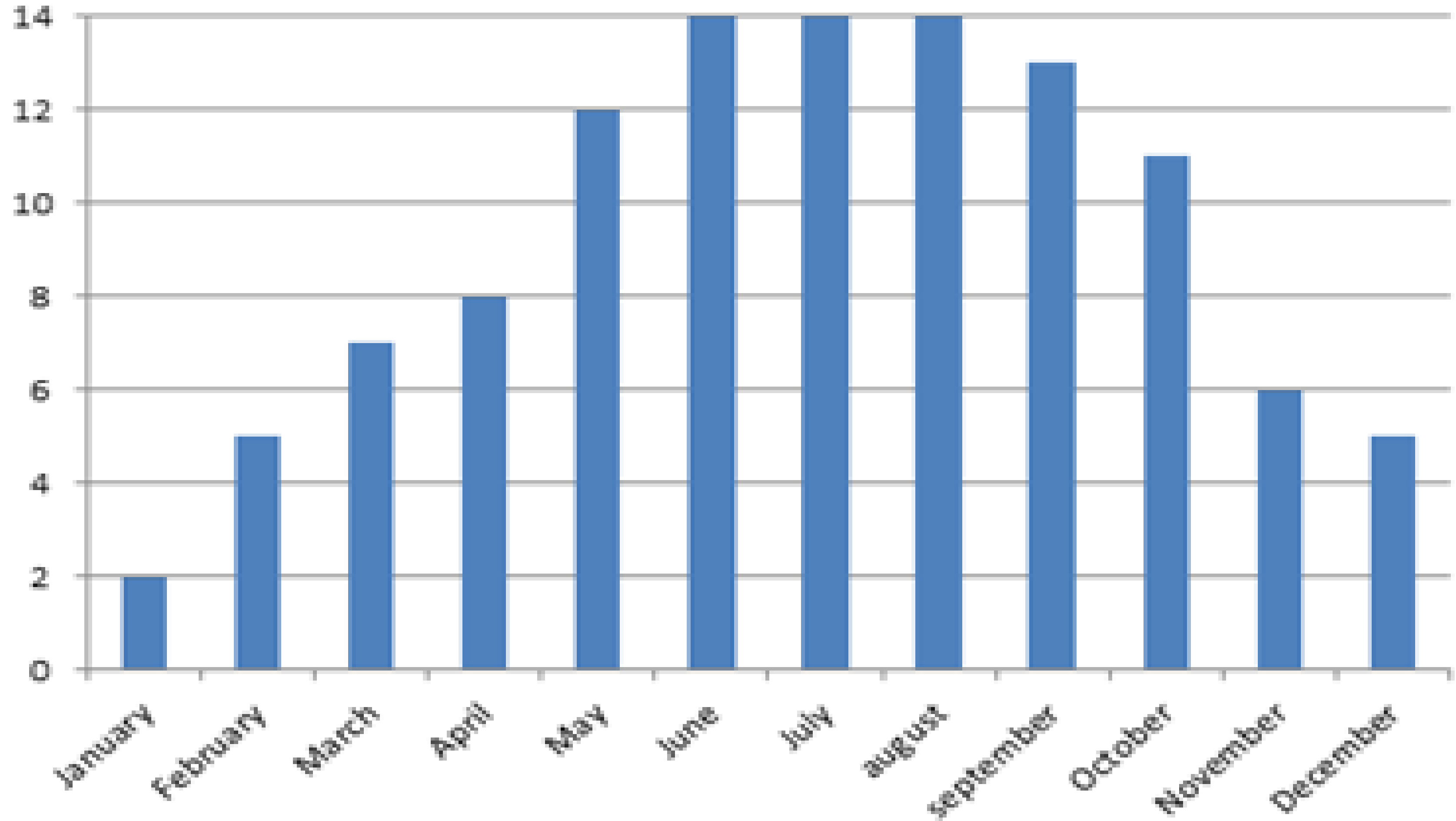
High level impact risk

3. Contractor for roof steel space truss abandoned the project in September 2014

Change of the beginning of construction works (from middle od July 2014 to middle of April 2014)

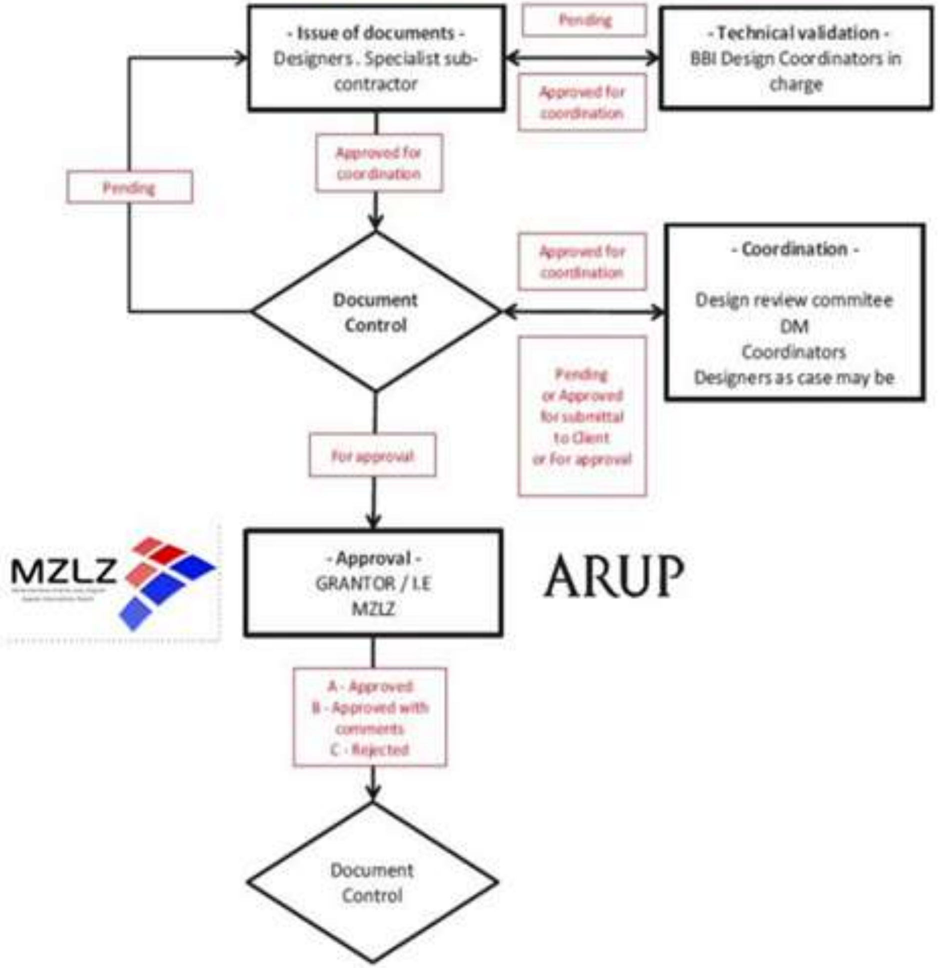


Number of IGH design team members employed during 2014



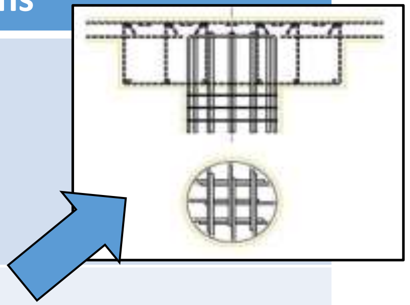
- Documentation management and exchange of information is handled through ACONEX platform
- Code structure for identification of the documentation:

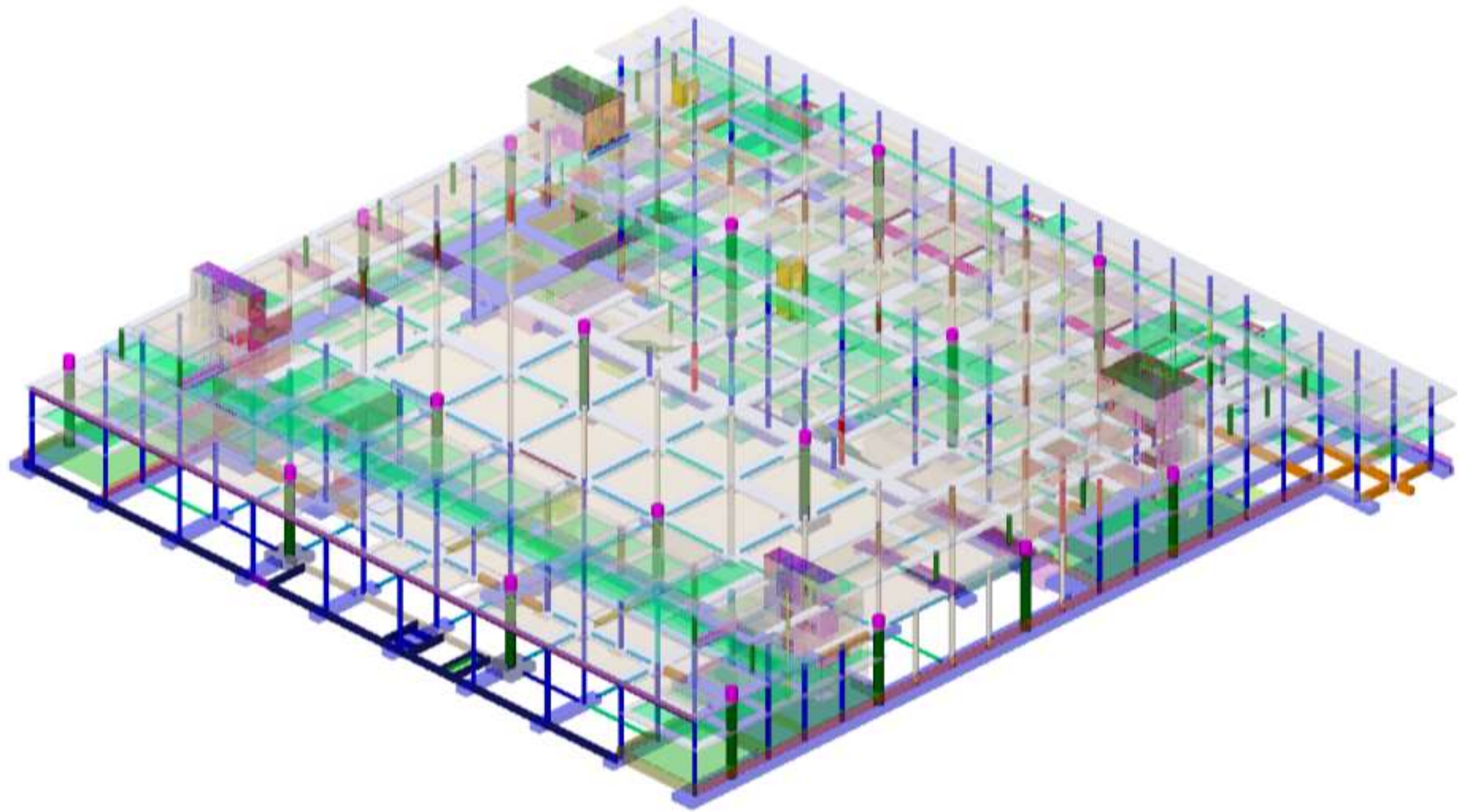
Control and flow of documentation

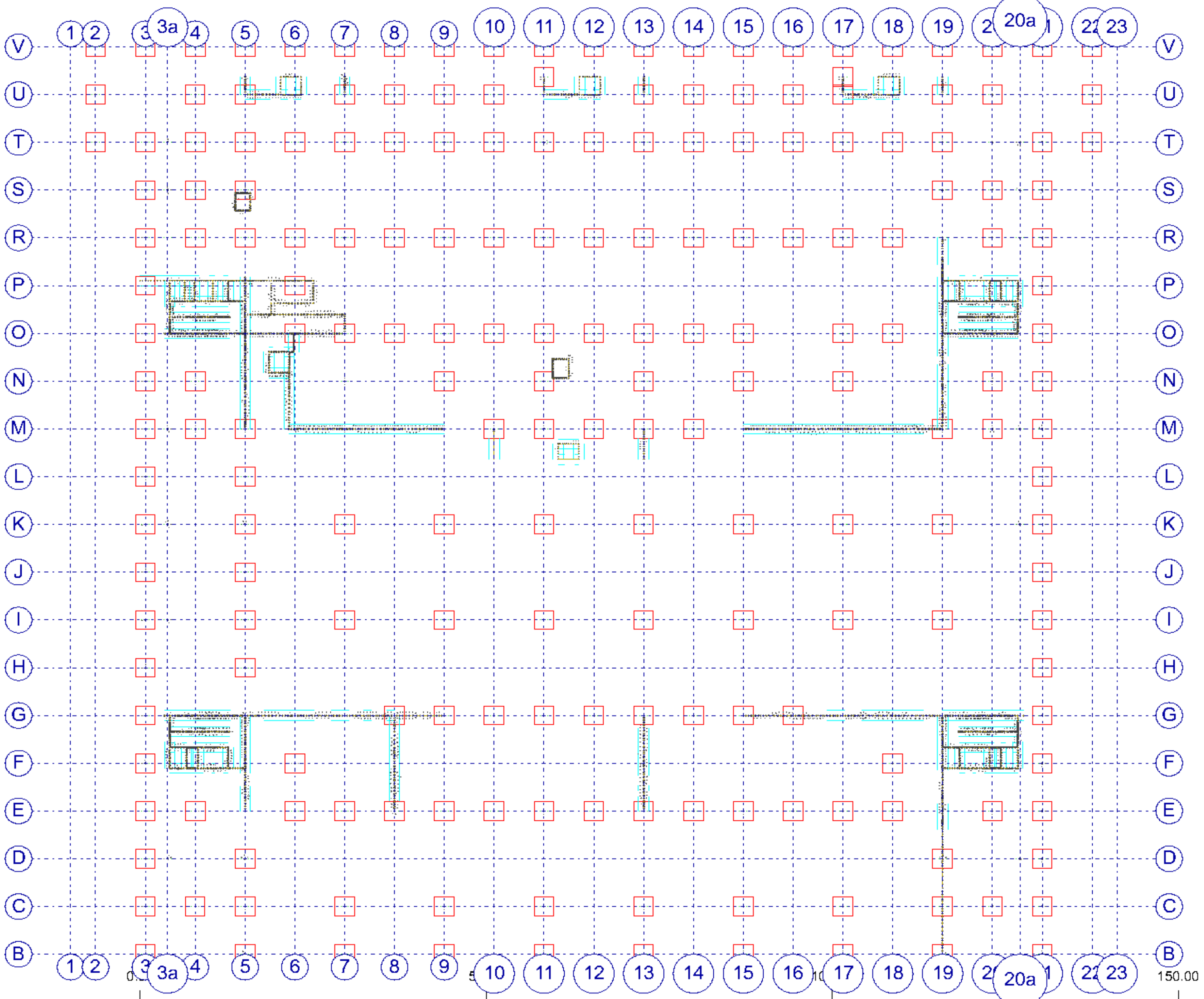


Concrete structure

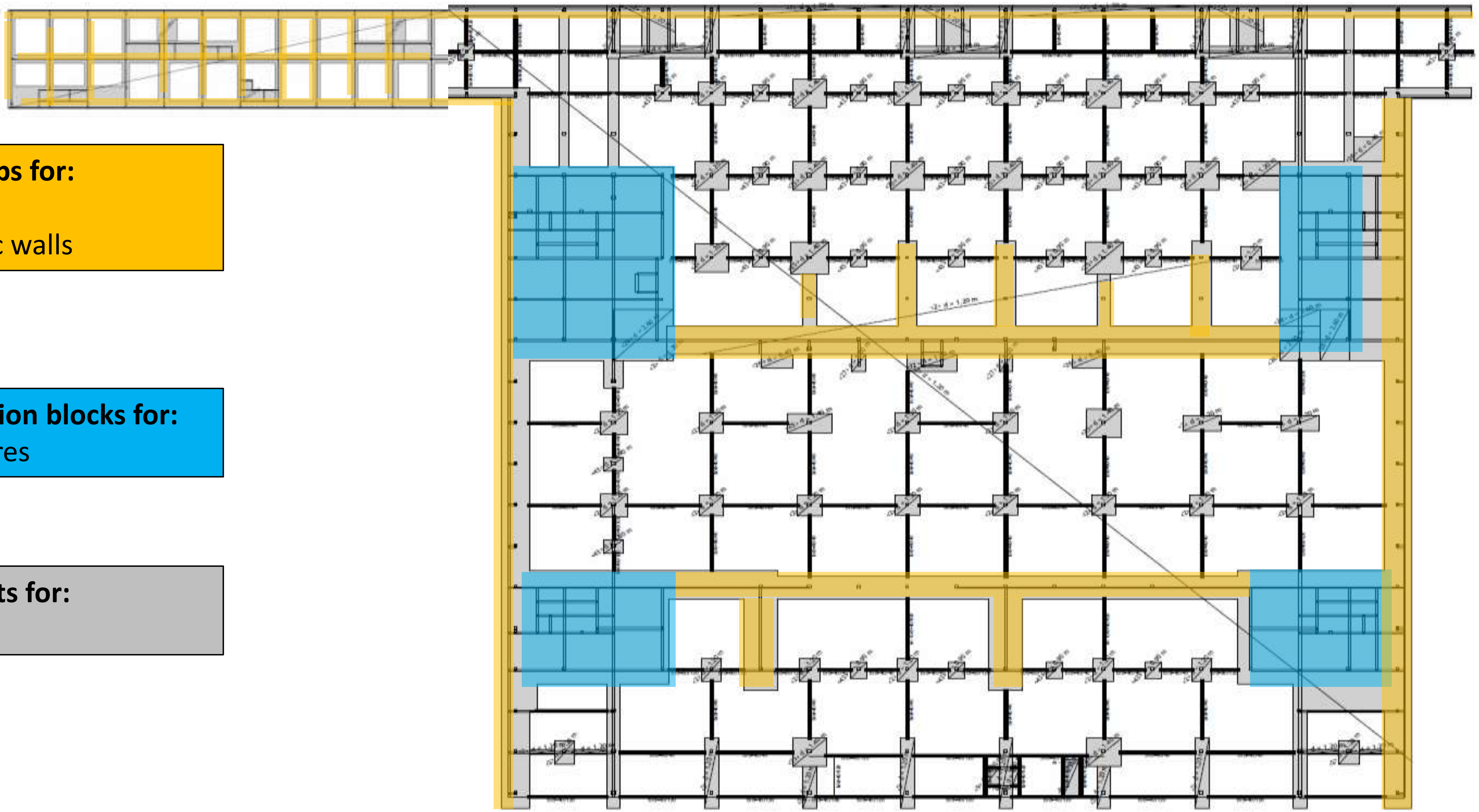
	Element	Type	Size / thickness	Spans
MAIN BUILDING	Vertical elements	ANTISEISMIC: Concrete cores Shear walls Columns	20, 25, 30, 40 i 50 cm 60/60 - 70/70 cm Φ70, Φ80 cm	
	Floor slabs	Prestressed concrete monolithic slabs with wide and shallow beams	1st floor slab: Beam 160/55 cm Slab 18cm 2nd and 3rd floor slab: Beam 300/55 cm Slab 25cm	7.2 x 14.4 m 14.4 x 14.4 m
PIERS	Frames	ANTISEISMIC: 3 RC frames longitudinally Transversal RC frames every 7.2 m Shear walls	Columns Φ70 1st floor: Edge Beam 70/80 cm 2nd floor: Edge Beam 70/70 cm 50 cm	7.2 m
	Floor slabs	RC monolithic slabs	1st floor slab: Slab 22cm 2nd floor slab: Slab 25cm	7.2 x 14.4 m






1 2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20a 22 23
V U T S R P O N M L K J I H G F E D C B
150.00

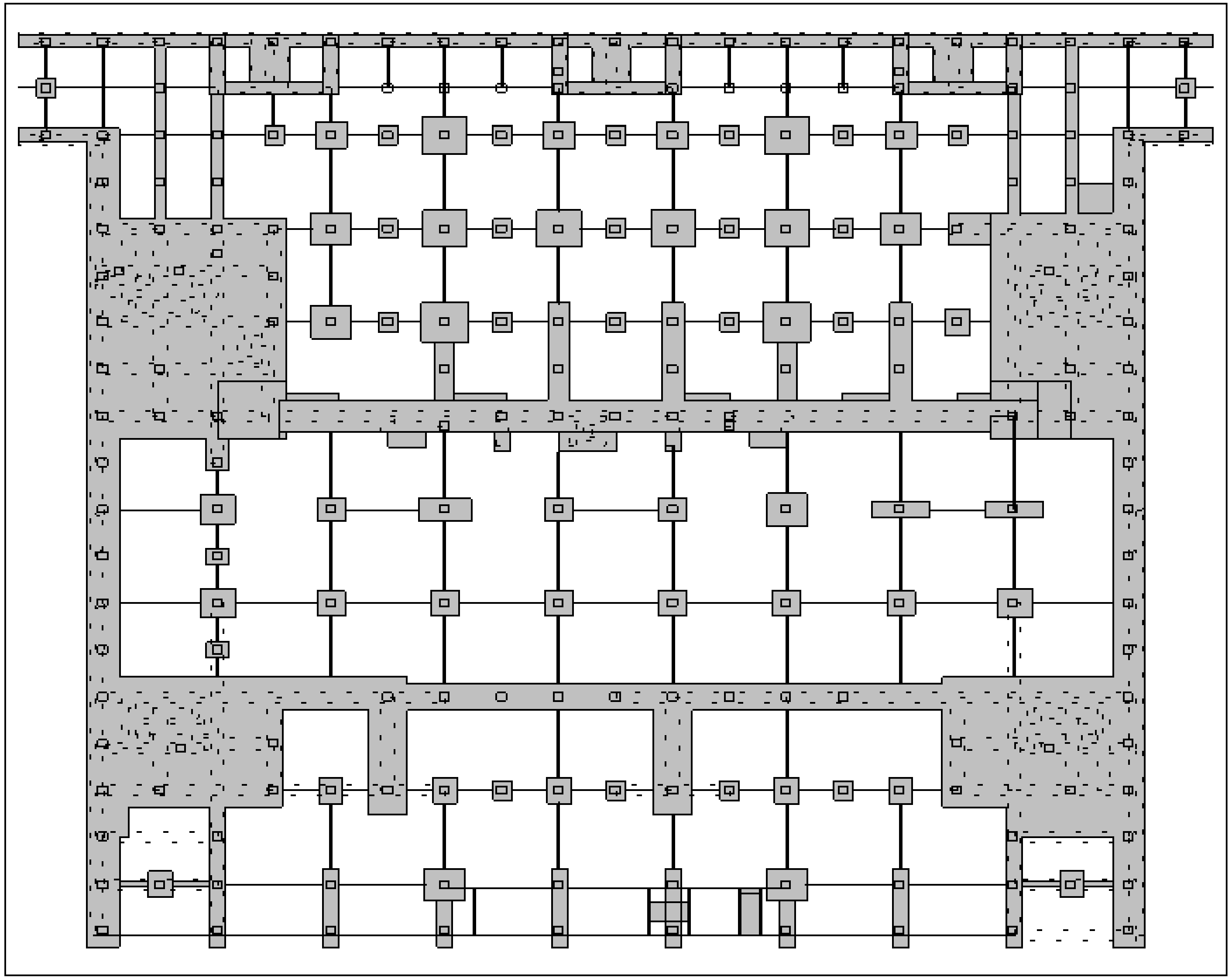
Foundations

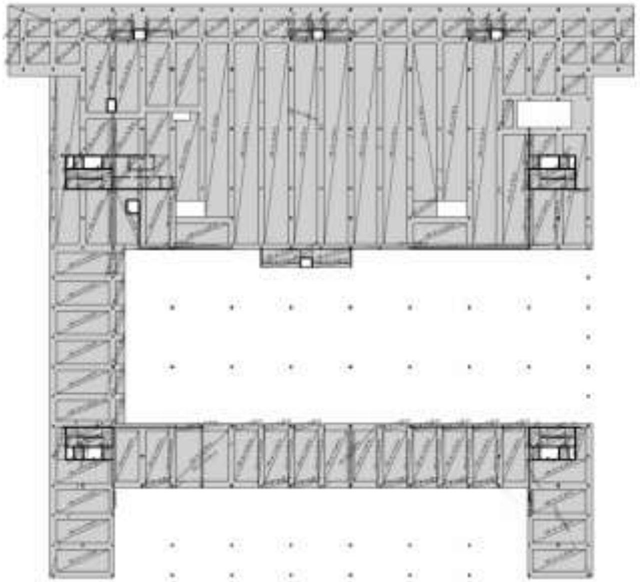


Foundation strips for:
- facade walls
- main seizmic walls

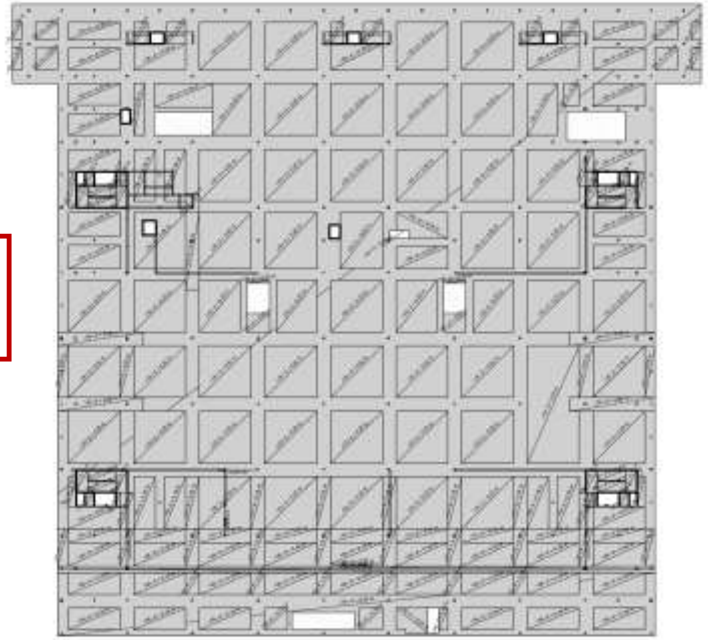
Hollow foundation blocks for:
- 4 seizmic cores

Foundation foots for:
- columns

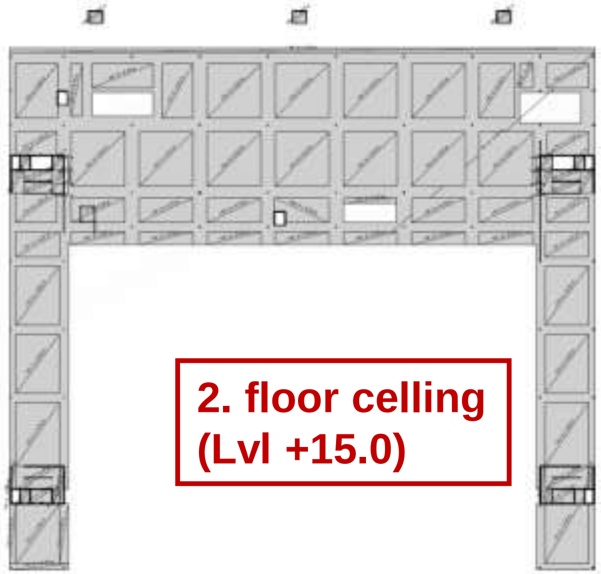




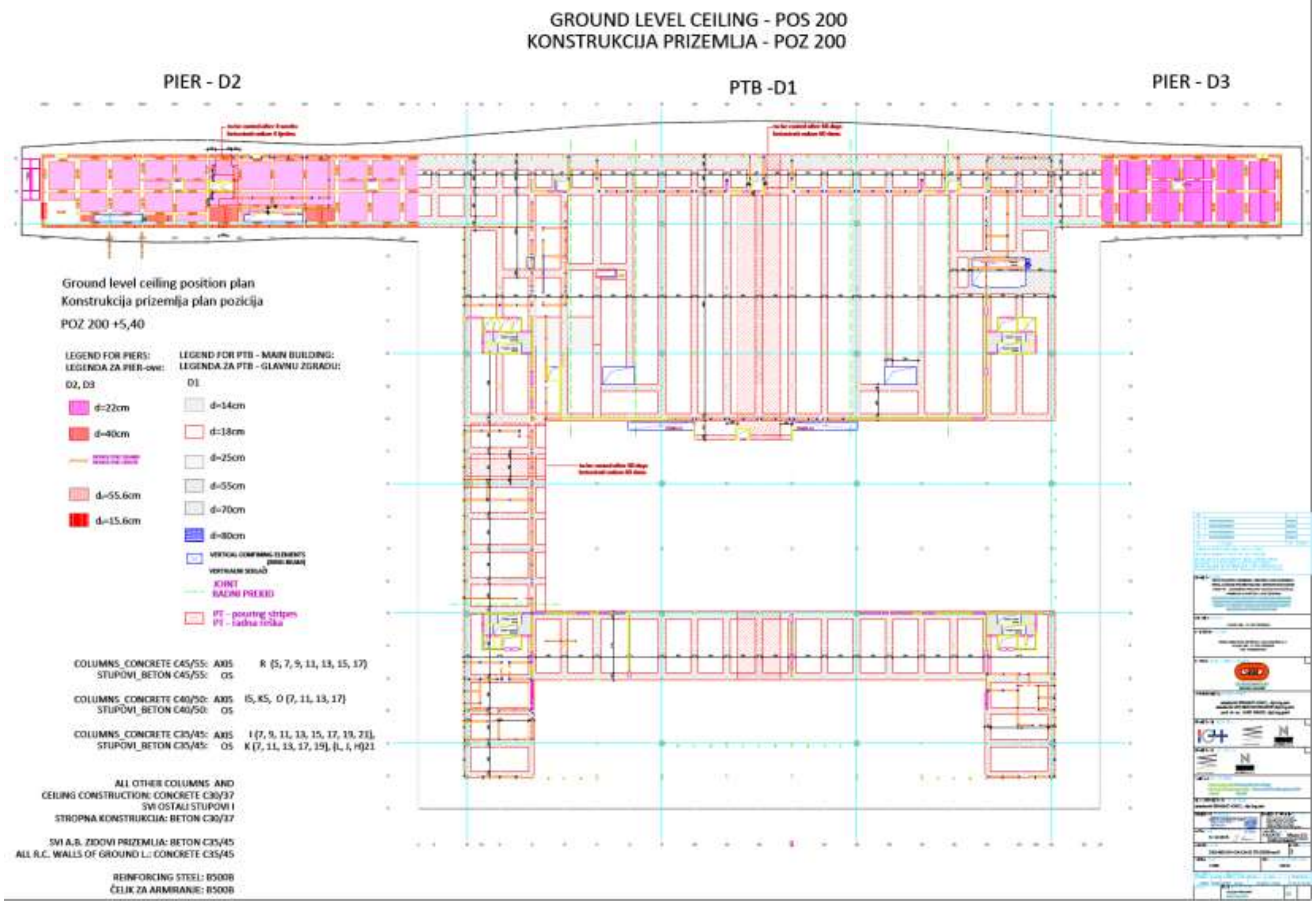
Ground floor celling
(Lvl +5.40)



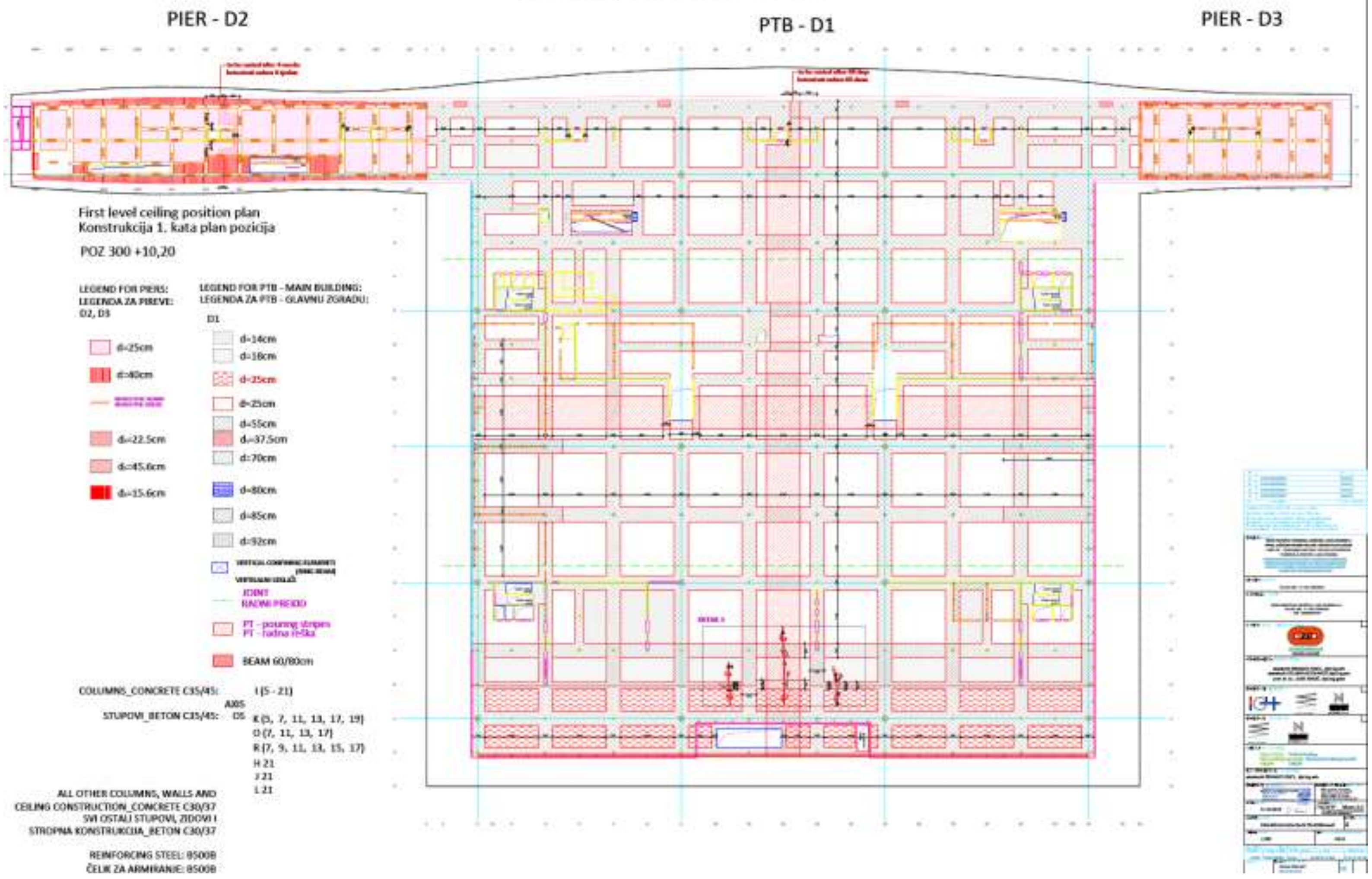
1. floor celling
(Lvl +10.20)

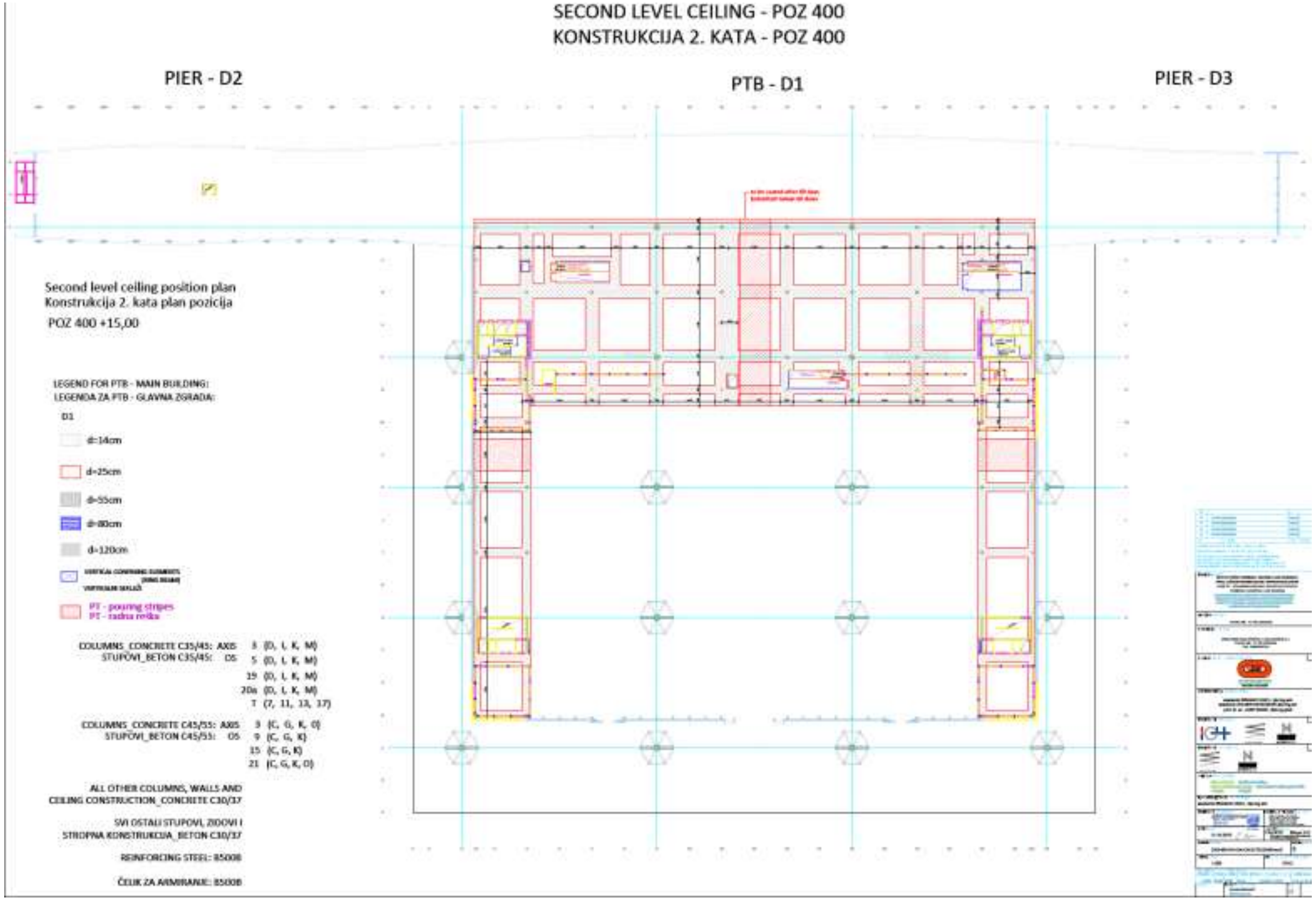


2. floor celling
(Lvl +15.0)

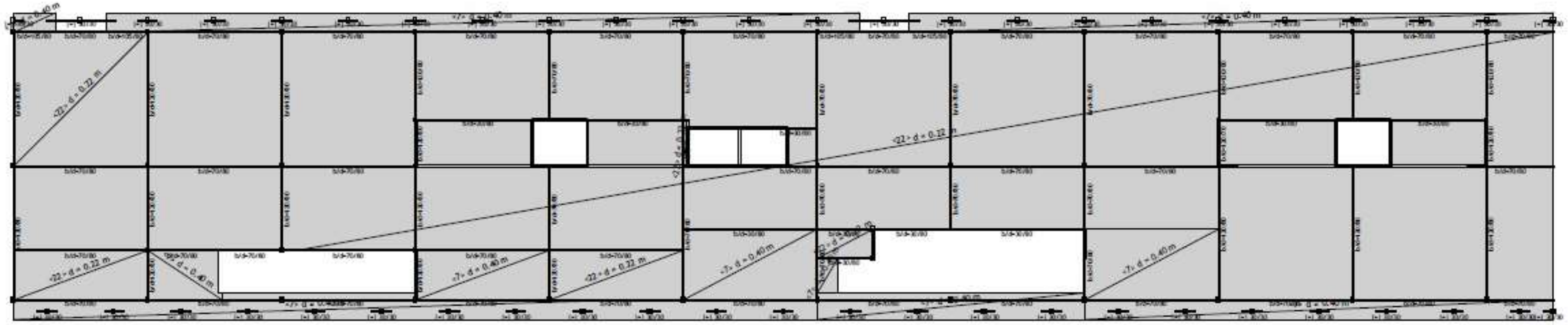

GROUND LEVEL CEILING - POS 200
KONSTRUKCIJA PRIZEMLJA - POZ 200
PIER - D2
PTB -D1
PIER - D3
Ground level ceiling position plan
Konstrukcija prizemlja plan pozicija
POZ 200 +5,40
LEGEND FOR PIERS:
LEGENDA ZA PIER-ove:
D2, D3
d=22cm
d=40cm
d=55.6cm
d=15.6cm
LEGEND FOR PTB - MAIN BUILDING:
LEGENDA ZA PTB - GLAVNU ZGRADU:
D1
d=14cm
d=18cm
d=25cm
d=55cm
d=70cm
d=80cm
VERTICAL CONFINING ELEMENTS
JOINT
RADNI PREKID
PT - pouring stripes
PT - radna traka
COLUMNS_CONCRETE C45/55: AXIS R (5, 7, 9, 11, 13, 15, 17)
STUPOVI_BETON C45/55: OS
COLUMNS_CONCRETE C40/50: AXIS I5, K5, O (7, 11, 13, 17)
STUPOVI_BETON C40/50: OS
COLUMNS_CONCRETE C35/45: AXIS I (7, 9, 11, 13, 15, 17, 19, 21),
STUPOVI_BETON C35/45: OS K (7, 11, 13, 17, 19), (L, J, H)21
ALL OTHER COLUMNS AND
CEILING CONSTRUCTION: CONCRETE C30/37
SVI OSTALI STUPOVI I
STROPNA KONSTRUKCIJA: BETON C30/37
SVI A.B. ZIDOVI PRIZEMLJA: BETON C35/45
ALL R.C. WALLS OF GROUND L.: CONCRETE C35/45
REINFORCING STEEL: B500B
ČELIK ZA ARMIRANJE: B500B

FIRST LEVEL CEILING - POZ 300
KONSTRUKCIJA 1. KATA - POZ 300

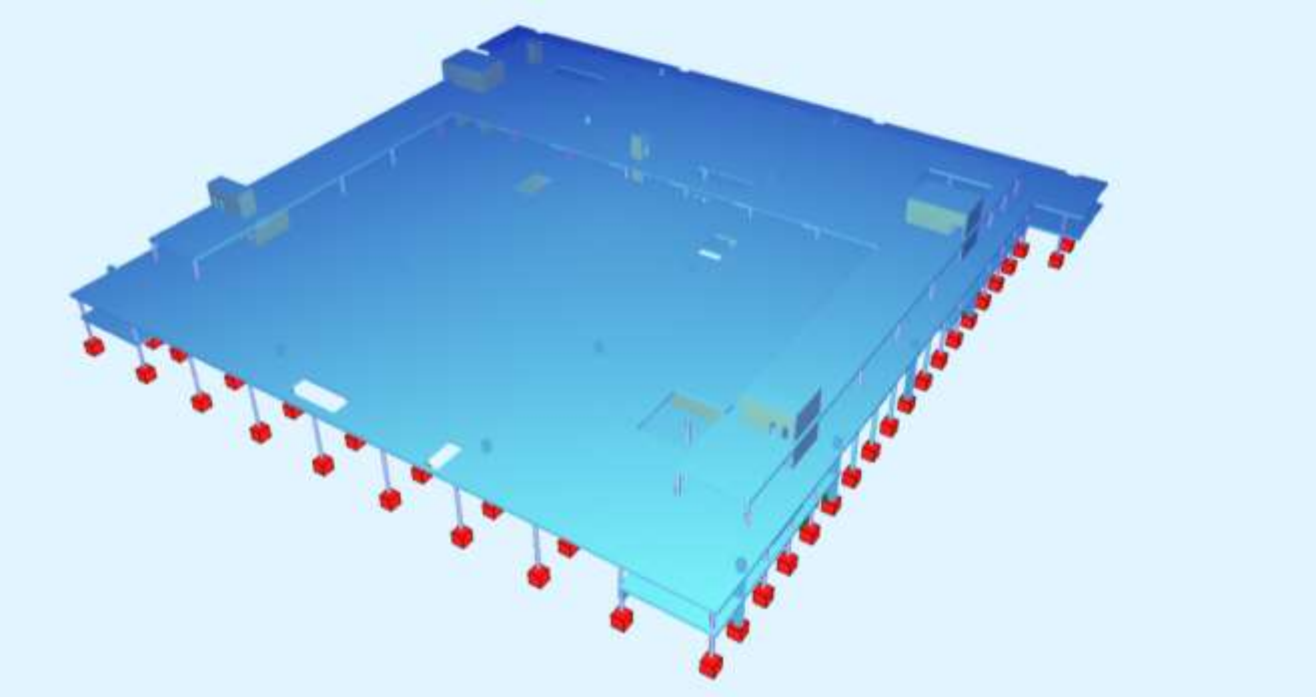


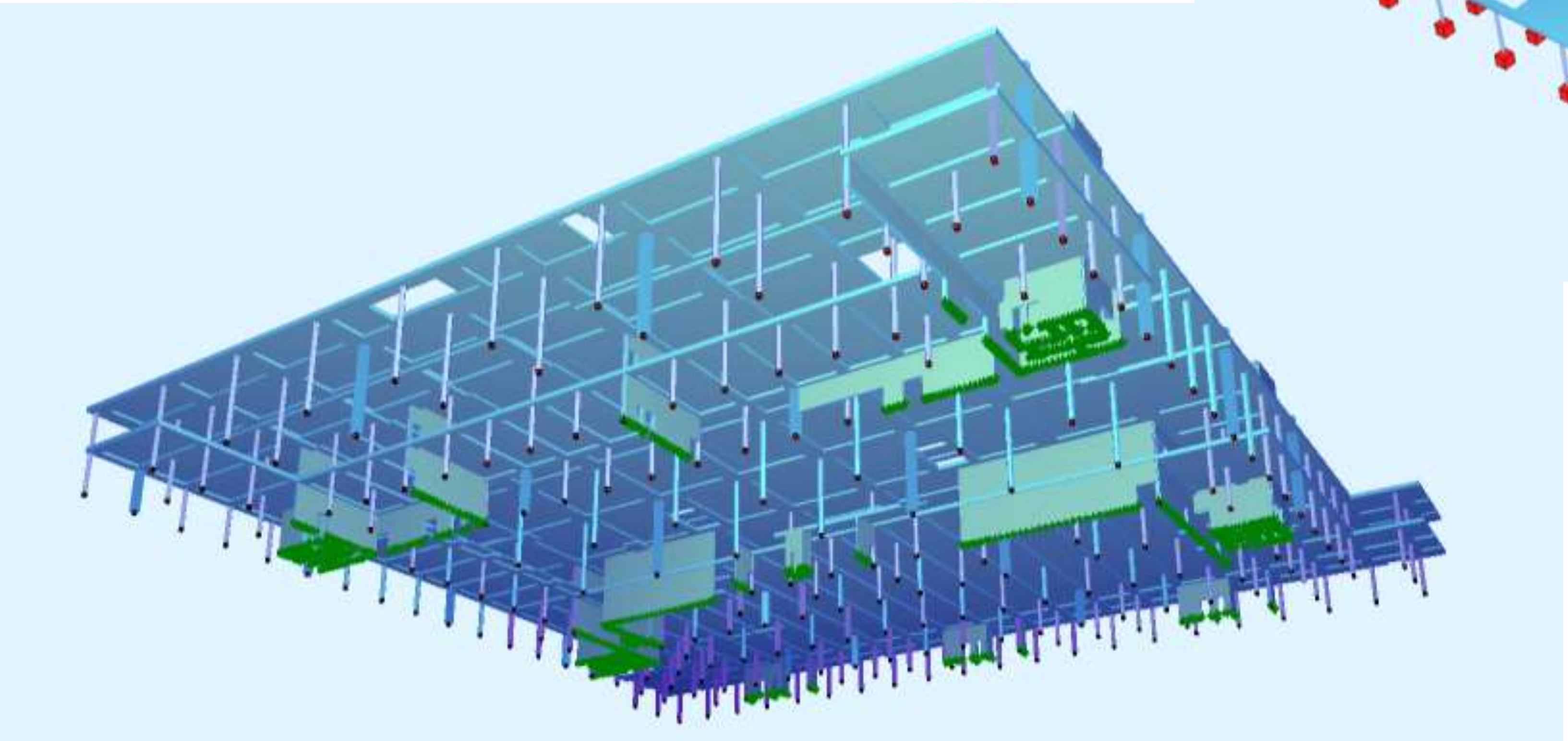

SECOND LEVEL CEILING - POZ 400
KONSTRUKCIJA 2. KATA - POZ 400
PIER - D2
PTB - D1
PIER - D3
Second level ceiling position plan
Konstrukcija 2. kata plan pozicija
POZ 400 +15,00
LEGEND FOR PTB - MAIN BUILDING:
LEGENDA ZA PTB - GLAVNA ZGRADA:
D1
d=14cm
d=25cm
d=55cm
d=80cm
d=120cm
PT - pouring stripes
PT - radna reška
COLUMNS_CONCRETE C35/45: AXIS
STUPOVI_BETON C35/45: OS
3 (D, I, K, M)
5 (D, I, K, M)
19 (D, I, K, M)
20a (D, I, K, M)
T (7, 11, 13, 17)
COLUMNS_CONCRETE C45/55: AXIS
STUPOVI_BETON C45/55: OS
3 (C, G, K, O)
9 (C, G, K)
15 (C, G, K)
21 (C, G, K, O)
ALL OTHER COLUMNS, WALLS AND
CEILING CONSTRUCTION_CONCRETE C30/37
SVI OSTALI STUPOVI, ZIDOVI I
STROPNA KONSTRUKCIJA_BETON C30/37
REINFORCING STEEL: B500B
ČELIK ZA ARMIRANJE: B500B

**Ground floor celling
(Lvl +5.40)**

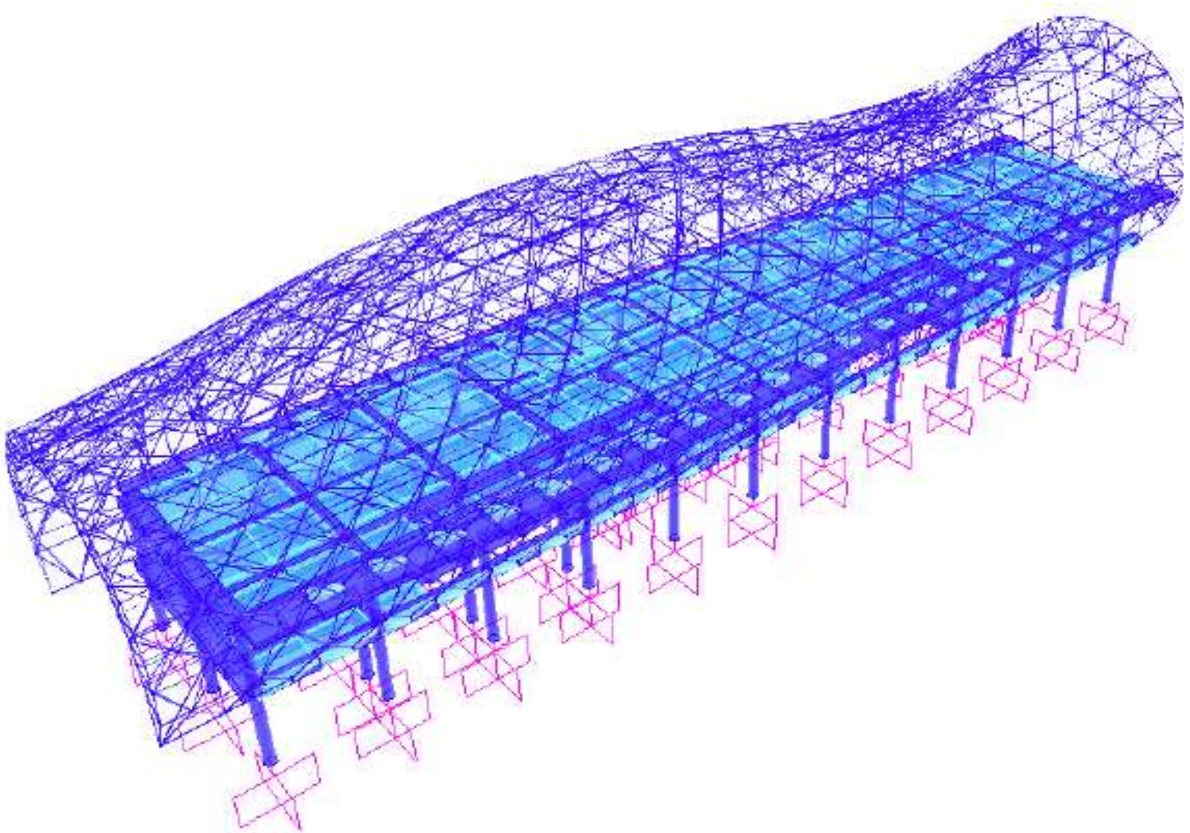


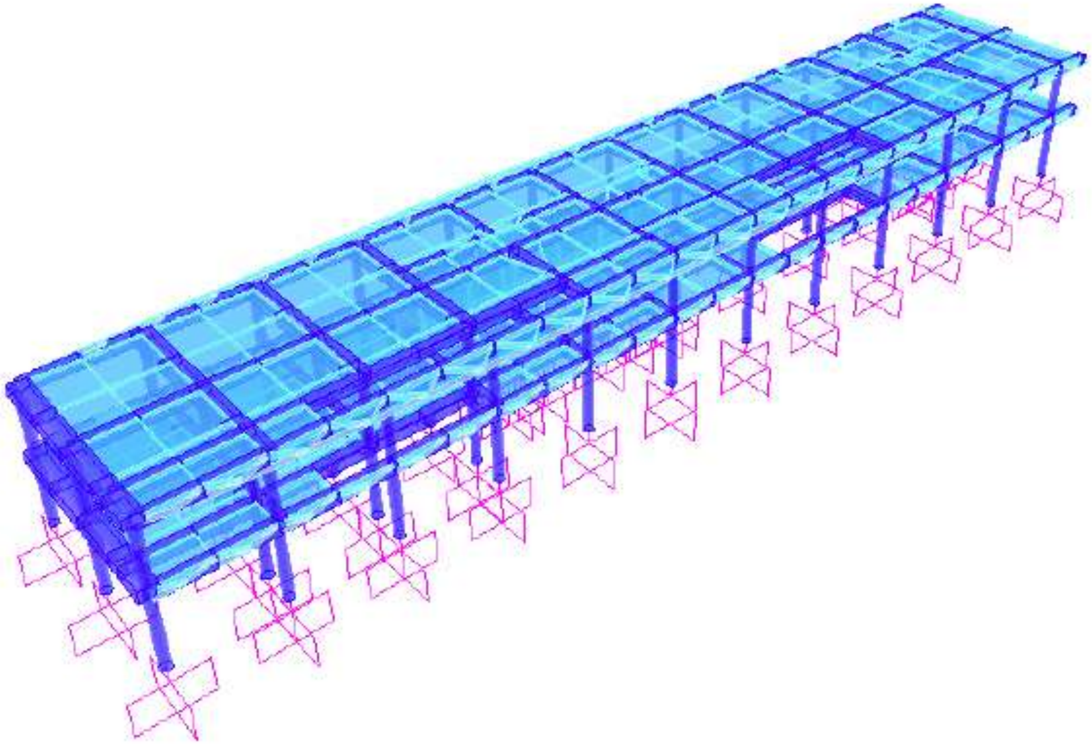
**1. floor selling
(Lvl +10.20)**



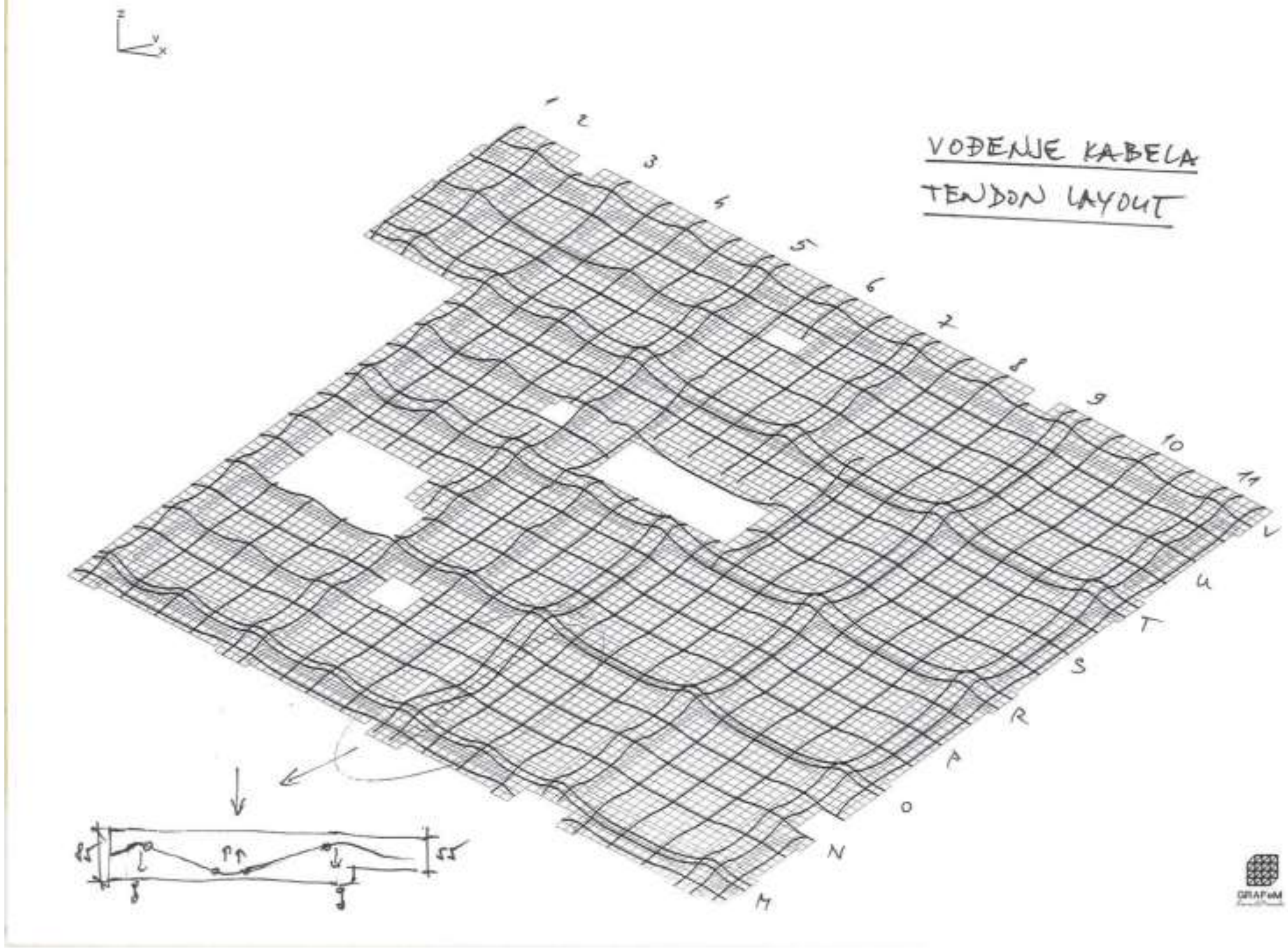


Space frame construction of the piers for horizontal and vertical actions

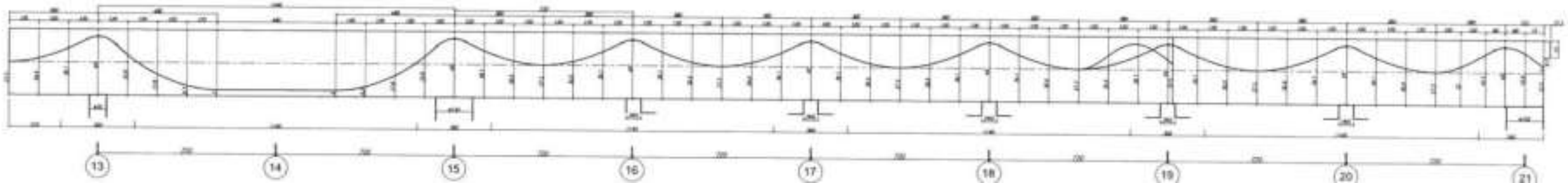




Complete floor slab is concreted in 4 separated parts and monolitized after 6 months when most of creep and shrinkage is realized


VODENJE KABELA
TENDON LAYOUT
1
2
3
4
5
6
7
8
9
10
11
V
U
T
S
R
P
O
N
M

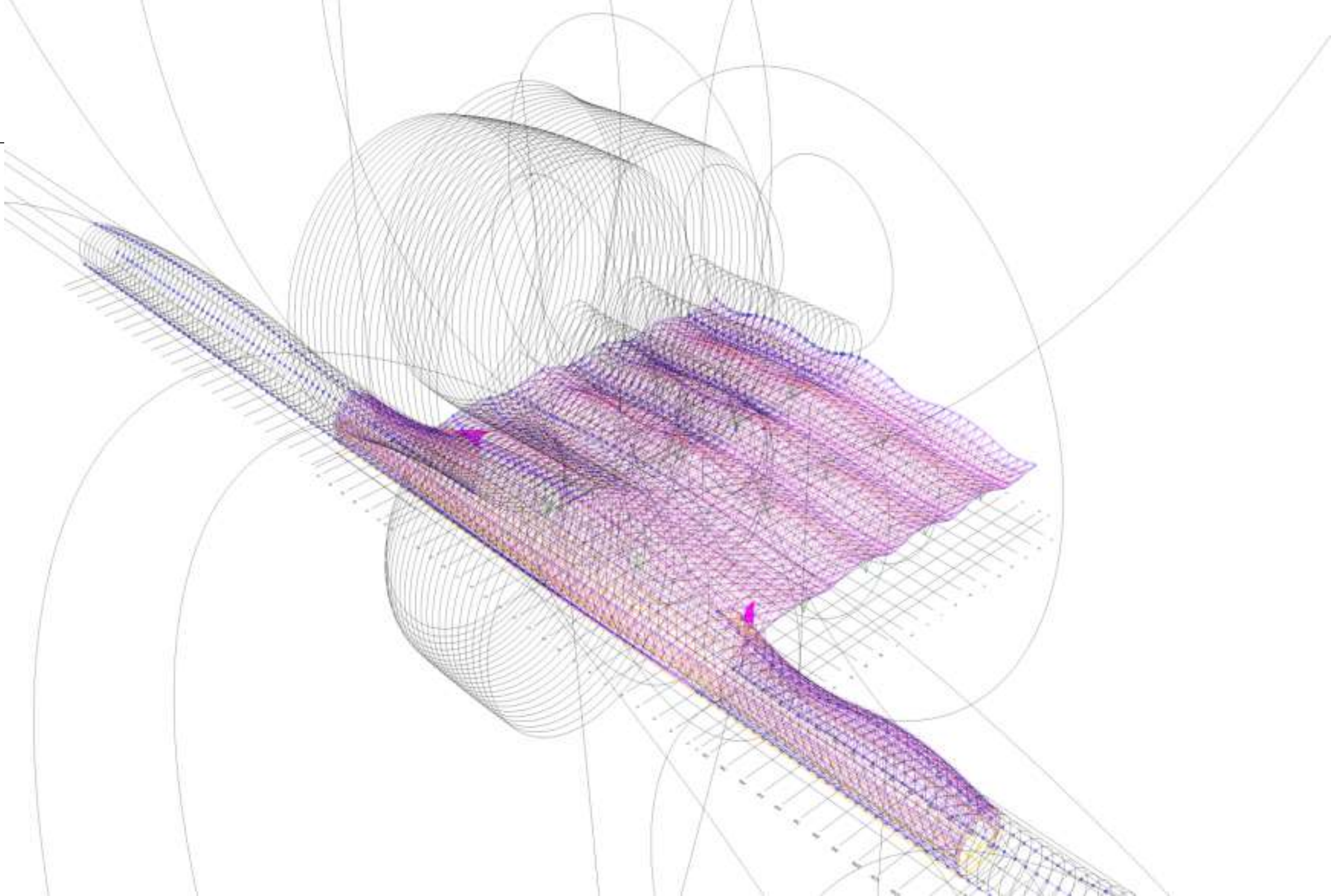
BEAM TENDON LAYOUT, DIRECTION X, AXIS G



Steel roof structure

- Steel structure is primarily used for roof supporting

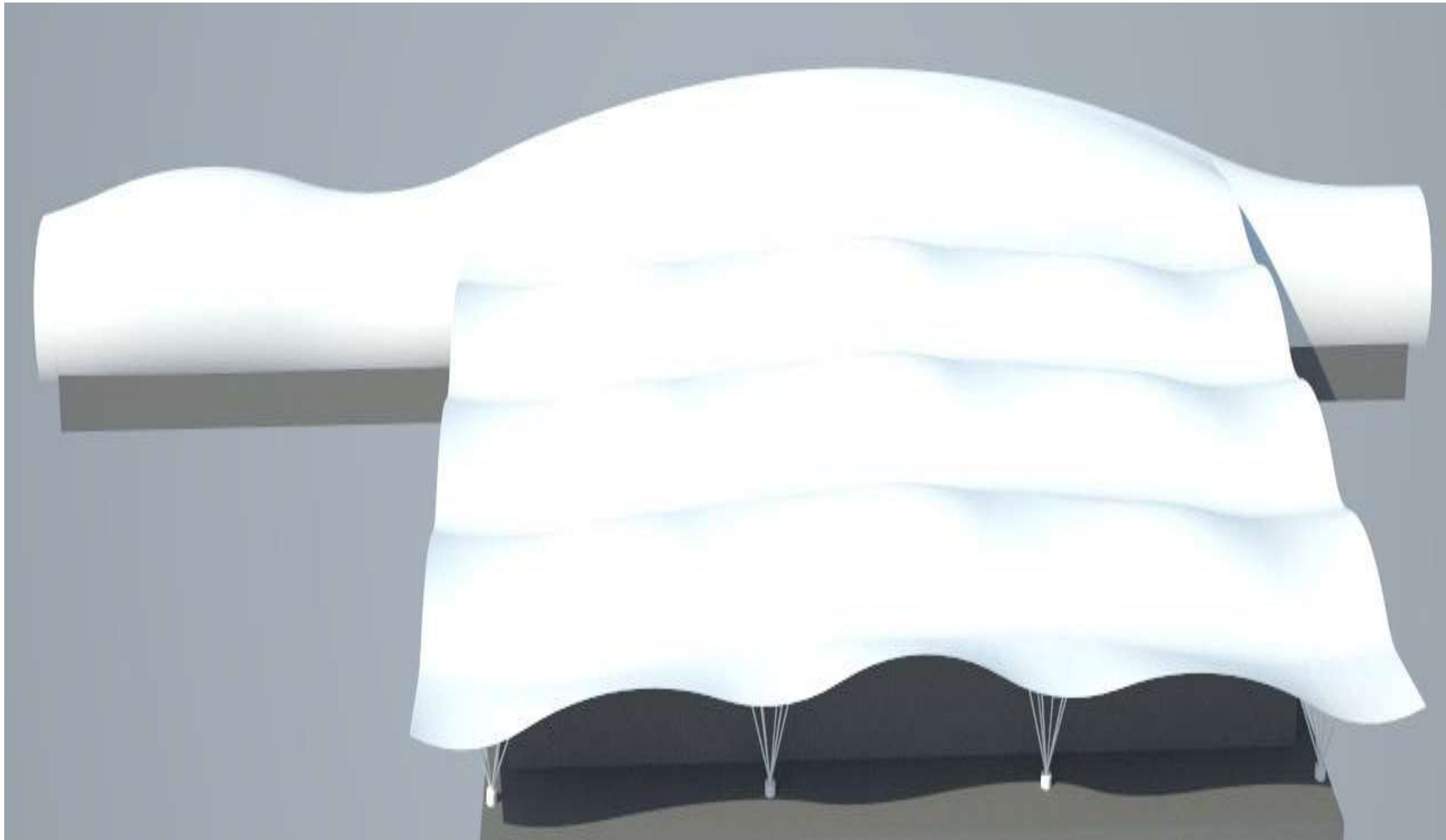
- Generation of the roof surface is done using circle sections (minimum radius 30 m) in both directions with tangential lines in transition areas



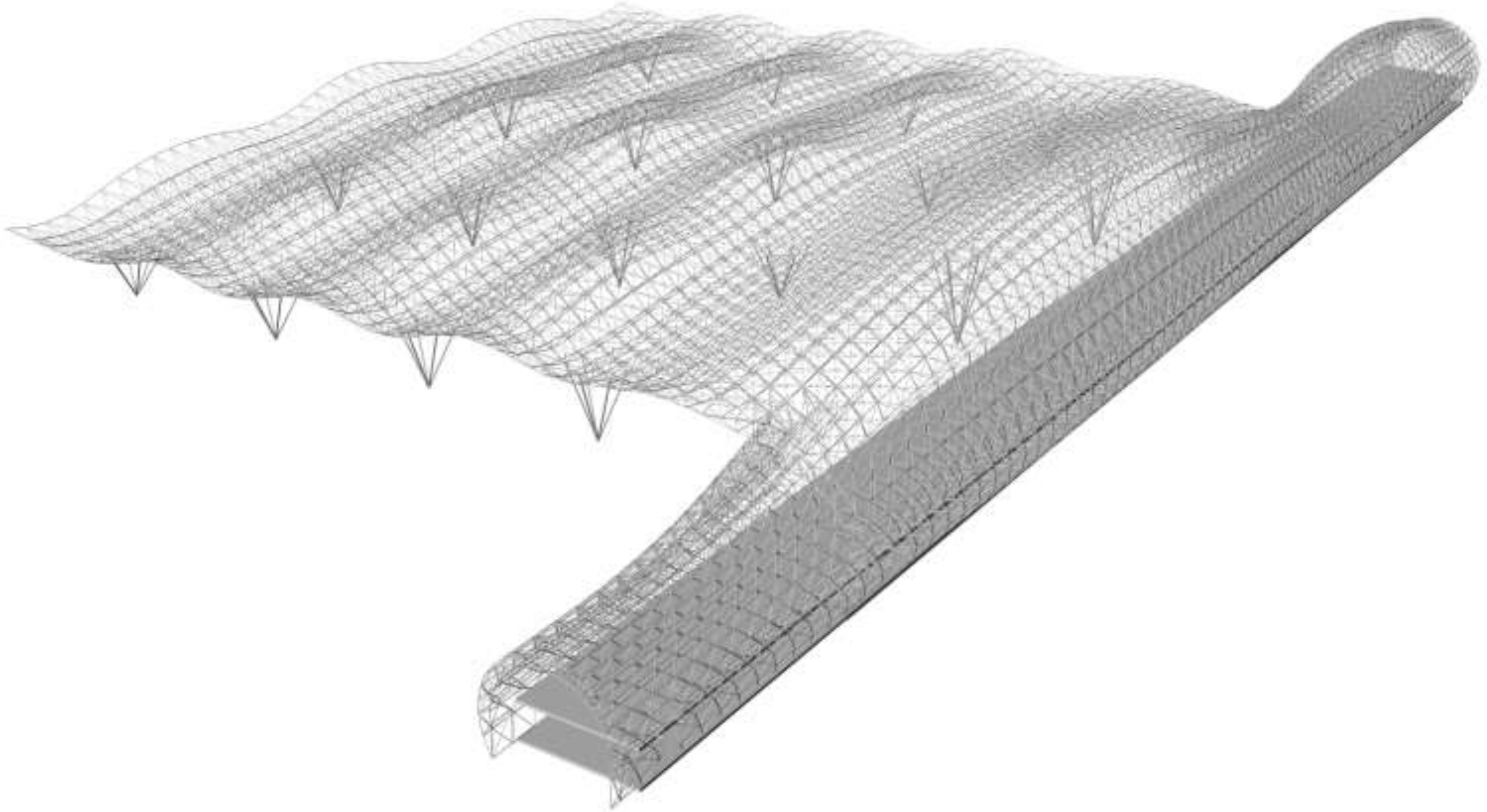
- Result of this generation is the roof of wavy shape in both directions, merged with the facade facing the runway which has a tubular shape with variable elevation.

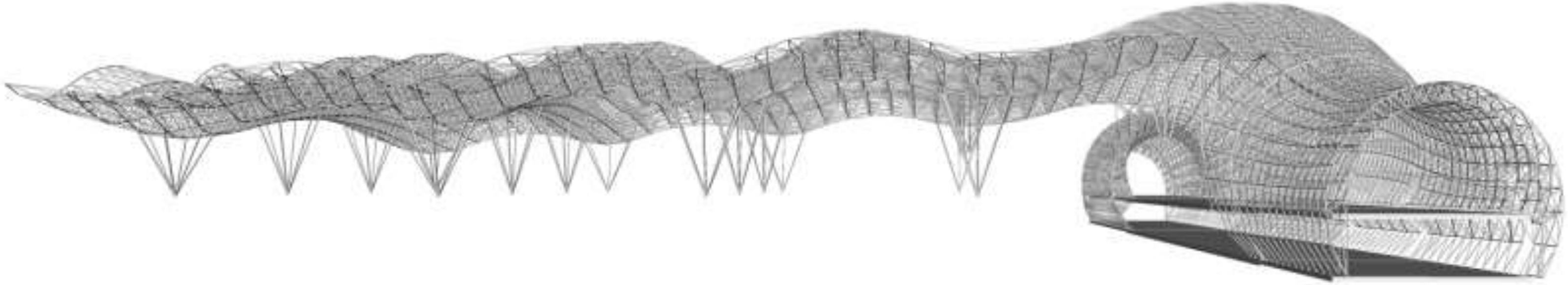
- Piers roofs on both sides of the main building are tubular with variable height.

- Between the space trusses of the main building and the piers is a dilatation separating space trusses (and also concrete floors).

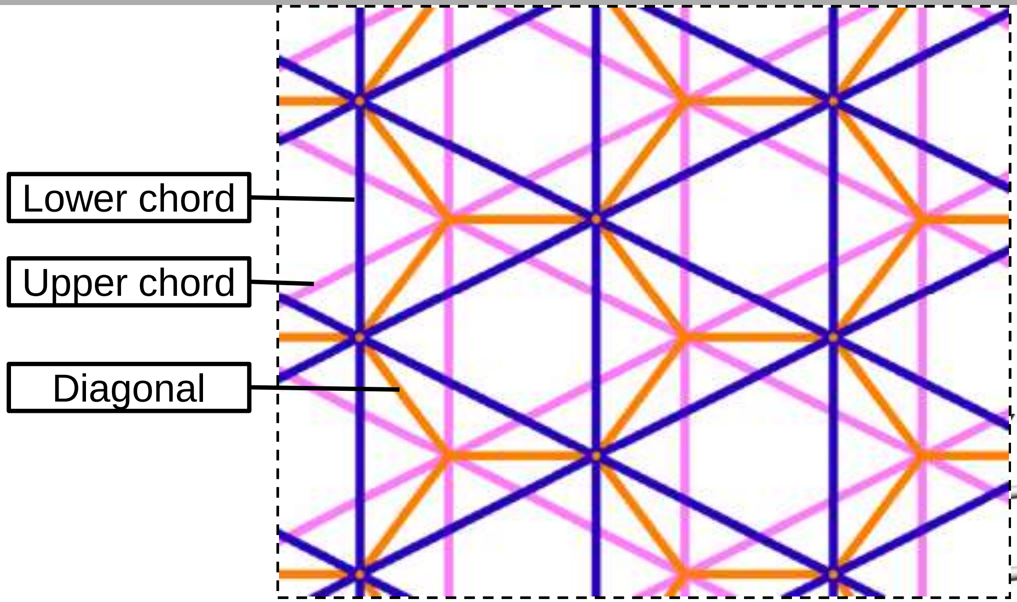


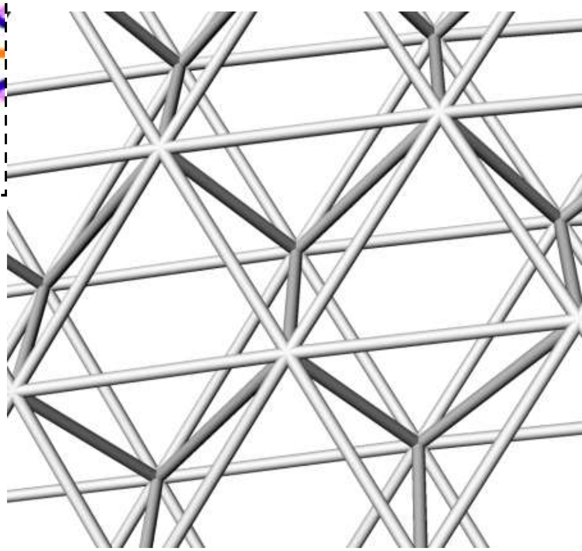
View of the complete roof space truss – total of 25.780 truss members!

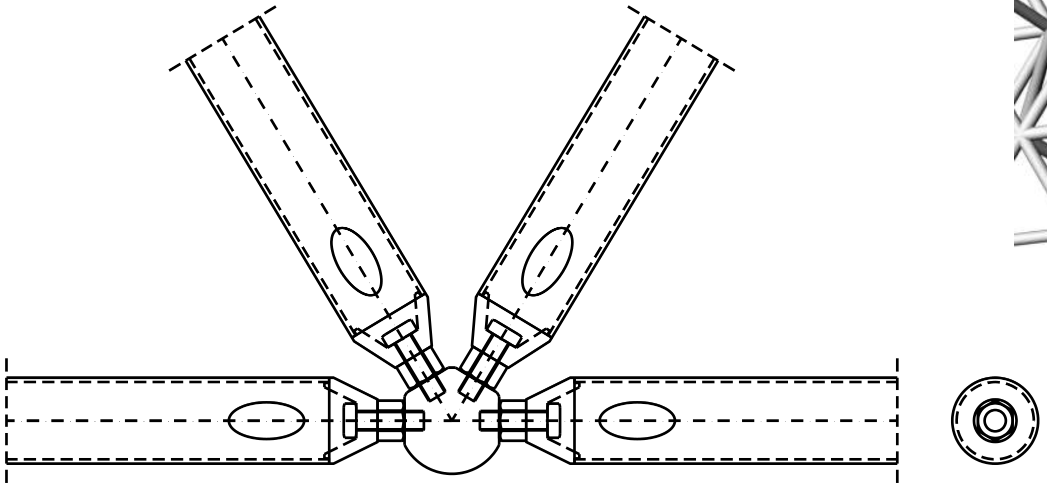




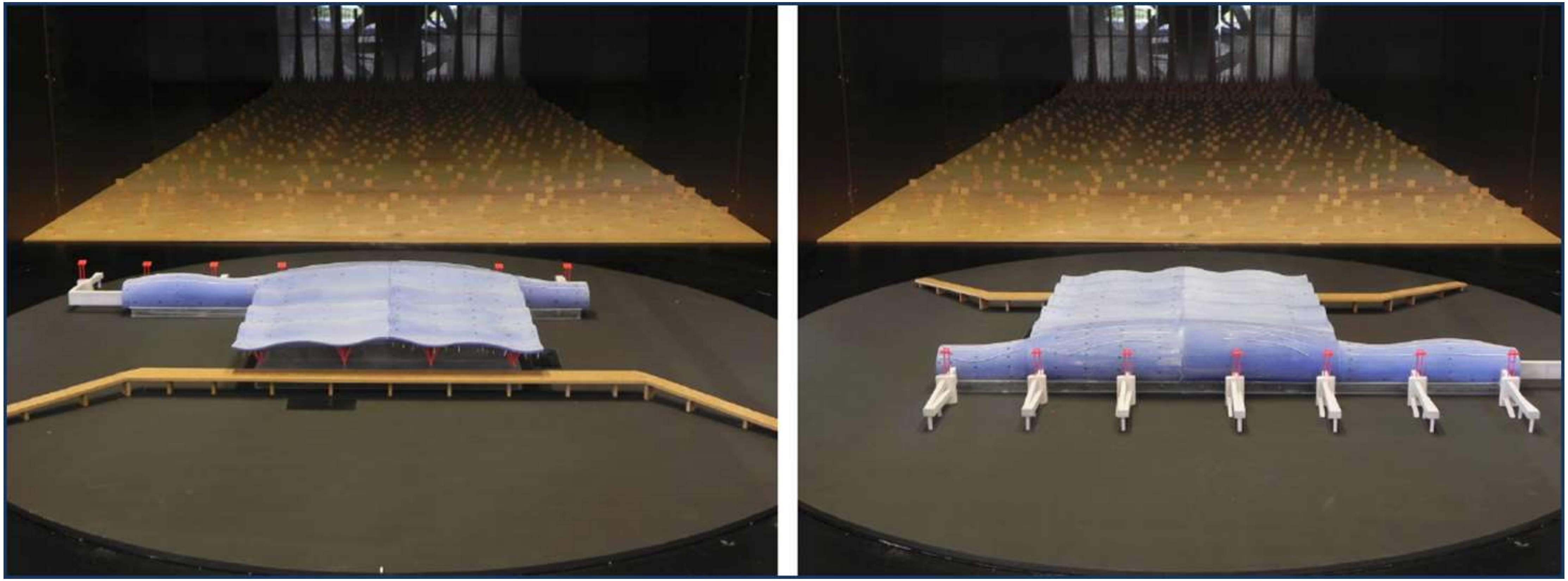
- The roof structure of the main building is a steel space truss structure.
- The structure is made of tubular circular members (ranging from Ø76.1x2.9 to Ø219.1x20 mm) with connecting elements and spherical nodes with threaded holes.
- The basic plan-view disposition of the main building comprises triangular grid shapes with each triangle having the base of 3.6 m and the height of 3.6 m. These triangles define the axes of the chord truss members.
- The grid of the bottom chord is displaced 1.8 m longitudinally and 1.2 m transversely in respect to the top chord.



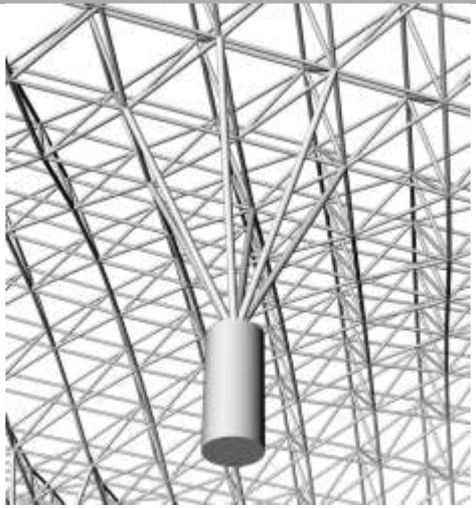




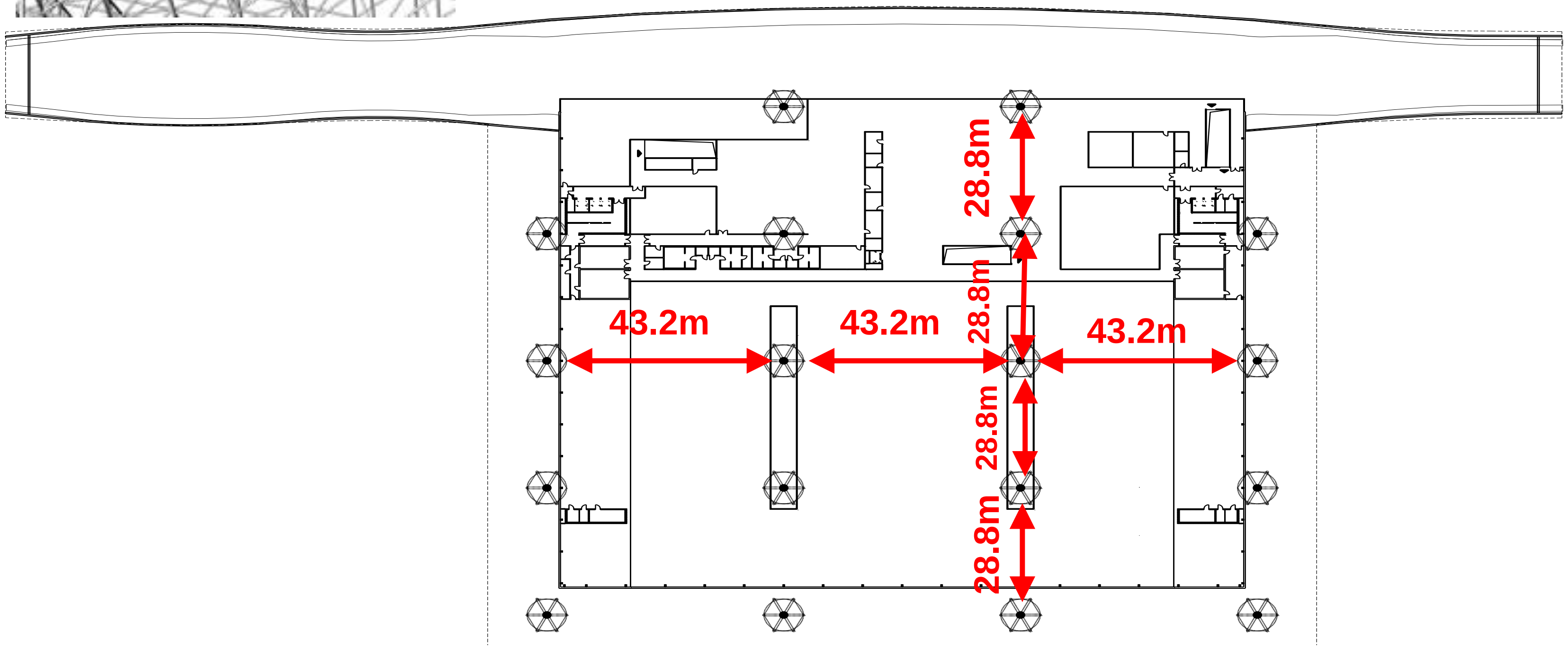
Wind tunnel test



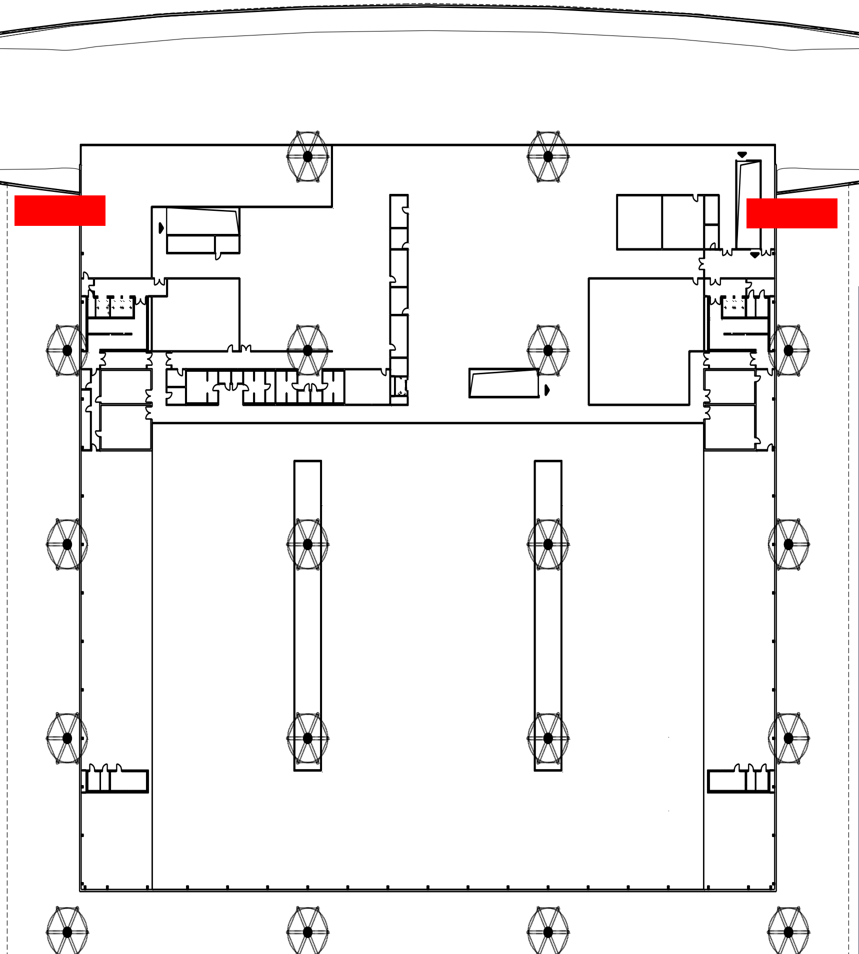
F3X 76.1×2.9 M20
G3X 88.9×3.2 M20
G5X 88.9×4.5 M20
H3X 108×4 M20
H3Y 108×4 M27
I3X 114×4,5 M20
I3Y 114×4,5 M27
K3X 127×4 M20
K5Y 127×4 M27
M3X 139.7×4 M20
M3Y 139.7×4 M27
M3Z 139.7×4 M33
N1X 159×4.5 M20L
N1Y 159×4.5 M33
N3X 159×5.6 M20L
N3Y 159×5.6 M33
N5X 159×8 M33
N5H 159×8 M42
N5Z 159×8 M48
P1X 219.1×7.1 M33L
P1H 219.1×7.1 M48
P3B 219.1×10 M33
P3J 219.1×10 M56L
P7A 219.1×20 M56L
P7B 219.1×20 M64L

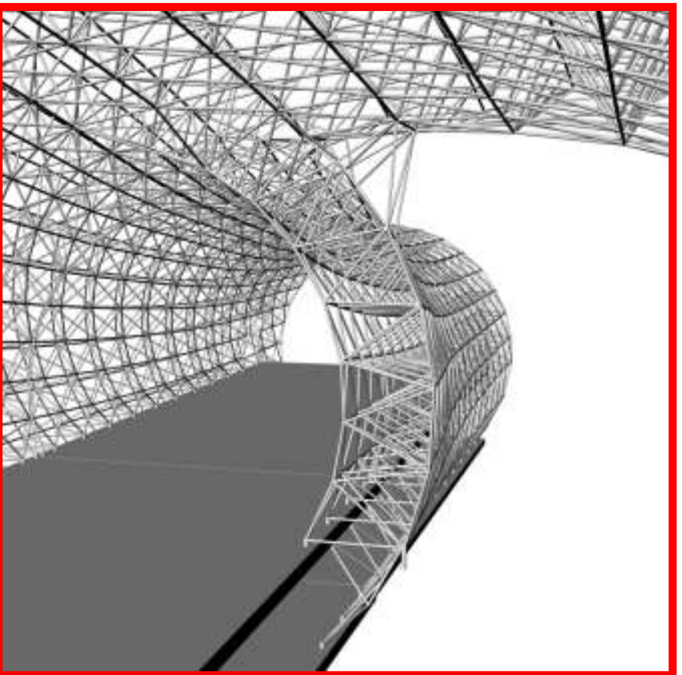


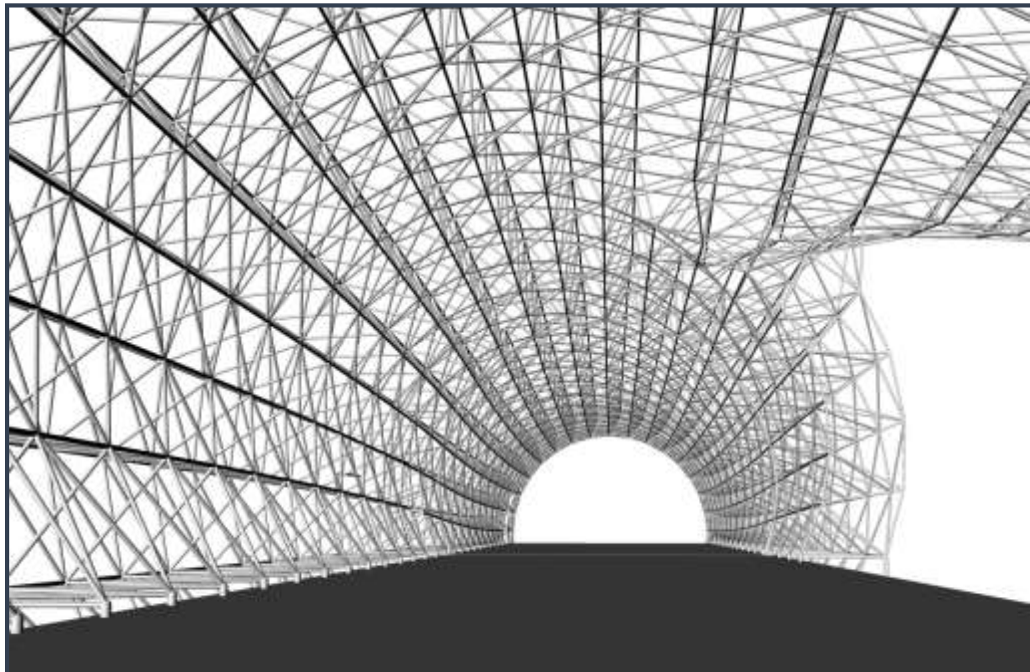
- The spans of the space truss are 43.2 m parallel to the direction of the pier and 28.8 m perpendicular to pier direction.
- The main building roof structure is supported by 18 columns resting on reinforced-concrete pedestals at the levels +10.20 m and +15.00 m.
- Each column comprises 6 members (Ø406.4×16 and Ø406.4×20) connecting to 6 nodes at the top and one node

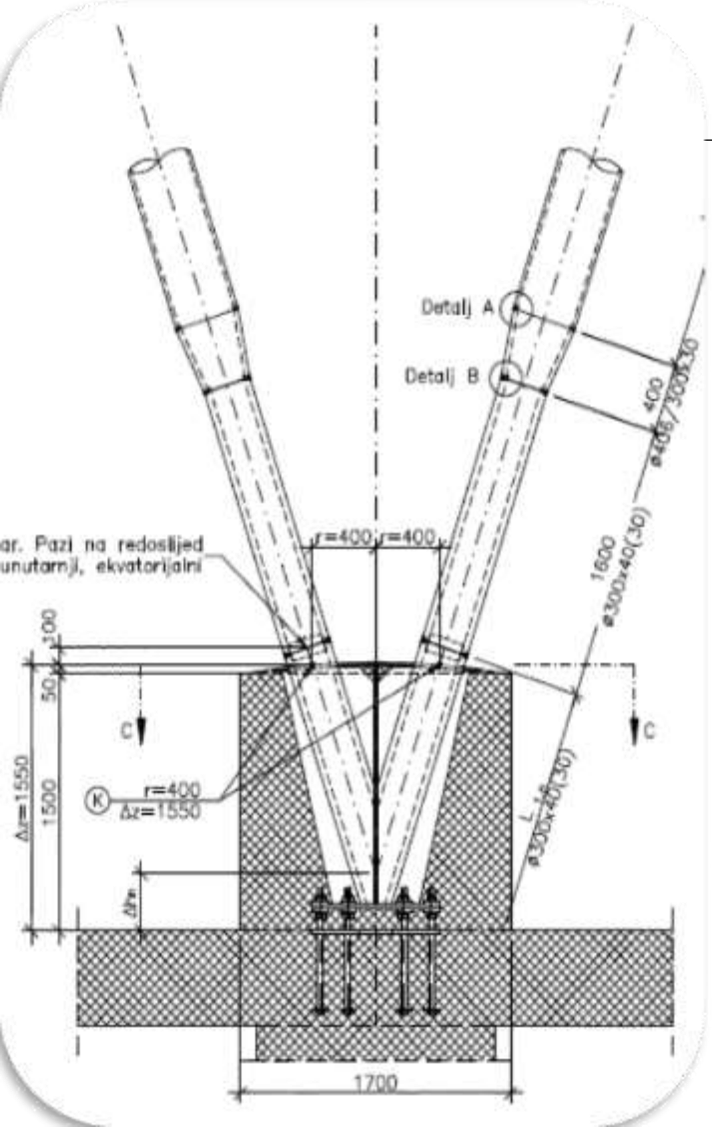


- Near the connection of the building and the pier, columns are omitted and the roof is supported by truss walls which continue into the pier structure
- Pier truss construction is thus integrated into the main building truss, so both appear as one continuity (one emerging from another)





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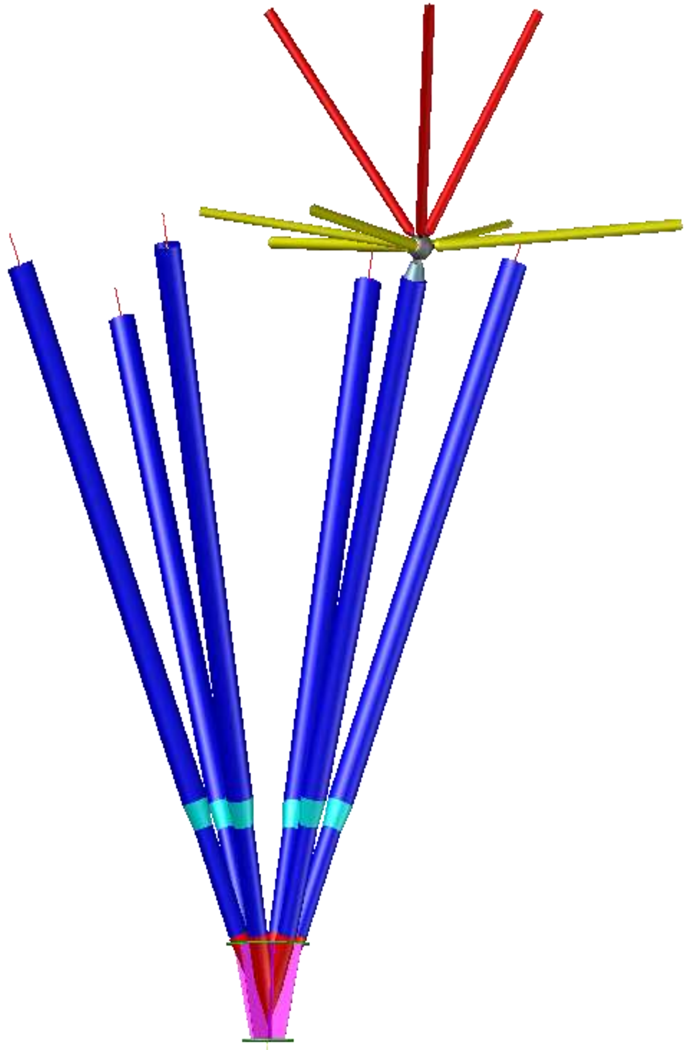
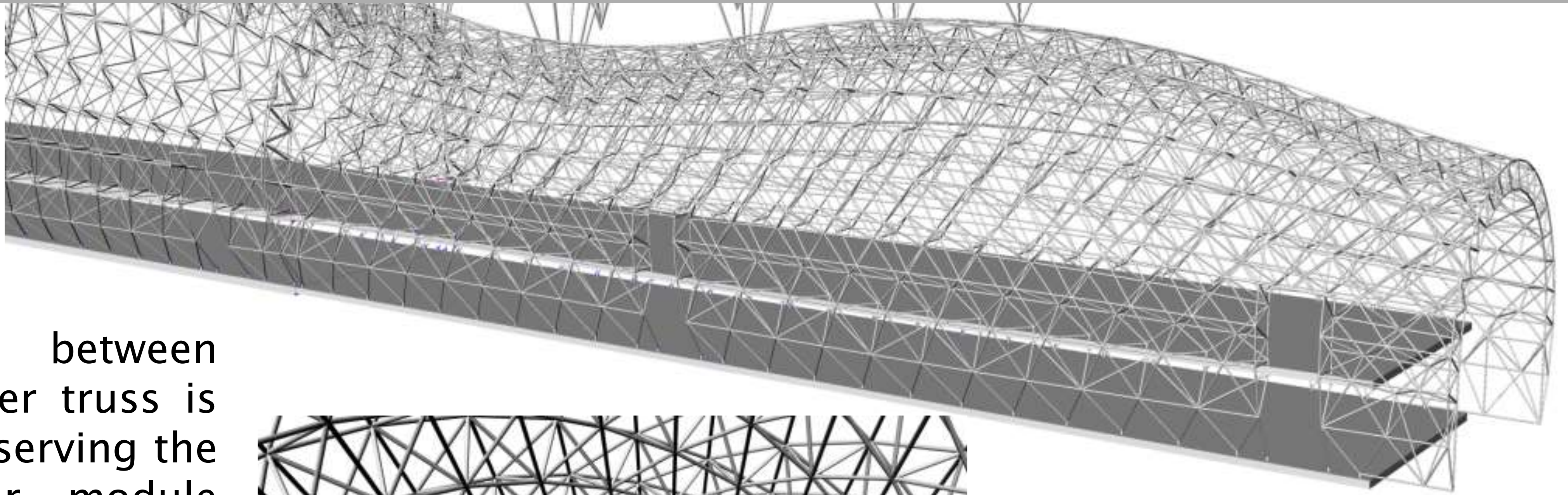
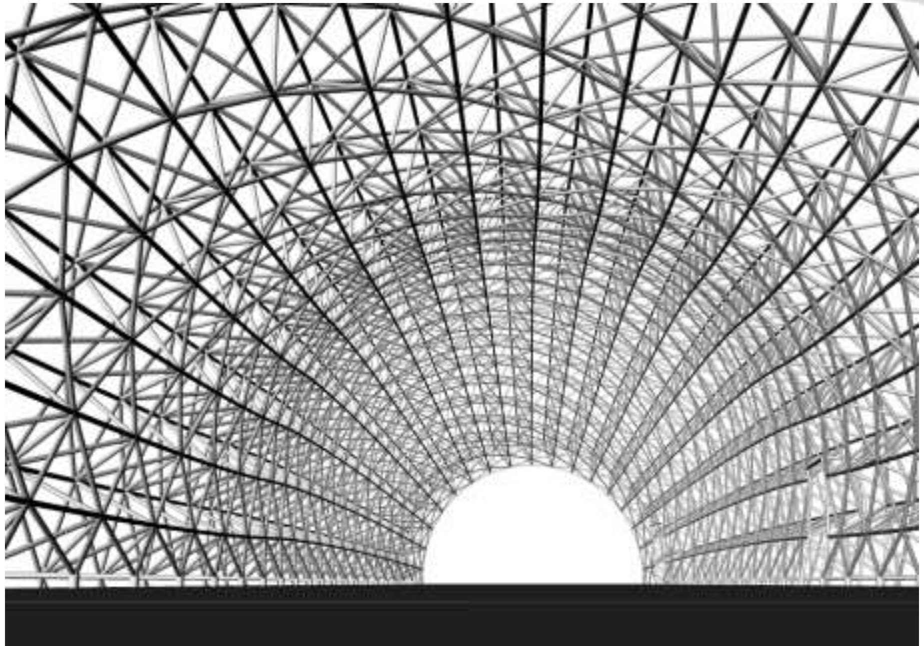
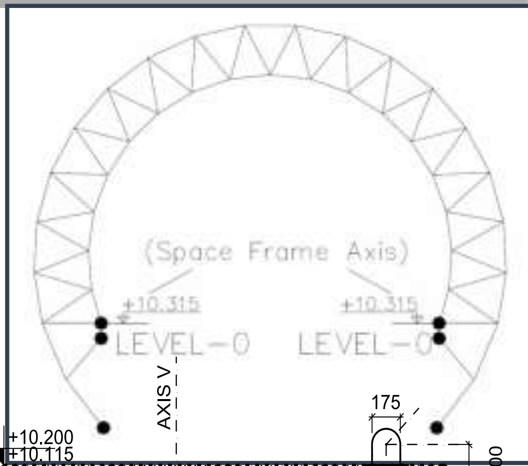


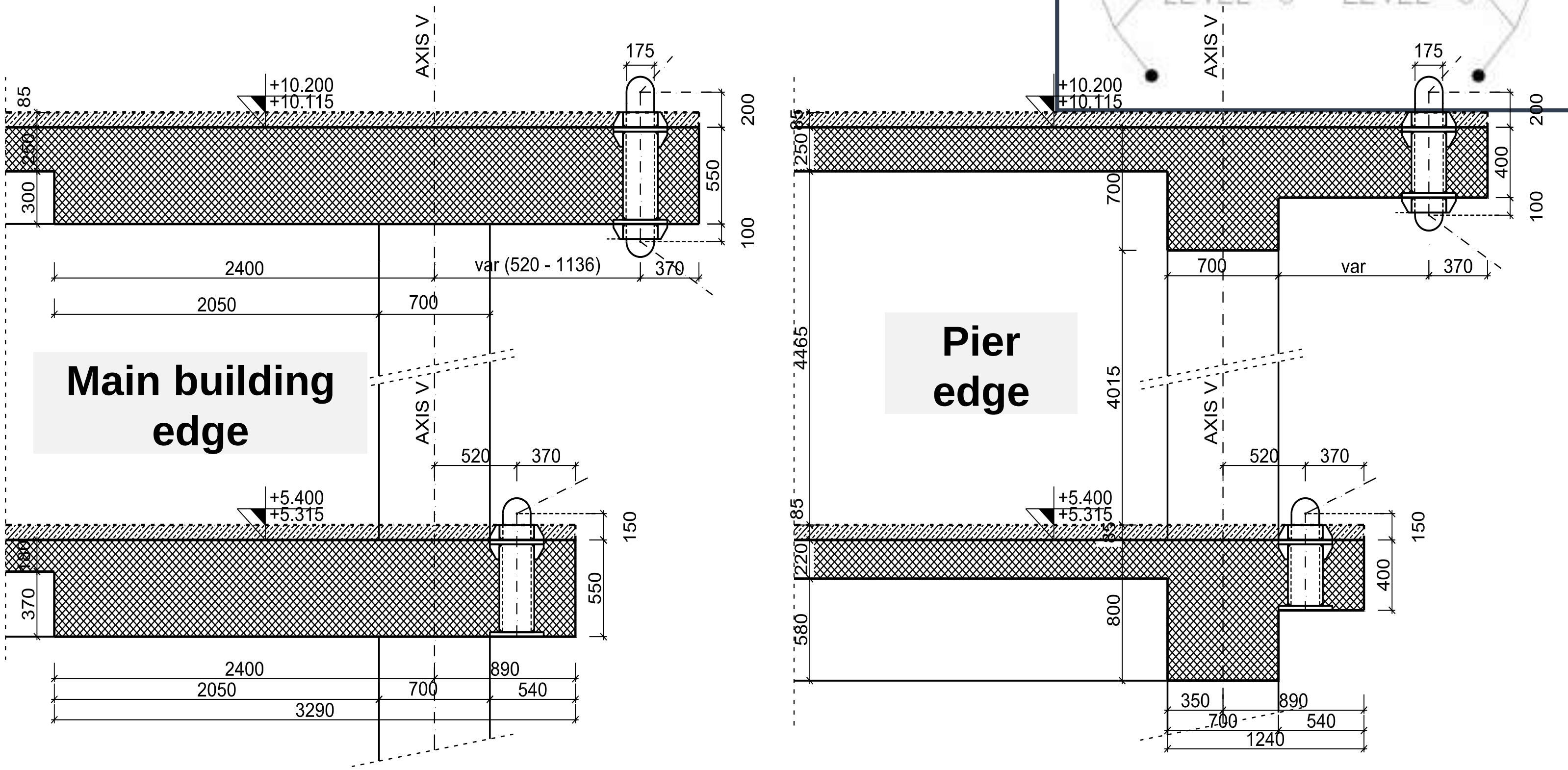


- Transition between building and pier truss is achieved by preserving the same triangular module and adjusting its size depending on the roof height
- Pier truss height of 1.4 m is gradually increasing as the pier is beginning to merge with main building until it reaches the height

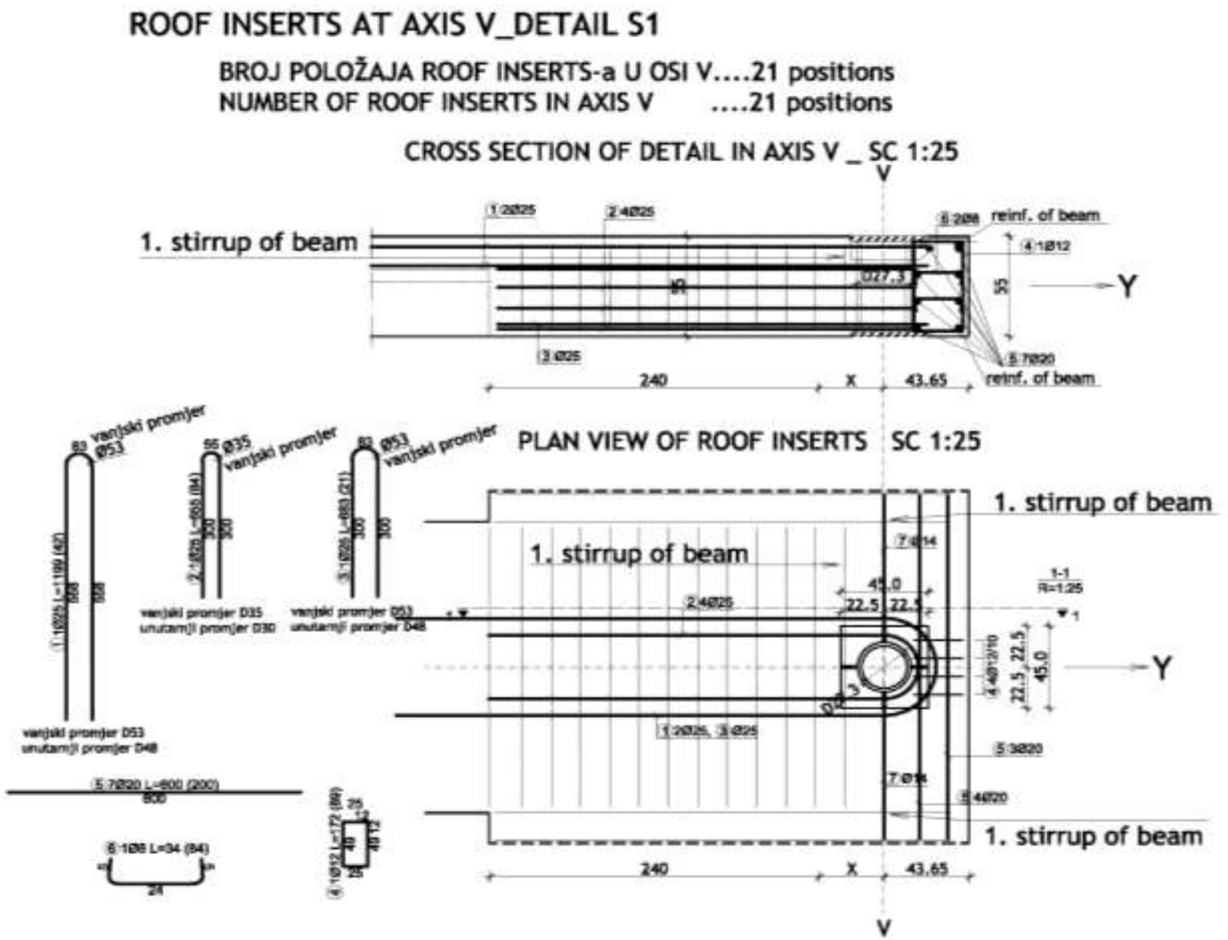


- On the airside, roof space truss is descending as a facade and is supported by anchors in the concrete floor slabs
- Floor slabs are cantilevered to allow the truss members to reach them
- Outer truss chord is anchored in the first floor slab (lvl +5.4 m), and the inner chord is anchored in the second floor slab (lvl +10.2 m).
- Also, truss diagonals are anchored in the bottom face of the upper slab

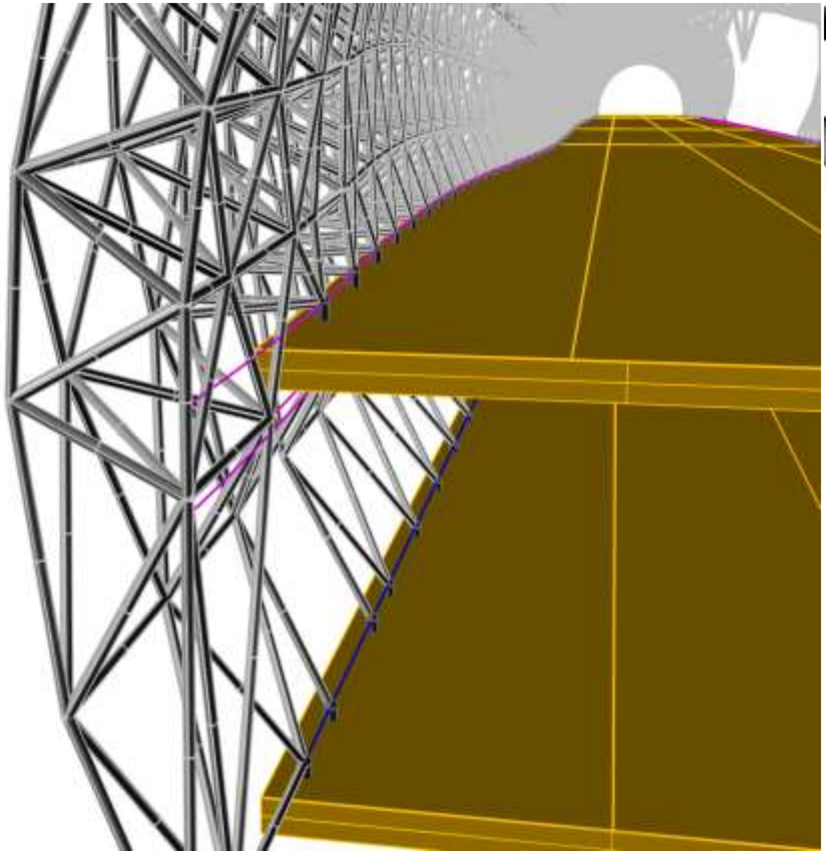


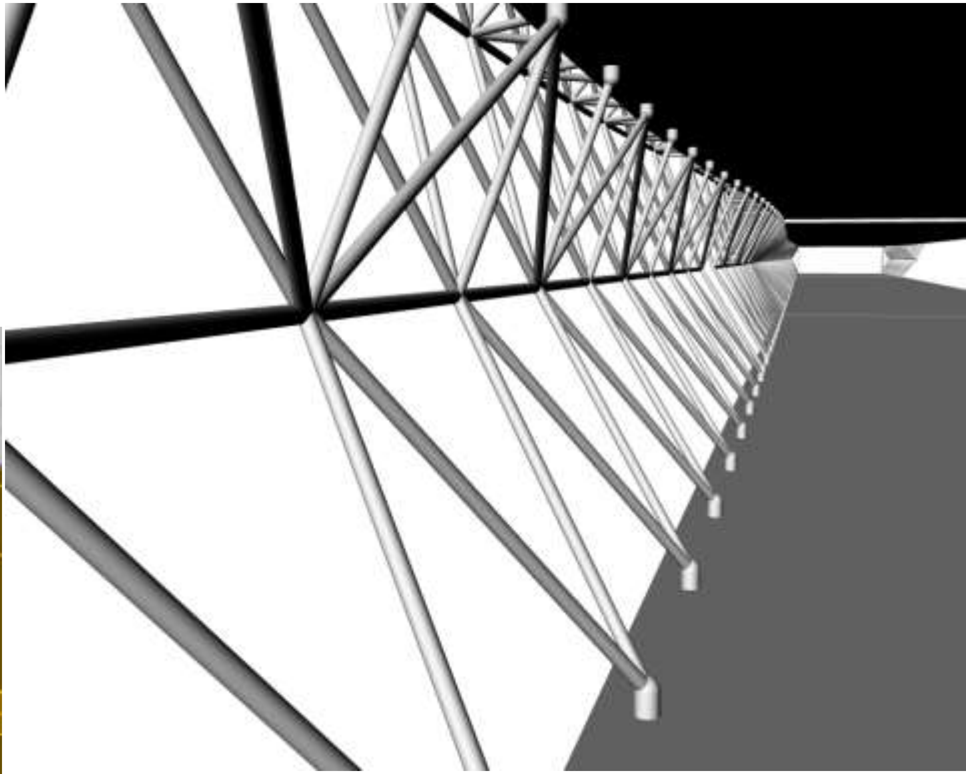


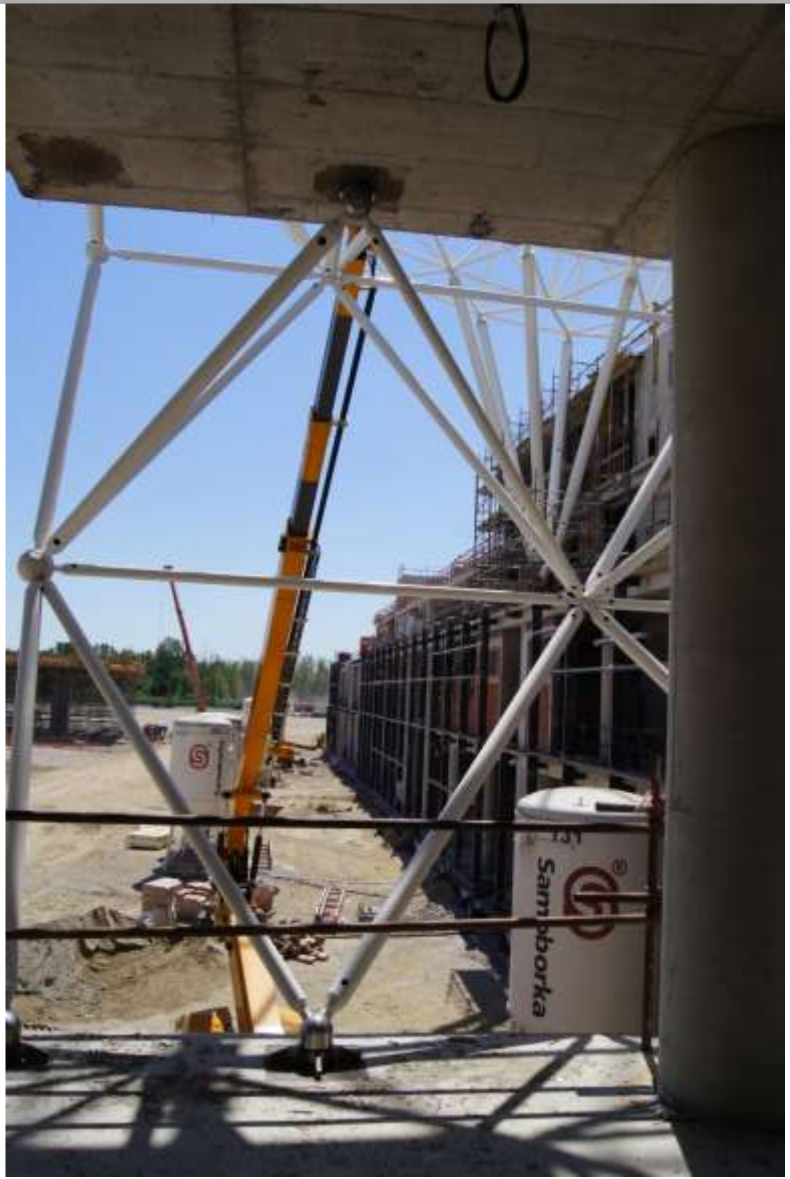
Detail of reinforcement around anchors – large tension and compression forces from truss members are taken over by reinforcement loops in the floor slab



- Thickness of the edge of the slab where the anchors are installed is 55 cm (main building) and 40 cm (piers)
- Lower anchors line is straight, but the upper is curved due to variable height of the roof and changing height of the truss (1.4 m -> 3 m).
- This curvature is achieved by variable width of the floor slab on level +10.2 m



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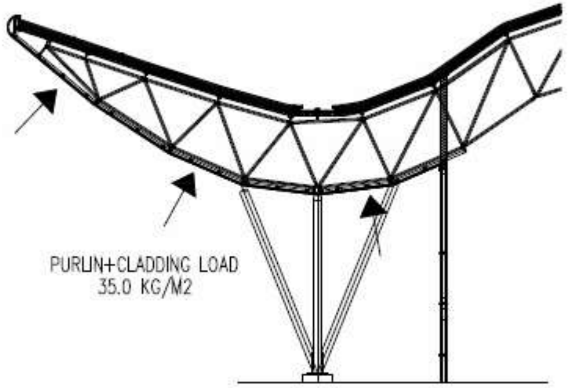
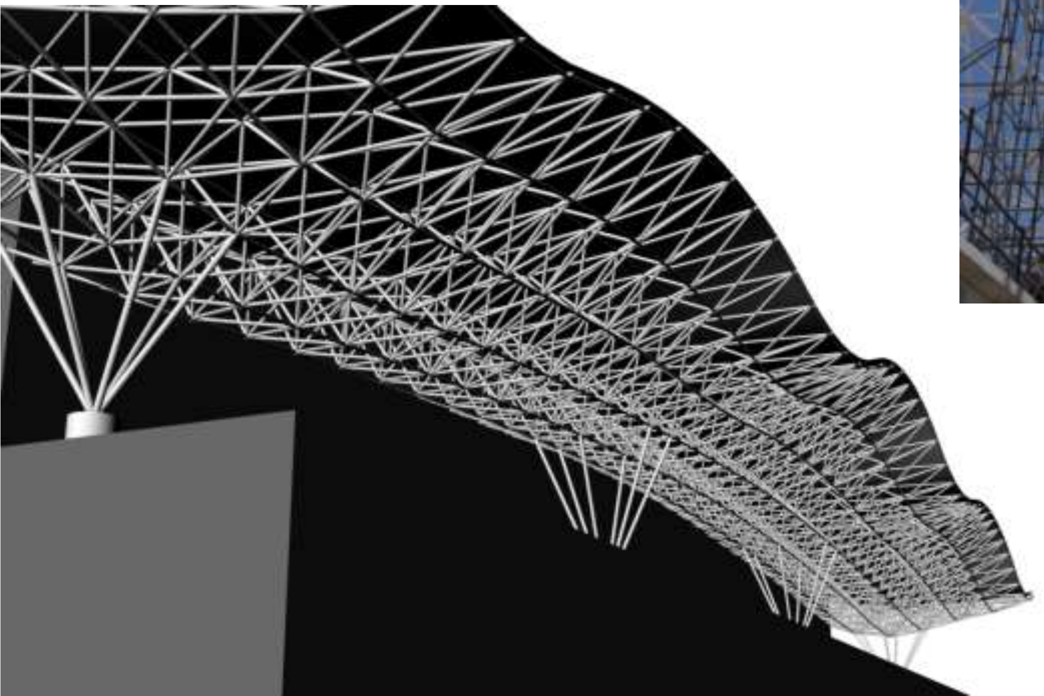
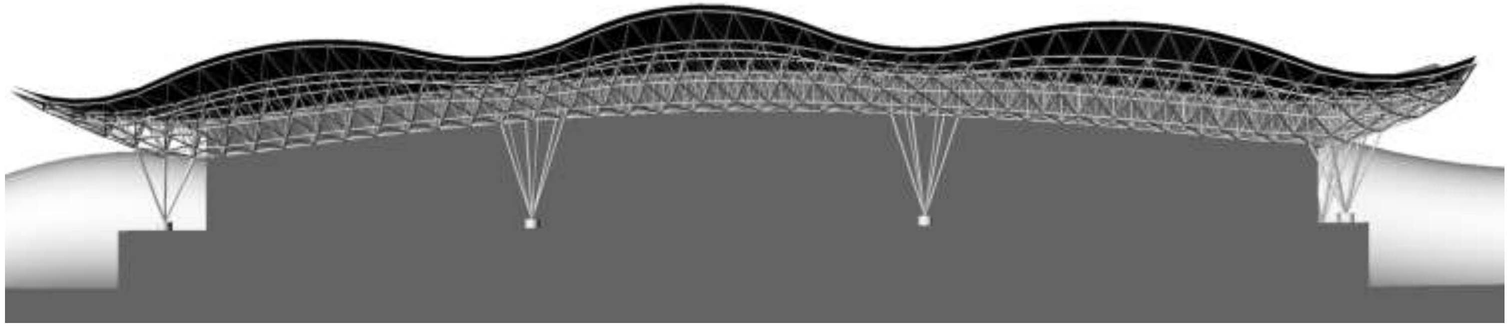
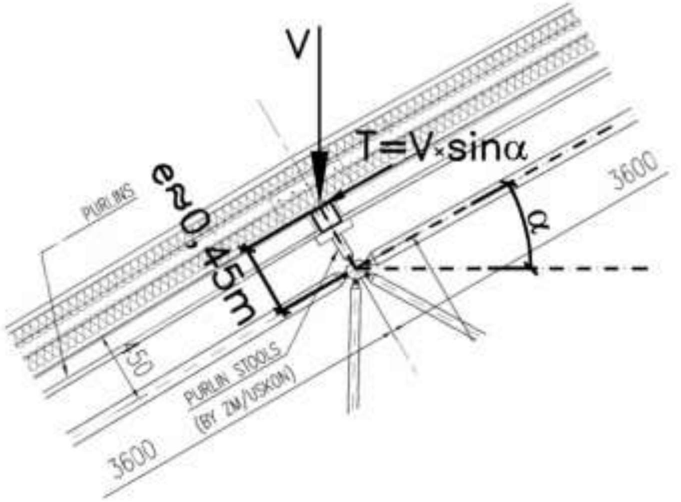
View of the overhanging edges of the truss, reaching outside of the building

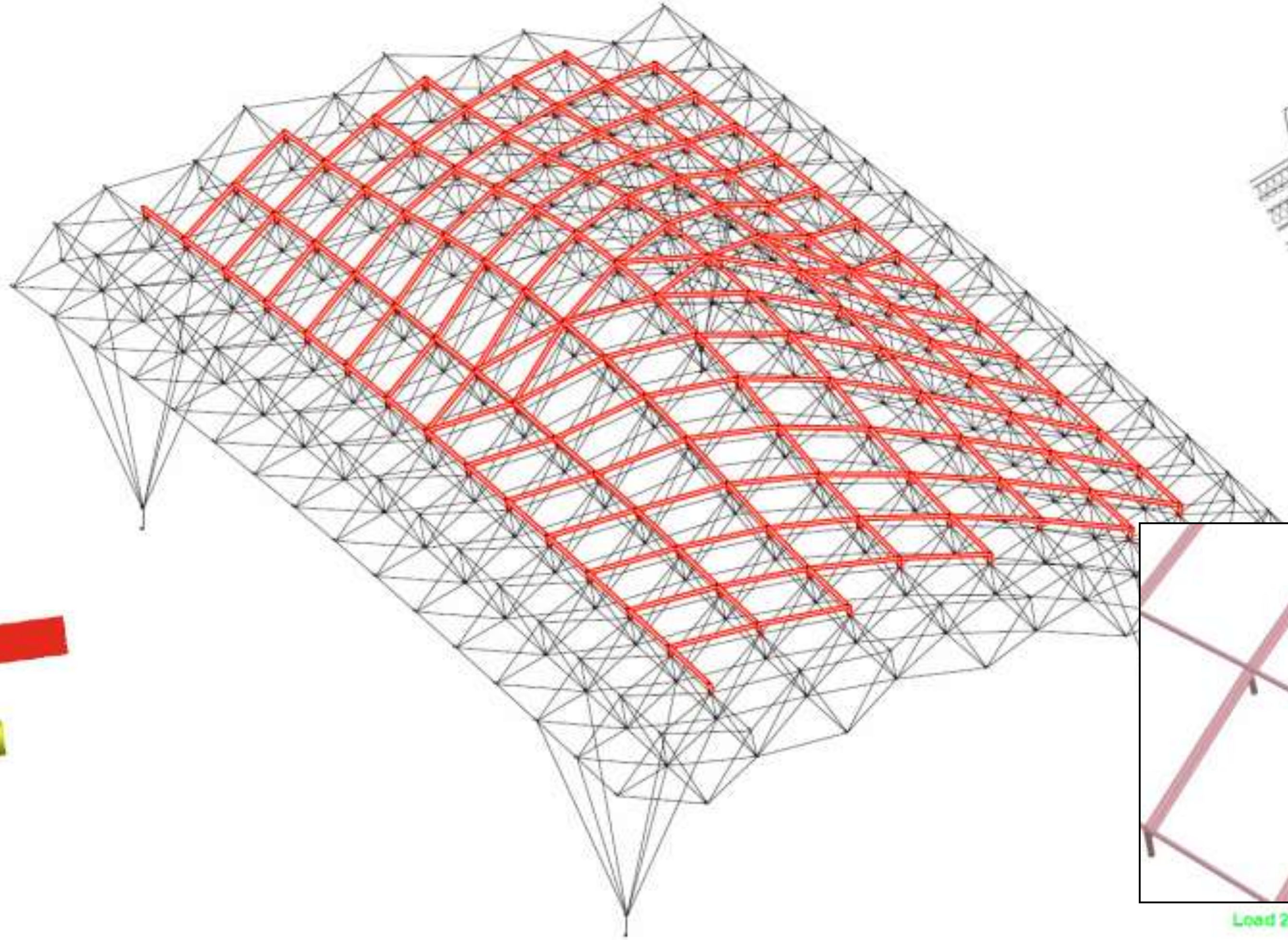


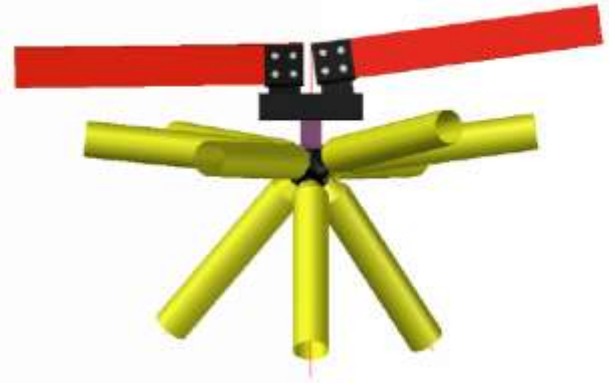


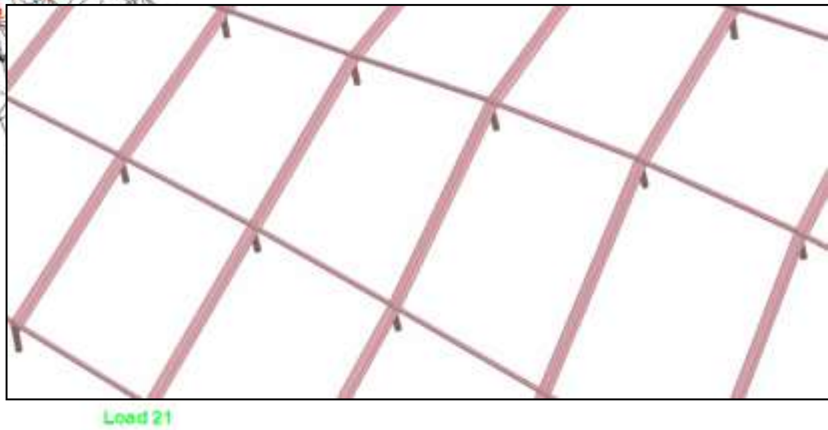


Connection of the purlins for the roof sheeting

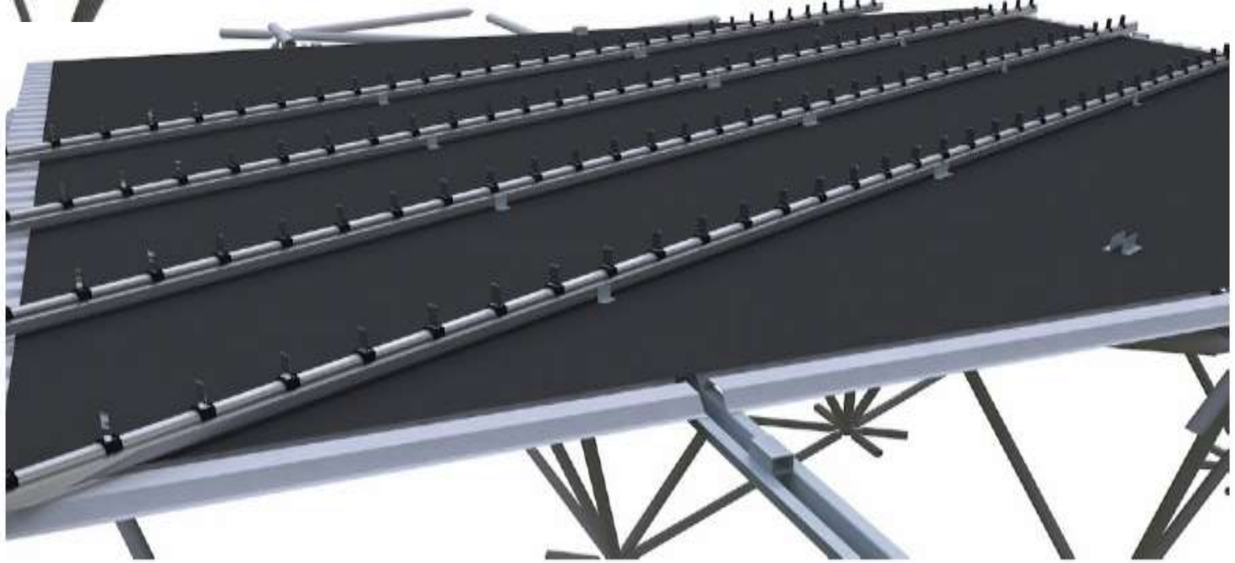


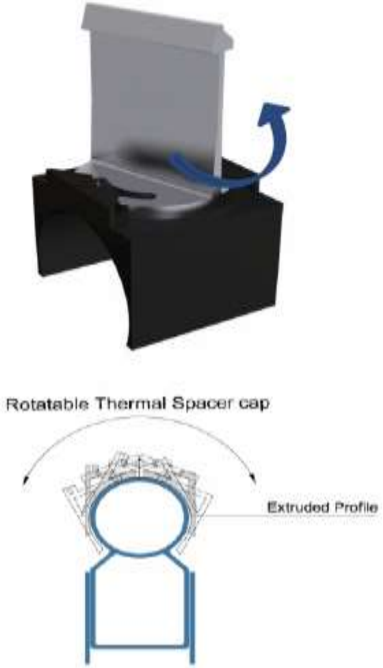




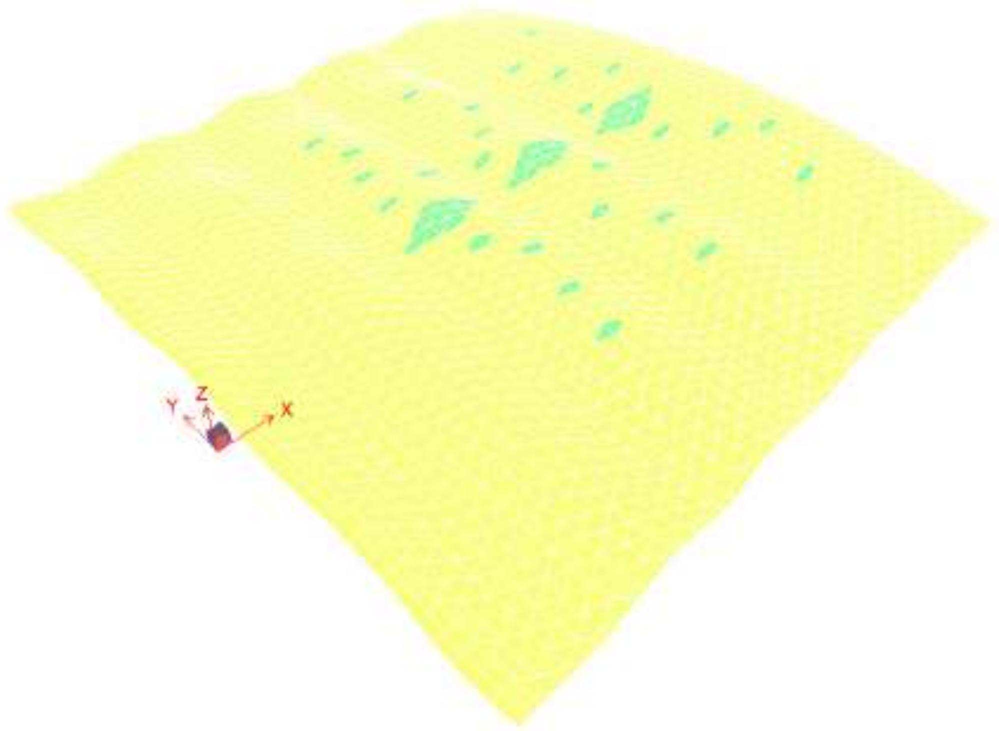


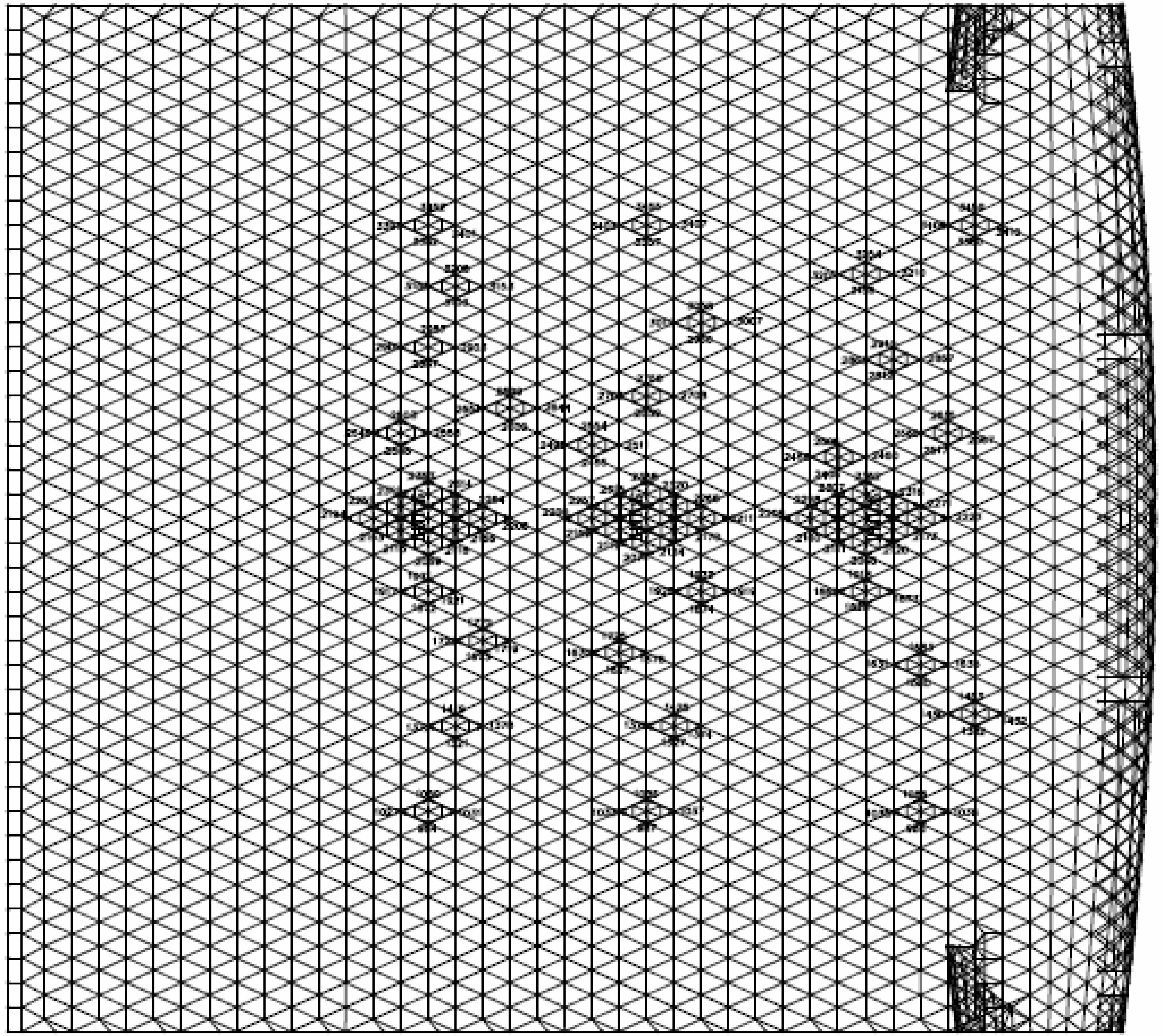
Roof sheeting: BEMO-STANDING SEAM ROOF





Roof skylight areas



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CONCLUSIONS

- Croatian government signed a concessionary agreement with French company Bouygues for the erection of the terminal according to the winning design by Branko Kincl, Velimir Neidhardt and Jure Radic.
- New Zagreb airport terminal is a perfect blend between architecture, urbanism, environment and construction.
- The form of the architectural expression is directly derived from the natural conception of the load bearing structure. No elements have been forcibly added to satisfy only one need, but rather to be a part of the multifunctional solution.

Airport Franjo Tuđman declared the best in Europe in the category up to 5 mil. Passengers

According to the ACI / ASQ Satisfaction Survey, Airport Franjo Tudjman was named the best airport in Europe in the airport group of 2 to 5 million passengers in 2018

6.3.2019.

Thank you for your attention