CONSTRUCTION MANAGEMENT SIMULATION CENTRE at Lodz University of Technology

Architectural design of an academic facility with simulation hall and office spaces.

Project Description

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Lodz University of Technology
Lodz 2013

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Drawings

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1. General Information

1.1 Subject of the Project

The following work was created as the final project of the Architecture Engineering bachelor course at Lodz University of Technology. The project consists of the architectural design of a proposed new building for Lodz University of Technology.

The designed building is supposed to house the Construction Management Simulation Centre: a new academic facility providing simulation training for the students of the construction-affiliated university courses as well as the professionals active in the construction industry. The CMSC unit is crucial to the proposal, therefore its requirements are decisive for the architectural solution. The new building is also supposed to provide a presentation room, lecture hall, office spaces for the university organisations (BEST, ESN-EYE, The University Development Foundation etc.) and a 24h working space for students.

The designed spaces will be located on levels 0, +1, +2 and in a hall of height equal with the building.

1.2 Scope of the design

- The CMSC Simulation Hall in the large-volume building part with its height equal to the overall building height
- The CMSC office and the rooms required for its functioning, adjacent to the Simulation Hall, on levels +1, +2
- The office spaces located on levels 0, +1, +2
- The presentation room accessed from the 0 level
- The lecture hall with its floor located on level +1, two levels high
- The student working space, located on level +2
- The entrance hall, transportation and sanitary services

2. Description of the topic

2.1 Origin of the idea

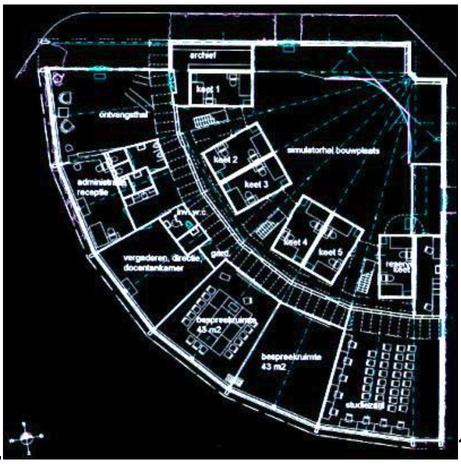
Currently a variety of simulation centres provide training in fields like aeronautics or medicine, often with the use of virtual reality systems and other specialised equipment. The Construction Management Simulation Centre for Lodz University of Technology is a proposal of a training facility based on three existing centres in the world which offer the modern simulation technology to the construction industry. The first one, called Building Management Simulation Centre, was created in year 2004 in Leeuvarden, Netherlands. Similar centres were established in Coventry, UK (2009) and in Melbourne, AU (2012).
In case of the project proposed for Lodz, the idea of CMSC design and its functional structure are based mainly on the Advanced Construction Technology Simulation Centre (ACT-UK) located in Coventry University Techno Park. The ACT-UK building (designed by *Robothams*) was visited by the author in 2011, during a simulation training organised for the students of Coventry University.

2.2 Working principles

The aim of the Construction Management Simulation Centre for Lodz University of Technology is to enhance training by making its participants feel as if they were in a real construction site environment. However, this happens without putting them to real hazards of the construction process. The simulation effect is achieved by combining the use of:

a) Realistic surroundings: offices arranged in the site huts, clothing, equipment
b) Virtual reality model of a project under construction
c) Interaction with the actors playing the roles of various construction employees and other people, depending on the scenario being put into action

The Simulation Hall is the core of the facility: it contains a set of typical construction site huts arranged around the central space of the hall. Each container constitutes a fully equipped office of a site supervisor. The space in the middle of the hall is flanked by a curved screen, 16m long, which provides the panoramic display of the computer model. The space provided for the simulation environment has to be large enough in volume to provide enough site huts for a reasonable number of participants and to accommodate any equipment or arrangement set up for the purpose of a training scenario. For this reason the simulation centre requires <u>a large-span hall.</u>

1.


[1]

2.


[2]

Examples: ***1.*** *Floor plan of the BMSC in Leeuvarden.* ***2.*** *View of the simulation hall in Coventry.*

To maximise the realism of the simulation, the supervisors are not present in the Simulation Hall. Instead, they monitor the action development from the Control Room, with the use of video cameras and microphones installed in the site huts. As a result of the functioning principles of the Simulation Centre, and because of its quasi theatre-backstage character, the CMSC requires the use of a hall and a number of rooms placed adjacently on several levels and connected according to the sequence of events during a training session.

[1] **B. de Vries, S. Verhagen, A.J. Jessurun (2001)** *Building Management Simulation Centre*
Pretoria: Proceedings of the CIB-W78 International Conference on IT Construction in Africa

[2] **Robothams (2009)** *ACT-UK National Centre for Advanced Construction Technology*
Website: http://www.robothams.co.uk/projects/colleges.html

3. Location of the building

3.1 Current use of the building lot

The lot proposed for the location of the designed building is situated in Lodz, on the north-west fringe of the Campus A of Lodz University of Technology. It is on the corner of streets: Żwirki, which serves as the northern boundary of the lot, and Politechniki, which is the western boundary.

The land in consideration belongs to the university, it is fenced along the adjacent streets. From the southern side the lot is defined by a slope, where the terrain level falls down by approx. 1.5 m. From the east a mild slope provides the driveway to the parking site that presently occupies most of the building lot. The fringes of the lot are covered by a rather random greenery.

1

2


Location overview:* *1. *East: entrance to the parking lot.* ***2.*** *South: Level change as the lot boundary.*

3.2 Potential of the location

Although currently neglected, the lot constitutes a very exposed and interesting location for a new building. The attractiveness of the discussed spot grows mainly from its possibility to provide a focal point for a number of axes existing in the surrounding urban layout. The evident directions are shown below:

a) The main axis of the park setting located to the west, on the other side of the street (Park im. księcia Józefa Poniatowskiego), leads the viewer towards an undefined space:

b) The closing view of the Żwirki street, lacking the culmination of the vertical fascade patterns:

c) The axis of Politechniki street in direction of south, the meeting point of streets. For the people coming from the north - the “gateway” to the areas occupied by the university. Lack of landmark that could inform and invite. On the functional level: no possibility to enter the campus from this spot:

4. Functional layout

4.1 Design assumptions

Assumed Program: The Construction Management Simulation Centre is the priority function of the building, thus lending its name to the whole project. However, to make the investment more beneficial to the university and to raise the academic performance of the proposed design, it is assumed that the building will contain additional functions:

- Auditory for the purpose of CMSC courses and other university lectures and events
- Presentation hall to house exhibitions, meetings and to serve as the space for informal meetings during events organised in the auditory
- Office spaces for several university organisations that lack working spaces or whose offices are scattered across university campus
- Working space for students that will be open for 24h/day and 7 days/week, providing the place for uninterrupted work at any time when such need occurs

Assumed interaction with the surroundings: The exposed location at the northern border of the technical university campus makes it necessary to consider an additional function of the building as the representative “university gate”. As a result, the following constraints are taken into account in the design:

- Possibility of entering the campus through the building
- Widened pedestrian area in front of the entrance to the building
- Relocation of the large volume elements with closed envelope away from the representative spots
- Location of a distinct, symmetrical element of considerable scale at the closing of the park axis
- Shaping the building plan to meet the layout of the campus corner spot and to open for the visitors
- Stretching the plan in the directions of existing frontages of university buildings / along the campus borders

4.2 Plan layout optimisation

Design Assumption	Convenient location or shaping of a building function or element			
	Auditory Presentation Hall	Office	CMSC Simulation Hall	Communication
Possibility of entering the campus through the building				Yes
Widened pedestrian area in front of the entrance to the building		Yes		Yes
Relocation of the large volume elements with closed envelope away from representative spots			Yes	
Location of a distinct, symmetrical element of a considerable scale at the closing of the park axis	Yes			
Shaping the building plan to meet the layout of the campus corner spot and to open for visitors		Yes		Yes
Stretching the plan in the directions of existing frontages of university buildings / along the campus borders	Yes		Yes	Yes

5. Solution for the floor plan

5.1 Summary of spaces

The function layout sets up the division of the building space into lecturing space and exhibition space, office rooms, the break spaces for employees, simulation centre hall, the rooms dedicated to the simulation centre, and the utility spaces. Depending on the floor plan arrangement, the entrances to the rooms are from the general communication space or from the adjacent functionally related spaces.

Level 0

Signature	FUNCTION	AREA
0.0	Communication	279,98
0.1	Bicycle storage	34,99
0.2	Locker room	15,56
0.3	Reception & Cloakroom	35,41
0.4	Office	45,77
0.5	Utility room	8,33
0.6	Toilet: Disabled	9,27
0.7	Toilet: Women	25,74
0.8	Toilet: Men	24,86
0.9	Participants lounge	35,68
0.10	Actor & Coach office	48,13
0.11	Bathroom	5,55
0.12	Equipment storage	34,96
0.13	Simulation Hall	433

Level +1

Signature	FUNCTION	AREA
1.0	Communication	191,49
1.1	Office	83,36
1.2	Office	26,82
1.3	Office	46,57
1.4	Break room	16,42
1.5	Utility room	8,33
1.6	Toilet: Disabled	9,27
1.7	Toilet: Women	25,74
1.8	Toilet: Men	24,86
1.9	Control Room	36,24
1.10	CMSC management	34,96
1.11	Server room	9,31
1.12	Conference room	33,12
1.13	Auditory	284,05

Level +2

Signature	FUNCTION	AREA
2.0	Communication	144,09
2.1	Office	64,37
2.2	Office	63,27
2.3	Office	44,77
2.4	Break room	16,42
2.5	Utility room	8,33
2.6	Toilet: Disabled	9,27
2.7	Toilet: Women	25,74
2.8	Toilet: Men	24,86
2.9	24 h Student computer lab	139,59

Area by level:

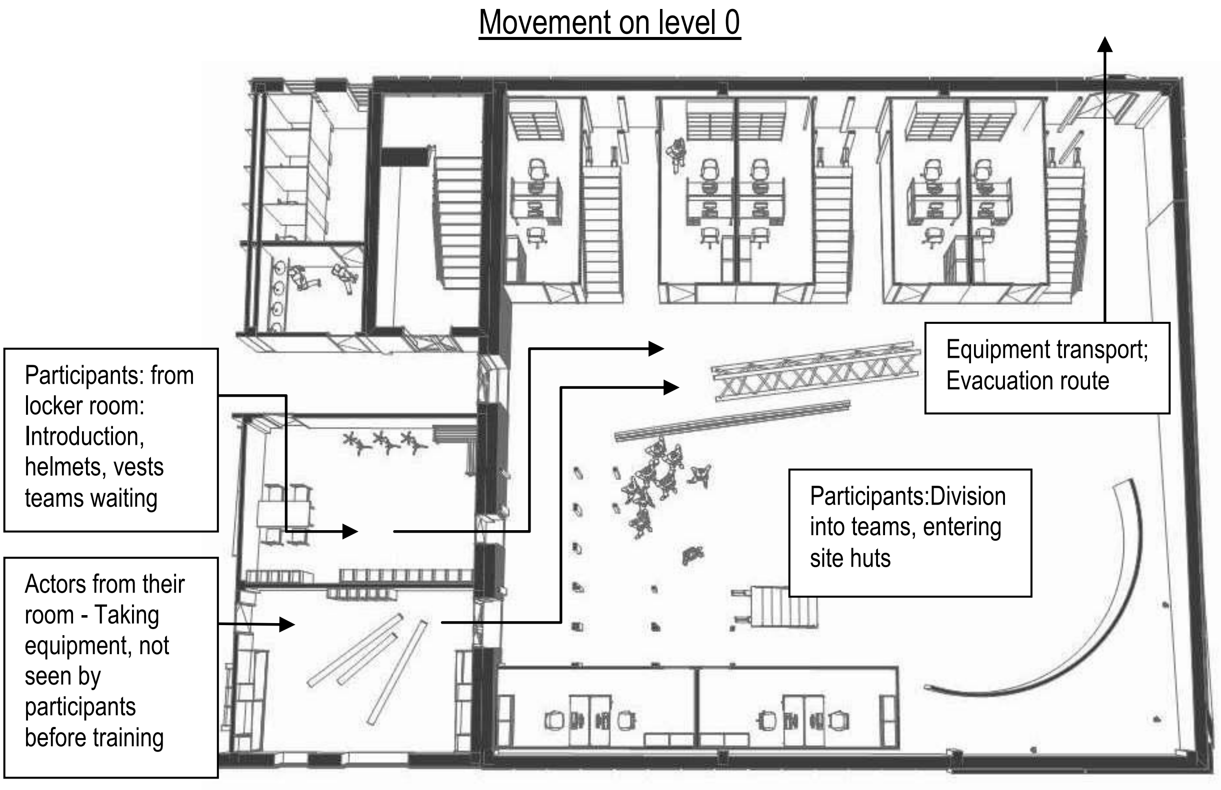
Level 0 1037,23 m²

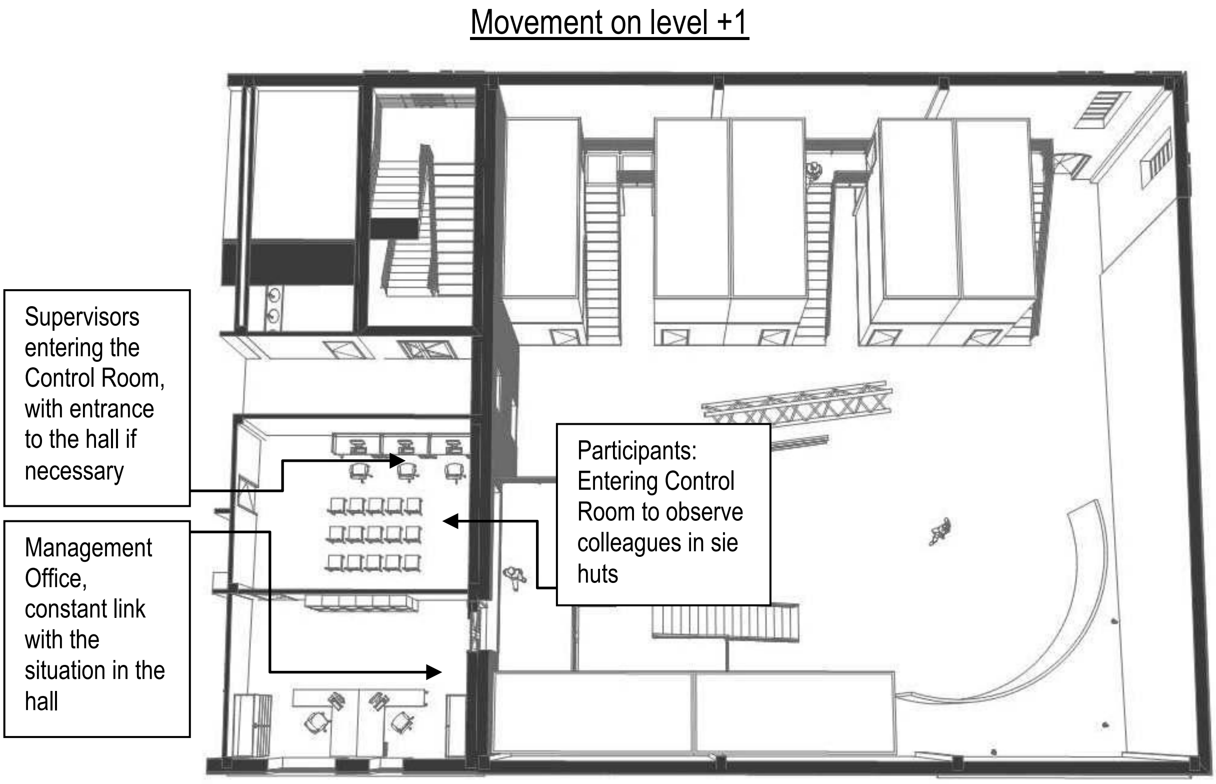
Level +1 830,54 m²

Level +2 540,71 m²

Total Area **2408,48 m²**

5.2 CMSC function sequence





6. Communication

6.1 Vertical transport

The maximum number of building users is anticipated as 240 for the most populated floor: level +1, which contains the lecture hall for 186 seats. The design assumes two inner staircases, 150 cm wide, one adjacent to the simulation hall, one adjacent to the lecture hall. The southern staircase continues above the level +2 to give the possibility of entering the roof. The vertical transport is supported by the elevator, placed in the central building core, next to the technical riser.

6.2 Horizontal communication

The horizontal communication in the building is through the perpendicular corridors layout. The communication pattern on Level 0 assumes the possibility of passage through the building, between the entrance on the corner of streets Politechniki and Żwirki, and the south-east entrance leading to the university campus. Additional entrance is provided next to the corner entrance, which leads through the bicycle storage. The simulation hall has auxiliary entrance to the side of Żwirki street, only for technical or evacuation purpose.

The accumulation of users moving towards the presentation hall, towards the simulation hall, users intending to get on level +1 and level +2, and the pedestrians crossing the building to enter the university campus is accommodated by the central courtyard on the level 0.

7. Working spaces

The design proposes the office spaces of various size, from managerial office to a multi desk space. The office height is set as 2,8 m from the floor to the level of hanged ceiling (3,5 m on level 0), which should be correct with the assumption that the air-conditioning will be provided in the working spaces. The office spaces fulfill the minimum floor area per person equal to 2 m². The distance from the working spaces to the generally available toilets will not exceed 75m. The height of the ceiling is set as 2,8 m (3,5 m on level 0). The centrally located office spaces on each level provide a break room for the employees, to be equipped with kitchen appliances and a dining place.

8. Access for handicapped users

The ground floor is accessed from the level of pavement. Levels +1 and +2 are accessed with the use of escalator, designed to be used by disabled people. On each floor there exists a separate toilet for handicapped people, which fulfills the required moving space of 1.5 m diameter. The simulation hall is accessed from the level of ground floor.

9. Technical spaces

On each level of the building exists a utility room provided for cleaning and other technical / small storage purposes. On each floor there is an entrance to the technical riser, on levels 0 and +2 this is located in adjacent rooms, on level +1 the entrance is from the corridor. A server space for IT equipment is provided on the level +1, accessed from the corridor.

10. Interior fittings

Flooring types:

- In the CMSC Simulation Hall the flooring should be provided in form of polished concrete surface.
- In the lecture hall, in the Actor & Coach room and the Control room on level +1, in the student lab and conference room on level +2, in all office spaces and break rooms, the flooring should be provided in the form of a raised floor covered with carpet.
- All other spaces should be provided with cement floor covered with terracotta.

Interior partitions:

- Erected with the use of a gypsum-carton wall system.

Ceiling type:

- Hanged ceilings on profiles, with fitted lighting system, providing empty spaces for installation of ventilation and electrical appliances

11. Fire safety

11.1 Building characteristcs

In the highest point, the height of building is equal to 13,44 m. The building may be ranked in the class of middle-height buildings (SW).

Number of levels above the ground level: 3

Fire danger of the category: ZL I

Anticipated fire safety class of the building: B

11.2 Evacuation ways

Evacuation from levels +1 and +2 is assumed through the two staircases. The conditions for evacuation are assumed according to the maximum number of users at level +1 which is 250 people. The stair width provided is above 1,2 m.

Each floor is provided with two evacuation exits. The distance between the evacuation exits is above 5 m.

For the rooms with one evacuation way, the length of that way is below 30 m.

The evacuation way width is above 1,4 m.

The maximum distance from any room to an evacuation staircase is below 40 m.

12. Infrastructure

It is assumed that the building will be connected to the existing municipal service lines for telephone, electricity, water, heat, canalisation and rainfall canalisation.

13. Elevation materials

13.1 Brickwork

Type: Yellow clinker brick

Elevation Drawings: North Elevation, East Elevation, South Elevation

13.2 Cladding Materials

Type: Wallplank System – coil coated aluminium – grey

Elevation Drawings: North Elevation, South Elevation, East Elevation, West Elevation

Type: Ventilated elevation panel system, Kronoplan Color or similar, white

Elevation Drawings: South Elevation, West Elevation

13.3 Glazing

Type: Pilkington Planar SentryGlass System or similar, of increased glass stiffness

Elevation Drawings: East Elevation, West Elevation

13.4 Curtain Walling

Type: Dortech Technal Visible Grid or similar, with insert profiles to allow commercial door system and casement windows to be incorporated into the curtain wall grid

Elevation Drawings: West Elevation

13.5 Entrance Doors

Type: Glass door on stainless steel Frame construction for double action glass doors

Elevation Drawings: East Elevation, West Elevation

14. Construction overview

14.1 Construction types

The bearing structure of the CMSC building for Lodz University of Technology is designed as a post-and-lintel construction. It is assumed that over majority of spaces the used type of slab will be the monolithic slab.

A different solution is proposed for two parts of the designed building:

- Auditory on level +1
- Simulation Hall

14.2 Solution for large spans

Because of the requirement for vast undivided and uninterrupted spaces in these building parts, it is necessary to provide a large-span solution for the roof. The solution proposed in the project is to use a system of prefabricated concrete elements. These include prefabricated large-span beams supported on prefabricated columns according to the provisions of a chosen system. The way the roof will rest on the beams depends on the chosen variant of the system.

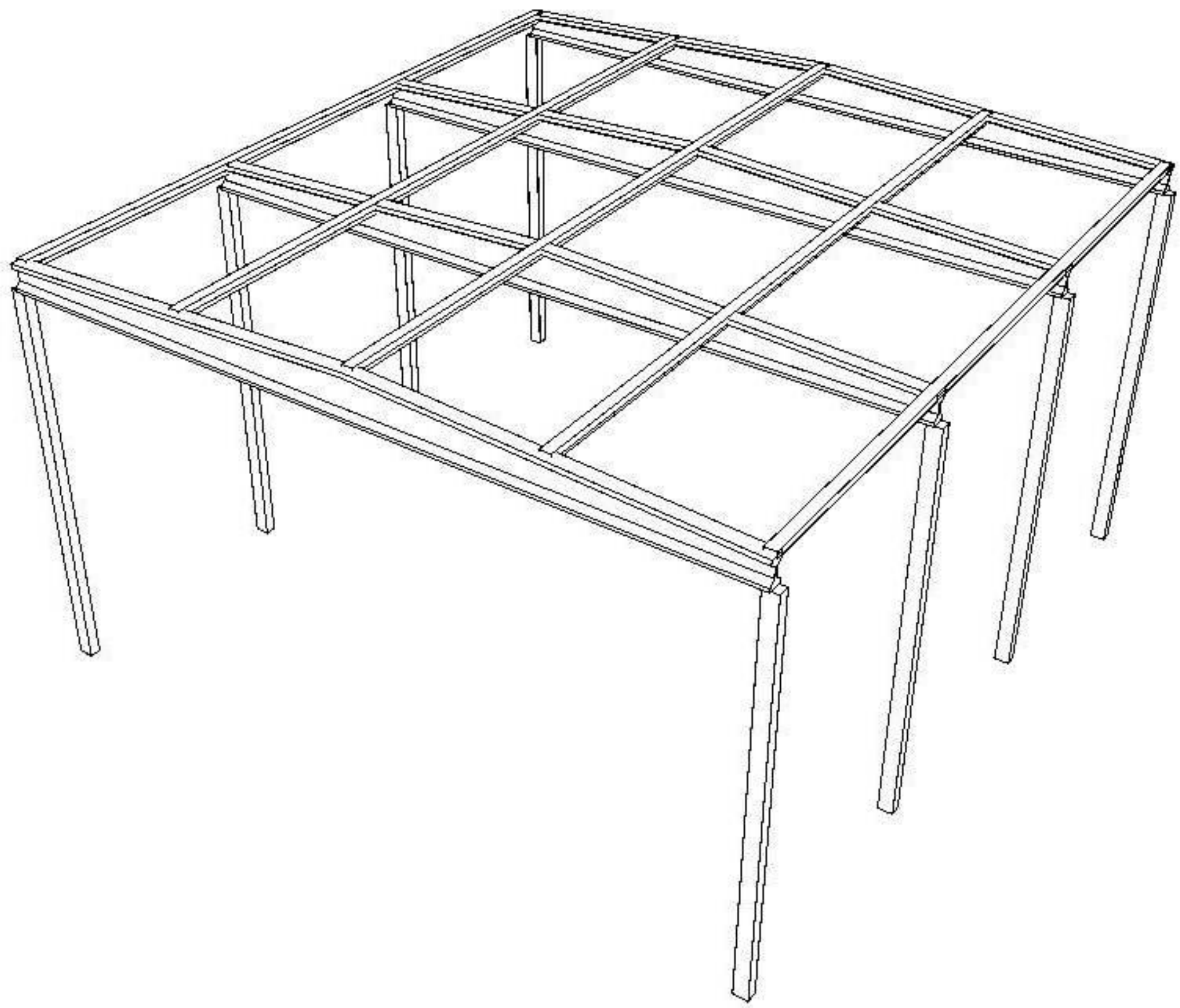
<u>Variant 1: Auditory</u>

- Main lintel structure: prefabricated concrete beams for slabs, I 700 / 300 or I 900 / 300 type (signature according to *Ergon)* or similar; SPAN: 1500 cm
- Auxiliary lintel structure: none
- Slab structure: precast slab elements, SP 160 type (signature according to *Ergon*) or similar;
  12 x elements, width: 120 cm
  1 x element, width 0.68 cm
- Cover: poured concrete slab, thickness: 14 cm
- Layers of the roof

Variant 2: Simulation Hall

- Main lintel structure: prefabricated concrete beams for sloped roofs, IV 1250 type (signature according to *Ergon)* or similar; SPAN: 2070 cm
- Auxiliary lintel structure: perpendicular lintels; SPAN: 700 cm
- Slab structure: precast slab elements, SP 160 type (signature according to *Ergon*) or similar; Supported on auxiliary lintel system
- Layers of the roof

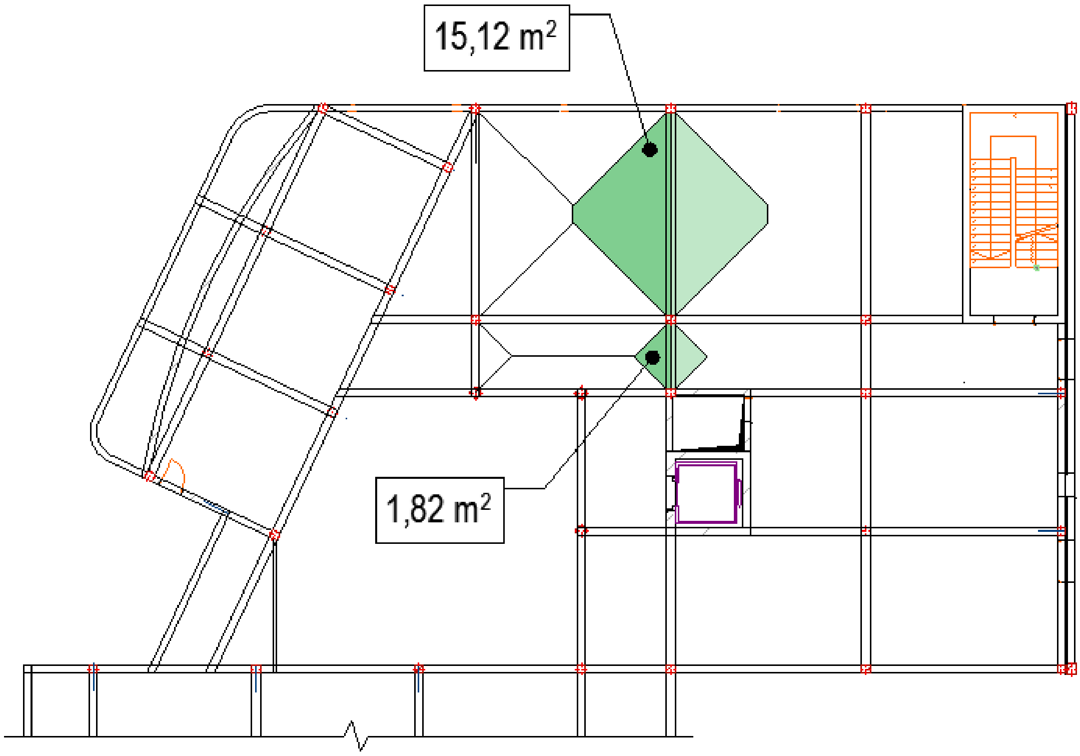
Perspective view: *Bearing structure of the Simulation Hall*

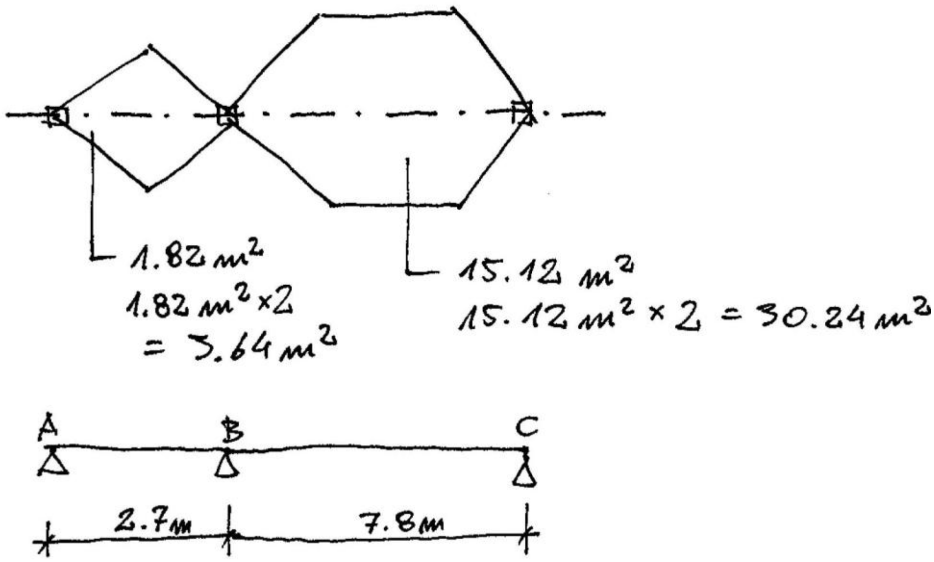


15. Design of a typical construction element

15.1 Reinforced concrete beam

This section concerns the structural design to be carried out for the Construction Management Simulation Centre project. The beam chosen for the presentation of a typical construction element design is located on Level 0. It was marked as Beam-1.1. Its location within the building structure and the concentration of loads are shown below:





15.2 Summary of loads

Summary of loads				
		Charact. Load (kN/m^2)	Design Factor	Design Load (kN/m^2)
Permanent				
Permanent load on the slab				
floor: tiles 2 cm		0,42	1,35	0,57
leveling cement 5 cm	0,04x24	0,96	1,35	1,30
polystyrene 4 cm	0,04x0,45	0,02	1,35	0,03
hanged ceiling panels	0,015x19	0,285	1,35	0,38
Fitting: SUM		**1,69**		**2,27**
Load from partition walls		**1,25**	1,35	**1,69**
Fitting & Partitions: SUM		**3,87**		**3,96**
Slab self-weight				
reinforced concrete monolithic slab: thickness: 18 cm	0,18x25	**4,5**	1,35	**6,08**
Total				**10,04**
Variable				
Corridor		**4,00**	1,50	**6,00**
Office		**2,50**	1,50	**3,75**

15.3 Design actions per metre

PERMANENT ACTION G_K

FITTING : $3.96 \frac{kN}{m^2}$

SLAB : $6.08 \frac{kN}{m^2}$

VARIABLE ACTION Q_K

CORRIDOR : $6.00 \frac{kN}{m^2}$

OFFICE : $3.75 \frac{kN}{m^2}$

$L_1 = 2.7\ m \qquad W_1 / m = 21.63 \frac{kN}{m}$

$L_2 = 7.8\ m \qquad W_2 / m = 53.46 \frac{kN}{m}$

15.4 Determination of internal forces

STIFFNESS

$$AB \quad \frac{3}{4} \times \frac{I}{L_1} = \frac{3}{4} \times \frac{1}{2.7} = 0.278$$

$$BC \quad \frac{3}{4} \times \frac{I}{L_2} = \frac{3}{4} \times \frac{1}{7.8} = 0.096$$

FIXED END MOMENTS

$$M_{BA} = \frac{wL^2}{8} = \frac{21.63 \frac{kN}{m} \times (2.7m)^2}{8} = 19.71\ kNm$$

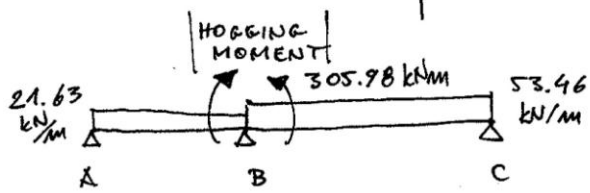
$$M_{BC} = \frac{wL^2}{8} = \frac{53.46 \frac{kN}{m} \times (7.8m)^2}{8} = 406.56\ kNm$$

DISTRIBUTION

DISTRIBUTION FACTORS : $0.278 + 0.096 = 0.374$

$$\frac{0.278}{0.374} = 0.74 \qquad \frac{0.096}{0.374} = 0.26$$

	0.74	0.26	
0	19.71	-406.56	0
	286.27	100.58	
0	305.98	305.98	0



$$L_1 \times R_A = \left(21.63 \frac{kN}{m} \times 2.7m \times 1.35\right) - 305.98\ kNm$$

$$R_A = -227.14\ kNm / 2.7m$$

$$R_A = -84.13\ kN$$

$$R_B = \left(21.63 \frac{kN}{m} \times 2.7m\right) - (-84.13\ kN)$$

$$R_B = -142.53$$

$$M_{AB} = \left(R_A \times \frac{L_1}{2} \right) - \left(W_1 \times \frac{L_1^2}{2} \right)$$

$$M_{AB} = -113.58\ kNm - \left(21.63\ \frac{kN}{m} \times \frac{(1.35)^2}{2} \right)$$

$$M_{AB} = -113.58\ kNm - 19.71\ kNm$$

$$\underline{M_{AB} = -133.29\ kNm}$$

$$L_2 \times R_c = -\left(53.49\ kNm \times 7.8\ m \times 3.9\ m \right)$$

$$-305.98\ kNm$$

$$\underline{R_c = -169.27\ kNm}$$

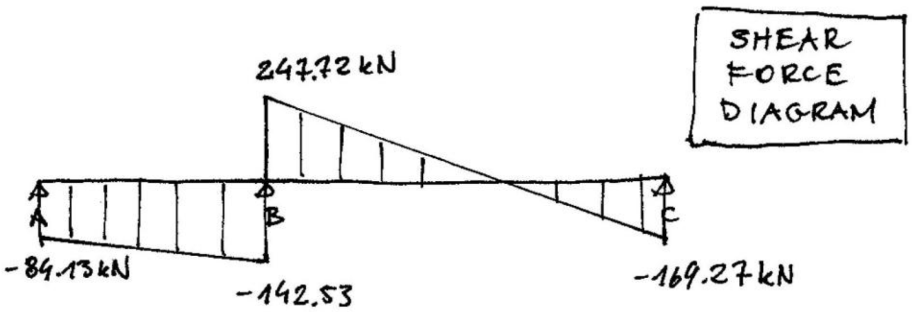
$$R_B = \left(53.46\ kN/m \times 7.8m \right) - 169.27kN$$

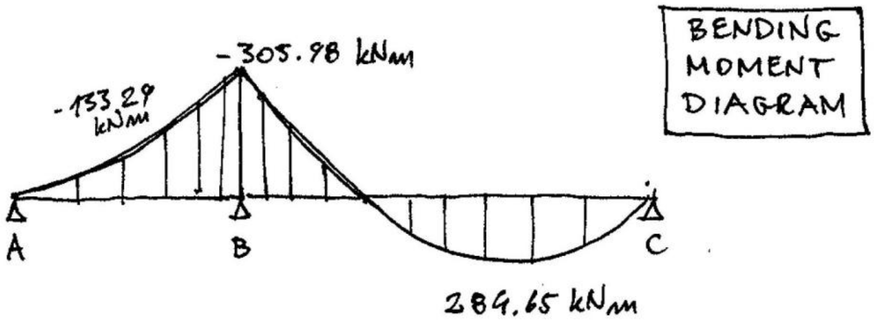
$$\underline{R_B = 247.72\ kN}$$

$$M_{Bc} = \left(169.27\ kN \times 3.9m \right) - \left(53.49\ \frac{kN}{m} \times \frac{(3.9\ m)^2}{2} \right)$$

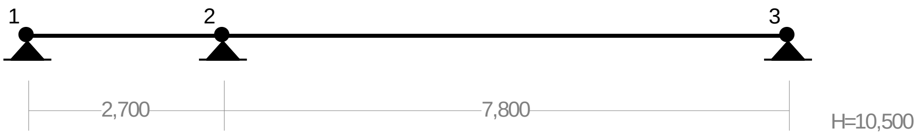
$$M_{Bc} = 660.153\ kNm - 375.5\ kNm$$

$$\underline{M_{Bc} = 284.65\ kNm}$$

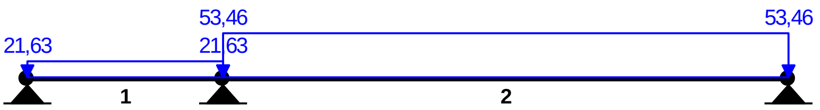




The internal forces that were determined in the traditional calculation are now checked with the use of the computer program for structural analysis RM-WIN:



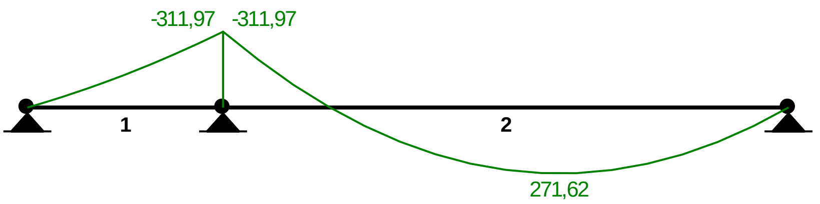
Beam layout



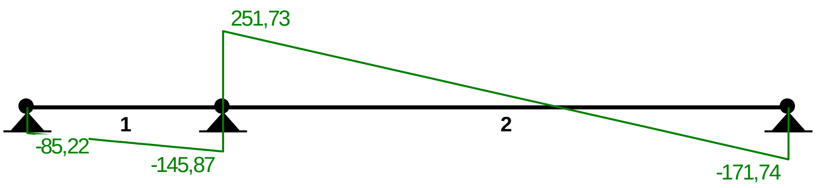
Loading

Reactions

Beanding Moment Diagram



Shear Force Diagram

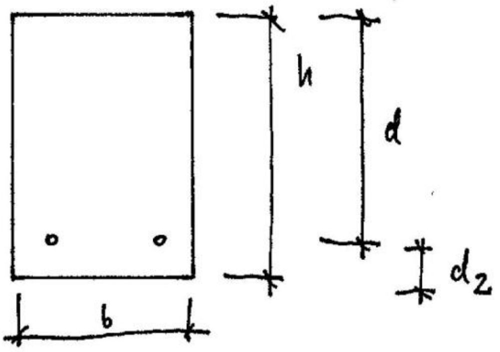


15.5 Determination of the section dimensions for the beam

The analysis of the beam carried with the use of computer program confirmed internal forces determined previously – with a slight correction. The values of the bending moment and shear forces obtained from the computer analysis are now used in the design of the beam section.

- The calculations are carried according to the procedures for designing reinforced concrete structures, contained in Eurocode 2.
- The following design assumes a singly-reinforced beam with 0% redistribution of the load. In such case the K value for the beam section must be lower than K' = 0.208.

1) SECTION PARAMETERS



CONCRETE CLASS: C 25/30

CHARACTERISTIC STEEL STRENGTH: $f_{yk} = 500 \frac{N}{mm^2}$

$M_1 = 312$ kNm

$M_2 = 272$ kNm

$M_1 > M_2$

- DETERMINE K FROM $K = \frac{M}{b d^2 f_{ck}}$ $f_{ck} = 25$
- DETERMINE K' FROM TABLE 4.
  FOR 0% REDISTRIBUTION → $K' = 0.208$
- ASSUME NO COMPRESSION REINFORCEMENT
  $K < K'$ for $K' = 0.208$

The formula for K presented above is employed in a computer spreadsheet, where the value of K'= 0.208 is taken as the independent parameter. The purpose of the spreadsheet is to determine the most efficient section dimensions with the assumption of no compression reinforcement, and K < K'= 0.208.

The whole spreadsheet table is presented in the Attachments section of the Project Description. The chosen values for the beam section are in the fragment of the table.

4				5			
b	**d**	**K**	**CHECK**	**b**	**d**	**K**	**CHECK**
250	100	4,992	NO	300	100	4,160	NO
250	150	2,219	NO	300	150	1,849	NO
250	160	1,950	NO	300	160	1,625	NO
250	170	1,727	NO	300	170	1,439	NO
250	180	1,541	NO	300	180	1,284	NO
250	190	1,383	NO	300	190	1,152	NO
250	200	1,248	NO	300	200	1,040	NO
250	210	1,132	NO	300	210	0,943	NO
250	220	1,031	NO	300	220	0,860	NO
250	230	0,944	NO	300	230	0,786	NO
250	240	0,867	NO	300	240	0,722	NO
250	250	0,799	NO	300	250	0,666	NO
250	260	0,738	NO	300	260	0,615	NO
250	270	0,685	NO	300	270	0,571	NO
250	280	0,637	NO	300	280	0,531	NO
250	290	0,594	NO	300	290	0,495	NO
250	300	0,555	NO	300	300	0,462	NO
250	310	0,519	NO	300	310	0,433	NO
250	320	0,488	NO	300	320	0,406	NO
250	330	0,458	NO	300	330	0,382	NO
250	340	0,432	NO	300	340	0,360	NO
250	350	0,408	NO	300	350	0,340	NO
250	360	0,385	NO	300	360	0,321	NO
250	370	0,365	NO	300	370	0,304	NO
250	380	0,346	NO	300	380	0,288	NO
250	390	0,328	NO	300	390	0,274	NO
250	400	0,312	NO	300	400	0,260	NO
250	410	0,297	NO	300	410	0,247	NO
250	420	0,283	NO	300	420	0,236	NO
250	430	0,270	NO	300	430	0,225	NO
250	440	0,258	NO	300	440	0,215	NO
250	450	0,247	NO	300	450	0,205	**YES**
250	460	0,236	NO	300	460	0,197	**YES**
250	470	0,226	NO	300	470	0,188	**YES**
250	480	0,217	NO	300	480	0,181	**YES**
250	490	0,208	**YES**	300	490	0,173	**YES**
250	500	0,200	**YES**	300	500	0,166	**YES**

Conclusion: The chosen dimensions are b = 300 mm and d = 450 mm. Although two other sections where indicated before, this section will limit the beam height, which is important from the architectural standpoint.

15.6 Determination of the reinforcement area

FOR $M = 312$ kNm

- FROM THE SPREADSHEET: $K = 0.205 < K' = 0.208$

$b = 300$ mm ASSUME $d_2 = 30$ mm

$d = 450$ mm $h = 480$ mm

2) TENSION REINFORCEMENT

- CALCULATE LEVER ARM:

$$z = \frac{d}{2}\left[1 + \sqrt{1 - 3.53K}\right]$$

$$z = \frac{450}{2}\left[1 + \sqrt{1 - (3.53 \times 0.205)}\right]$$

$$z = 225\left[1 + \sqrt{1 - 0.724}\right]$$

$$z = 287 \quad (z_{MAX} = 0.95 \times 450 = 427.5\text{mm O.K.})$$

2) CALCULATE REINFORCEMENT AREA

$$A_s = \frac{M}{0.87 \times f_{yk} \times z}$$

FOR $M = 312$ kNm

$$A_s = \frac{312 \times 10^6}{0.87 \times 500 \times 287}$$

$$A_s = 2500\ \text{mm}^2 \quad (1.85\%\ A_c)$$

FOR $M = 272\ kNm$

$$A_s = \frac{272 \times 10^6}{0.87 \times 500 \times 287}$$

$$A_s = 2178\ mm^2 \quad (1.61\ \%\ A_c)$$

MIN REINFORCEMENT REQUIREMENT: TABLE 6. $f_{ck} = 25$

$f_{ctm} = 2.6$

$$A_{s_{MIN}} = \frac{0.26 \times f_{ctm} \times 6 \times d}{f_{yk}}$$

$$A_{s_{MIN}} = \frac{0.26 \times 2.6 \times 300 \times 450}{500} = 182.5\ [mm^2]\ (0.14\%\ A_c)$$

$$A_{s_{MAX}} = 0.04 \times A_c = 5400\ [mm^2]\ (4\%\ A_c)$$

$M = 312\ kNm$

$A_s = 2500\ mm^2$ O.K.

$M = 272\ kNm$

$A_s = 2178\ mm^2$ O.K.

15.7 Provision of tension reinforcement

The design assumes the following reinforcement configuration:

- For span AB of the beam the required bar section area is 2500 mm².
- Provide 2 # 32 bars of A = 1610 mm² & 2 # 25 bars of A = 982
- Total section area of the tension reinforcement: A (AB) = 2592 mm²

- For span BC of the beam the required bar section area is 2178 mm².
- Provide 2 # 32 bars of A = 1610 mm² & 2 # 20 bars of A = 628
- Total section area of the tension reinforcement: A (BC) = 2238 mm²

Because the diameter of some bars will be of considerable size (32 mm), raise the h of the section to h = 500 mm.

15.8 Provision of shear reinforcement

SHEAR REINFORCEMENT

FROM TABLE 7 : CONCRET STRUT CAPACITY FOR $f_{ck} = 25$:

$\cot\theta = 2.5$

$$\nu_{ED} = \frac{V_{ED}}{b_w \times z} \qquad V_{ED} = 247.72\,kN$$

$$\nu_{ED} = \frac{247.72 \times 10^3}{300 \times 287} = 2.877$$

$$V_{Rd\,MAX(\cot\theta = 2.5)} = 3.10$$

$\nu_{ED} < V_{Rd_{MAX}}$ O.K.

DETERMINE REINFORCEMENT AREA AND SPACING

$$\frac{A_{sw}}{s} = \frac{\nu_{ED} \times b_w}{f_{ywd} \times \cot\theta} = \frac{2.877 \times 300}{0.87 \times 500 \times 2.5}$$

$$\frac{A_{sw}}{s} = \frac{863.1}{946.125} = 0.912$$

CHECK MAX SPACING : $S_{max} = 0.75\,d = 0.75 \times 450\,mm = 337.5\,mm$

TRY 12 mm bars ($113\,mm^2$)

$$s = \frac{113\,mm^2}{0.912} = 123.9$$

→ TAKE 120 mm SPACING FOR MAX SHEARS

Therefore provide 12mm bars at min 120 mm spacing.

16. References

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