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The use of modern design tools in BIM technology. Conceptual design of Community Centre in Rzeszow

Dissertação apresentada para a obtenção do grau de Mestre em Engenharia Civil na Especialidade de Mecânica Estrutural

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RESUMO

Em primeiro lugar, foi utilizado o modelo de edifício projetado pelo arquiteto. O Modelo continha muitos erros e não possuia sistema de suporte de carga, colunas e vigas. Para o propósito deste projeto, o modelo foi redesenhado no software Revit. Uma vez que o projeto foi aprovado para transferência para o software do robô, descobriu-se que não é possível passar diretamente do Revit - Robot. O modelo foi salvo em um arquivo .smxx e em seguida, no Robot carregado como arquivo .smxx. Elementos foram alterados, paredes e tetos de cortina foram convertidos para os revestimentos. Os elementos de aço foram agrupados e foram atribuídos aos tipos relevantes de elementos desenhados. O próximo passo foi definir as combinações de carga e de carga, porque descobriu-se que as seções IPE são muito pequenas,por isso o conceito foi alterado. O teto composto foi escolhido a partir de um catálogo, e as vigas mistas foram contadas manualmente. As características calculadas das vigas foram designados para as vigas no programa robot e os cálculos foram repetidos. Outros elementos foram calculados no programa. Conexões foram criadas e o modelo foi enviado para o Revit. A última parte foi a criação de desenhos e listas de itens.

Palavras-chave: Tecnologia BIM; Centro Comunitario em Rzeszow; REVIT; estruturas metalicas.

ABSTRACT

First, the model of building designed by the architect was used. Model contained many errors, and did not contain load bearing system; columns and beams. For the purpose of this project, model was redesigned in the Revit software. Once the project has been approved for transfer to the Robot software, it turned out that it is not possible to directly link towards Revit - Robot. The model was saved to a .smxx file, then in Robot loaded with .smxx file. Elements were changed, curtain walls and ceilings were converted into the claddings. The steel elements were grouped and they have been assigned to the relevant types of designed elements. The next step was to define the load and load combinations. Because it turned out that the IPE sections are too small, the concept was changed. The composite ceiling was chosen from a catalog, and the composite beams were counted manually. Calculated characteristics of beams were assigned to the beams in the Robot and calculations were repeated. Other elements have been calculated in the program. Connections were created and model was sent to Revit. The last part was creating drawings and schedules of items.

Keywords: BIM technology; Community Centre in Rzeszow; Revit; steel structures

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NOTATION

Upper Latin letters

A	cross-sectional area
A_a	cross-sectional area of the structural steel section
A_c	cross-sectional area of concrete
A_s	cross-sectional area of reinforcement
A_v	shear area of a structural steel section
E	modulus of elasticity
E_a	modulus of elasticity of structural steel
$E_{c,eff}$	effective modulus of elasticity for concrete
E_{cm}	secant modulus of elasticity of concrete
H_{Ed}	total design horizontal load
I_a	second moment of area of the structural steel section
I_y	second moment of area about y-y axis
L	span
L_e	equivalent span
M_{Ed}	design bending moment
$M_{pl,a,Rd}$	design value of the plastic resistance moment of the structural steel section
$M_{pl,Rd}$	design value of the plastic resistance moment of the composite section with full shear connection
M_{Rd}	design value of the resistance moment of a composite section or joint
N_c	design value of the compressive normal force in the concrete flange
$N_{c,f}$	design value of the compressive normal force in the concrete flange with full shear connection
N_{cr}	elastic critical force for the relevant buckling mode based on the gross cross sectional properties
N_{Ed}	design value of the axial force
P_{Rd}	design value of the shear resistance of a single connector
V_{Ed}	total design vertical load on the frame transferred by the storey (storey thlust)
$V_{pl,Rd}$	design value of the plastic resistance of the composite section to vertical shear

Lowercase Latin lerwes

b	width of the flange of a steel section; width of slab
b_{eff}	total effective width
b_{ei}	effective width of the concrete flange on each side of the web
b_0	distance between the centres of the outstand shear connectors
d	diameter of the shank of a stud connector
d_c	distance between the steel reinforcement in tension to the extreme fibre of the composite slab in compression;
e_{sc}	distance from the steel reinforcement in tension to the extreme fibre of the composite slab in tension
f_{cd}	design value of the cylinder compressive strength of concrete
f_{ck}	dharacteristic value of the cylinder compressive strength of concrete at 28 days
f_{sd}	design value of the yield strength of reinforcing steel
f_u	specified ultimate tensile strength
f_y	yield strength
h	height of the structure, storey height
h_a	depth of the structural steel section
h_c	thickness of concrete above the main flat surface of the top of the ribs of the sheeting
h_p	overall depth of the profiled steel sheeting excluding embossments
h_{sc}	overall nominal height of a stud connector
k_t	reduction factor for resistance of a headed stud used with profiled steel sheeting transverse to the beam
m	number of columns in a row
n	number of shear connectors
n_r	number of stud connectors in one rib
s	longitudinal spacing centre-to-centre of the stud shear connectors
s_t	transverse spacing centre-to-centre of the stud shear connectors
t_f	thickness of a flange of the structural steel section
t_w	thickness of the web of the structural steel section
x_{pl}	distance between the plastic neutral axis and the extreme fibre of the concrete slab in compression

Lowercase Greek letters

α	factor
α_{cr}	factor by which the design loads would have to be increased to cause elastic instability in a global mode
α_h	reduction factor for height h applicable to columns
α_m	reduction factor for the number of columns in a row
γ_c	partial factor for concrete
γ_v	partial factor for design shear resistance of a headed stud
$\delta_{H,Ed}$	horizontal displacement at the top of the storey, relative to the bottom of the storey
ε	$\sqrt{235/f_y}$, where fy is in N/mm2
η	degree of shear connection
θ_f	angle
$\bar{\lambda}$	non dimensional slende111ess
ν	reduction factor to allow for the effect of longitudinal compression on resistance in shear
$\emptyset$	global initial sway imperfection
$\emptyset_0$	basic value for global initial sway imperfection

ACRONYMUS

AEC	Architecture Engineering Construction
BIM	Building Information Modeling
BCF	BIM Collaboration Format
CAD	Computer Aided Design
IDM	Information Delivery Manual
IFC	Industry Fundation Classes
IFD	International Framework Dictionary
MVD	Model View Definitions

1 Introduction

1.1 Importance of BIM technology

Construction is a sector that must meet ever-growing demands. The consequence of change and development is continuous improvement solutions, allowing for grouping, processing and publishing data on the building at any time, and the whole team involved with the project. In the United States, Canada, Great Britain and Scandinavia, technology BIM is used to create projects. The European Parliament adopted new rules for public procurement and concession contracts. Revolutionary change is the end of the “dictatorship of the lowest price”, which is the curse of public procurement. The introduction of the criterion of “the highest economic advantage” is to provide the public authorities to give greater attention to quality, the impact on the environment and social benefits offers, but still considering the price and costs arising from life cycle shown in the product offering. Important is the recommendation for use in public tenders for the construction and design, building information modeling - BIM. It is why BIM technology should be explored and used.

BIM technology is portrayed in glowing terms, and is the only drawback is the cost of its application. But how is it really? BIM is not only about cooperation between the participants of the project, it is also about a software which must allow for this cooperation. In this document the possibilities of collaboration software ArchiCAD, Revit, and Robot and work on a model obtained from the architect will be verified. What more, the following assumptions of BIM technology will be checked:

- a faithful reproduction of reality
- saving time
- control - auto-save feature and function references to the history of the project are supposed to give assurance that the work on the model has been preserved
- better cooperation between project participants
- conflict detection and resolution, collision detection
- focus on details
- excellent presentation - 3D model, the actual appearance, speed of creation interesting views.

1.2 Organization of the document

- Chapter 2 – What is BIM?

It will be explained what is BIM technology, it main idea. Based on the levels of cooperation and progress, the maturity levels of BIM will be defined. There will be presented the possibilities and assumptions, and goals to be achieved in the future. Standards and BIM software will be a summary of this chapter.

- Chapter 3 - The application of BIM in project

There will be presented the project which will be implemented in this document. Architect's assumptions will be presented. The first changes will be proposed, the analytical model will be created, and finally the analytical model will be transferred to the Robot.

- Chapter 4 - Transfer of model from Revit to Robot

In this chapter construction calculations will be carried out. Elements will be verified and their cross sections will be updated. Connections between the elements will be created.

- Chapter 5 - Updating model in Revit

Return from Robot to Revit and update the project. Creation of drawing documentation.

- Chapter 6 - Conclusion

Conclusions about the course of the work will be presented.

2 Building Information Modeling

2.1 What is BIM?

There exist a lot of definitions about what is BIM. In the easiest way in can be defined as parametric 3D model that contains information about itself. It allows the engineers and other AEC professionals (architects, quality surveyors...) involved in project to enrich building with intelligent "building blocks". Every block is "self aware" of what it is, each interacts with the other elements of building. For example, window integrates into a wall in the project. The wall itself contains information concerning its function (separation of spaces or supporting) insulation, its thickness, the dimensions of its openings, color etc. BIM model is made of all this BIM components and is the basis to define what BIM is about (Cellier I. 2013).
The elements of three-dimensional model are an accurate reflection of components which will be built. All model is exact virtual copy of building. During the whole process model is constantly enriched with details and improved. Because of a continuous flow of information is much easier to take over the entire project. When the design is completed, models contains all needed information and data for procedures related to the construction process, the pricing, design prefabrication. BIM models can be used for calculation related to energy efficiency, sunlight and statics. It is the base of the exchange of information between the involved in the project, see Figure 1 (Jankowski B., Prokocki J., Krzemiński M. 2015).

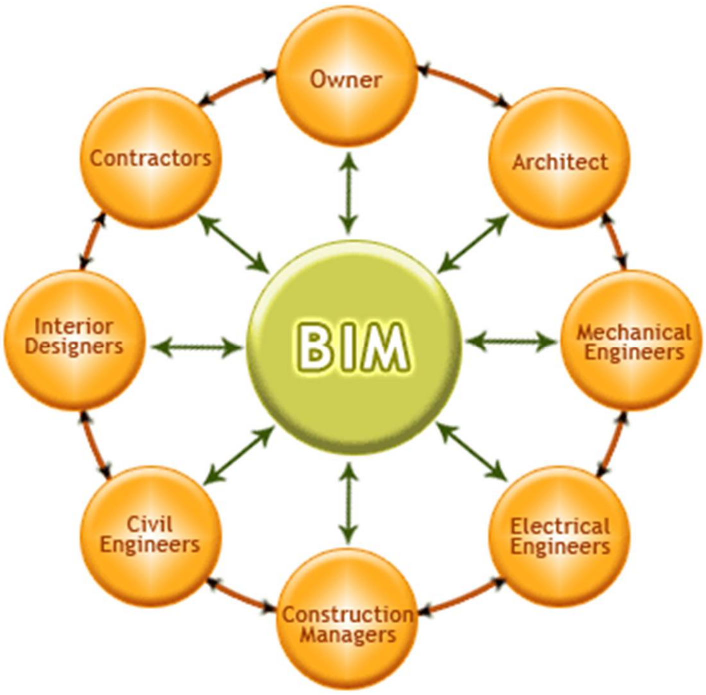


Figure 1 Major participants in a BIM (Vaughan K. 2012)

The main idea of BIM is to allow project participants to cooperate in high level and to support them. Accurate chosen programs helps to cooperate in a more effective, cheaper and smarter way. By putting information from all participants to one model it is easier to avoid collisions and, choose the best possible solution. An important part of BIM is that it allows a very good information flow and good coordination of documentation, as well as helping to eliminate mistakes and misunderstandings among all participants in a design project.
The key of effective communication and cooperation between stakeholders in BIM technology is the possibility to exchange models and BIM data between programs different producers. It is possible because of IFC - open and universal BIM data exchange format.

2.2 Levels of BIM maturity

Levels of sophistication (Figure 2) in use of BIM defined by UK Government:

'Level 0' Doesn't give possibility to manage CAD, in 2D, data exchange using paper (or electronic paper).

'Level 1' It is possible manage CAD in 2D or 3D format, using a collaborative tool that provide a common data environment and a standardized approach to format and data structure. Commercial data management will be by cost management and standalone finance packages with no integration.

'Level 2' Management in 3D environment, the important fact is collaboration not necessarily on a single model. The form of exchange the information is the crucial aspect and common file format, that enables every organization to combine their own data with other in order to make a federated BIM model, to be able to carry out interrogative checks on it. IFC or COBie file format is used to share design information. This level may utilise also 4D scheduling and/or 5D cost estimating.

'Level 3' Full collaboration between all participants, disciplines using a single, shared model that is held in a centralized repository. All parties are able to modify that same model, this remove completely the risk of conflicting information. (Out-Law, 2012).

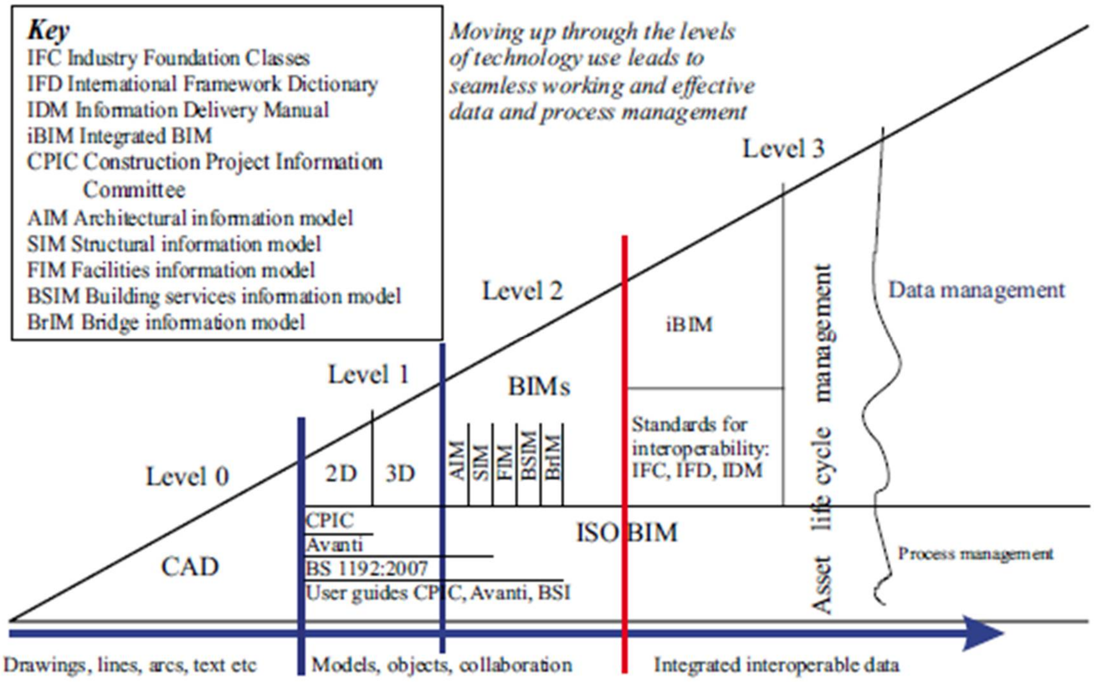


Figure 2 Levels of information management, data sharing and collaborative working (Dinesen B., Nisbet N. 2010)

The maturity levels of BIM are define by using the concepts like of 4D, 5D and 6D to indicate the benefits and elements of more and more complex BIM models see Figure 3. BIM can be used in wide spectrum of construction projects. To gain all benefits of BIM's capabilities, the collaboration must be used. BIM provides a collaborative framework between all participants, allow the free-flow of information and data about object that is being designed and also how will be constructed.

The Levels from 0 to 3 of BIM maturity are not the same to the next dimensions of BIM data. Additionally to 3D drawn information, next data can be contained at 4D, 5D and 6D. In Level 2 or Level 3 all of these dimensions could be found. (NBS, 2014)

3D

- ❖ Existing Conditions Models
  - Laser scanning
  - Ground Penetration
  - Radar (GPR) conversions
- ❖ Safety & Logistics Models
- ❖ Animations, renderings, walkthroughs
- ❖ BIM driven prefabrication
- ❖ Laser accurate BIM driven field layout

4D

SCHEDULING

- ❖ Project Phasing Simulations
- ❖ Lean Scheduling
  - Last Planner
  - Just In Time (JIT) Equipment Deliveries
  - Detailed Simulation Installation
- ❖ Visual Validation for Payment Approval

5D

ESTIMATING

- ❖ Real time conceptual modeling and cost planning (Dprofiler)
- ❖ Quantity extraction to support detailed cost estimates
- ❖ Trade Verifications from Fabrication Models
  - Structural Steel
  - Rebar
  - Mechanical/Plumbing
  - Electrical
- ❖ Value engineering
  - What-if scenarios
  - Visualizations
  - Quantity Extractions
- ❖ Prefabrication Solutions
  - Equipment rooms
  - MEP systems
  - Multi-Trade Prefabrication
  - Unique architectural and structural elements

Figure 3 BIM Dimensions

2.3 Standards in construction

BIM is about sharing structural data. Initially with making sure that the produced work, at each level, now or in the future can be used by other people. Doing anything again should be more effective by re-using not only own skills but also the efforts of others.
There are five basic methodology standards (Table 1).

Table 1 - BIM Standards (www.buildingsmarttech.org 2011)

IDM – Information Delivery Manuals ISO/FDIS 29481-1:2010

- ❖ Integrates with workflow management.
- ❖ How to capture requirements for application developers to meet.
- ❖ How specific required information exchanges can be documented.

IFC – Information for Construction ISO 16739 – 2005/2013

- IFC STEP files and IFC XML files define portable file structures.
- Includes design, processes, resources, participants.
- What information can be re-used.

IFD – International Framework Dictionary ISO 12006-3:2007

- Includes proprietary dialects such as "Revit-speak", "Bentley-speka".
- Includes multiple languages.
- Catalogues terms and concepts.

BCF – BIM Collaboration Format buildingSMART BCF

- 'Simplified' open standard XML schema.
- Encodes messages to allow workflow communication between BIM software tools.

MVD – Model View Definitions buildingSMART MVD

- Supporting the data exchange over the life-cycle of a project.
- Provides implementation guidance (or implementation agreements) for all IFC concepts (classes, attributes, relationship, property sets, quality definitions, etc.)

In the following part of this document IFC file format will be using to data exchange between different software. Information contained in IFC file are shown in Figures 2 and 3.

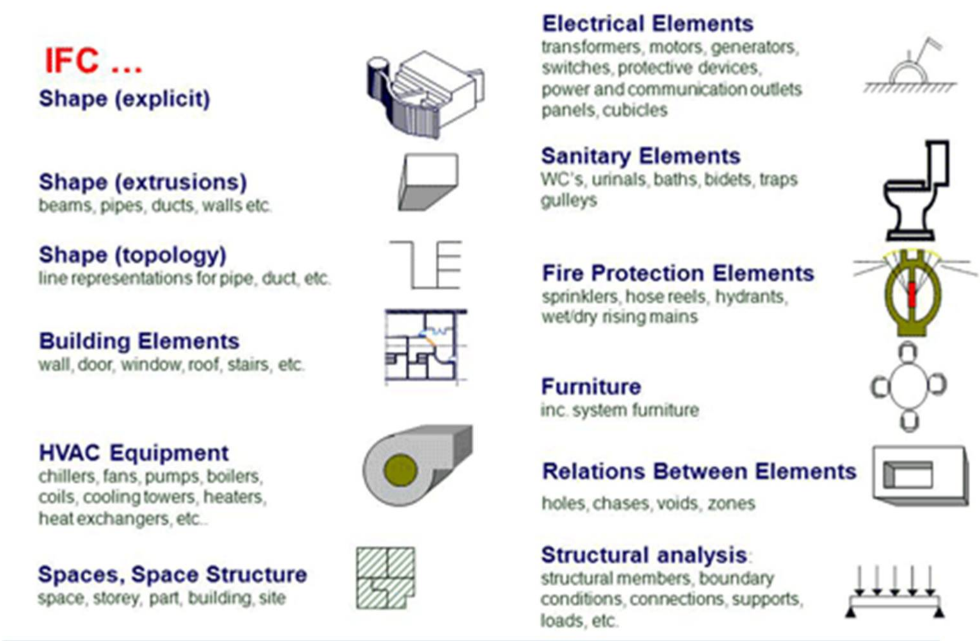


Figure 4 Information contained in IFC file 1/2 (www.thenbs.com)

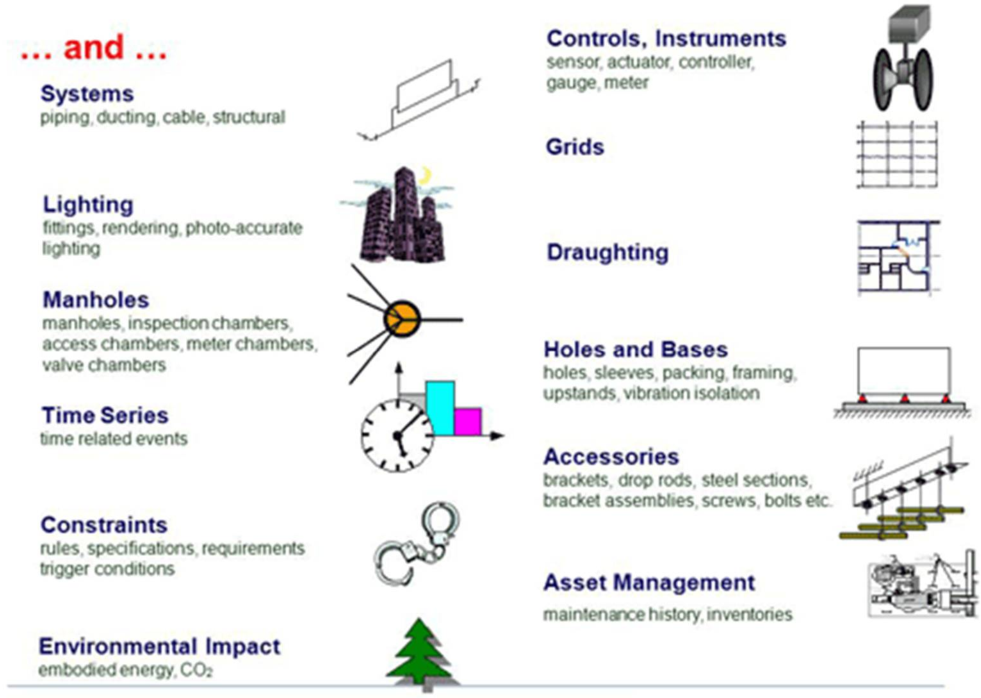


Figure 5 Information contained in IFC file 2/2 (www.thenbs.com)

2.4 Software Survey

There are a number of different software available that implement BIM. Some of them and the possibility of use are shown in Figure 4.

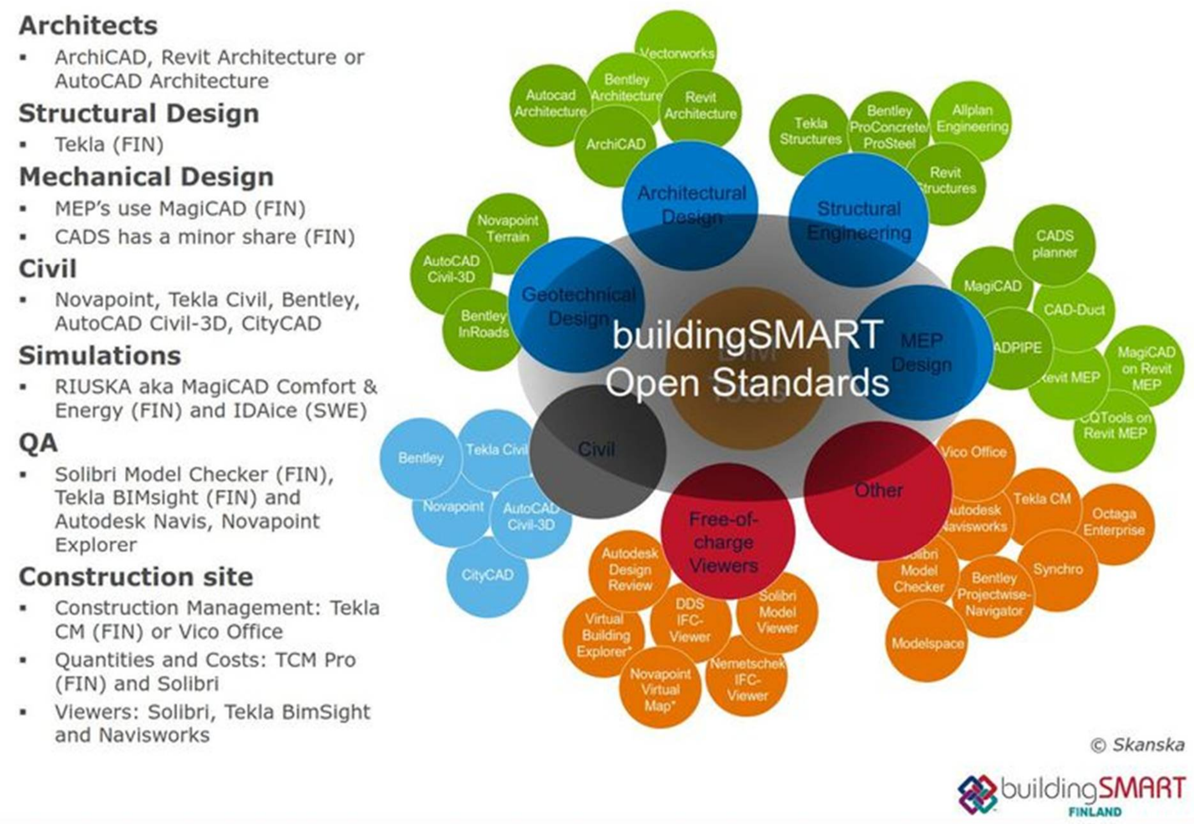


Figure 6 OpenBIM Software (geospatial.blogs.com)

3 The application of BIM in project

3.1.1 Architecture

The architectural project of Community Centre in Rzeszow was designed by Katarzyna Siembida-Klucha. The building is asymmetric and consist of three main solids which interpenetrate themselves and was divided into three parts due to destiny: workshop, office part and exhibition space. Project also contain a suggestion of building's structure, about materials and load bearing system.
The shape of building is irregular and because of that the author suggested steel skeleton frame as a load bearing system. This solution let to shape freely space and to overcome long distances. The columns are spaced in 5 m or 10 m from each other. Between the columns are steel girders. Floors are supported by system of steel beams that transfer loads from floors to girders. There is no steel elements described above in the architectural model, everything need to be put in Revit software.

The following initial considerations about structural elements are described as follows:

Fundaments:

- The author proposed to realize reinforced standard footings on 1,2 m depth below ground level;

Columns:

- Hot rolled steel columns, H beam type;

Beams:

- Hot rolled steel beam, I beam type;

Walls:

- **Exterior walls:** Columns in exterior walls are spaced from 2 m to 3 m from each other. Author conception was changed from reinforced walls to steel-framed solutions and as non-load-bearing walls;
- **Partition walls:** The wall construction consists of two layers gypsum wall-board on each side attached to steel construction with isolation inside. Partition walls are designed as non-load bearing walls;

Ceilings:

- The first floor 'ground' is made as a concrete slab. Other ceilings are made as concrete and supported by steel beams that are in 0,6 m spacing;

Stairs and ramp:

- Stairs and ramps are made of reinforced concrete;

Elevator shaft:

- Reinforced concrete construction;

Floor plans of designed building are shown in Figures 4, 5 and 6.

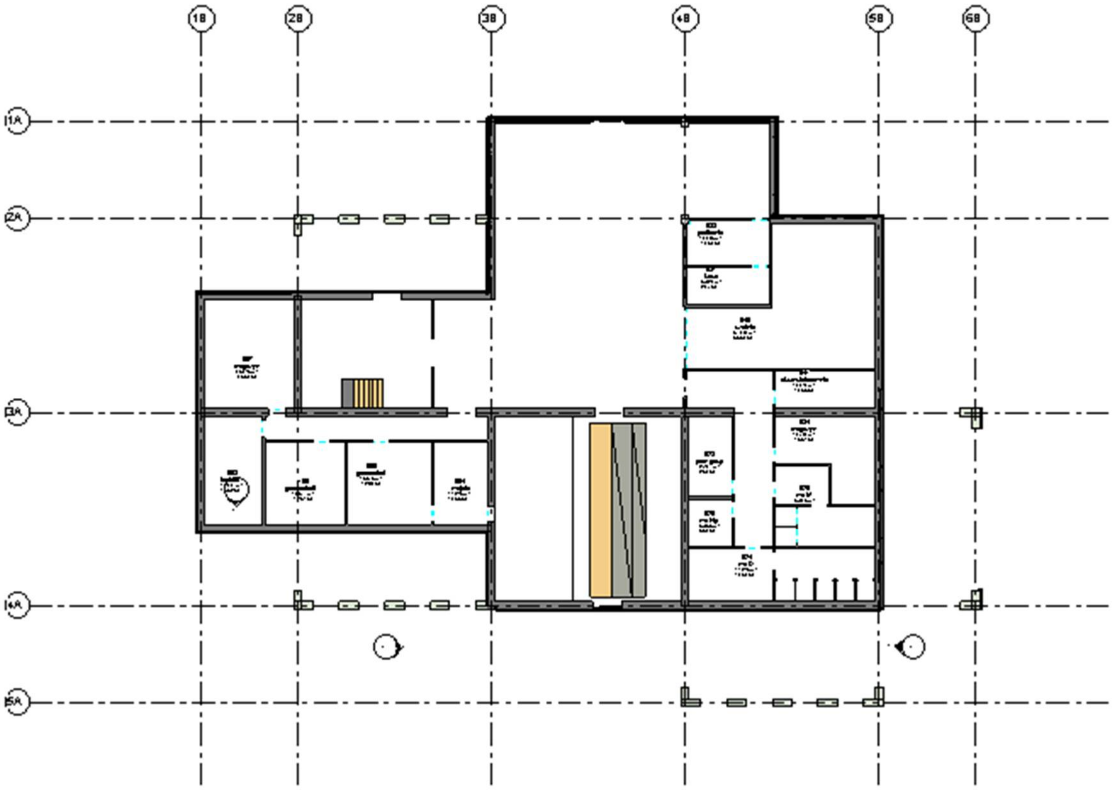


Figure 7 Ground floor

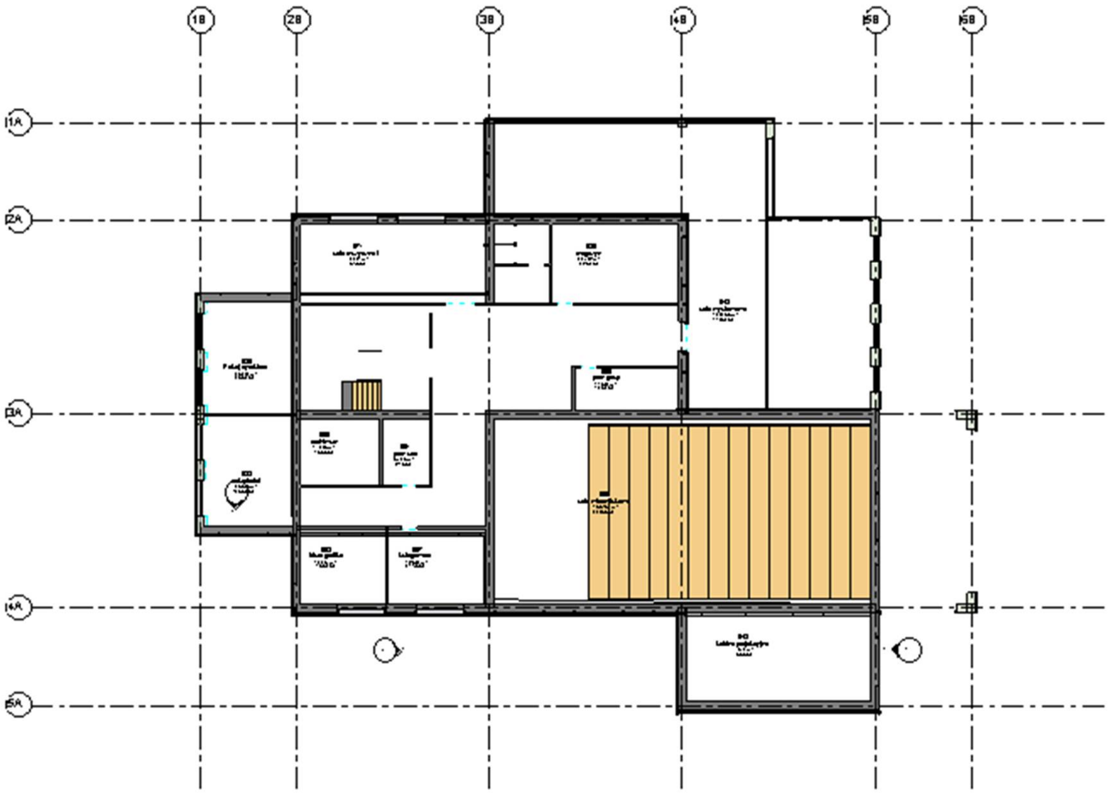


Figure 8 First floor

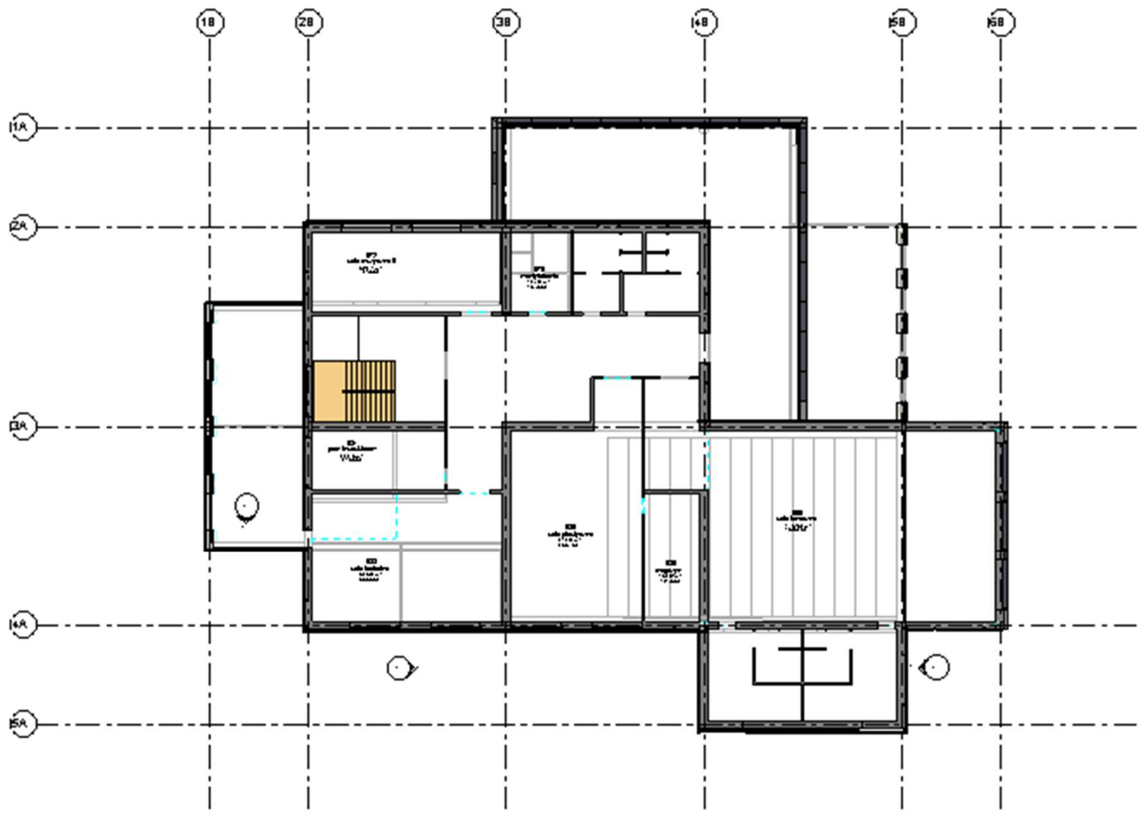


Figure 9 Second floor

Community Centre in Rzeszów has to fulfill three functions. There is space for exhibitions and events: auditorium, big main hall, exhibition hall. Another parts of building are workshops and offices.

3.1.2 Customization and transformation of the building model

In this chapter the model of construction created by the architect in Archicad was put to Revit. What is important in this step is to check if building model designed by Archicad is well prepared to use to future work. BIM is about information flow between architect and constructor, in this project there are information about shape but not about materials. Materials were defined in project description.

The first step is saving the file as IFC format. Before that to prepare model export, the structural elements can filtered by using elements classification, layers, layer combination, display settings, selection modes and so on. The entire building can be also exported without any filtering. This is what was done in this case. After that the IFC file was opened in Revit.

The model of construction was created using blocks as it shown at Figure 10, so every part of load bearing system was replaced by the structural elements.

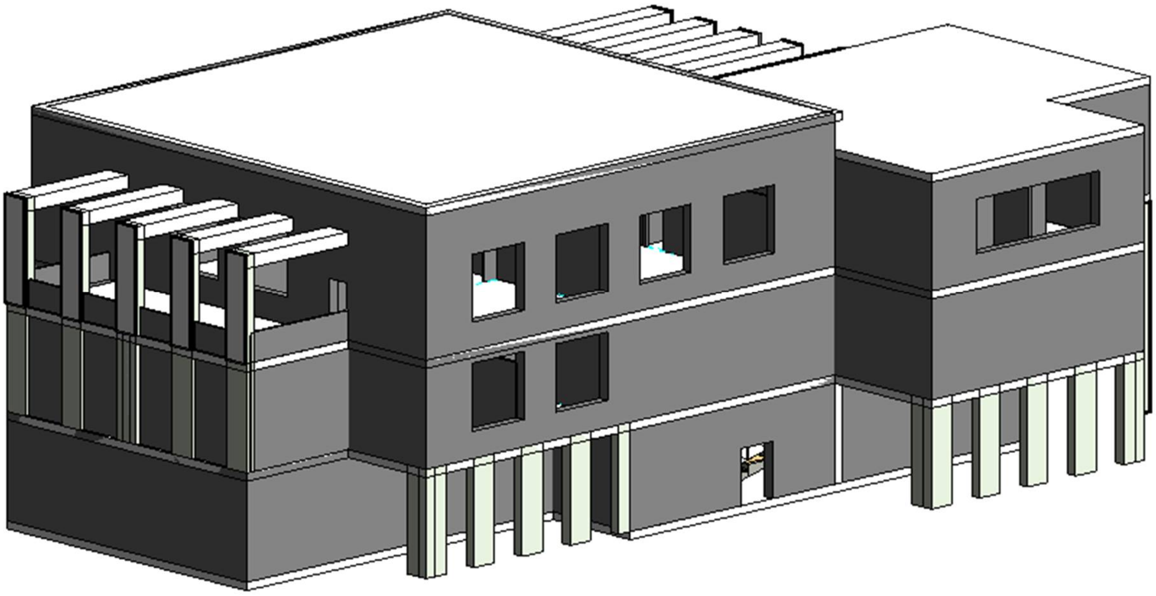


Figure 10 Model of the building created by architect

The load bearing system was proposed as steel-skeleton frame. To make present construction correct beams, columns were added. The prepared load bearing system is shown in Figure 11.

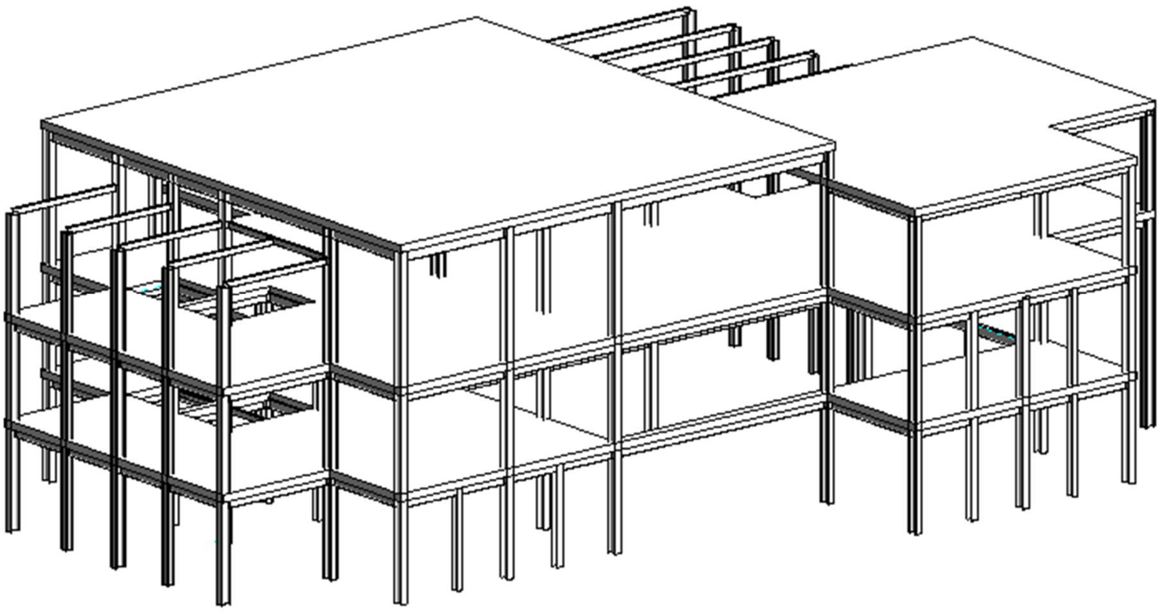


Figure 11 Load bearing system of building

What was changed comparing with assumptions of architect it is walls from reinforced concrete walls to light walls on steel frame. Walls were designed as curtain wall, which main task is to distribute the load from the wind on the steel skeleton. Ceilings were made as composite; and supported by steel beams that are in 2,5 m spacing.

To simplified model following elements were deleted, and instead of them appropriate loads were added:

- ❖ Elevator and elevator shaft

- ❖ Stairs and stairs shaft
- ❖ Partition walls

What more, construction of the stands in auditorium is independent from load bearing system of building, loads will be transferred directly to the proper fundamentals, which are not case of this document as well as the stands construction. Thus, imposed loads of the stands and dead loads will not be taken into consideration.

3.1.3 Analytical model

In Revit software, the structural elements the associated analytical model are created concurrently. There are few rules which are worth remembering. In this case analytical model was very important to trouble-free future work and was prepared to transfer and calculation in Robot.

Connections between structural elements are implicitly created as pinned connection in Revit. This will not be changed in Revit, after transferring the building model to software Robot, changes connected with analytical characteristics will be made. Connection between beam and column will be modified. The boundary conditions were chosen as pinned. The analytical model of building is shown in Figure 12.

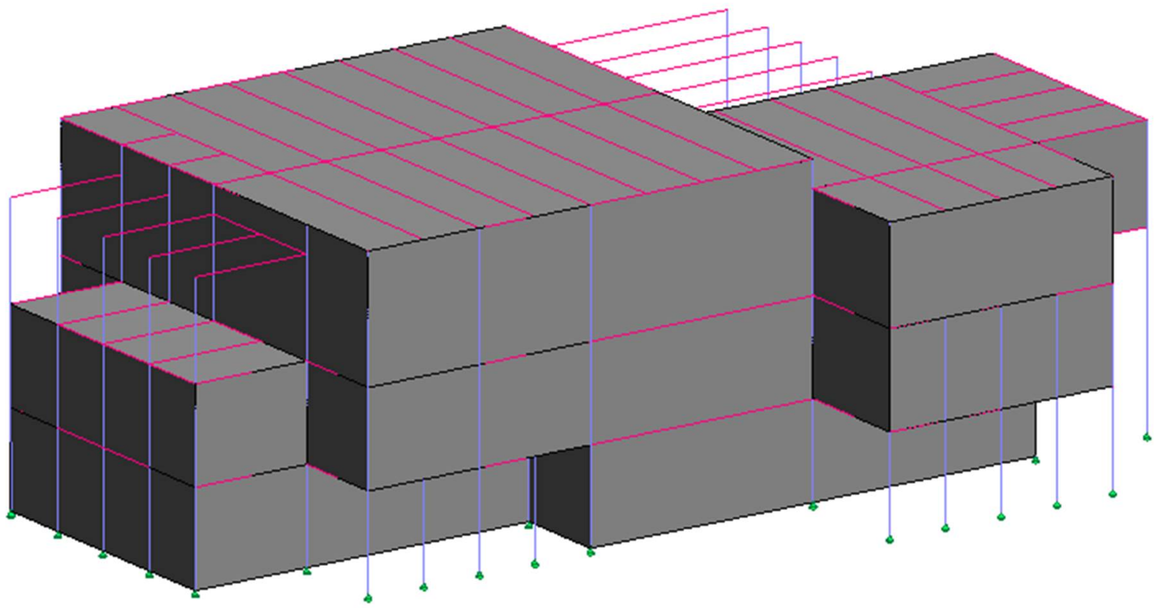


Figure 12 Analytical model

Analytical model is creating together with structural elements, and what is important that just at the beginning this two models are dependent, after that both models are edited separately. If the goal is calculation the entire construction in program such as Robot it is crucial to make sure that the analytical model is correct. The nodes have to be connected, in other way it will not be possible to get correct result. To find any mistakes and incompatibilities the filtration of nodes condition should be use like it is shown in Figure 13. The result of filtration is shown in Figure 14. Red color means that node is unconnected, but in this case it is not mistake because there is boundary element. Yellow means that this node was changed by user, previously this node had been unconnected or connection had not been suitable. Green color was assigned to connected nodes.

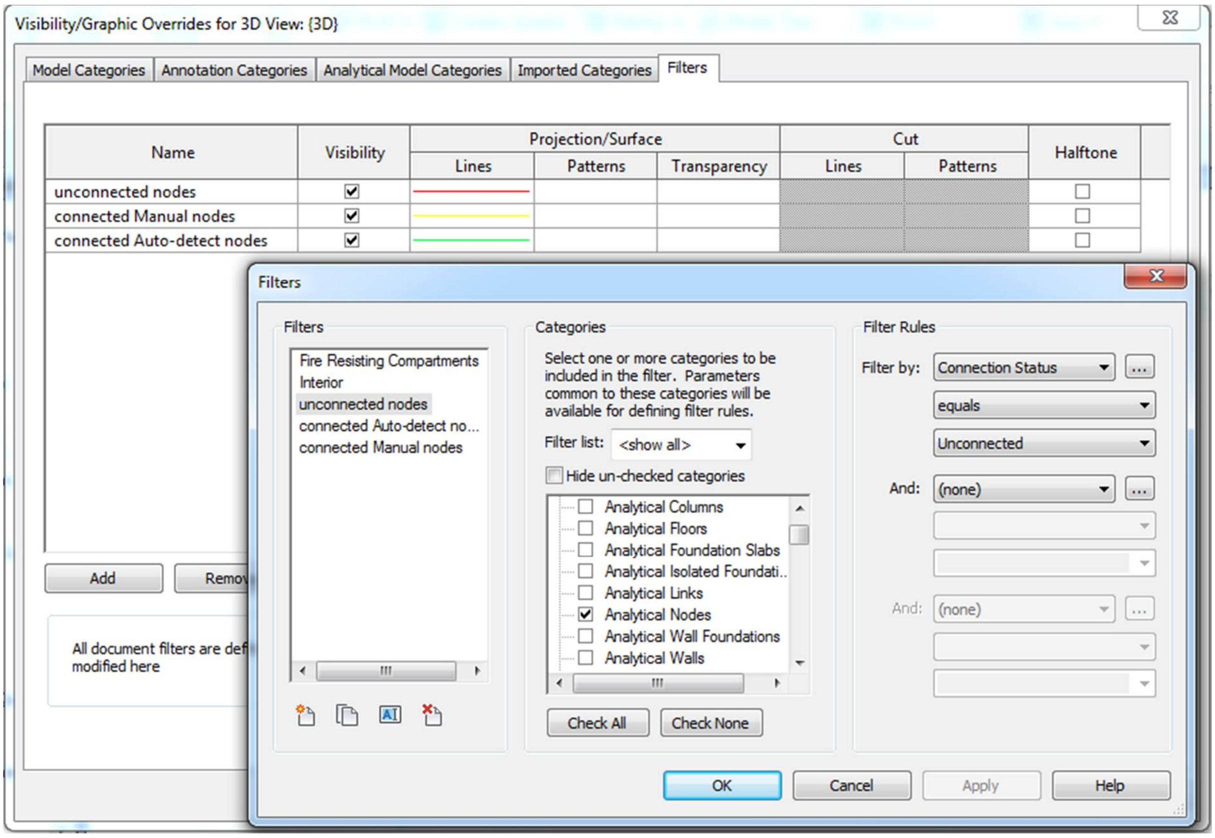


Figure 13 Filters used to checking connection status of nodes

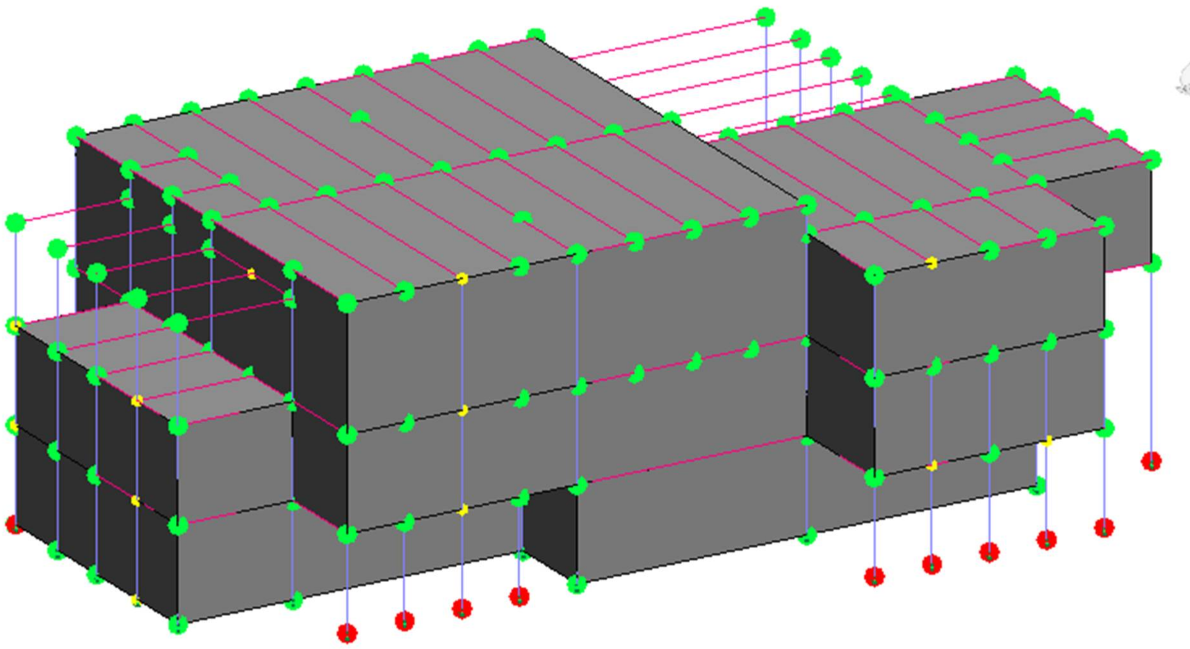


Figure 14 Analytical model after improvements

There are few things at which constructor should look more carefully. First, in analytical model settings there are parameters define that when two construction elements are at a distance equal to or less than specified value, the analytical model of element which was created as a second disappears (Figure 15). This will happen when 'Analytical auto detect' for analytical models is active. It is very dangerous and causes errors like unconnected beam with wall and floor or wall with floor.

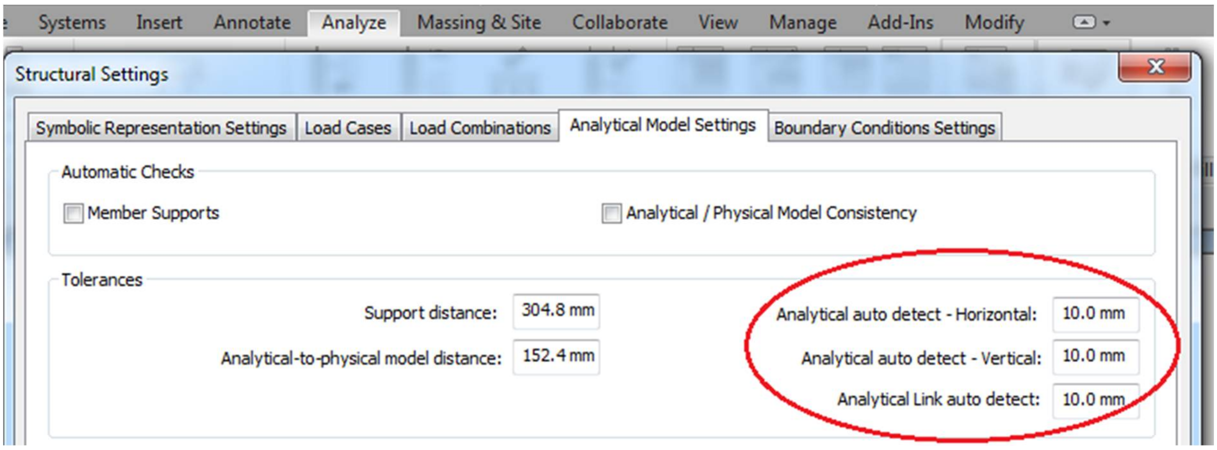


Figure 15 Analytical model settings

It is good if this value is less than half of the thickness of the thinnest wall in Revit. In this document it wasn't enough, so the less value was established. After that it turned out that floors on the edge are not connected with beams. The reason is that the architect drew the floors along the external points of walls and columns, and the analytical model of floors was created in the same lines. Before changing value of auto detection it was invisible. If architect or engineer does not know how the analytical model is created, the correction of defects will cost a lot of time.

3.2 Transfer of model from Revit to Robot

The link between Revit and Robot allows to make the exchange of information about analytical structure. It enables firms to insert analysis-related data to the Revit model, next use that model (and data) directly for analysis in Robot, and after that update the Revit model using the analysis results. The structural designer creates the physical and analytical model in Revit software and next sends the analytical model using one of possible way to a structural engineer, and uses Robot for structural analysis. (Autodesk, 2012)

There are two ways of model transfer between Revit and Robot. One of them is direct integration which allows and second, sending to the intermediate file (.smxx). First way does not work in Revit 2015, when user try to send model using direct integration he gets 'run time error'. Thus, analytical model was sent to the intermediate file (.smxx), and next was opened in Robot. The steps of integration were shown in Figure 16.

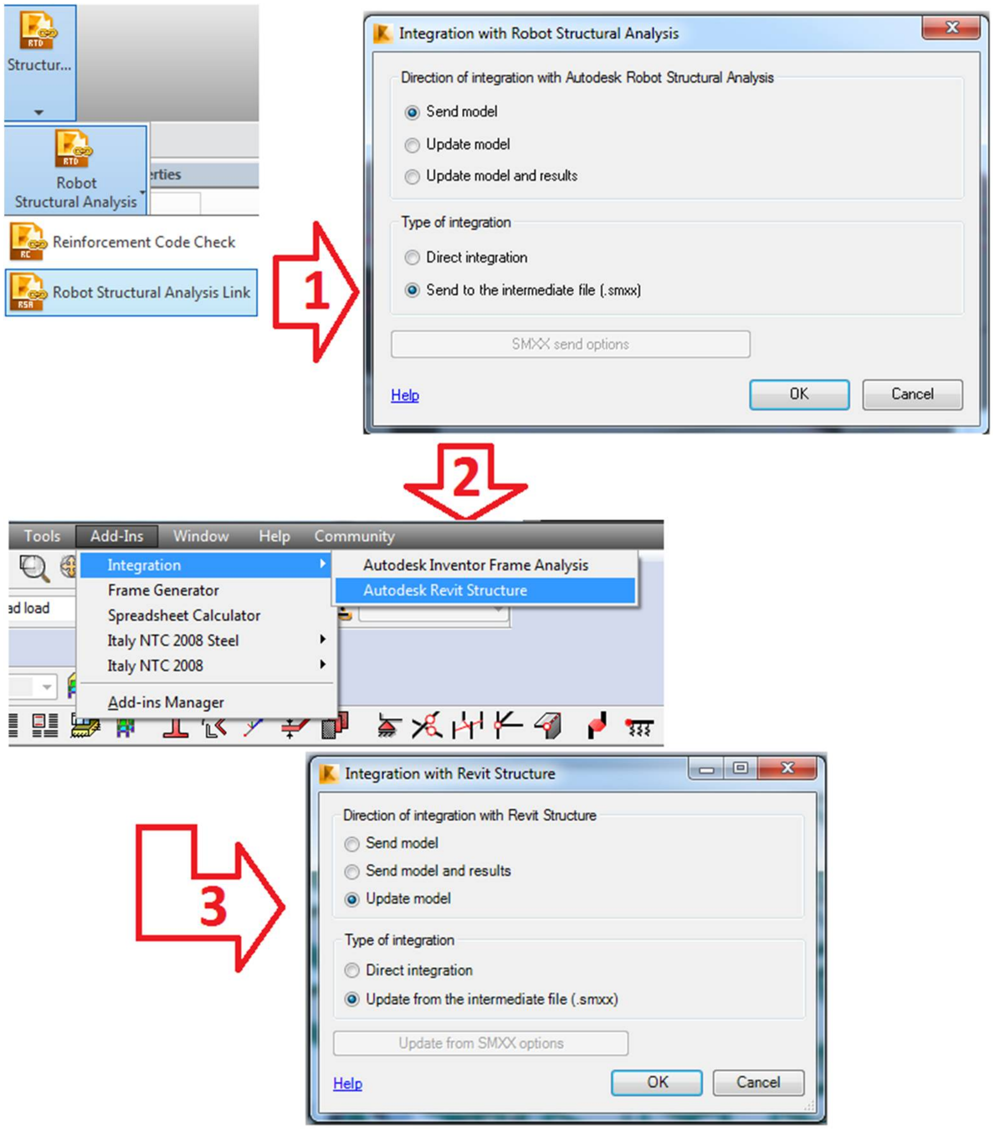


Figure 16 Software integration

3.3 Work with analytical model in Robot Structural Analysis Professional

After opening Robot software and file with analytical model, first step is to set the task preference. Calculation will be performed according the Eurocodes.

Next step is not obligatory but necessary if the entire work in Robot is to be easier. The creation of groups elements is helpful to faster work, to finding elements with the same parameters, elements that work in the same way, or in the same floor. The groups of elements found in this project are:

- Primary beams on 1st and 2nd floor
- Primary beams on 3rd floor
- Secondary beams on 1st and 2nd floor
- Secondary beams on 3rd floor
- Interior columns on 1st floor
- Interior columns on 2nd floor
- Interior columns on 3rd floor
- Columns in Exterior walls and Exterior columns on 1st floor

- Columns in Exterior walls and Exterior columns on 2nd floor
- Columns in Exterior walls and Exterior columns on 3rd floor

This groups were created to differentiate the cross sections of elements. The column on 3rd floor will be working under less loads than the column on the 2nd and 1st floor. The same concerns beams, secondary beams are less laden than primary beams.

How it was mentioned before, the connections between elements are created as Pinned-Pinned in Revit software. In building were spacing of columns is 10 m it is not a good solution because of high values of bending moment and beam deflection. Thus, all connections were changed to Fixed-Fixed. What more, to prevent re changing the type of connections, the new name of Fixed-Fixed connection was created. In other way after updating model in Revit, connections would return to its original state.

When the groups are created, the types of elements need to be defined and assigned to corresponding elements. The Beams and the columns are drawn from node to node, there are one type of element for beams and one for columns. Definitions of those elements was shown in Figure 17.

The definition of walls and ceilings are the next task in this part of work. Actually it is not possible to calculate composite ceiling in Robot software, so instead of concrete ceilings, the panels were set. This will make faster calculation and reduces possibility of error related with mesh. The dead and imposed loads on floors will be distributed on the beams through the panels. The composite ceiling will be calculated in another software. The walls were changed for claddings that allow wind load distribution. The changed and improved analytical model of the building in Robot software was shown in Figure 18.

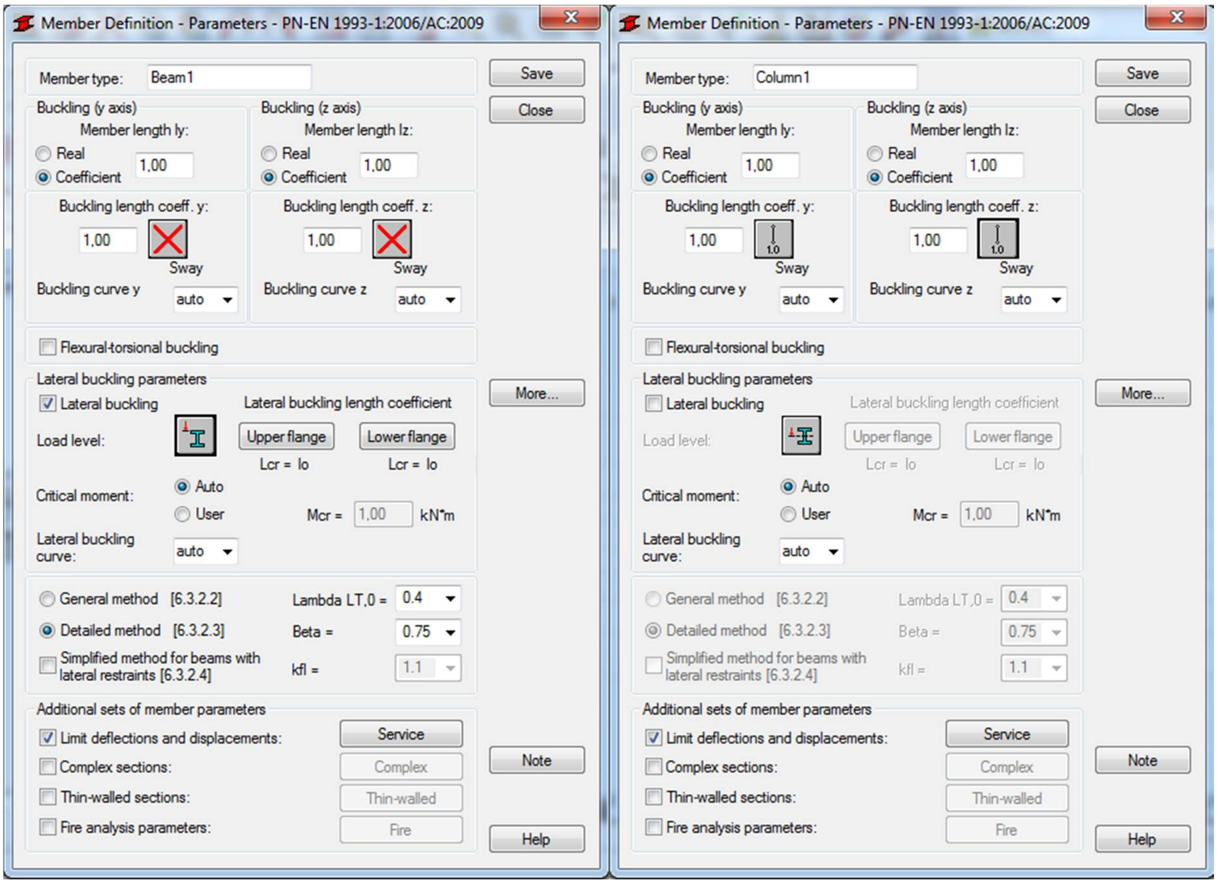


Figure 17 Definitions of elements

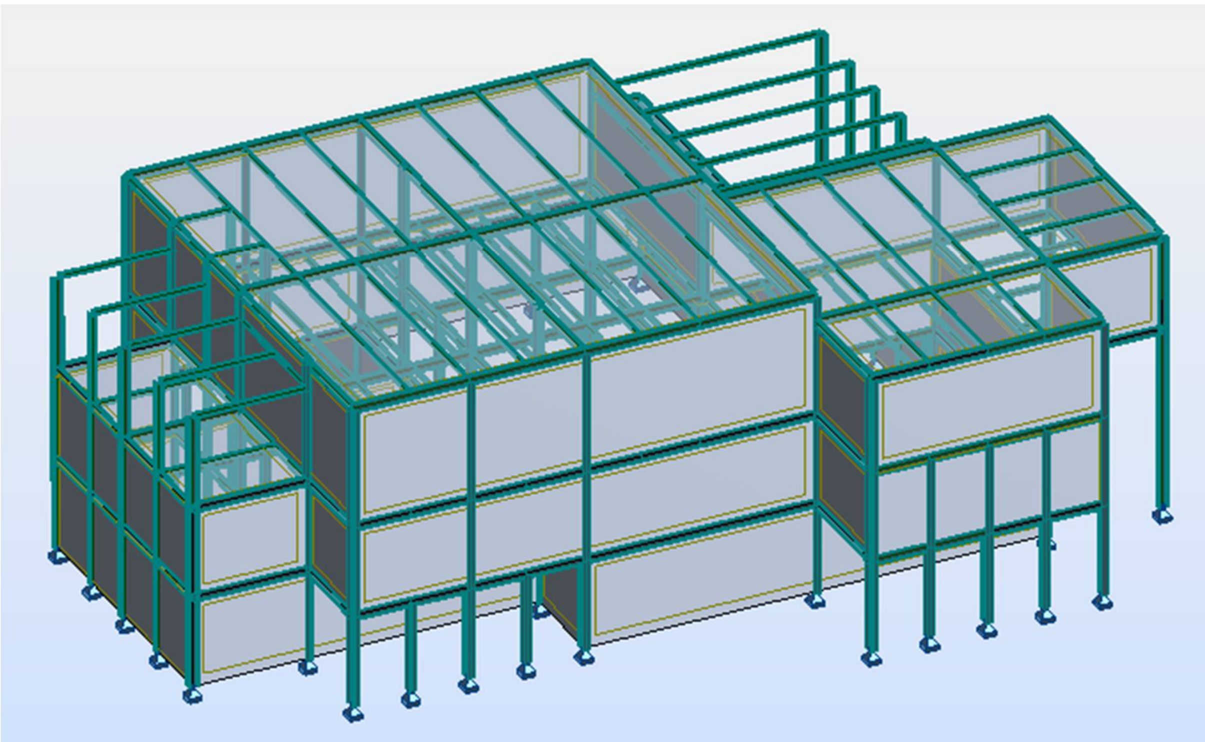


Figure 18 The building model in Robot software

3.4 Definition of the loads acting on the building

Calculation of load was performed according to Eurocode, respectively:
EN 1991-1-1:2004 – imposed load on floors, self-weight
EN 1991-1-3:2003 – wind load
EN 1991-1-4:2005 – snow load

3.4.1 Self-weight

The self-weight of columns and beams will be automatically calculated by software.

Walls

- Exterior walls

Exterior wall were designed as light steel infill walls shown in Figure 13 that self-weight is 3 kN/m.

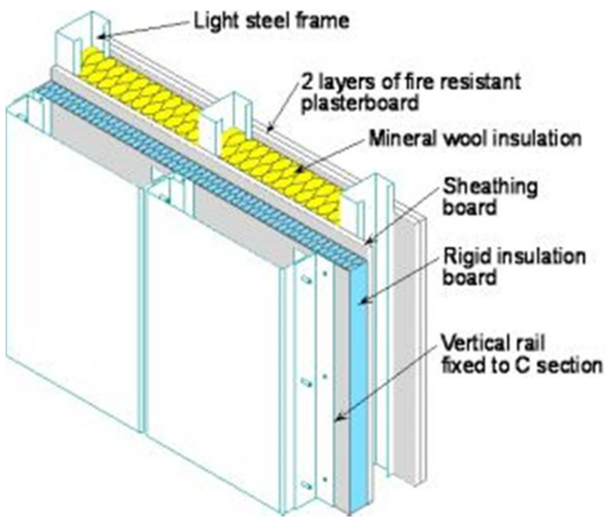


Figure 19 Light steel infill walls with metal rain-screen (www.steelconstruction.info)

- Partition walls

Community center is one of that kind of building that requires very high coefficient of sound isolation, high fire resistance class and, because of its height and the requirements related to the function, provide high mechanical resistance. The selected wall construction is shown in Figure 14a.

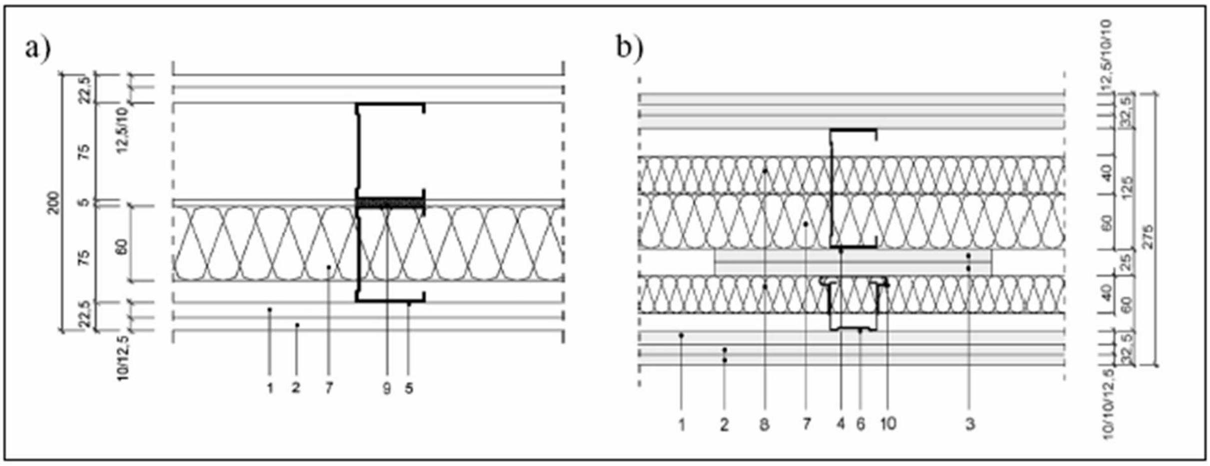


Figure 20 Construction of partition walls (http://warunkibudowlane.pl/)

1 – Gypsum fiber boards 12.5 mm, 2 – Gypsum fiber boards 10 mm, 3 – strips of gypsum fiber board 12.5 mm, 4 – Profile CW 125 × 0.6 mm, 5 – Profile CW 75 × 0.6 mm, 6 – CW profile 50 × 0.6 mm, 7 – 60 mm of mineral wool, 40 kg / m3, 8 – 40 mm of mineral wool, 40 kg / m3, 9 – Insulating tape, laminated on both sides, 10 – spring connector. (Ujma A., Ambicki W. 2013)

Self-weight of partition walls is 2,64 kN/m.

Ceilings

Load of concrete and metal deck and other layers of ceiling will be added as uniformly distributed load.

Because of various ceiling finishes in building (ceramic, industrial floor, hardwood, carpet) in every area of building the maximum load of top layer were applied.

Table 2 - Layers of floor

Layer	Thickness [m]	volumetric weight [kN/m^3]	characteristic value [kN/m^2]
Hardwood	0,02	7	0,14
Cement	0,02	24	0,48
Damp proof membrane	-	-	0,02
Insulation	0,05	0,3	0,02
Concrete slab	0,15	25	3,75
Metal deck	0,009	-	0,91

Self-weight is 5,32 kN/m^2

Stairs

Stairs were designed by architect as reinforced concrete construction, but next the conception was changed to steel construction with wooden steps. The self-weight is 2,2 kN/m and will be added as line load on the edge of ceiling. Stairs will not be calculated in this document.

Elevator shaft

An elevator with the elevator shaft is the system Easy Move and, was chosen from Vimec company products. The elevator shaft is self-supporting structure so the self-weight and living loads will not be taken into consideration. Catalog is available in Annex 1.

Imposed load on floors

According to Eurocode 1 the imposed loads q_k were assigned to proper spaces. The building was divided into three parts due to destiny: workshop, office part and exhibition space. Instead of partition walls according to Eurocode 1 the self-weight was added to the imposed loads of floors as a uniformly distributed load q_{k1} and, because self-weight is > 2 kN/m and ≤ 3 kN/m q_{k1} = 1,2 kN/m^2. In the table 2 are shown chosen values of the loads.

Table 3- Imposed load on floors

Specific Use	Category	q_k [kN/m^2]	q_{k1} [kN/m^2]	q_k+q_{k1} [kN/m^2]
Workshops	C4	5,0	1,2	6,2
Office areas	B	3,0	1,2	4,2
Exhibition areas	C3	5,0	1,2	6,2
Stores and archives	E1	7,5	1,2	8,7
corridors	C5	5,0	1,2	6,2
stairs	A	2,0	0,0	2,0
balconies	A	2,5	0,0	2,5

3.4.2 Snow load

To simplified snow load was added as a uniformly distributed load of 1 kN/m2 on exterior horizontal surface as it is shown in Figure 15.

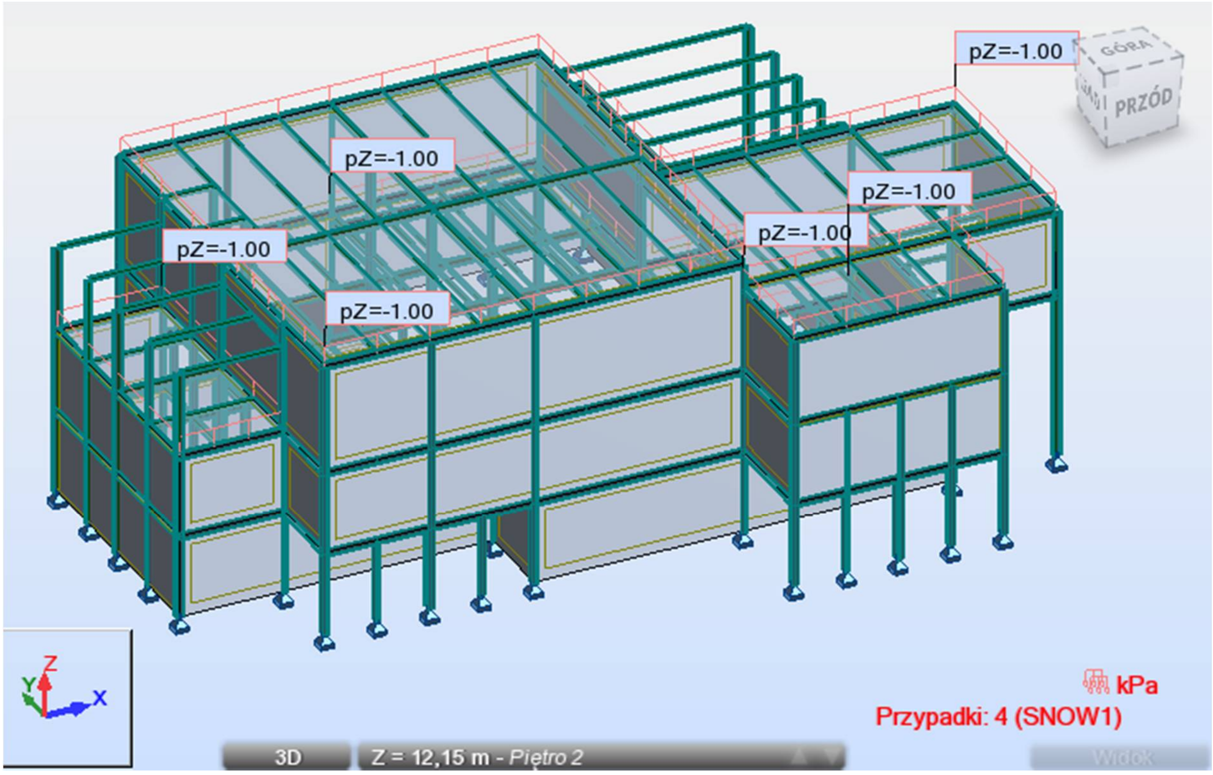


Figure 21 Snow load

3.4.3 Wind load

Wind load simulation was performed in Robot Structural Analysis Professional. Irregular shape of building makes difficult manual calculations of wind load. Four wind directions were chosen to simulation (Figure 22). According EN 1991-1-3, due to location of building the speed of wind is 22 m/s. Results of simulation was presented in Figure 23. Each one of load case corresponds to one direction of the wind and was included separately in loads combinations.

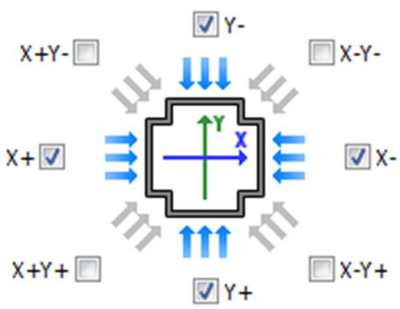


Figure 22 Directions of wind

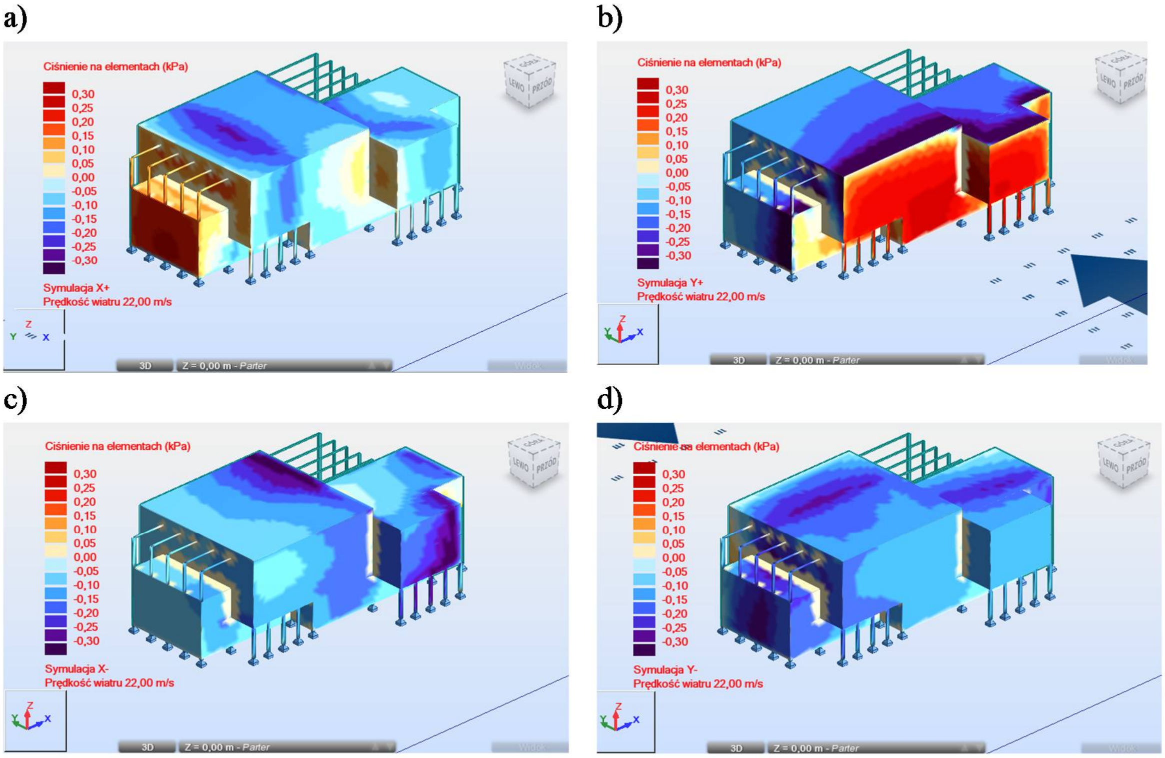


Figure 23 Wind load simulation in Robot Structural Analysis Professional 2015

All loads acting on construction were defined as it shown in Figure 24, while the loads combinations was shown in Figure 25.

1	Self-Weight
2	Dead load
3	Imposed load
4	Snow load
5	Wind load simulation X+ 22 m/s
6	Wind load simulation Y+ 22 m/s
7	Wind load simulation X- 22 m/s
8	Wind load simulation Y- 22 m/s

Figure 24Types of loads

3.4.4 Ultimate limit states

Combinations of actions for persistent and transient design situations were set up according to EN 1990 and the following equations:

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"} + \text{"} \gamma_p P \text{"} + \text{"} \gamma_{Q,1} \psi_{0,1} Q_{k,1} \text{"} + \text{"} \sum_{i>1} \gamma_{Q,i} \psi_{o,i} Q_{k,i} \tag{1}$$

$$\sum_{j\geq 1} \xi_j \gamma_{G,j} G_{k,j} \text{"} + \text{"} \gamma_p P \text{"} + \text{"} \gamma_{Q,1} Q_{k,1} \text{"} + \text{"} \sum_{i>1} \gamma_{Q,i} \psi_{o,i} Q_{k,i} \tag{2}$$

Where

" + "	Implies ”to be combined with”
$\sum$	Implies ”the combined effect of”
ξ	Is a reduction factor for unfavourable permamant actions G

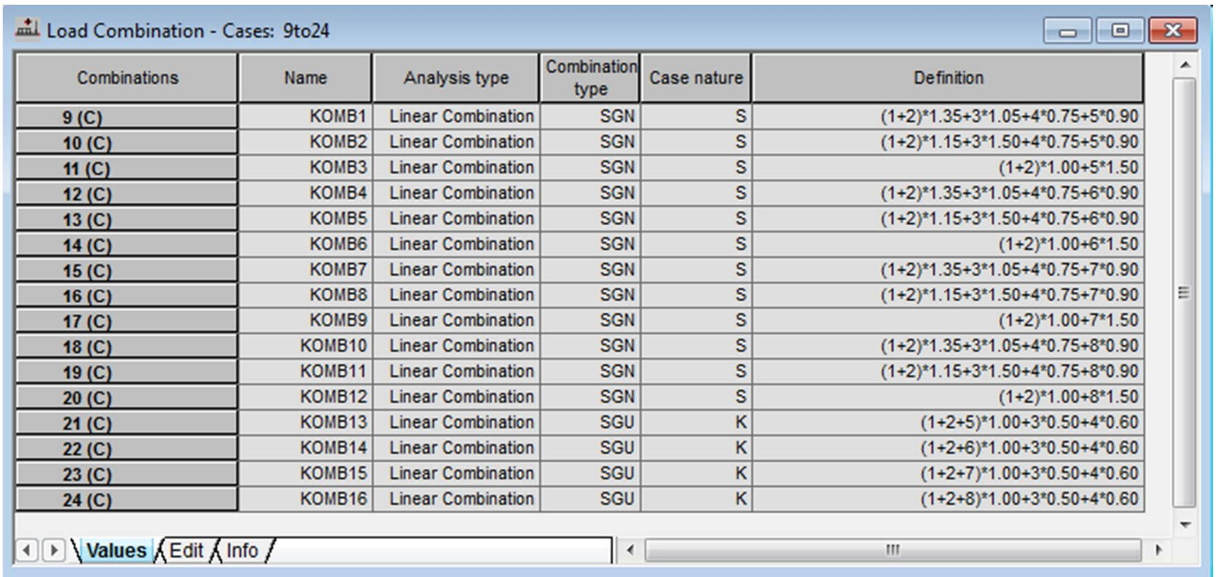
For this expressions values of ξ and γ are recommended:
$\xi = 0,85$
$\gamma_{G,j} = 1,35$
$\gamma_{Q,i} = 1,50$
The values of ψ factors for buildings:
Imposed loads in building $\psi_0 = 0,7$
Snow loads on building ($H \leq 1000$ m a.s.l.) $\psi_0 = 0,5$
Wind load on building $\psi_0 = 0,6$

3.4.5 Serviceability limit states

The following equations was used to for combination creation:

$$\sum_{j\geq 1} G_{k,j}\text{" + "P" + "}Q_{k,1}\text{" + "}\sum_{i>1} \psi_{o,i} Q_{k,i} \tag{3}$$

The created combinations were shown in Figure 25.


Load Combination - Cases: 9to24

Combinations	Name	Analysis type	Combination type	Case nature	Definition
9 (C)	KOMB1	Linear Combination	SGN	S	(1+2)*1.35+3*1.05+4*0.75+5*0.90
10 (C)	KOMB2	Linear Combination	SGN	S	(1+2)*1.15+3*1.50+4*0.75+5*0.90
11 (C)	KOMB3	Linear Combination	SGN	S	(1+2)*1.00+5*1.50
12 (C)	KOMB4	Linear Combination	SGN	S	(1+2)*1.35+3*1.05+4*0.75+6*0.90
13 (C)	KOMB5	Linear Combination	SGN	S	(1+2)*1.15+3*1.50+4*0.75+6*0.90
14 (C)	KOMB6	Linear Combination	SGN	S	(1+2)*1.00+6*1.50
15 (C)	KOMB7	Linear Combination	SGN	S	(1+2)*1.35+3*1.05+4*0.75+7*0.90
16 (C)	KOMB8	Linear Combination	SGN	S	(1+2)*1.15+3*1.50+4*0.75+7*0.90
17 (C)	KOMB9	Linear Combination	SGN	S	(1+2)*1.00+7*1.50
18 (C)	KOMB10	Linear Combination	SGN	S	(1+2)*1.35+3*1.05+4*0.75+8*0.90
19 (C)	KOMB11	Linear Combination	SGN	S	(1+2)*1.15+3*1.50+4*0.75+8*0.90
20 (C)	KOMB12	Linear Combination	SGN	S	(1+2)*1.00+8*1.50
21 (C)	KOMB13	Linear Combination	SGU	K	(1+2+5)*1.00+3*0.50+4*0.60
22 (C)	KOMB14	Linear Combination	SGU	K	(1+2+6)*1.00+3*0.50+4*0.60
23 (C)	KOMB15	Linear Combination	SGU	K	(1+2+7)*1.00+3*0.50+4*0.60
24 (C)	KOMB16	Linear Combination	SGU	K	(1+2+8)*1.00+3*0.50+4*0.60

Figure 25 Load combinations

3.5 Calculation and dimensioning of elements

As first, the linear analysis was performed. Forces acting on construction were calculated and the cross sections of elements was defined. After the actualization of the analytical model the type of global analysis will be checked and the analysis will be configured if necessary.
After first calculations it turned out that the biggest IPE cross sections are not enough for primary and secondary beams. One of possible solution to the problem is to design composite

beams and slab. Another options are the fabricated beams with web openings and cellular composite beams. In this case the first option was chosen and the next actions were taken:

- Every second beam that supports ceiling was removed, now distance between beams is 5 m.
- After the transfer of the analytical model to Robot software, elements were divide on each node. After removing many beams the model of building was incorrect as shown in Figure 26, there was a lot of unnecessary nodes. After adjustments (Figure 27) the analytical model became more clear and separated nodes were removed.

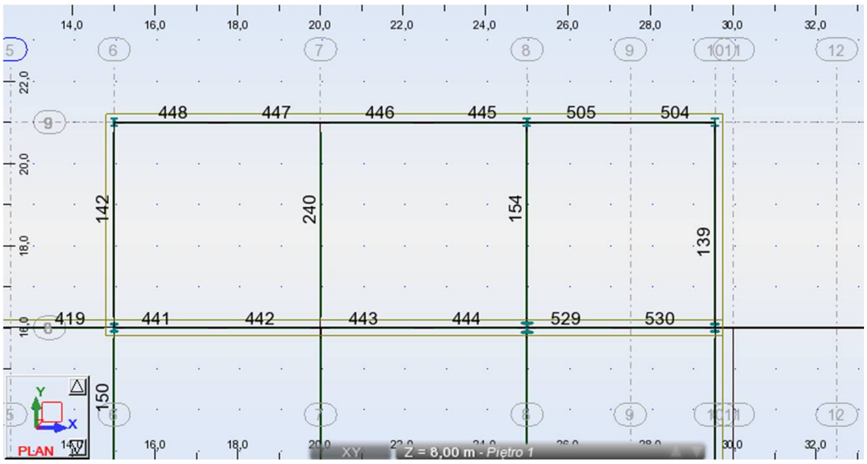


Figure 26 The analytical model before adjustments

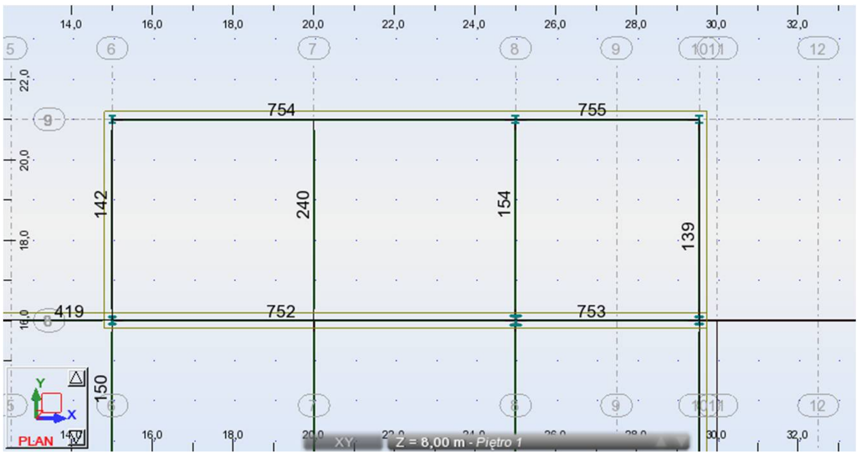


Figure 27 The analytical model after adjustments

- Instead of slabs the claddings were applied, one direction load distribution.
- Every primary beam were ignored in load distribution from claddings, the distribution was shown in Figure 28.

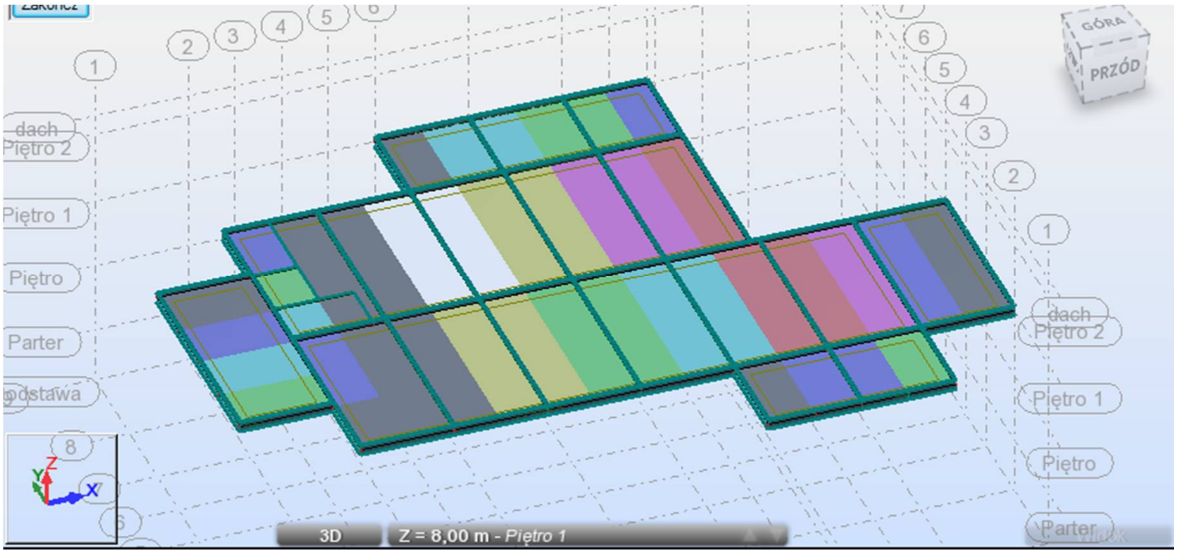


Figure 28 Load distribution from claddings

Stories of building were shown in Figure 29. Beams in Y axis support slabs and are integrated with it. Those beams together with slab will be manually calculated.

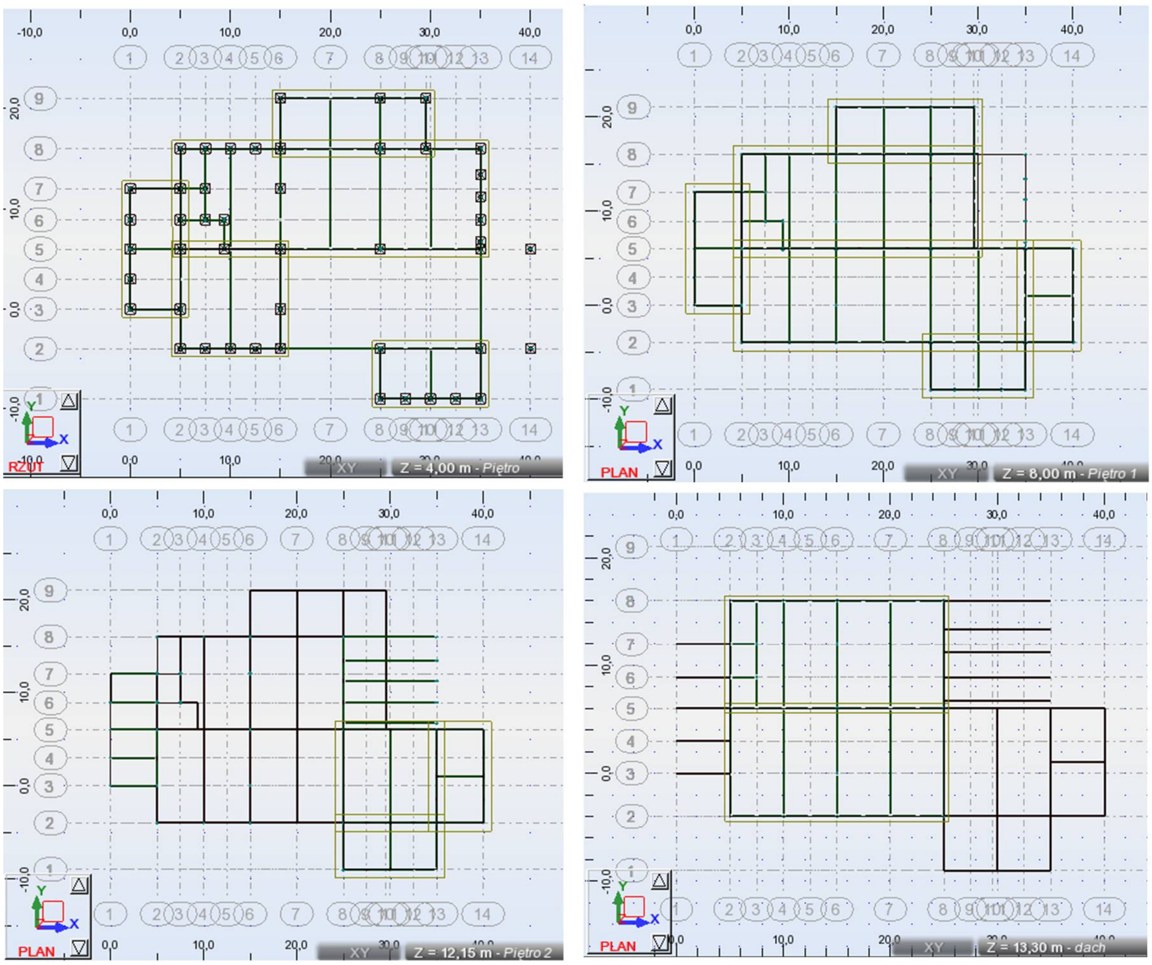


Figure 29 Building stories

3.6 Structural Analysis

There are four types of global analysis :

Analysis Type	Initial Geometry	Deformed Geometry	Linear material behavior	Non-linear material behavior
First-order elastic	✓		✓	
Second-order elastic		✓	✓	
First-order plastic	✓			✓
Second-order plastic		✓		✓

Figure 30 Analysis types

According EN1993-1-1, first-order analysis may be applied for portal frames with shallow roof slopes less than 26° and beam-and-column type plane frames in buildings if the criterion (4) is satisfied for each storey and provided that the axial compression in the rafters or beams is not significant, α_{cr} should be calculated as it shown below.

$$\alpha_{cr} = \left(\frac{H_{Ed}}{V_{Ed}}\right)\left(\frac{h}{\delta_{H,Ed}}\right) \quad (4)$$

Where:

α_{cr}	Is the factor the design loading would have to be multiplied to cause elastic instability in a global mode
H_{Ed}	Is the horizontal reaction at the bottom of the storey
V_{Ed}	Is the total vertical load at the bottom of the storey
h	Is the storey high
$\delta_{H,Ed}$	Is the horizontal deflaction at the top of the storey under consideration relative to the bottom of the storey, with all horizontal loads applied to the structure

The following criteria have to be satisfied to use a first-order analysis:

Table 4 - Action that need to be taken depending on the value of α_{cr}

Limits on α_{cr}	Action
$\alpha_{cr} \geq 10$	First order Analysis

$10 > \alpha_{cr} > 3$	First order analysis plus amplification or effective length method
$\alpha_{cr} \leq 3$	Second order analysis

In this case the frame with the biggest deflections were chosen to calculation (Figure 31).

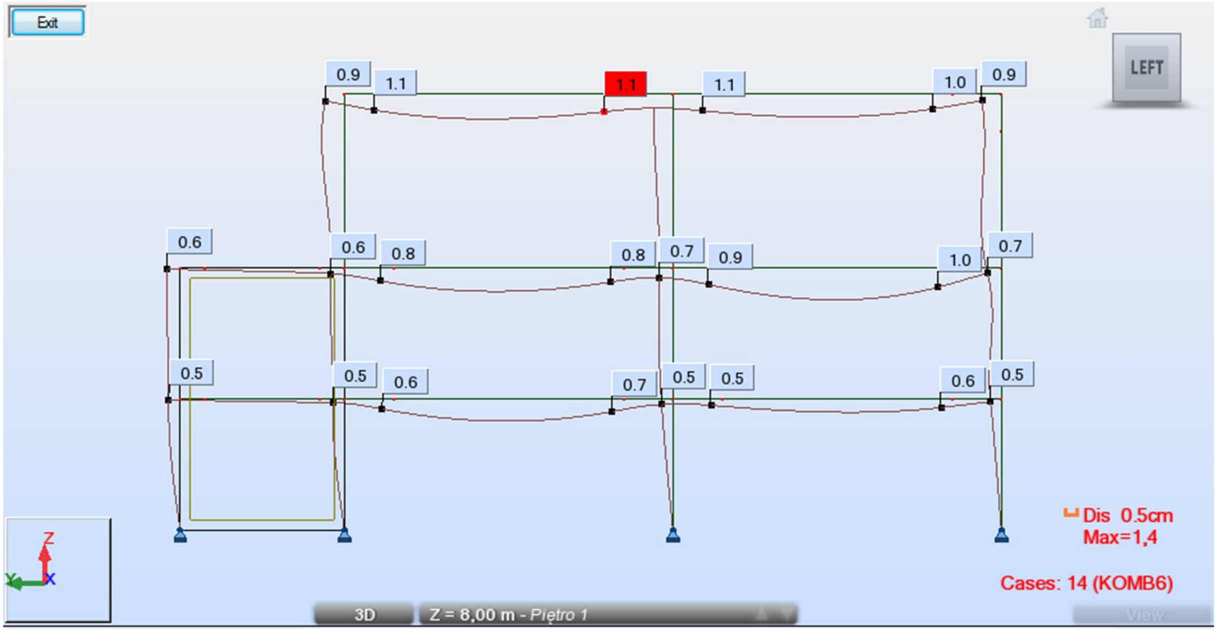


Figure 31 Global deformations

The internal forces in this frame was shown in Figure 32 and 33.

Figure 32 Fx Force

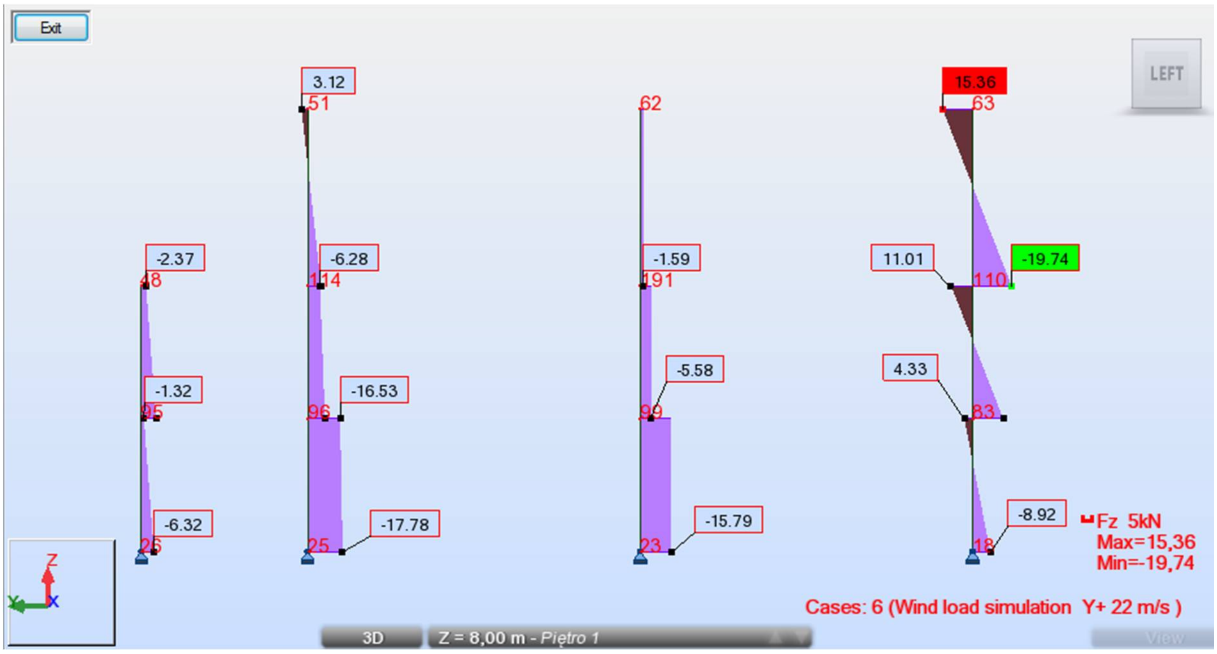


Figure 33 Fz Force

Global imperfections

PN-EN 1993-1-1/5.3.2

$$V_{Ed} = \sum N = 194{,}27 + 2051{,}49 + 2953{,}29 + 824{,}54 = 6023{,}59\ kN$$

$$H_{Ed} = 6{,}32 + 17{,}78 + 15{,}79 + 8{,}92 = 48{,}81\ kN$$

$$H_{Ed} = 48{,}81\ kN < 0{,}15 \cdot V_{Ed} = 0{,}15 \cdot 6023{,}59 = 903{,}5\ kN$$

Sway imperfections have to be regarded.

$$\emptyset = \emptyset_0 \cdot \alpha_h \cdot \alpha_m$$

$$\emptyset_0 = \frac{1}{200}, \alpha_h = \frac{2}{\sqrt{h}} = \frac{2}{\sqrt{13{,}3}} = 0{,}55\ \ but\ \frac{2}{3} \leq \alpha_h \leq 1{,}0 \rightarrow \ \ \alpha_h = \frac{2}{3}$$

$$N_{śr} = \frac{\sum N}{4} = \frac{6023{,}59}{4} = 1505{,}9\ kN$$

$$N_{Ed} = 164{,}27 < 0{,}5\ N_{śr} = 0{,}5 \cdot 1505{,}9 = 752{,}9\ kN \rightarrow m = 3$$

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = \sqrt{0{,}5\left(1 + \frac{1}{3}\right)} = 0{,}816$$

$$\emptyset = \emptyset_0 \cdot \alpha_h \cdot \alpha_m = \frac{1}{200} \cdot \frac{2}{3} \cdot 0{,}816 = 2{,}71 \cdot 10^{-3}$$

$$H_{d,1} = \emptyset \cdot V_{Ed,1} = 2{,}71 \cdot 10^{-3} \cdot (248{,}71 + 822{,}10 + 288{,}18) = 3{,}7\ kN$$

$$H_{d,2} = \emptyset \cdot V_{Ed,2} = 2{,}71 \cdot 10^{-3} \cdot (794{,}72 + 1350{,}19 + 4{,}97) = 5{,}8\ kN$$

$$H_{d,3} = \emptyset \cdot V_{Ed,2} = 2{,}71 \cdot 10^{-3} \cdot (1000{,}34 + 773{,}28 + 527{,}21) = 6{,}2\ kN$$

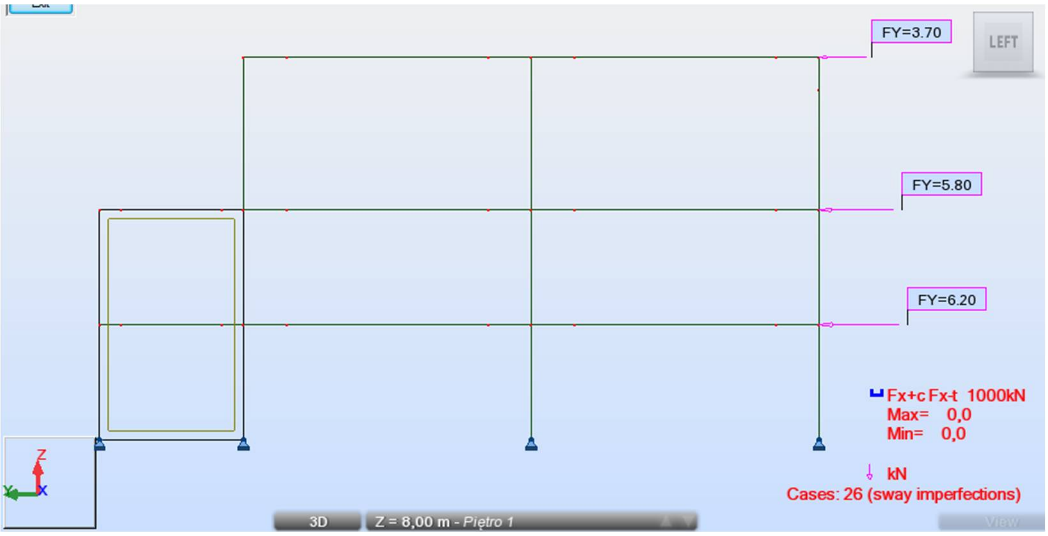


Figure 34 Sway imperfections forces

Local imperfections

PN-EN 1993-1-1/5.3.2

Local bow imperfections cannot be neglected when conditions are met:

- at least one moment resistant joint at one member end - the condition has been met
- $\bar{\lambda} > 0{,}5 \cdot \sqrt{\frac{A \cdot f_y}{N_{Ed}}}$ $lub\ N_{Ed} > 0{,}25 \cdot N_{cr}$

Column: HEB 450

$$N_{cr} = \frac{\pi^2 \cdot E \cdot I_y}{l_y^2} = \frac{\pi^2 \cdot 210 \cdot 10^3 \cdot 57680 \cdot 10^4}{4450^2} = 22993 \cdot 10^3\ N = 22993\ kN$$

$$N_{max} = 2953{,}29 < 0{,}25 \cdot 22993 = 5748\ kN$$

Local bow imperfections may not be neglected.

Global analysis

PN-EN 1993-1-1/5.2.1

First order analysis may be used, when

- $\alpha_{cr} \geq 10$

Data from Figure

$\delta_{H,Ed,1} = 2{,}0\ mm$

$\delta_{H,Ed,2} = 2{,}0\ mm$

$\delta_{H,Ed,3} = 5{,}0\ mm$

1st level

$H_{Ed,1} = H_{Ed} + H_{d,1} = 3{,}12 + 15{,}36 + 3{,}7 = 22{,}18\ kN$

$V_{Ed,1} = 248{,}71 + 822{,}10 + 288{,}18 = 1358{,}99\ kN$

$$\alpha_{cr,1} = \left(\frac{H_{Ed,1}}{V_{Ed,1}}\right) \cdot \left(\frac{h}{\delta_{H,Ed,1}}\right) = \frac{22{,}18}{1358{,}99} \cdot \frac{5300}{2{,}0} = 43{,}3 \geq 10 \rightarrow OK$$

2nd level

$H_{Ed,1} = H_{Ed} + H_{d,1} = 2{,}37 + 6{,}28 + 1{,}59 + 8{,}73 + 5{,}8 = 24{,}77\ kN$

$V_{Ed,1} = 794{,}72 + 1350{,}19 + 4{,}97 = 2149{,}88\ kN$

$$\alpha_{cr,1} = \left(\frac{H_{Ed,1}}{V_{Ed,1}}\right) \cdot \left(\frac{h}{\delta_{H,Ed,1}}\right) = \frac{24{,}77}{2149{,}88} \cdot \frac{4000}{2{,}0} = 23{,}0 \geq 10 \rightarrow OK$$

3rd level

$H_{Ed,1} = H_{Ed} + H_{d,1} = 1{,}32 + 16{,}53 + 5{,}58 + 11{,}15 + 6{,}2 = 40{,}78\ kN$

$V_{Ed,1} = 1000{,}34 + 773{,}28 + 527{,}21 = 2300{,}83\ kN$

$$\alpha_{cr,1} = \left(\frac{H_{Ed,1}}{V_{Ed,1}}\right) \cdot \left(\frac{h}{\delta_{H,Ed,1}}\right) = \frac{40{,}78}{2300{,}83} \cdot \frac{4000}{5{,}0} = 14{,}2 \geq 10 \rightarrow OK$$

3.7 Composite slabs and beams

In the buildings were the distances between supporting element walls or columns are long, composite ceilings and beams are recommended. Thanks to that the useful height of stories increases and the thickness of ceiling is reduced. The cross section of composite beams is lower than non-composite element. Unfortunately it is not possible to take into account the cooperation between beam and ceiling in Robot software. Properties composite element will be calculated outside Robot and then characteristics of element will be set up in software.

Composite slab

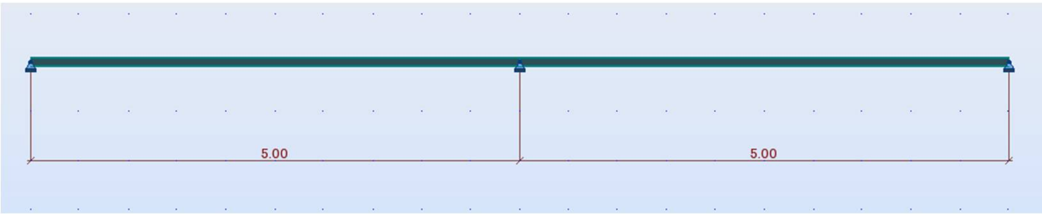


Figure 35 Static scheme of slab

Geometric parameters

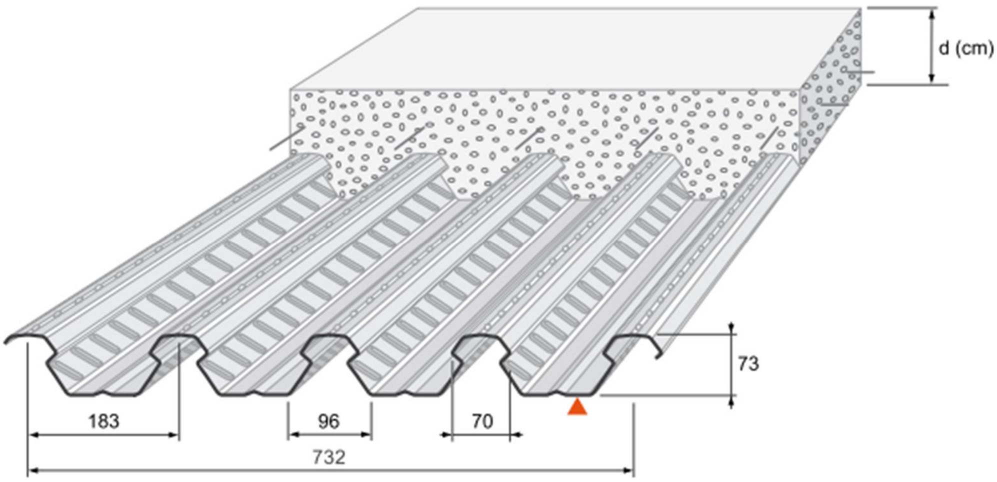


Figure 36 Cofrastra 70

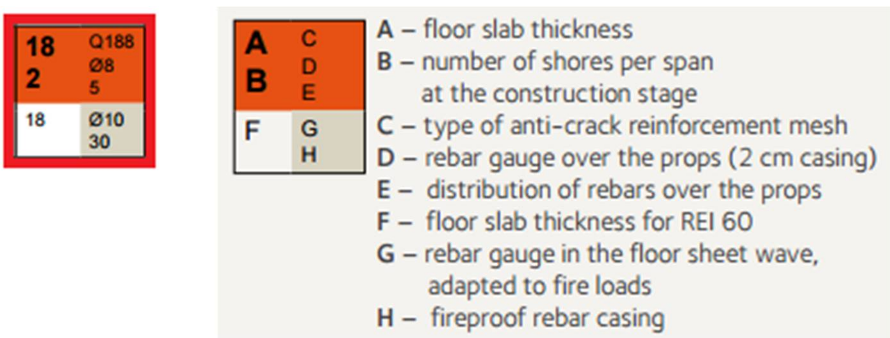


Figure 37 Parameters for double-span slab (arcelormittal.com)

Material characteristics

Steel decking: $f_y = 355\ N/mm^2$

Concrete: C25/30; $f_c = 25\ N/mm^2$

Construction conditions:

$$h_c = 167\ mm > 50\ mm \rightarrow OK$$
$$h = 240\ mm > 90\ mm \rightarrow Ok$$

The brochure of Cofrastra 70 is available in Annex 1.

Composite beams

Data

Composite beam on 2 supports

Continuous slab on 3 supports

Beam span 10 m

Distance between beams = 5 m

Geometrical characteristics and material properties

Beam: IPE 450

h = 450 mm

b = 190 mm

t_w = 9,4 mm

t_f = 14,6 mm

f_y = 350 N/mm^2

Steel decking: $f_y = 350\ N/mm^2$

Floor sheet geometrical data

Cofrastra 70 geometrical data

b_s [cm]	b_b [cm]	b_o [cm]	b_r [cm]	h_p [cm]
18,30	8,70	11,30	4,00	7,3

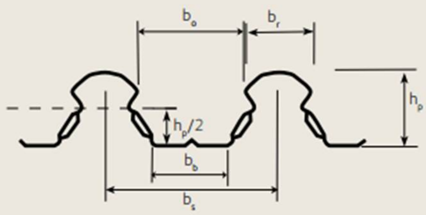


Figure 38 Geometrical parameters of metal deck

Concrete: C25/30

h_c = 180 mm

b_{eff} = 5000 mm

$f_c = 25\ N/mm^2$

Connectors:
d = 22 mm
h_{sc} = 100 mm
longitudinal spacing: e_{sc} = 183 mm
transverse spacing: s_t = 55 mm
f_u = 450 N/mm^2

The distance between the axis of the connector and the edge of the shelf

PN-EN 1994-1-1/5.4.1.2

$$\frac{190-55-22}{2} = 56{,}5\,mm > 20\,mm \rightarrow OK$$

Calculation of the stiffness of the composite beam

PN-EN 1994-1-1/5.4.1.2

$$b_0 = s_t = 55\,mm$$

$$L_e = 0{,}7 \cdot L = 0{,}7 \cdot 10000 = 7000\,mm$$

$$b_{ei} = \frac{L_e}{8} = \frac{7000}{8} = 875\,mm$$

$$b_{eff} = b_0 + \sum b_{ei} = 55 + 2 \cdot 875 = 1805\,mm < 5000\,mm$$

$$\mathrm{n} = \frac{E_a}{E_{c,eff}} = \frac{E_a}{\frac{E_{cm}}{2}} = \frac{2 \cdot 210000}{31000} = 13{,}55$$

$$b = \frac{b_{eff}}{n} = \frac{1805}{13{,}55} = 133{,}2\,mm$$

$$x_0 = \frac{A_a \cdot \frac{h_a}{2} + b \cdot h_c \cdot \left(h_a + h_p + \frac{h_c}{2}\right)}{A_a + h_c \cdot b}$$

$$= \frac{9880 \cdot \frac{450}{2} + 133{,}2 \cdot 180 \cdot \left(450 + 73 + \frac{180}{2}\right)}{9880 + 180 \cdot 133{,}2} = 497{,}6\,mm$$

The neutral axis is in the metal deck.

Moment of inertia of span cross section

$$I_1 = I_a + A_a\left(x_0 - \frac{h_a}{2}\right)^2 + \frac{b \cdot h_c^3}{12} + b \cdot h_c \cdot \left(h_a + h_p + \frac{h_c}{2} - x_0\right)^2$$

$$= 33740 \cdot 10^4 + 9880 \cdot \left(497{,}6 - \frac{450}{2}\right)^2 + \frac{133{,}2 \cdot 180^3}{12}$$

$$+ 133{,}2 \cdot 180 \cdot \left(450 + 73 + \frac{180}{2} - 497{,}6\right)^2$$

$$= 143329 \cdot 10^4\,mm^4$$

Stiffness

$$B_1 = E \cdot I_1 = 210 \cdot 10^3 \cdot 143329 \cdot 10^4 = 300991\ kNm^2$$

Calculation of the stiffness of the composite beam over the props

PN-EN 1994-1-1/5.4.1.2

$$b_0 = s_t = 55\ mm$$

$$L_e = 0{,}25 \cdot (L + L) = 0{,}25 \cdot 20000 = 5000\ mm$$

$$b_{ei} = \frac{L_e}{8} = \frac{5000}{8} = 625\ mm$$

$$b_{eff} = b_0 + \sum b_{ei} = 55 + 2 \cdot 625 = 1305\ mm < 5000\ mm$$

$$A_s = 2560\ mm^2$$

$$x_0 = \frac{A_a \cdot \frac{h_a}{2} + A_s \cdot (h_a + h_p + h_c - a_1)}{A_a + A_s} = \frac{9880 \cdot \frac{450}{2} + 2560 \cdot (450 + 73 + 180 - 20)}{9880 + 2560} = 318{,}6\ mm$$

The neutral axis is in the beam.

Moment of inertia over the props

$$I_1 = I_a + A_a\left(x_0 - \frac{h_a}{2}\right)^2 + A_s \cdot (h_a + h_p + h_c - a_1 - x_0)^2$$

$$= 33740 \cdot 10^4 + 9880 \cdot \left(318{,}6 - \frac{450}{2}\right)^2 + 2560 \cdot (450 + 73 + 180 - 20 - 318{,}6)^2 = 75832 \cdot 10^4\ mm^4$$

Stiffness

$$B_1 = E \cdot I_1 = 210 \cdot 10^3 \cdot 75832 \cdot 10^4 = 159247\ kNm^2$$

Ultimate limit states

PN-EN 1994-1-1/6.6.4.2

Conectors

$$b_0 = s_t = 55\ mm$$

$$L_e = 0{,}7 \cdot L = 0{,}7 \cdot 10000 = 7000\ mm$$

$$b_{ei} = \frac{L_e}{8} = \frac{7000}{8} = 875\ mm$$

$$b_{eff} = b_0 + \sum b_{ei} = 55 + 2 \cdot 875 = 1805\ mm < 5000\ mm$$

Number of bolts in one rib of metal deck: $n_r = 2$
Thickness of metal deck: t = 1,0 mm
$k_{t,max} = 0,6$

$$k_t = \frac{0,7}{\sqrt{n_r}} \cdot \frac{b_0}{h_p} \cdot \left(\frac{h_{sc}}{h_p} - 1\right) = \frac{0,7}{\sqrt{2}} \cdot \frac{113}{73} \cdot \left(\frac{150}{73} - 1\right) = 0,79 > 0,6 \rightarrow k_t = 0,6$$

Design load-bearing capacity of bolts

PN-EN 1994-1-1/6.6.3.1

$$\frac{h_{sc}}{d} = \frac{150}{22} = 6,81 \quad \rightarrow \alpha = 1,0$$

Concrete C25/30 $\rightarrow f_{ck} = 25MPa, \quad E_{cm} = 31GPa,$

$$P_{Rd,1} = \frac{0,8 \cdot f_u \cdot \pi \cdot \frac{d^2}{4}}{\gamma_v} = \frac{0,8 \cdot 450 \cdot \pi \cdot \frac{22^2}{4}}{1,25} = 109478N = 109,5kN$$

$$P_{Rd,2} = \frac{0,29 \cdot \alpha \cdot d^2 \cdot \sqrt{f_{ck} \cdot E_{cm}}}{\gamma_v} = \frac{0,29 \cdot 1,0 \cdot 22^2 \cdot \sqrt{25 \cdot 31000}}{1,25} = 98852N$$
$$= 98,9kN$$

$$P_{Rd} = k_t \cdot \min(P_{Rd,1}; P_{Rd,2}) = 0,6 \cdot (109,5; 98,9) = 0,48 \cdot 98,9 = 59kN$$

Degree of shear connection; coefficient

PN-EN 1994-1-1/6.2.1.2

$$\eta = \frac{N_c}{N_{c,f}}$$

Where:

Connection between beam and slab

$$A_c = b_{eff} \cdot h_c = 1805 \cdot 180 = 324900\ mm^2$$

$$f_{cd} = \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_c} = 1,0 \cdot \frac{25}{1,4} = 17,86\ N/mm^2$$

$$N_{c,f} = 0,85 \cdot f_{cd} \cdot A_C = 0,85 \cdot 17,86 \cdot 324900 = 4932 \cdot 10^3 N = 4932\ kN$$

Number of sheared bolts

$$n = 2 \cdot \frac{L_b}{e_{sc}} = 2 \cdot \frac{10000}{183} = 110$$

$$N_c = 0{,}5 \cdot n \cdot P_{Rd} = 0{,}5 \cdot 110 \cdot 59 = 3245\ kN$$

$$\eta = \frac{N_c}{N_{c,f}} = \frac{3245}{4930} = 0{,}67$$

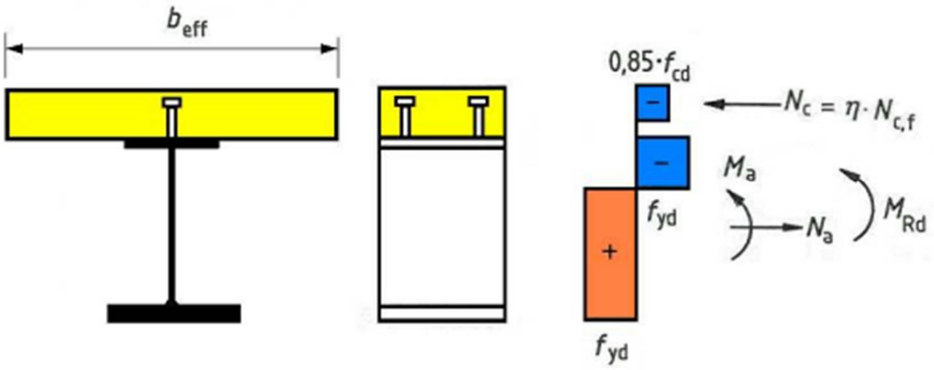


Figure 39 Plastic stress distribution under sagging bending for partial shear connection (Biegus A. 2012)

Plastic bearing capacity under sagging bending in span

$$N_a = A_a \cdot f_y \cdot \frac{1}{\gamma_{M0}} = 9880 \cdot 355 \cdot \frac{1}{1{,}0} = 3458 \cdot 10^3 N$$

$$N_a = 3458\ kN < N_{c,f} = 0{,}85 \cdot A_c \cdot f_{cd} = 4932\ kN$$

The neutral axis is in the slab.

$$x_{pl} = \frac{A_a \cdot f_y}{0{,}85 \cdot b_{eff} \cdot f_{cd}} = \frac{3458 \cdot 10^3}{0{,}85 \cdot 1805 \cdot 17{,}86} = 126{,}2\ mm$$

$$d_c = \frac{h_a}{2} + h_p + h_c = \frac{450}{2} + 73 + 180 = 478$$

$$M_{pl,Rd} = f_y \cdot A_a \cdot \left(d_a - \frac{x_{pl}}{2}\right) \cdot \frac{1}{\gamma_{M0}} = 355 \cdot 9880 \cdot \left(450 - \frac{126{,}2}{2}\right) \cdot \frac{1}{1{,}0} =$$

$$= 1276 \cdot 10^6 Nmm = 1276\ kNm$$

$$M_{pl,a,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_{M0}} = \frac{1702 \cdot 10^3 \cdot 355}{1{,}0} = 596\ \ kNm$$

$$M_{Rd} = M_{pl,a,Rd} + \left(M_{pl,Rd} - M_{pl,a,Rd}\right)\frac{N_c}{N_{c,f}} = 596 + (1276 - 596)\frac{3245}{4932}$$

$$= 1043\ kNm$$

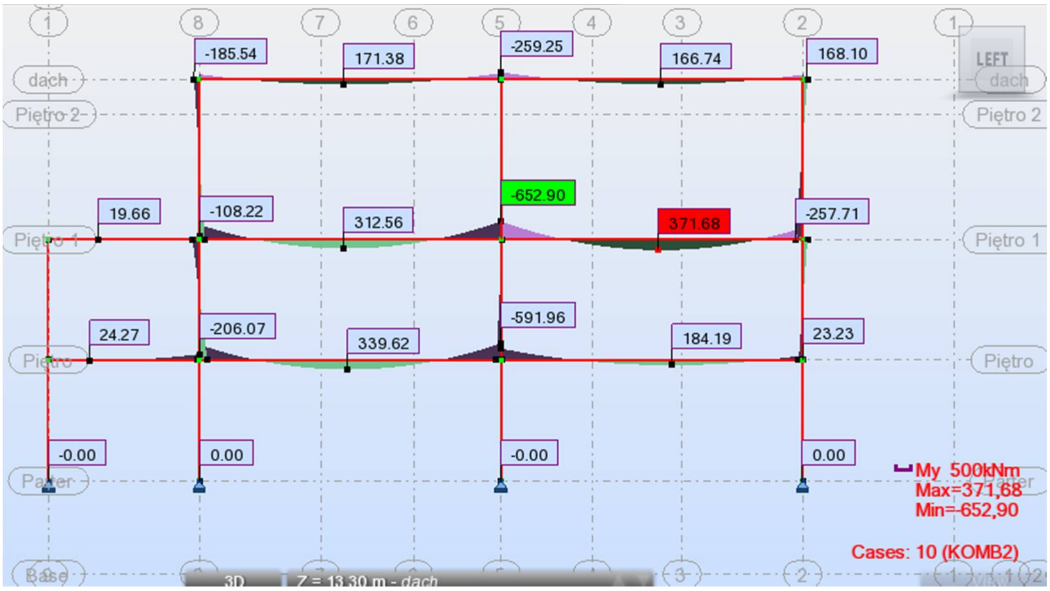


Figure 40 Diagram of bending moment

$$M_{Ed} = 371{,}68\ kNm$$

$$\frac{M_{Ed}}{M_{pl,Rd}} = \frac{371{,}68}{1043} = 0{,}36 < 1{,}0 \rightarrow OK$$

Longitudinal shear

PN-EN 1992-1-1/6.2.4

$$\Delta F_{Ed} = \frac{N_{c,f}}{2} = \frac{4932}{2} = 2466\ kN$$

$$h_c = h_f = 180\ mm$$

$$\Delta x \approx \frac{10000}{2} = 5000mm$$

$$v_{Ed} = \frac{\Delta F_{Ed}}{h_f \cdot \Delta x} = \frac{2466 \cdot 10^3}{180 \cdot 5000} = 2{,}74\ N/mm^2$$

$$v_{Ed} < \nu \cdot f_{cd} \cdot sin\theta_f \cdot cos\theta_f$$

$$\nu = 0{,}6 \cdot \left(1 - \frac{f_{ck}}{250}\right) = 0{,}6 \cdot \left(1 - \frac{25}{250}\right) = 0{,}54$$

$$\theta_f = 45^{\circ}$$

$$v_{Ed} = 2{,}74\frac{N}{mm^2} < 0{,}54 \cdot 17{,}86 \cdot 0{,}5 = 4{,}82\ \frac{N}{mm^2}$$

The compression struts will not be crushed.

Bearing capacity over the props

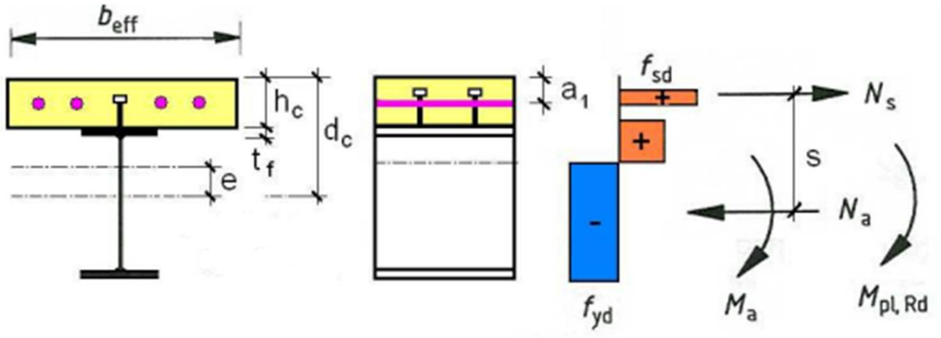


Figure 41 Plastic stress distribution under sagging bending for partial shear connection over the props (Biegus A. 2012)

$b_0 = s_t = 55\ mm$

$L_e = 0{,}25 \cdot (L + L) = 0{,}25 \cdot 20000 = 5000\ mm$

$b_{ei} = \frac{L_e}{8} = \frac{5000}{8} = 625\ mm$

$b_{eff} = b_0 + \sum b_{ei} = 55 + 2 \cdot 625 = 1305\ mm < 5000\ mm$

$A_s = 2560\ mm^2$

$$x_o = e = \frac{f_{sd} \cdot A_s}{2 \cdot f_{yd} \cdot t_w} = \frac{435 \cdot 2560}{2 \cdot 350 \cdot 9{,}4} = 169\ mm$$

$$d_c = \frac{450}{2} + 73 + 180 = 478\ mm$$

$$s = d_c - \frac{e}{2} - a_1 = 478 - \frac{169}{2} - 20 = 373\ mm$$

$$M_{pl,Rd} = M_{pl.a,Rd} + f_{sd} \cdot A_s \cdot s = 596 \cdot 10^6 + 435 \cdot 2560 \cdot 373 = 1011\ kNm$$

$$M_{Ed} = 652{,}8\ kNm$$

$\frac{M_{Ed}}{M_{pl,Rd}} = \frac{652{,}8}{1011} = 0{,}65 < 1{,}0 \rightarrow OK$

Transverse shear

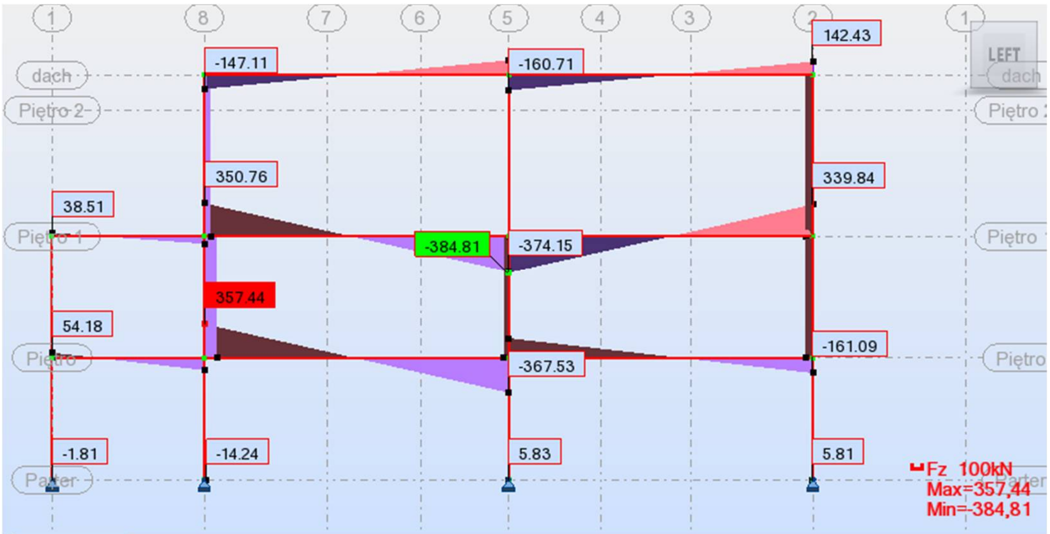


Figure 42 Diagram of Fz forces

$$\frac{h_w}{t_w} = \frac{450 - 2 \cdot 14,6}{9,4} = 44,8 < \frac{72\varepsilon}{\eta} = 72\frac{0,81}{1,0} = 58,3 \ \ , zatem$$

PN-EN 1993-1-1/6.2.6

$$V_{pl,Rd} = \frac{A_v \cdot \frac{f_y}{\sqrt{3}}}{\gamma_{M0}} = \frac{5090 \cdot \frac{355}{\sqrt{3}}}{1,0} = 1043 \cdot 10^3 N = 1043\ kN$$

$$\frac{V_{Ed}}{V_{pl,Rd}} = \frac{357,44}{1043} = 0,34 < 1,0 \rightarrow OK$$

Because $V_{Ed} < 0,5 \cdot V_{pl,Rd}$ The design value of the shear force does not influent on the design resistance for bending.

3.8 Changes in the model

Next step is to modify characteristics of beam in Robot. The beams were divided in 3 section in relative 0,15L/ 0,7L/0,15L (Figure 43). After dividing beam to appropriate parts, characteristics were assigned to them (Figure 44). This action was taken for all primary and secondary beams. In this case elements 333 and 392 are over the props, and element 391 is in the span.

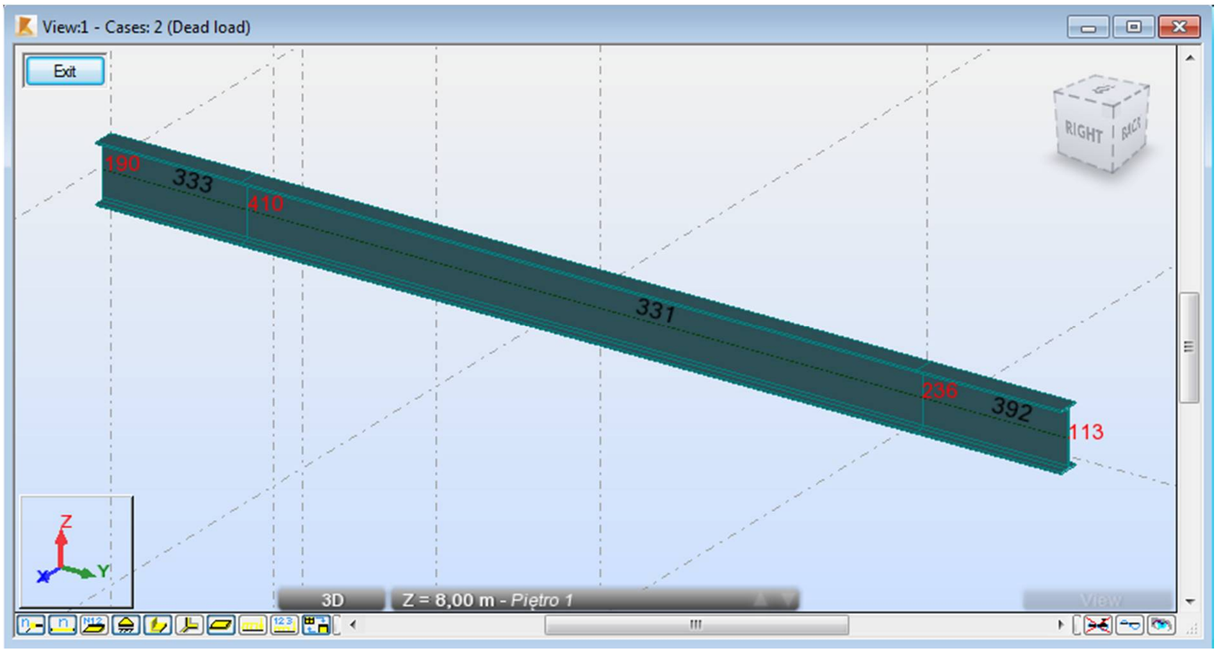


Figure 43 The division of composite beams

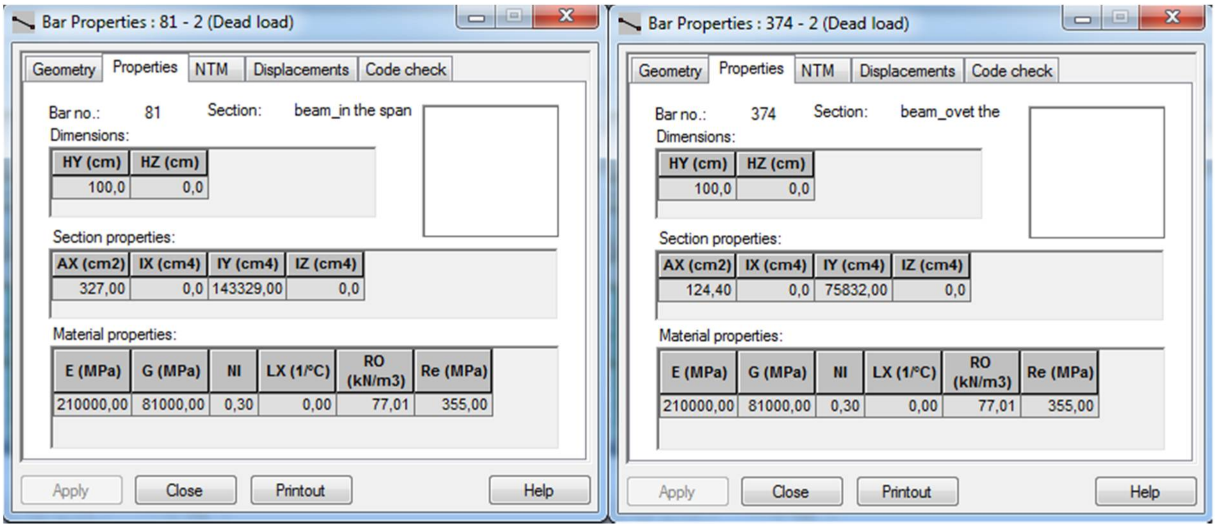
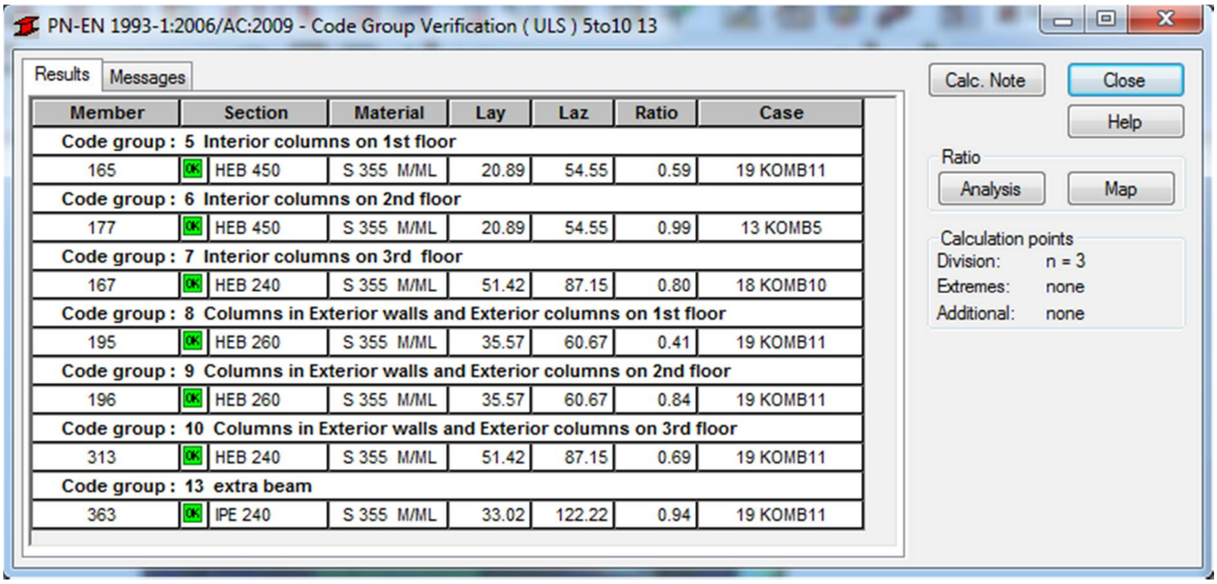


Figure 44 Characteristic of composite beam; on the left in the span, the on right over the props

When changes were done, calculations were performed again. This time columns and beams that does not support slab were verified. Composite beams were calculated manually and the new cross section does not allow to verified them in Robot software. Result of the final verification can be seen in Figure 45, and all calculations are available in Annex 1



PN-EN 1993-1:2006/AC:2009 - Code Group Verification (ULS) 5to10 13

Member	Section	Material	Lay	Laz	Ratio	Case
Code group : 5 Interior columns on 1st floor						
165	OK HEB 450	S 355 M/ML	20.89	54.55	0.59	19 KOMB11
Code group : 6 Interior columns on 2nd floor						
177	OK HEB 450	S 355 M/ML	20.89	54.55	0.99	13 KOMB5
Code group : 7 Interior columns on 3rd floor						
167	OK HEB 240	S 355 M/ML	51.42	87.15	0.80	18 KOMB10
Code group : 8 Columns in Exterior walls and Exterior columns on 1st floor						
195	OK HEB 260	S 355 M/ML	35.57	60.67	0.41	19 KOMB11
Code group : 9 Columns in Exterior walls and Exterior columns on 2nd floor						
196	OK HEB 260	S 355 M/ML	35.57	60.67	0.84	19 KOMB11
Code group : 10 Columns in Exterior walls and Exterior columns on 3rd floor						
313	OK HEB 240	S 355 M/ML	51.42	87.15	0.69	19 KOMB11
Code group : 13 extra beam						
363	OK IPE 240	S 355 M/ML	33.02	122.22	0.94	19 KOMB11

Figure 45 Result of the final verification

Finally, to prevent the conversion of connections types in Revit, the release "Blocked" was created as shown in the Figure 46. Because Revit will not recognize the name, will not be able to replace the fixed connections for pined.

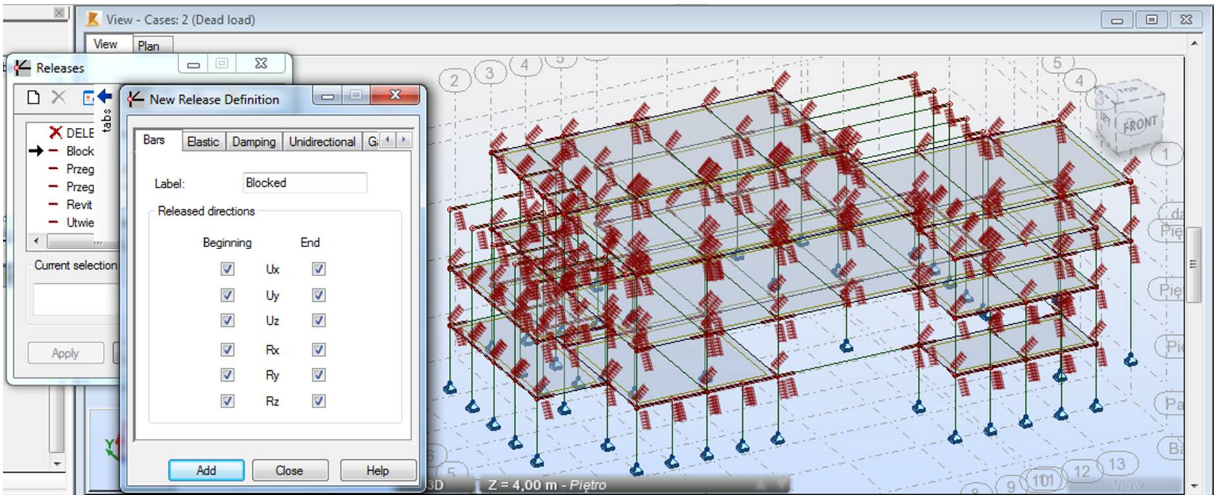


Figure 46 Releases in analytical model

3.9 Creating connections in Robot software

To check possibility of exchange of information related to connections, few of them were modeled and calculated. At the beginning it should be noted that the Robot has a poor database of connections and there are many restrictions in their creation.

Five connections were created, two on the ends of the beam and the others at the ends of a column. If the transfer to Revit successfully goes, two workshop drawings of the beam and column will be received. The connections created were shown in Figure 46. The verification were performed for all of them. The first is a fixed connection of secondary beam with the column.

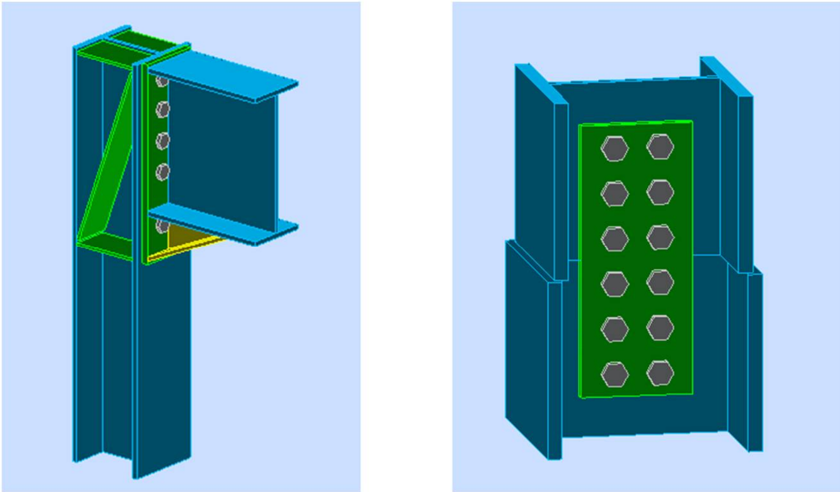


Figure 47 The connections 1/2

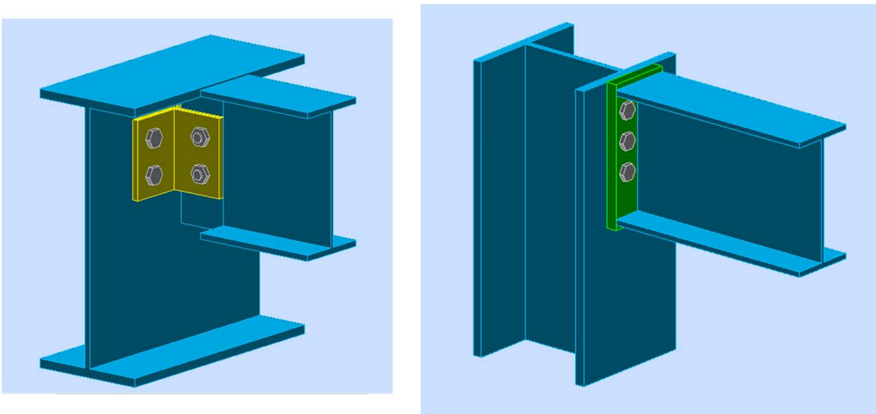


Figure 48 The connections 2/2

3.10 Updating model in Revit

First stem is updating model in Revit software. This time the option "send model" was chosen, and in option, steel connections were selected. There appeared one warning (Figure 49). The first on the left connection, shown in Figure 48 was not recognized by Revit software. It is recommended to use Advance Steel Design to create steel connections, in Revit it cannot be done without extra apps.

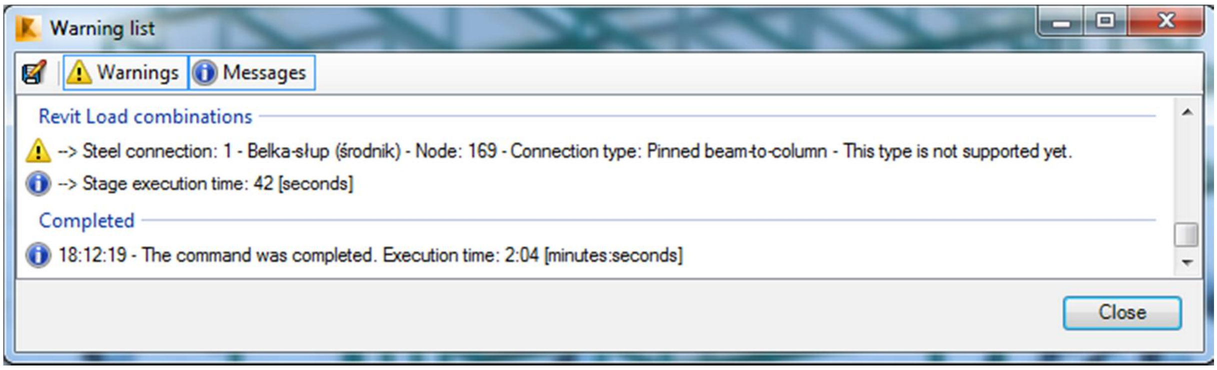


Figure 49 The warning list

After updating model it turned out that none of concoctions were transferred to Revit.
Next, what was done is creation of metal deck profile Cofrastra 70 in Revit (Figure). To create it .dwg file downloaded from producer website was used as a base.

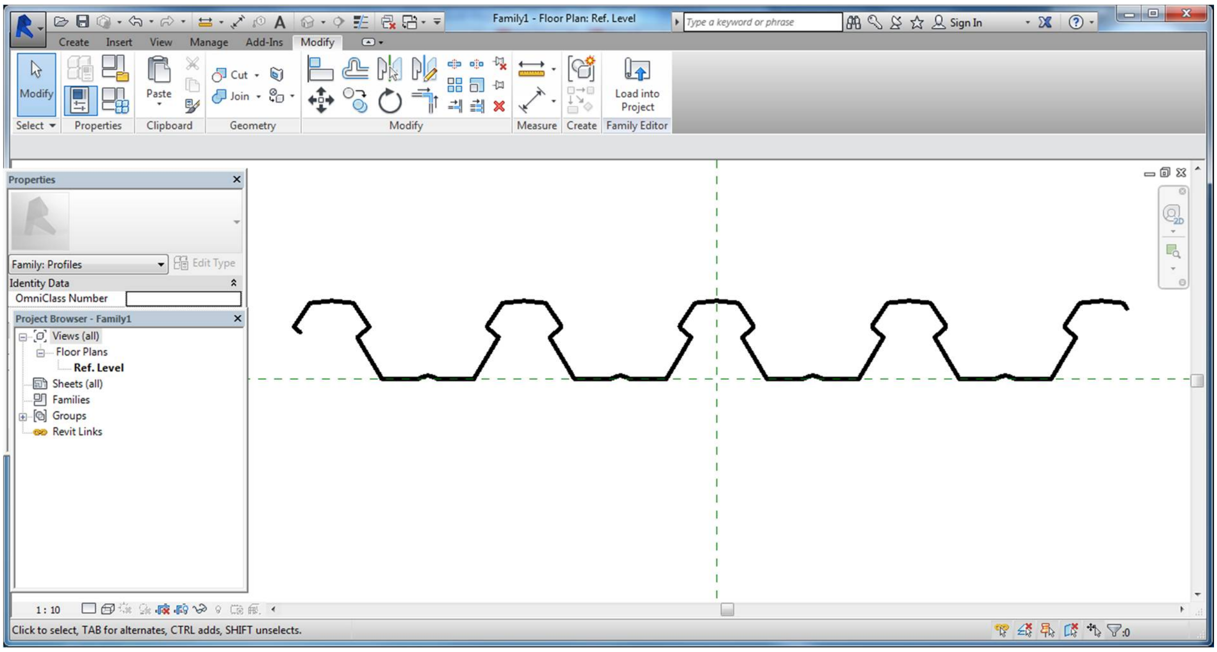


Figure 50 Metal deck Cofrastra 70 profile

After creating a profile, cross section of new ceiling was defined. Slabs transferred from the Robot were converted into the ceiling Cofratsra 70. Exterior walls were actualized as a curtain wall and then converted into architectural Base Wall Generic 200 to visualize their position and thickness. Ultimately, these walls have to be the light on a steel grate, and there are not that kind of walls in Revit. The interior walls were removed at the beginning of the model customization because their realization in the model was very messy. Thus, the current model contains columns, beams, floors, exterior walls and fundaments.

At the end, the drawings and schedules of materials and components were created. It is a very quick and simple in Revit software. Program generates schedules for multiple category and can be easily tailored to the needs.

Drawings also generate in a very simple way but the quality leaves a lot to be desired. It is worse when it comes to their description. Tagging elements can perform very fast but messy. Nevertheless, if necessary, to generate specific section can be done very quickly, and anything is change in the model is automatically changed to the drawings.

4 Conclusion

BIM among other things, is as perfect as programs used by designers. In this document the basic tools was Revit software and Robot Structural Analysis Professional. The performed work shows that, both programs have many advantages, user need to know how to use it, but also disadvantages. Need to be aware of many things to work successfully. Know where to look for answers in the program. In summary:

- To save time engineer, architect and constructor must cooperate from the beginning. The architect must create the architectural model having in mind how is created the analytical model. Here, a case of slab shows the best situation. The analytical model of the slab is created on its edge. When the architect draw a slab on the front of the column, analytical models of elements will not be linked. So, at the beginning it need to be determine how the model will be created, otherwise improve his condition is time-consuming. In a well-developed efficient system designers collect and exchange data, collaborating and providing a necessary information.
- With the access to the current object model investor, contractor and designer can watch the progress of the design work and in an accessible manner to oversee the design process.
- The modification of the project - conceptual changes introduced in the project are applied to the 3D model and automatically reflected in the reports of quantitative and project documentation. Because of this, the preparation of drawings and schedules becomes easy and less time-consuming.
- Thanks to a faithful reproduction of reality it is more easily to design and choose solutions. The user is able to easily judge the validity of the decisions taken which speed up the process.
- IFC format that is useful, it allows to move information between programs, but unfortunately not all the information. So it was in this case, the part of building information was not transferred from ArchiCAD to Revit.
- Despite the possible transfer information between programs Revit and Robot, elements are often not recognized because of different databases.

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ANNEX 1

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*
ANALYSIS TYPE: Code Group Verification

CODE GROUP: 5 Interior columns on 1st floor
MEMBER: 165 **POINT:** 2 **COORDINATE:** x = 0.50 L = 2.00 m

LOADS:
Governing Load Case: 19 KOMB11 (1+2)*1.15+(3+8)*1.50+4*0.75

MATERIAL:
S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: HEB 450

h=45.0 cm	gM0=1.00	gM1=1.00	
b=30.0 cm	Ay=169.84 cm2	Az=79.68 cm2	Ax=218.00 cm2
tw=1.4 cm	Iy=79890.00 cm4	Iz=11720.00 cm4	Ix=442.00 cm4
tf=2.6 cm	Wply=3982.37 cm3	Wplz=1197.66 cm3	

INTERNAL FORCES AND CAPACITIES:

N,Ed = 2949.40 kN	My,Ed = 37.55 kN*m	Mz,Ed = -12.08 kN*m	Vy,Ed = 6.04 kN
Nc,Rd = 7739.00 kN	My,Ed,max = 75.09 kN*m	Mz,Ed,max = -24.17 kN*m	Vy,c,Rd = 3481.03 kN
Nb,Rd = 6003.62 kN	My,c,Rd = 1413.74 kN*m	Mz,c,Rd = 425.17 kN*m	Vz,Ed = 18.77 kN
	MN,y,Rd = 1020.00 kN*m	MN,z,Rd = 417.40 kN*m	Vz,c,Rd = 1633.12 kN
			Class of section = 1

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About y axis:		About z axis:	
Ly = 4.00 m	Lam_y = 0.27	Lz = 4.00 m	Lam_z = 0.71
Lcr,y = 4.00 m	Xy = 0.98	Lcr,z = 4.00 m	Xz = 0.78
Lamy = 20.89	kzy = 0.56	Lamz = 54.55	kzz = 1.27

VERIFICATION FORMULAS:
Section strength check:
N,Ed/Nc,Rd = 0.38 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.91 = 0.00 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,c,Rd = 0.00 < 1.00 (6.2.6.(1))
Vz,Ed/Vz,c,Rd = 0.01 < 1.00 (6.2.6.(1))
Global stability check of member:
Lambda,y = 20.89 < Lambda,max = 210.00 Lambda,z = 54.55 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.48 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.59 < 1.00 (6.3.3.(4))

Section OK !!!

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*

ANALYSIS TYPE: Code Group Verification

CODE GROUP: 6 Interior columns on 2nd floor
MEMBER: 177 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

LOADS:
Governing Load Case: 13 KOMB5 (1+2)*1.15+(3+6)*1.50+4*0.75

MATERIAL:
S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: HEB 450

h=45.0 cm	gM0=1.00	gM1=1.00	
b=30.0 cm	Ay=169.84 cm2	Az=79.68 cm2	Ax=218.00 cm2
tw=1.4 cm	Iy=79890.00 cm4	Iz=11720.00 cm4	Ix=442.00 cm4
tf=2.6 cm	Wply=3982.37 cm3	Wplz=1197.66 cm3	

INTERNAL FORCES AND CAPACITIES:

N,Ed = 1893.11 kN	My,Ed = -69.93 kN*m	Mz,Ed = 117.43 kN*m	Vy,Ed = 84.10 kN
Nc,Rd = 7739.00 kN	My,Ed,max = 226.29 kN*m		Mz,Ed,max = -218.97 kN*m
	Vy,T,Rd = 3480.98 kN		
Nb,Rd = 6003.62 kN	My,c,Rd = 1413.74 kN*m	Mz,c,Rd = 425.17 kN*m	Vz,Ed = 74.06 kN
	MN,y,Rd = 1244.95 kN*m	MN,z,Rd = 425.17 kN*m	Vz,T,Rd = 1633.10 kN
			Tt,Ed = 0.00 kN*m
			Class of section = 1

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About y axis:		About z axis:	
Ly = 4.00 m	Lam_y = 0.27	Lz = 4.00 m	Lam_z = 0.71
Lcr,y = 4.00 m	Xy = 0.98	Lcr,z = 4.00 m	Xz = 0.78
Lamy = 20.89	kzy = 0.55	Lamz = 54.55	kzz = 1.13

VERIFICATION FORMULAS:
Section strength check:
N,Ed/Nc,Rd = 0.24 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.22 = 0.21 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,T,Rd = 0.02 < 1.00 (6.2.6-7)
Vz,Ed/Vz,T,Rd = 0.05 < 1.00 (6.2.6-7)
Tau,ty,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Tau,tz,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Global stability check of member:
Lambda,y = 20.89 < Lambda,max = 210.00 Lambda,z = 54.55 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.75 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.99 < 1.00 (6.3.3.(4))

Section OK !!!

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*
ANALYSIS TYPE: Code Group Verification

CODE GROUP: 7 Interior columns on 3rd floor

MEMBER: 167 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

LOADS:
Governing Load Case: 18 KOMB10 (1+2)*1.35+(3+8)*1.05+4*0.75

MATERIAL:
S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: HEB 240

h=24.0 cm	gM0=1.00	gM1=1.00	
b=24.0 cm	Ay=89.60 cm2	Az=33.24 cm2	Ax=106.00 cm2
tw=1.0 cm	Iy=11260.00 cm4	Iz=3920.00 cm4	Ix=103.00 cm4
tf=1.7 cm	Wply=1053.15 cm3	Wplz=498.42 cm3	

INTERNAL FORCES AND CAPACITIES:

N,Ed = 958.63 kN	My,Ed = 9.64 kN*m	Mz,Ed = 25.76 kN*m	Vy,Ed = 7.70 kN
Nc,Rd = 3763.00 kN	My,Ed,max = 9.64 kN*m	Mz,Ed,max = 25.76 kN*m	Vy,T,Rd = 1836.39 kN
Nb,Rd = 1742.58 kN	My,c,Rd = 373.87 kN*m	Mz,c,Rd = 176.94 kN*m	Vz,Ed = -2.78 kN
	MN,y,Rd = 314.86 kN*m	MN,z,Rd = 176.76 kN*m	Vz,T,Rd = 681.28 kN
			Tt,Ed = -0.00 kN*m
			Class of section = 1

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About y axis:		About z axis:	
Ly = 5.30 m	Lam_y = 0.67	Lz = 5.30 m	Lam_z = 1.14
Lcr,y = 5.30 m	Xy = 0.80	Lcr,z = 5.30 m	Xz = 0.46
Lamy = 51.42	kzy = 0.62	Lamz = 87.15	kzz = 1.59

VERIFICATION FORMULAS:
Section strength check:
N,Ed/Nc,Rd = 0.25 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.27 = 0.09 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,T,Rd = 0.00 < 1.00 (6.2.6-7)
Vz,Ed/Vz,T,Rd = 0.00 < 1.00 (6.2.6-7)
Tau,ty,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Tau,tz,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Global stability check of member:
Lambda,y = 51.42 < Lambda,max = 210.00 Lambda,z = 87.15 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.48 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.80 < 1.00 (6.3.3.(4))

Section OK !!!

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*
ANALYSIS TYPE: Code Group Verification

CODE GROUP: 8 Columns in Exterior walls and Exterior columns on 1st floor
MEMBER: 195 **POINT:** 2 **COORDINATE:** x = 0.50 L = 2.00 m

LOADS:

Governing Load Case: 19 KOMB11 (1+2)*1.15+(3+8)*1.50+4*0.75

MATERIAL:
S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: HEB 260

h=26.0 cm	gM0=1.00	gM1=1.00	
b=26.0 cm	Ay=100.30 cm2	Az=37.15 cm2	Ax=118.00 cm2
tw=1.0 cm	Iy=14920.00 cm4	Iz=5130.00 cm4	Ix=124.00 cm4
tf=1.8 cm	Wply=1282.91 cm3	Wplz=602.25 cm3	

INTERNAL FORCES AND CAPACITIES:

N,Ed = 949.91 kN	My,Ed = 9.54 kN*m	Mz,Ed = -4.20 kN*m	Vy,Ed = 2.10 kN
Nc,Rd = 4189.00 kN	My,Ed,max = 19.07 kN*m	Mz,Ed,max = -8.40 kN*m	Vy,c,Rd = 2055.74 kN
Nb,Rd = 2789.67 kN	My,c,Rd = 455.43 kN*m	Mz,c,Rd = 213.80 kN*m	Vz,Ed = 4.77 kN
	MN,y,Rd = 397.65 kN*m	MN,z,Rd = 213.80 kN*m	Vz,c,Rd = 761.42 kN
			Class of section = 1

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About y axis:		About z axis:	
Ly = 4.00 m	Lam_y = 0.47	Lz = 4.00 m	Lam_z = 0.79
Lcr,y = 4.00 m	Xy = 0.90	Lcr,z = 4.00 m	Xz = 0.67
Lamy = 35.57	kzy = 0.58	Lamz = 60.67	kzz = 1.20

VERIFICATION FORMULAS:

Section strength check:
N,Ed/Nc,Rd = 0.23 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.13 = 0.01 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,c,Rd = 0.00 < 1.00 (6.2.6.(1))
Vz,Ed/Vz,c,Rd = 0.01 < 1.00 (6.2.6.(1))

Global stability check of member:
Lambda,y = 35.57 < Lambda,max = 210.00 Lambda,z = 60.67 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.32 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.41 < 1.00 (6.3.3.(4))

Section OK !!!

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*
ANALYSIS TYPE: Code Group Verification

CODE GROUP: 9 Columns in Exterior walls and Exterior columns on 2nd floor
MEMBER: 196 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

LOADS:
Governing Load Case: 19 KOMB11 (1+2)*1.15+(3+8)*1.50+4*0.75

MATERIAL:
S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: HEB 260

h=26.0 cm gM0=1.00 gM1=1.00
b=26.0 cm Ay=100.30 cm2 Az=37.15 cm2 Ax=118.00 cm2
tw=1.0 cm Iy=14920.00 cm4 Iz=5130.00 cm4 Ix=124.00 cm4
tf=1.8 cm Wply=1282.91 cm3 Wplz=602.25 cm3

INTERNAL FORCES AND CAPACITIES:

N,Ed = 633.56 kN My,Ed = 123.08 kN*m Mz,Ed = 13.89 kN*m Vy,Ed = 6.85 kN
Nc,Rd = 4189.00 kN My,Ed,max = -303.37 kN*m Mz,Ed,max = 13.89 kN*m
Vy,T,Rd = 2055.68 kN
Nb,Rd = 2789.67 kN My,c,Rd = 455.43 kN*m Mz,c,Rd = 213.80 kN*m Vz,Ed = -106.61 kN
MN,y,Rd = 436.49 kN*m MN,z,Rd = 213.80 kN*m Vz,T,Rd = 761.41 kN
Tt,Ed = 0.00 kN*m
Class of section = 1

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About y axis:
Ly = 4.00 m Lam_y = 0.47
Lcr,y = 4.00 m Xy = 0.90
Lamy = 35.57 kyy = 0.94

About z axis:
Lz = 4.00 m Lam_z = 0.79
Lcr,z = 4.00 m Xz = 0.67
Lamz = 60.67 kyz = 0.66

VERIFICATION FORMULAS:

Section strength check:

N,Ed/Nc,Rd = 0.15 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.00 = 0.14 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,T,Rd = 0.00 < 1.00 (6.2.6-7)
Vz,Ed/Vz,T,Rd = 0.14 < 1.00 (6.2.6-7)
Tau,ty,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Tau,tz,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)

Global stability check of member:

Lambda,y = 35.57 < Lambda,max = 210.00 Lambda,z = 60.67 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.84 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.67 < 1.00 (6.3.3.(4))

Section OK !!!

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*
ANALYSIS TYPE: Code Group Verification

CODE GROUP: 10 Columns in Exterior walls and Exterior columns on 3rd floor
MEMBER: 313 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

LOADS:

Governing Load Case: 19 KOMB11 (1+2)*1.15+(3+8)*1.50+4*0.75

MATERIAL:

S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: HEB 240

h=24.0 cm	gM0=1.00	gM1=1.00	
b=24.0 cm	Ay=89.60 cm2	Az=33.24 cm2	Ax=106.00 cm2
tw=1.0 cm	Iy=11260.00 cm4	Iz=3920.00 cm4	Ix=103.00 cm4
tf=1.7 cm	Wply=1053.15 cm3	Wplz=498.42 cm3	

INTERNAL FORCES AND CAPACITIES:

N,Ed = 309.18 kN	My,Ed = -33.00 kN*m	Mz,Ed = 72.82 kN*m	Vy,Ed = 28.57 kN
Nc,Rd = 3763.00 kN	My,Ed,max = -33.00 kN*m		Mz,Ed,max = 72.82 kN*m
	Vy,T,Rd = 1836.32 kN		
Nb,Rd = 1742.58 kN	My,c,Rd = 373.87 kN*m	Mz,c,Rd = 176.94 kN*m	Vz,Ed = 13.40 kN
	MN,y,Rd = 373.87 kN*m	MN,z,Rd = 176.94 kN*m	Vz,T,Rd = 681.26 kN
			Tt,Ed = 0.00 kN*m
			Class of section = 1

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About y axis:		About z axis:	
Ly = 5.30 m	Lam_y = 0.67	Lz = 5.30 m	Lam_z = 1.14
Lcr,y = 5.30 m	Xy = 0.80	Lcr,z = 5.30 m	Xz = 0.46
Lamy = 51.42	kzy = 0.57	Lamz = 87.15	kzz = 1.12

VERIFICATION FORMULAS:

Section strength check:

N,Ed/Nc,Rd = 0.08 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.00 = 0.42 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,T,Rd = 0.02 < 1.00 (6.2.6-7)
Vz,Ed/Vz,T,Rd = 0.02 < 1.00 (6.2.6-7)
Tau,ty,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Tau,tz,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)

Global stability check of member:

Lambda,y = 51.42 < Lambda,max = 210.00 Lambda,z = 87.15 < Lambda,max = 210.00 STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.46 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.69 < 1.00 (6.3.3.(4))

Section OK !!!

STEEL DESIGN

CODE: *PN-EN 1993-1:2006/AC:2009, Eurocode 3: Design of steel structures.*
ANALYSIS TYPE: Code Group Verification

CODE GROUP: 13 extra beam
MEMBER: 363 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

LOADS:
Governing Load Case: 19 KOMB11 (1+2)*1.15+(3+8)*1.50+4*0.75

MATERIAL:
S 355 M/ML (S 355) fy = 355.00 MPa

SECTION PARAMETERS: IPE 240

h=24.0 cm	gM0=1.00	gM1=1.00	
b=12.0 cm	Ay=27.30 cm2	Az=19.13 cm2	Ax=39.10 cm2
tw=0.6 cm	Iy=3890.00 cm4	Iz=284.00 cm4	Ix=13.30 cm4

tf=1.0 cm	Wply=366.65 cm3	Wplz=73.92 cm3

INTERNAL FORCES AND CAPACITIES:

N,Ed = 19.96 kN	My,Ed = -68.50 kN*m	Mz,Ed = 0.01 kN*m	Vy,Ed = 0.00 kN
Nc,Rd = 1388.05 kN	My,Ed,max = -68.50 kN*m		Mz,Ed,max = 0.01 kN*m
	Vy,T,Rd = 559.41 kN		
Nb,Rd = 1388.05 kN	My,c,Rd = 130.16 kN*m	Mz,c,Rd = 26.24 kN*m	Vz,Ed = 88.26 kN
	MN,y,Rd = 130.16 kN*m	MN,z,Rd = 26.24 kN*m	Vz,T,Rd = 392.02 kN
	Mb,Rd = 72.54 kN*m		Tt,Ed = -0.00 kN*m
			Class of section = 1

LATERAL BUCKLING PARAMETERS:

z = 1.00	Mcr = 82.83 kN*m	Curve,LT - b	XLT = 0.55
Lcr,low=3.29 m	Lam_LT = 1.25	fi,LT = 1.23	XLT,mod = 0.56

BUCKLING PARAMETERS:

About y axis:		About z axis:	
	kyy = 0.90		kyz = 0.54

VERIFICATION FORMULAS:

Section strength check:

N,Ed/Nc,Rd = 0.01 < 1.00 (6.2.4.(1))
(My,Ed/MN,y,Rd)^ 2.00 + (Mz,Ed/MN,z,Rd)^1.00 = 0.28 < 1.00 (6.2.9.1.(6))
Vy,Ed/Vy,T,Rd = 0.00 < 1.00 (6.2.6-7)
Vz,Ed/Vz,T,Rd = 0.23 < 1.00 (6.2.6-7)
Tau,ty,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)
Tau,tz,Ed/(fy/(sqrt(3)*gM0)) = 0.00 < 1.00 (6.2.6)

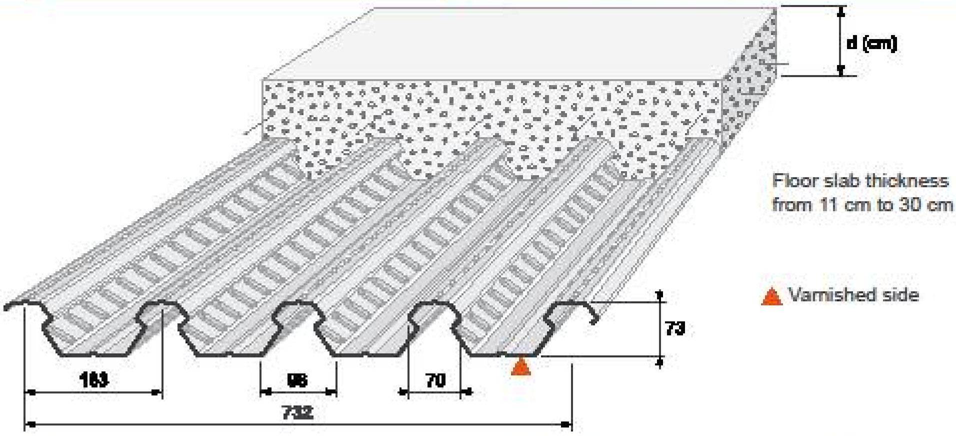
Global stability check of member:

My,Ed,max/Mb,Rd = 0.94 < 1.00 (6.3.2.1.(1))
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.86 < 1.00 (6.3.3.(4))
N,Ed/(Xz*N,Rk/gM1) + kzy*My,Ed,max/(XLT*My,Rk/gM1) + kzz*Mz,Ed,max/(Mz,Rk/gM1) = 0.58 < 1.00 (6.3.3.(4))

Section OK !!!

ANNEX 2

Cofrastra 70 corrugated sheet for composite floors



Application
Cofrastra 40 profiled steel sheeting is designed for the construction of reinforced concrete intermediate floors, terraces and flat roofs in all kinds of building structures, wherever static loads or low dynamic loads (office blocks, public buildings, high-rise structures, multi-storey car parks, warehouses) are expected. It distinguishes because of its high load capacity in mounting stage (during floor slab pouring)and, at the same time, it has high delamination endurance which has an influence on building floor sheets of big spans with big loading.

Material
Cofrastra 70 sheets are profiled using the technology of continuous roll forming of flat steel sheet S 350 GD, specified to PN-EN 10326:2006 and zinc-plated on both sides with zinc coat thickness of 275 g/m² (C1 and C2 corrosive environment). From outside the profiled steel can be additionally protected with organic coating by ArcelorMittal Construction coating system.

Formwork
At the construction stage, Cofrastra 40 profiled sheets form a non-dismountable flooring formwork, fastened to fixed props and shored, if required. The formwork sheeting must be continuous at bays and any edge trims must be supported on fixed props. There is not a possibility of sheet lap joining on props. That is why stoppers or flashing should be used on the intermediate props at any sheet edge trims. Individual sheets are stitched lengthwise. Thanks to their light weight of 10,05 kg/m² (for 0,75 mm thickness), the profiles can be manually handled despite the dimensions. The maximum length of a single profile should not exceed 15 m due to restricted handling and manipulation possibilities on a building site.

Cofrastra 70. Safe load tables

Arval by ArcelorMittal

Table of allowed spans for the construction stage of Cofrastra 70 sheet

	$f_{max} < L/180$			$f_{max} < L/250$			d-100			d-100		
Floor sheet thickness [mm]	0,75	0,88	1,00	0,75	0,88	1,00	0,75	0,88	1,00	0,75	0,88	1,00
Floor slab thickness [cm]	L [m]			L [m]			L [m]			L [m]		
12	3,05	3,22	3,36	2,84	3,00	3,10	2,38	2,81	3,22	2,68	3,16	3,62
13	2,96	3,12	3,26	2,75	2,90	3,03	2,27	2,69	3,08	2,55	3,02	3,46
14	2,88	3,04	3,17	2,67	2,82	2,94	2,17	2,57	2,95	2,44	2,89	3,31
16	2,81	2,94	3,04	2,53	2,67	2,79	1,99	2,37	2,73	2,24	2,67	3,06
18	2,68	2,82	2,95	2,42	2,55	2,66	1,85	2,21	2,54	2,08	2,48	2,85
20	2,57	2,71	2,83	2,32	2,45	2,56	1,73	2,06	2,38	1,94	2,32	2,68
22	2,48	2,61	2,73	2,24	2,36	2,47	1,62	1,94	2,24	1,83	2,19	2,52
24	2,40	2,53	2,64	2,16	2,28	2,39	1,53	1,84	2,12	1,72	2,07	2,39
26	2,32	2,45	2,57	2,10	2,21	2,32	1,45	1,74	2,02	1,63	1,96	2,27
30	2,17	2,32	2,43	1,99	2,10	2,20	1,31	1,58	1,83	1,48	1,78	2,06

Load-bearing capacity of the floor sheeting has been determined on the assumed flexural capacity as per PN EN 1993-1-3.
For a single-span system the load-bearing capacity has been determined for the deflection limit of L/180 and L/250.
The intermediate prop width for a multi-span system is 100 mm.
The table may be used in arrangements where shoring is applied. For systems where shoring of the sheet is not expected at the construction stage it is possible to extend the actual span (following and based on an analysis provided by the Technical Department of ArcelorMittal Construction Polska) to take advantage of the load-bearing capacity of the sheet used, with due consideration of the yield of the cross-section when the ULS is assessed for intermediate propped multi-span arrangements.

Nominal concrete consumption

Floor sheet thickness	cm	12	13	14	15	16	18	20	22	25	30
Concrete consumption	m^3/m^2	0,094	0,104	0,114	0,124	0,134	0,154	0,174	0,194	0,224	0,274
Floor slab theoretical weight*	kN/m^2	2,35	2,6	2,85	3,10	3,35	3,85	4,35	4,85	5,60	6,85

*In order to determine the total weight of the slab the weight of concrete, the deflection and the weight of the sheet profile must be taken into account. 25 kN/m^3 is the concrete specific gravity assumption.

Cofrastra 70. Safe load tables

Composite floor slab performance characteristics

h [cm]	COFRASTRA 70; 0,75mm			COFRASTRA 70; 0,88mm			COFRASTRA 70; 1,00mm		
	$M_{pl,Rd}$ [kNm/m]	V_{vRd} [kN/m]	I [cm⁴/m]	$M_{pl,Rd}$ [kNm/m]	V_{vRd} [kN/m]	I [cm⁴/m]	$M_{pl,Rd}$ [kNm/m]	V_{vRd} [kN/m]	I [cm⁴/m]
12	30,88	43,15	789	35,26	45,64	841	38,93	47,93	887
13	35,07	46,20	987	40,22	48,67	1051	44,60	50,95	1107
14	39,25	49,21	1215	45,18	51,66	1293	50,28	53,93	1361
15	43,43	52,17	1476	50,14	54,61	1569	55,96	56,86	1651
16	47,61	55,09	1771	55,10	57,51	1882	61,63	59,75	1979
18	55,98	60,80	2472	65,02	63,18	2624	72,99	65,39	2757
20	64,34	66,32	3334	74,94	68,68	3536	84,34	70,85	3712
22	72,71	71,67	4373	84,86	73,99	4632	95,70	76,14	4859
24	81,07	76,84	5604	94,78	79,13	5928	107,05	81,24	6213
28	97,80	86,65	8701	114,61	88,87	9182	129,76	90,92	9606

Fire resistance

Non-insulated floor slabs of at least 120 mm, constructed using Cofrastra 70 profiles, without extra reinforcement in bays have the fire endurance rating of min. REI 30. The minimum thicknesses of floor slabs which guarantee that the fireproof insulation requirements are met are shown in the table.

A proper design of additional reinforcement developed on the basis PN EN 1994-1-2, Appendix D and applied in a special casing to the wave sections of the slab ensures a fire stop rating which exceeds REI 30. The approach to dimensioning and essential characteristics have been included in AT-15-6138/2009. Further details can also be obtained from the Technical Department of ArcelorMittal.

REI	30	60	90	120	180
Thickness [cm]	12	12	13	15	19

Acoustic insulation

Floor acoustic characteristics without a suspended ceiling depend on floor slab weight and are compliant with:

Floor slab thickness	12	13	14	15	20	25	30
Acoustic insulation R_w $(C;C_{tr})$ dB(A)	47 (-1;-4)	48(-1;-5)	48(-1;-4)	49(-1;-5)	53(-2;-7)	55(-1;-7)	58(-2;-7)

Cofrastra 70. Safe load tables

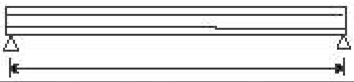
Arval

Load bearing capacity of the floor and delamination
According to PN EN 1994-1-1, the load-bearing capacity of the floor beam as far as the delamination of sheeting is concerned is verified using one of the following two equivalent methods: the evaluation of m-k values and the partial composition method. The parameters required to check this aspect of load-bearing capacity have been determined during laboratory strength tests carried out at the Building Research Institute, using methods compliant with PN-EN-1994-1-1 attachment B.3.

m Mpa	k MPa	T_{Rd} Mpa
254,16	0,09	0,18

Safe load tables (composite stage)

Continuous floor slab – single-span



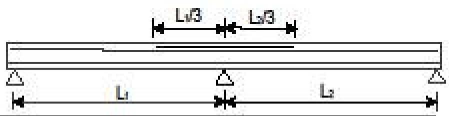
Span lenghts of the support structure [mm]

Q_k [kN/m²]	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
1,5	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 1 Q131 12 Ø6 20	12 1 Q131 12 Ø8 30	12 1 Q131 12 Ø8 30	13 1 Q131 13 Ø8 30	15 2 Q131 15 Ø10 30	17 2 Q188 17 Ø10 30	19 3 Q188 19 Ø10 30
2,5	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 1 Q131 12 Ø6 30	12 1 Q131 12 Ø8 30	12 1 Q131 12 Ø8 30	14 1 Q131 14 Ø10 30	16 2 Q188 16 Ø10 30	18 2 Q188 18 Ø10 30	20 3 Q188 20 Ø12 35
3,5	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 1 Q131 12 Ø6 30	12 1 Q131 12 Ø6 30	13 1 Q131 13 Ø10 30	15 2 Q131 15 Ø10 30	17 2 Q188 17 Ø10 30	20 2 Q188 20 Ø10 30	22 3 Q221 22 Ø12 30
4,5	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 1 Q131 12 Ø6 30	12 1 Q131 12 Ø6 30	14 1 Q131 14 Ø10 30	16 2 Q188 16 Ø10 30	18 2 Q188 18 Ø10 30	21 2 Q188 21 Ø12 30	23 3 Q221 23 Ø12 30
6,0	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø8 30	12 1 Q131 12 Ø8 30	13 1 Q131 13 Ø10 30	15 1 Q131 15 Ø10 30	17 2 Q188 17 Ø10 30	19 2 Q188 19 Ø12 30	22 3 Q221 22 Ø12 30	24 3 Q257 24 Ø12 30
8,0	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø6 20	12 0 Q131 12 Ø8 30	12 1 Q131 12 Ø10 30	14 1 Q131 14 Ø10 30	16 2 Q188 16 Ø10 30	19 2 Q188 19 Ø10 30	21 2 Q188 21 Ø12 30	24 3 Q257 24 Ø12 30	

Cofrastra 70. Safe load tables

Arval

Continuous floor slab – double-span



Span lenghts of the support structure [mm]

Q_k [kN/m²]	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
1,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 1 Q131 Ø6 12	12 1 Q131 Ø6 9	13 1 Q131 Ø8 13	15 2 Q131 Ø8 11	16 2 Q131 Ø10 15	18 2 Q188 Ø10 13
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	13 Ø8 30	15 Ø8 30	16 Ø8 30	18 Ø8 30
2,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 13	12 1 Q131 Ø6 9	12 1 Q131 Ø6 7	13 1 Q131 Ø8 10	15 2 Q188 Ø8 9	16 2 Q131 Ø10 12	18 2 Q188 Ø12 15
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	13 Ø8 30	15 Ø8 30	16 Ø8 30	18 Ø10 30
3,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 13	12 1 Q131 Ø6 9	12 1 Q131 Ø6 7	13 1 Q131 Ø8 10	15 2 Q188 Ø12 16	16 2 Q131 Ø12 14	18 2 Q188 Ø12 12
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	13 Ø8 30	15 Ø8 30	16 Ø10 30	18 Ø10 30
4,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 13	12 0 Q131 Ø6 9	12 1 Q131 Ø8 11	12 1 Q131 Ø8 8	13 1 Q131 Ø10 10	15 2 Q131 Ø8 6	16 2 Q131 Ø10 8	18 2 Q188 Ø16 19
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	12 Ø8 30	13 Ø8 30	15 Ø10 30	16 Ø10 30	18 Ø10 30
6,0	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 11	12 0 Q131 Ø6 7	12 1 Q131 Ø6 5	13 1 Q131 Ø8 7	14 1 Q131 Ø10 9	16 2 Q131 Ø12 12	18 2 Q188 Ø12 11	20 3 Q188 Ø10 7
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	12 Ø8 30	13 Ø8 30	14 Ø10 30	16 Ø10 30	18 Ø10 30	20 Ø10 30
8,0	12 0 Q131 Ø6 14	12 0 Q131 Ø6 13	12 0 Q131 Ø6 8	12 0 Q131 Ø8 9	13 1 Q131 Ø10 11	14 1 Q131 Ø8 6	16 2 Q131 Ø12 12	18 2 Q188 Ø8 5	19 2 Q188 Ø12 9	21 3 Q188 Ø10 6
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	13 Ø8 30	14 Ø10 30	16 Ø10 30	18 Ø10 30	19 Ø10 30	21 Ø12 30

A B	C D E
F	G H

A – floor slab thickness
B – number of shores per span at the construction stage
C – type of anti-crack reinforcement mesh
D – rebar gauge over the props (2 cm casing)
E – distribution of rebars over the props
F – floor slab thickness for REI 60
G – rebar gauge in the floor sheet wave, adapted to fire loads
H – fireproof rebar casing

Assumptions for the Tables

- all loads shown in the table are characteristic values
- assumed concrete grade: C25/30
- assumed reinforcement steel grade: A-IIIN (RB500W)
- assumed load safety factor: 1.5
- assumed floor sheet gauge: 0.75 mm
- all span lenghts are measured at centre lines of the props
- tables based on equal lenght spans

Cofrastra 70. Safe load tables

Arval

Continuous floor slab – triple-span

Span lenghts of the support structure [mm]

Q_k [kN/m²]	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
1,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 1 Q131 Ø6 14	12 1 Q131 Ø6 11	13 1 Q131 Ø6 9	15 2 Q131 Ø8 13	16 2 Q188 Ø10 18	18 2 Q188 Ø10 16
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 30	13 Ø8 30	15 Ø8 30	16 Ø8 30	18 Ø10 30
2,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 1 Q131 Ø6 11	12 1 Q131 Ø6 8	13 1 Q131 Ø8 12	15 2 Q131 Ø6 5	16 2 Q131 Ø8 9	18 2 Q188 Ø8 8
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 30	12 Ø8 30	13 Ø8 30	15 Ø8 30	16 Ø10 30	18 Ø10 30
3,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 12	12 1 Q131 Ø6 8	12 1 Q131 Ø8 11	13 1 Q131 Ø8 9	15 2 Q131 Ø6 5	16 2 Q131 Ø12 16	18 2 Q188 Ø12 15
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	12 Ø8 30	13 Ø8 30	15 Ø10 30	16 Ø10 30	18 Ø10 30
4,5	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 10	12 1 Q131 Ø6 7	12 1 Q131 Ø8 9	14 1 Q131 Ø10 13	16 2 Q131 Ø10 12	17 2 Q188 Ø10 10	19 3 Q188 Ø8 6
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø6 30	12 Ø8 30	12 Ø8 30	14 Ø10 30	16 Ø10 30	17 Ø10 30	19 Ø10 30
6,0	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 12	12 0 Q131 Ø6 8	12 1 Q131 Ø8 10	13 1 Q131 Ø8 8	15 2 Q131 Ø12 16	17 2 Q188 Ø12 15	19 2 Q188 Ø8 6	21 3 Q188 Ø12 12
	12 Ø6 20	12 Ø6 20	12 Ø6 20	12 Ø8 30	12 Ø8 30	13 Ø10 30	15 Ø10 30	17 Ø10 30	19 Ø10 30	21 Ø12 30
8,0	12 0 Q131 Ø6 14	12 0 Q131 Ø6 14	12 0 Q131 Ø6 9	12 0 Q131 Ø8 11	13 1 Q131 Ø10 13	14 1 Q188 Ø12 15	16 2 Q131 Ø12 14	18 2 Q188 Ø12 12	20 2 Q188 Ø10 8	22 2 Q221 Ø16 18
	12 Ø6 20	12 Ø6 20	12 Ø6 30	12 Ø8 30	13 Ø8 30	14 Ø10 30	16 Ø10 30	18 Ø10 30	20 Ø12 30	22 Ø12 30

Objaśnienia do tabeli

12	Q131 Ø6 11
1	
12	Ø6 30

12 cm – total thickness of the composite floor slab (cm) for REI 30

1 – number of shores per span at the construction stage

Q131 – type of anti-crack reinforcement mesh

Ø 6 mm – rebar gauge over the props (2 cm casing)

11 cm – distribution of rebars over the props

Ø 6 mm – rebar gauge in the floor sheet wave, calculated to withhold fire loads for REI 60

12 cm – floor slab thickness for REI 60

q – operational load
q – q1 + g1
q1 – changing load
g1 – static load
L- Span lenghts of the support structure
n - number of floor slab spans

e.g. L – 3500
n – 3
q1–2,5 kN/m²
g1–1 kN/m²
q – 3,5 kN/m²
taken from Table 3.

Cofrastra 70. Safe load tables

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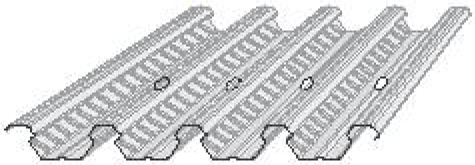
Additional service

Punching
Cofraplus 60 may be manufactured with pre-punched openings for connectors to join floor beams with the floor slab. This version is designated as COFRASTRA 70P. All relevant calculations and production of pre-punched profiles are made on demand.

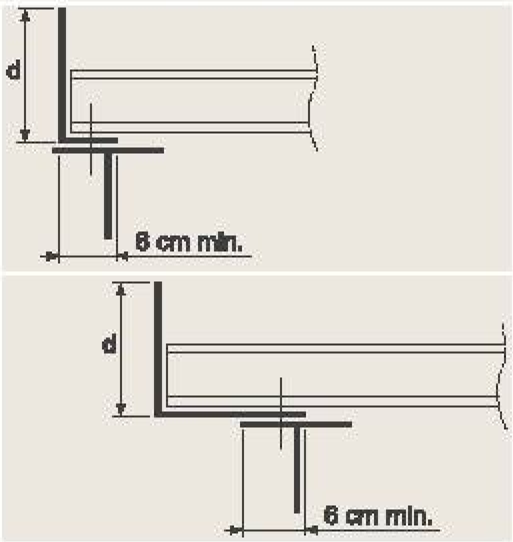
Cofrastra 70P
Ready-made punching system



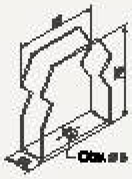
Formwork of the floor slab edge
A zinc-coated steel strip, bended at the right angle, provides the formwork of the floor slab edge. Standard lengths of the flashing are as follows: from 2 to 4 m.

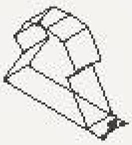
Floor slab thickness [cm]	Sheet edging thickness [mm]
≤11	1,20
12 - 14	1,50
≥ 15	2,00

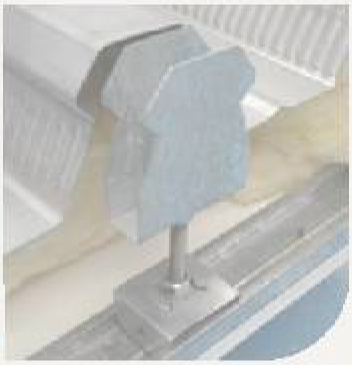
On the building site other additional and unavoidable accessories and materials must be provided.



Expanded plastic sealants







Cofrafix clamps – used in suspended floors with safe working load of 1,2 kN / suspension rod.

Cofrastra 70. Safe load tables

Reinforcement meshes

The crosswise spacing of the bars is adjusted in a stepless manner a = 300 – 500 mm
The lengthwise spacing of the bars b = 100, 150, 200 mm

Mesh types	The lengthwise spacing of the bars x diameter The crosswise spacing of the bars x diameter	Mesh sheet length Mesh sheet width	Ends projections on their length Ends projections on their width		Mesh sheet weight	The lengthwise bars reinforcement section The crosswise bars reinforcement section
	[mm]	[m]	[mm]		[kg]	[cm²/m]
Q 131	150 x 5,0	5,00	100	100	22,5	1,31
	150 x 5,0	2,15	25	25		1,31
Q 188	150 x 6,0	5,00	100	100	32,4	1,88
	150 x 6,0	2,15	25	25		1,88
Q 221	150 x 6,5/5,0-4/4	5,00	100	100	33,7	2,21
	150 x 6,5	2,15	25	25		2,21
Q 257	150 x 7,0	5,00	100	100	44,1	2,57
	150 x 7,0	2,15	25	25		2,57
Q 295	150 x 7,5/5,5-4,4	5,00	100	100	44,2	2,95
	150 x 7,5	2,15	25	25		2,95
Q 335	150 x 8,0	5,00	100	100	57,7	3,35
	150 x 8,0	2,15	25	25		3,35
Q 377	150 x 6,0d-6,0-4/4	6,00	100	100	67,6	3,77
	100 x 7,0	2,15	25	25		3,77
Q 378	150 x 8,5/6,0-4/4	6,00	150	150	66,7	3,78
	150 x 8,5	2,15	25	25		3,78
Q443	150 x 6,5/6,5-4/4	6,00	100	100	78,3	4,43
	100 x 7,5	2,15	25	25		4,43
Q 513	150 x 7,0d/7,0-4/4	6,00	100	100	90,0	5,13
	100 x 8,0	2,15	25	25		5,13
Q 524*	150 x 10,0	5,00	100	100	90,1	5,24
	150 x 10,0	2,15	25	25		5,24
Q 670	150 x 8,0d/8,0-4/4	6,00	100	100	115,4	6,70
	100 x 9,0	2,15	25	25		6,70

*10 mm wire mesh are manufactured in accordance with DIN 488. Configuration and structure can be done according to Customers' demands.