



# Structural Analysis

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*No design without structural analysis*



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## Loads

### 1. Dead load

- bearing construction:
  - $\gamma_c = 25,0 \text{ kN/m}^3$
- facade:
  - Walls on external perimeter (including windows)
  - only ground level and above
  - $8,0 \text{ kN/m}$
- Interior:
  - Finishing, pavement, embedded services, partitions
  - $3,0 \text{ kN/m}^2$



## Loads

### 2. Loads induced by environment

- Snow:
  - Acts on the roof and on the external (parking) area
  - $q_k = 1,70 \text{ kN/m}^2$
- Wind:
  - Calculated as described in EC 1 - EN 1991-1-4, 2010:12
  - Building assumed to be below 1000 m above sea level
  - Terrain category IV is assumed
  - Load is rising linear between height of 10 m to the top (19 m)
  - Wind is only acting on the vertical surfaces and is only set on one side of the building
  - No wind forces (friction) on the sides parallel to the wind direction



## Loads

### 2. Loads induced by environment

–Calculation of the wind loads:

- Facade acts as 2-span-girder in global X-direction of FEM-model

Wind loads [kN/m] Support	h < 10 m	h > 10 m		
		3 <sup>rd</sup> level	4 <sup>th</sup> level	5 <sup>th</sup> level
End support	2,02	2,26	2,49	2,73
Middle support	6,74	7,53	8,31	9,1



## Loads

### 2. Loads induced by environment

–Calculation of the wind loads:

- Facade acts as 5-span-girder in global Y-direction of FEM-model

Wind loads [kN/m] Support	h < 10 m	h > 10 m		
		3 <sup>rd</sup> level	4 <sup>th</sup> level	5 <sup>th</sup> level
End support	1,82	2,04	2,25	2,46
1. Internal support	5,23	5,84	6,45	7,06
2. Internal support	4,5	5,03	5,55	6,08



## Loads

### 3. Loads caused by the use

- Dwelling (apartments, living):
  - Level 1 to 5, and roof (as service load)
  - $q_k = 2,00 \text{ kN/m}^2$
- Public areas
  - Ground level, offices, Stairs
  - $q_k = 4,00 \text{ kN/m}^2$
- Parking:
  - Levels below ground, external parking area
  - $q_k = 2,50 \text{ kN/m}^2$



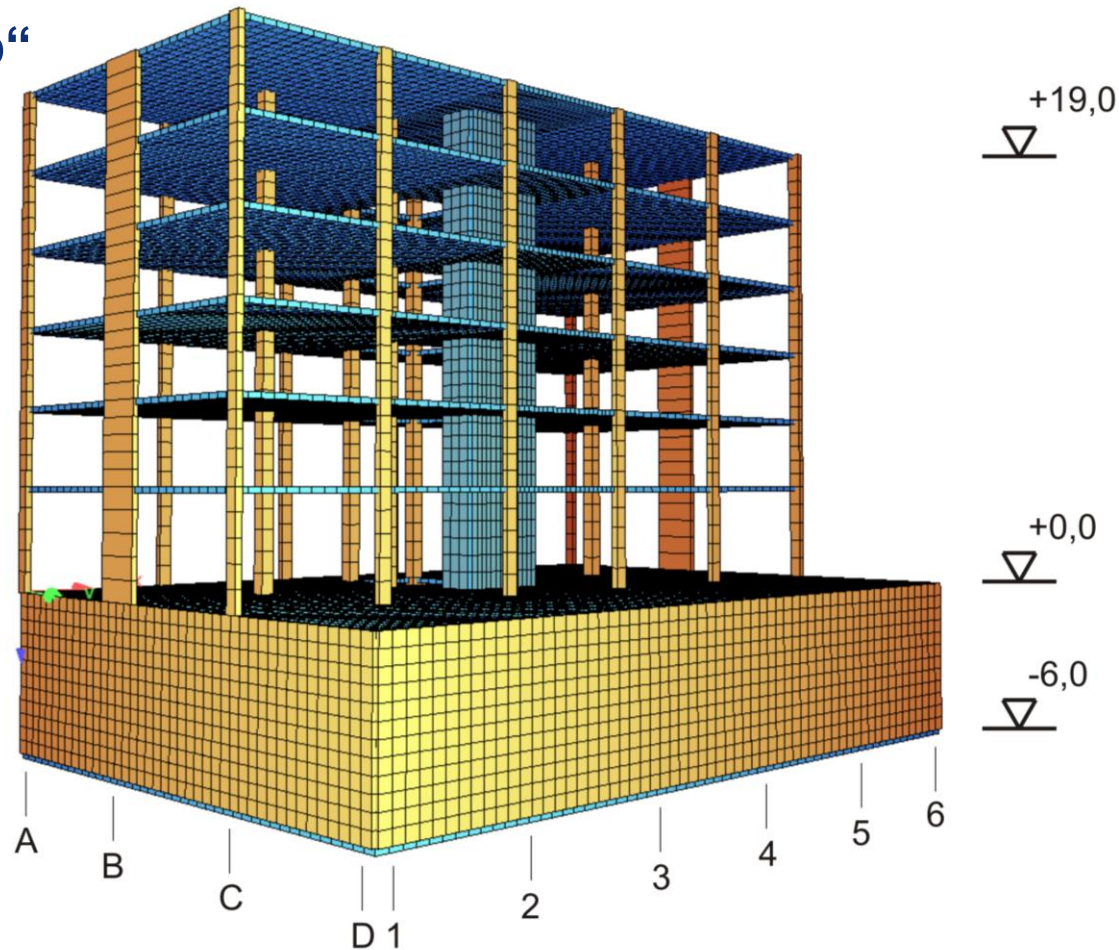


Type of Exposure	Load name	Value of load	Combination factors	
			$\Psi_0$	$\Psi_2$
Dead load	dead load of construction dead load of interior dead load of facade	Variable values 3.0 kN/m <sup>2</sup> 8.0 kN/m	-	
Environmental load 1	wind	0.77 kN/m <sup>2</sup> below 10 m 1.09 kN/m <sup>2</sup> at 19 m	0,6	0
Environmental load 2	snow on roof or external area	1.70 kN/m <sup>2</sup>	0,5	0
Service load 1	dwelling (level 1-6) stairs, office (level 0)	2.00 kN/m <sup>2</sup> 4.00 kN/m <sup>2</sup>	0,7	0,3
Service load 2	parking (level -1, -2, external area)	2.50 kN/m <sup>2</sup>	0,7	0,6



## Finite Element Model

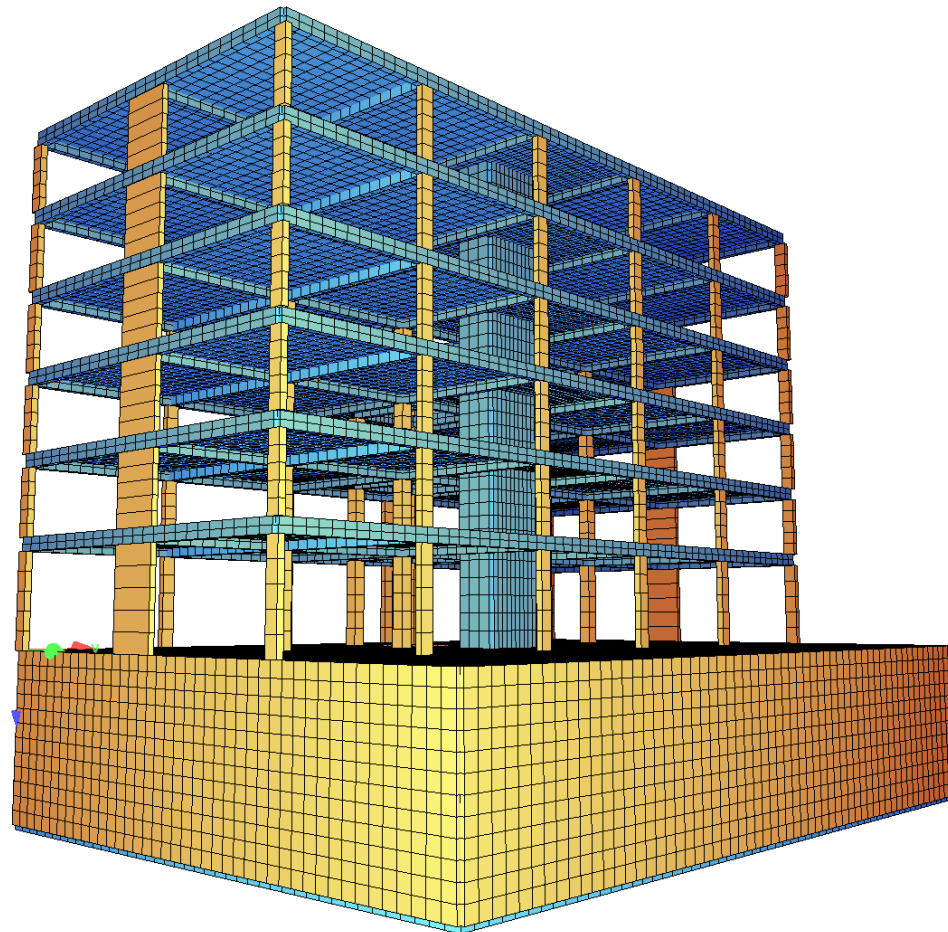
### Type „Flat slab“





## Finite Element Model

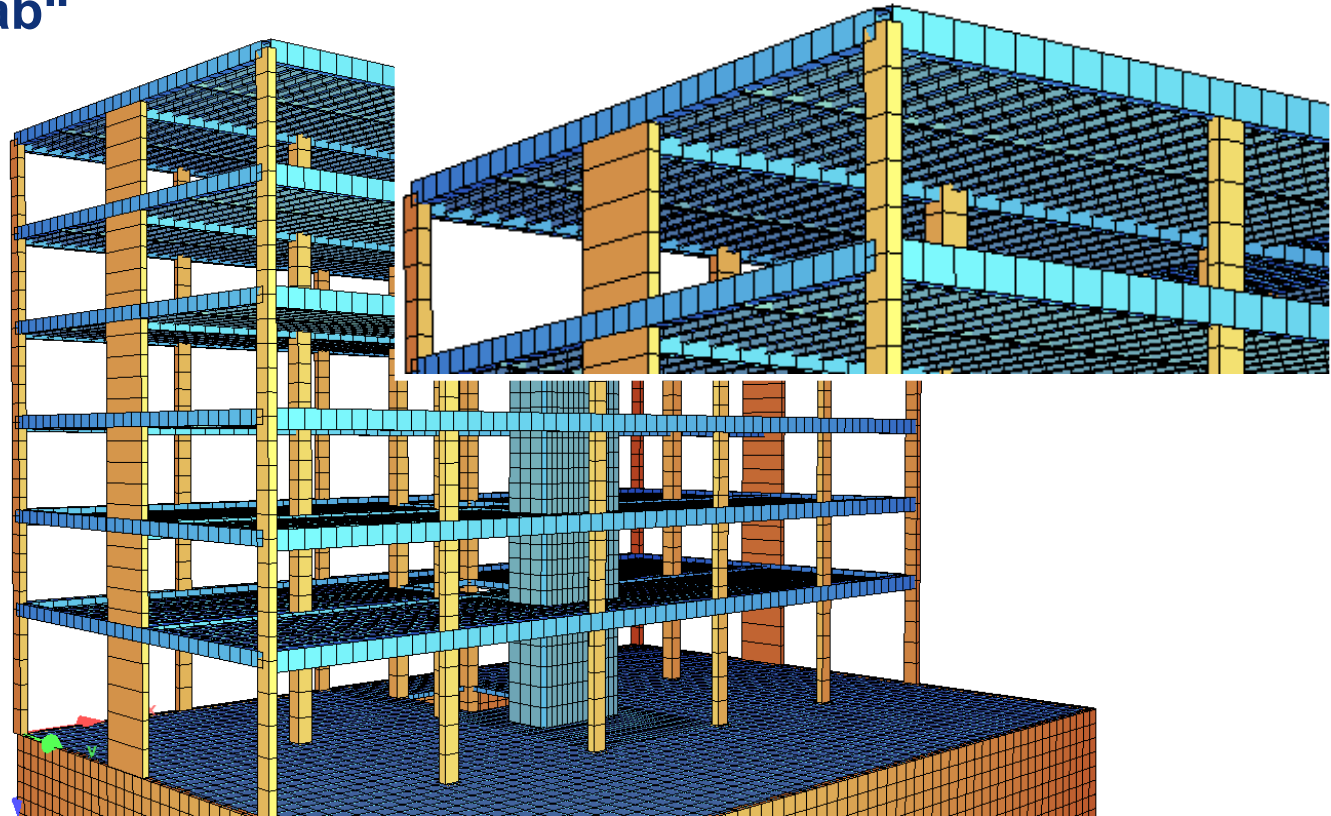
### Type „Beam slab“





## Finite Element Model

### Type „Italian slab“





## Finite Element Model

### Modeling:

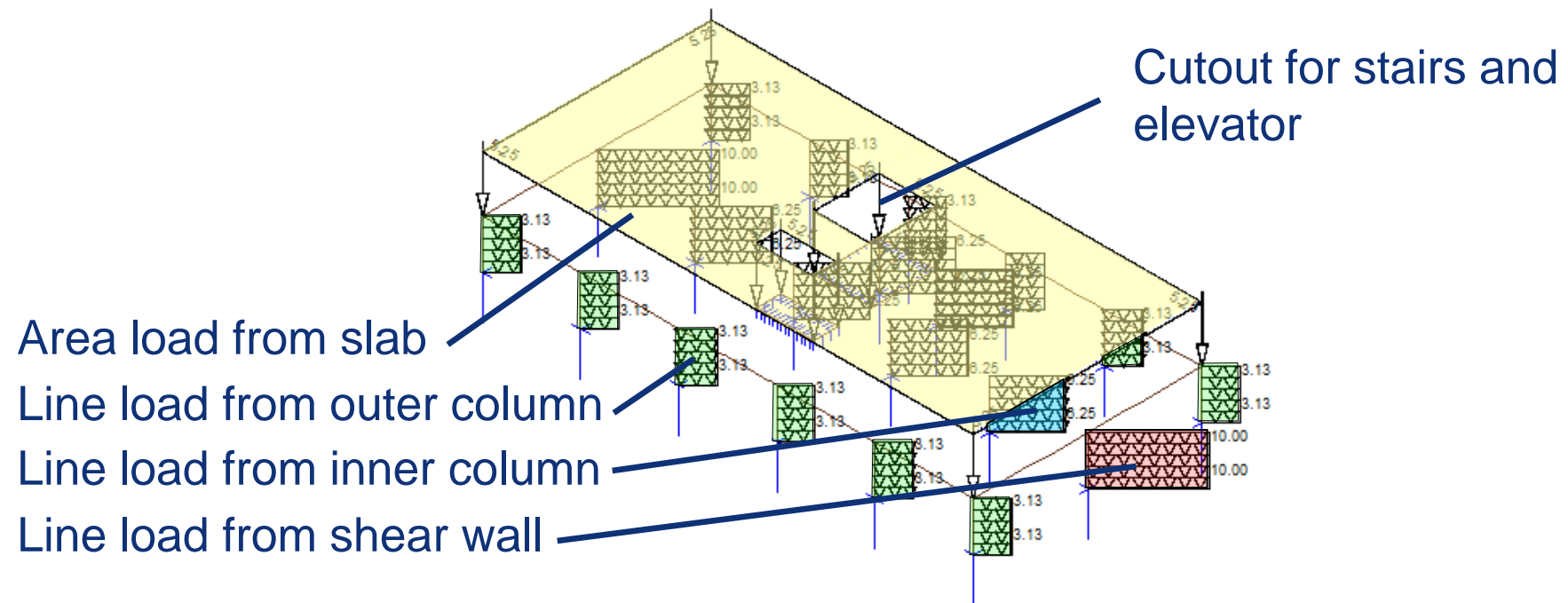
- Slabs are modeled as plate elements
- Columns and outer shear walls are represented by rod elements
- Shear walls in the center of the building are modeled as plate elements
- Beams for type „2-way slab with beams“ and type „slab with embedded elements“ are modeled as plate elements and as rod elements (combined)
- Rod elements provide easier evaluation



## Load Cases

### 1. Load Case 1 – Dead load of the construction

- Calculated by SOFiSTiK
- For better overview only a single level is shown:

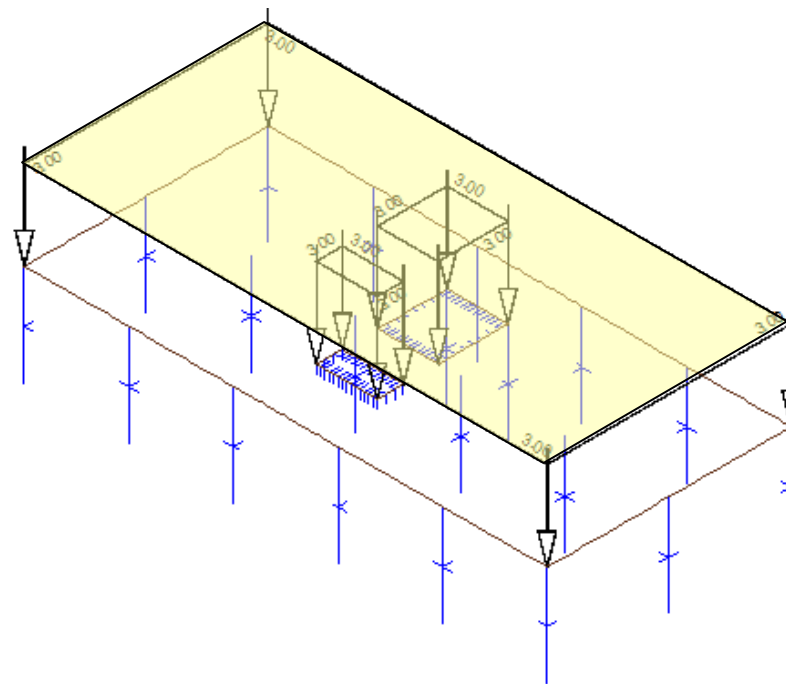




## Load Cases

### 2. Load Case 2 – Dead load of the interior

- For better overview only the roof is shown:

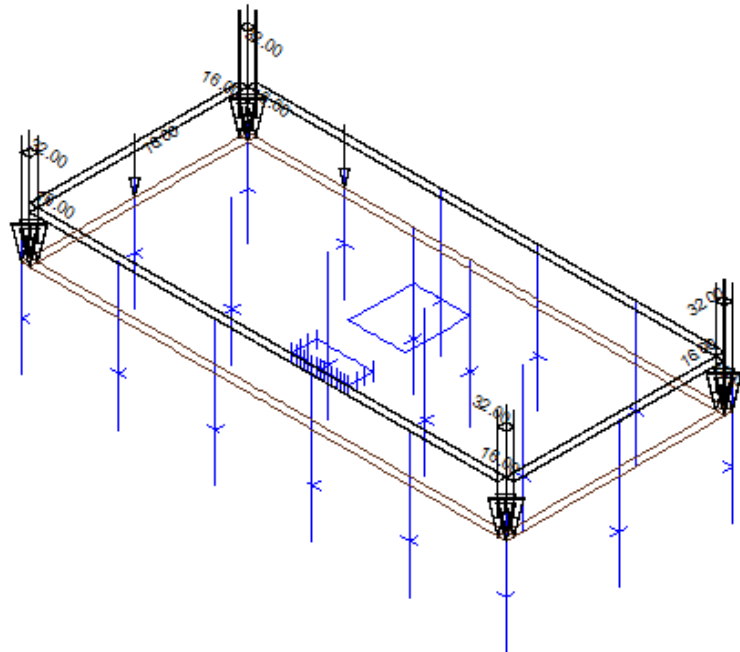




## Load Cases

### 3. Load Case 3 – Dead load of the facade

- Area load, set on the outmost row of finite elements
- For better overview only one level is shown:



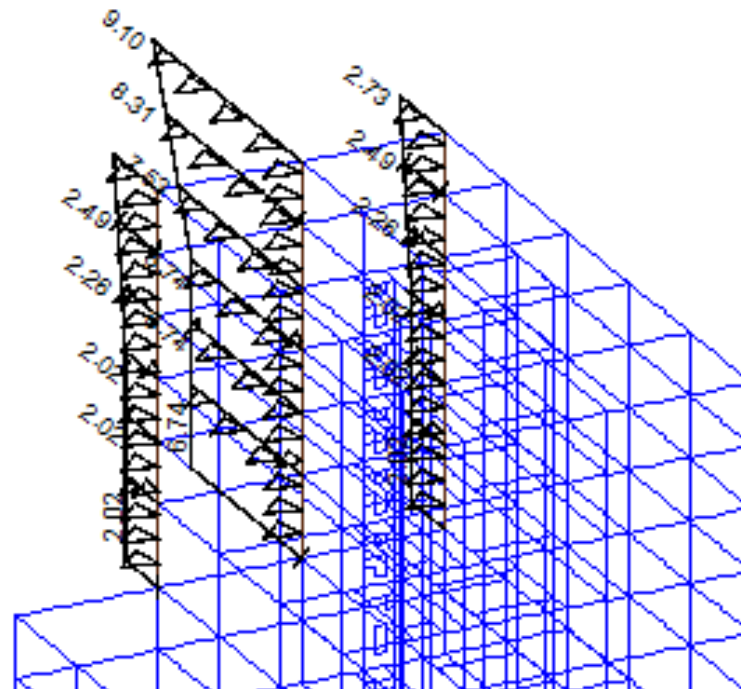
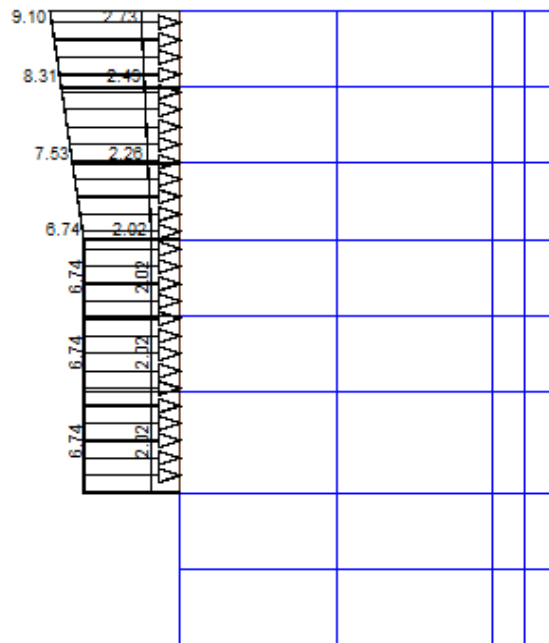




## Load Cases

### 4. Load Case 51 – Wind in global X - direction

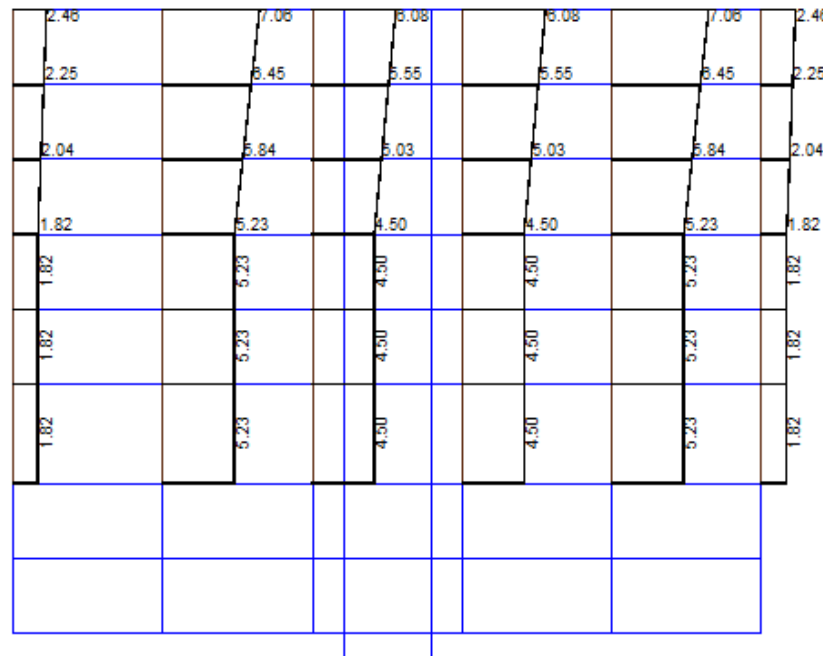
- Facade acts as a 2-span-girder between columns



## Load Cases

## 5. Load Case 101 – Wind in global Y - direction

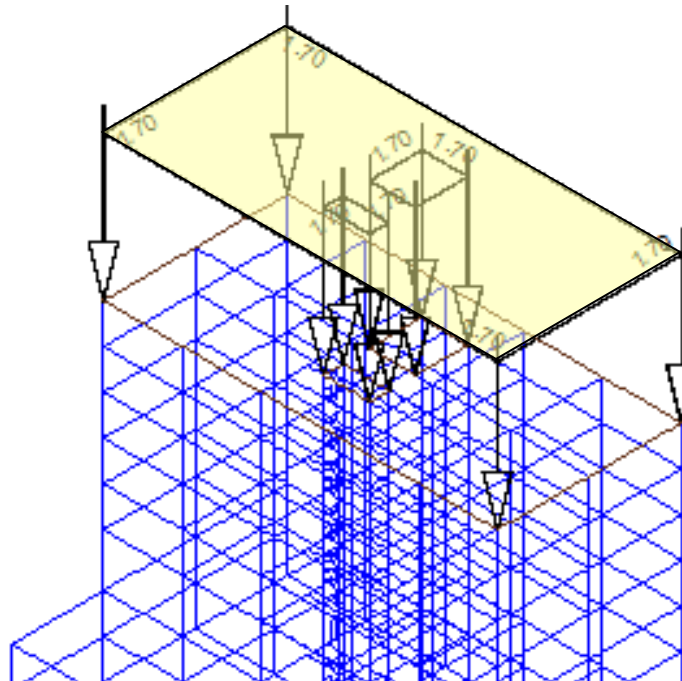
- Facade acts as a 5-span-girder between columns





## Load Cases

### 6. Load Case 201 – Snow on roof

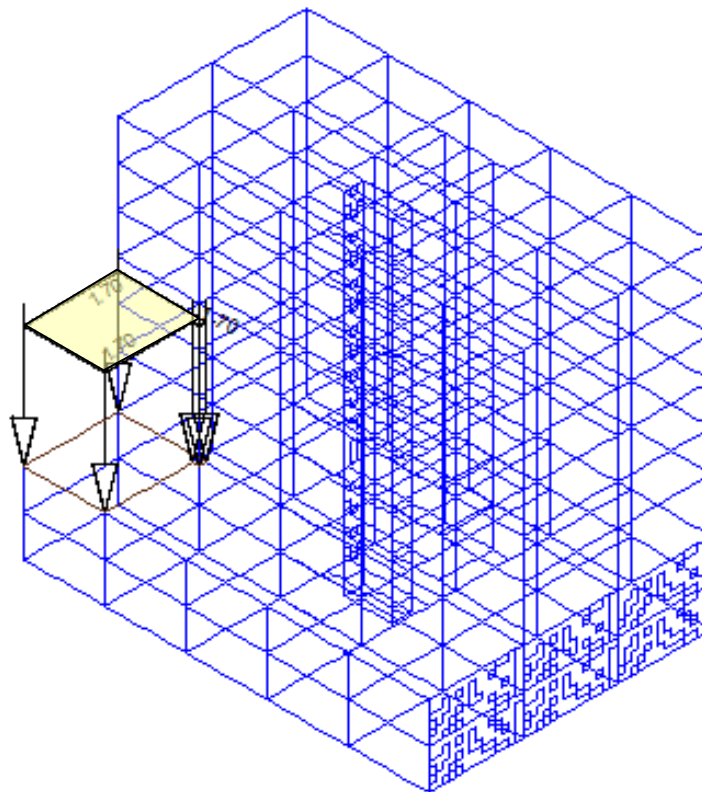




## Load Cases

### 7. Load Case 202 – Snow on external parking area

- Load cases 203 to 206 with load in the next fields

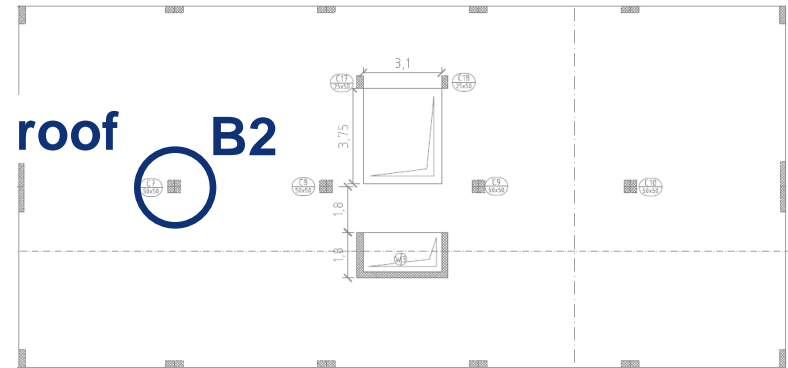
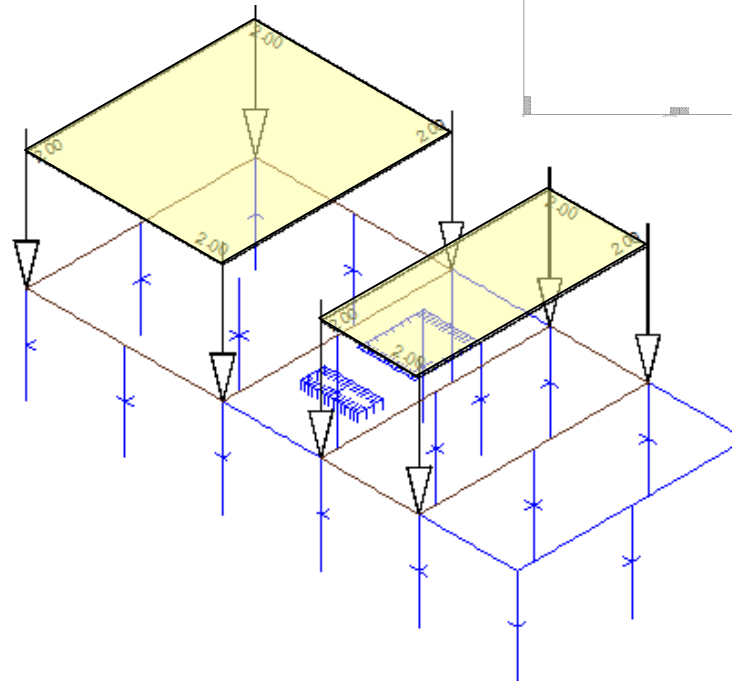




## Load Cases

### 8. Load Case 1326 – Service load on the roof

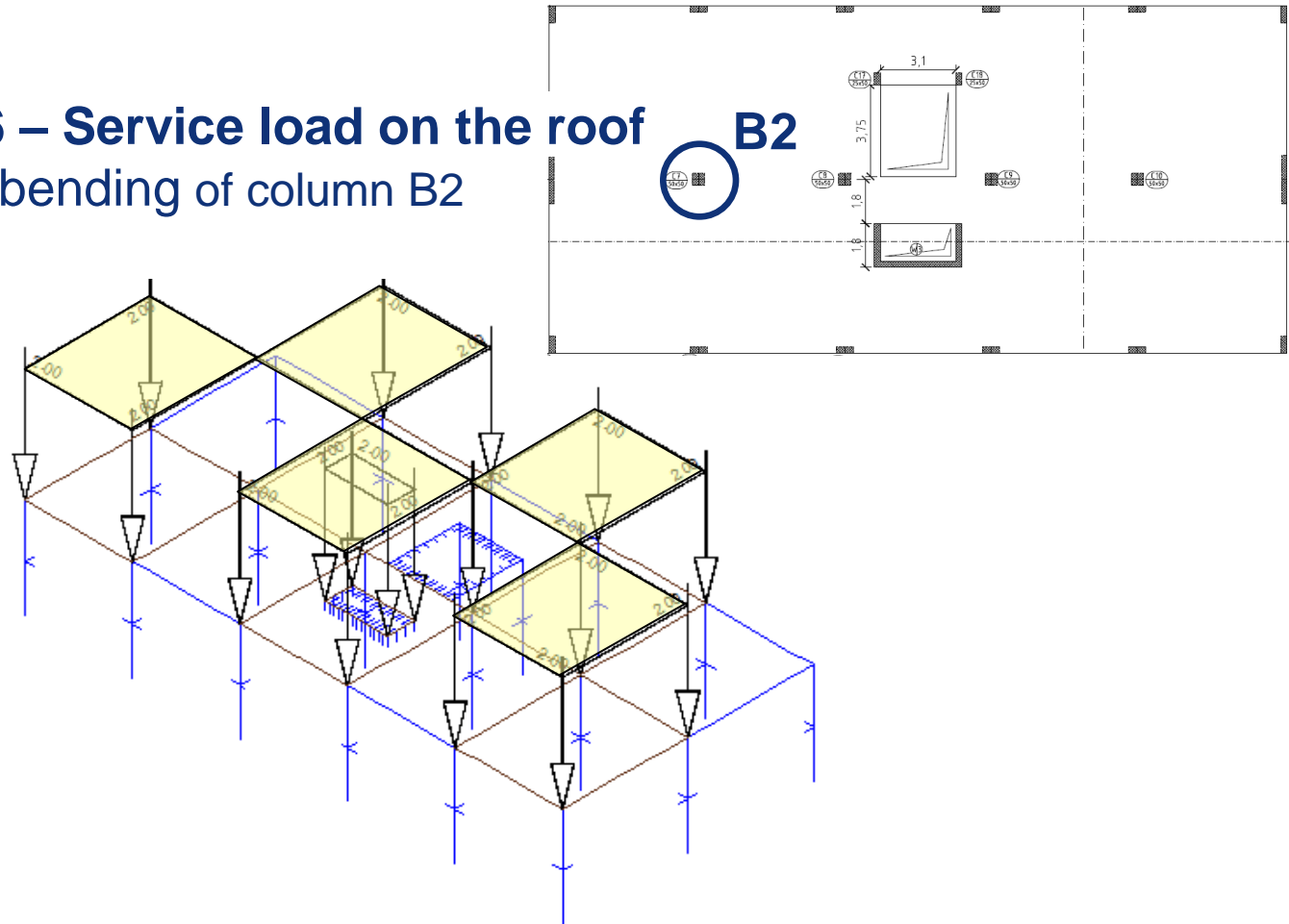
- For max. normal force in column B2



## Load Cases

## 9. Load Case 1356 – Service load on the roof

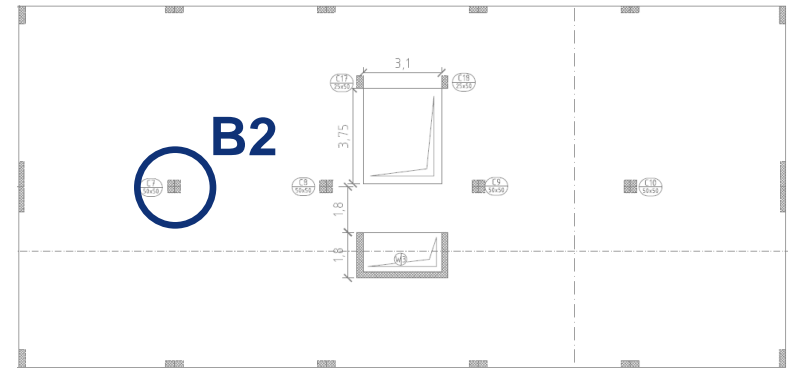
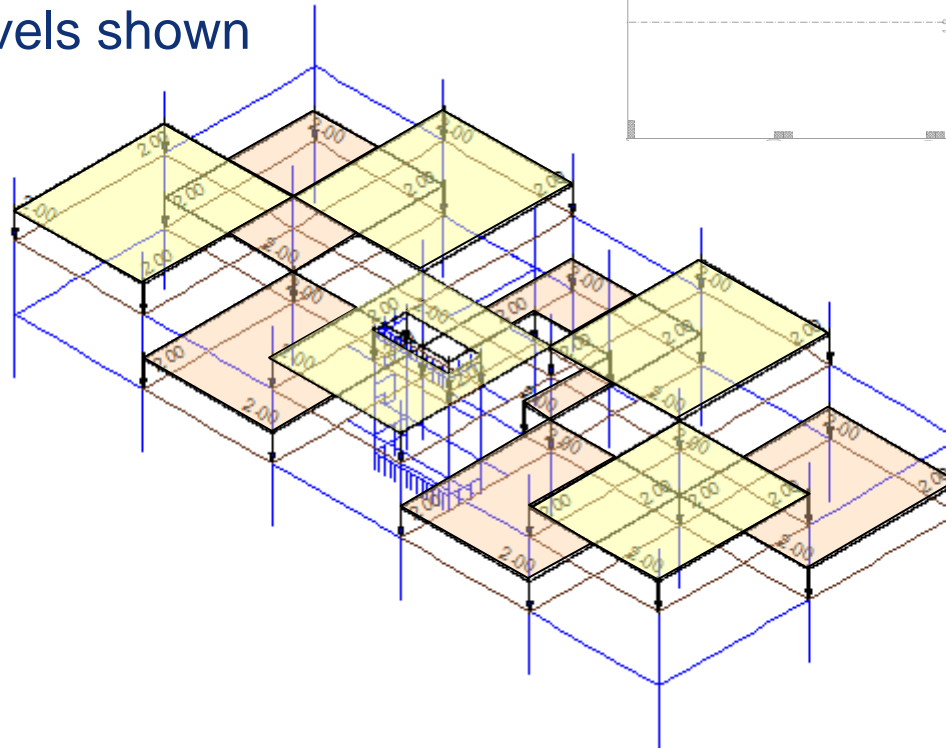
- For bi-axial bending of column B2



## Load Cases

## 9. Load Case 10001 – Service load

- For bi-axial bending of column B2
- Only 2 levels shown

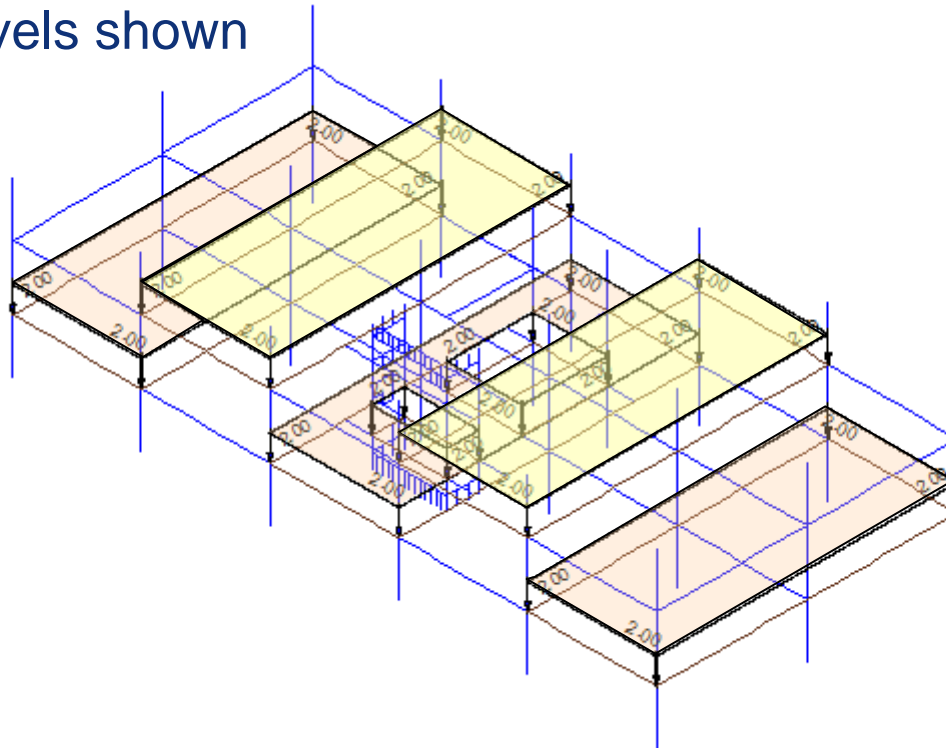




## Load Cases

### 9. Load Case 10011 – Service load

- For uni-axial bending & for max. field moments in the beams (axis B)
- Only 2 levels shown



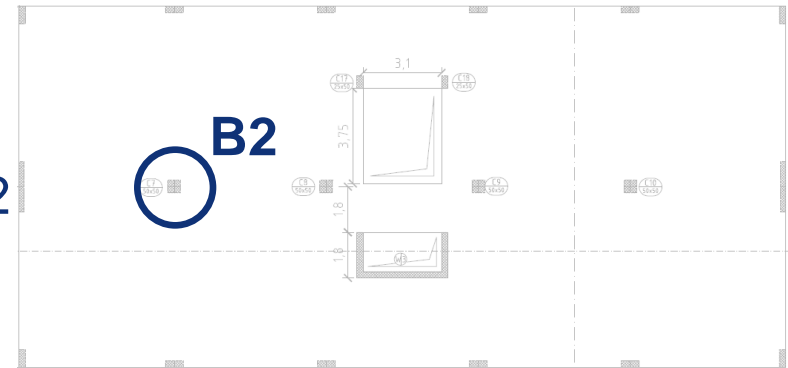
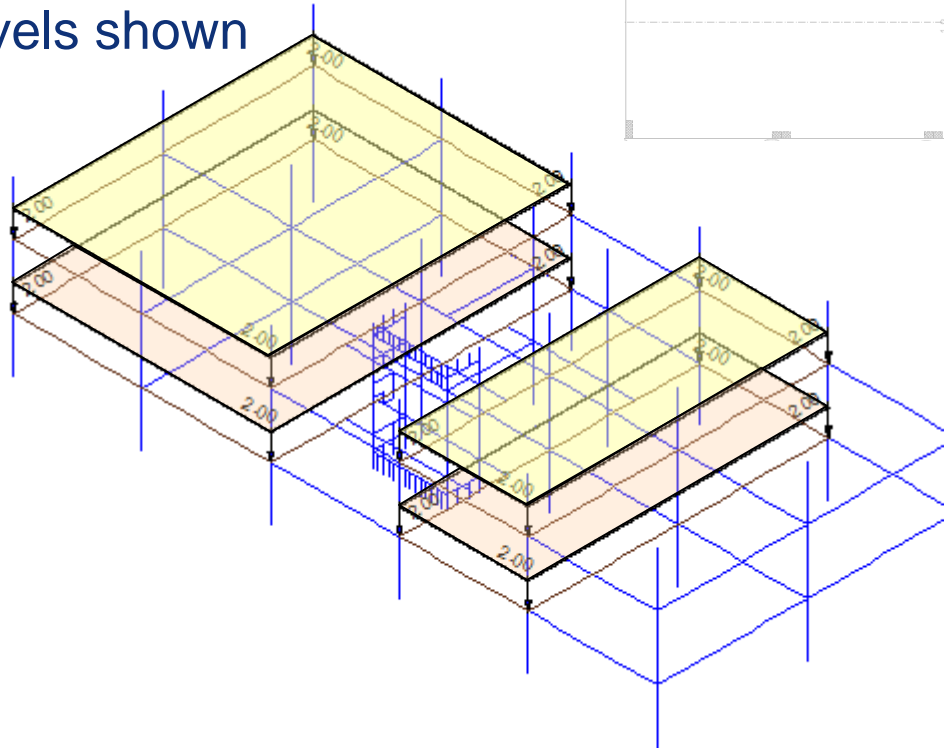




## Load Cases

### 9. Load Case 10021 – Service load

- For max. normal force in column B2
- Only 2 levels shown

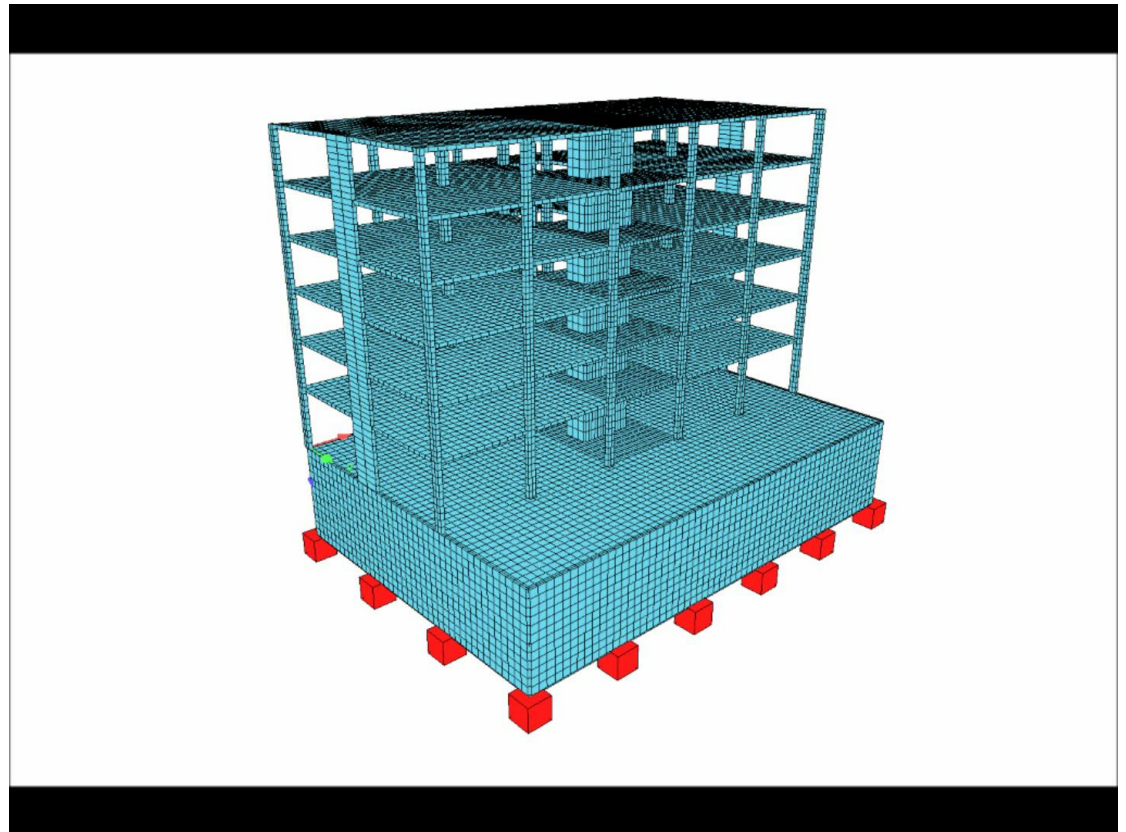




## Results of the structural analysis

### 1. Deformations

- Load Case 1 (dead load):

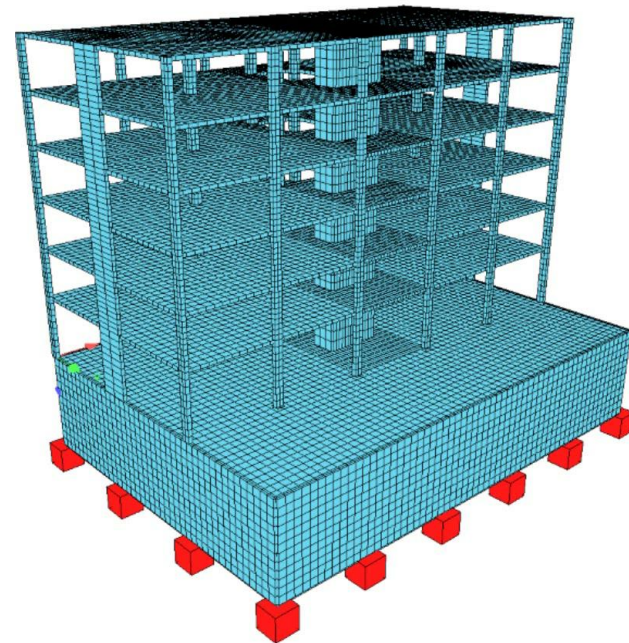




## Results of the structural analysis

### 1. Deformations

- Load Case 3 (facade):

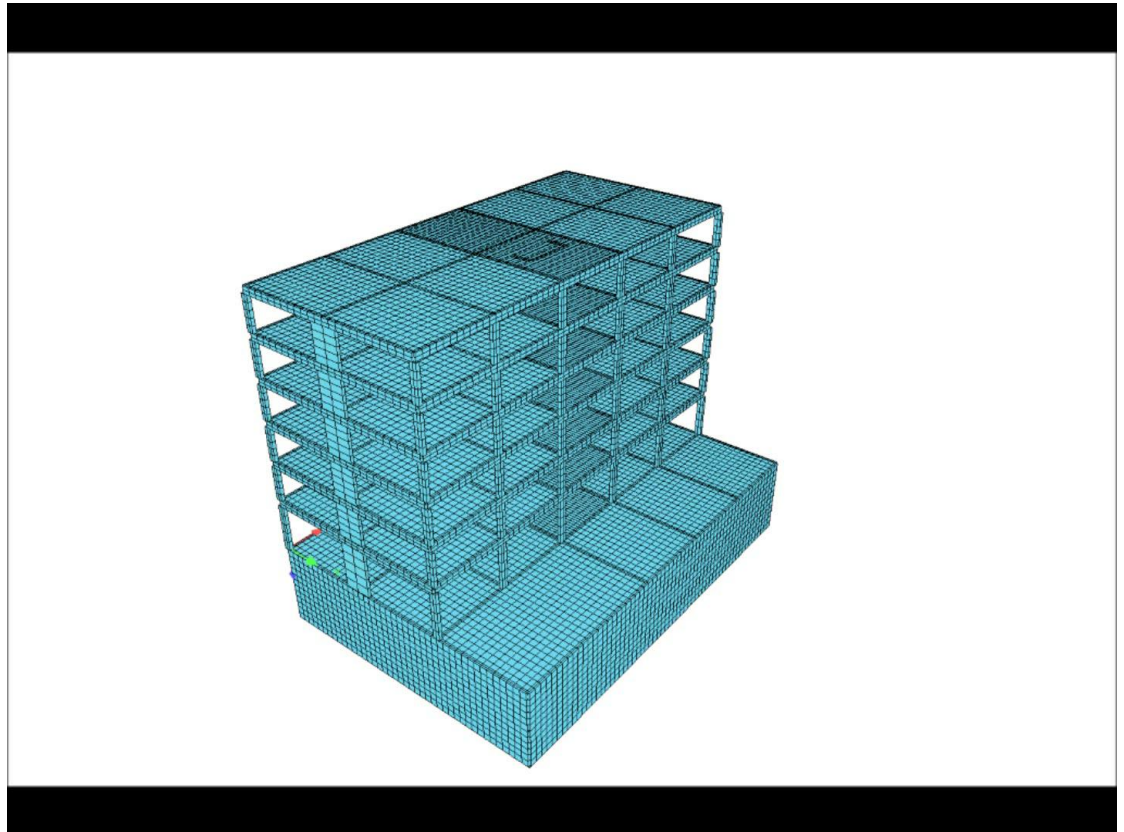




## Results of the structural analysis

### 1. Deformations

- Load Case 51 (wind in global X):

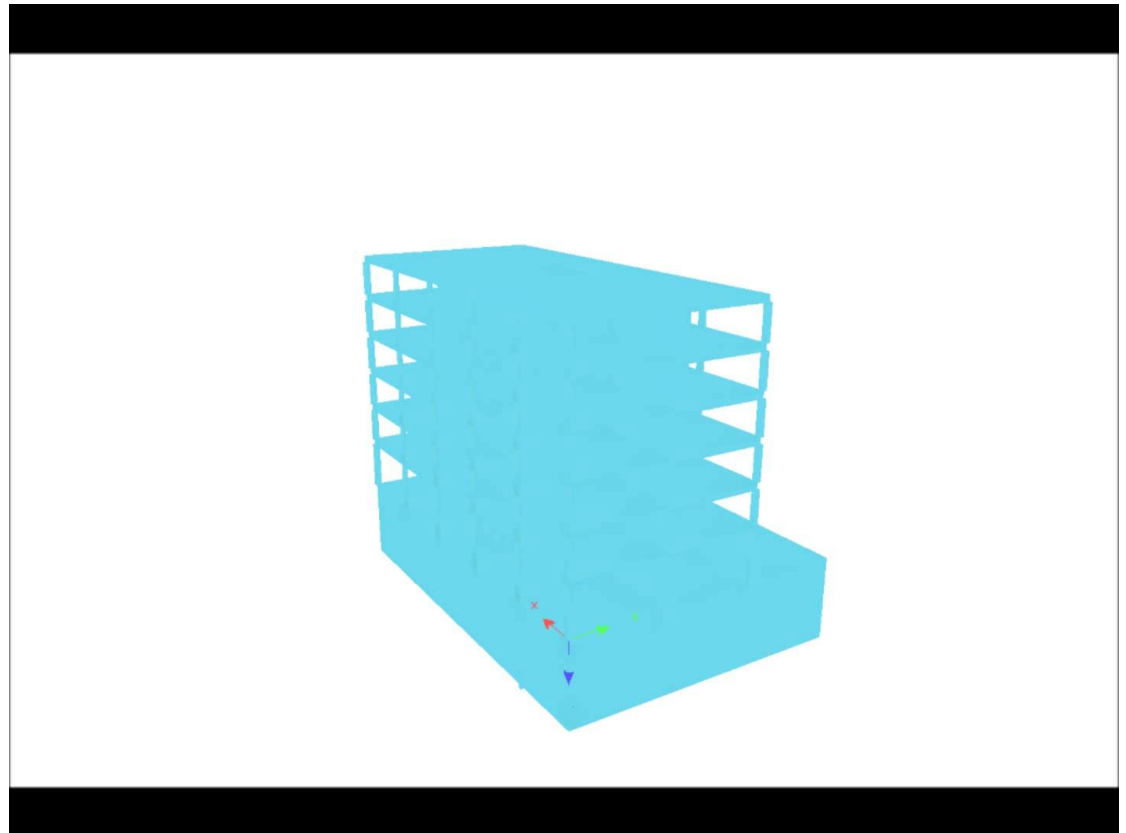




## Results of the structural analysis

### 1. Deformations

- Load Case 101 (wind in global Y):

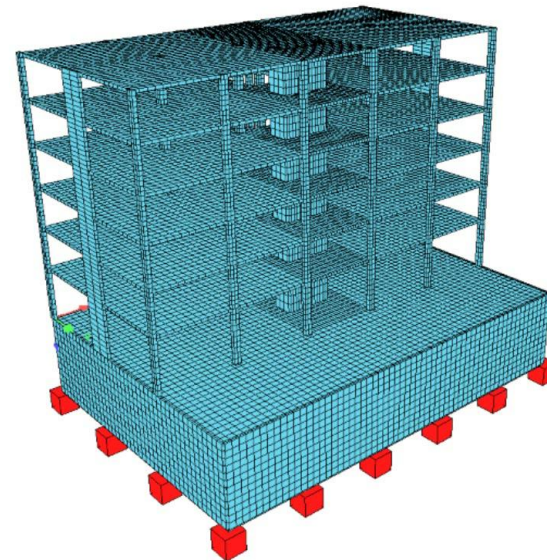
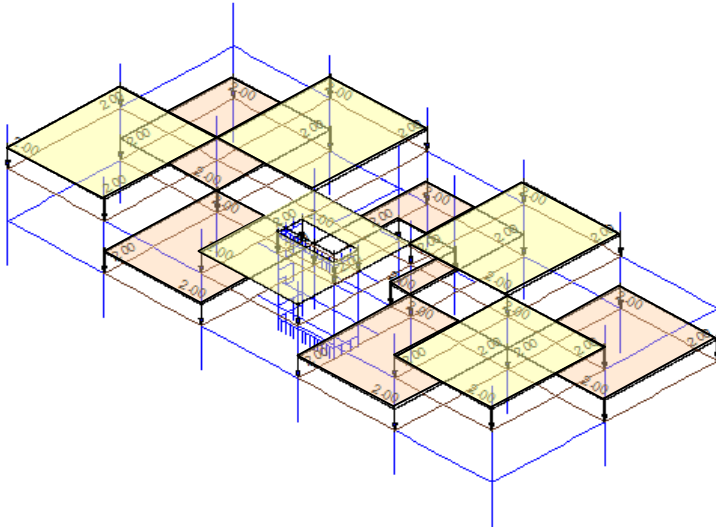




## Results of the structural analysis

### 1. Deformations

- Load Case 10001 (service load, arrangement 1):



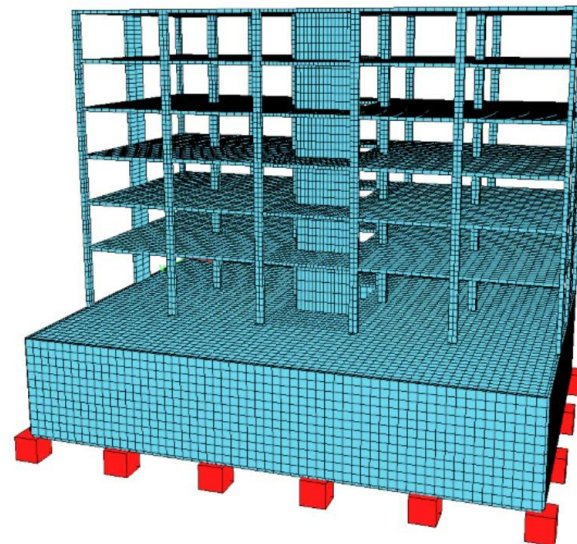
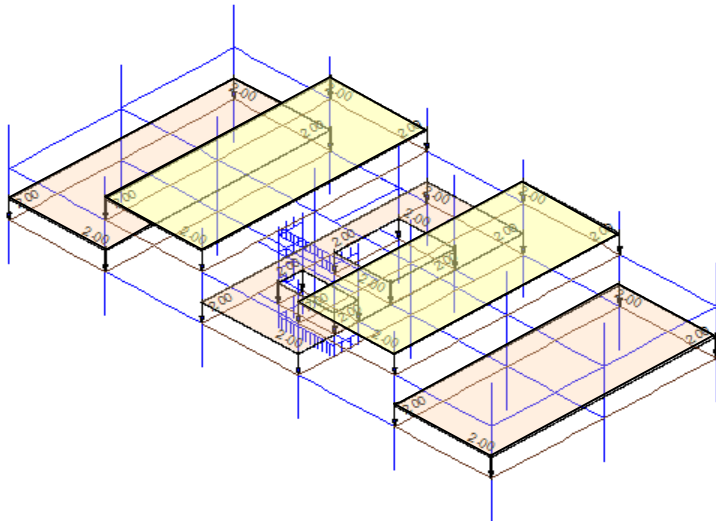




## Results of the structural analysis

### 1. Deformations

- Load Case 10011 (service load, arrangement 2):

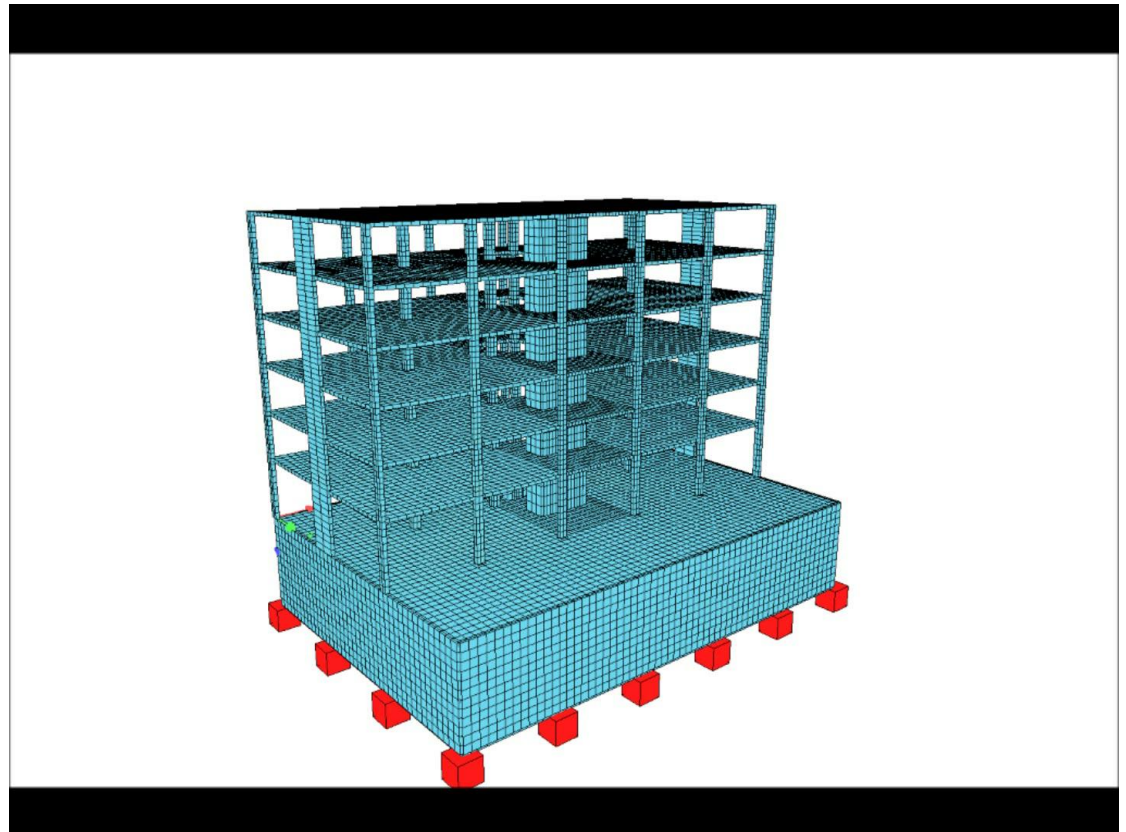
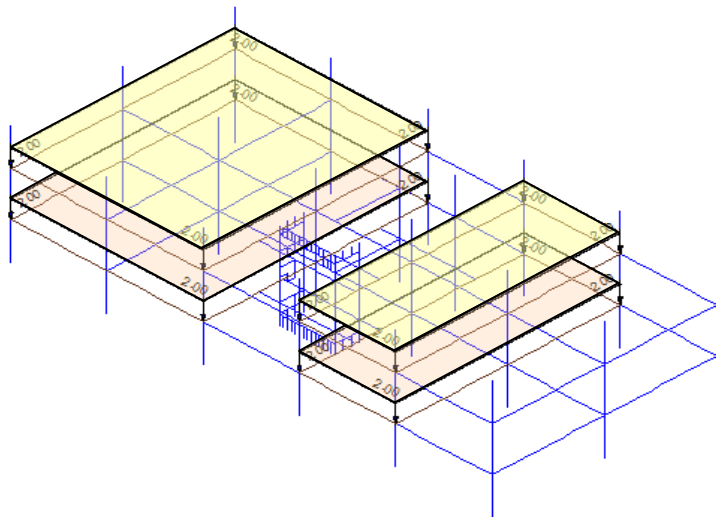




## Results of the structural analysis

### 1. Deformations

- Load Case 10021 (service load, arrangement 3):







## Results of the structural analysis

### Provided Data:

- Punching forces for slab design for type „Flat slab“ at the columns A1 and B2 in dwelling level
- Internal moments and shear forces for the 2-span-beam in axis 2 (2-way slab on beams) for ultimate limit state
- Internal moments and shear forces for the 5-span-beam in axis B (slab with embedded elements) for ultimate limit state
- Internal moments and shear forces for the design of column B2 and shear wall B1 for ultimate and serviceability limit state
- Bearing reactions for the design of the foundation of column B2 for ultimate and serviceability limit state

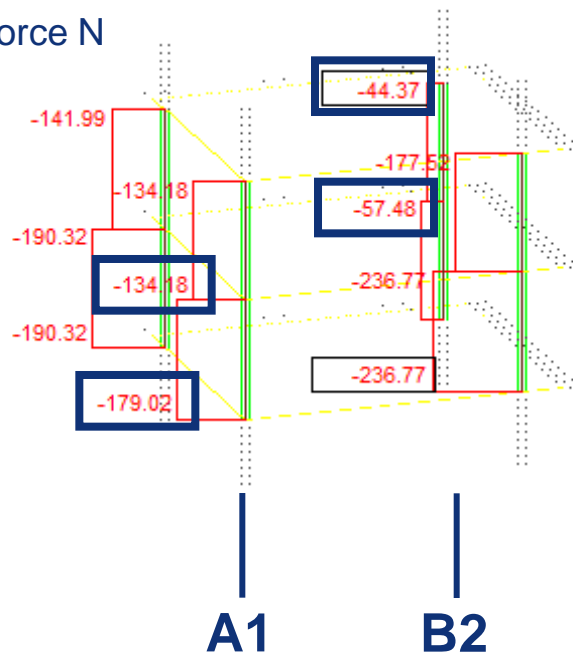


## Results of the structural analysis

### 2. Punching

- Difference in normal force in the columns equals punching force

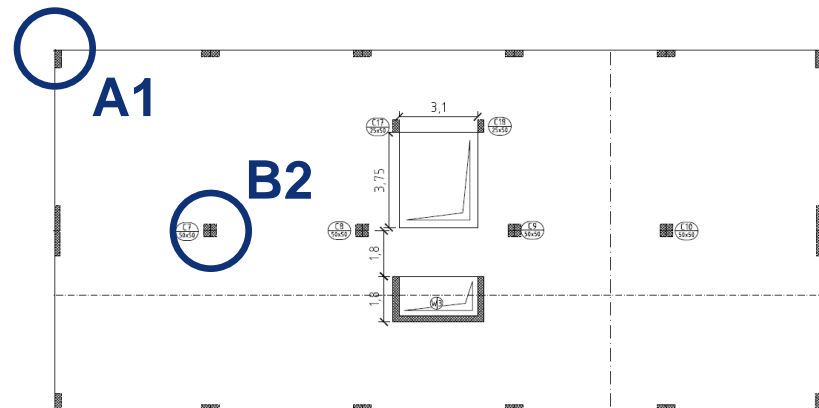
Normal force N  
in [kN]



E.g. load case 3 (facade):

For A1:  $\Delta N = 179.02 - 134.18 = 44,84 \text{ KN}$

For B2:  $\Delta N = 57,48 - 44,37 = 13,11 \text{ KN}$





## Results of the structural analysis

### 2. Punching

- This leads to the following table for all (authoritative) load cases:

Load Case	A1: $V_{Ed}$ [kN]	B2: $V_{Ed}$ [kN]
Dead load of construction	43,03	245,78
Dead load of interior	24,57	146,18
Dead load of facade	44,84	13,11
Service load, arrangement 1	-2,10	49,10
Service load, arrangement 2	-1,14	46,39
Service load, arrangement 3	16,39	97,23
Service load, arrangement 4	16,37	97,40

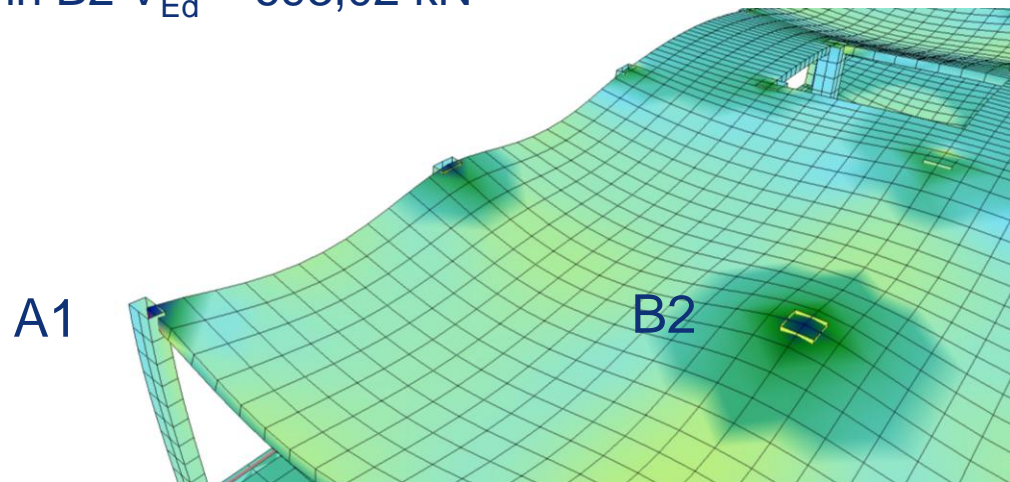


## Results of the structural analysis

### 2. Punching

– And leads to the following desing values by superposition:

- Flat slab at column A1  $V_{Ed} = 176,48 \text{ kN}$
- Flat slab at column B2  $V_{Ed} = 693,02 \text{ kN}$

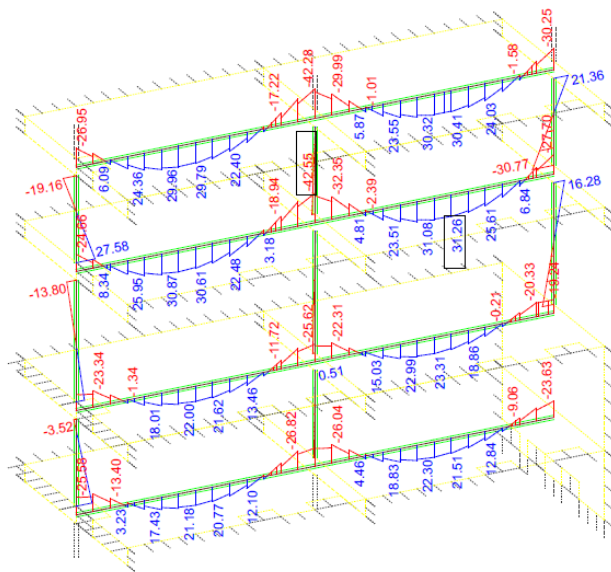


## Results of the structural analysis

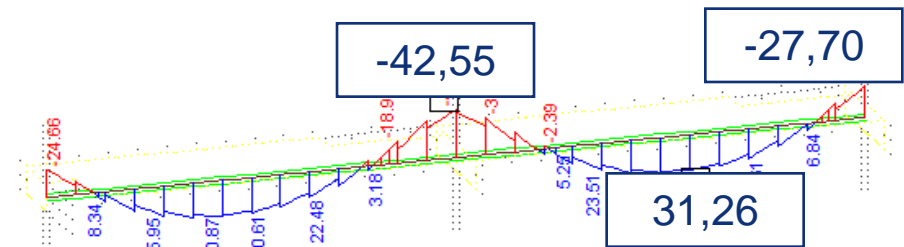
### 3. Internal forces and moments for beams in Axis 2, respectively B

- E.g. Load Case 1:

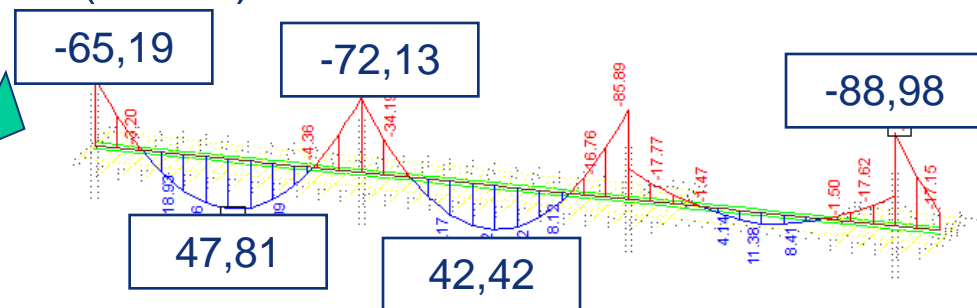
**Int. moment  $M_y$   
in [kNm]**



## Calculation of frame



For 2-way slab with beams, 2 spans  
(axis 2)



For slab with embedded elements,  
first 3 of 5 spans shown (axis B)



## Results of the structural analysis

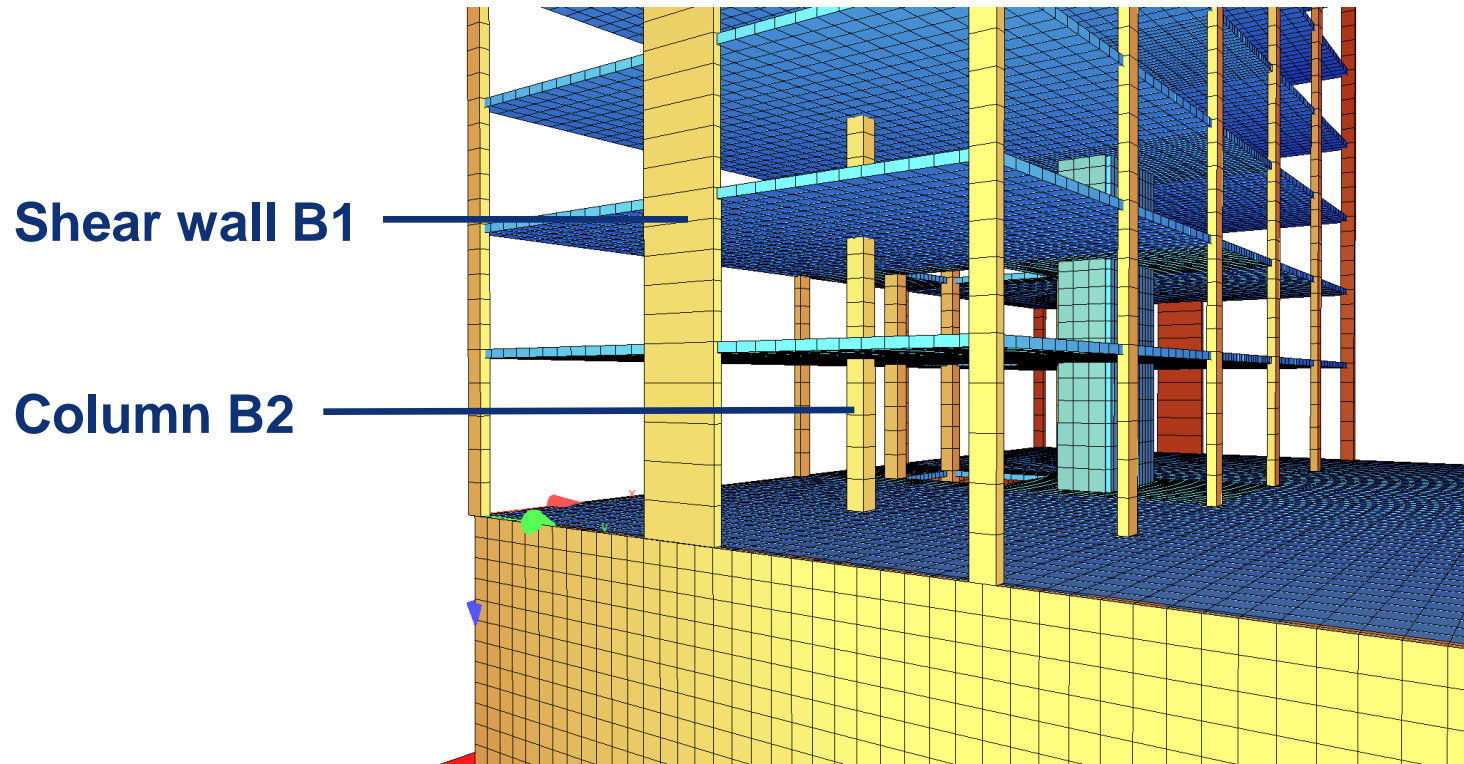
### **3. Internal forces and moments for beams in Axis 2, respectively B**

- Automatic superposition gives results for moments and shear forces:
  - Maximum shear force at all supports
  - Minimum moments at all supports
  - Maximum moments in span 1 (and in span 2 for slab with embedded elements)
  - Minimum moments in spans 2 and 3 for slab with embedded elements



## Results of the structural analysis

### 3. Internal forces and moments for column B2 and shear wall B1





## Results of the structural analysis

### **3. Internal forces and moments for column B2 and shear wall B1**

- Calculated analogous to the beams
- Superposition for the following values:
  - Max. and min. shear force in both local directions
  - Max. and min. internal moment in both local directions
  - Max. and min. normal force
- Calculated for the bottom end of column B2 in the 2<sup>nd</sup> level below ground
- also the values that belong to these superpositions have been calculated for the top end of this column
- Shear wall B1 is calculated in ground level





## Results of the structural analysis

### 3. Internal forces and moments for column B2 and shear wall B1

– e.g. for column B2 bottom end, ultimate limit state:

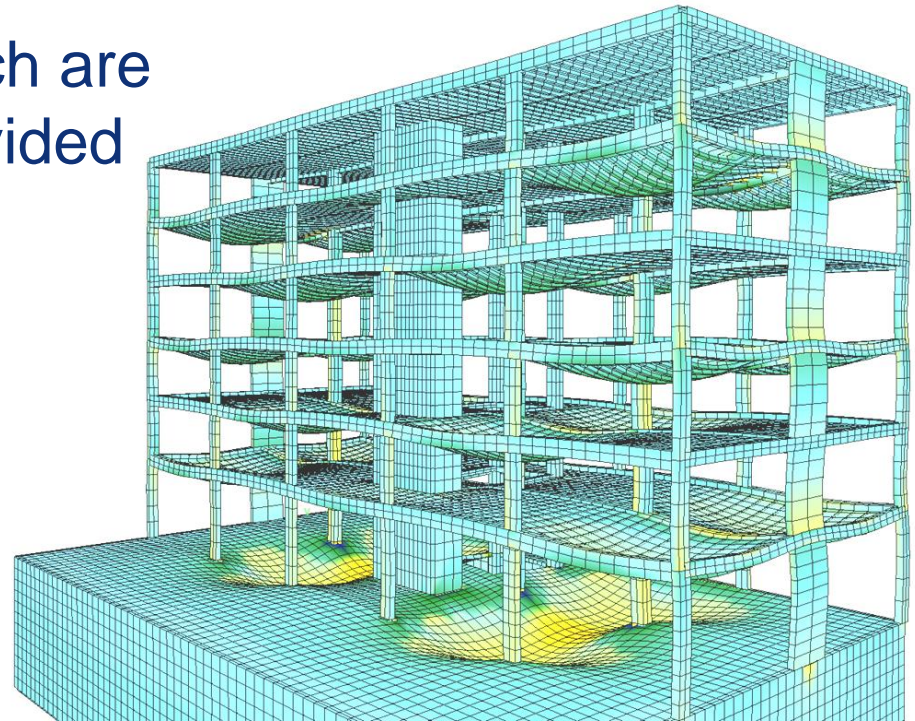
$$\gamma_G \cdot G \oplus \gamma_{Q,1} \cdot Q_1 \oplus \gamma_{Q,i} \cdot \Sigma(\psi_{0,i} \cdot Q_i)$$

Superposition	N <sub>d</sub> [kN]	V <sub>y,d</sub> [kN]	V <sub>z,d</sub> [kN]	M <sub>y,d</sub> [kNm]	M <sub>z,d</sub> [kNm]	Considered load cases	
						Q <sub>1</sub>	Q <sub>i</sub>
max M <sub>y</sub>	-4517,82	0,23	-4,05	4,21	-0,31	101	203 - 206, 1356, 10111
max M <sub>z</sub>	-4827,82	4,46	1,88	-2,43	4,45	10111	51, 203- 206, 10011
max V <sub>y</sub>	-4827,82	4,46	1,88	-2,43	4,45	10111	51, 203- 206, 10011
max V <sub>z</sub>	-5139,33	-2,46	2,96	-3,26	-2,08	51	10031, 10101
max N	-4408,94	-1,83	2,27	-2,73	-1,38	51	202 – 205
min M <sub>y</sub>	-5300,62	-2,48	2,96	-3,64	-2,12	51	201, 1326, 10031, 10101
min M <sub>z</sub>	-5407,83	-4,65	-1,43	1,17	-4,85	10121	101, 201, 202, 1326, 10021
min V <sub>y</sub>	-5358,27	-4,81	-1,46	-2,09	-4,70	10121	201, 202, 1356, 10021
min V <sub>z</sub>	-4467,29	0,25	-4,05	4,20	-0,29	101	202 – 206, 10111
min N	-5697,49	-4,53	1,54	-2,36	-4,49	10031 & 1336	201, 10121



## Summary of Structural Analysis

- Full results can be found in the workshop report
- Some additional data, which are not in the report, were provided for the detailing





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