Hydropower plant 2 (10 MW)

Table of content

Appendix

1. GENERAL/MEASUREMENTS

1.1 STRCTURAL TYPE

This report describes the design of a hydropower plant located between baseline 2 and baseline 4.

The structure is exposed to the loads mentioned bellow.

- Dead load
- Water load
- Live load
- Earthquake load

1.2 PRODUCTION SCHEME

The production scheme assumes that the structure is cast-in situ.

1.3 FOUNDATION

The foundation assumes the bottom slab rests directly on solid unweathered rock.

Theoretical foundation level : +67.00

Water level at completion : see table below

Level	Remark
+90.60	10000 year
+79.65	Design flow conditions
+78.65	Normal operations
m	-

Water level during production fase : < +67.00

Backfill : rockfill

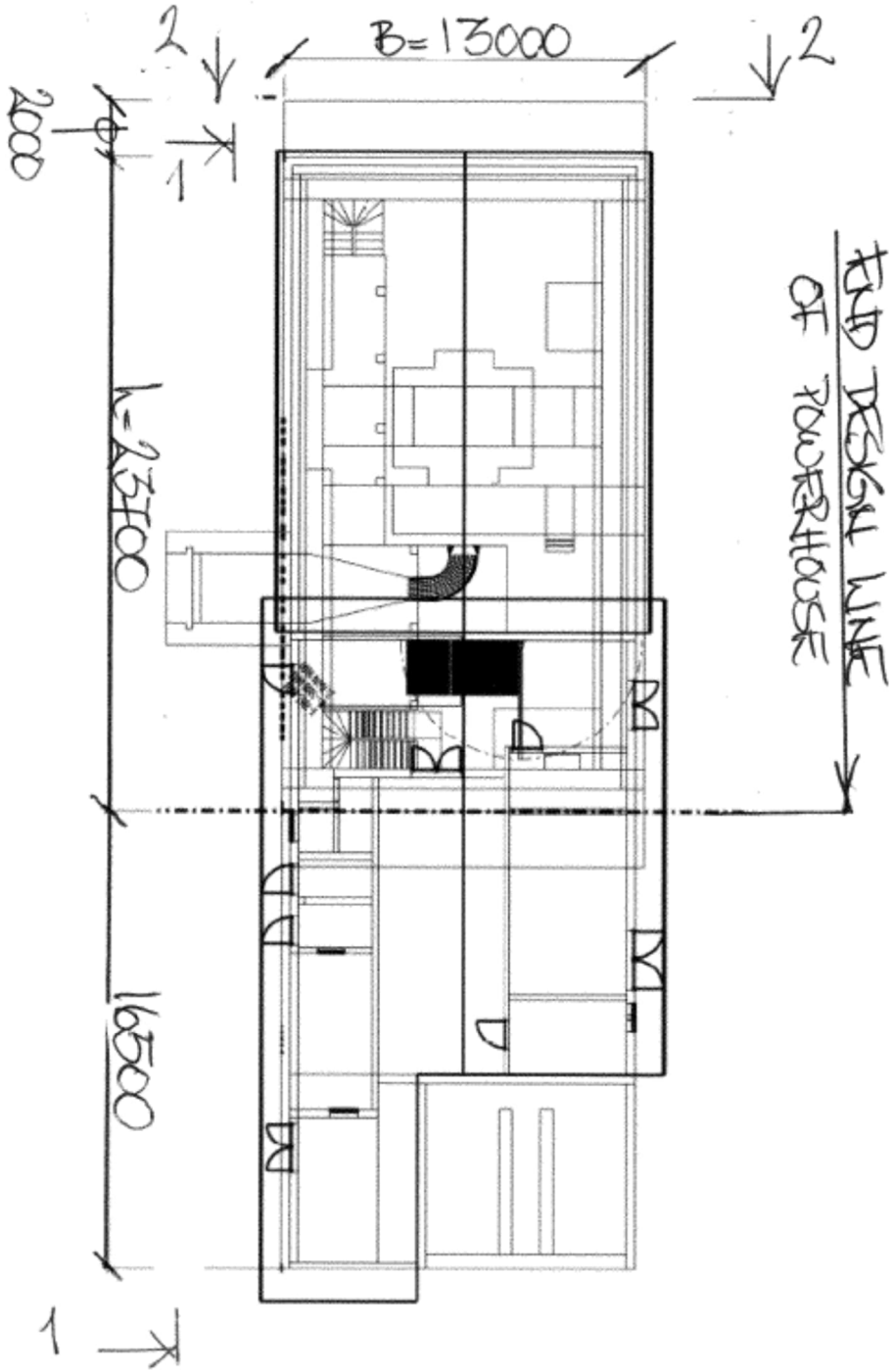
1.4 TECHNICAL SPECIFICATION AND BUILDNING CODE

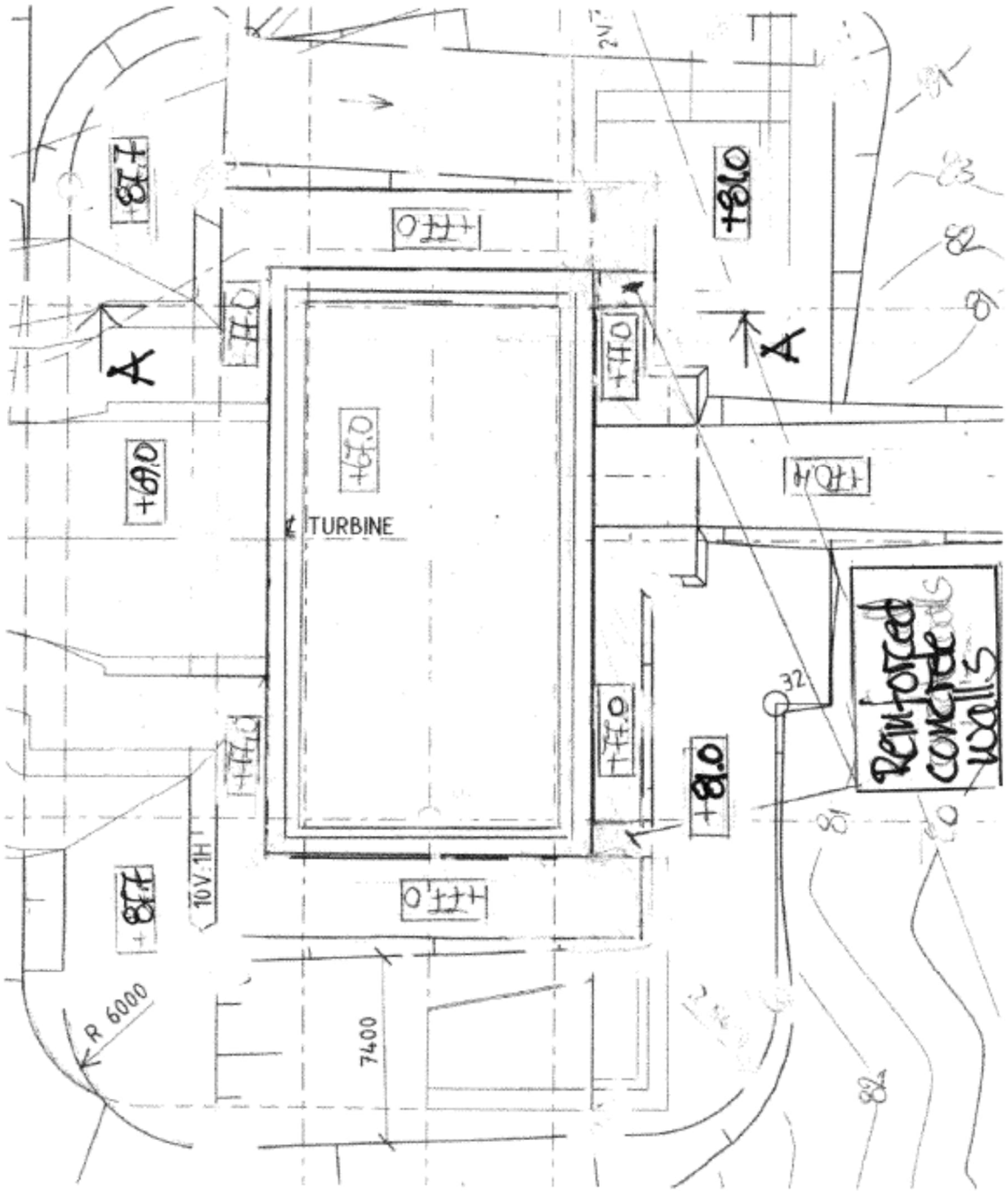
- Building Code Requirements for Structural Concrete (ACI 318-05)

1.5 MEASUREMENTS

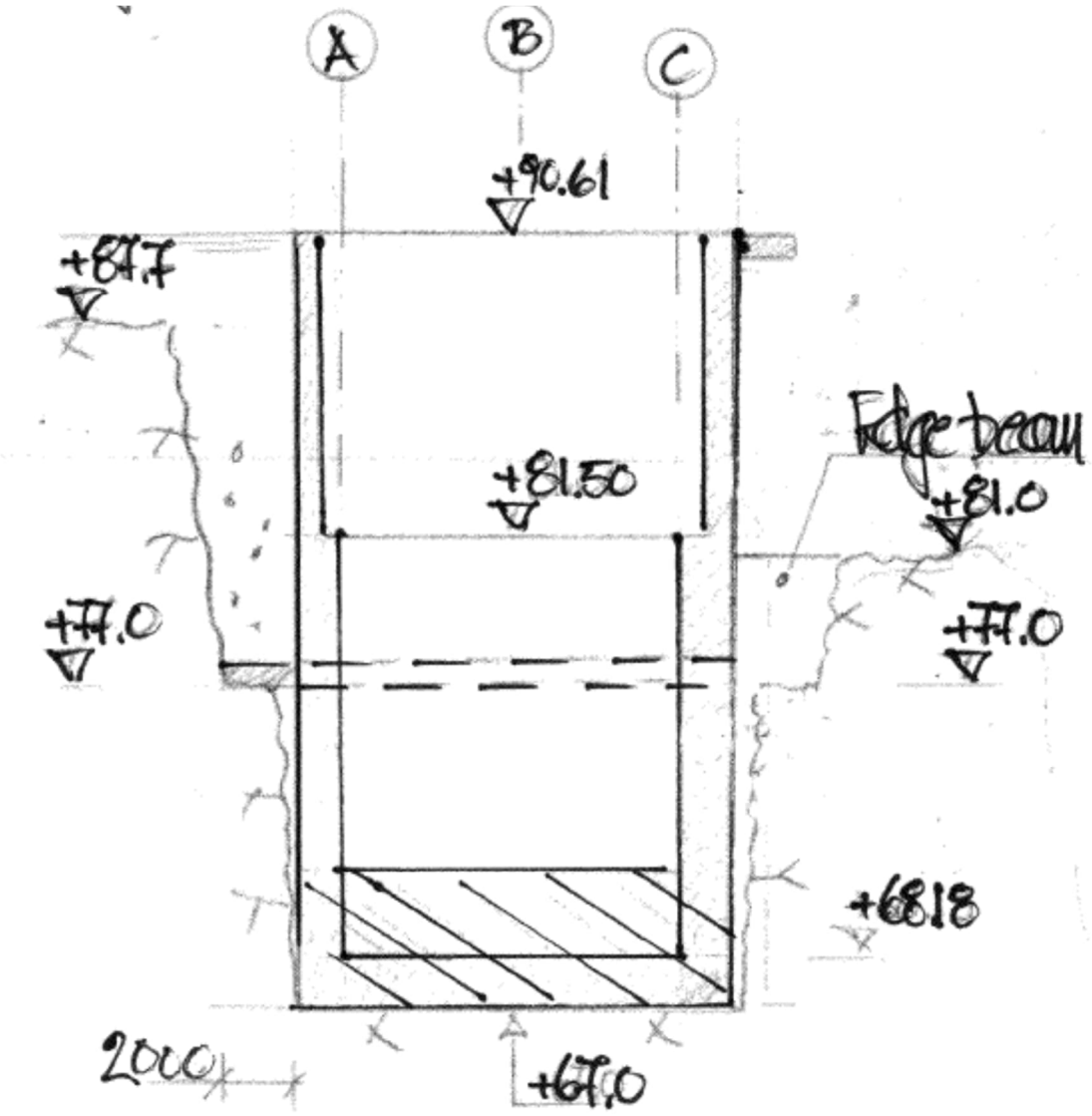
1.5.1 Orientation measurements

Plan view – structure :

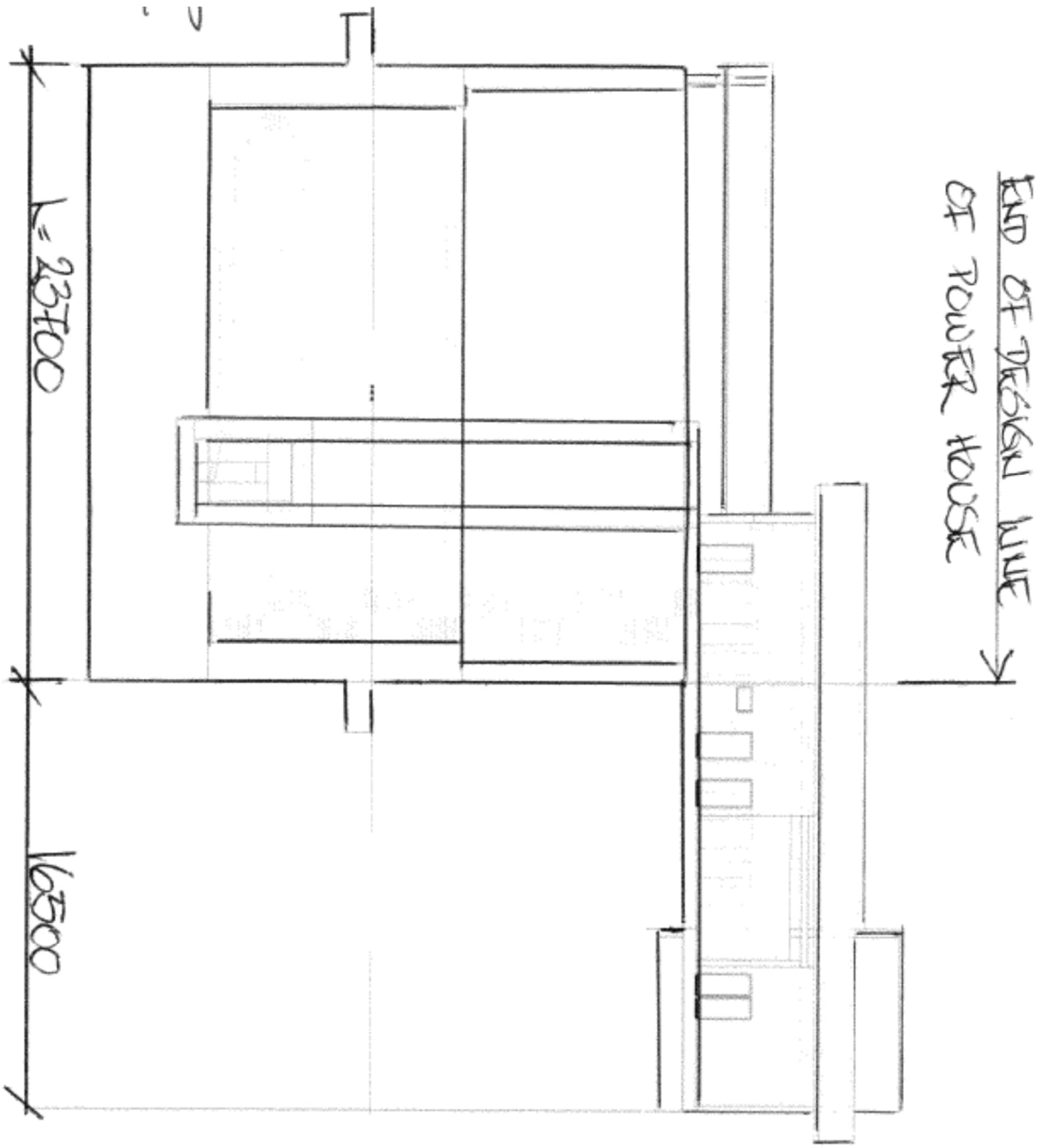



+81.0
+78.7
+69.0
+67.0
+77.0
TURBINE
+8.0
10V:1H
R 6000
7400
Reinforced concrete walls

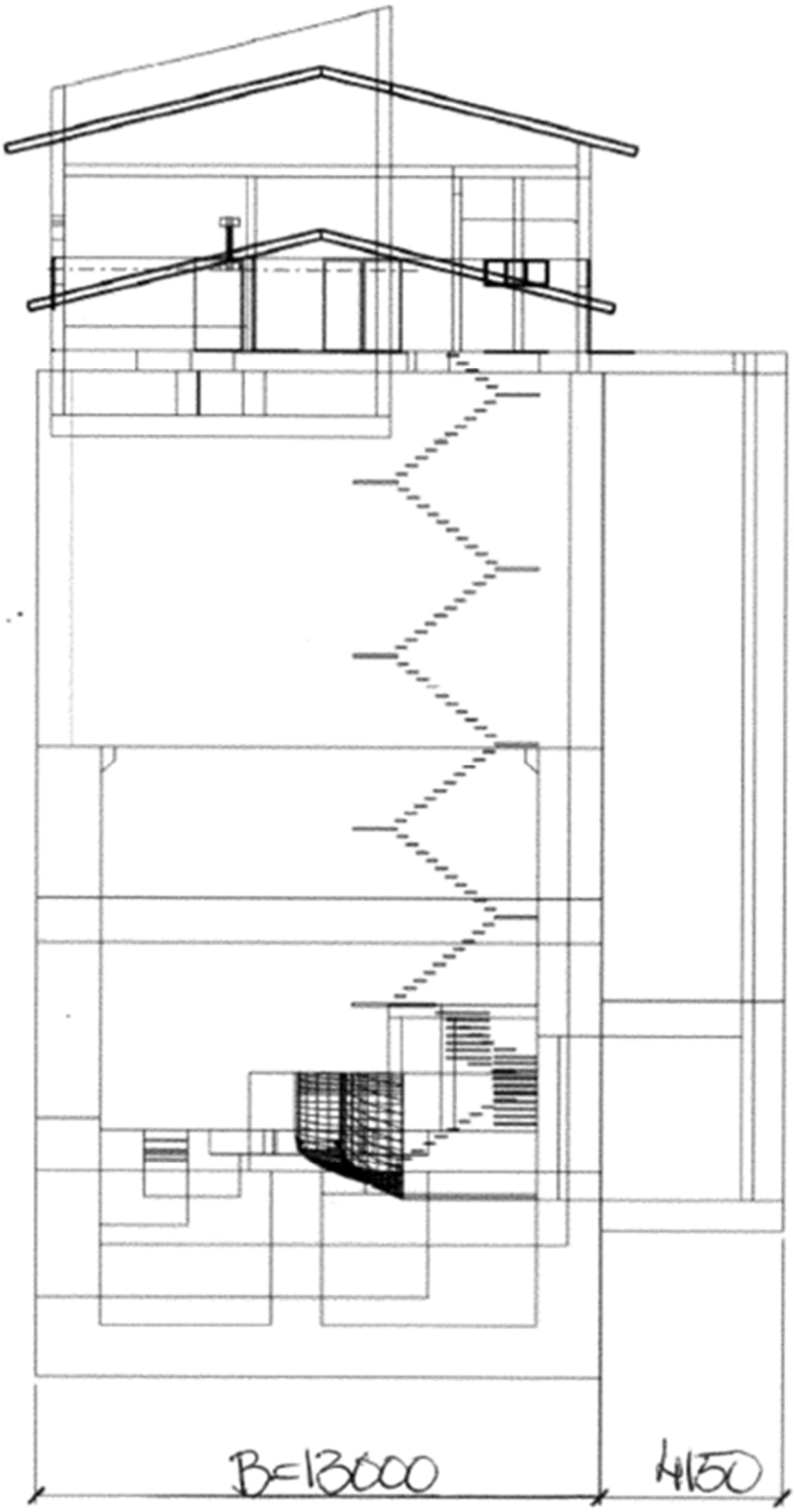
SECTION A - A :



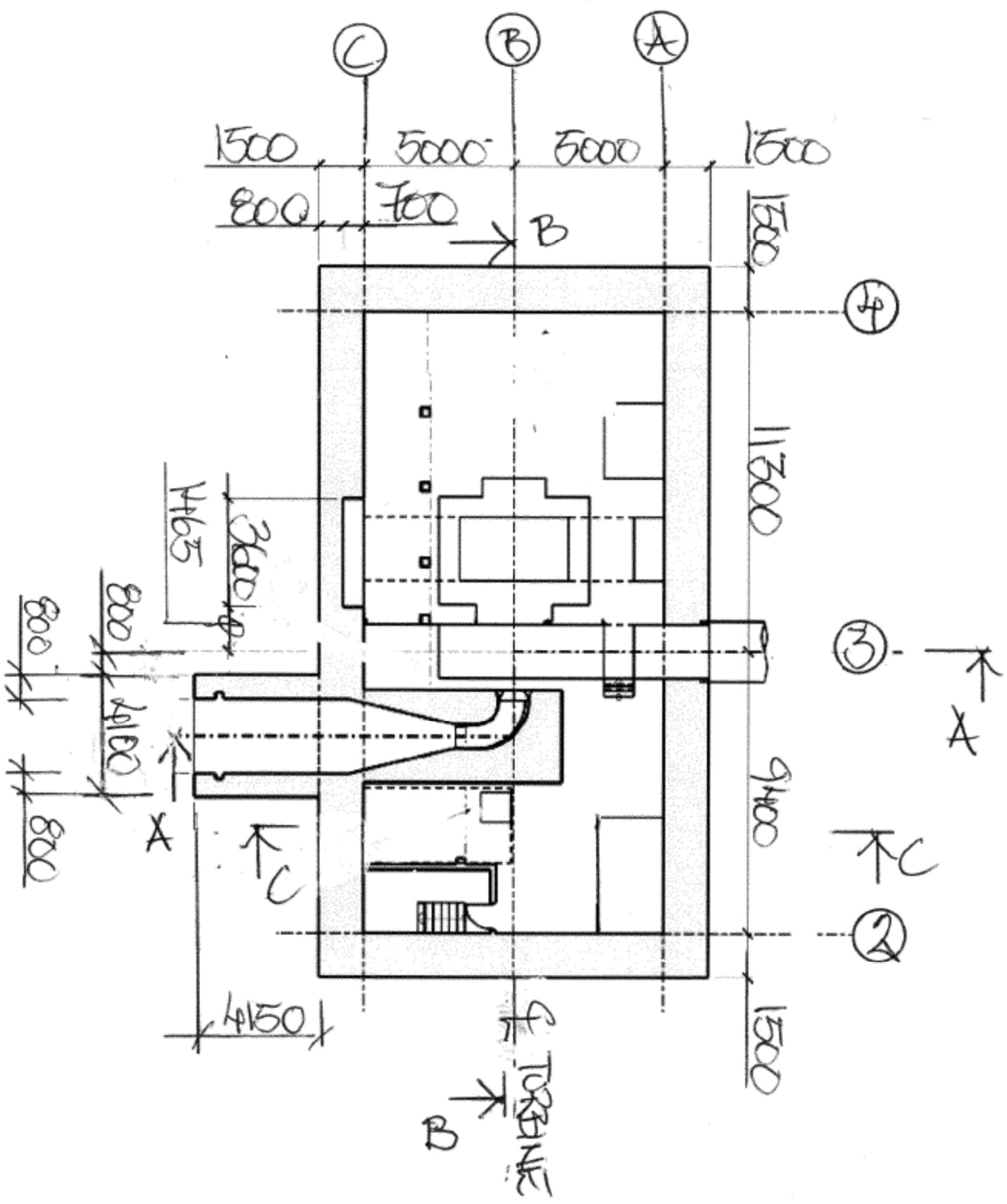
View 1-1 (longitudinal direction) :



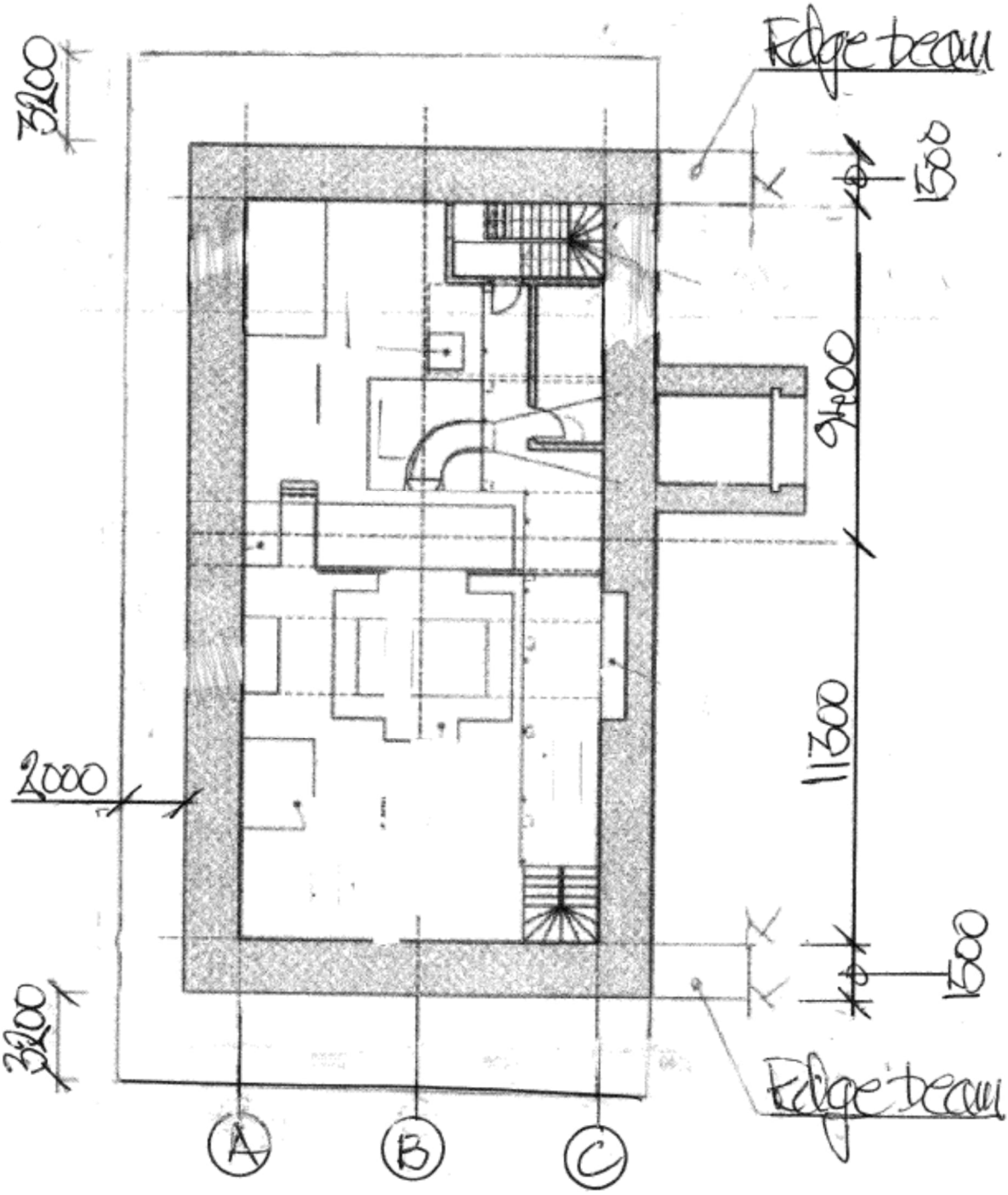
View 2-2 (transverse direction) :



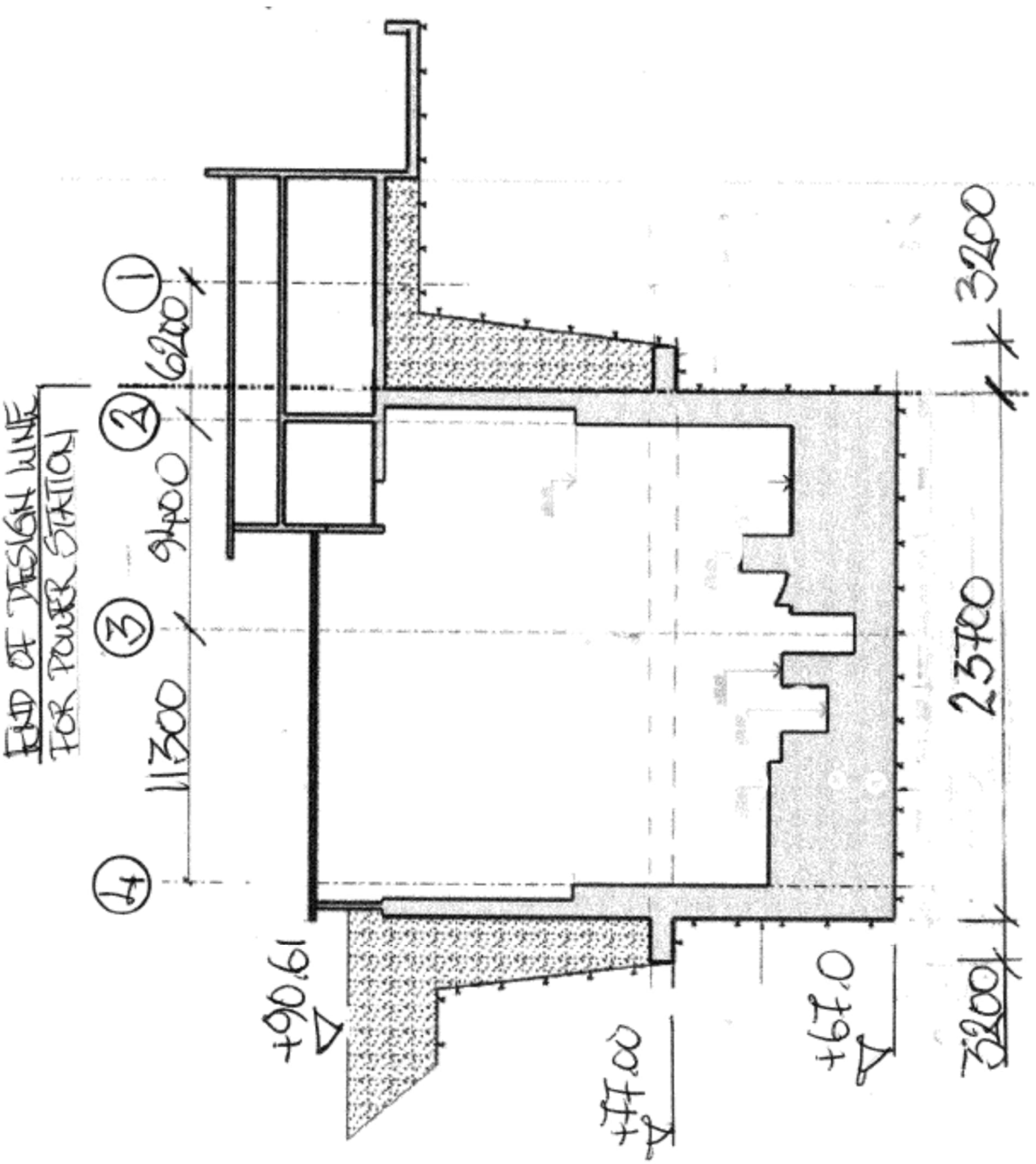
Plan section at level +72.69 :



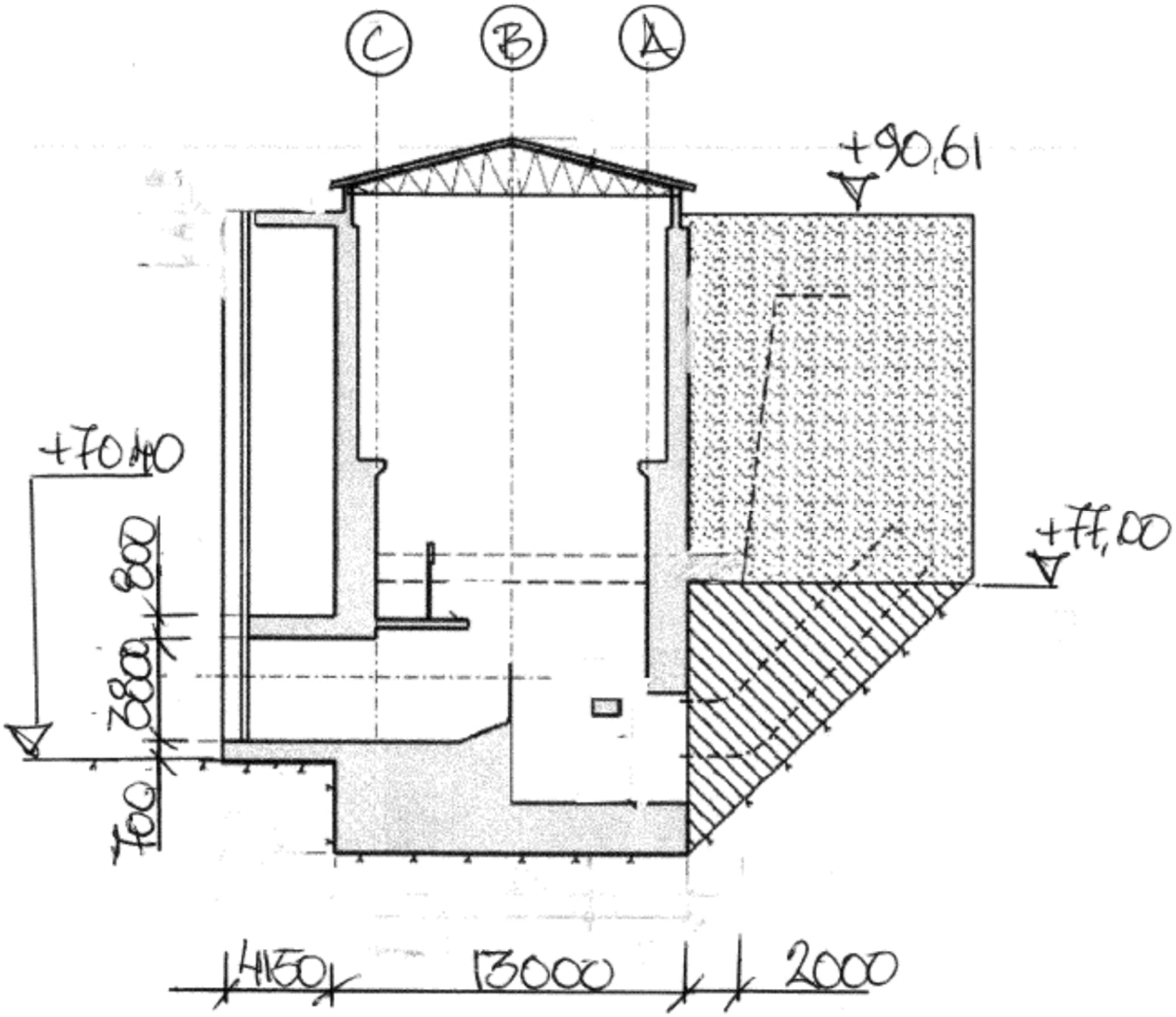
Plan section at level +75.60 :



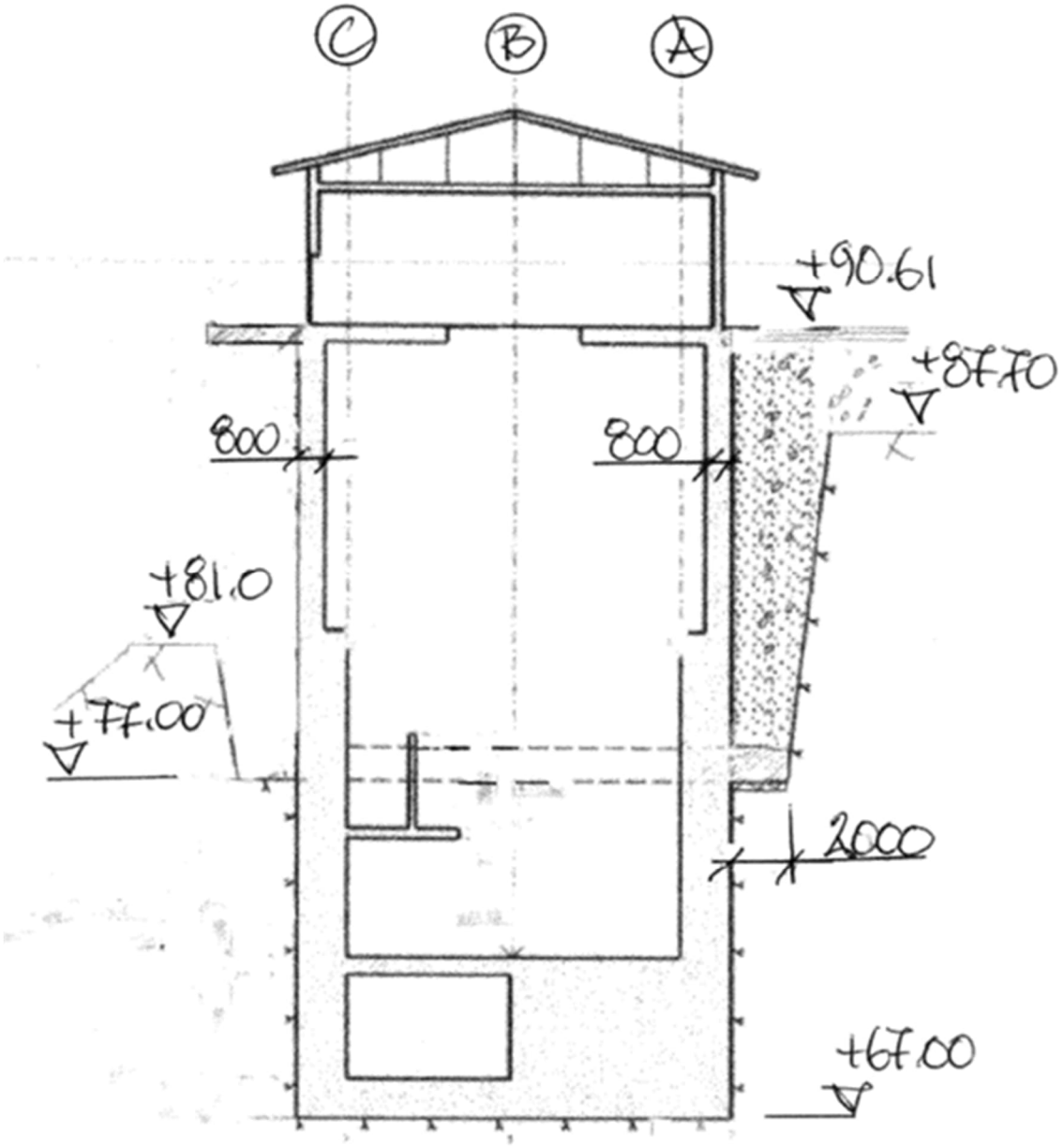
Longitudinal section along baseline B (section B-B):



Transversal section along water flow (Section A-A):

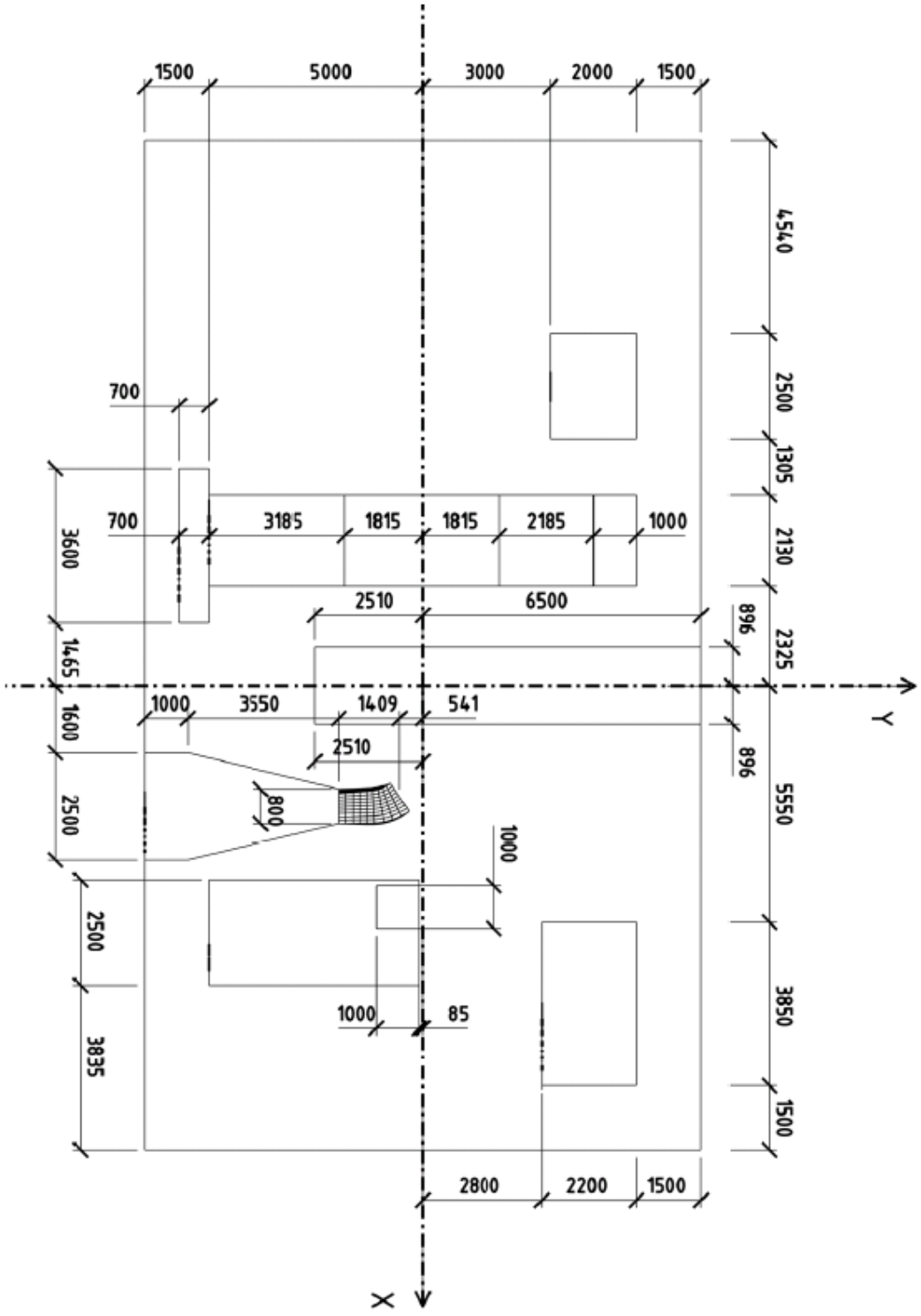


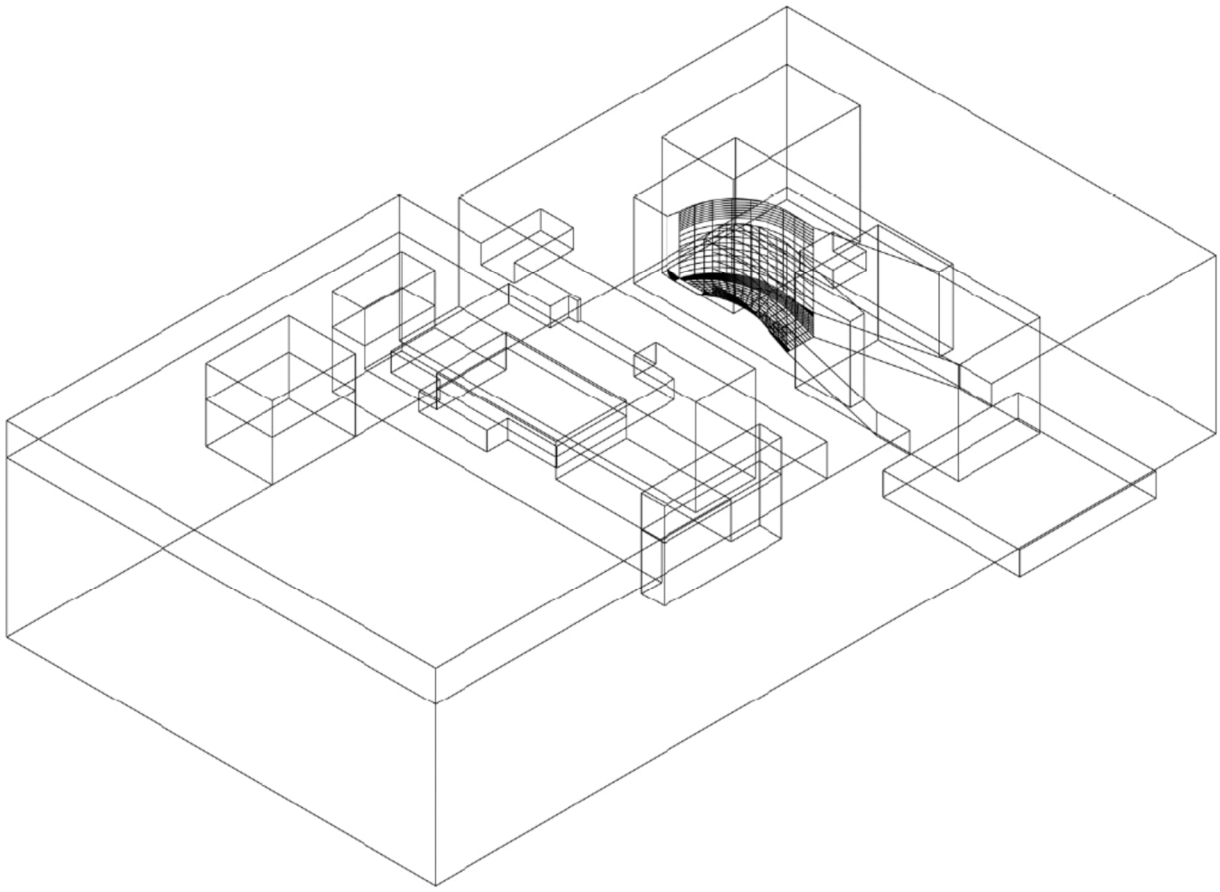
Transversal section along floor +71.73 (Section C-C):



1.5.4 Design measurements

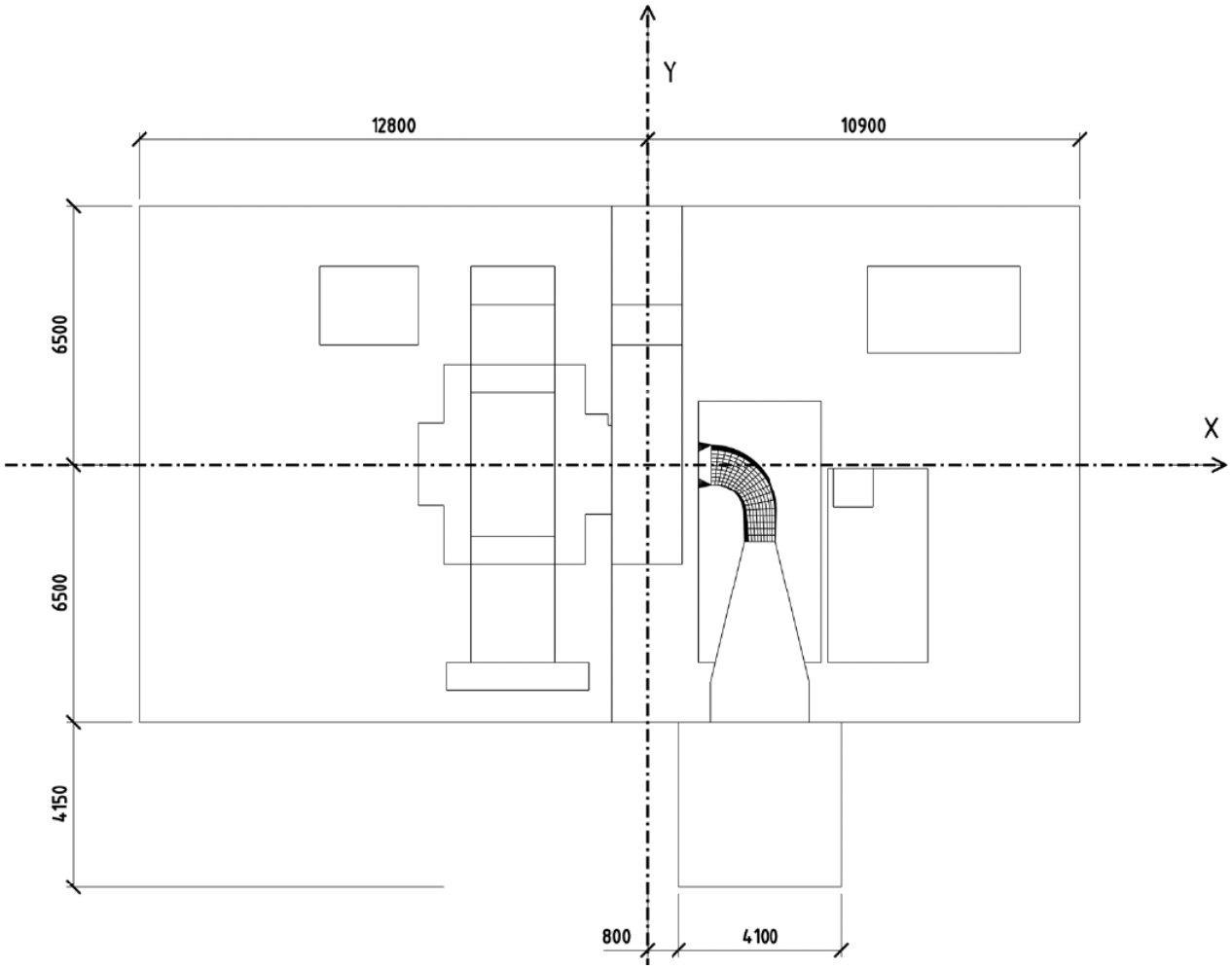
1.5.4.1 Floor 1

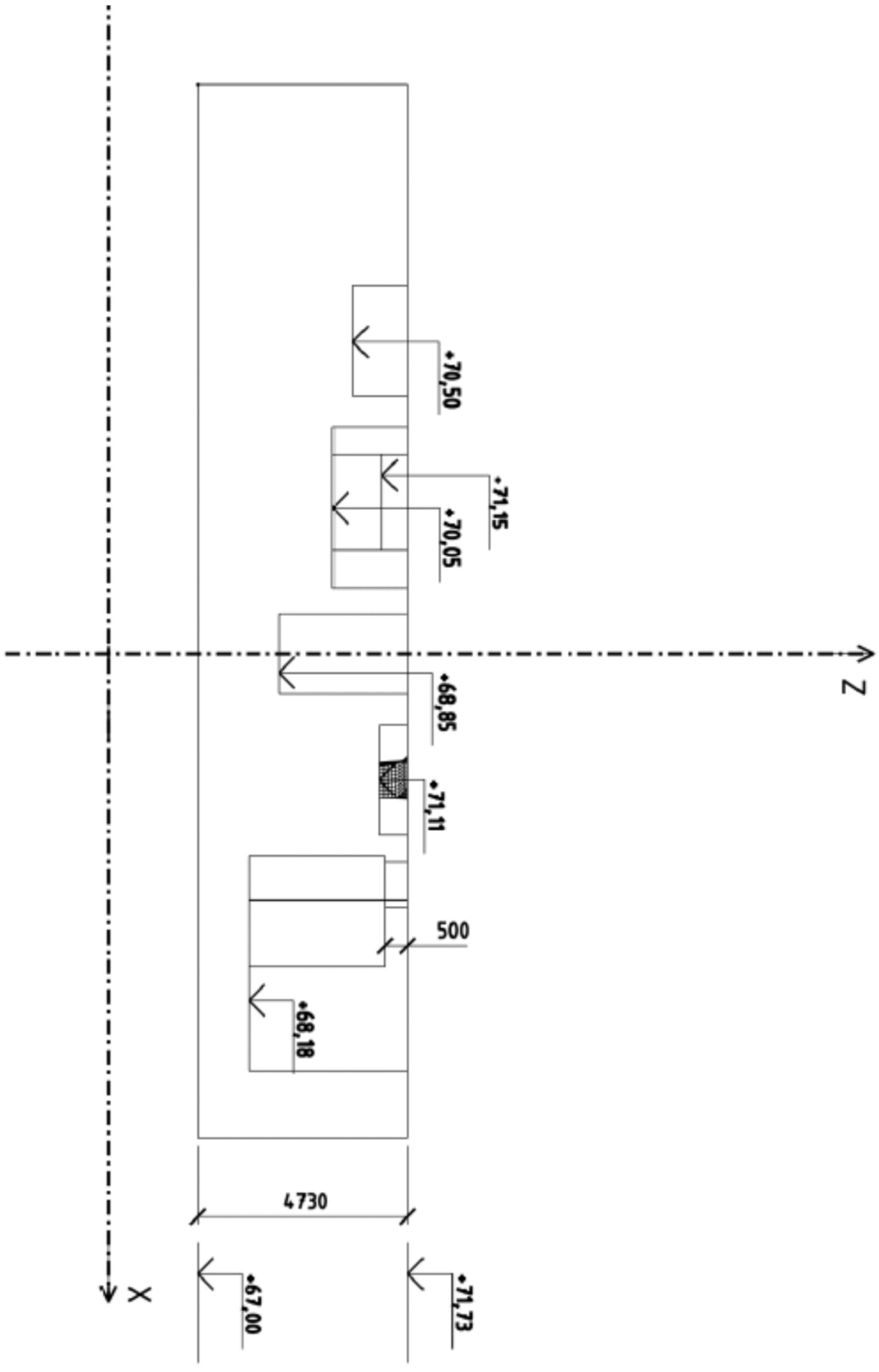




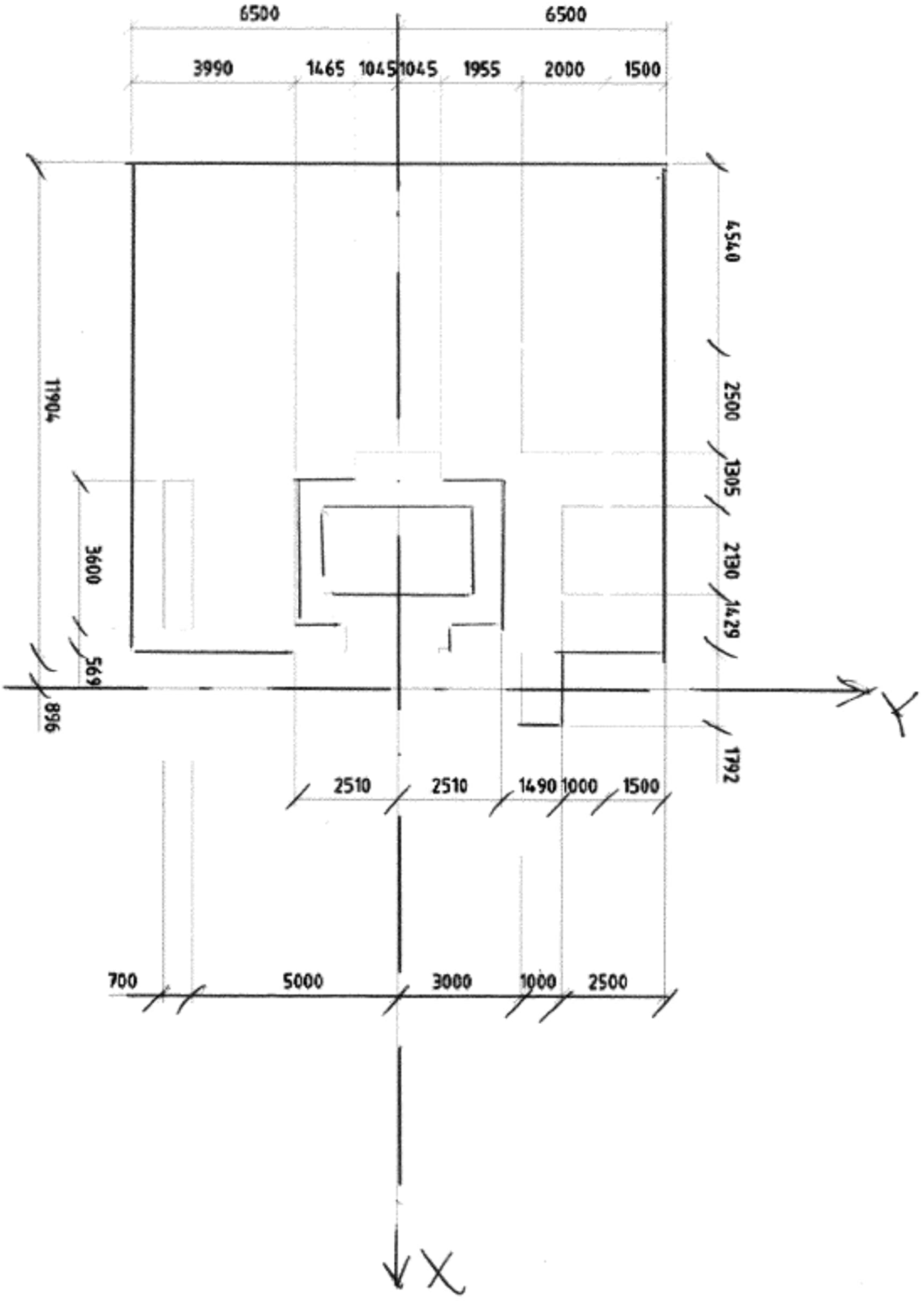
Remark Floor 1 consists of 4 parts termed Floor 1_1, Floor 1_2, Floor 1_3 and Floor 1_4.

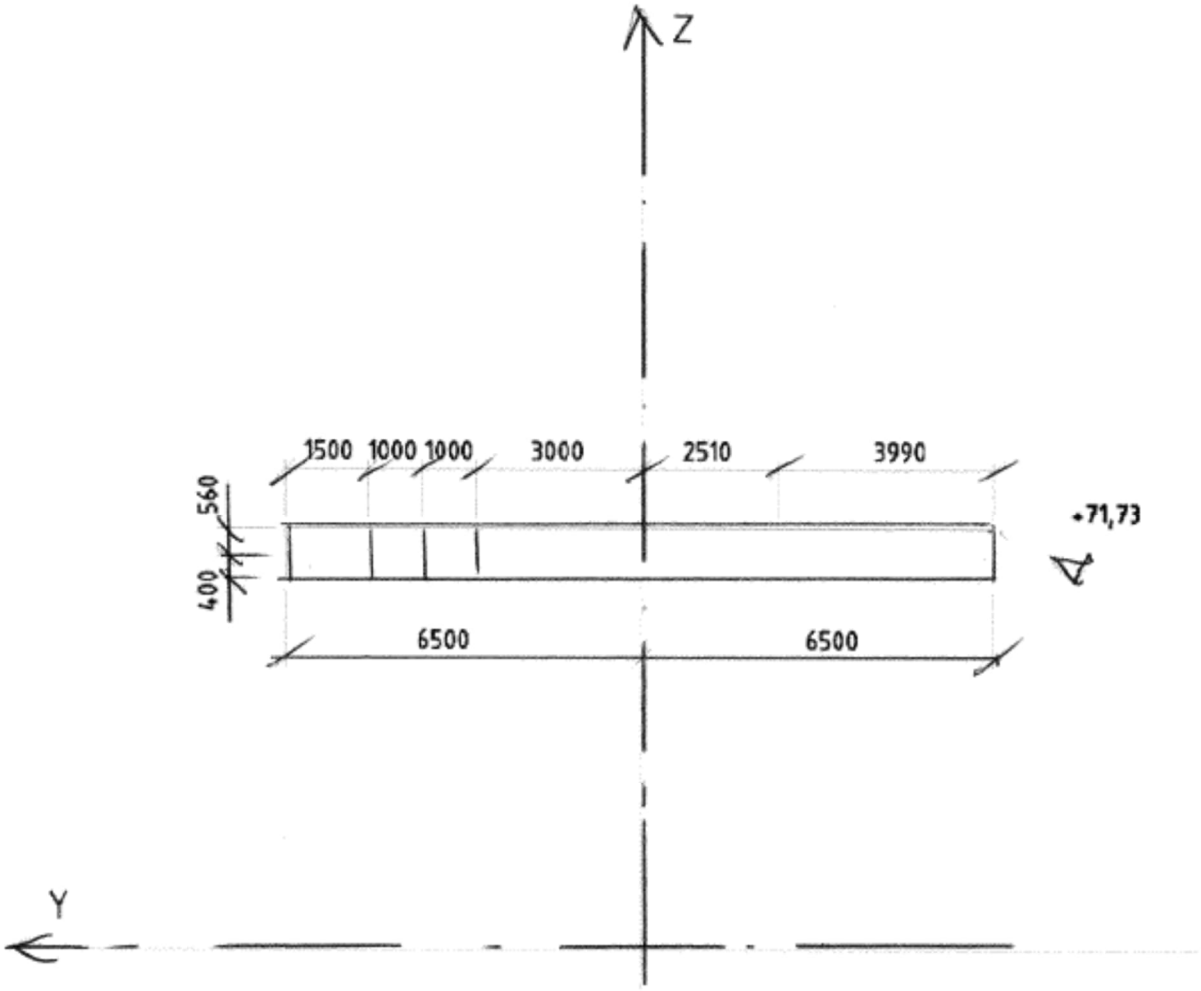
Floor 1_1 :



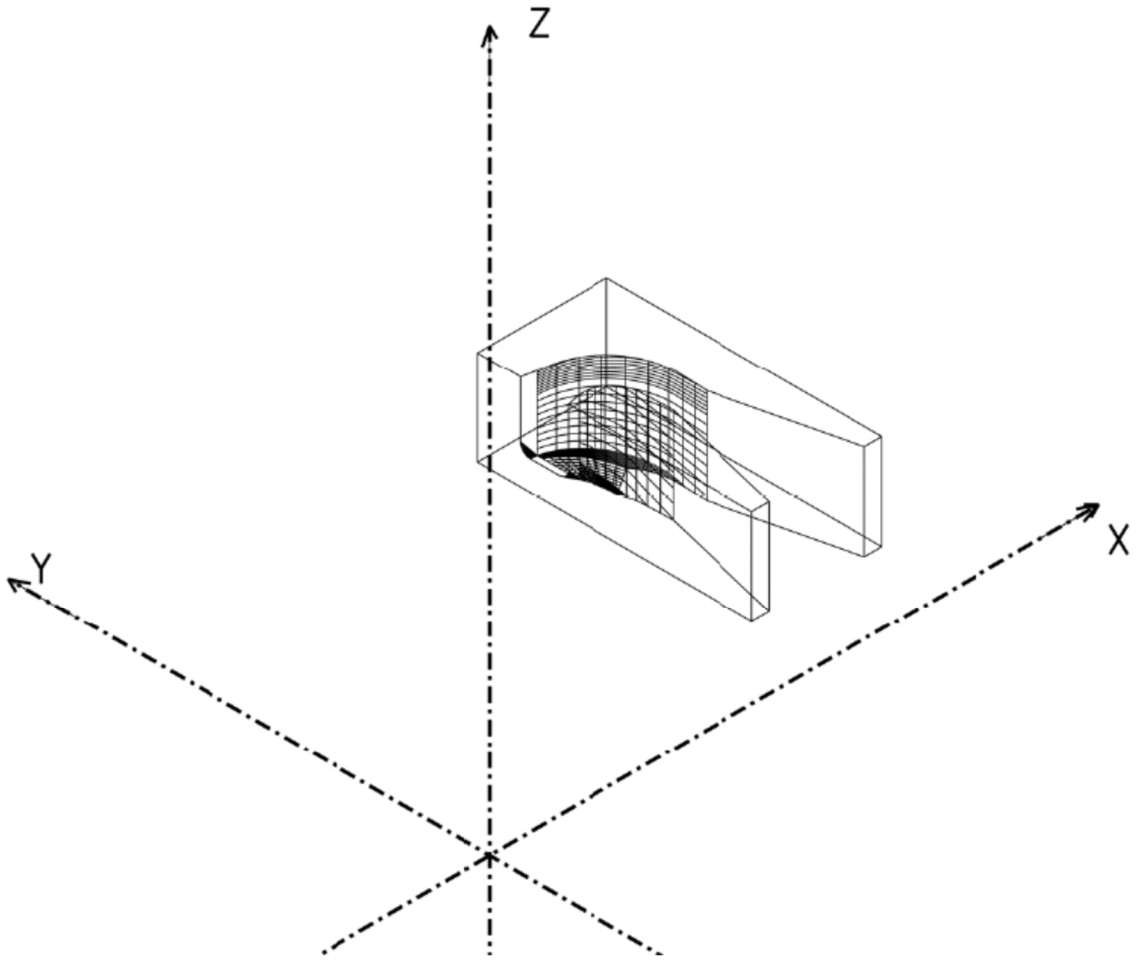

+70,50
+71,15
+70,05
+68,85
+71,11
500
+68,18
4730
+67,00
+71,73
Z
X

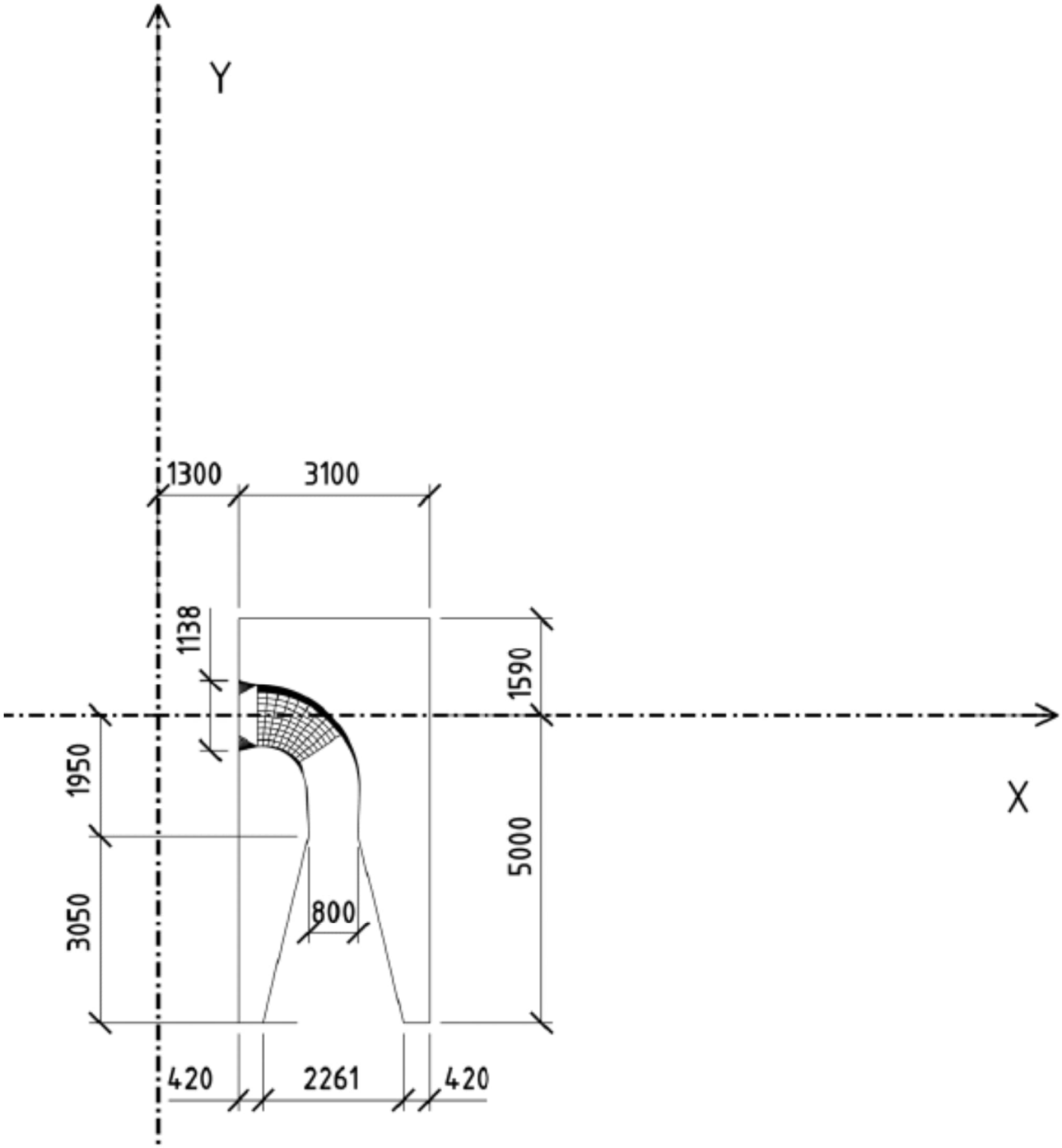
Floor 1, 2 :

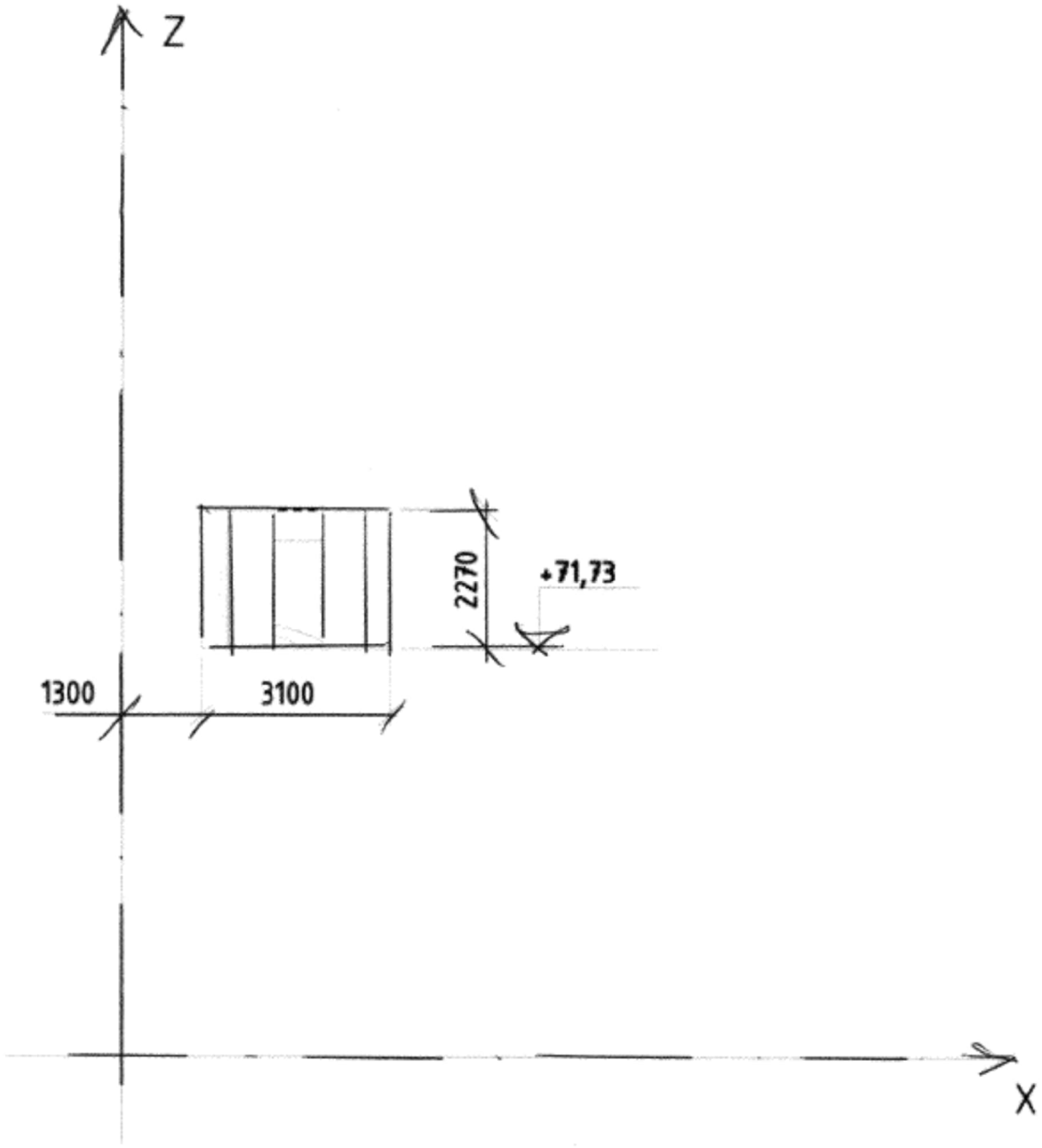

6500
6500
3990
1465
1045
1045
1955
2000
1500
4540
2500
1305
2130
1429
1792
11904
3600
569
896
2510
2510
1490
1000
1500
700
5000
3000
1000
2500
Y
X

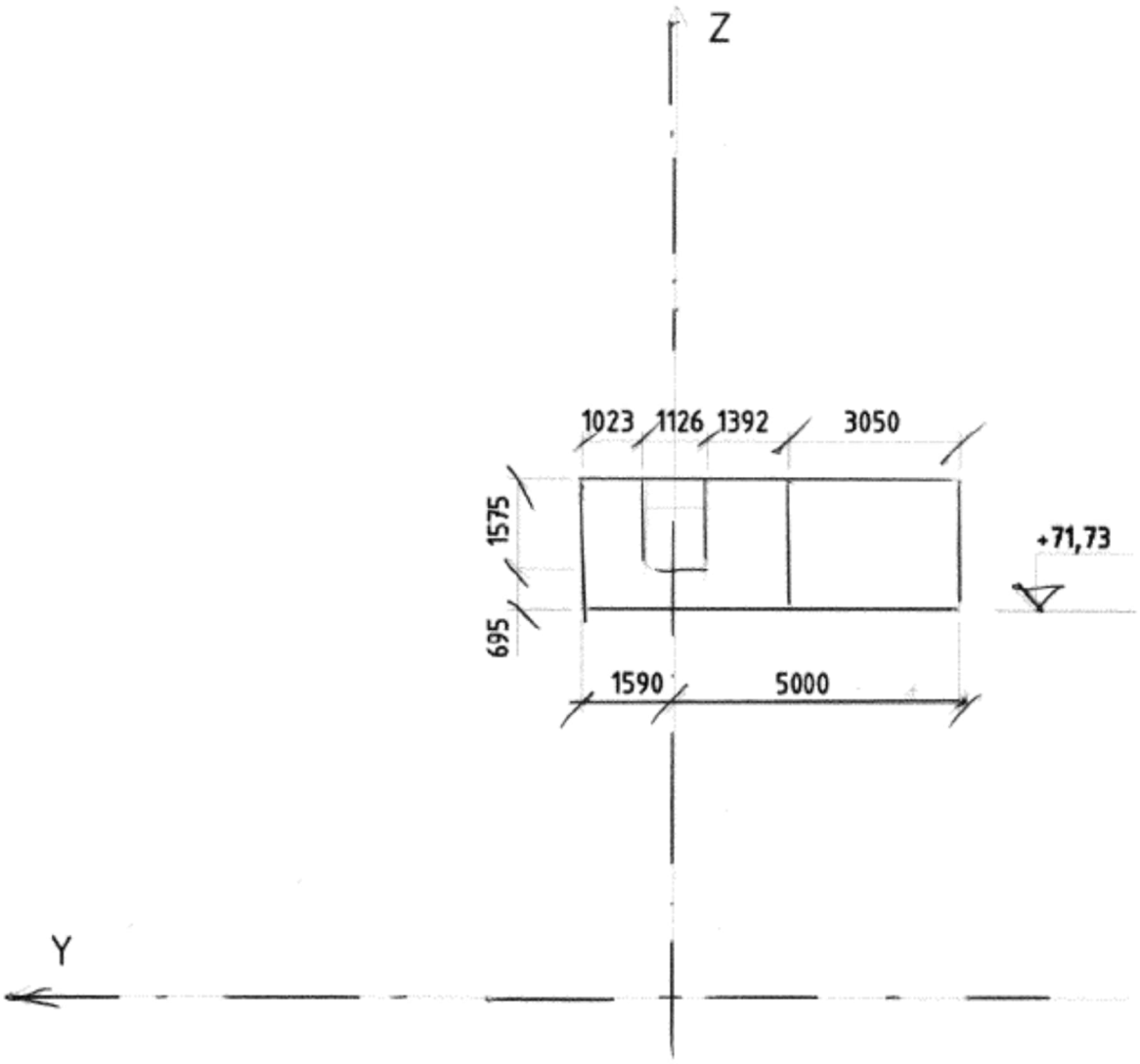

Z
1500
1000
1000
3000
2510
3990
560
400
+71,73
6500
6500
Y

Floor 1_3 :

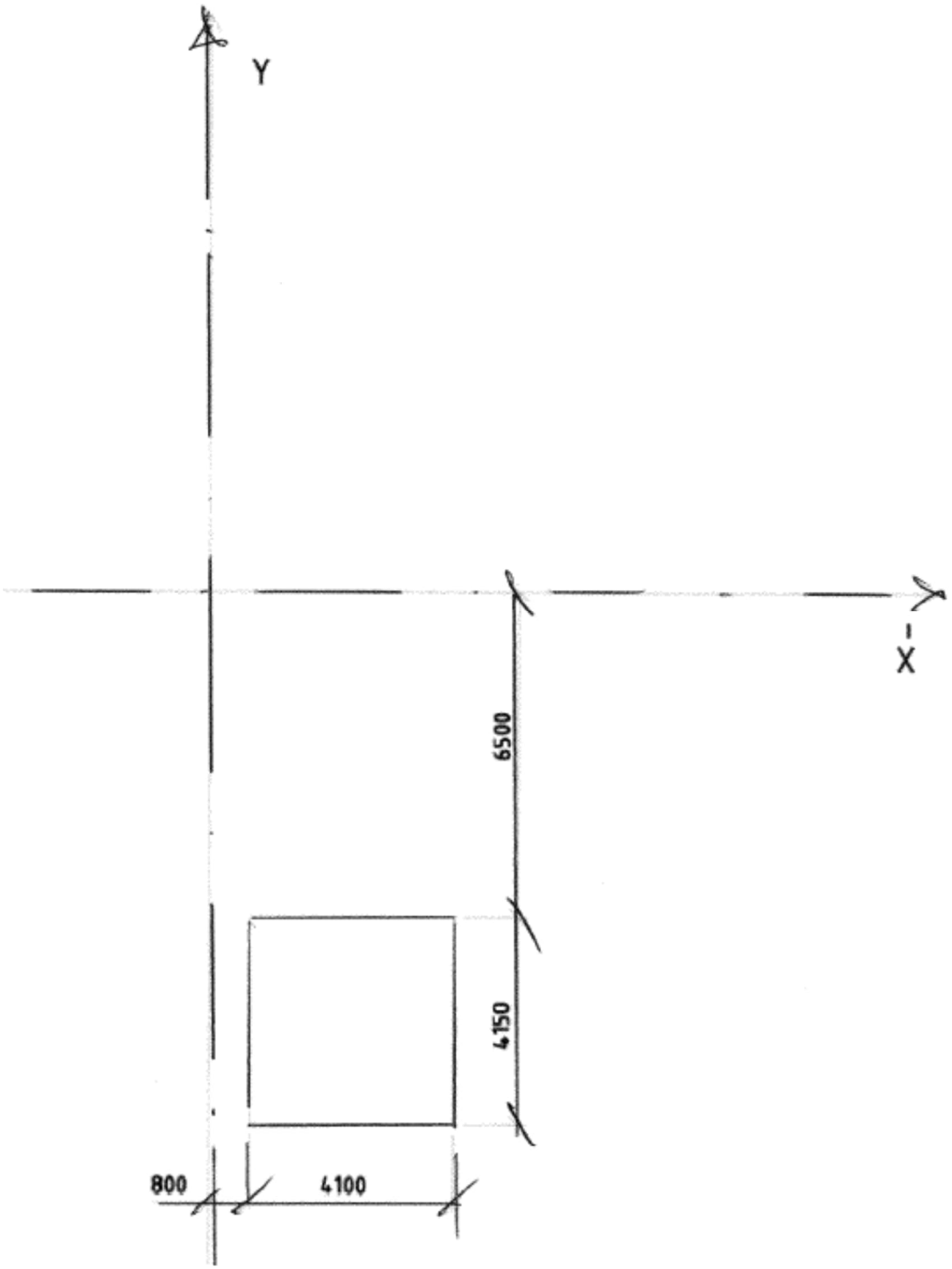


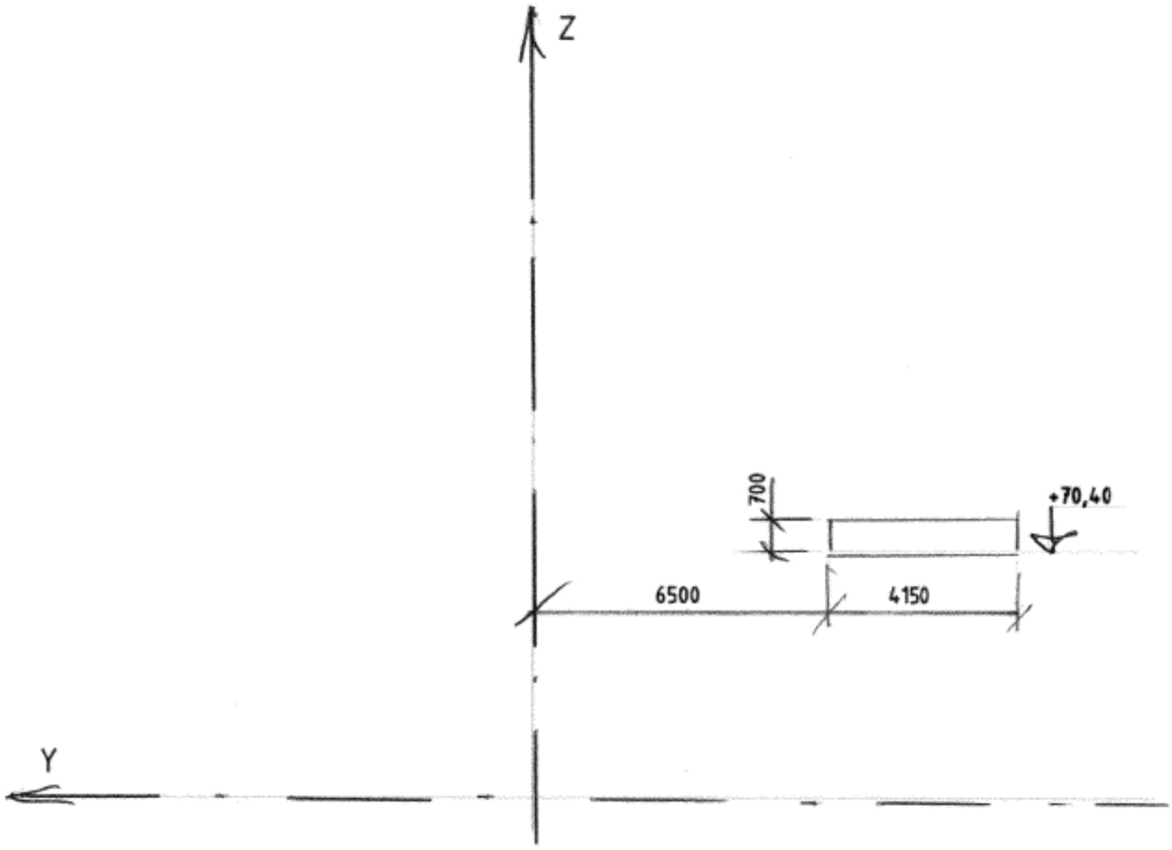

Y
X
1300
3100
1138
1590
1950
3050
5000
800
420
2261
420


Z
2270
+71,73
1300
3100
X

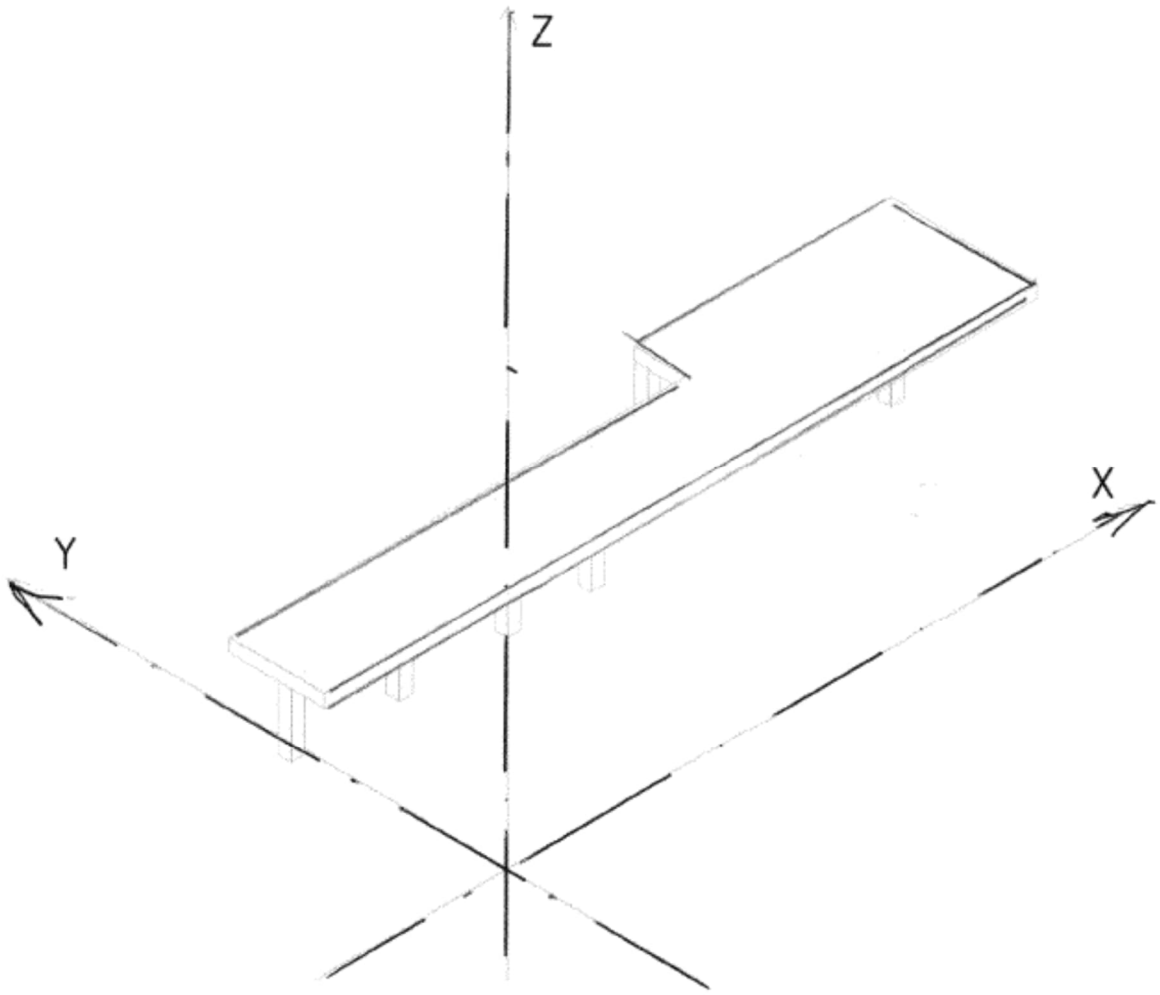

Z
1023
1126
1392
3050
1575
695
+71,73
1590
5000
Y

Floor 1_4:

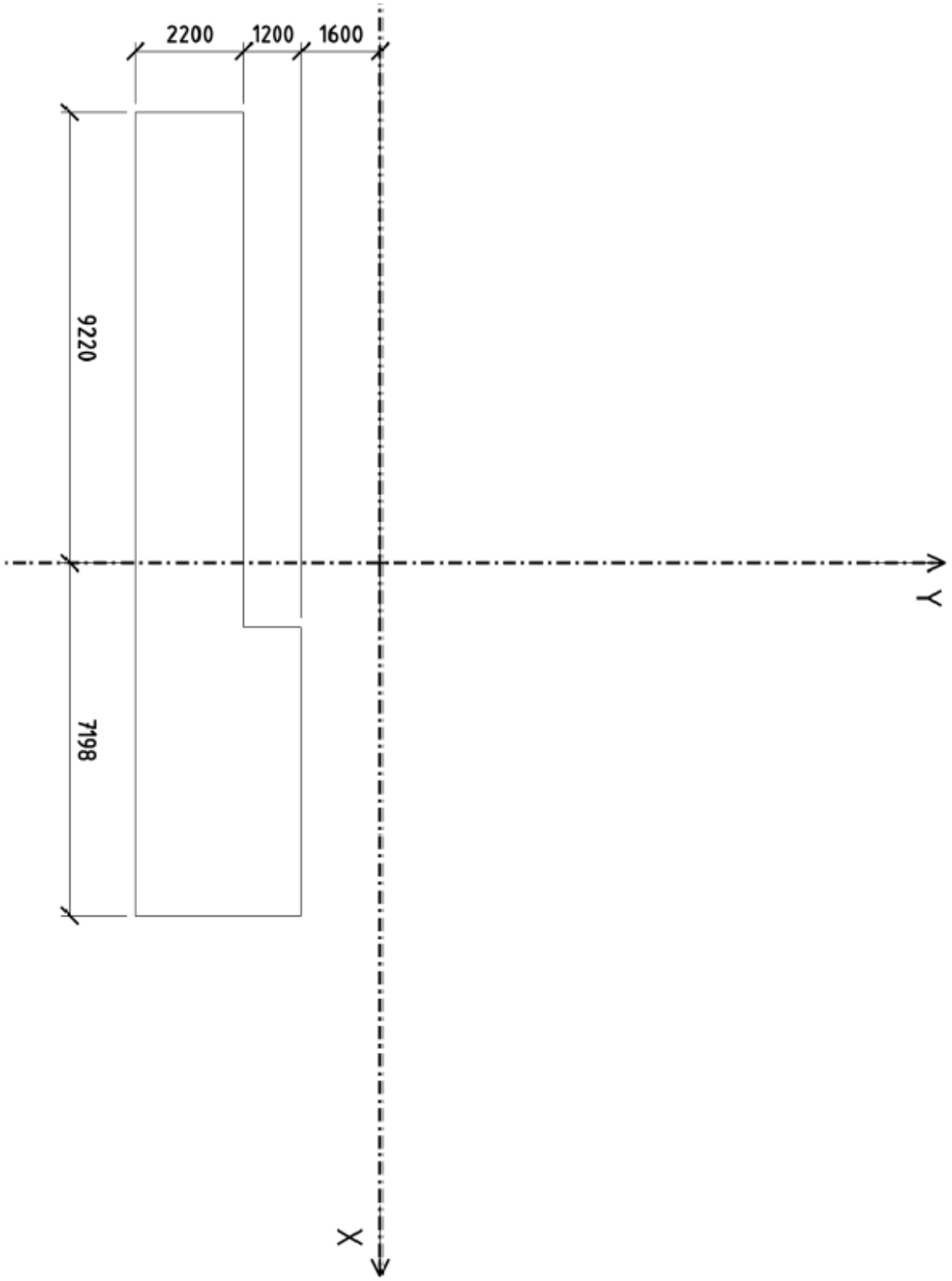


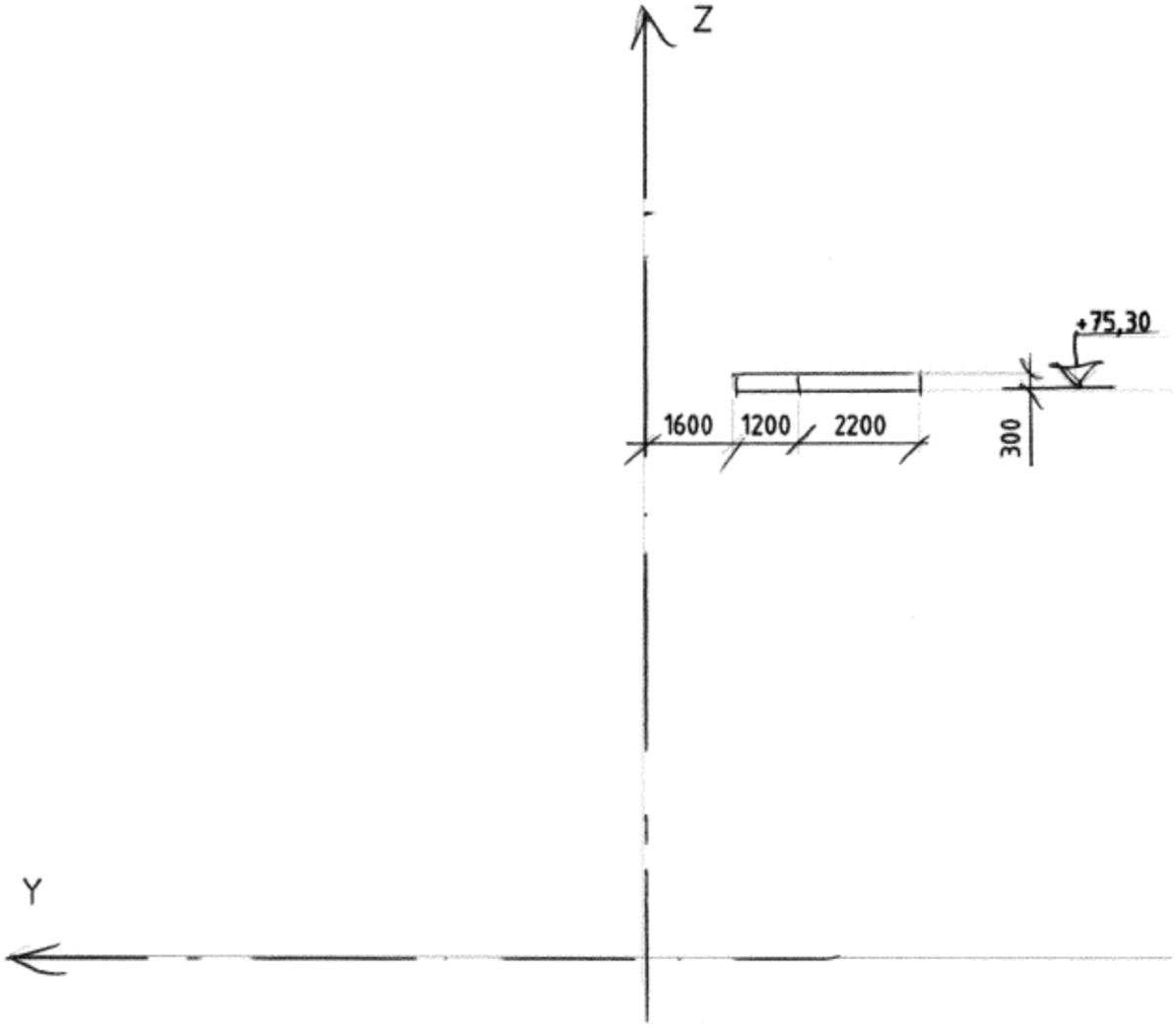

Z
700
+70,40
6500
4150
Y

1.5.4.2 Floor 2

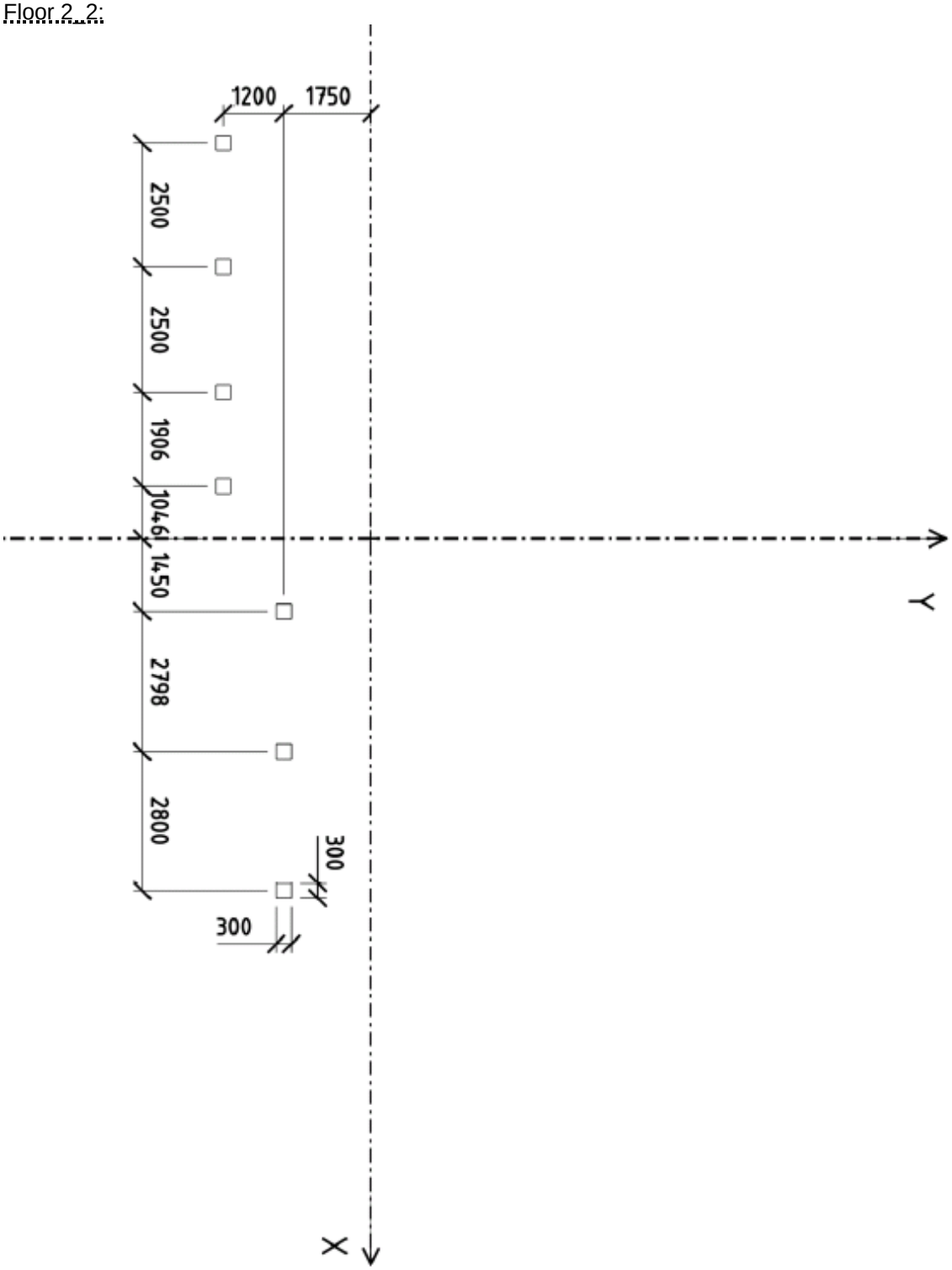


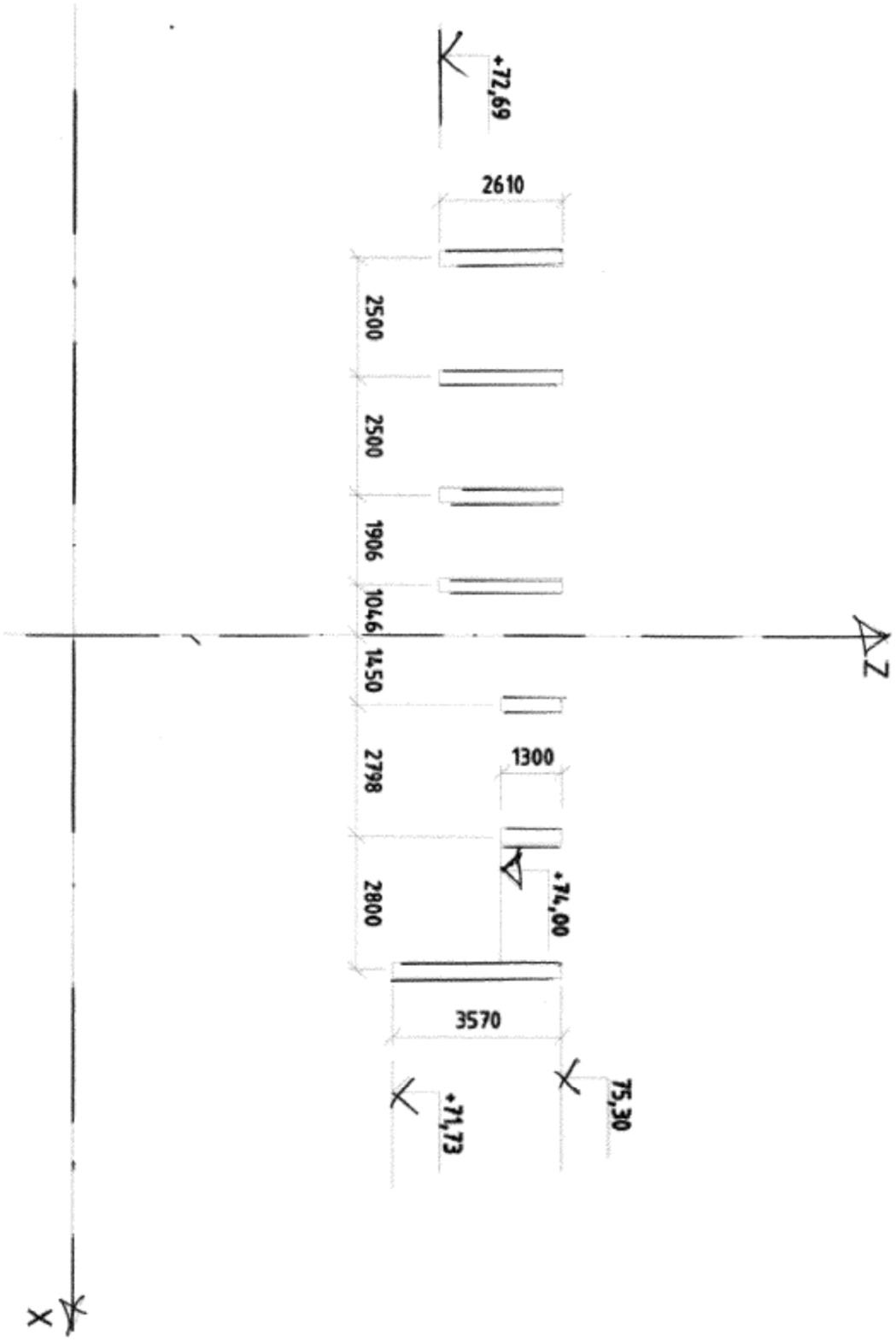
Floor 2_1 :



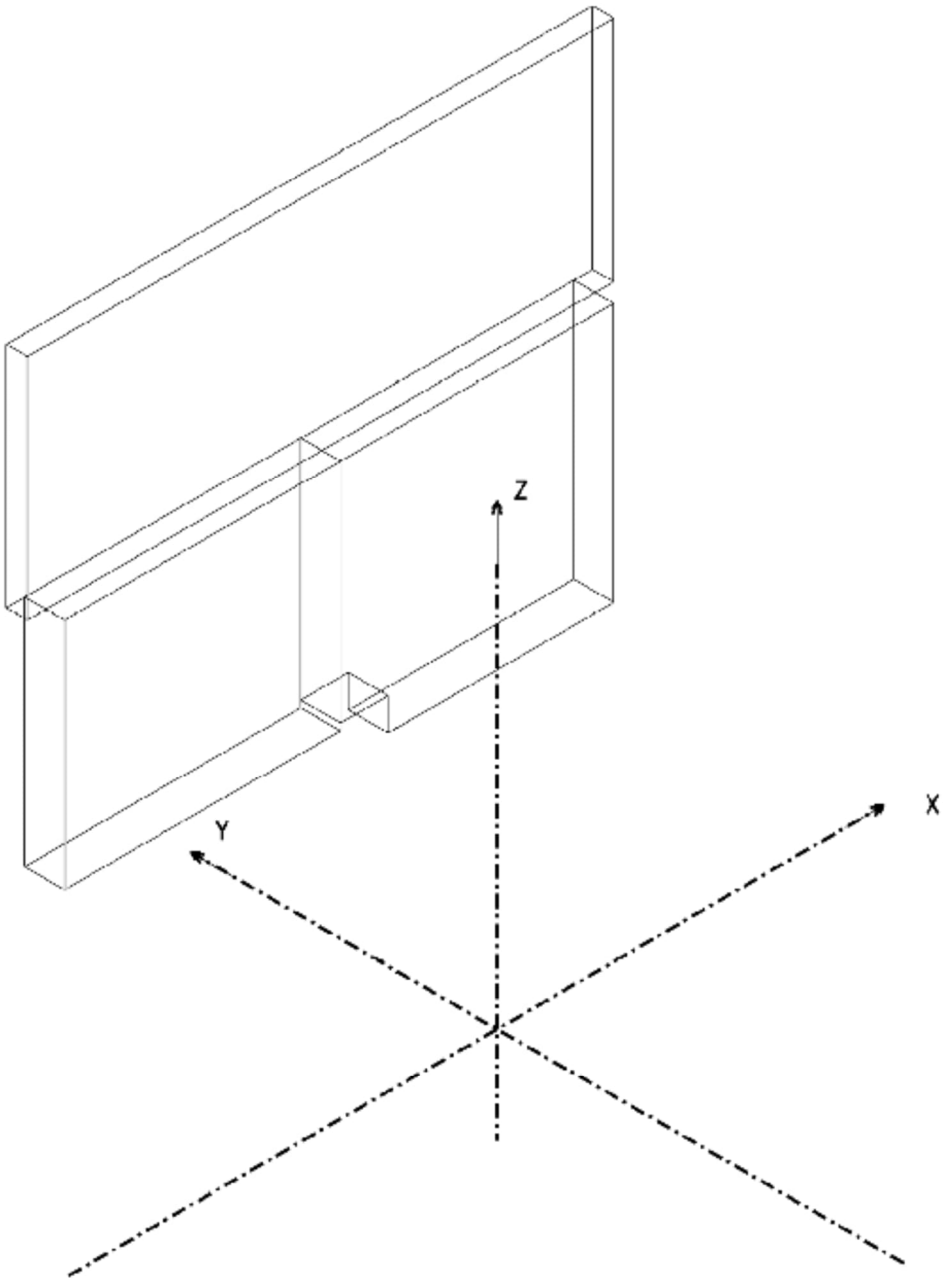

Z
+75,30
1600
1200
2200
300
Y

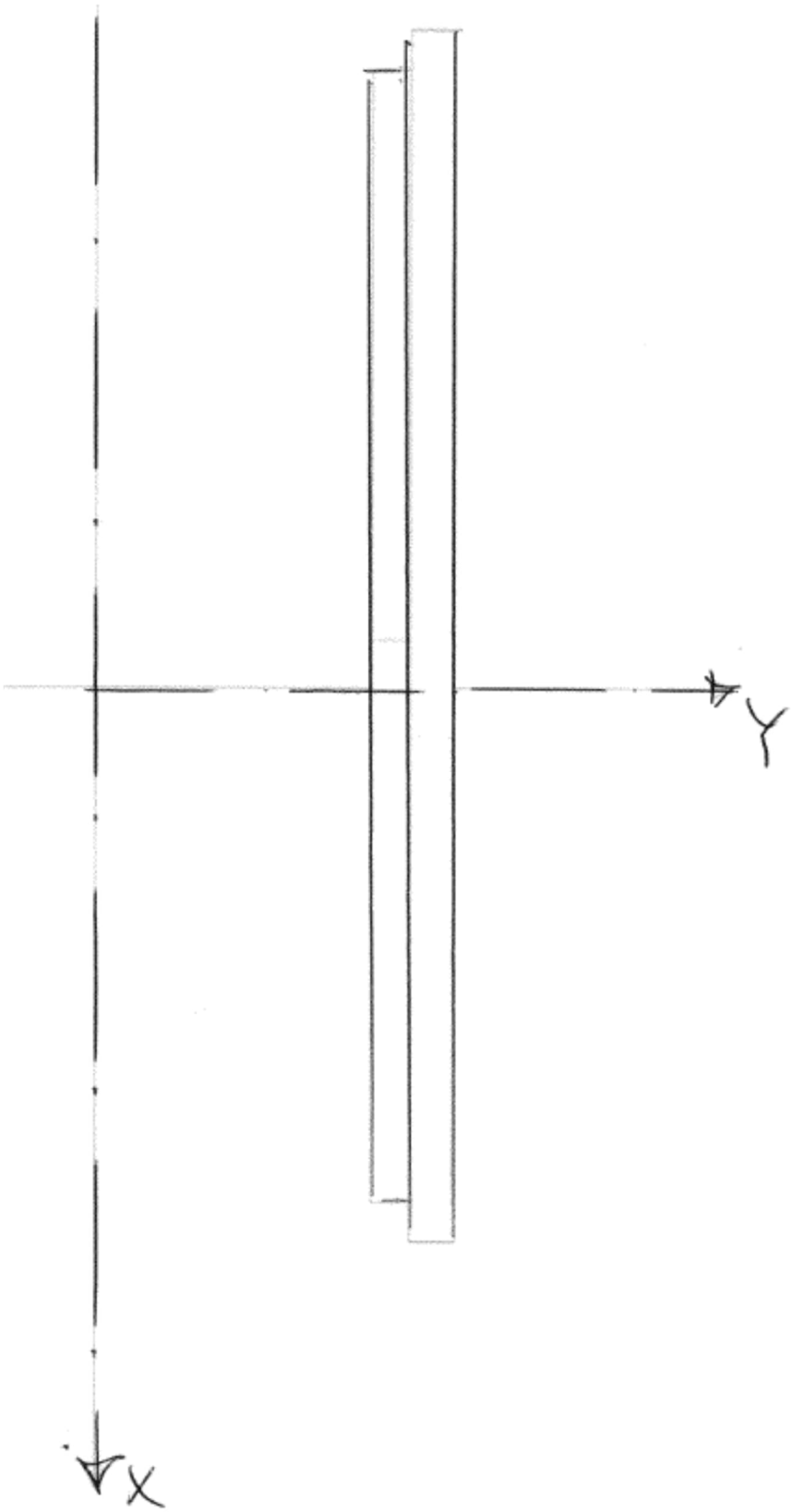
Floor 2_2:



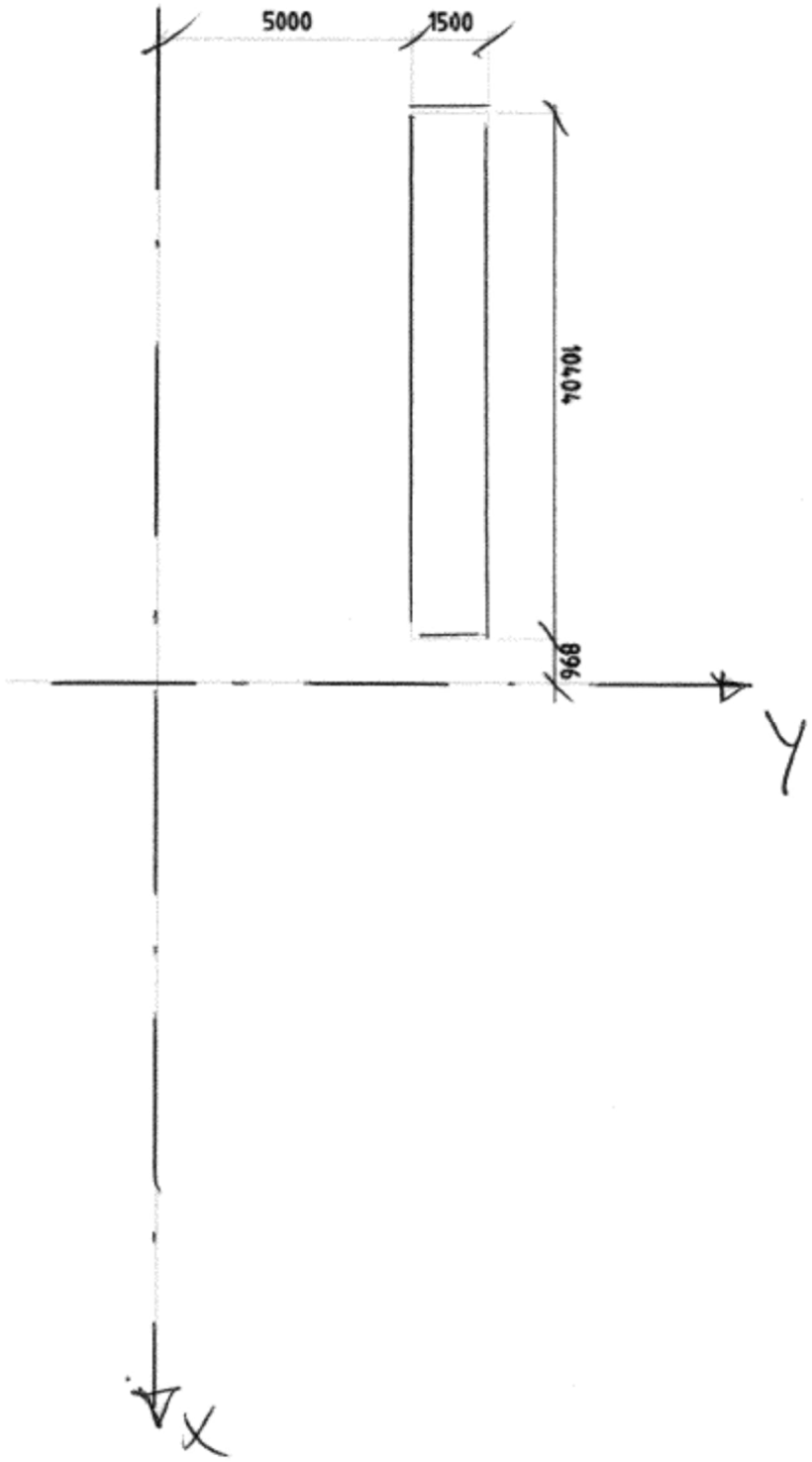

+72,69
2610
2500
2500
1906
1046
1450
2798
1300
2800
+74,00
3570
+71,73
75,30
Z
X

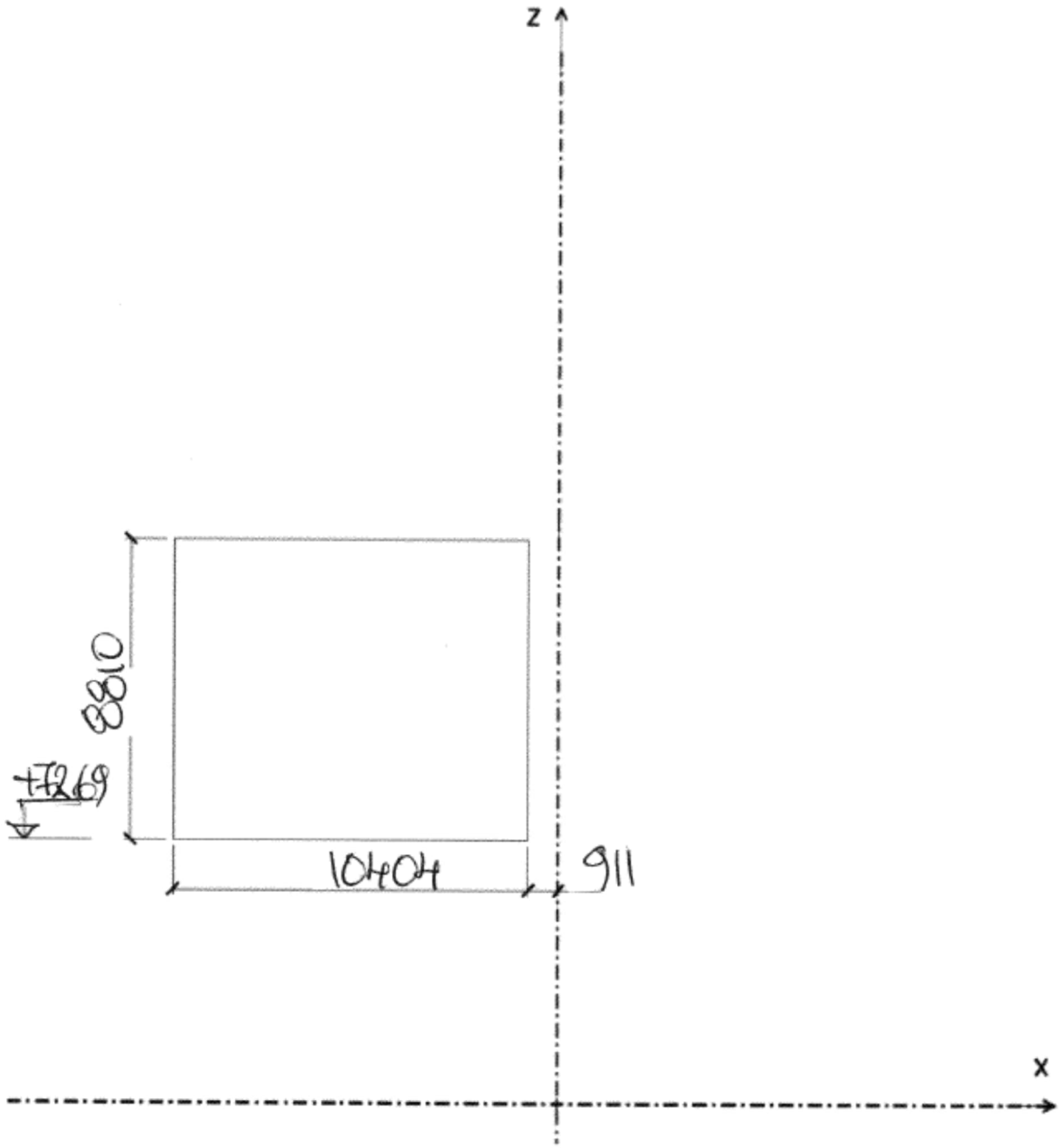
1.5.4.3 Wall 1


Z
X
Y

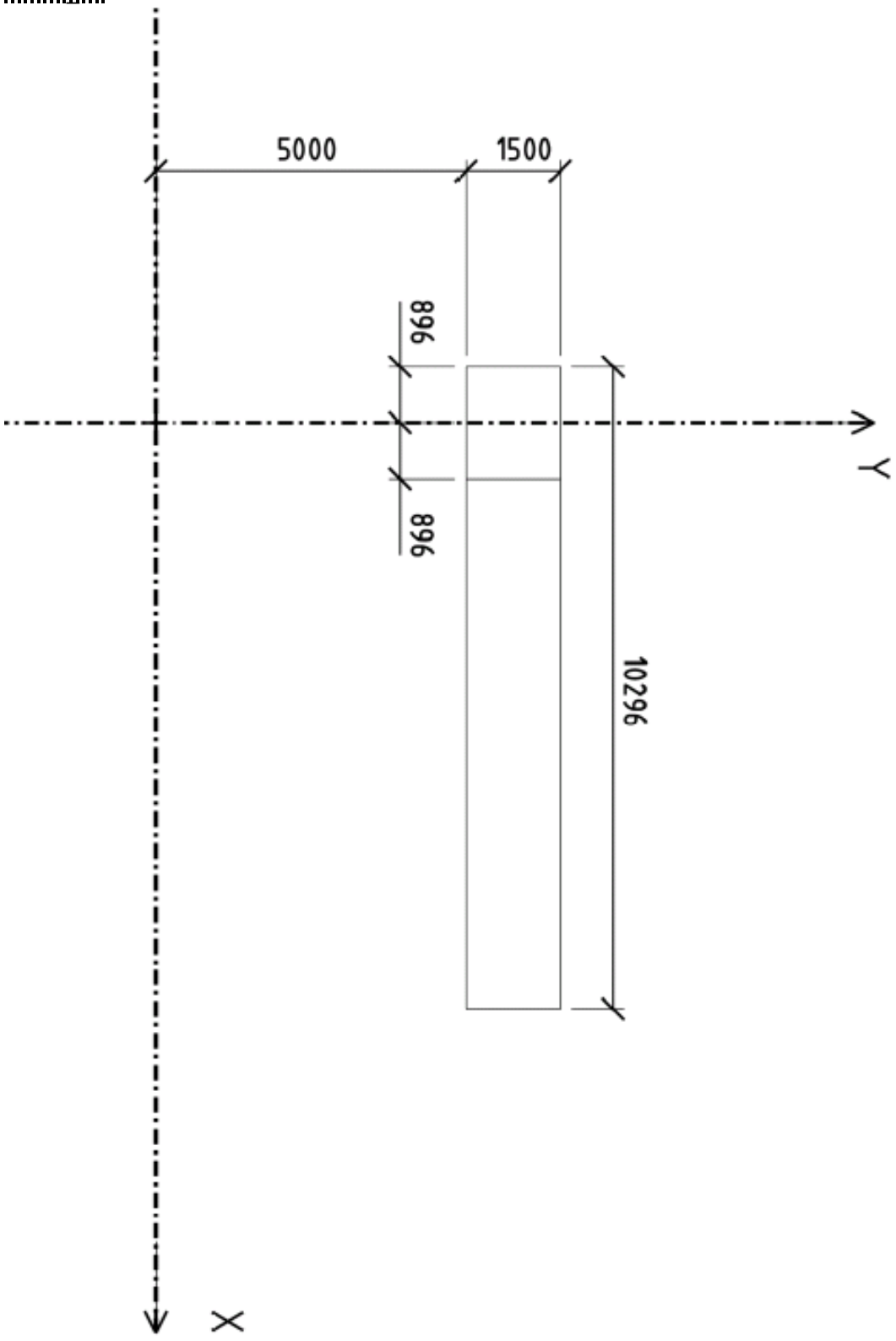

Y
X

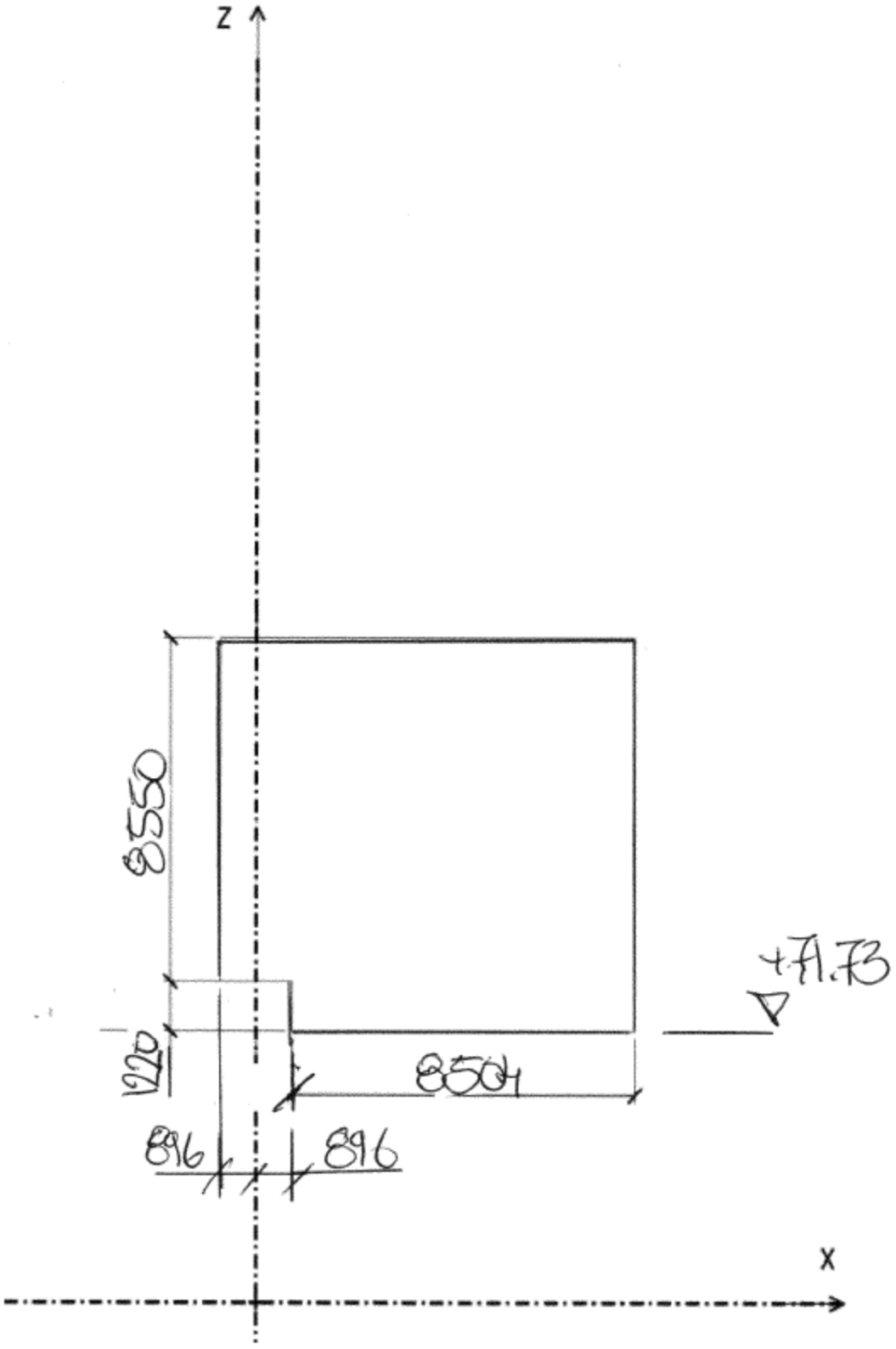
Wall 1_1 :



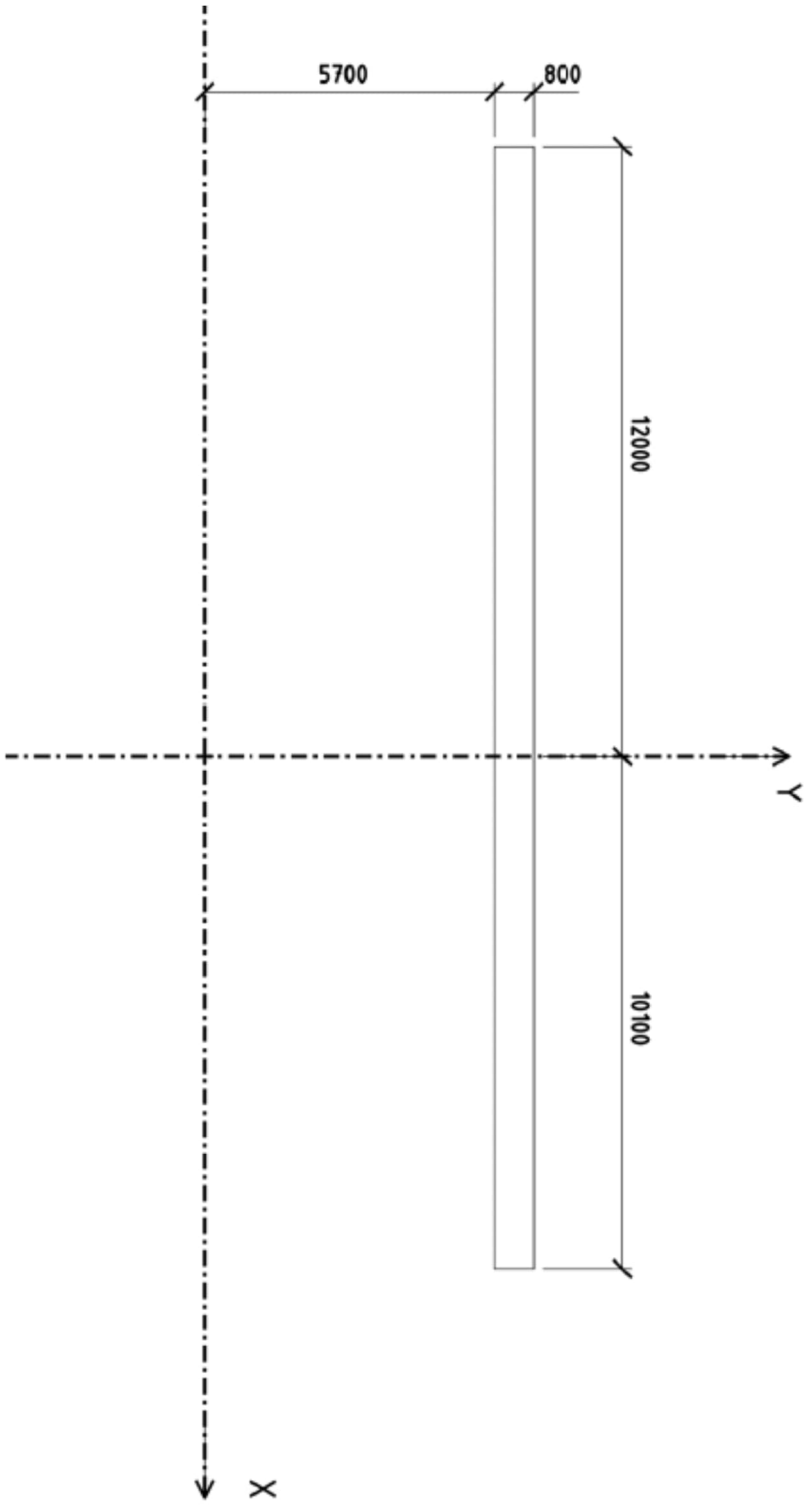

z
8810
+7269
10404
911
x

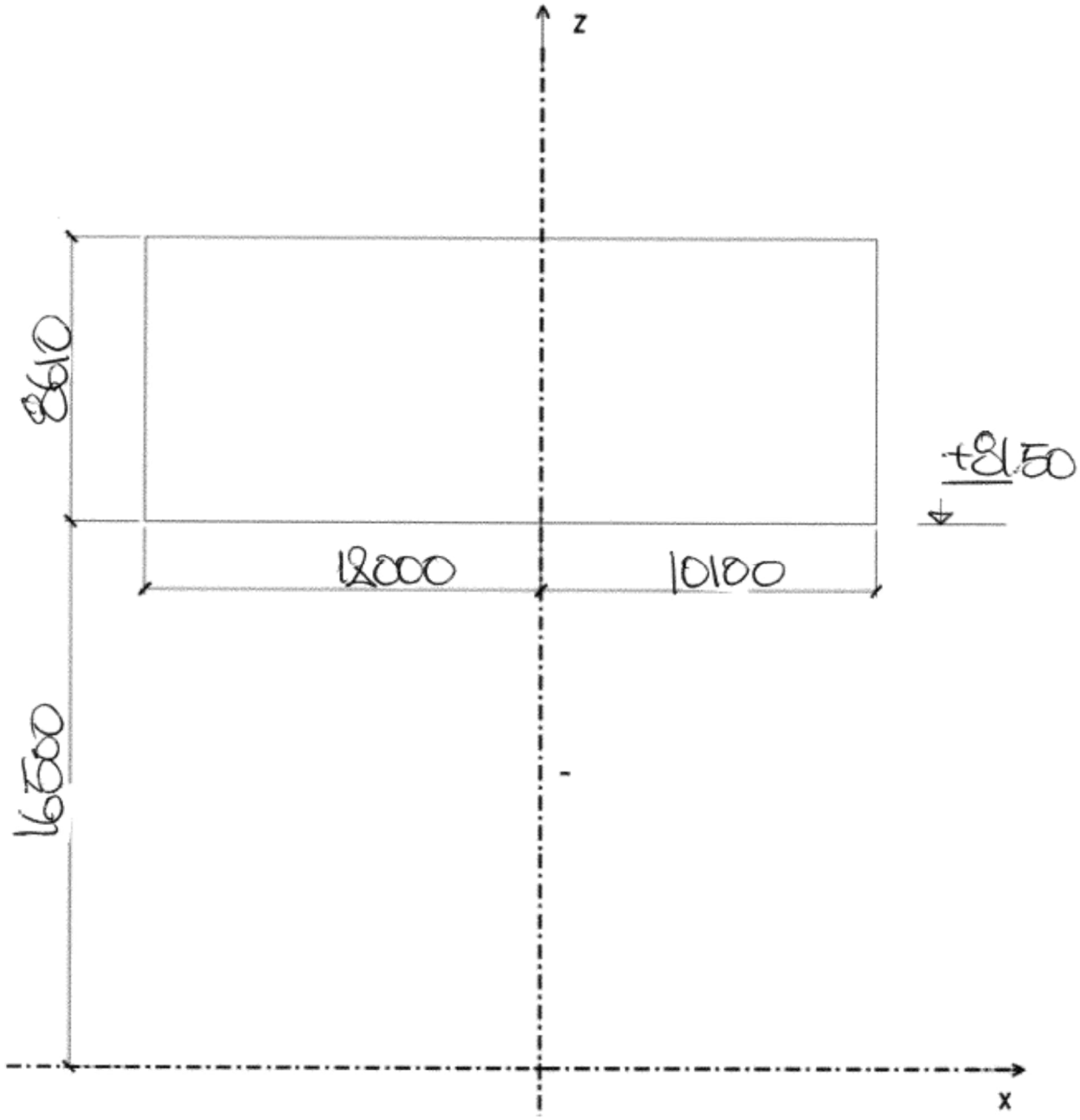
Wall 1_2 :



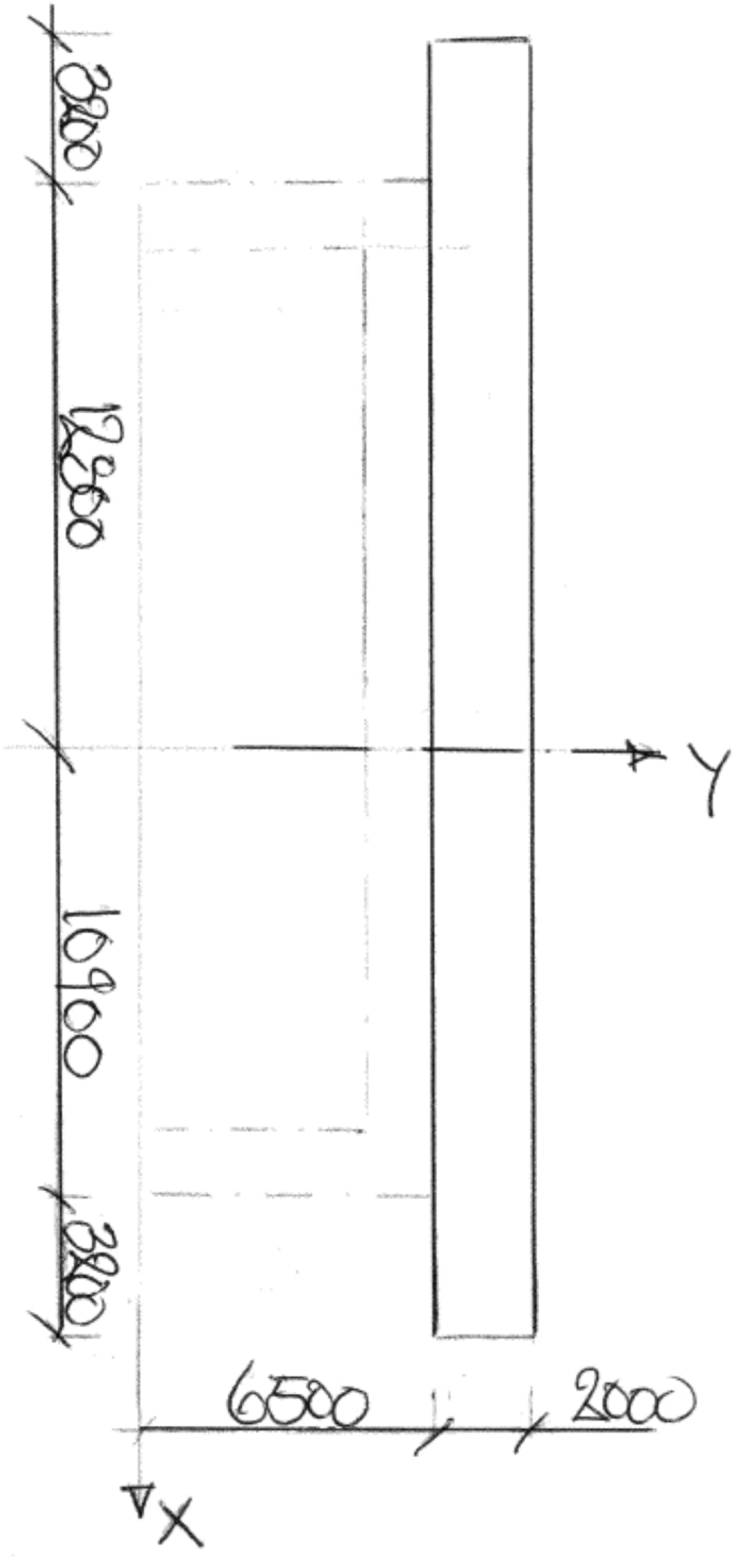

Z
8550
+71.73
1220
8504
896
896
X

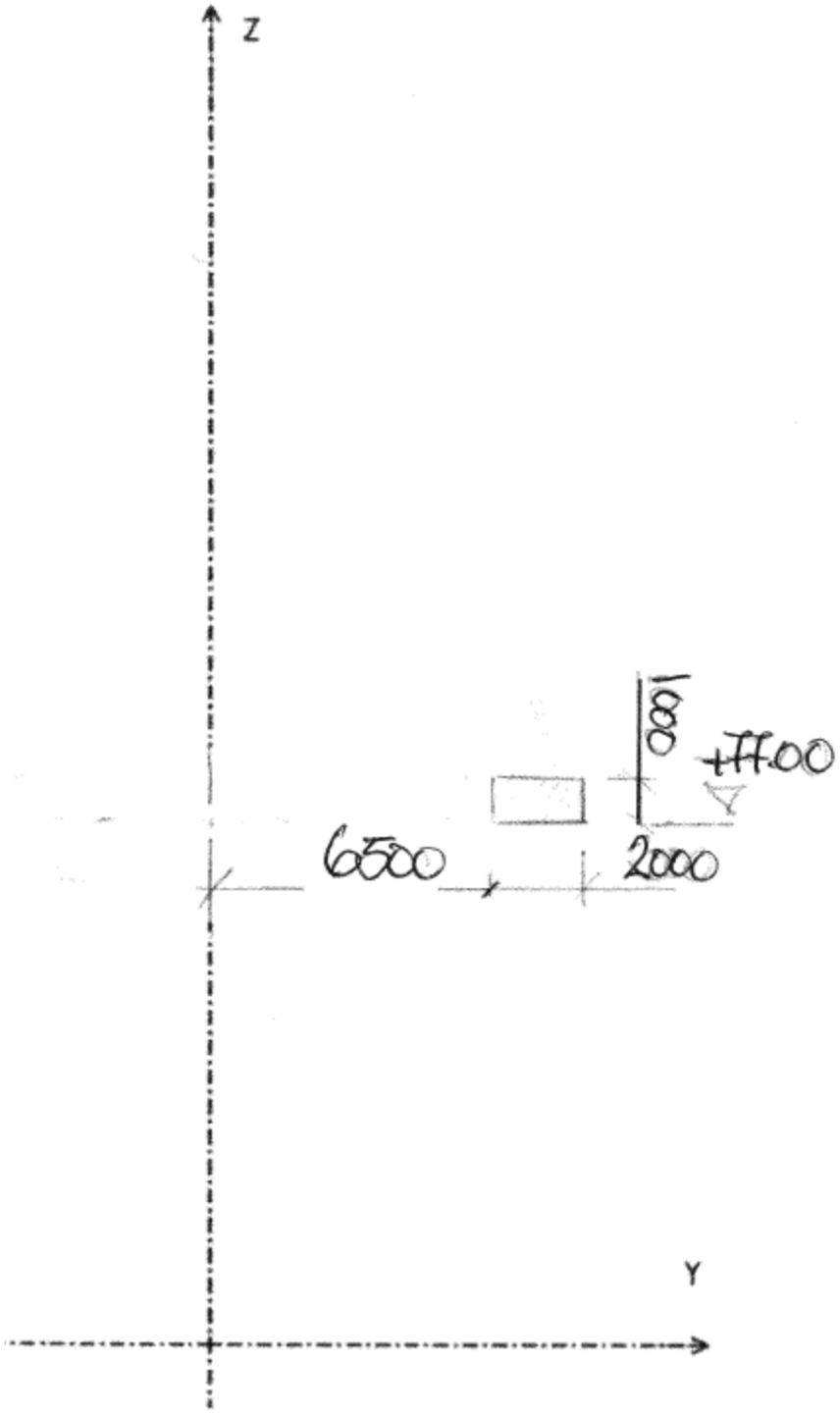
Wall 1_3 :



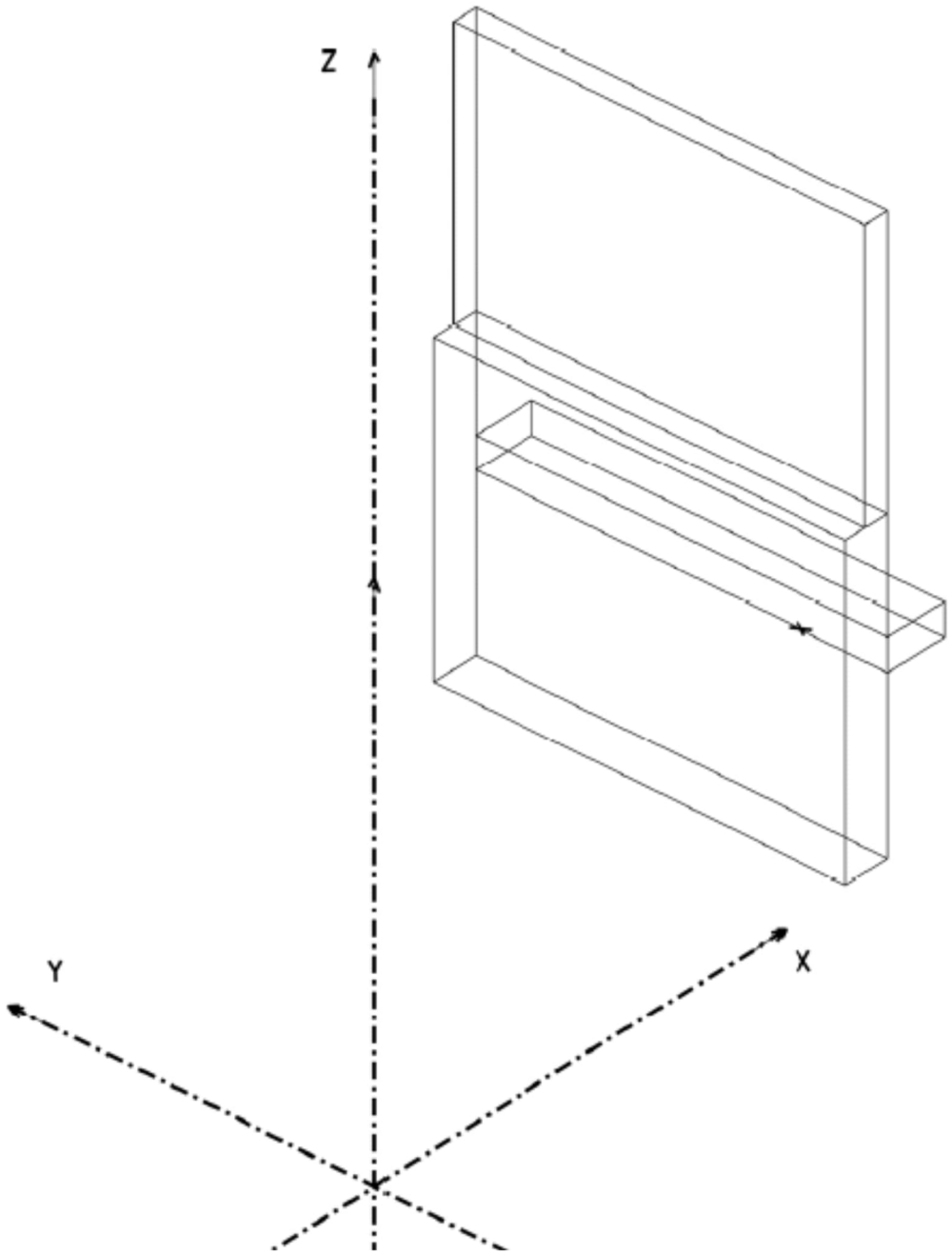

Z
8610
+81.50
12000
10100
16500
X

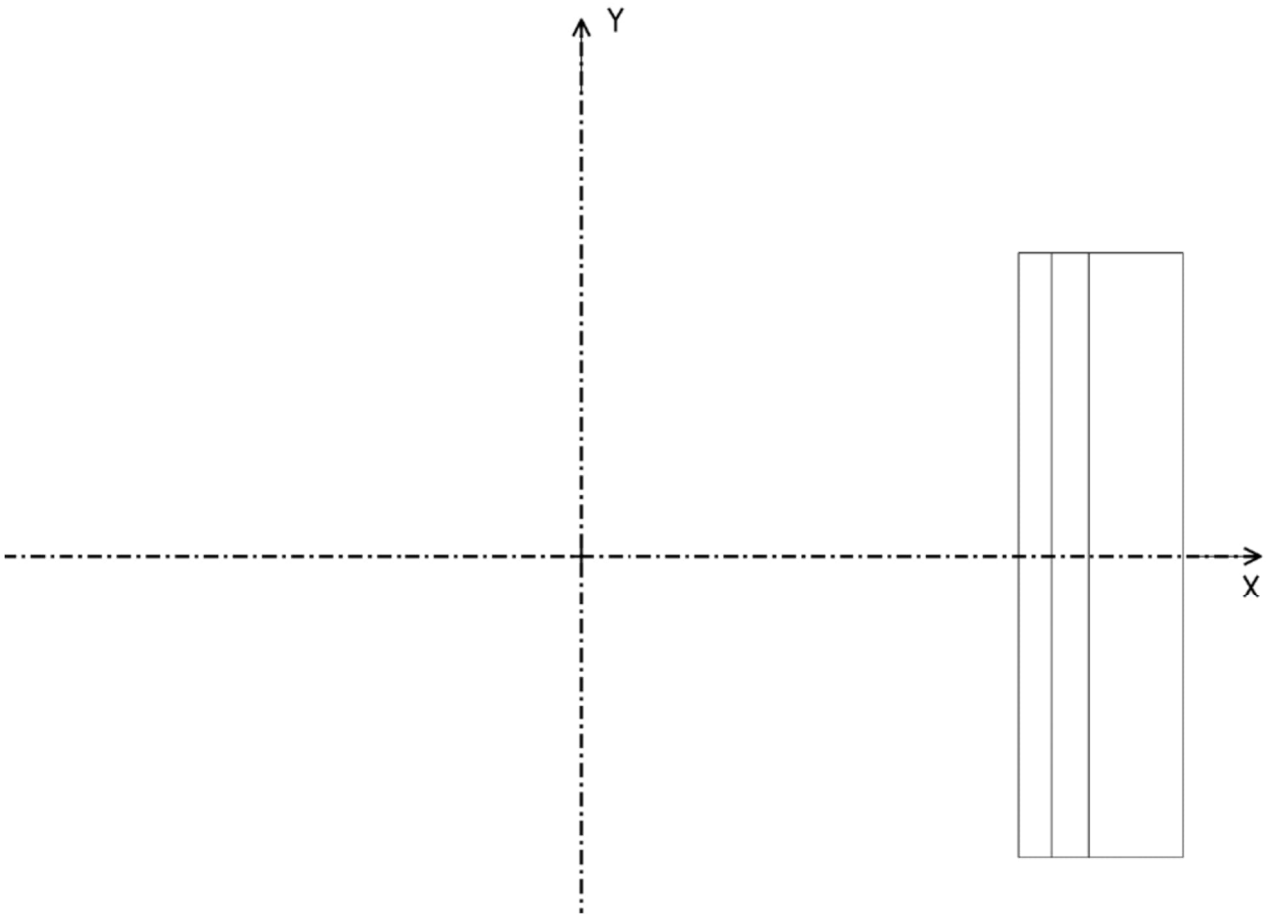
Wall 1_4 :



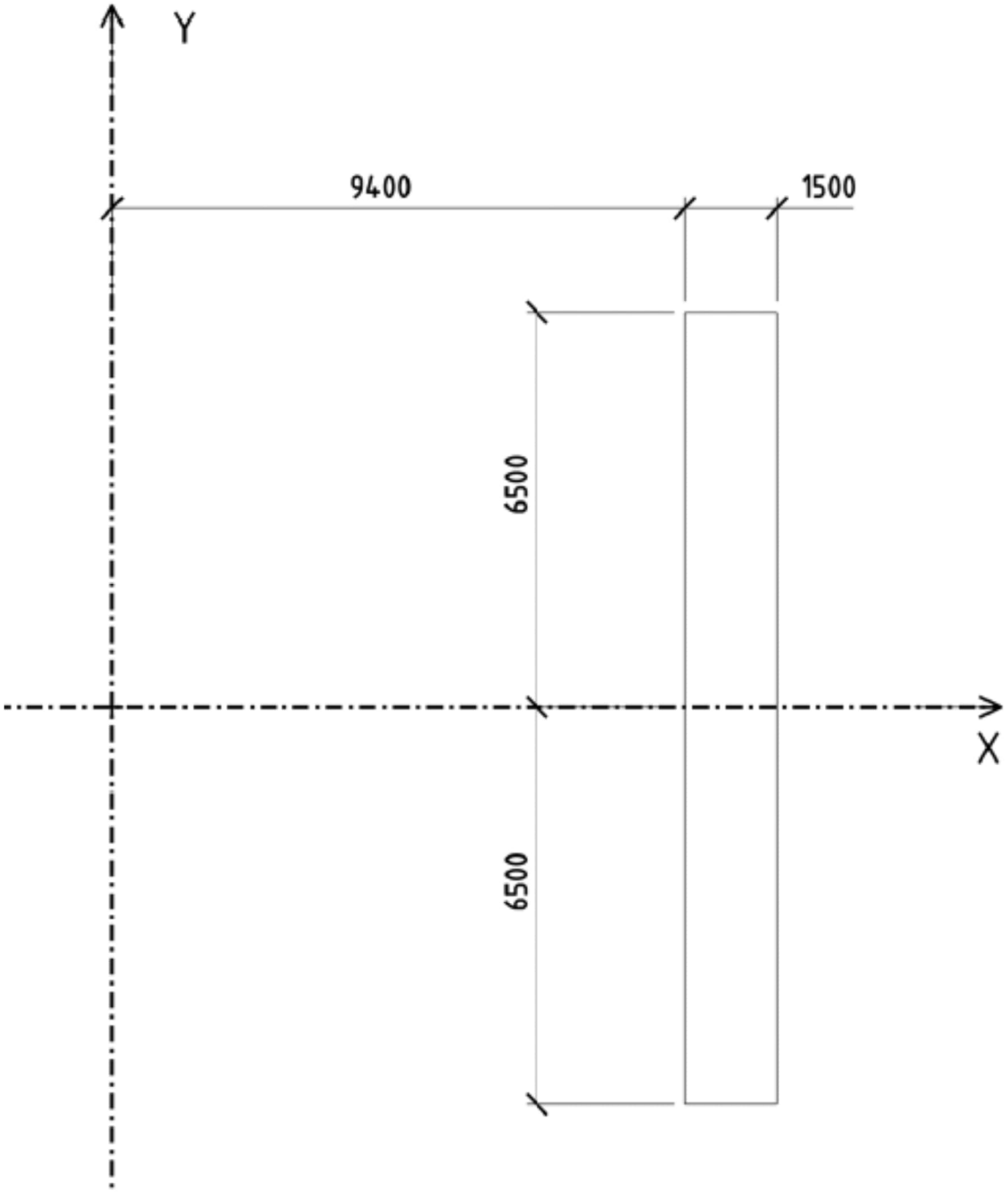

Z
1800
+77.00
6500
2000
Y

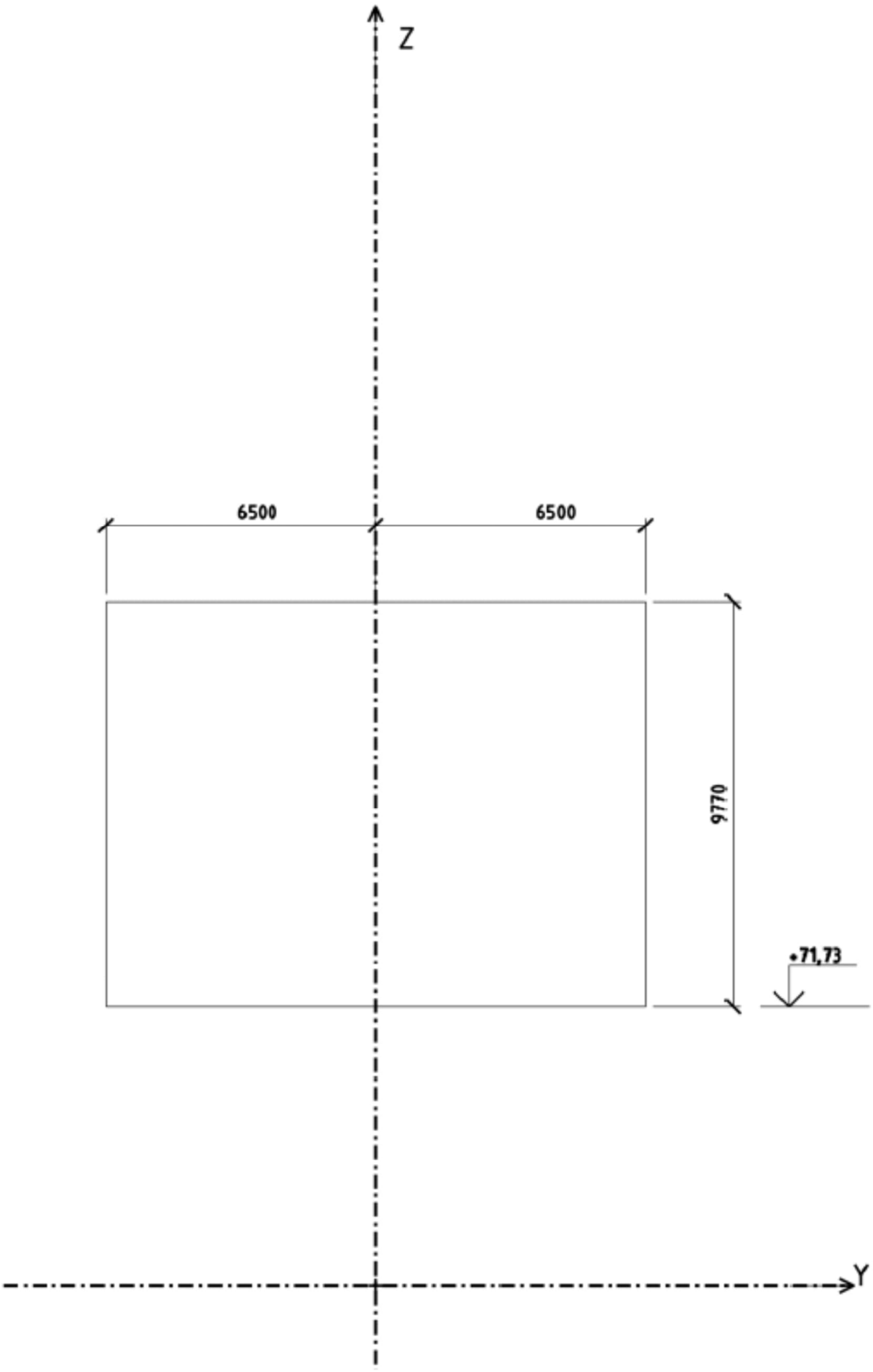
1.5.4.4 Wall 2



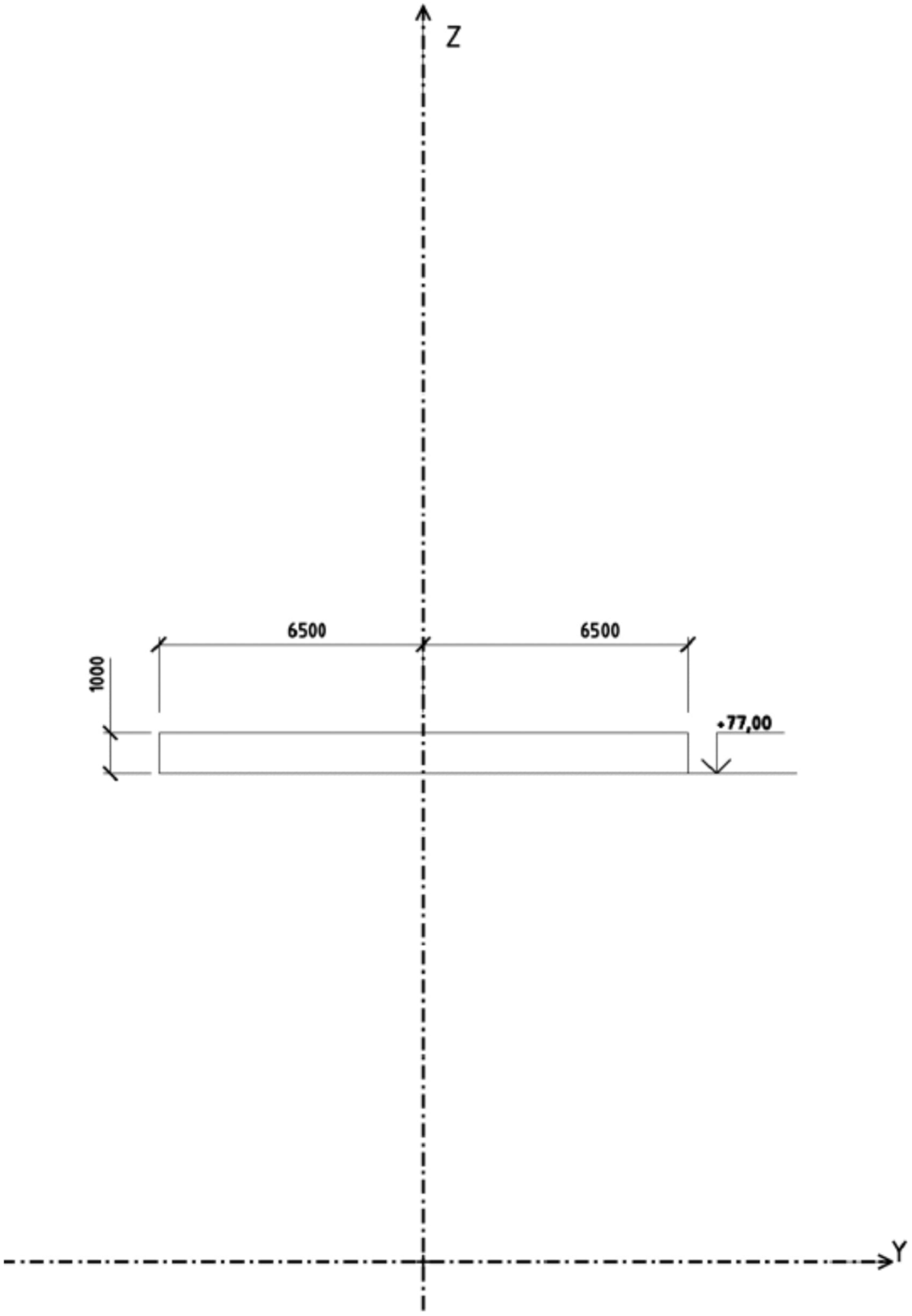

Y
X

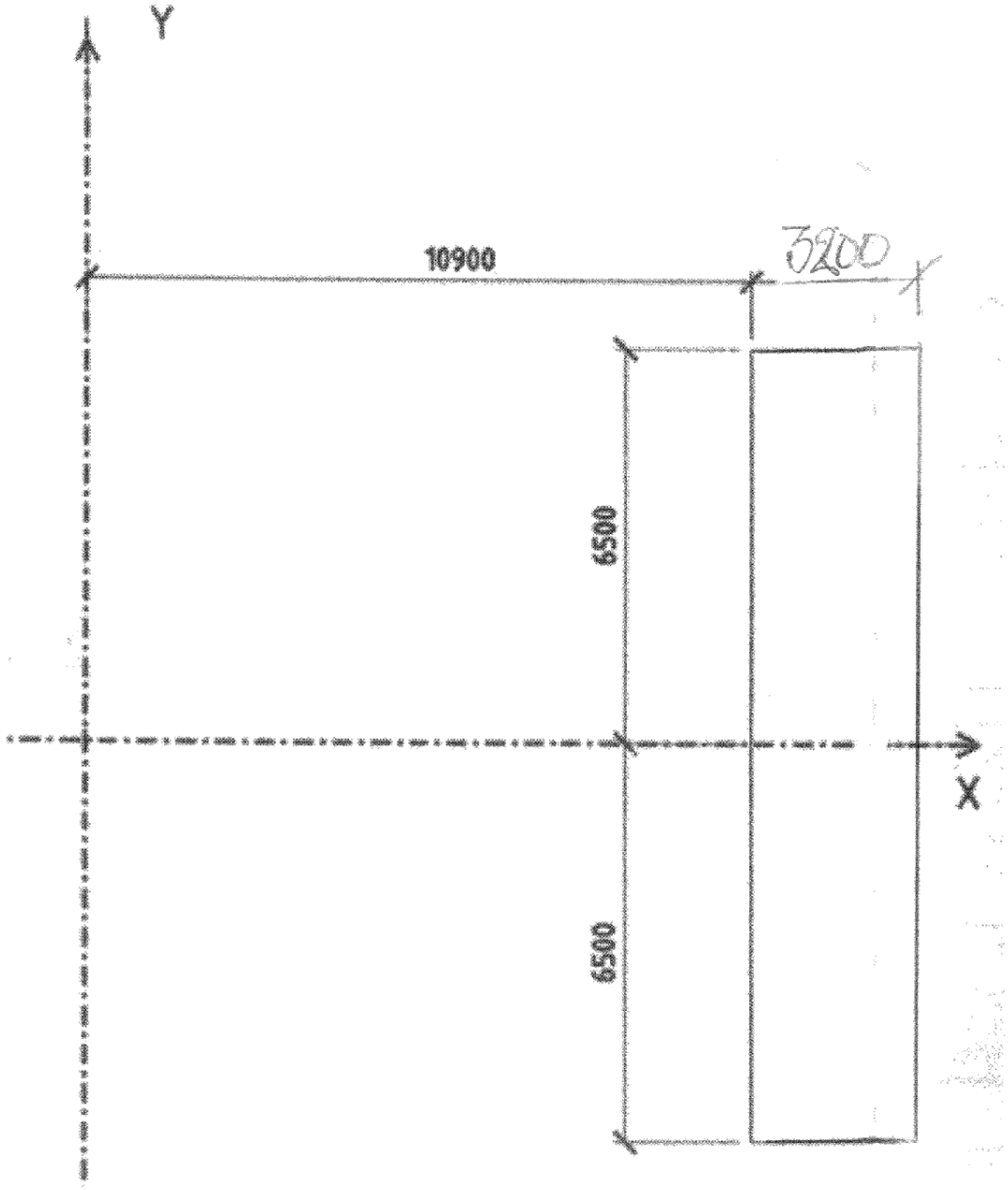
Wall 2_1 :



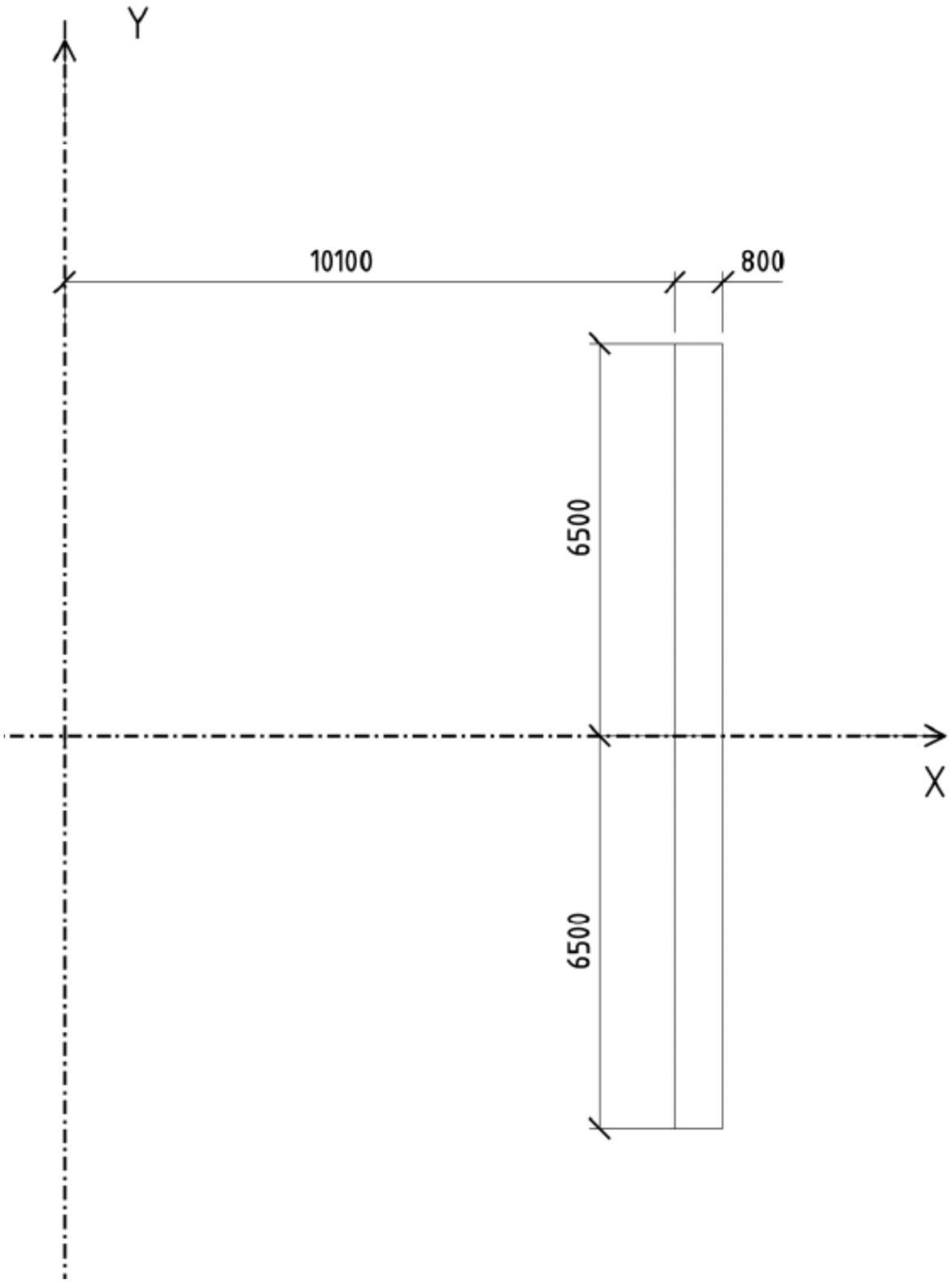

Z
6500
6500
9770
+71,73
Y

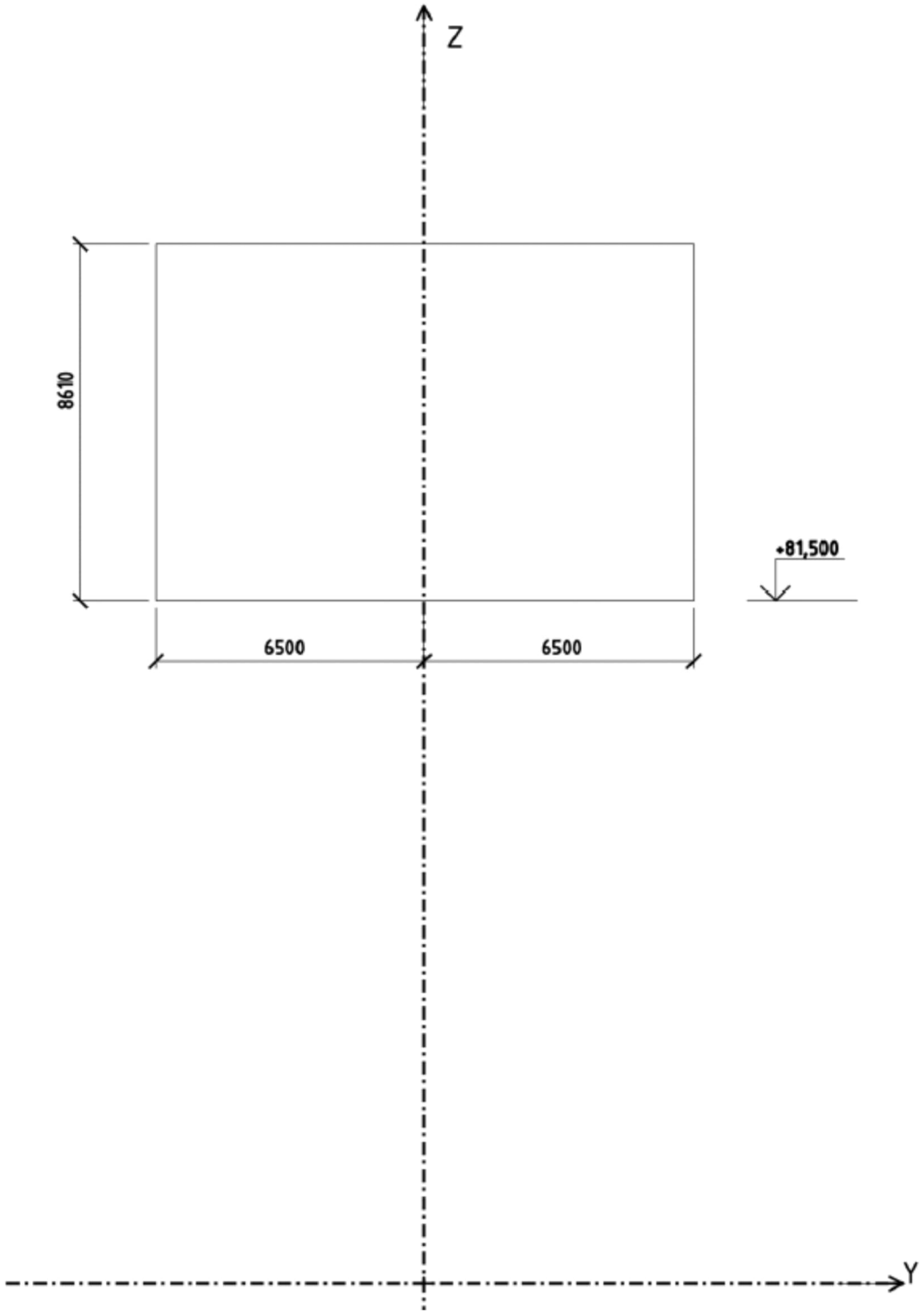
Wall 2_2 :



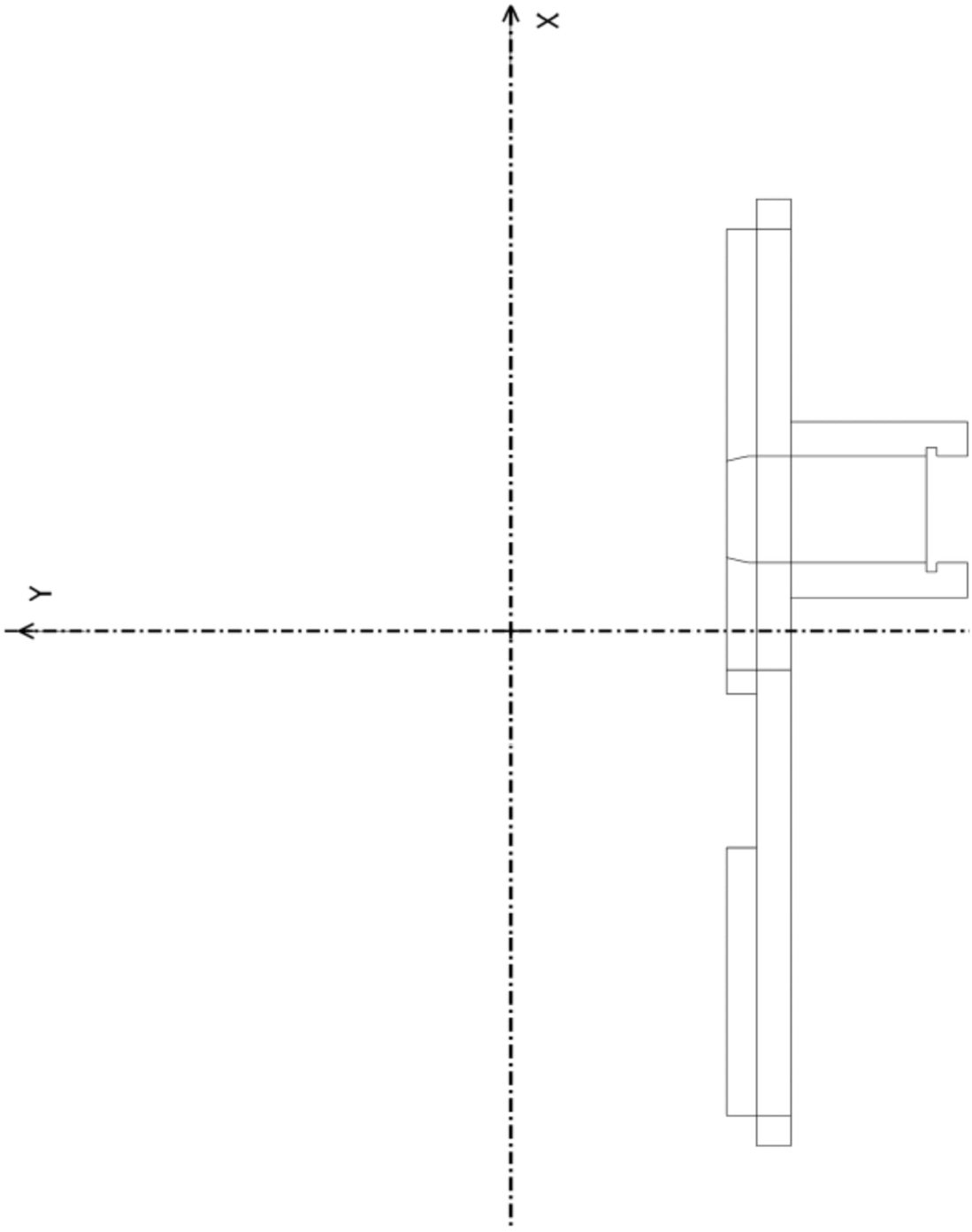

Y
10900
3200
6500
6500
X

Wall 2_3 :

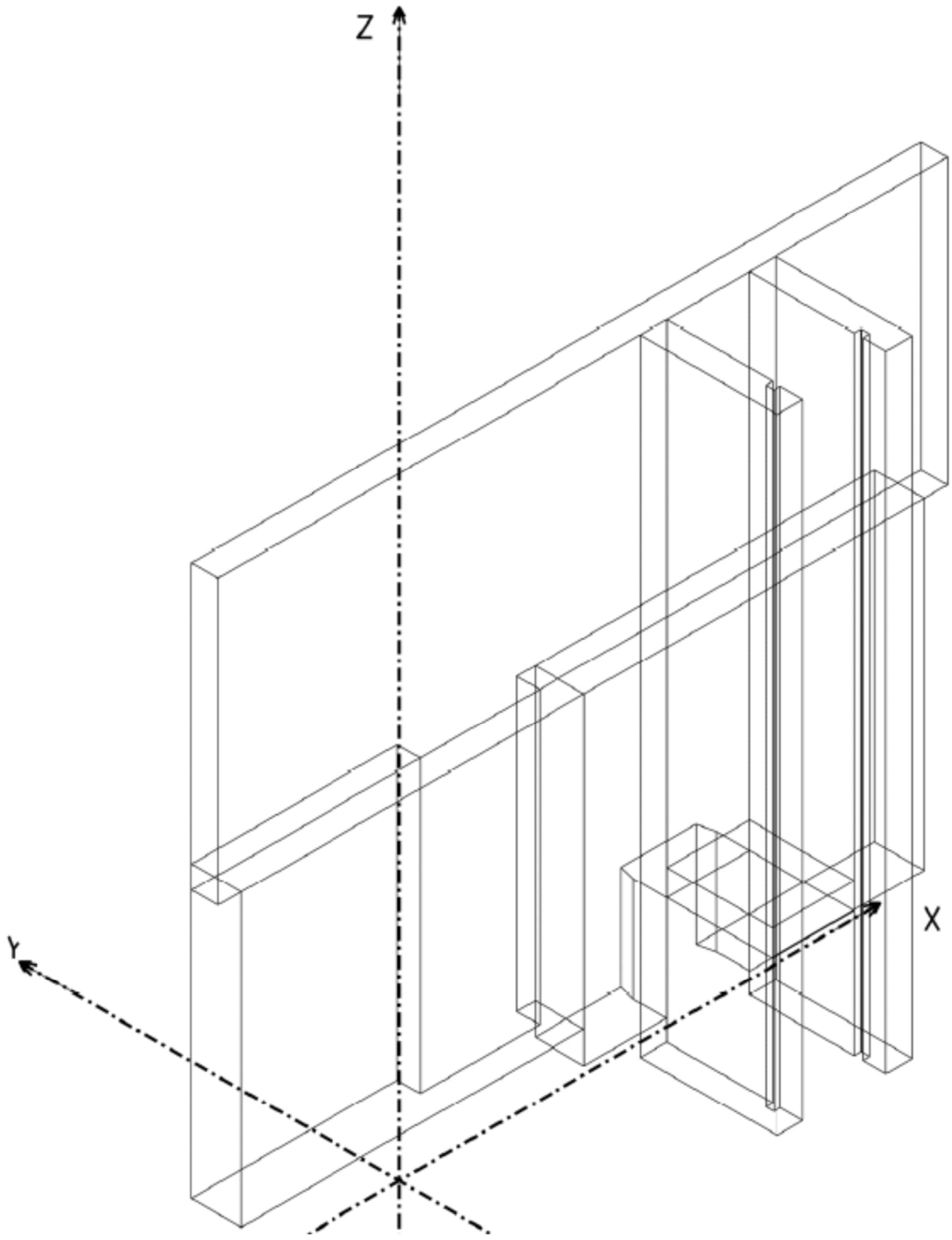



Z
8610
+81,500
6500
6500
Y

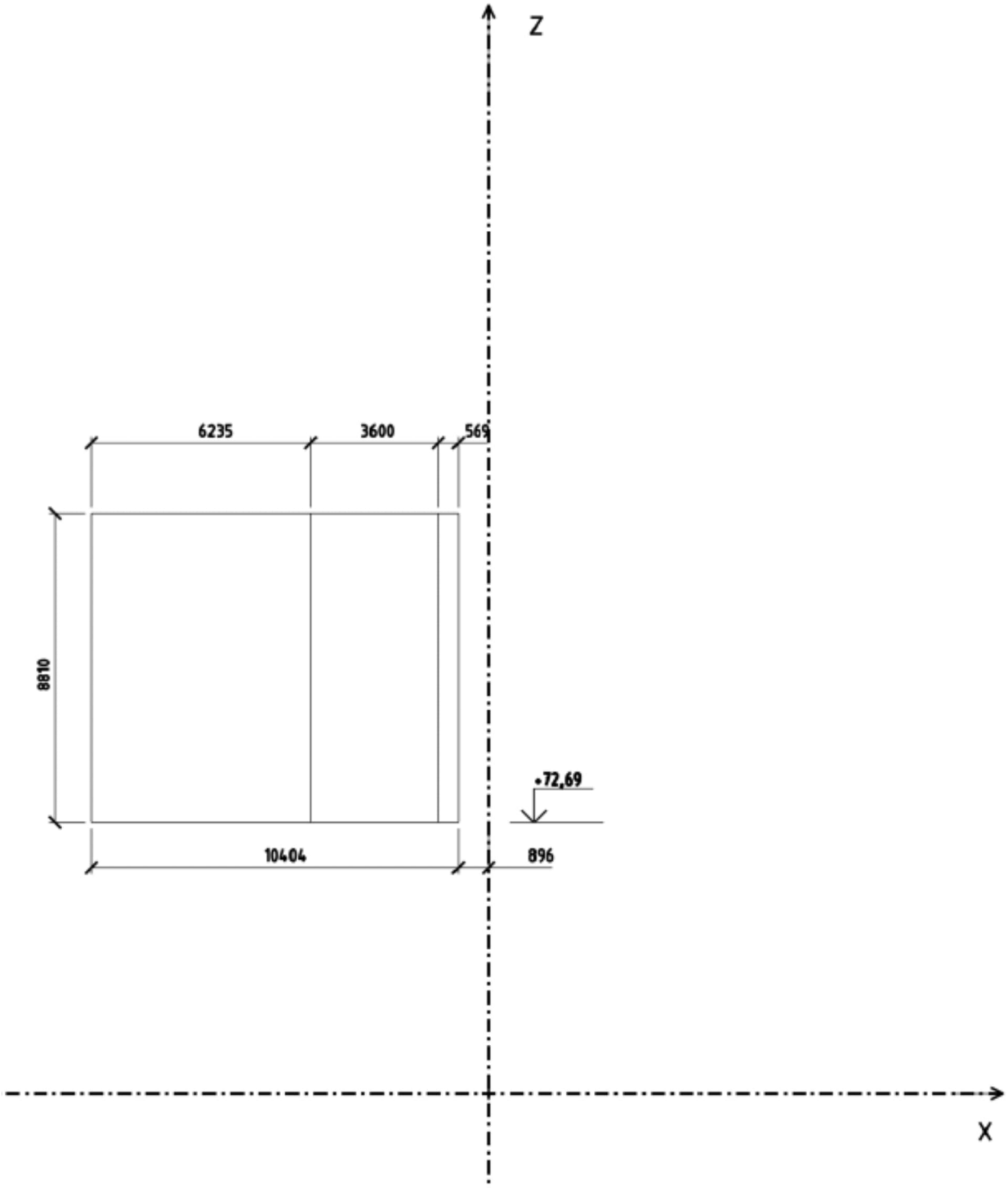
1.5.4.5 Wall 3

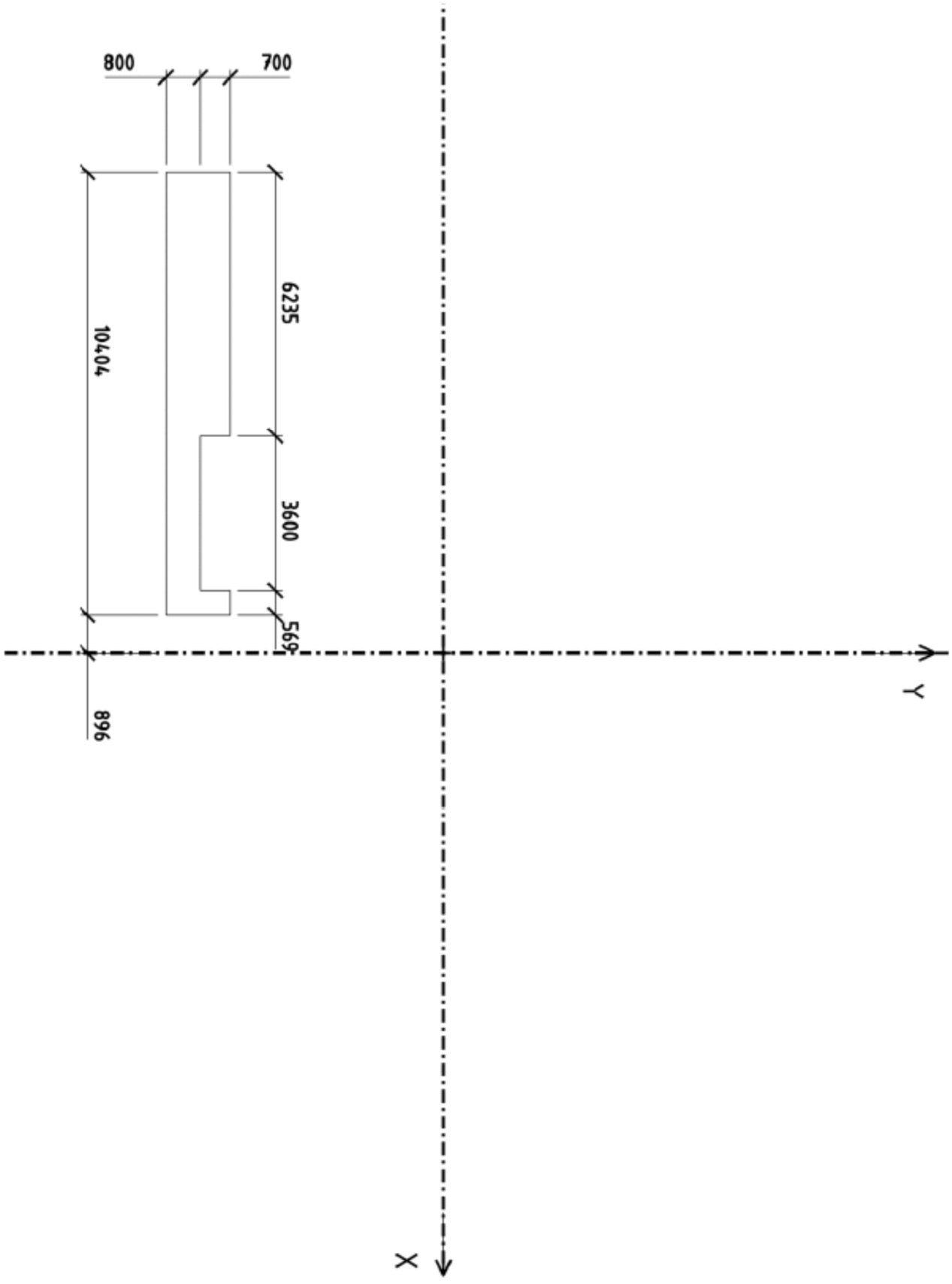


Remark Wall 3 consist of 6 different parts termed Wall 3_1, Wall 3_2, and Wall 4_3.

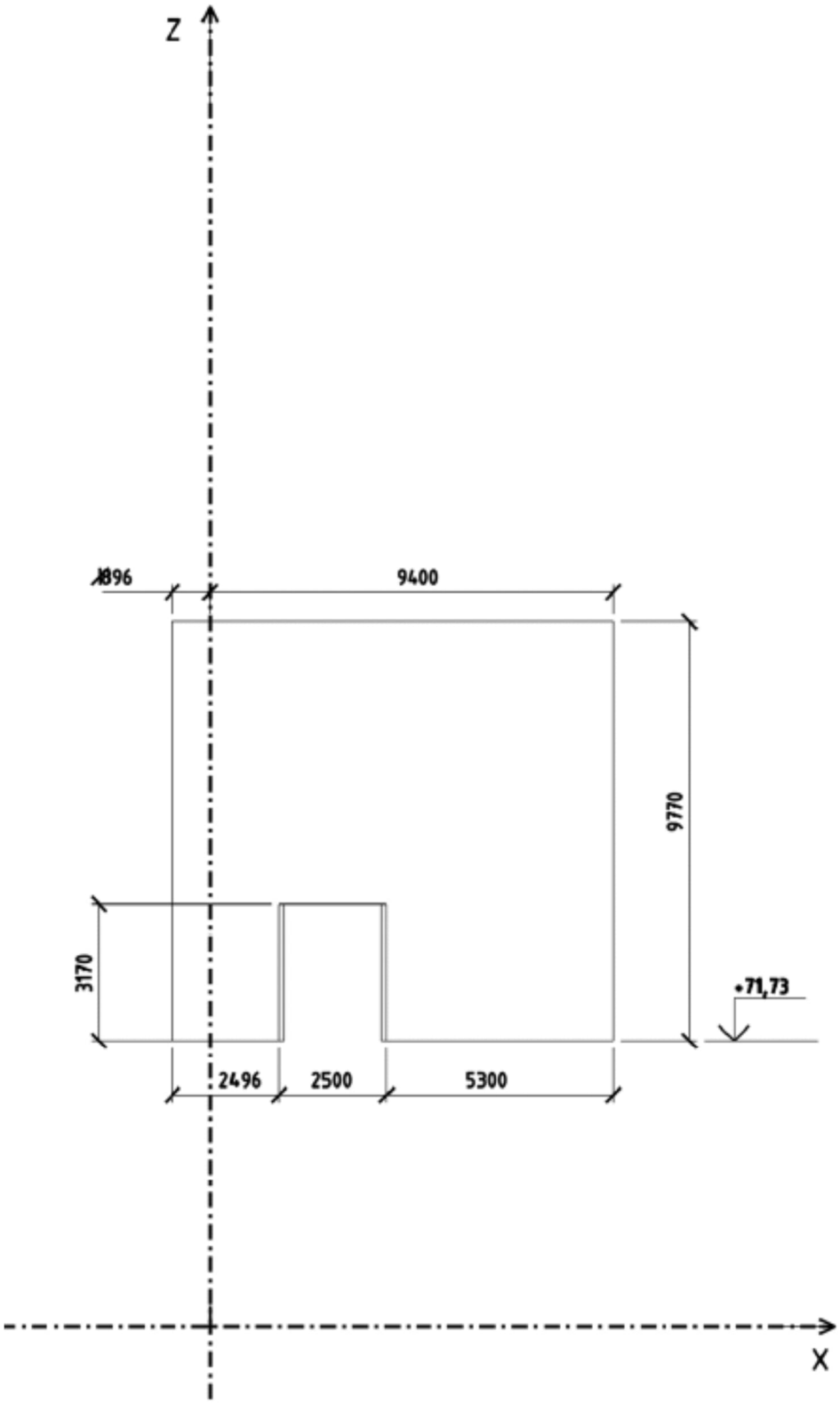

Z
Y
X

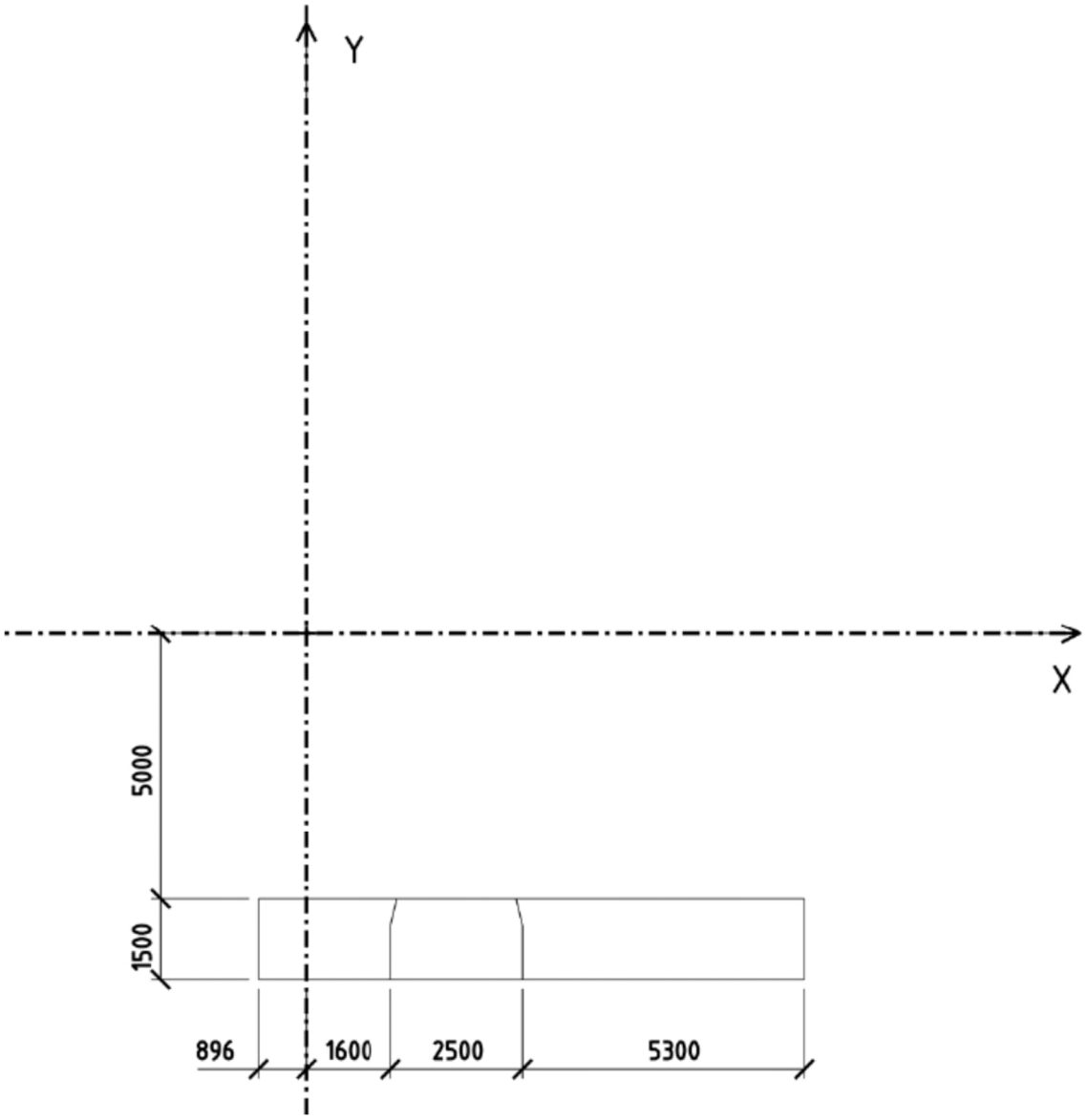
Wall 3_1 :



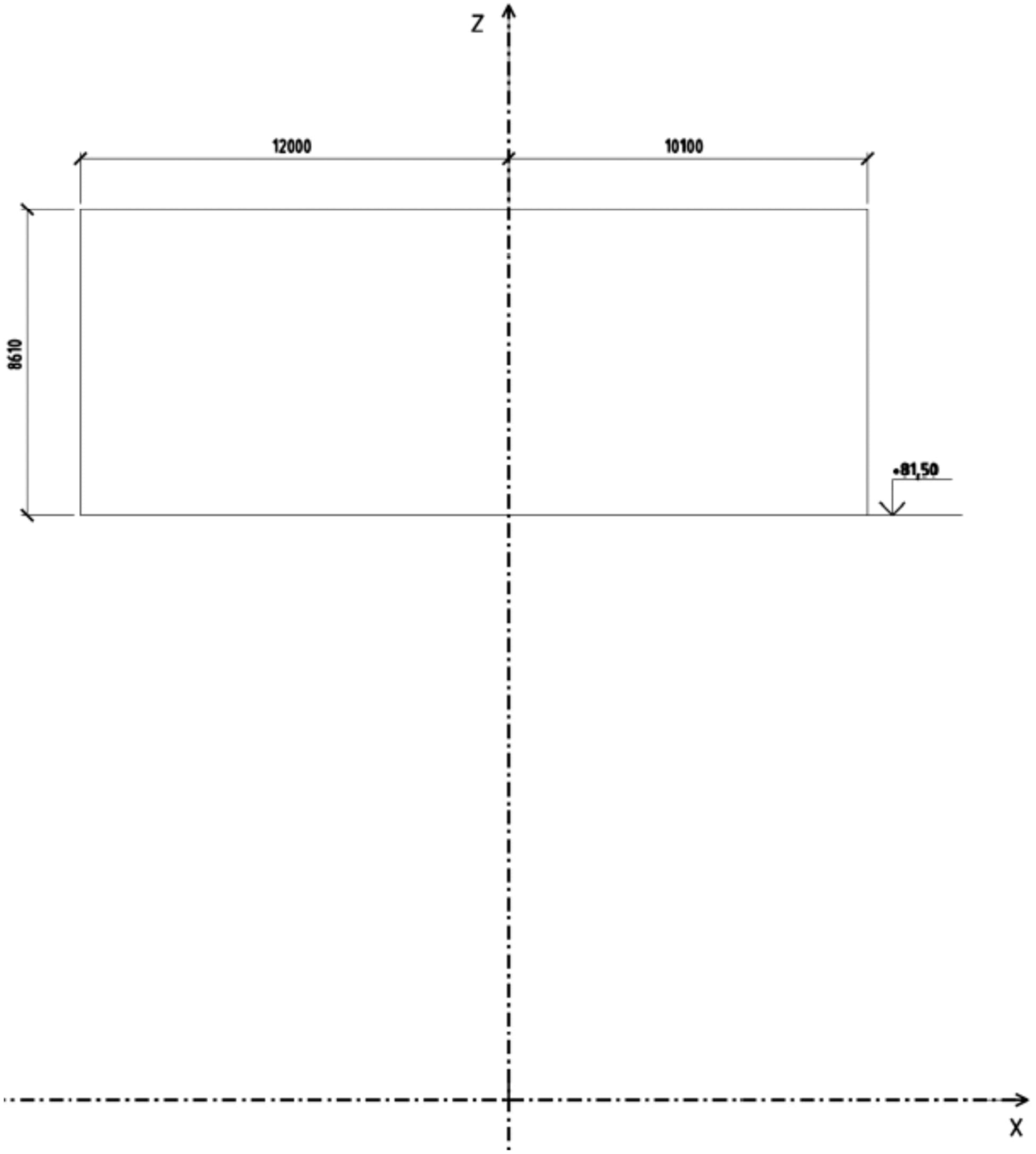

800
700
10404
6235
3600
569
898
Y
X

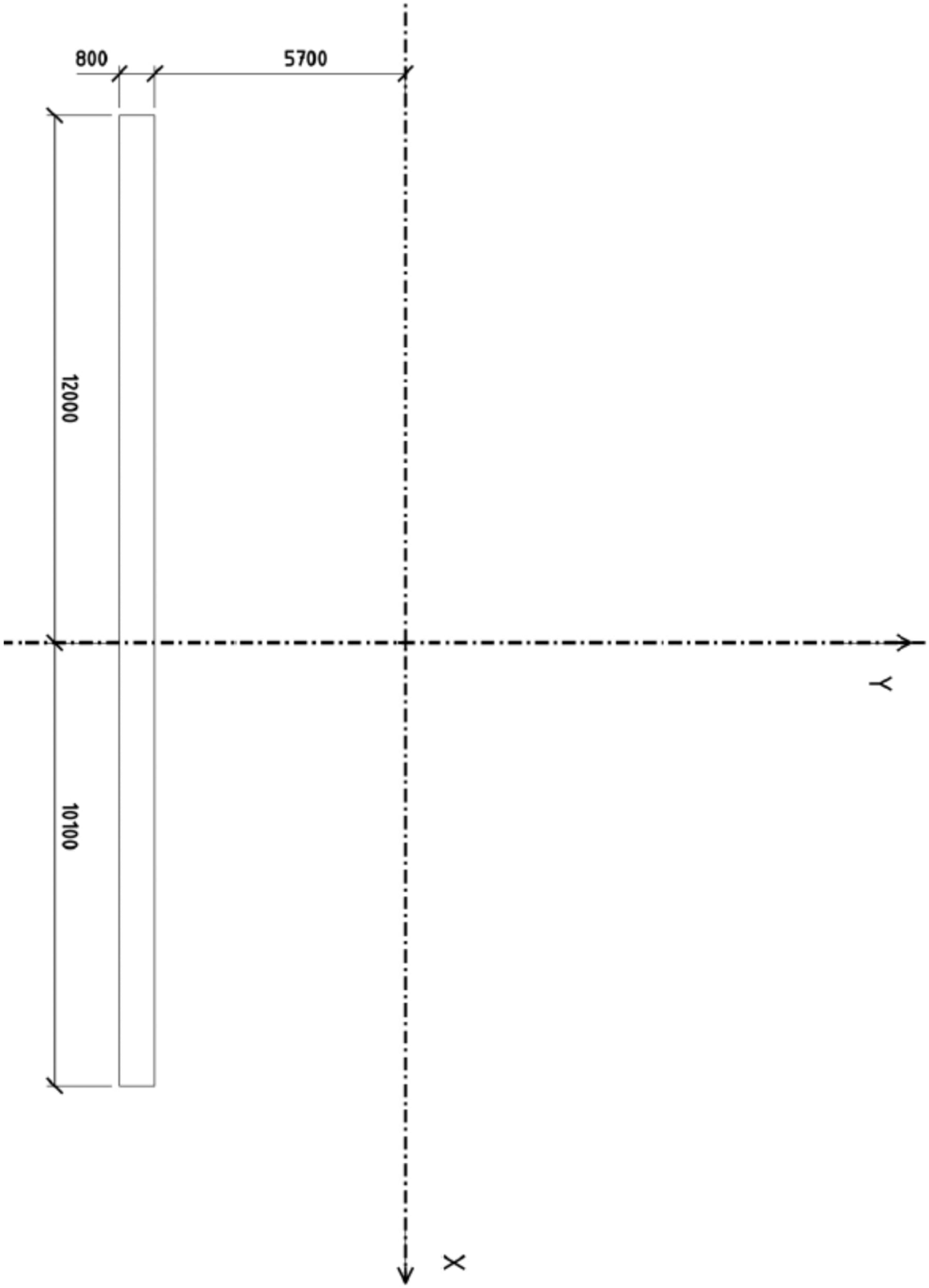
Wall 3_2:



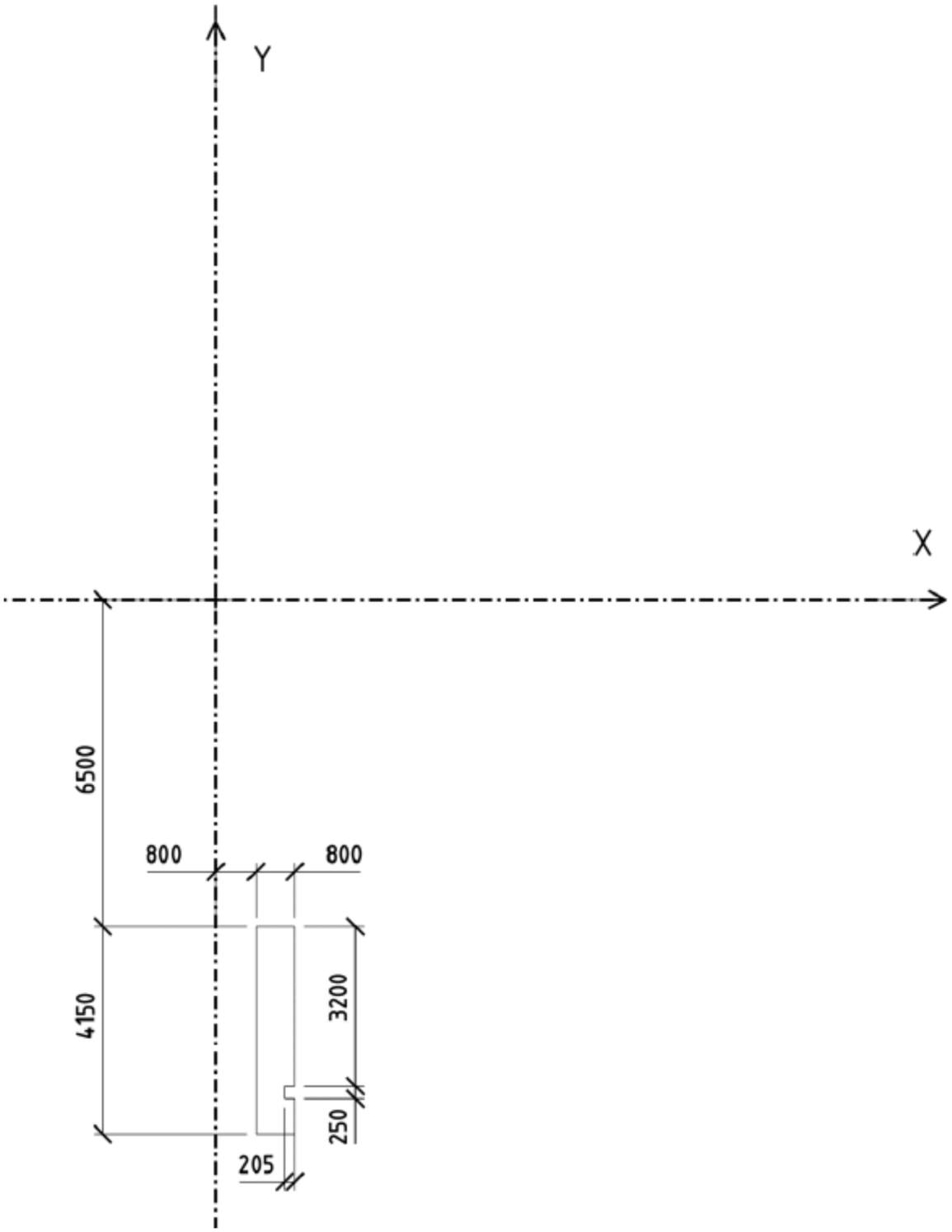

Y
X
5000
1500
896
1600
2500
5300

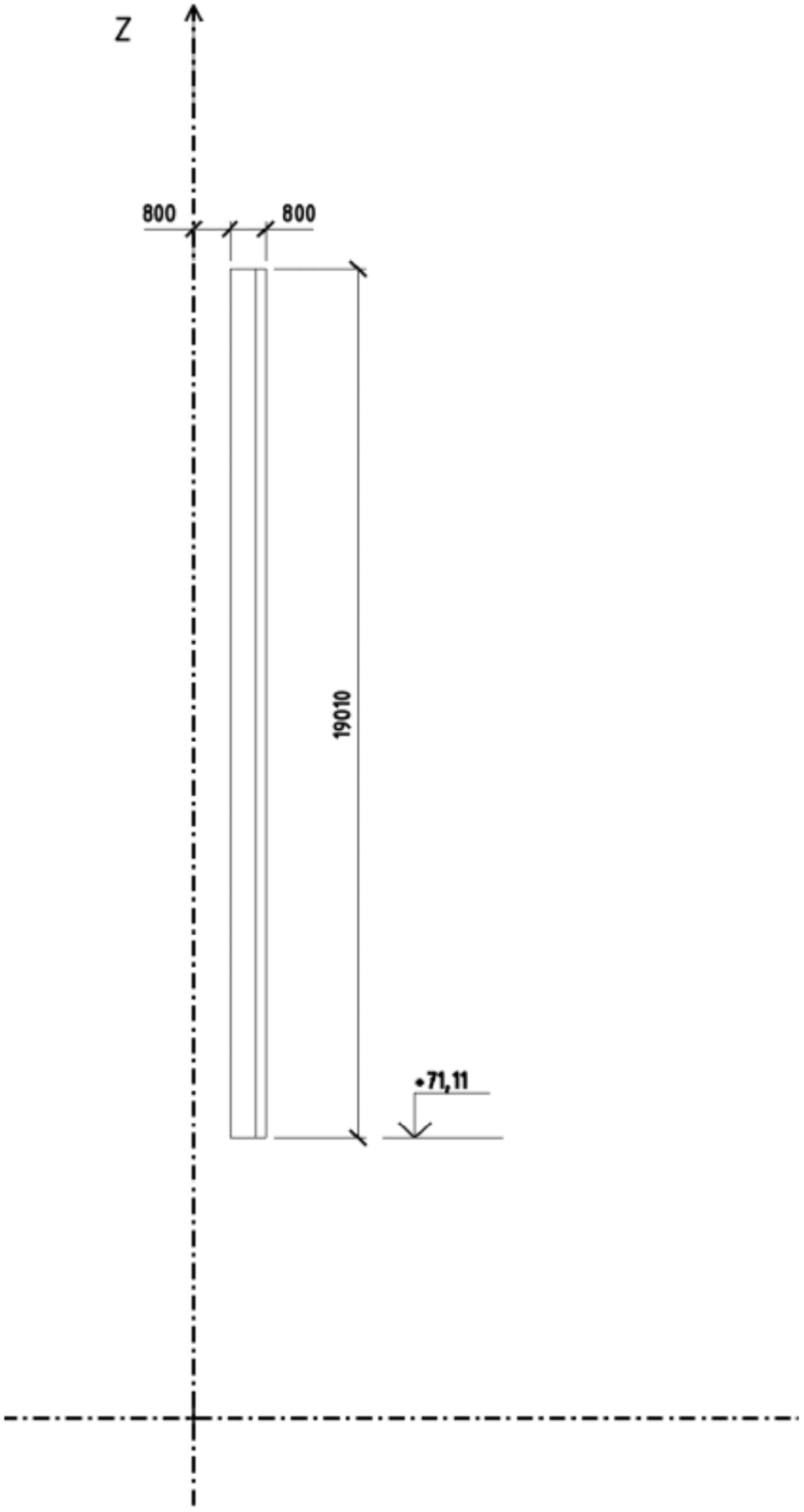
Wall 3_3 :



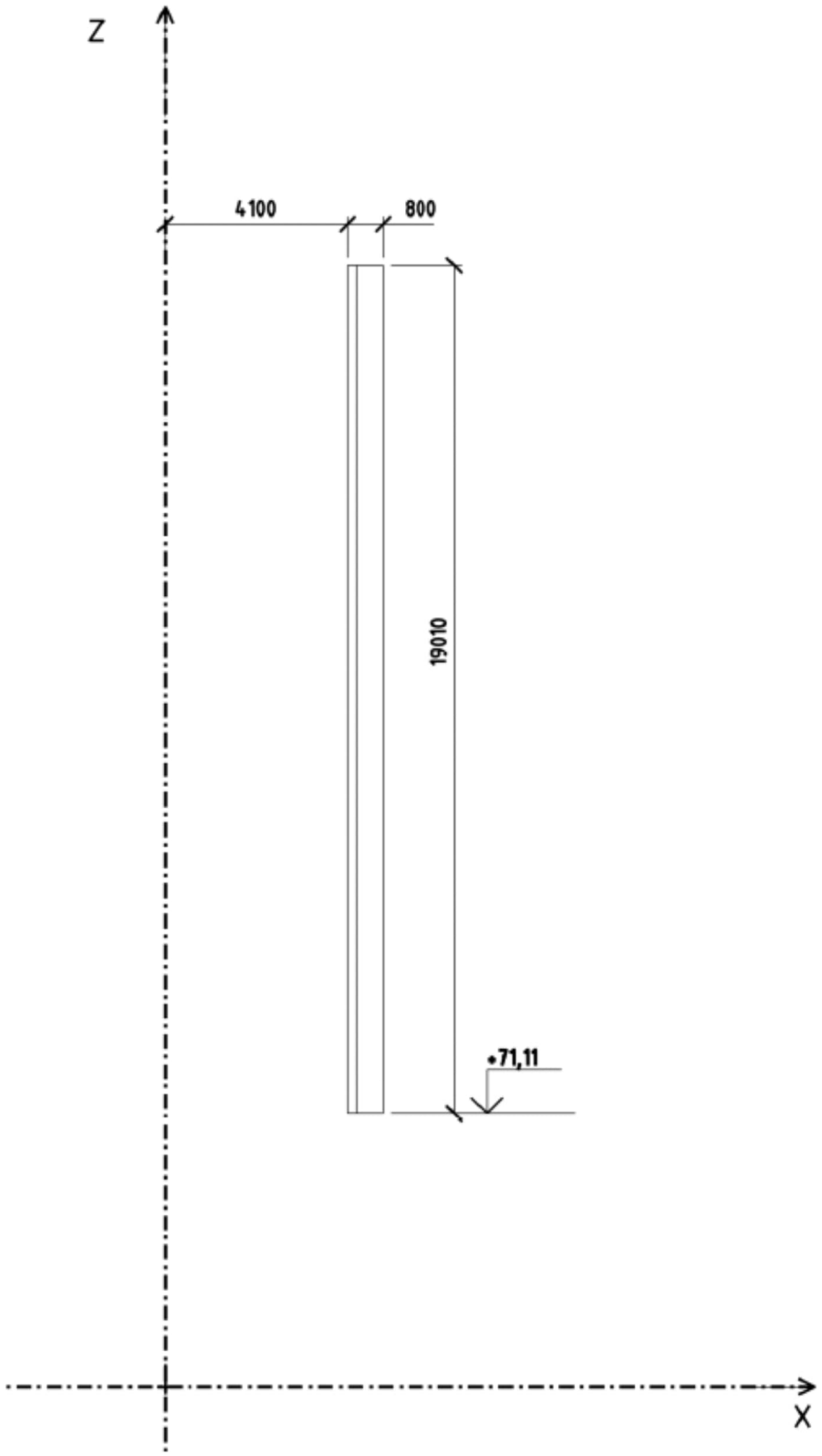

800
5700
12000
10100
Y
X

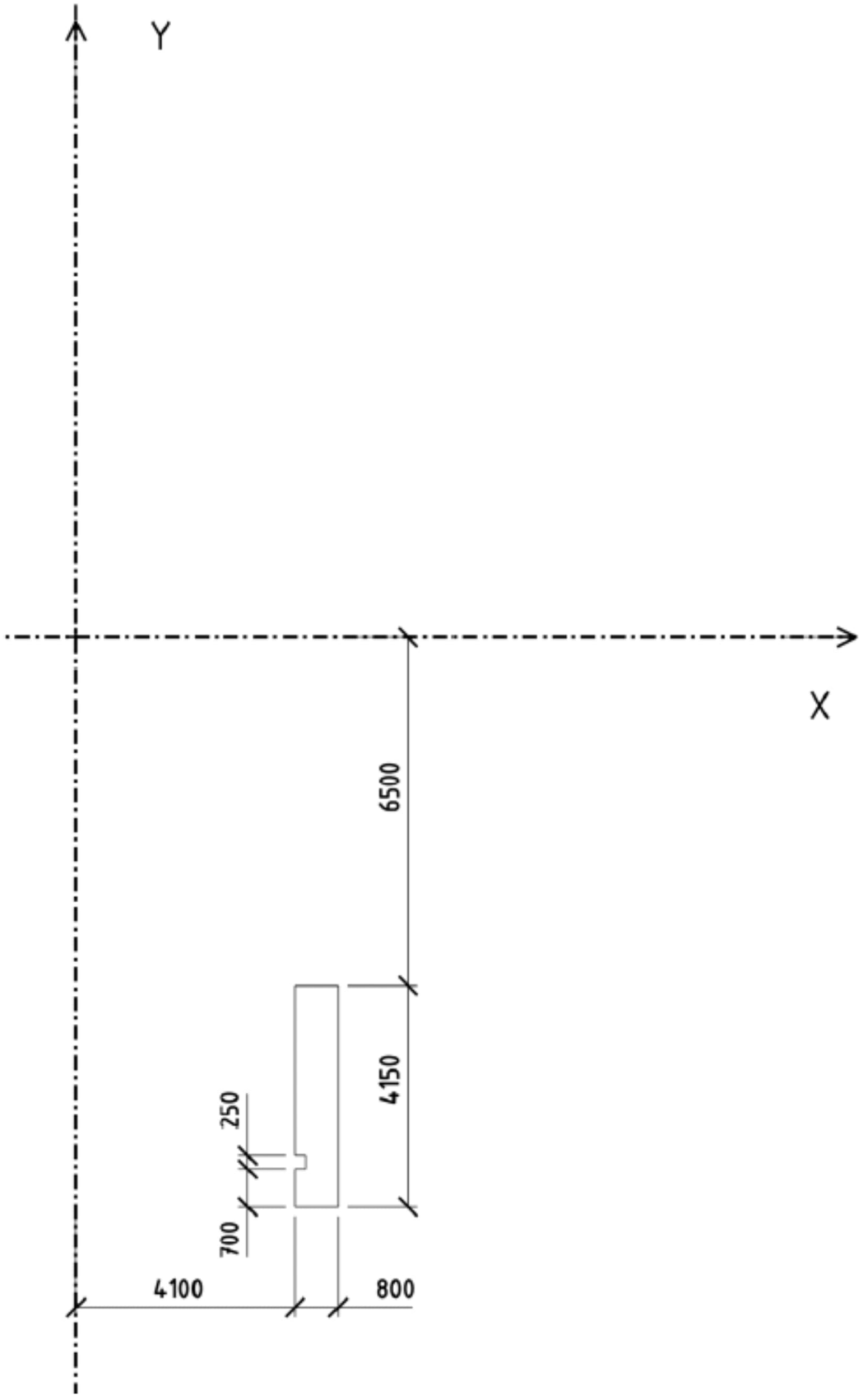
Wall 3_4 :



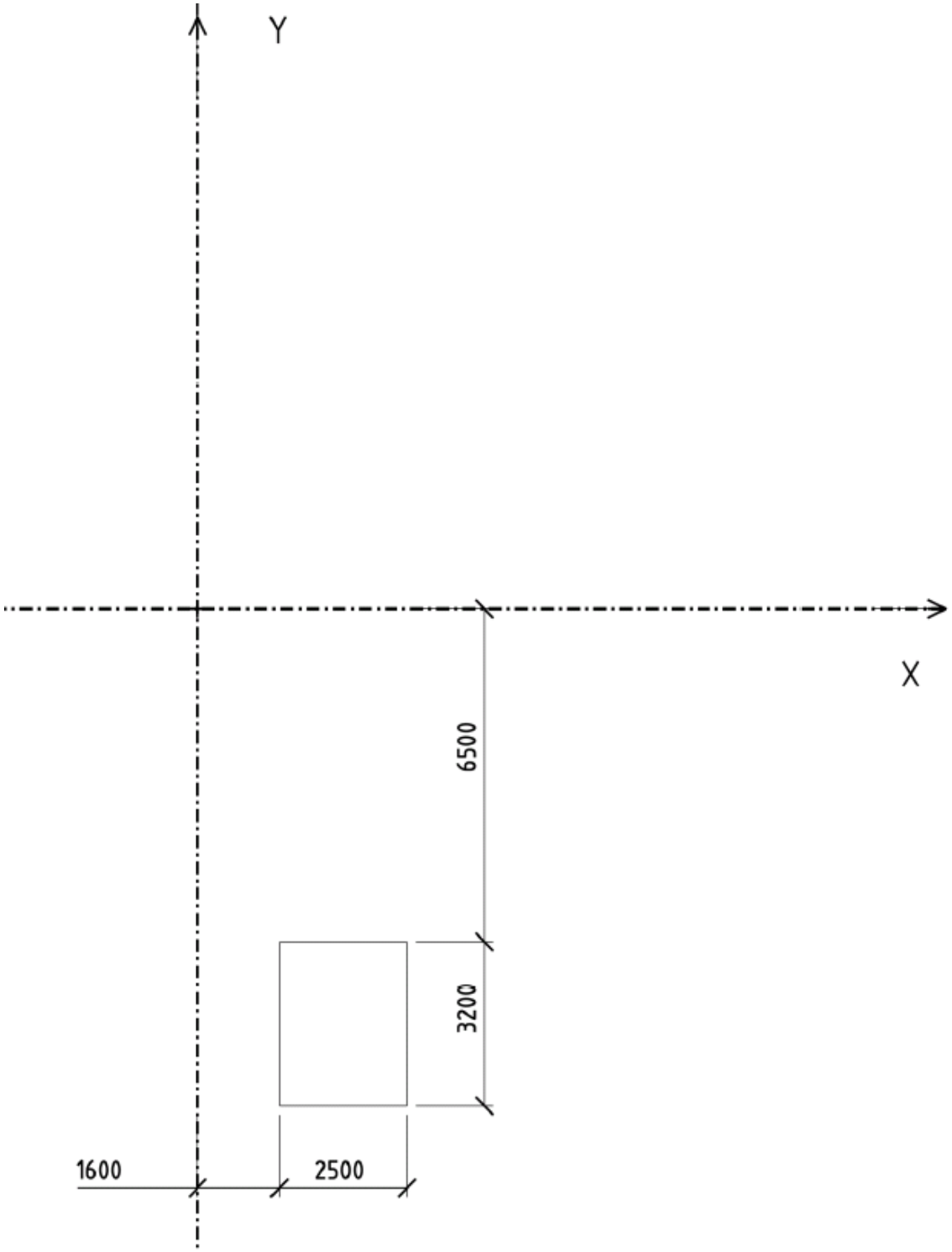

Z
800
800
19010
71,11

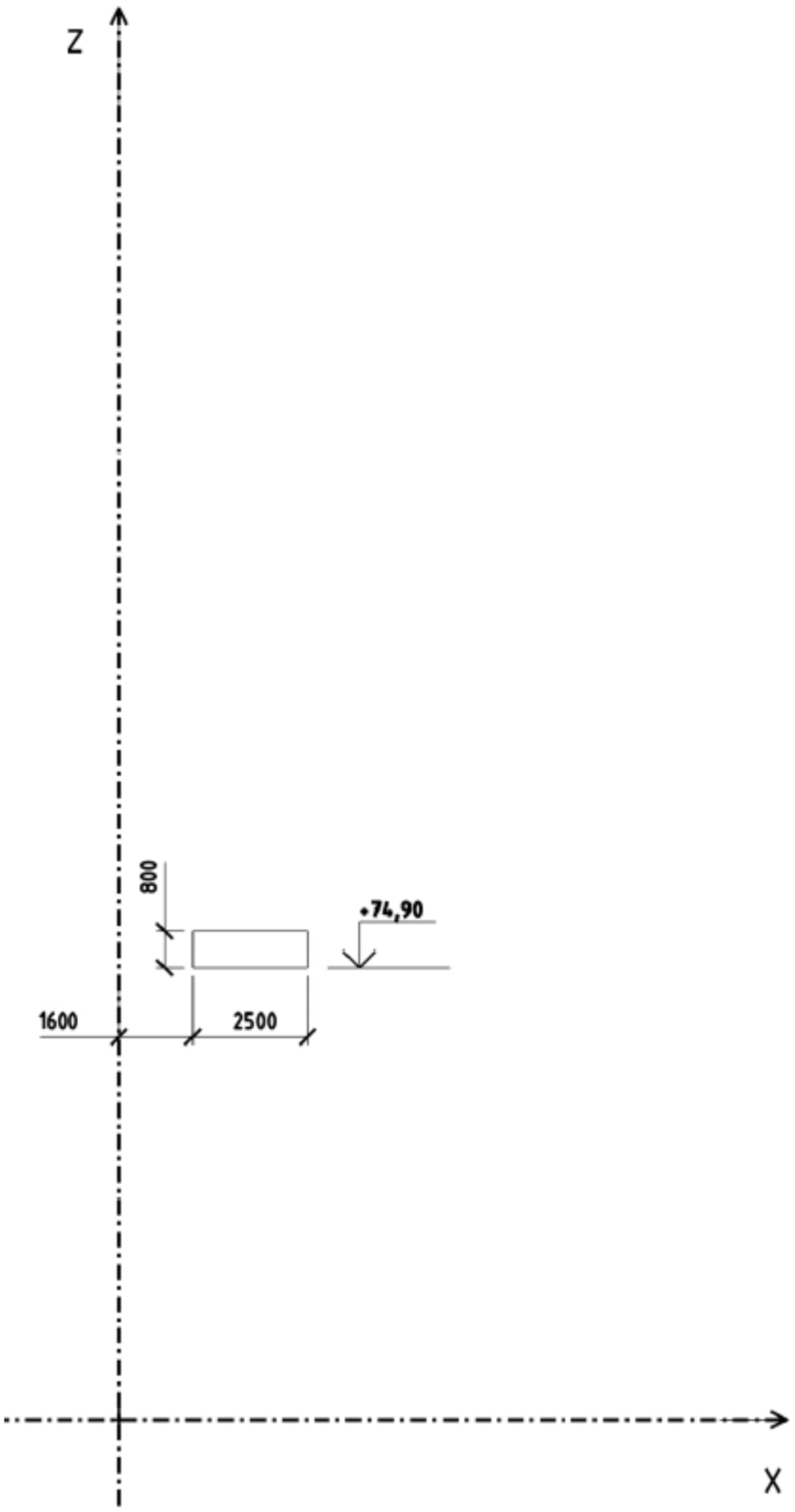
Wall 3_5 :



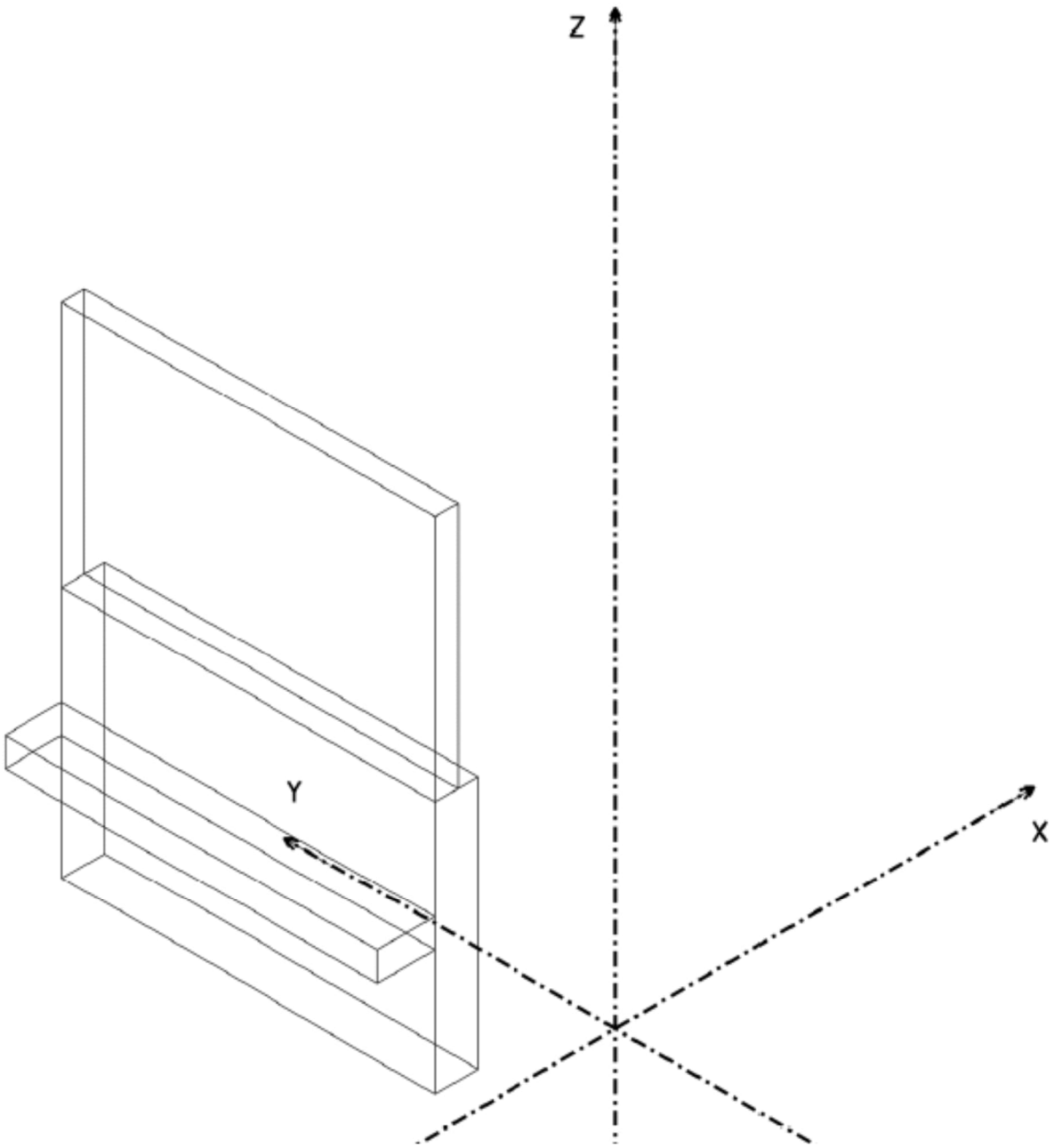

Y
X
6500
4150
250
700
4100
800

Wall 3_6 :

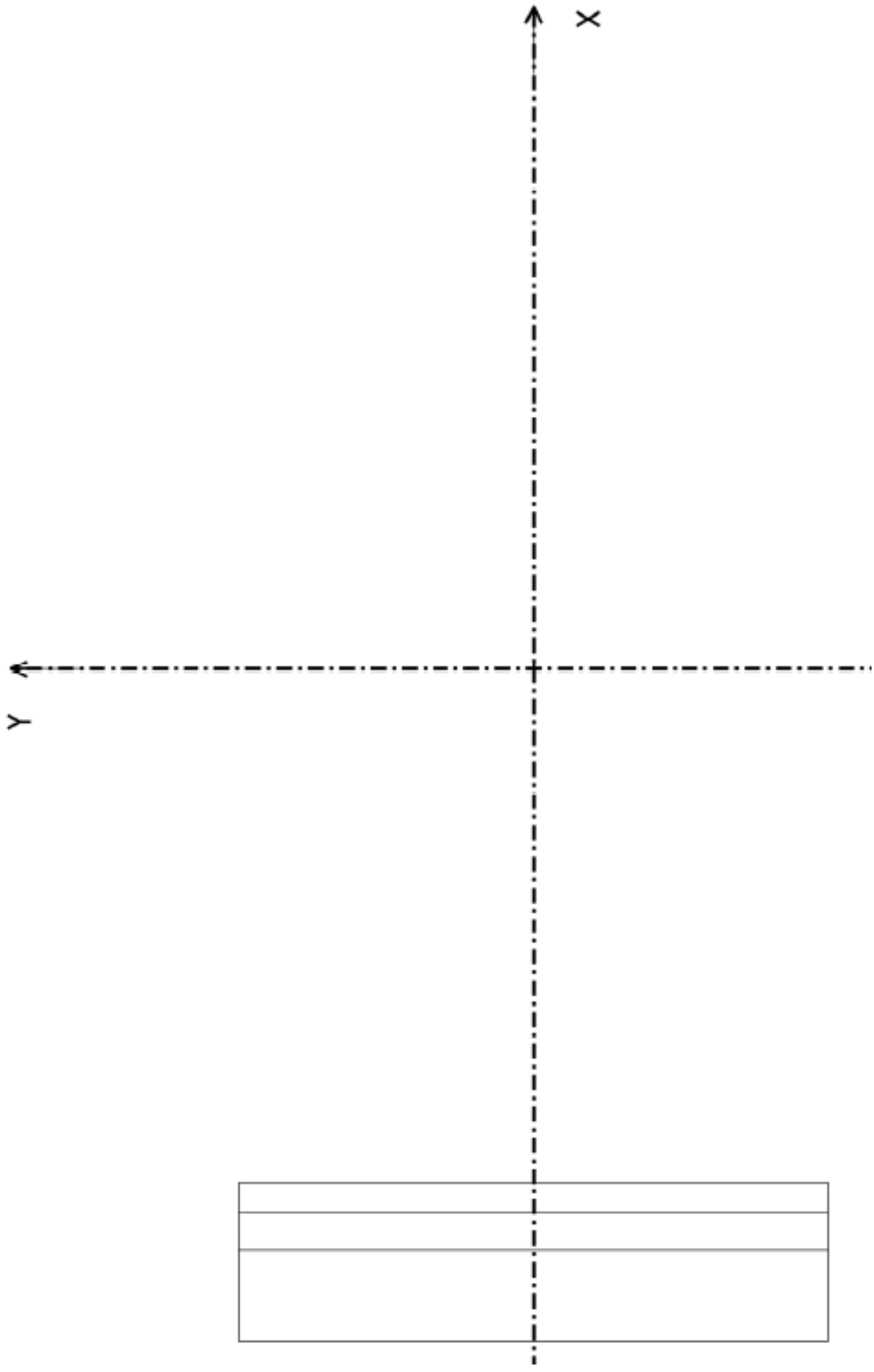



Z
800
+74,90
1600
2500
X

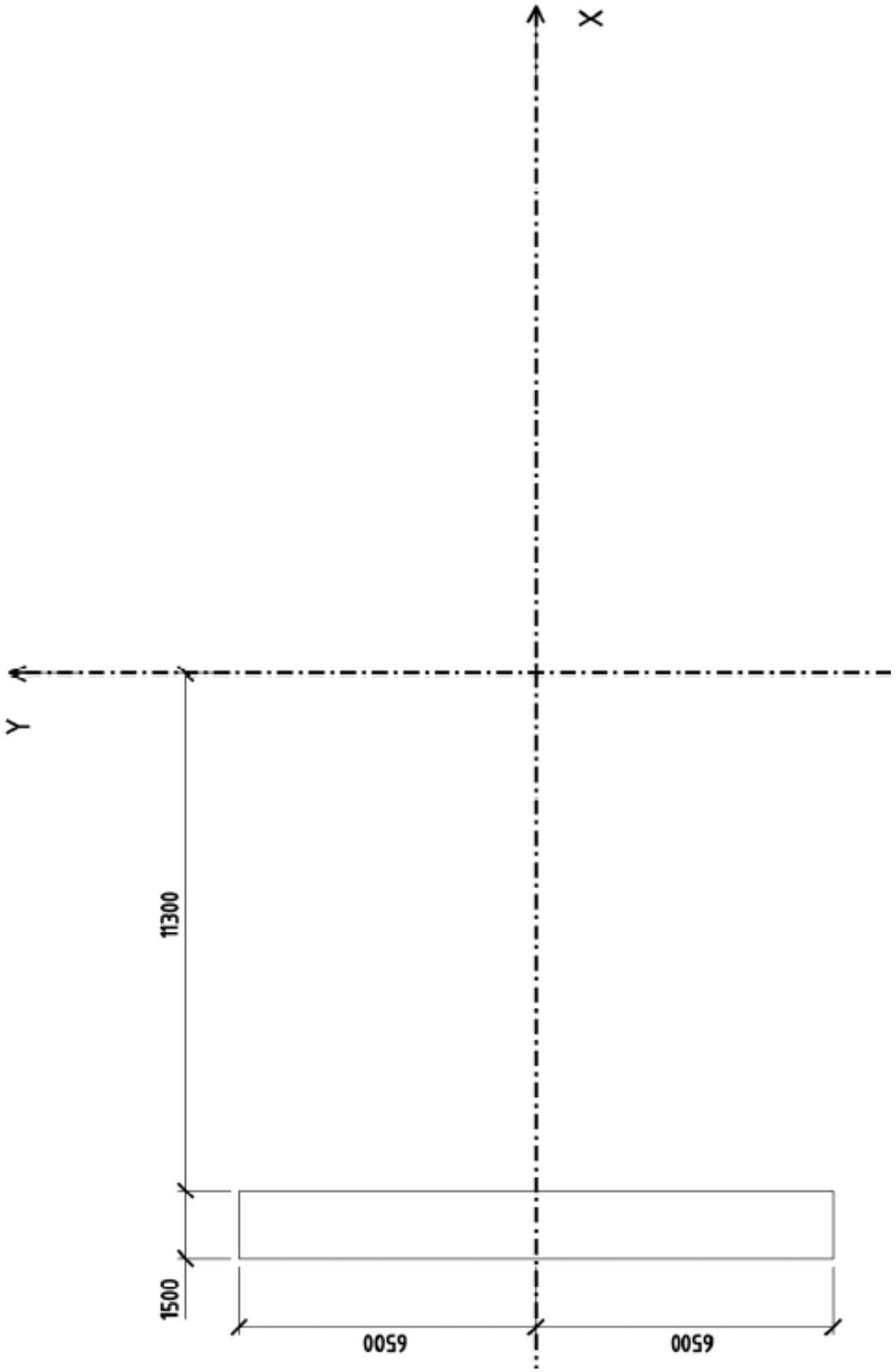
1.5.4.6 Wall 4

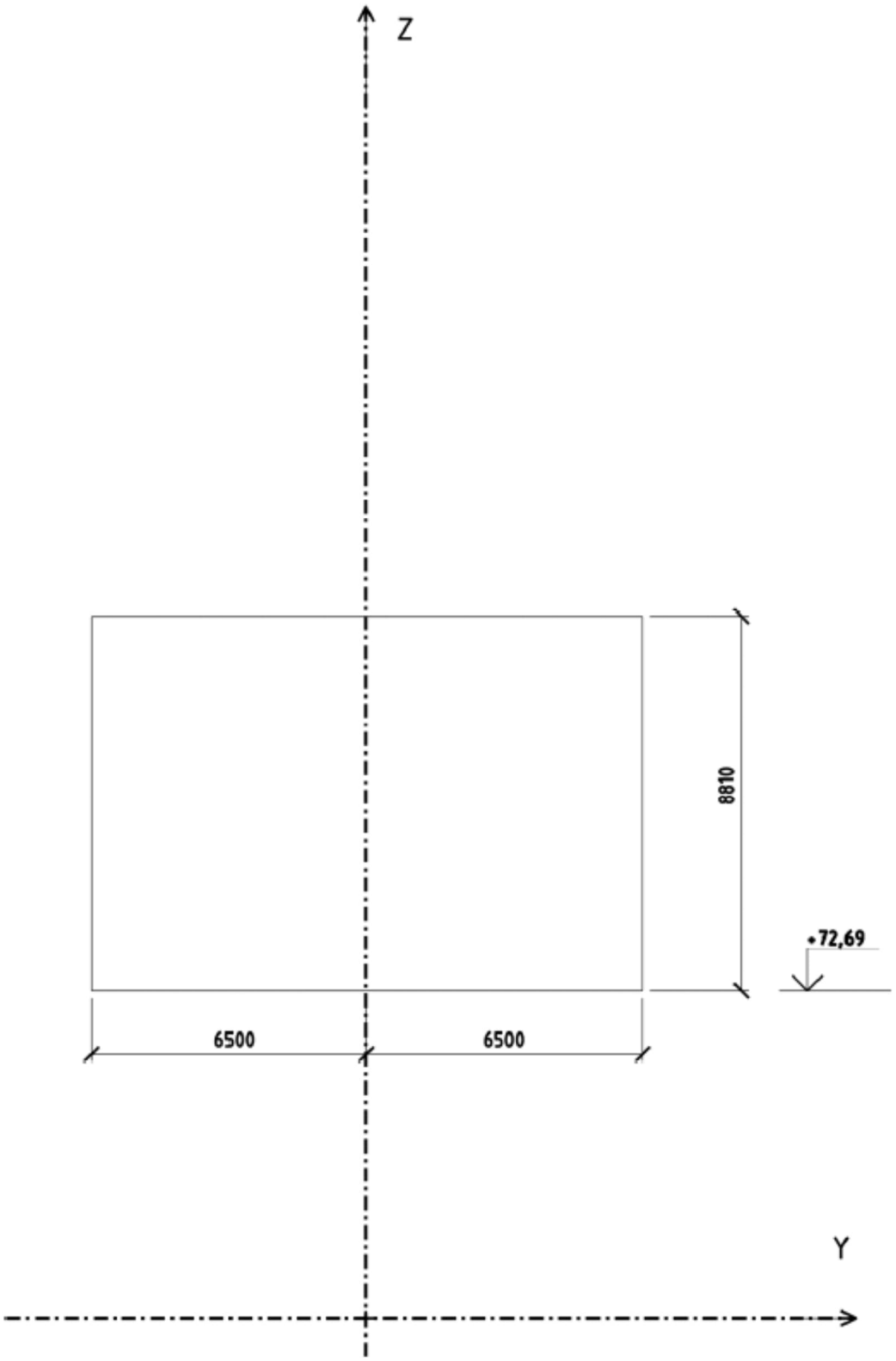


Remark Wall 4 consist of 3 different parts termed Wall 4_1, Wall 4_2 and Wall 4_3.

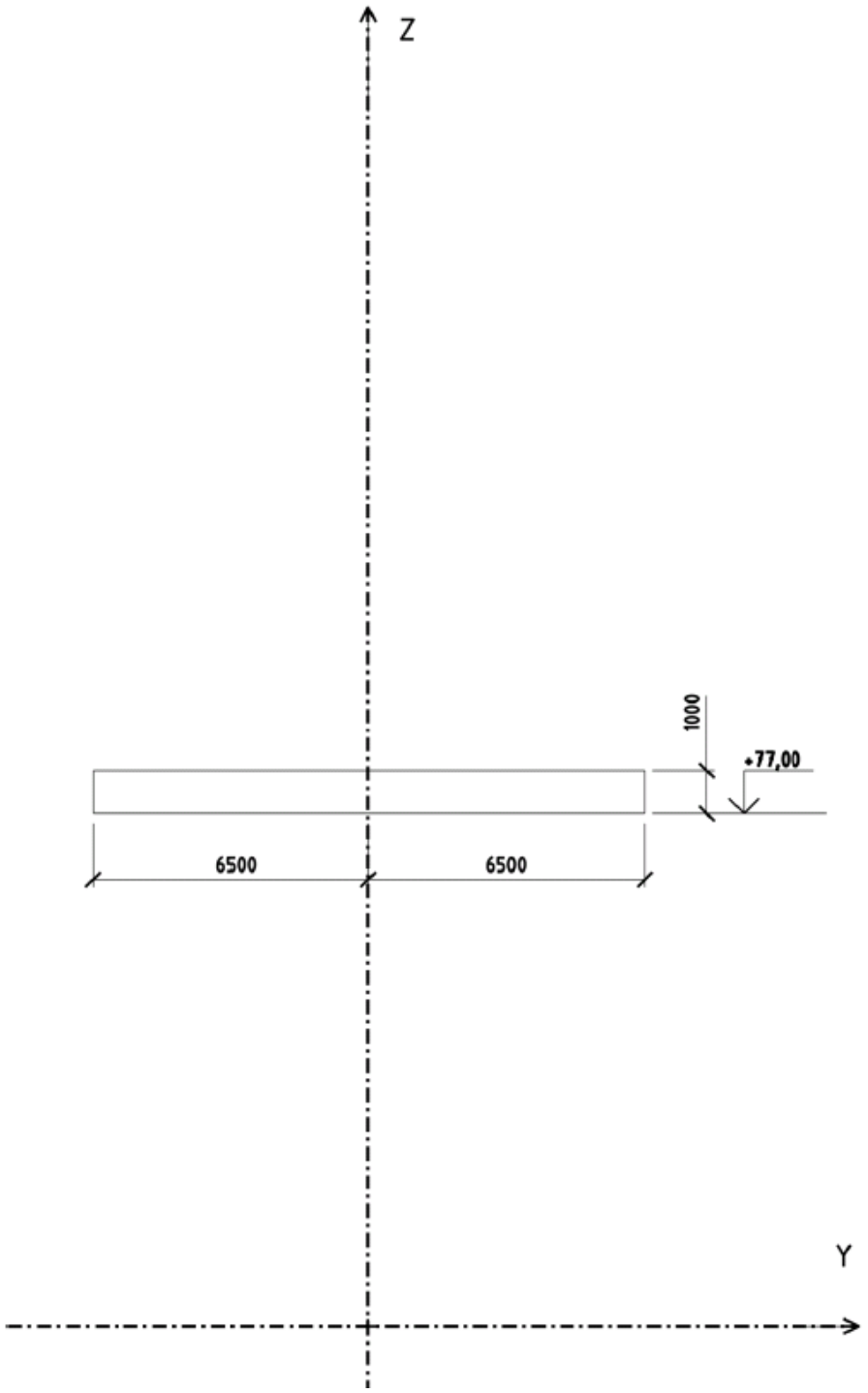

X
Y

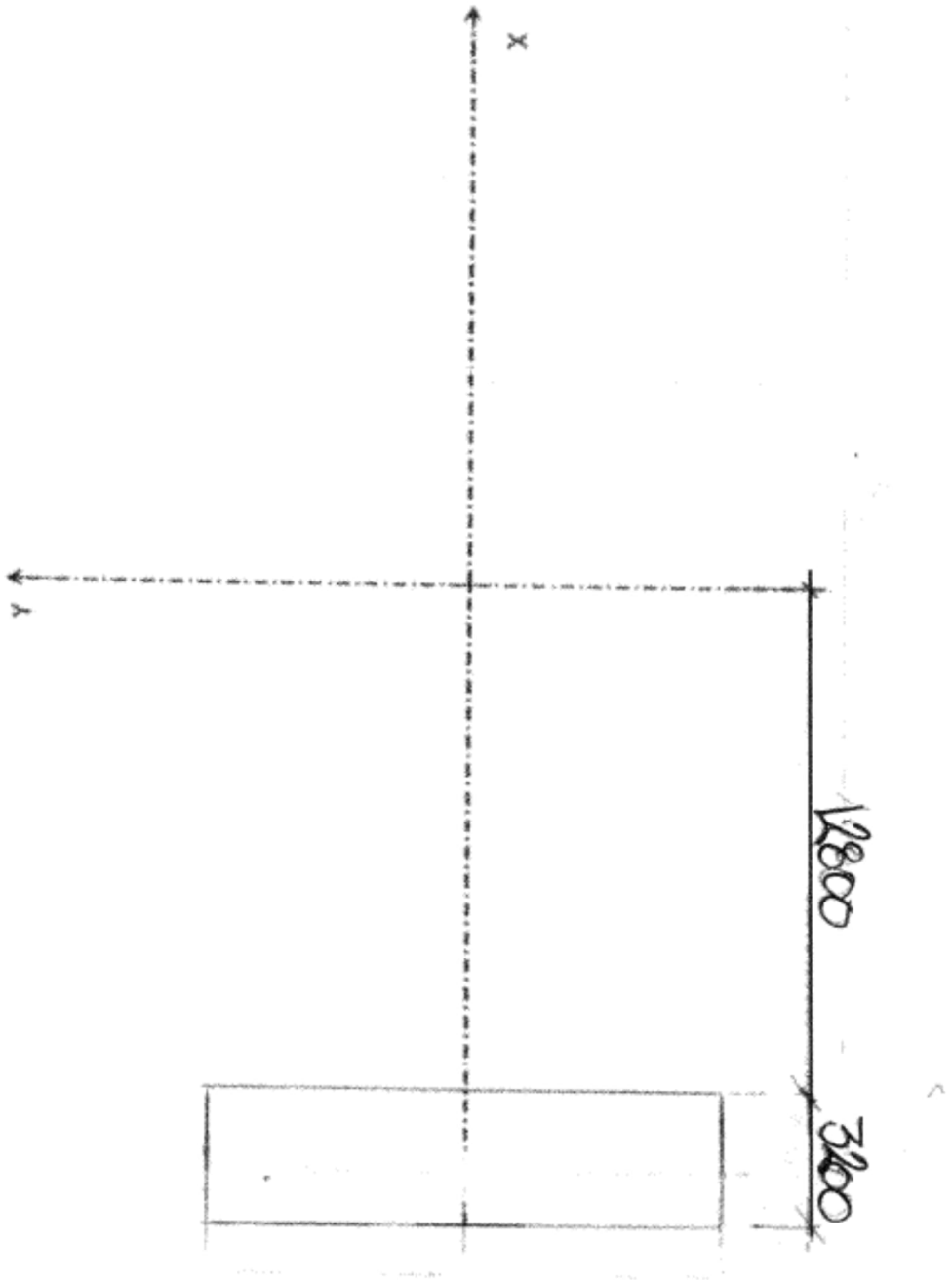
Wall 4_1 :



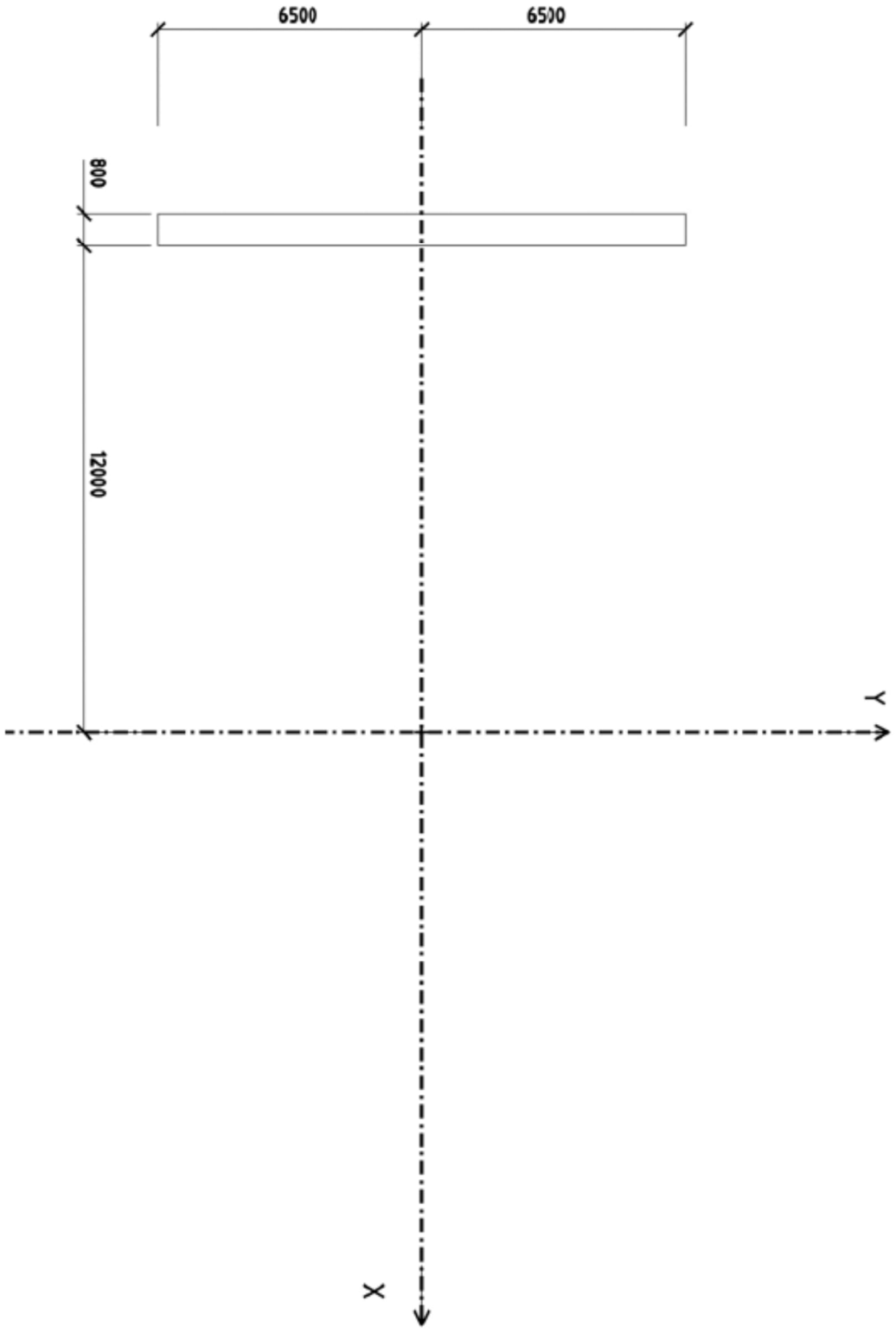

Z
8810
+72,69
6500
6500
Y

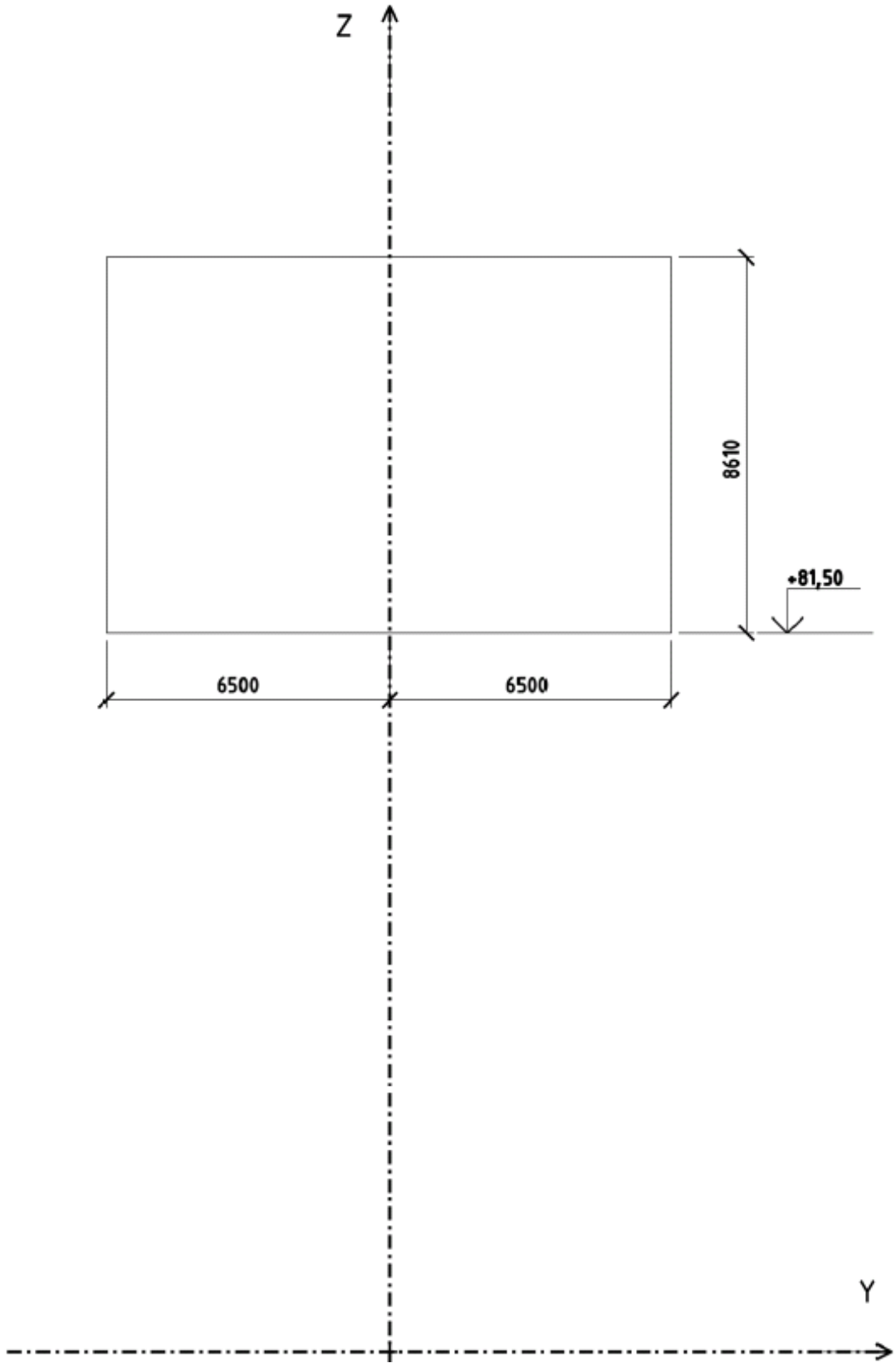
Wall 4_2 :




X
Y
2800
3400

Wall 4_3 :




Z
8610
+81,50
6500
6500
Y

2. STATICAL SYSTEM

2.1 GENERAL

The structure is designed as a reinforced concrete structure resting on unweathered rock.

The analysis is performed in two separate parts as seen below.

Part I : Analysis of bottom slab
Part II : Analysis of walls

2.1.1 Principle of Part I (Analysis of bottom slab)

The analysis of Part I is conducted using clamped or free rotational stiffness along edges where wall are situated. If there is a pit in connection to wall free rotational stiffness is introduced. If no pit is found then clamped rotational stiffness is introduced.

The bottom slab has varying thickness (1.18 m to 4.73 m). In the design however only a thickness of 1.18 m and 3.0 m are used on the safe side. The reason is to achieve production friendly reinforcement at “top”.

Loads applied to this structure is consists of ground pressure and dead weight.

Ground pressure is determined using a model where no overturning of structure is considered possible to due to edge beams and external slabs at base lines 2, 4 and A.

The edges beams act from level +67.0 to level +81.0.

The external slabs act from level +77.0 to level +78.0.

2.1.2 Principle of Part I (Analysis of walls)

The analysis of Part II is conducted using clamped rotational stiffness along edges of wall connected to level a top of bottom slab. I

In the water flow direction edge beams are modeled using support condition with rigid movement in the y-direction. The Boundary conditions act from level +67.0 to level +81.0 m.

The effect of the following parts Floor 1_4, Wall 2_2, Wall 3_4, Wall 3_5, Wall 3_6 and Wall 4_2 are only considered as loads. Not incorporating these parts into the analysis of walls in considered as on the safe side.

2.2 STATICAL MODELL

2.2.1 Model : Part I (Bottom slab)

In order to describe the structures geometry in first *POINTS* have to be defined. From these *LINES* and *SURFACES* are generated.

Shell elements are applied to *SURFACES*.

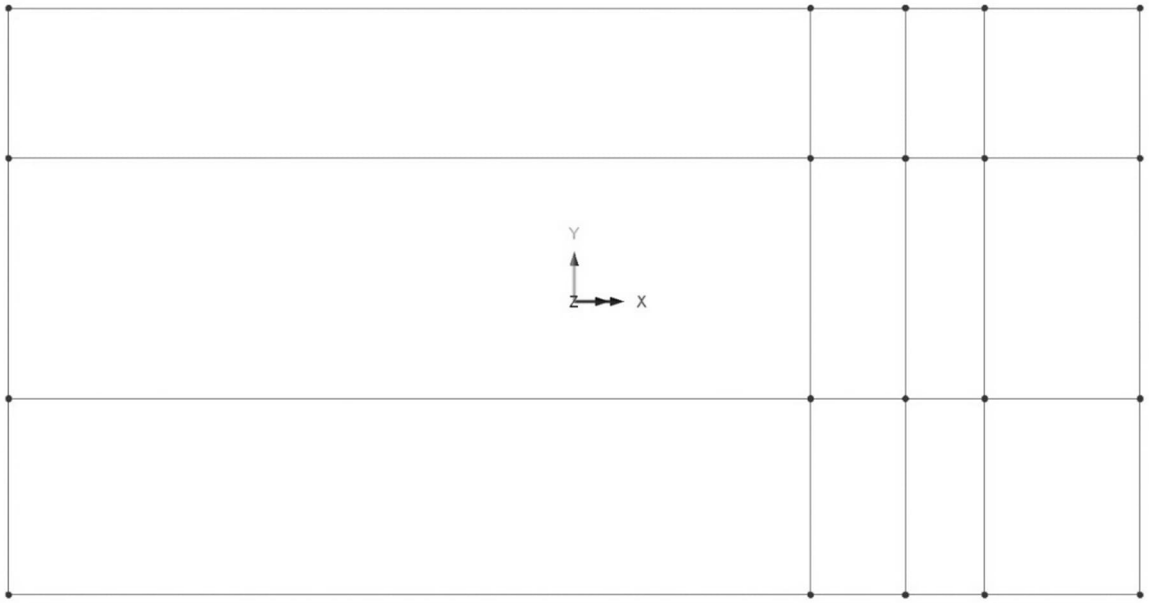
Beam elements are applied to *LINES.*

The following pictures are retrived from LUASAS in order to present a graphical presentation of *POINTS* and *SURFACES* used in the analysis.

All coordinates defining *POINTS* are presented in appendix 1.

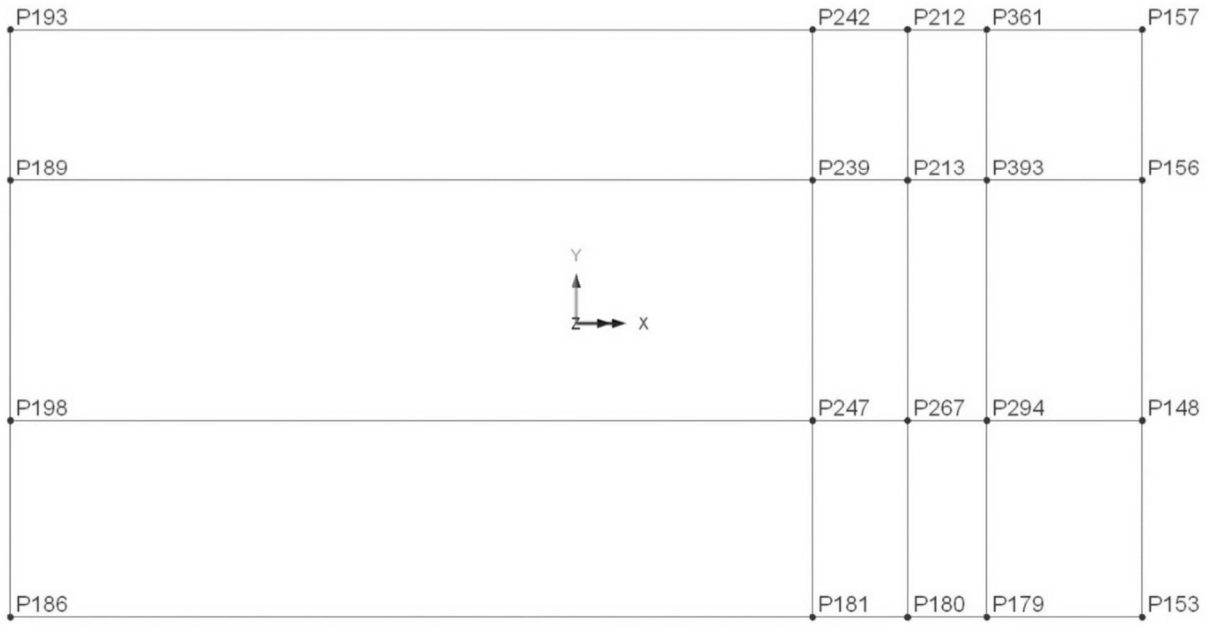
All *LINES* used to define *SURFACES* are presented in appendix 1.

Structural lines - overview :



2.2.1.1 Geometry : SURFACES

2.2.1.2 Geometry : POINTS

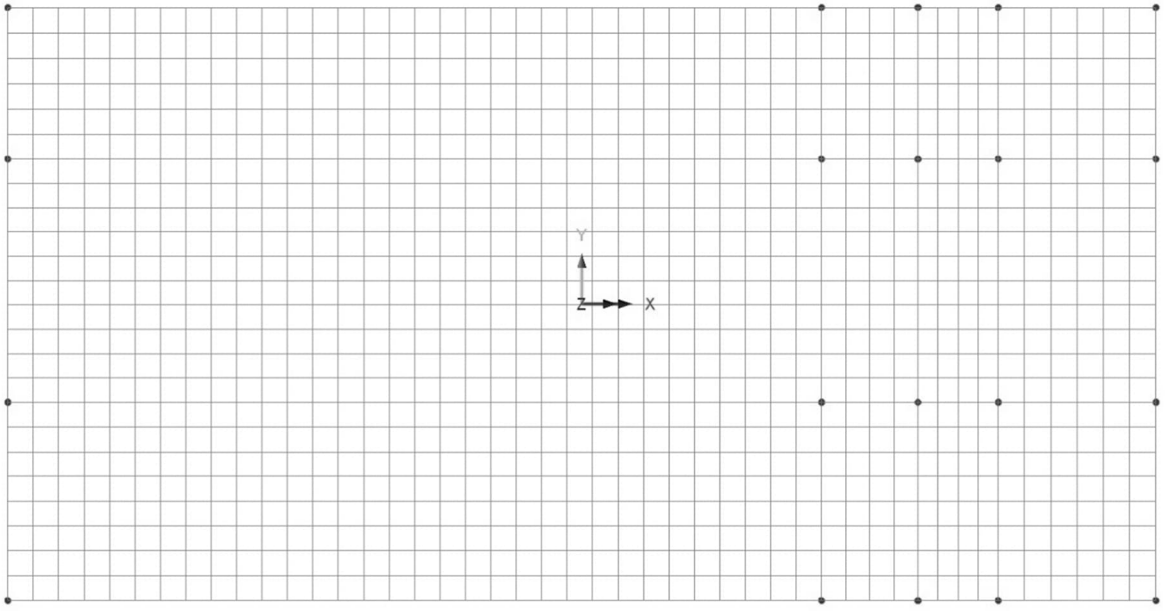


2.2.1.3 MESH

The proviously defined *SURFACES* are given attributes for generation of *MESH*.

During the generation of *MESH* the underlying *ELEMENTS* and *NODES* are created. They are found in appendix 1.

The structure is modelled with Shell elements (”Thick shell” / QTS4).



2.2.2 Model : Part II (Walls)

In order to describe the structures geometry in first *POINTS* have to be defined. From these *LINES* and *SURFACES* are generated.

Shell elements are applied to *SURFACES*.

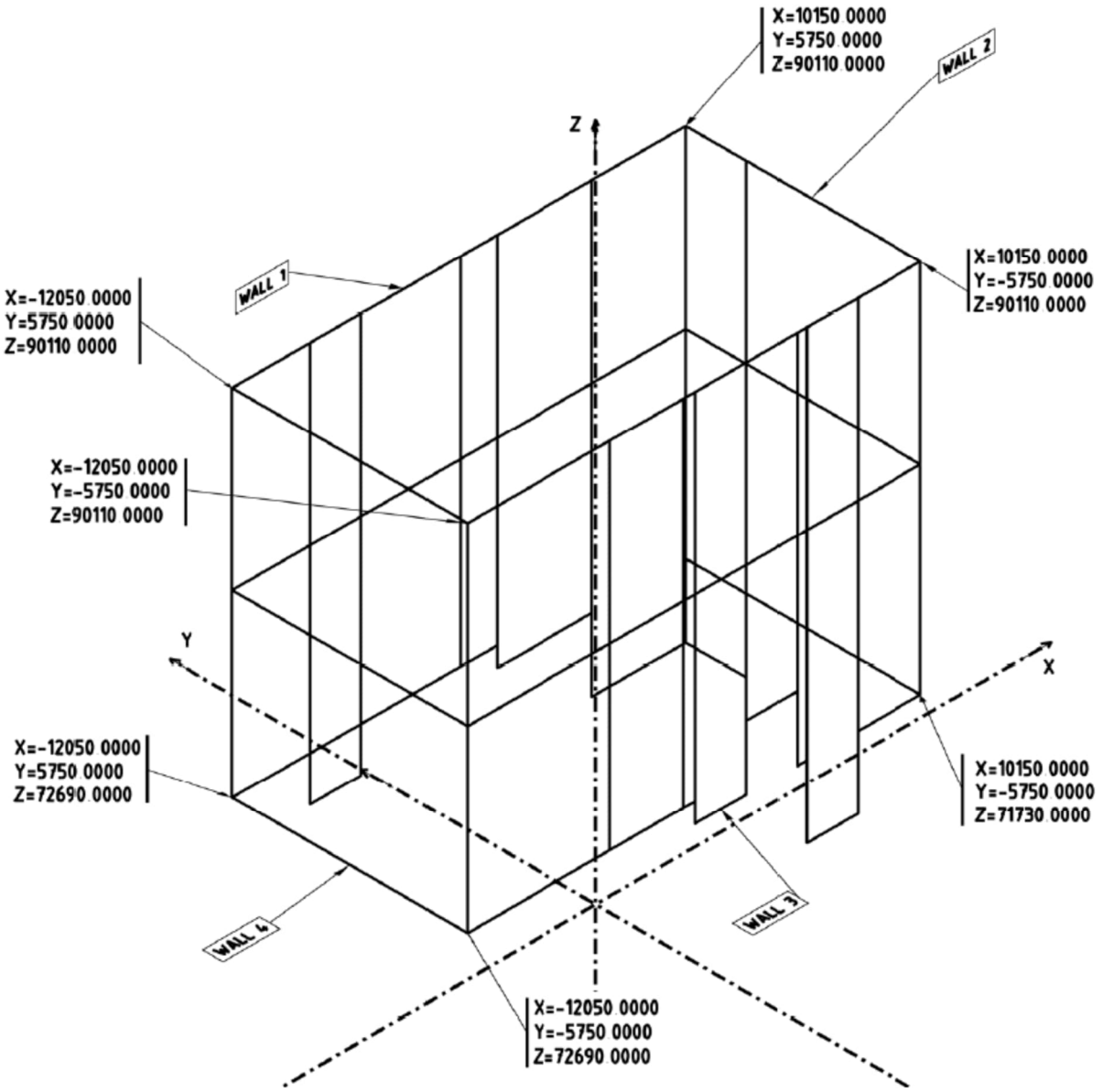
Beam elements are applied to *LINES*.

The following pictures are retrived from LUASAS in order to present a graphical presentation of *POINTS* and *SURFACES* used in the analysis.

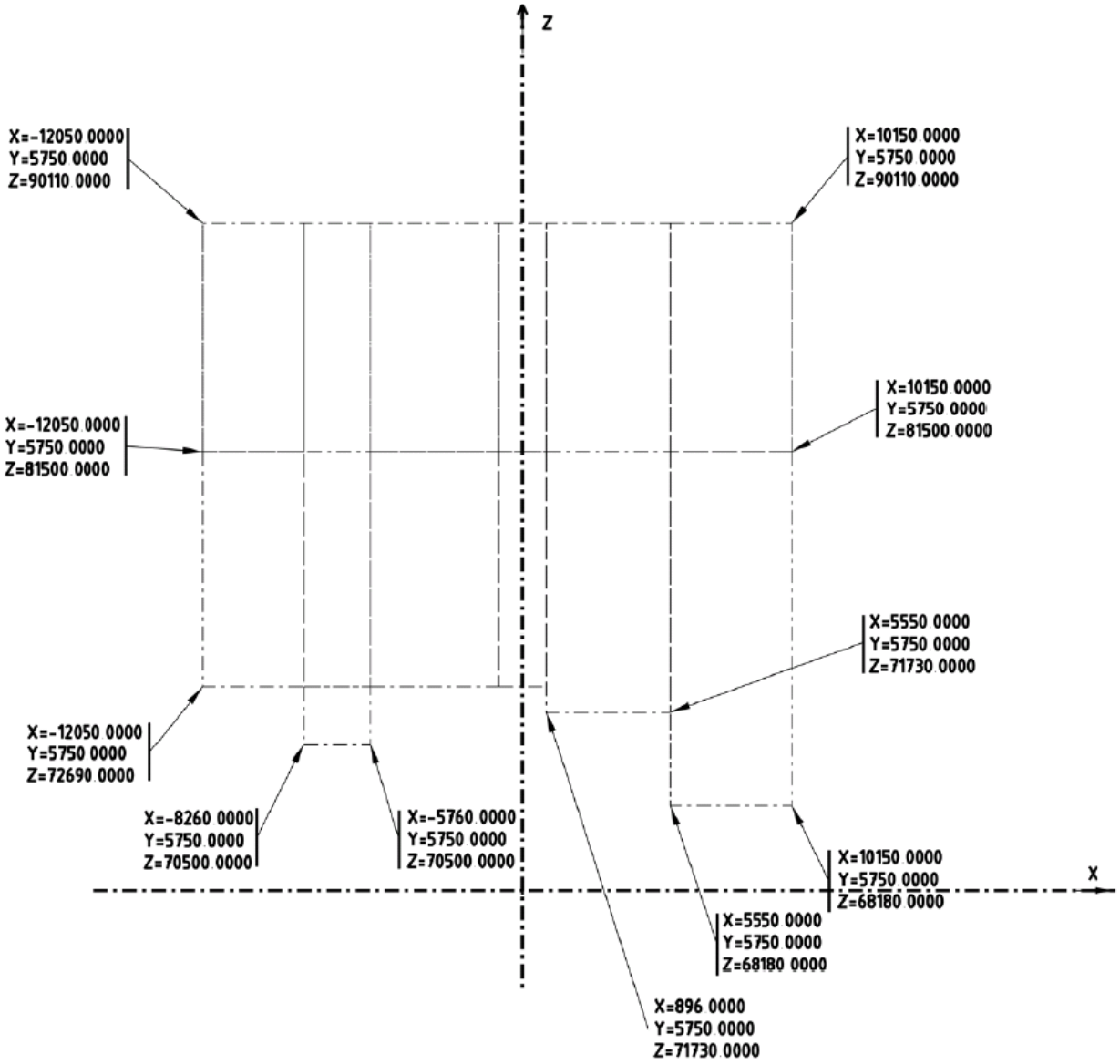
All coordinates defining *POINTS* are presented in appendix 2.

All *LINES* used to define *SURFACES* are presented in appendix 2.

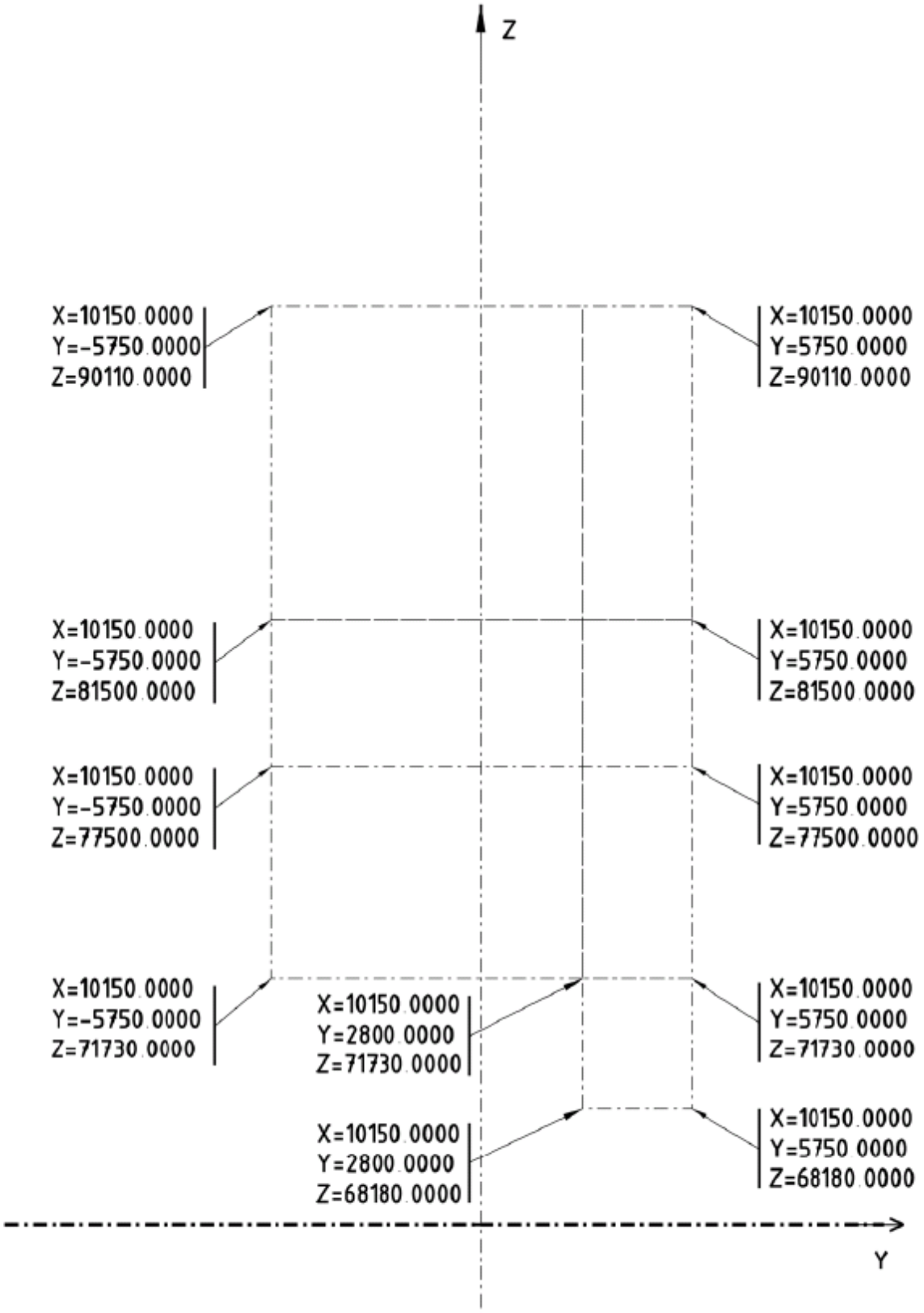
Structural lines - overview :

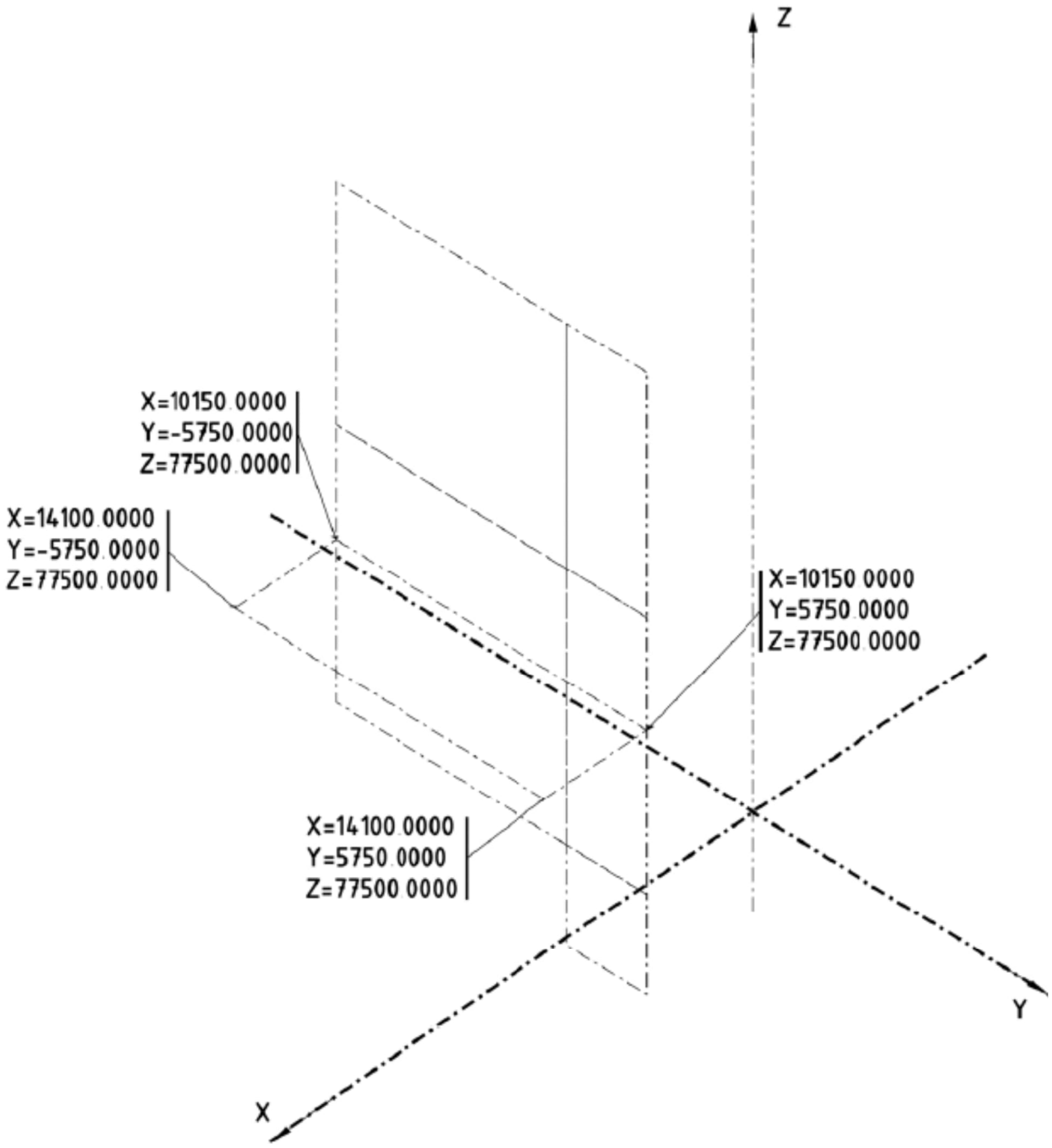


Structural lines – wall 1 :

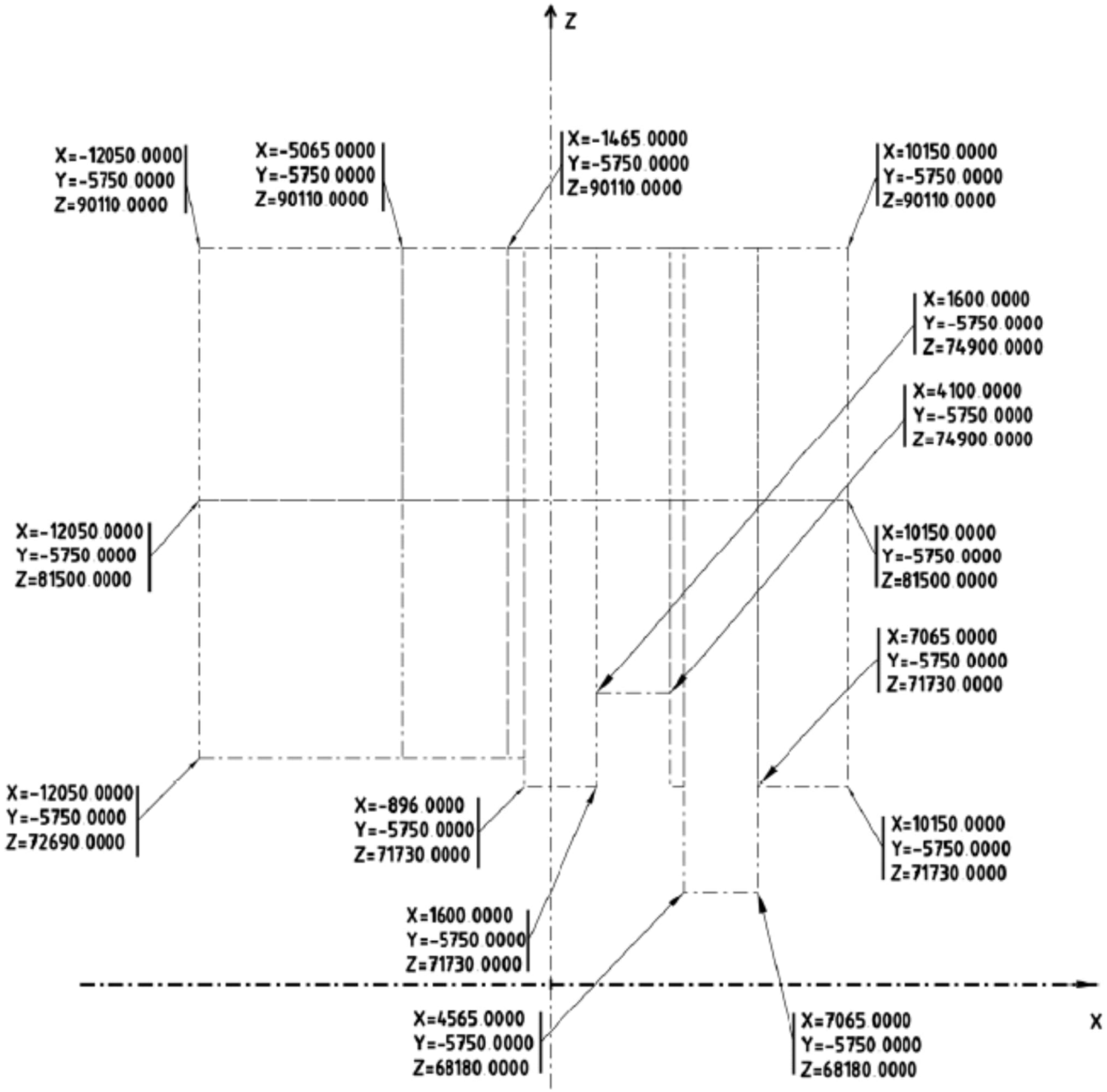


Structural lines – wall 2 :

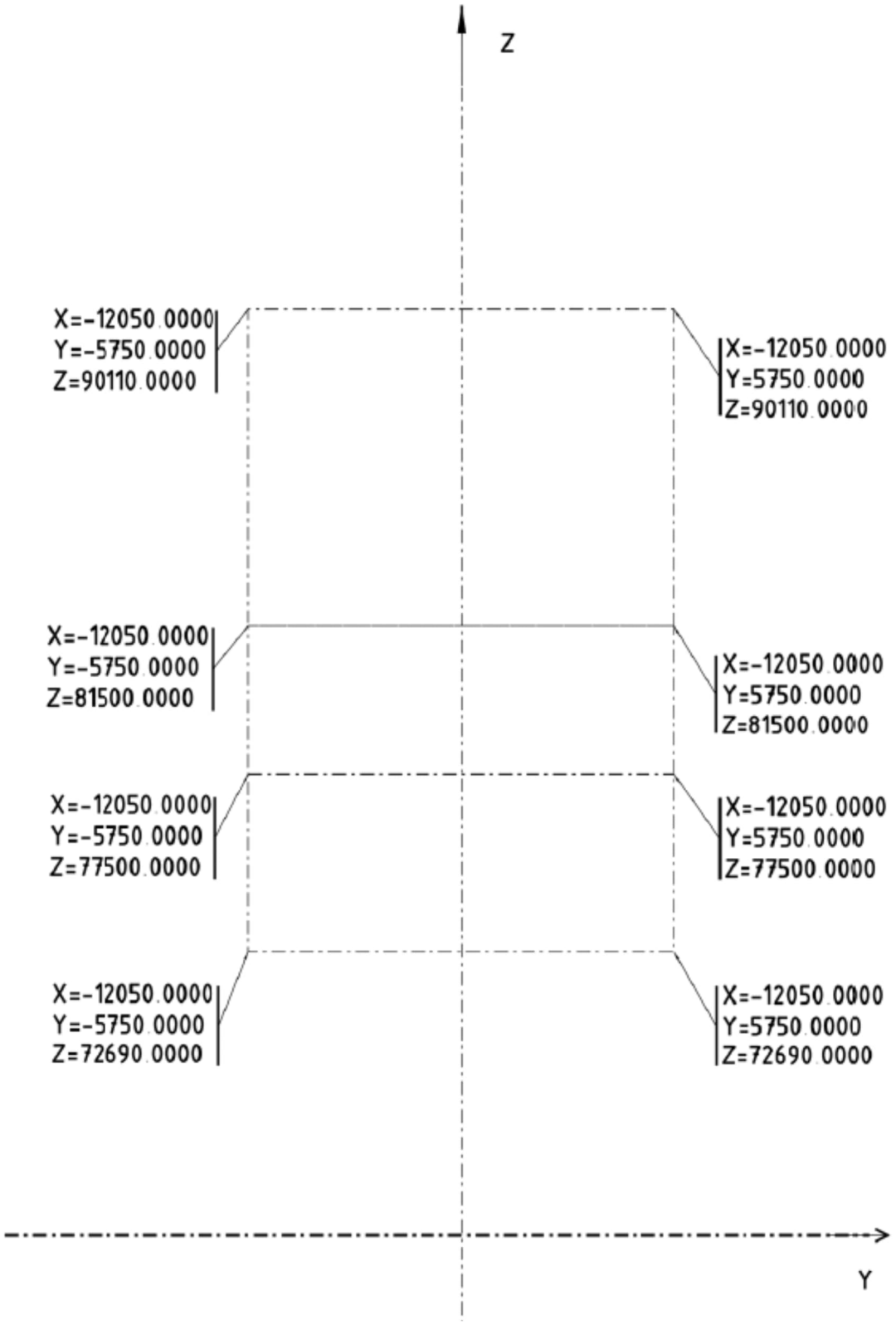


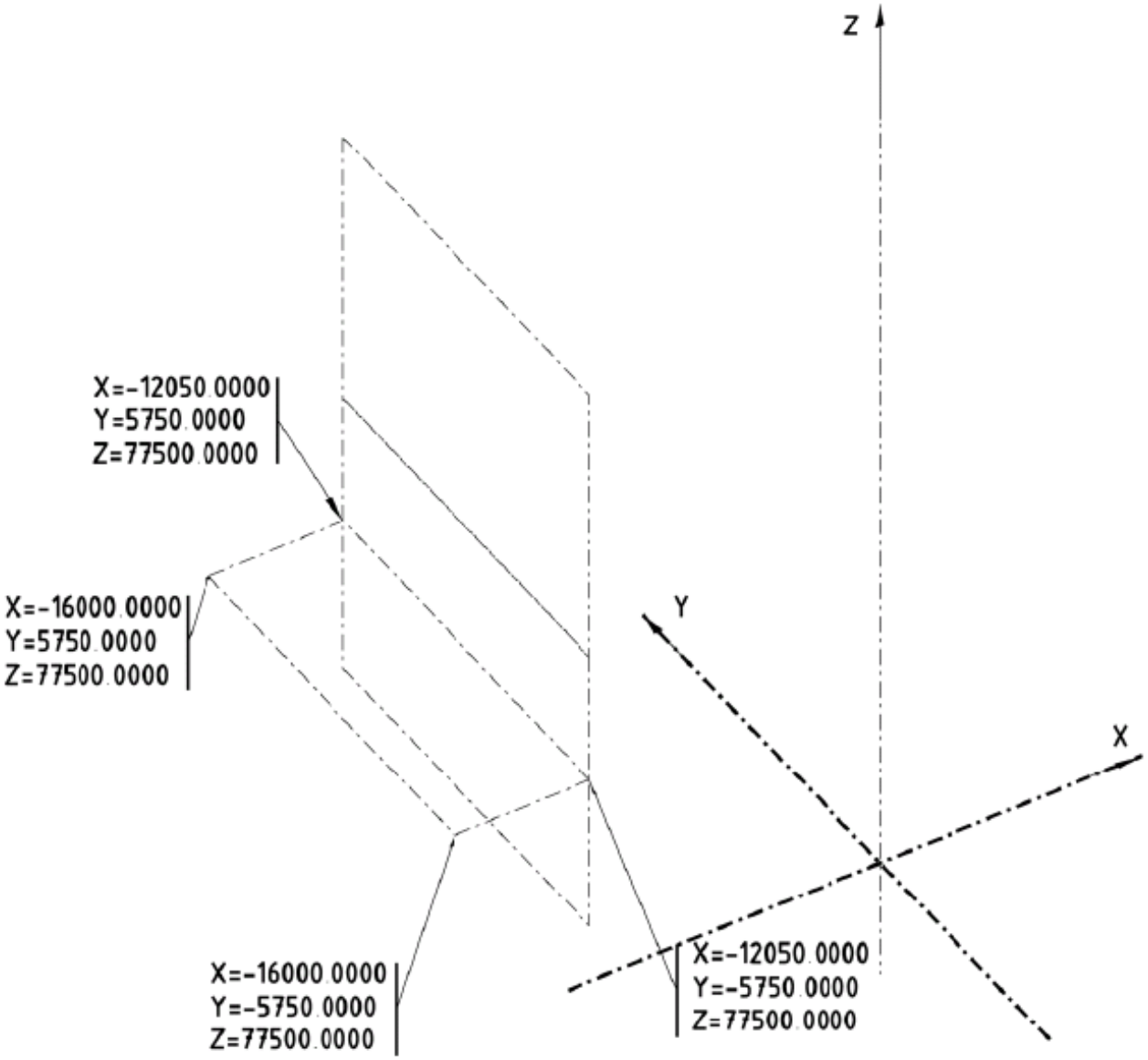

Z
X=10150.0000
Y=-5750.0000
Z=77500.0000
X=14100.0000
Y=-5750.0000
Z=77500.0000
X=10150.0000
Y=5750.0000
Z=77500.0000
X=14100.0000
Y=5750.0000
Z=77500.0000
Y
X

Structural lines – wall 3 :



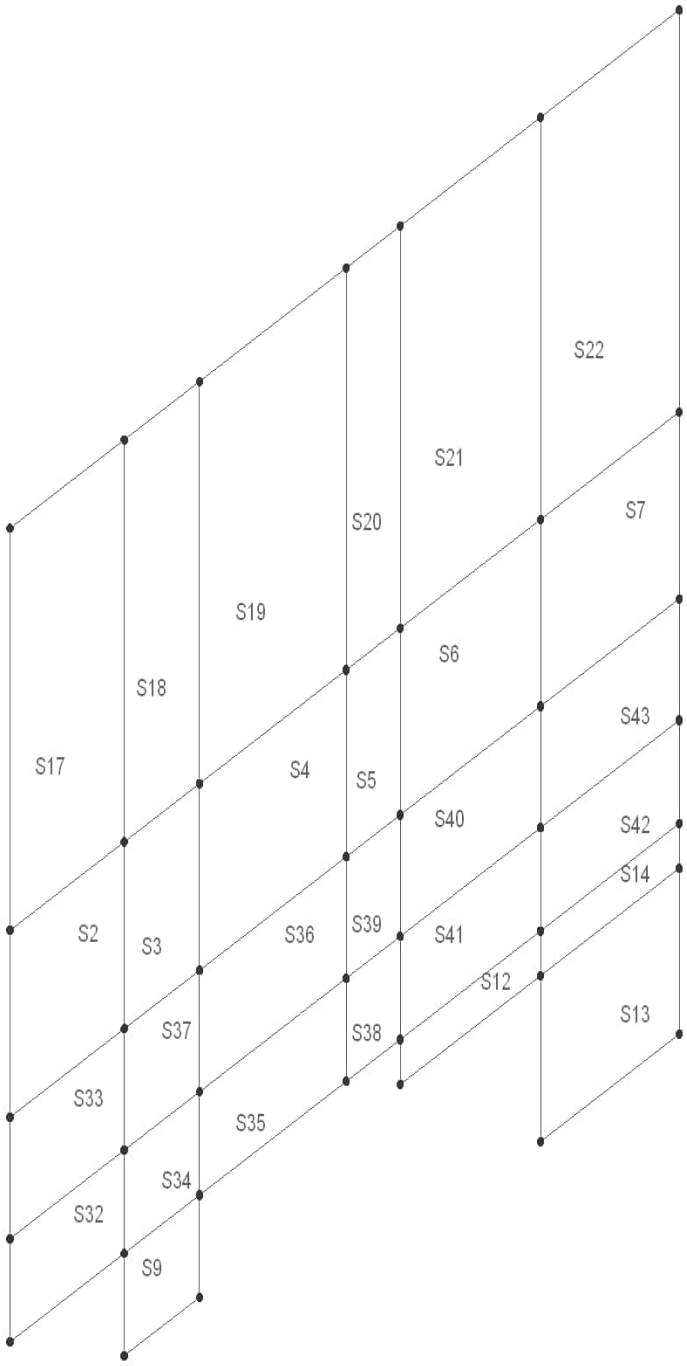
Structural lines – wall 4 :



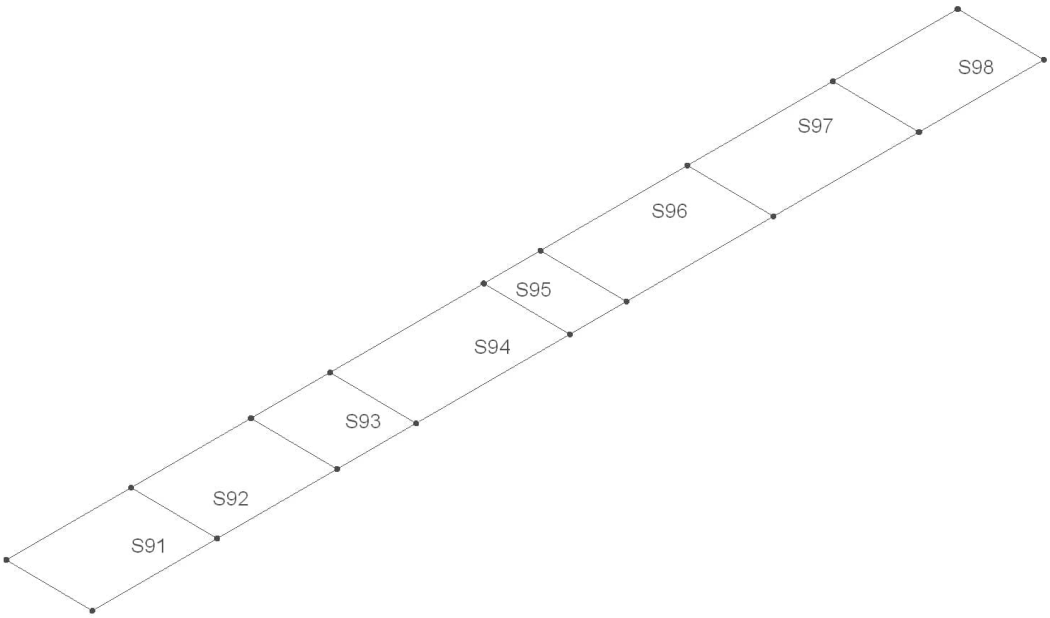

Z
X=-12050.0000
Y=5750.0000
Z=77500.0000
X=-16000.0000
Y=5750.0000
Z=77500.0000
Y
X
X=-16000.0000
Y=-5750.0000
Z=77500.0000
X=-12050.0000
Y=-5750.0000
Z=77500.0000

2.2.2.1 Geometry : SURFACES

Wall 1 :

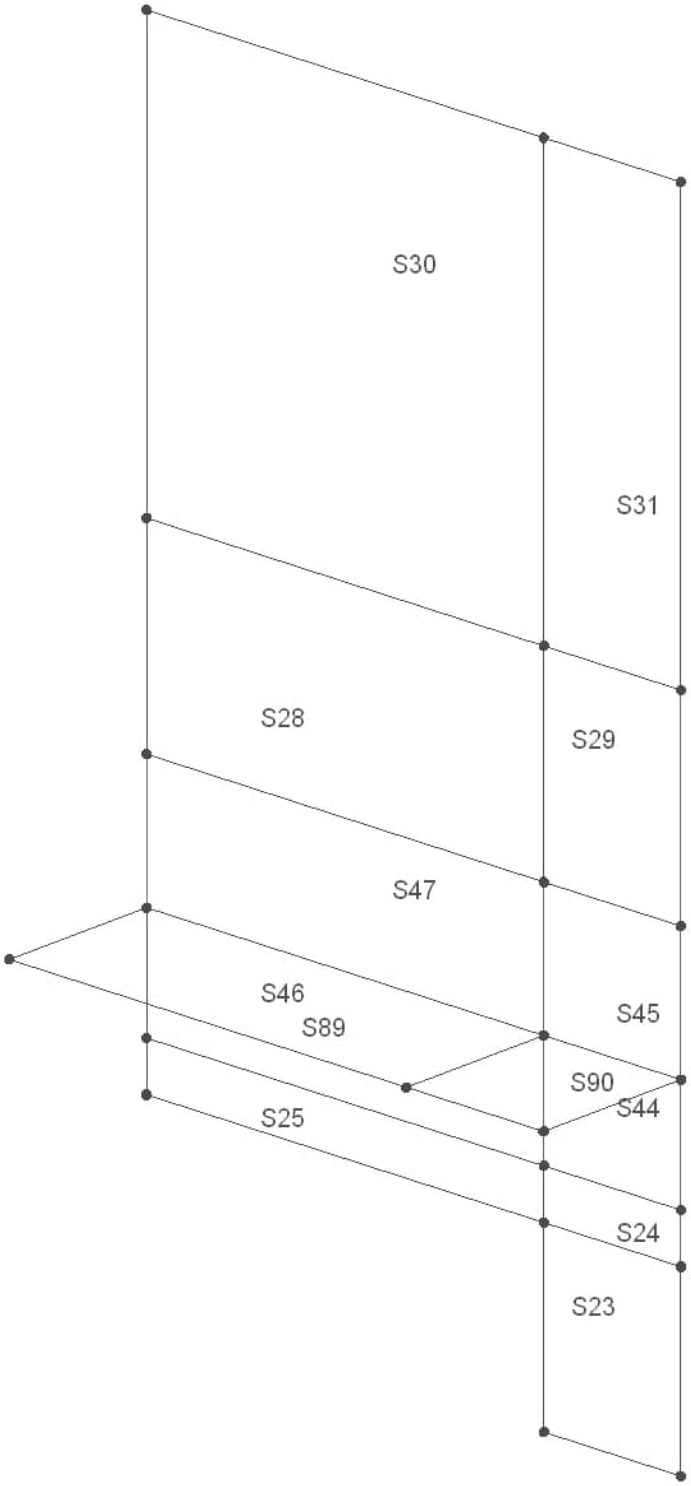


Remark Wall 1 excluding part Wall 1_4.

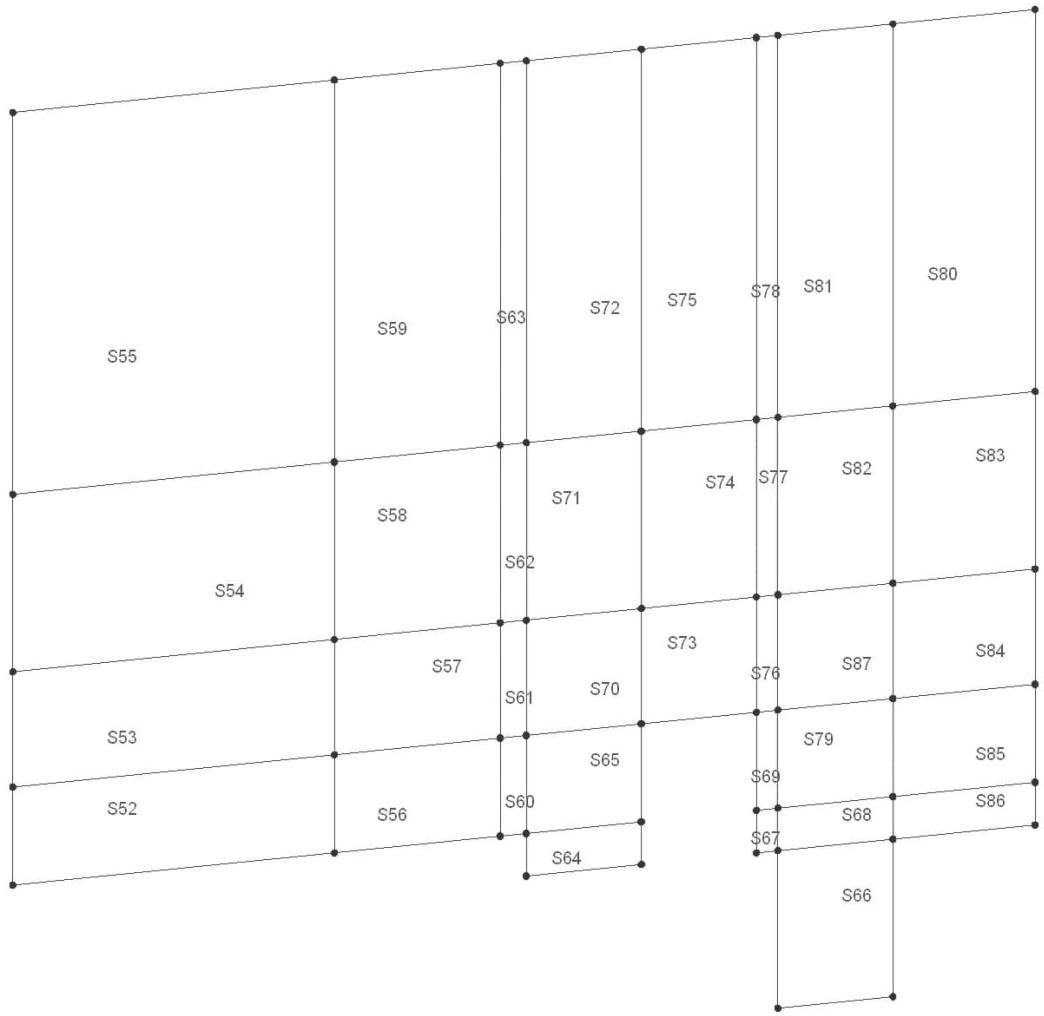


Remark Only part Wall 1_4 shown.

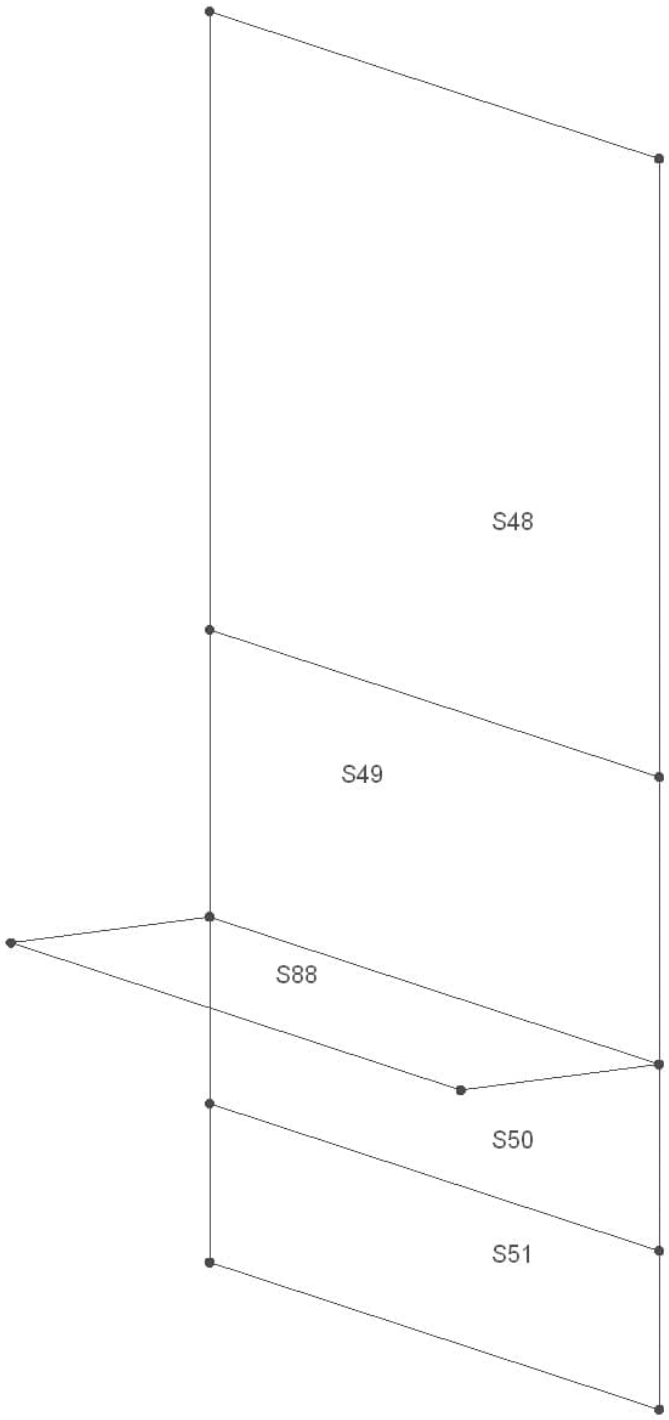
Wall 2 :



Wall 3 :

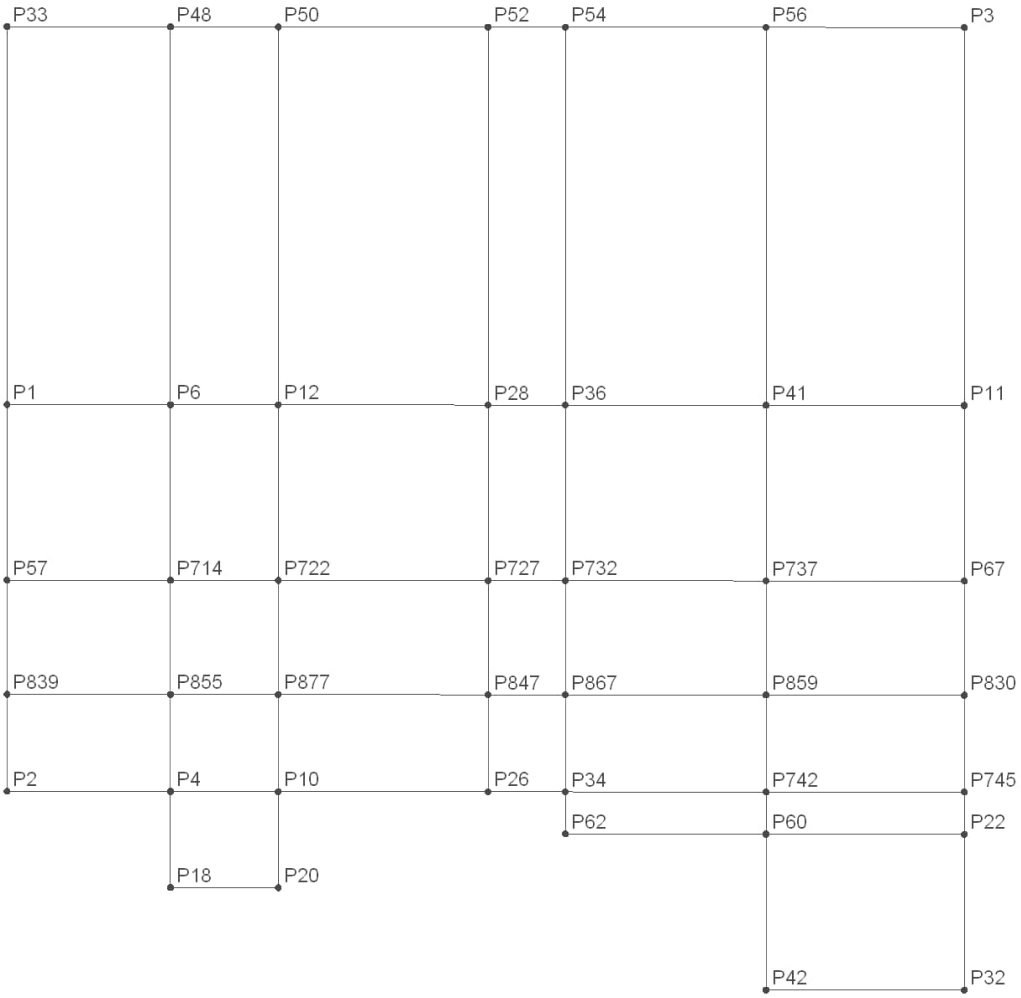

S55
S59
S63
S72
S75
S78
S81
S80
S54
S58
S62
S71
S74
S77
S82
S83
S53
S57
S61
S70
S73
S76
S87
S84
S52
S56
S60
S65
S79
S69
S68
S85
S64
S67
S86
S66

Wall 4 :

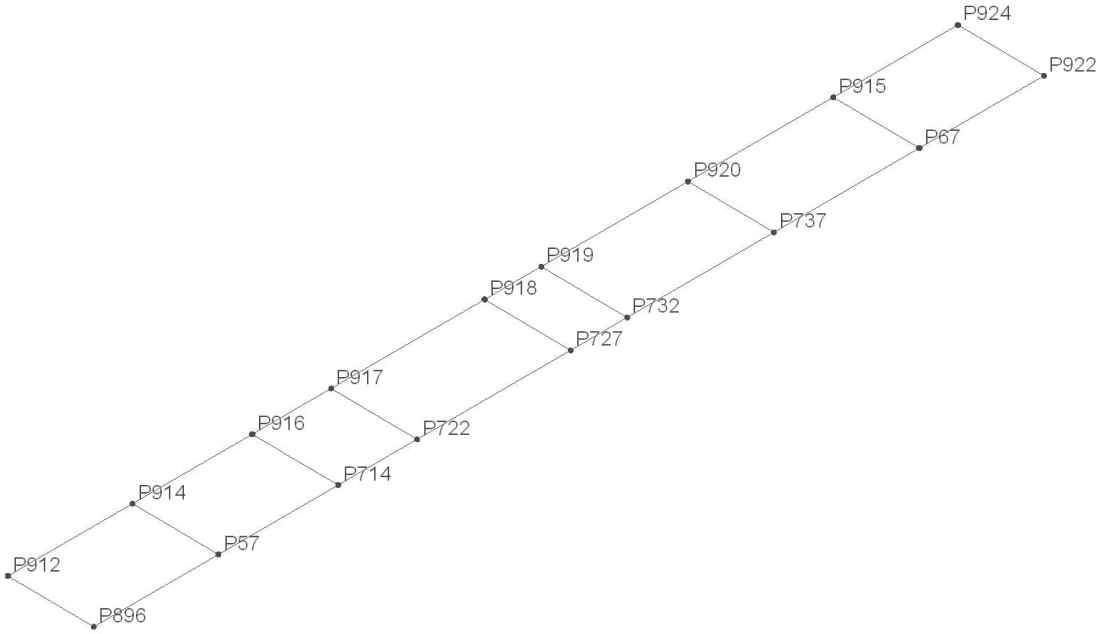


2.2.2.2 Geometry : POINTS

Wall 1 :

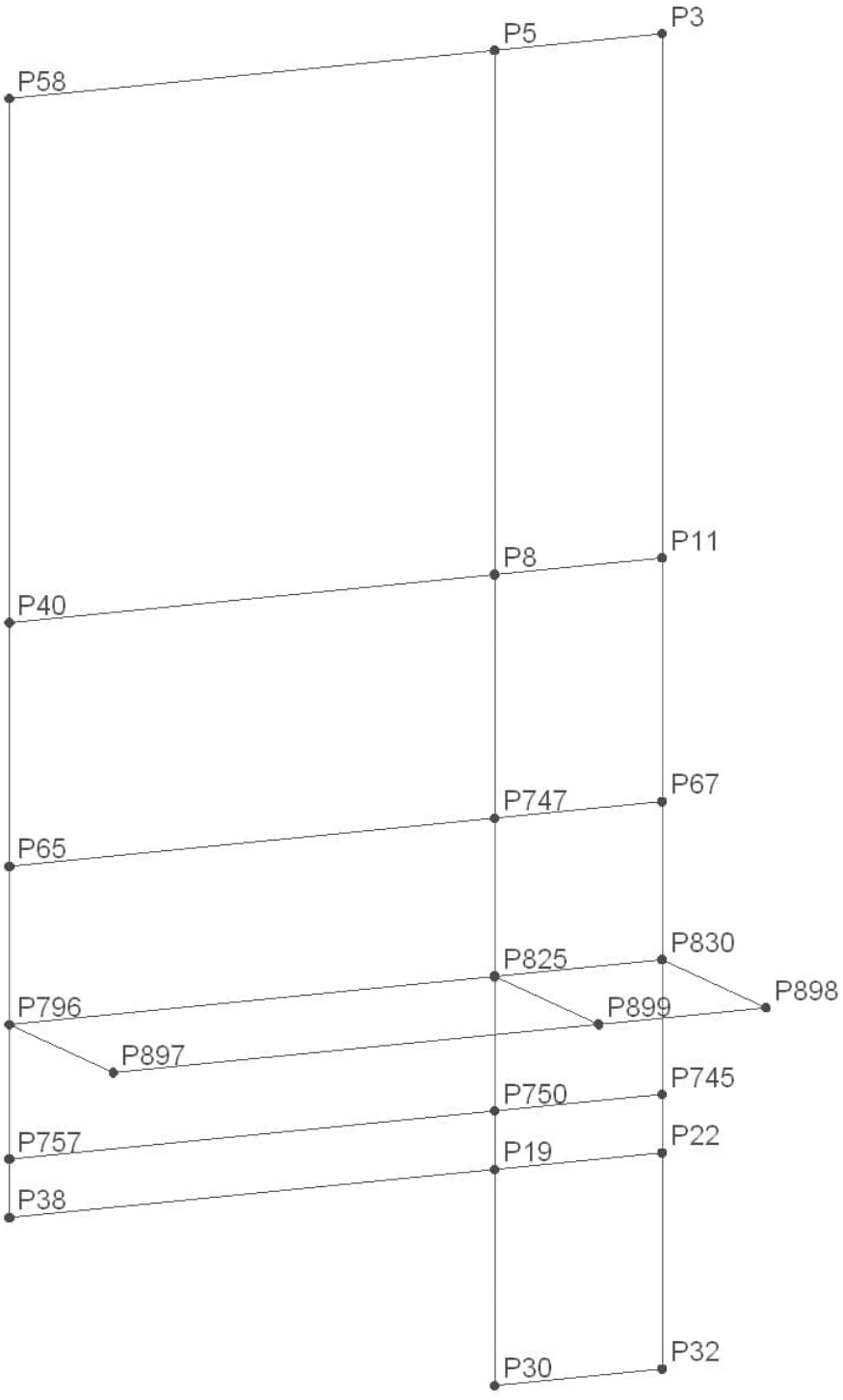


Remark Wall 1 excluding part Wall 1_4.

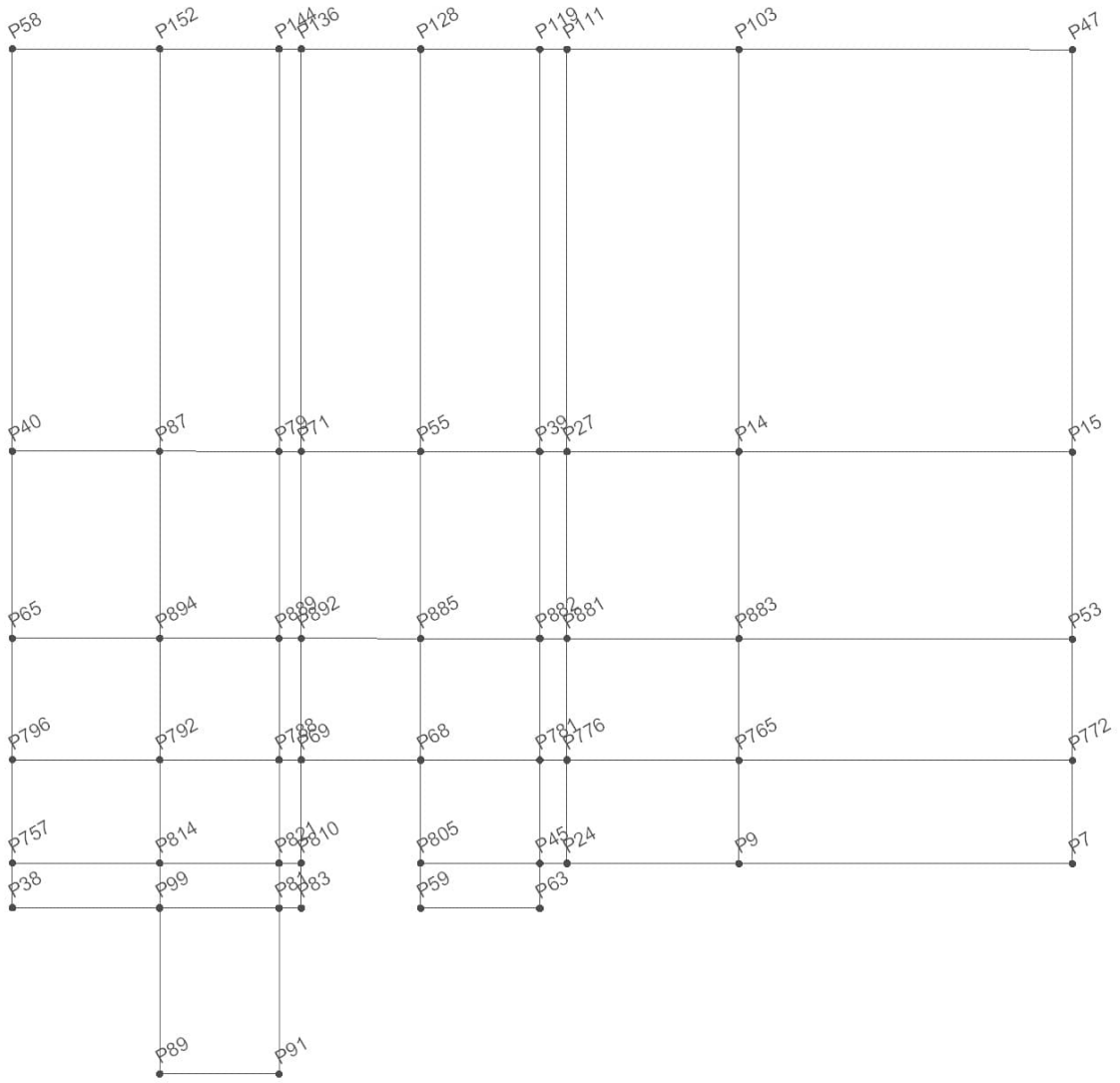


Remark Only part Wall 1_4 shown.

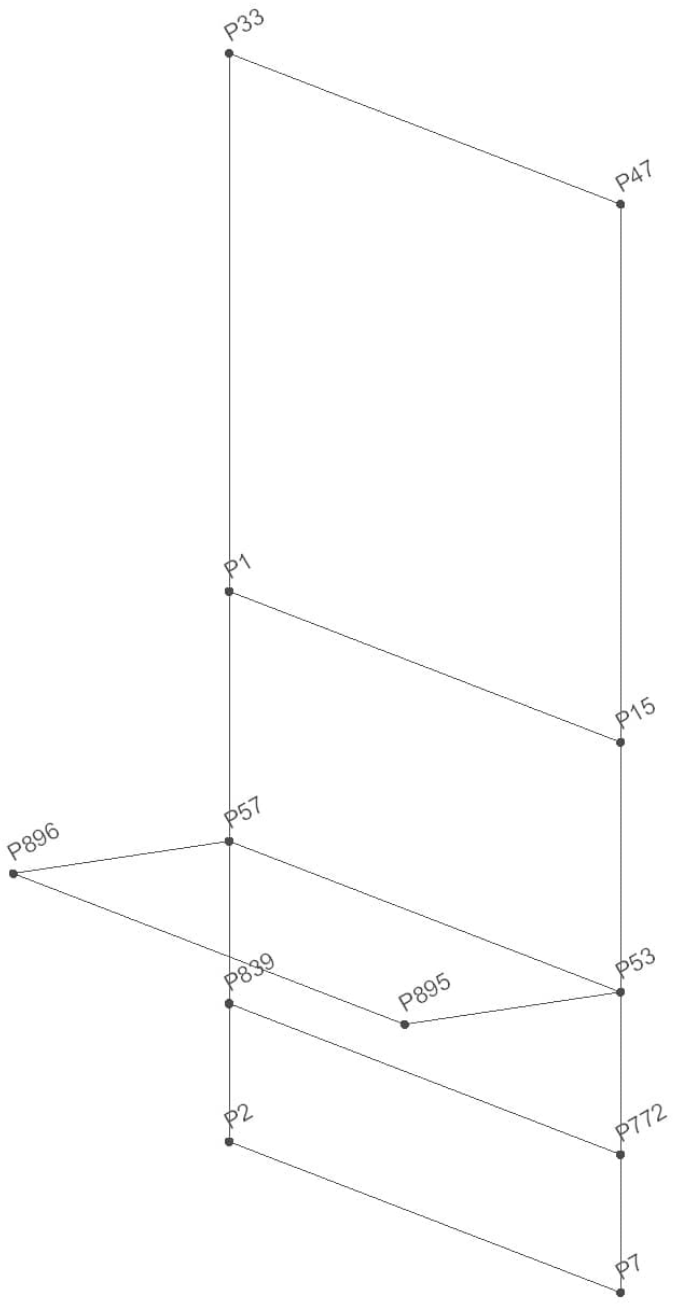
Wall 2 :


P3
P5
P58
P11
P8
P40
P67
P747
P65
P830
P825
P898
P796
P899
P897
P745
P750
P757
P22
P19
P38
P32
P30

Wall 3 :


P58
P152
P144
P136
P128
P119
P111
P103
P47
P40
P87
P79
P71
P55
P39
P27
P14
P15
P65
P894
P889
P892
P885
P882
P881
P883
P53
P796
P792
P788
P869
P68
P781
P776
P765
P772
P757
P814
P821
P810
P805
P45
P24
P9
P7
P38
P99
P831
P883
P59
P63
P89
P91

Wall 4 :



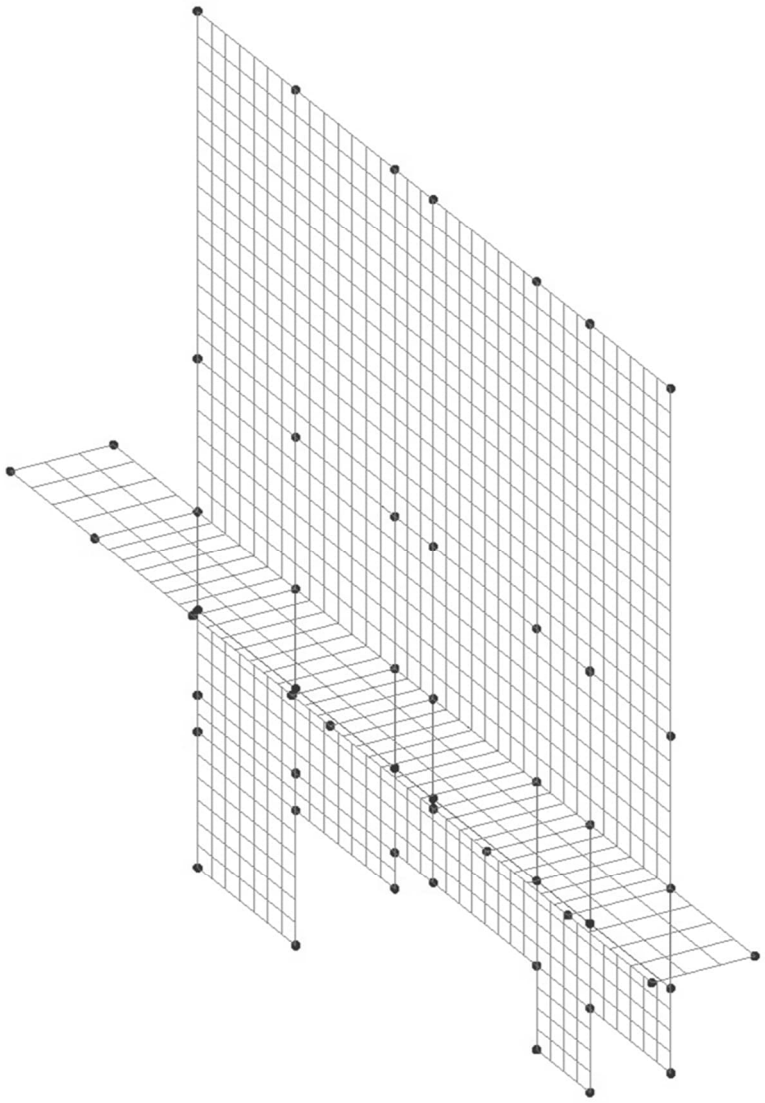
2.2.2.3 MESH

The proviously defined *SURFACES* are given attributes for generation of *MESH*.

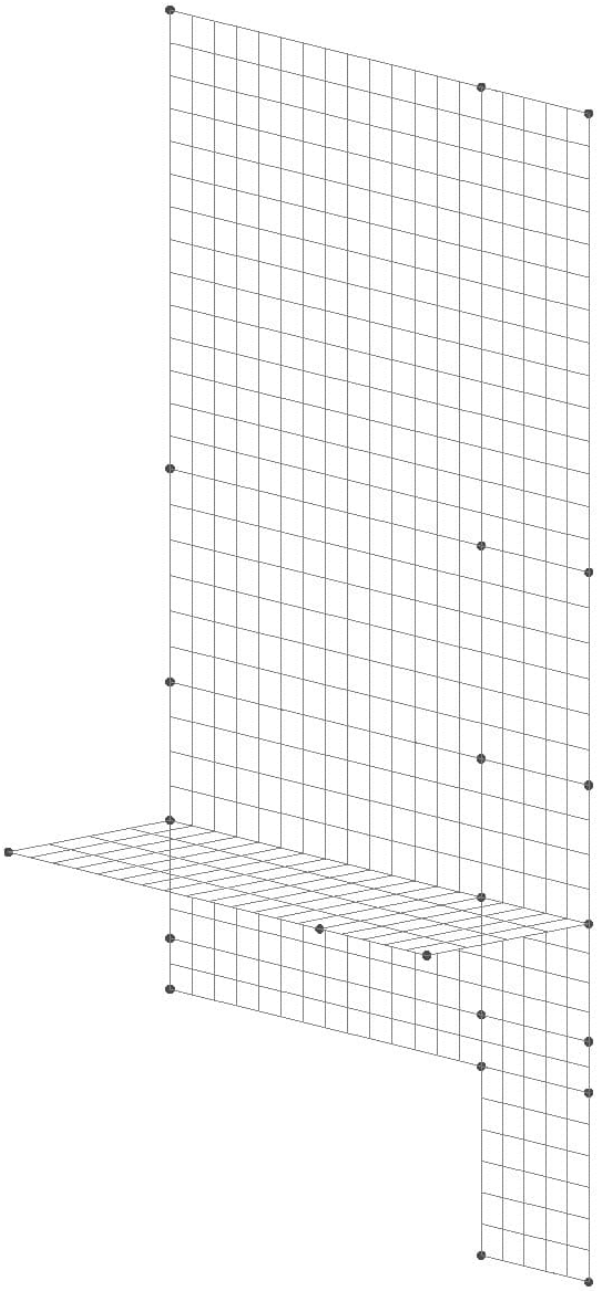
During the generation of *MESH* the underlying *ELEMENTS* and *NODES* are created. They are found in appendix 2.

The structure is modelled with Shell elements (”Thick shell” / QTS4) or as 3D thick beam elements (”Thick beam” / BMS3) .

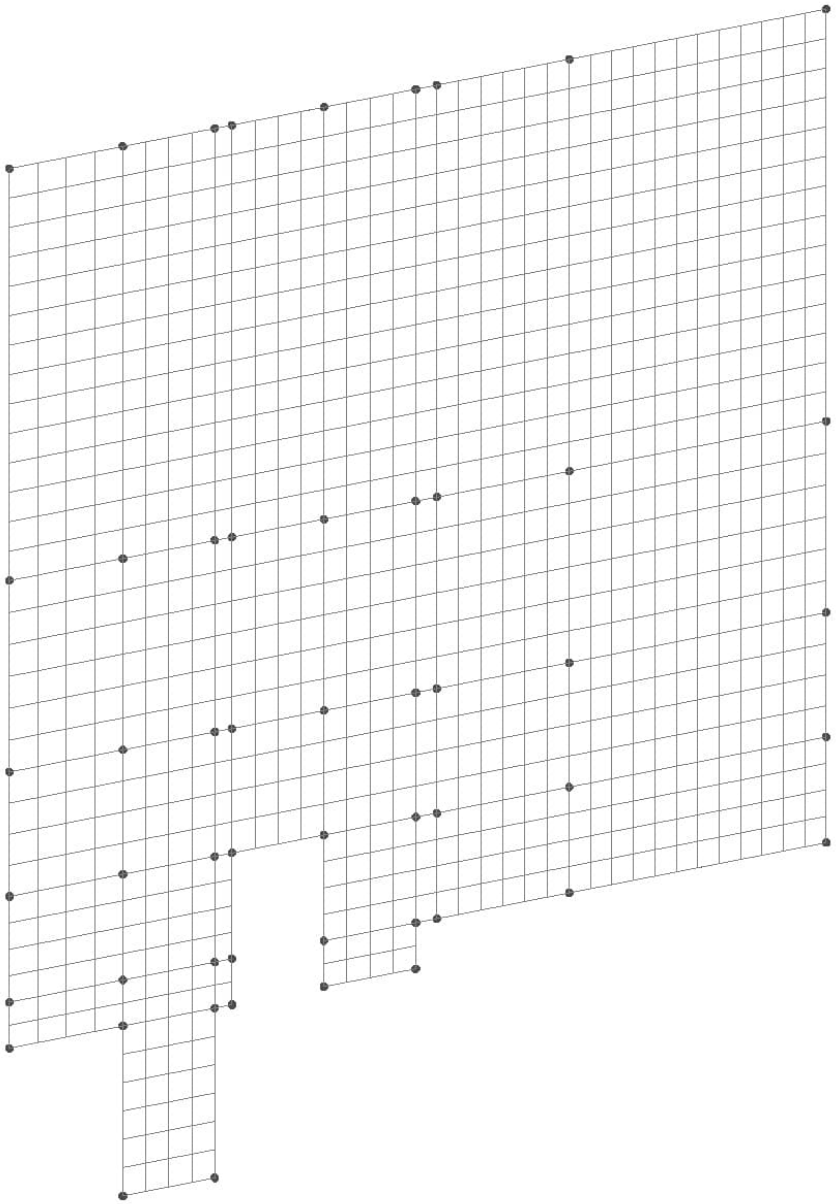
Wall 1 :



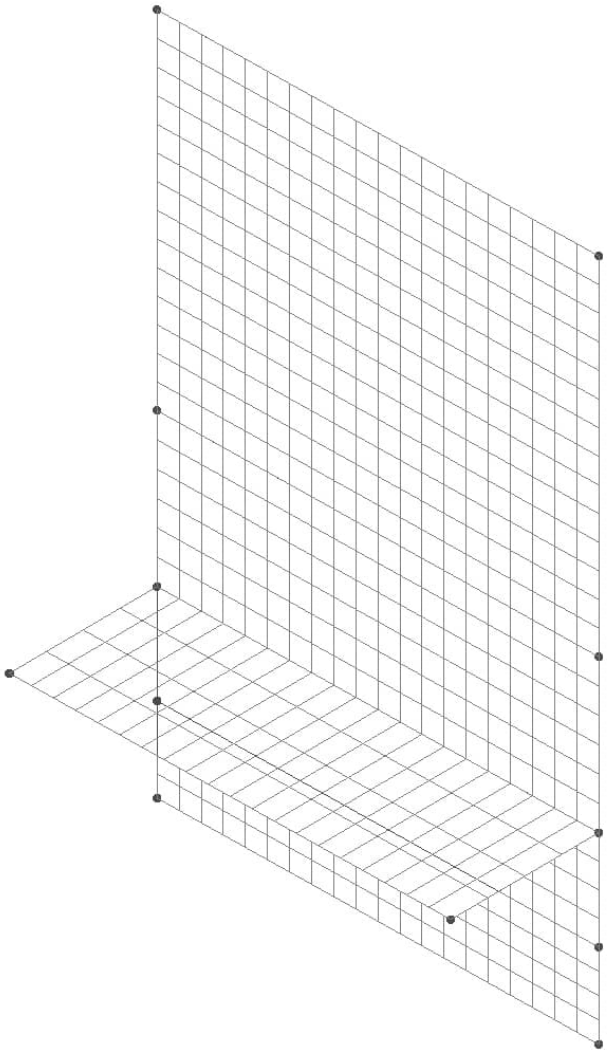
Wall 2 :



Wall 3 :



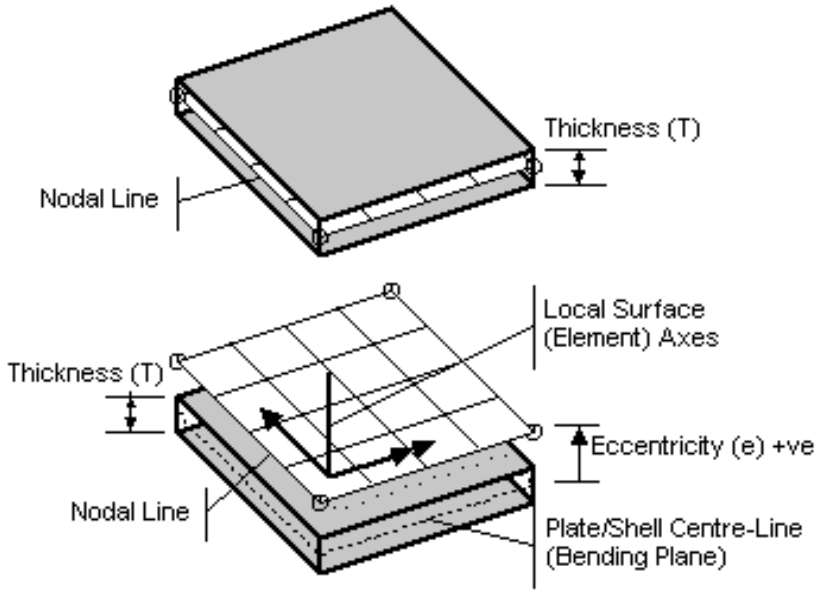
Wall 4 :



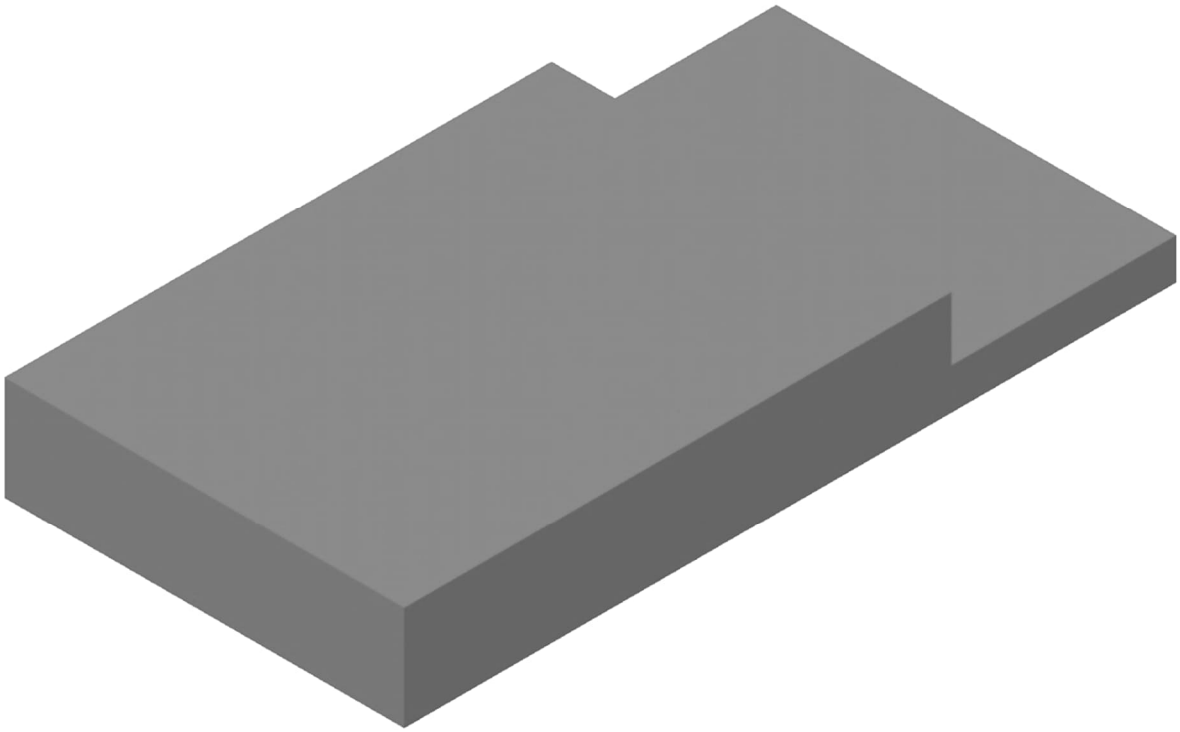
2.3 CROSSECTION PROPORTIES

2.3.1 Model : Part I (Bottom slab)

The structure is modeled with Shell elements (”Thick shell” / QTS4).

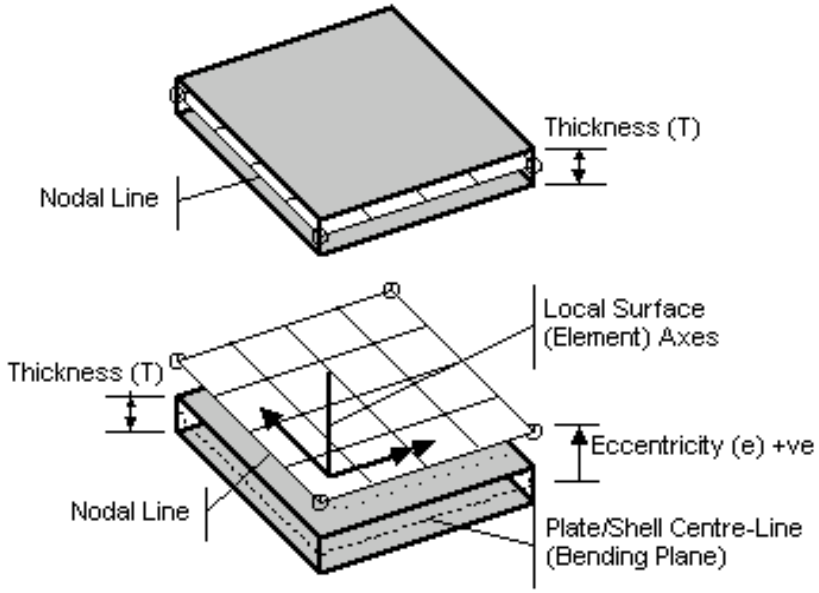


Type	t	e_z
Shell t = 1.18 m	1.18	0.91
Shell t = 3.00 m	3.00	0
-	m	m



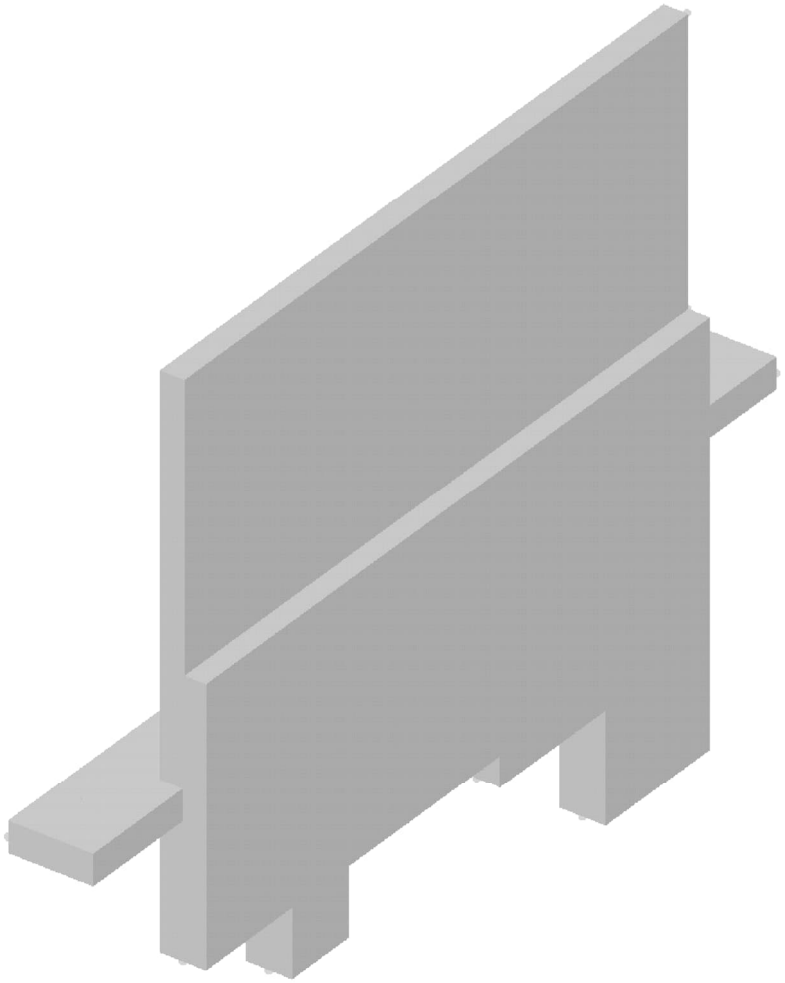
2.3.2 Model : Part II (Walls)

The structure is modeled with Shell elements (”Thick shell” / QTS4).



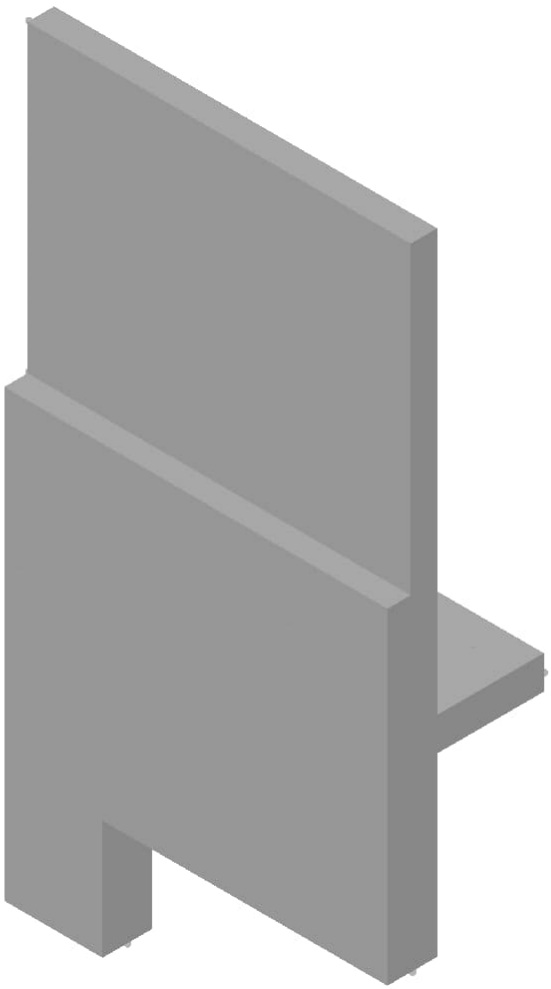
Type	t	e_z
Shell t=1.5m	1.500	0
Shell +t =0.8 m	0.800	0.350
Shell -t = 0.8 m	0.800	-0.350
Shell t = 0.001 m	0.001	0
-	m	m

View – Wall 1 :



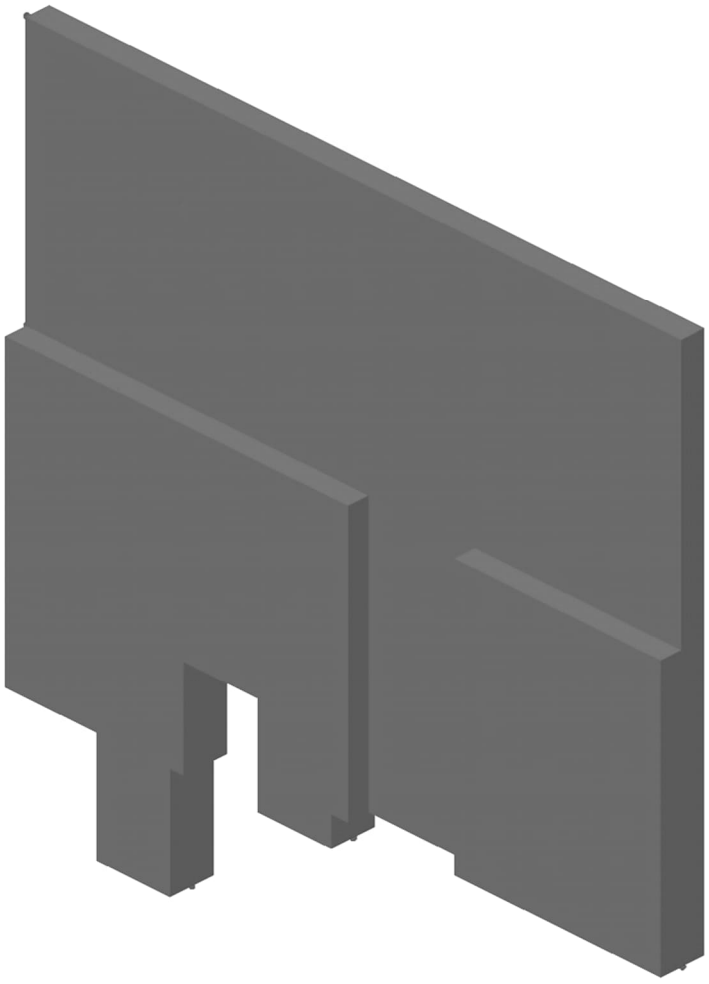
Structure	Type
Wall 1_1	Shell t = 1.50 m
Wall 1_2	Shell t = 1.50 m
Wall 1_3	Shell +t =0.80 m
Wall 1_4	Shell t = 1.00 m

View – Wall 2 :



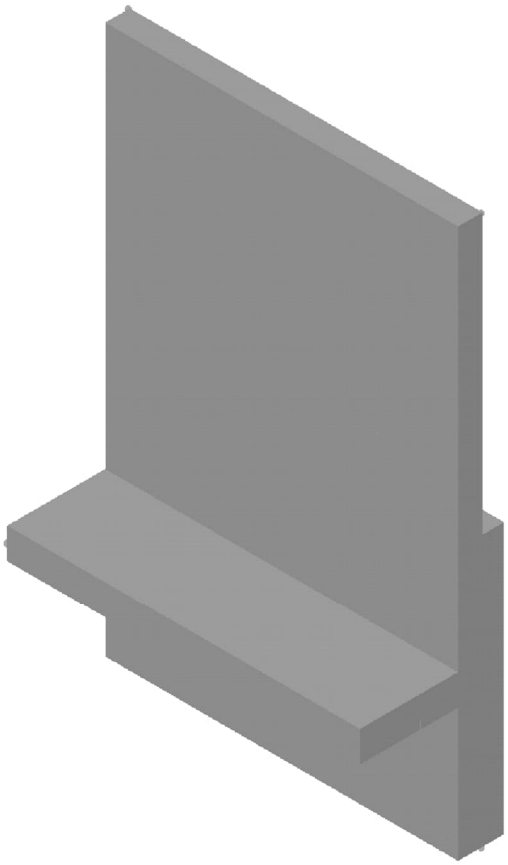
Structure	Type
Wall 2_1	Shell t = 1.50 m
Wall 2_2	Shell t = 1.00 m
Wall 2_3	Shell +t =0.80 m

View – Wall 3 :



Structure	Type
Wall 3_1	Shell t = 1.50 m
Wall 3_1	Shell –t = 0.80 m
Wall 3_2	Shell t = 1.50 m
Wall 3_3	Shell -t =0.80 m

View – Wall 4 :



Structure	Type
Wall 4_1	Shell t = 1.50 m
Wall 4_2	Shell t = 1.00 m
Wall 4_3	Shell -t =0.80 m

2.4 MATERIAL

Concrete : E_{ck} = 30 GPa

Material	Värde
E	$30 \cdot 10^6$ kPa
ν	0.2 *
ρ	2400 kg/m^3

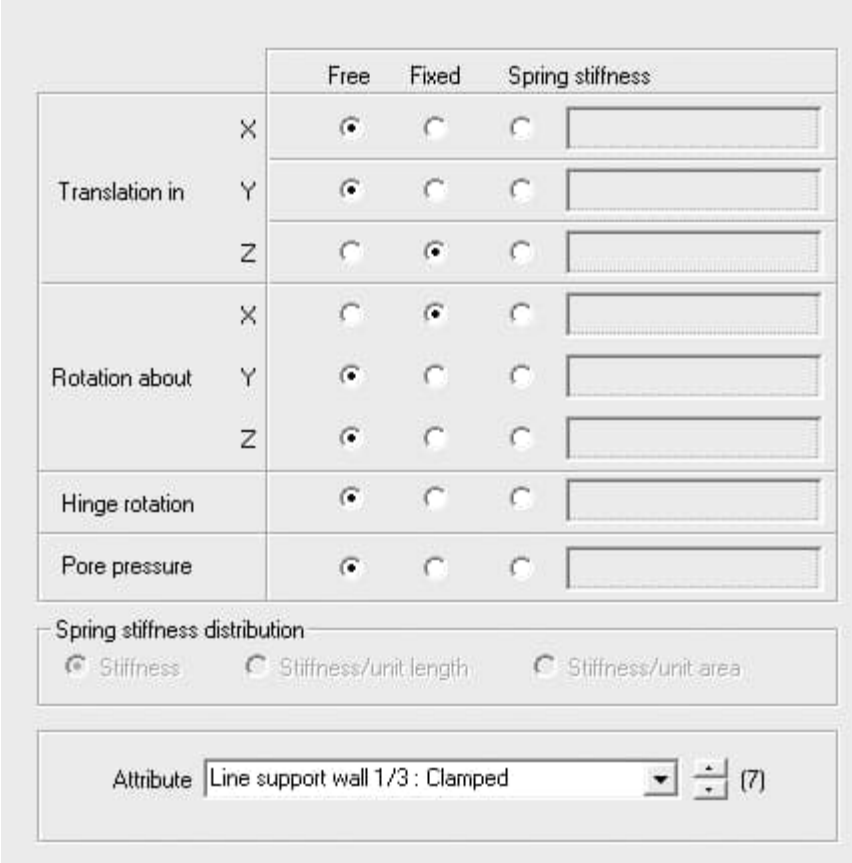
* = According to general engineering recommendation ν = 0 can be applied. However in the analysis ν = 0.002 is inserted.

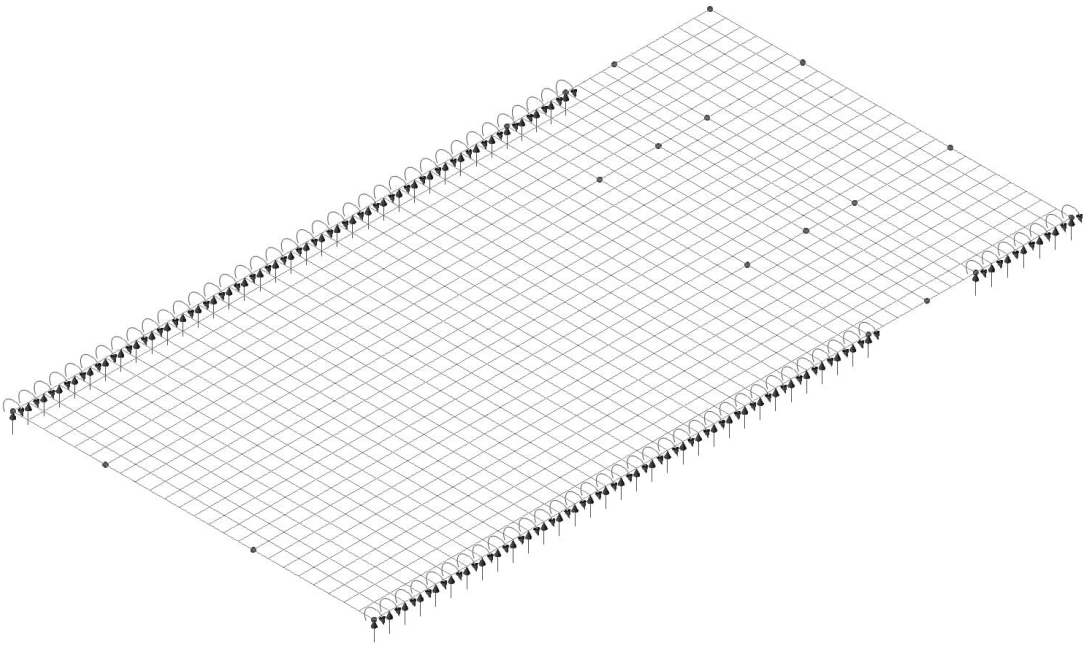
2.5 BOUNDARY CONDITIONS

The structure is studied in to separate parts. The boundary conditions for part I (bottom slab) and part II (walls) is presented in the following chapter.

2.5.1 Model : Part I (Bottom slab)

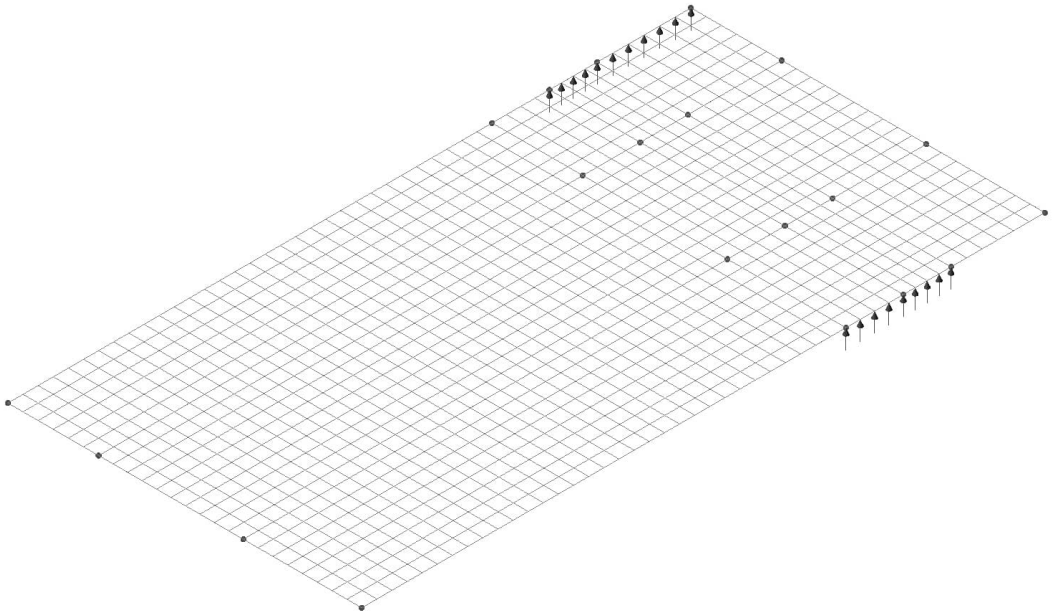
2.5.1.1 Boundary at foundation of wall 1/3 : “Line support wall 1/3:clamped”





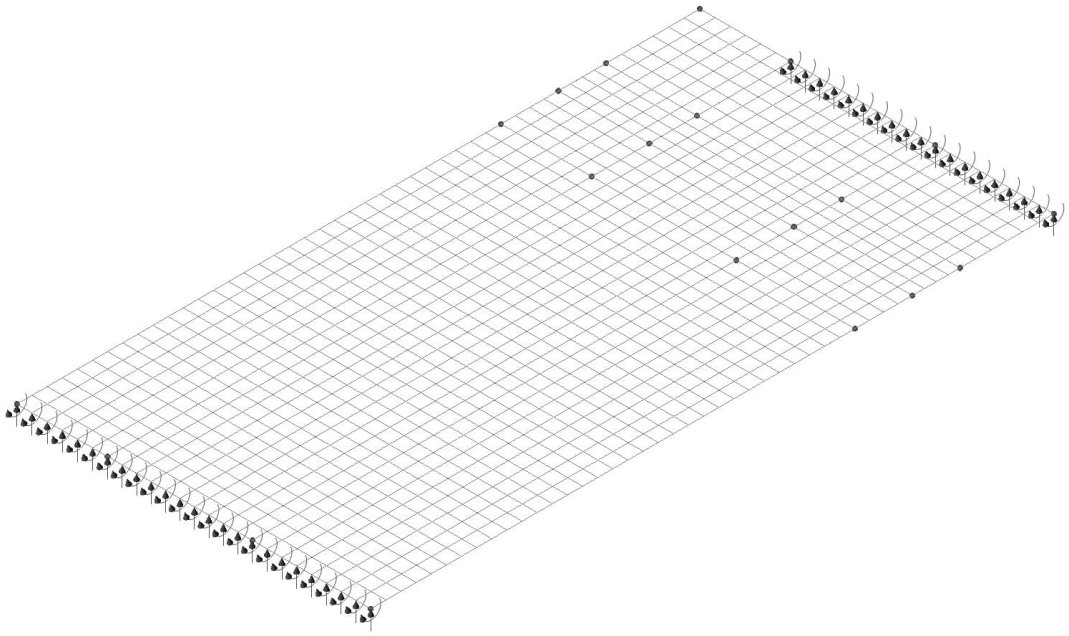
Remark Areas where there is concrete above the bottom slab. This corresponds to areas without pits.

2.5.1.2 Boundary at foundation of wall 1/3 : “Line support wall 1/3:free”

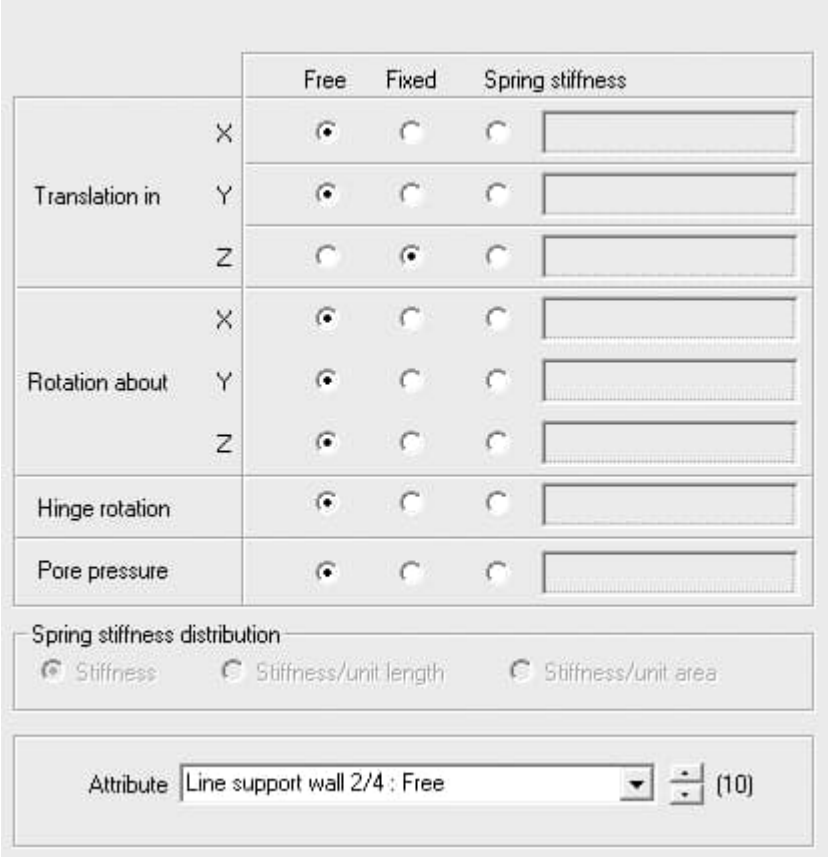


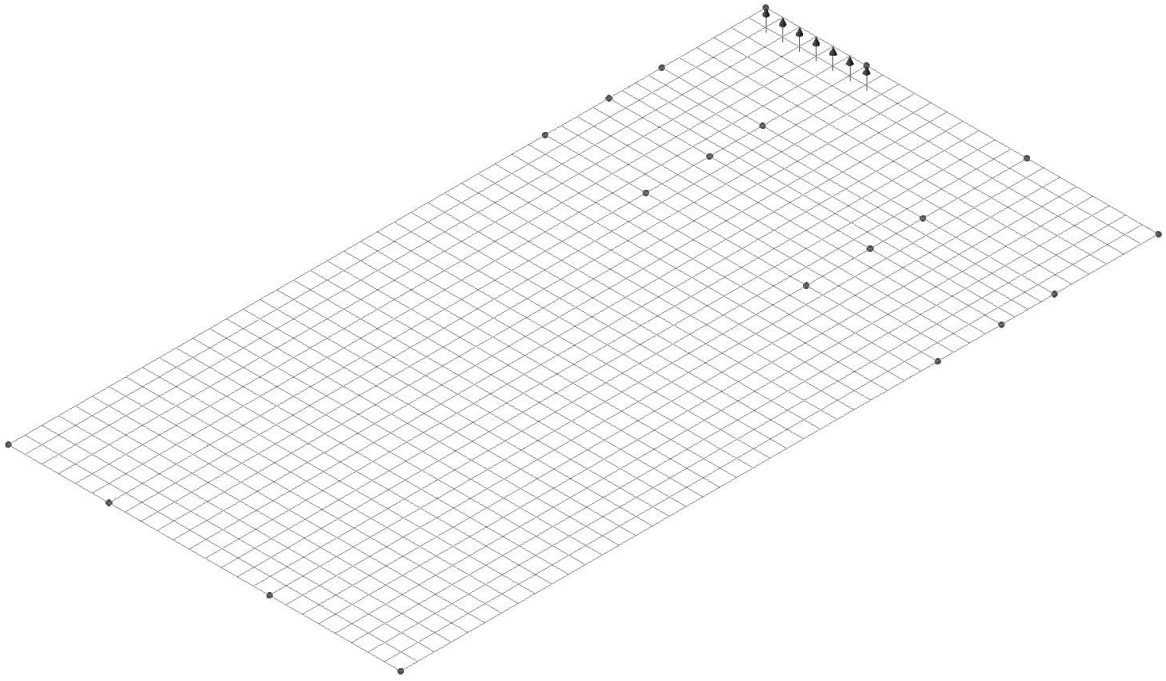
Remark Areas where there is no concrete above the bottom slab. This corresponds to areas with pits.

2.5.1.3 Boundary at foundation of wall 2/4 : “Line support wall 2/4:clamped”

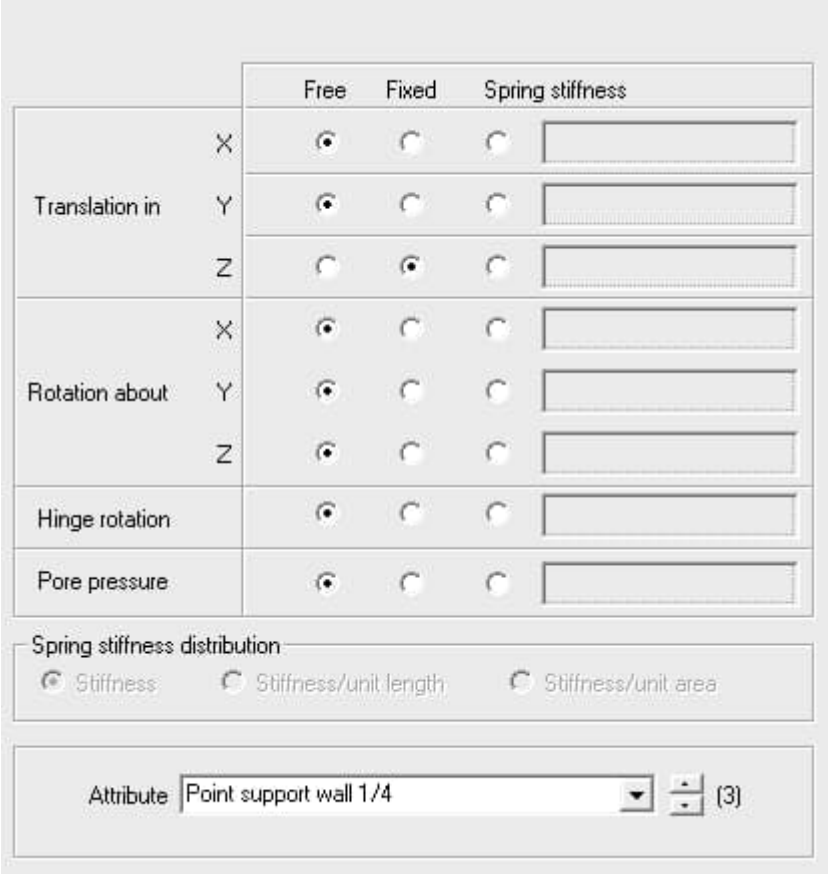


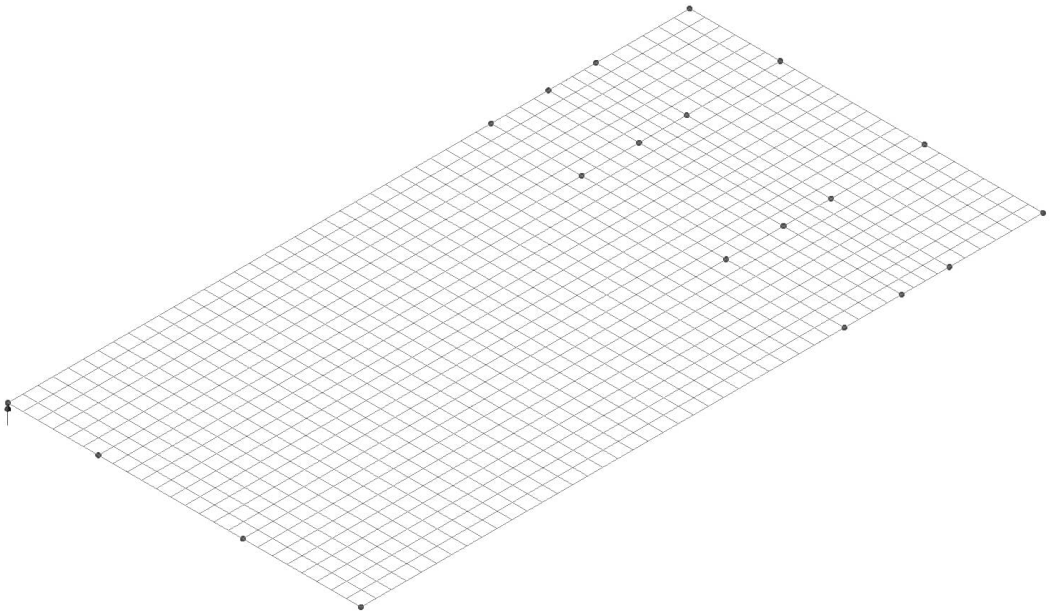
2.5.1.4 Boundary at foundation of wall 2/4 : “Line support wall 1/3:free”



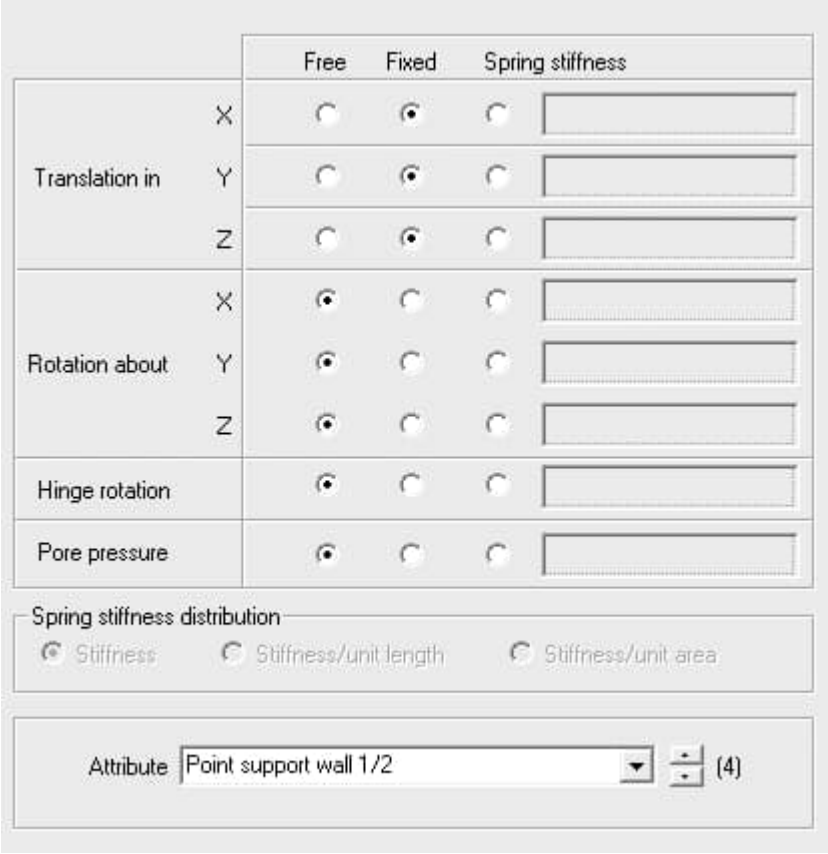


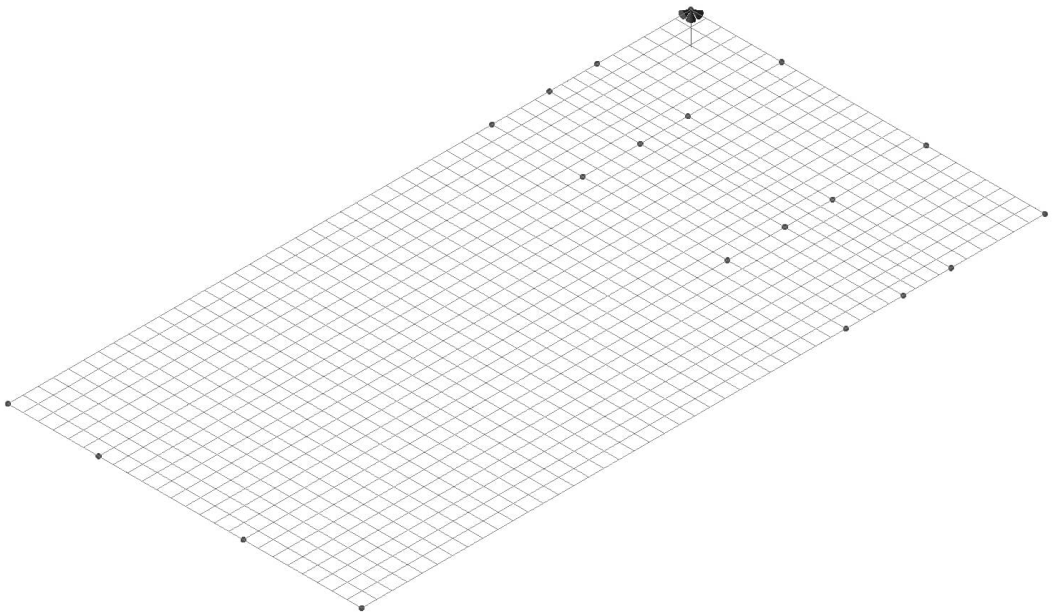
2.5.1.5 Boundary at foundation of wall 1/4 : “Point support wall 1/4”



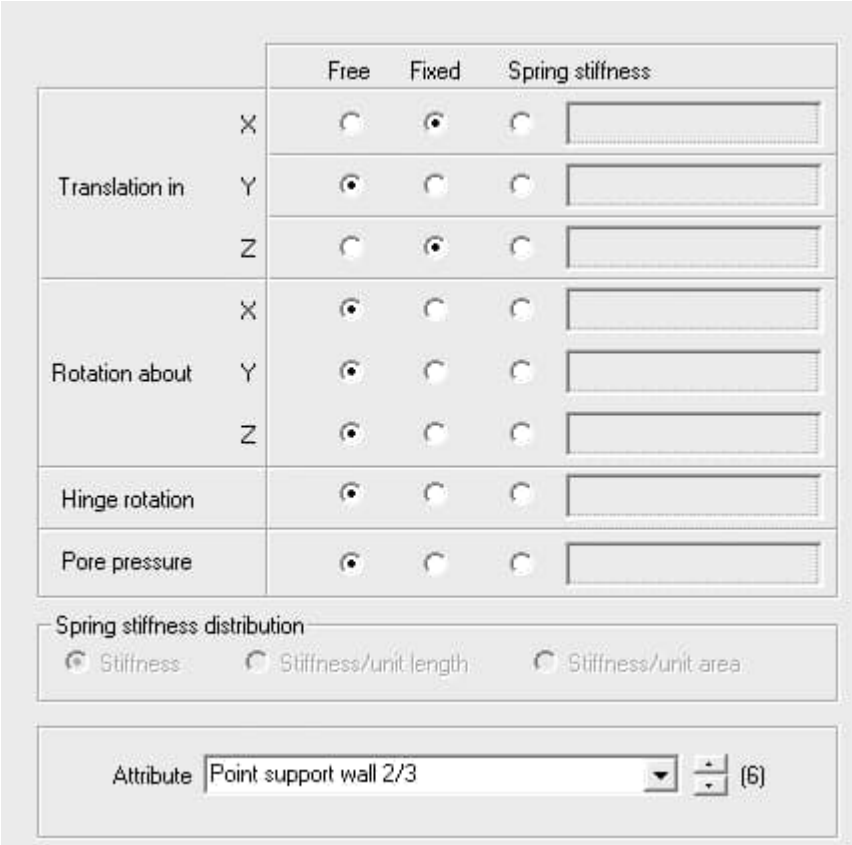


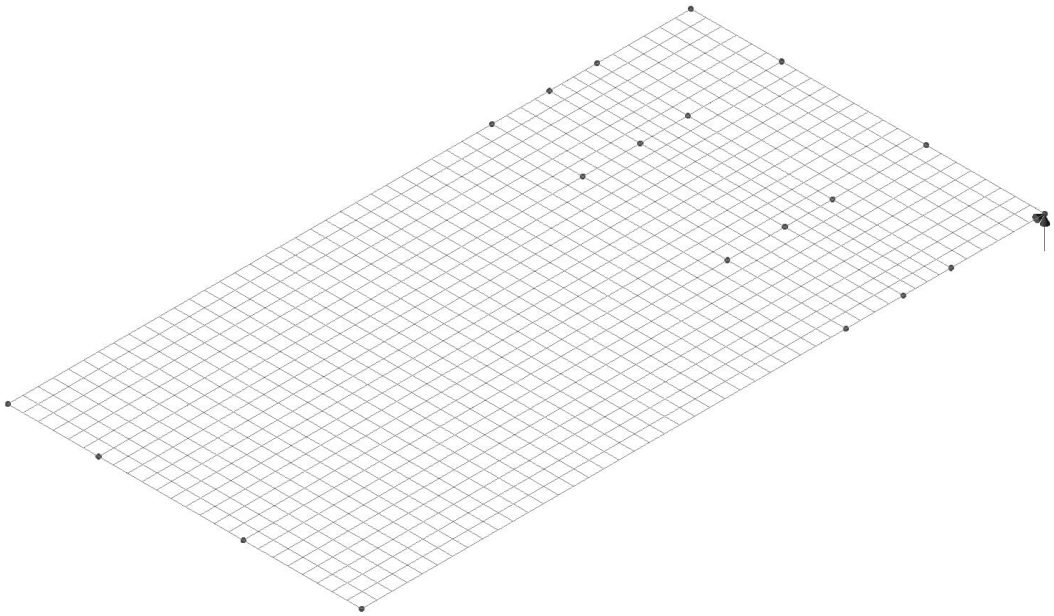
2.5.1.6 Boundary at foundation of wall 1/2 : “Point support wall 1/2”



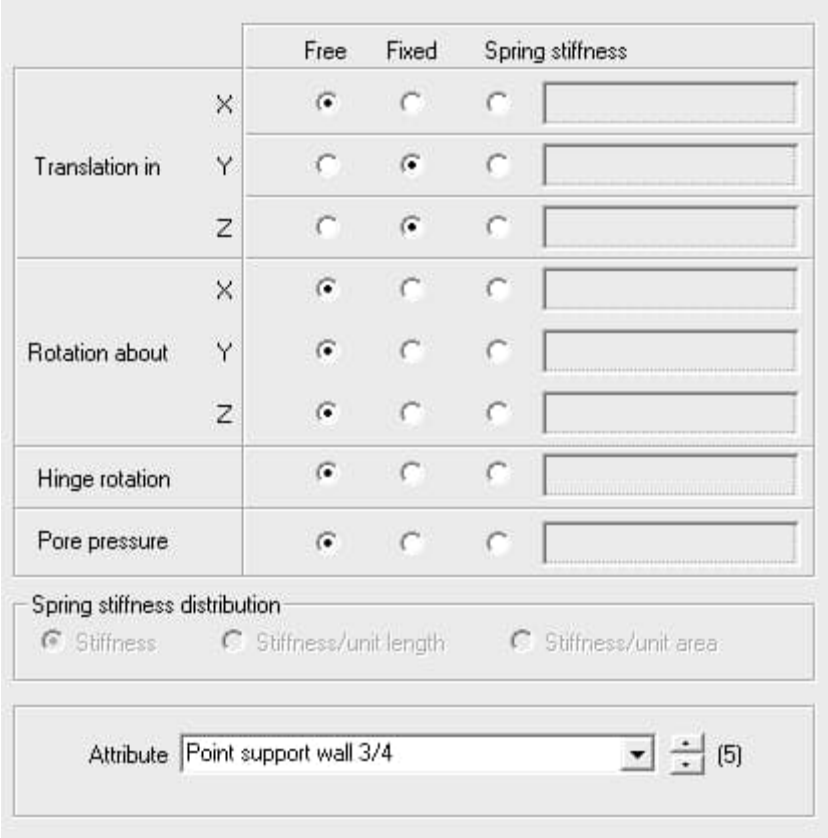


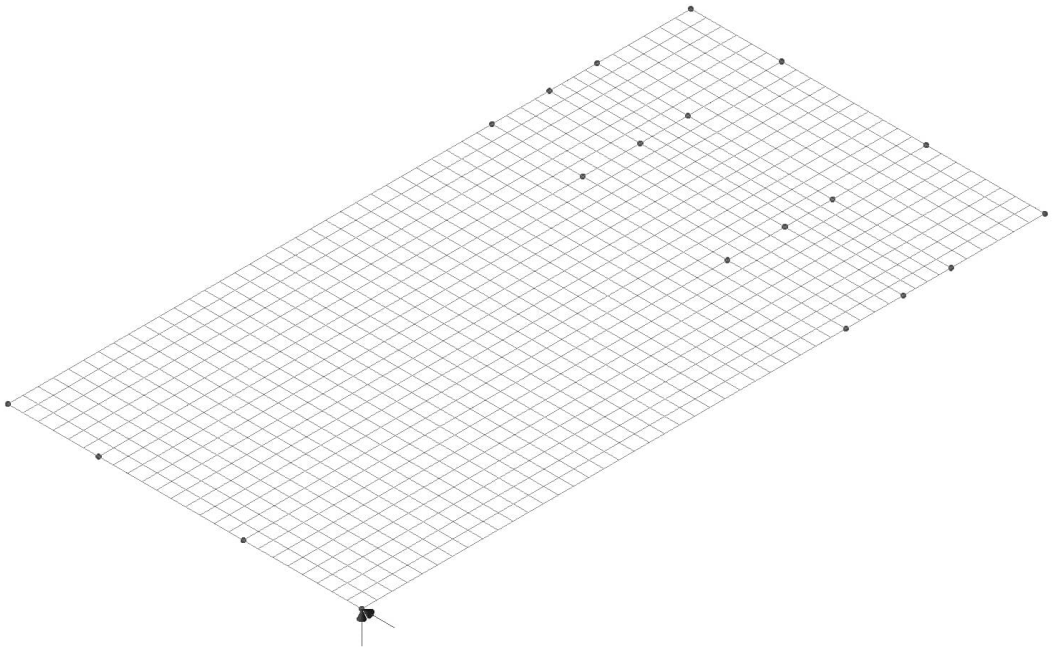
2.5.1.7 Boundary at foundation of wall 2/3 : “Point support wall 2/3”





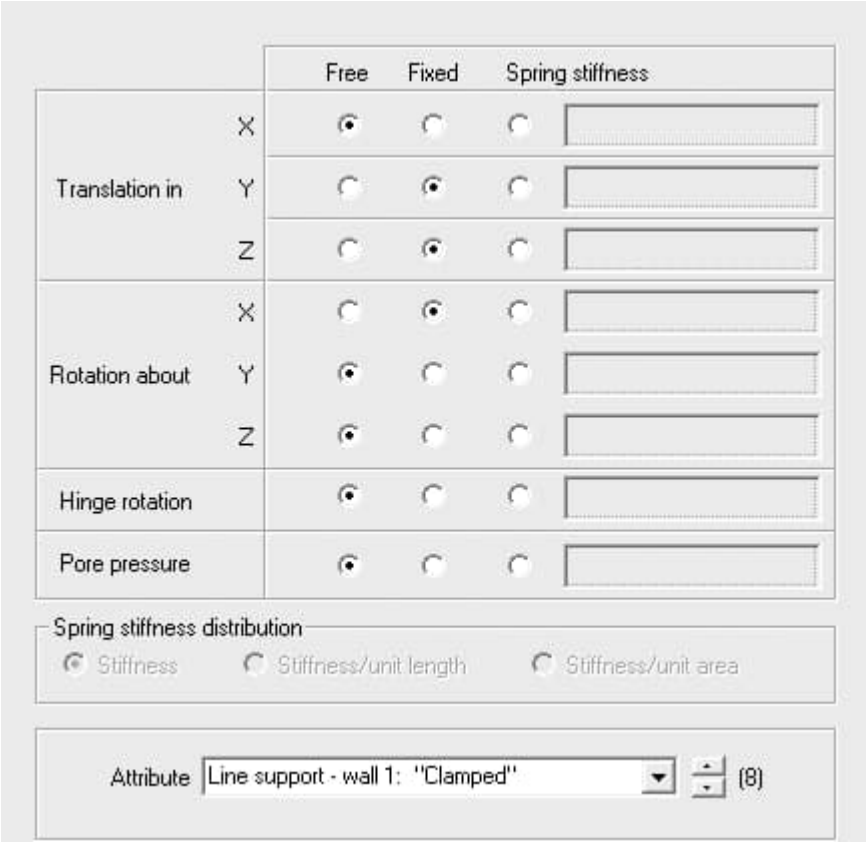
2.5.1.8 Boundary at foundation of wall 3/4 : “Point support wall 3/4”

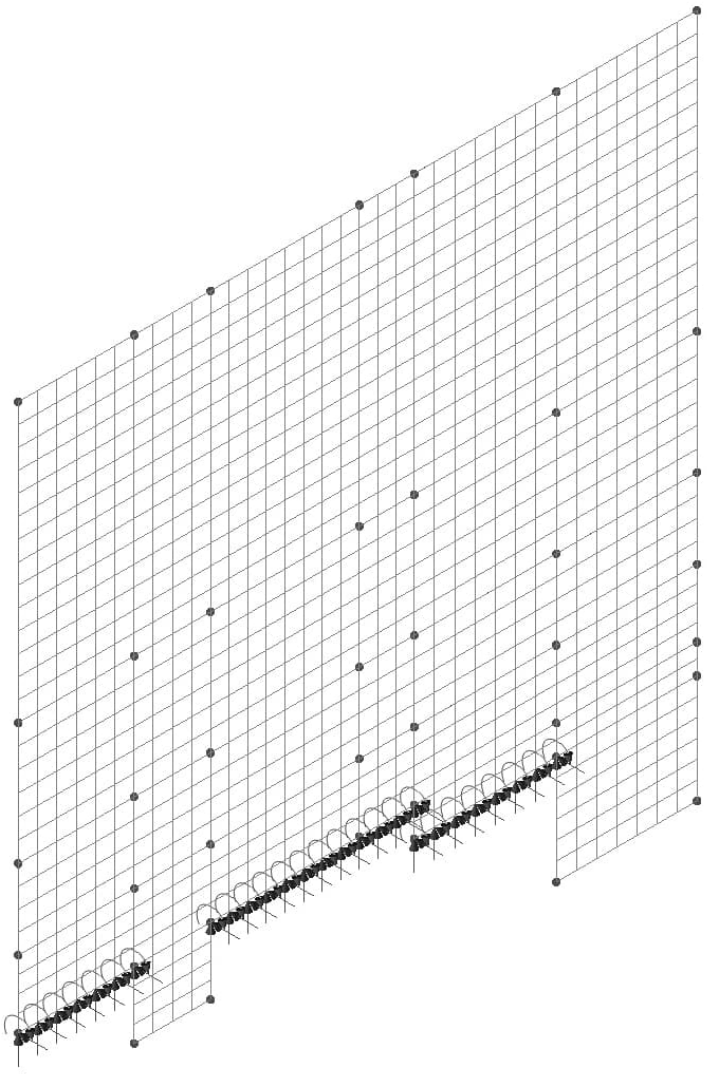




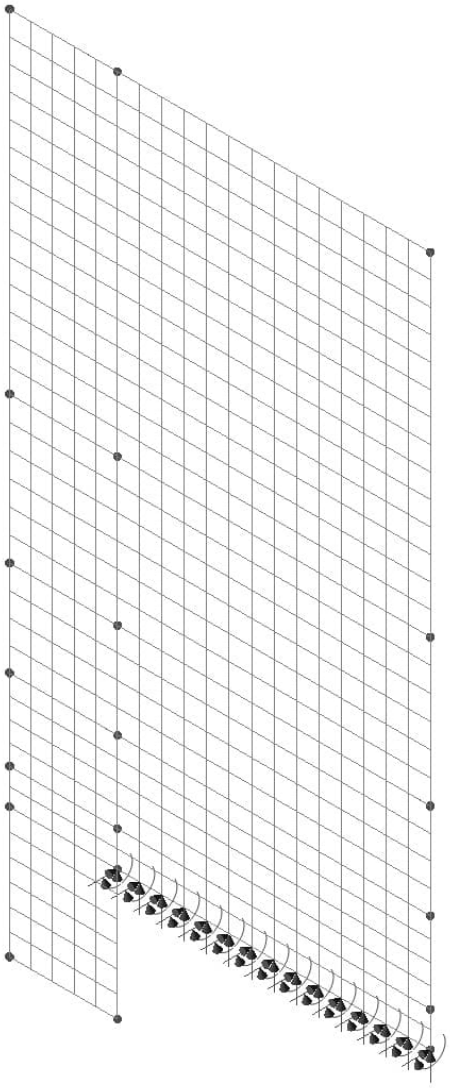
2.5.2 Model : Part II (Walls)

2.5.2.1 Boundary at foundation of wall 1 : “Line support – wall 1: Clamped”

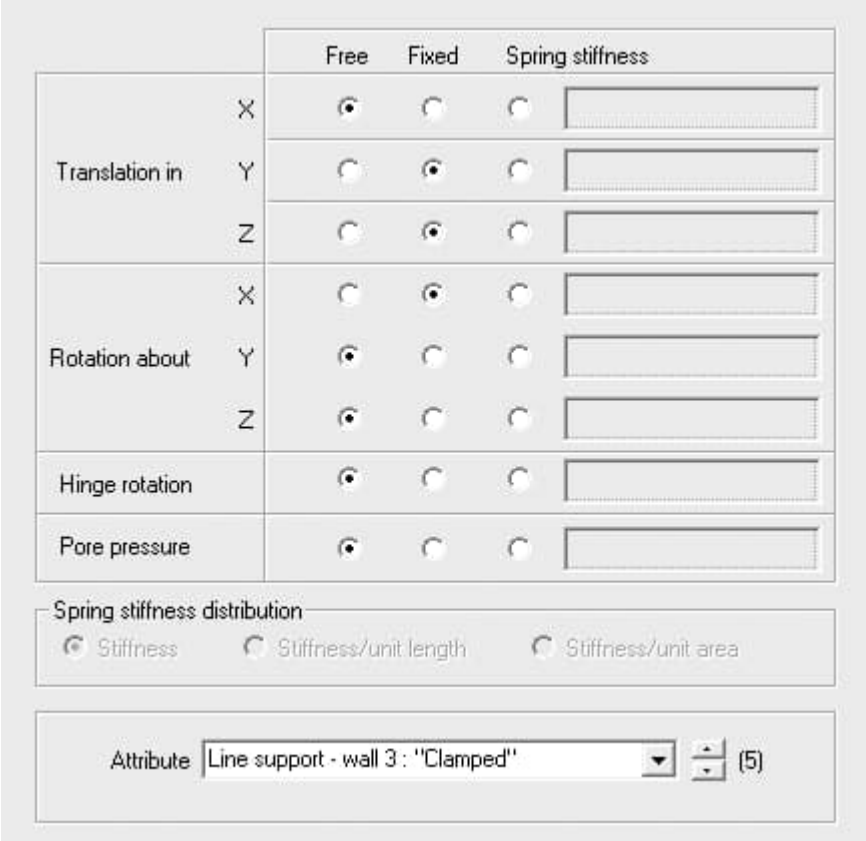


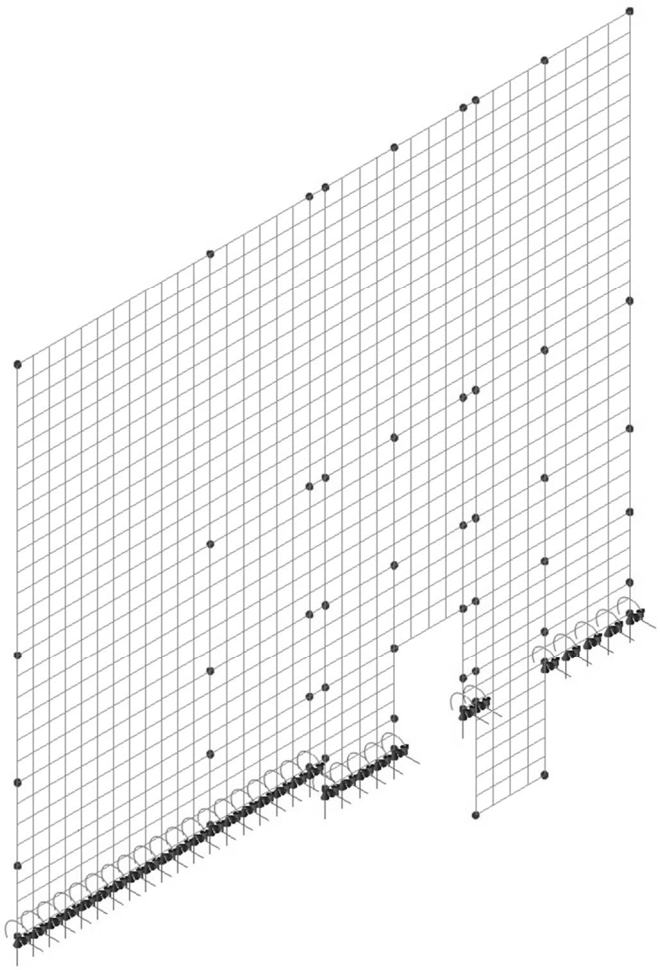


2.5.2.2 Boundary at foundation of wall 2 : “Line support – wall 2: Clamped”

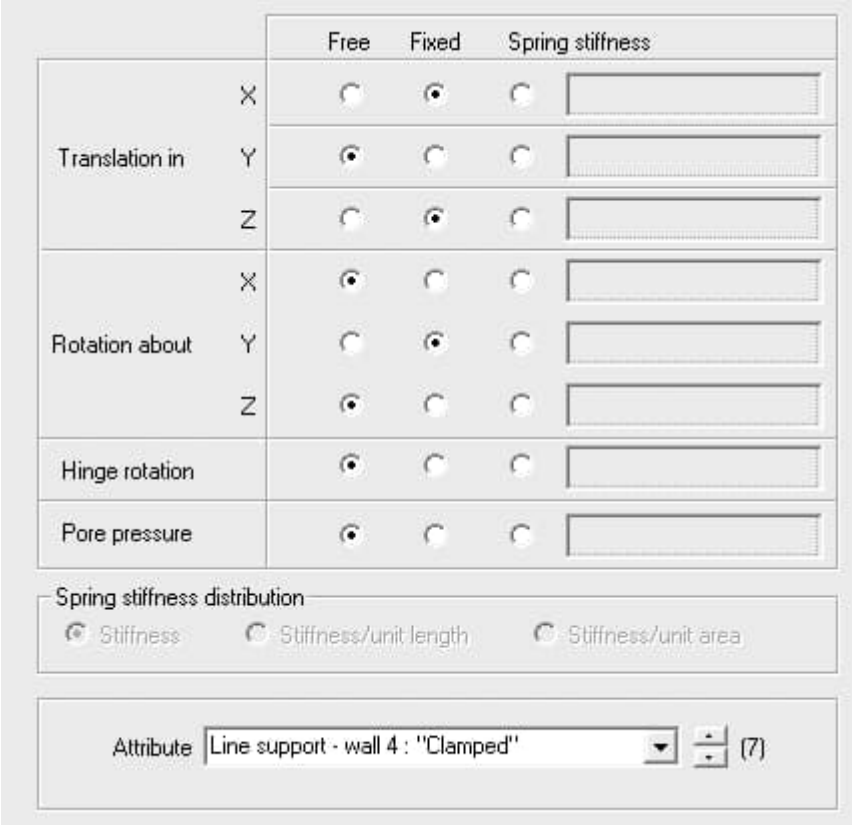


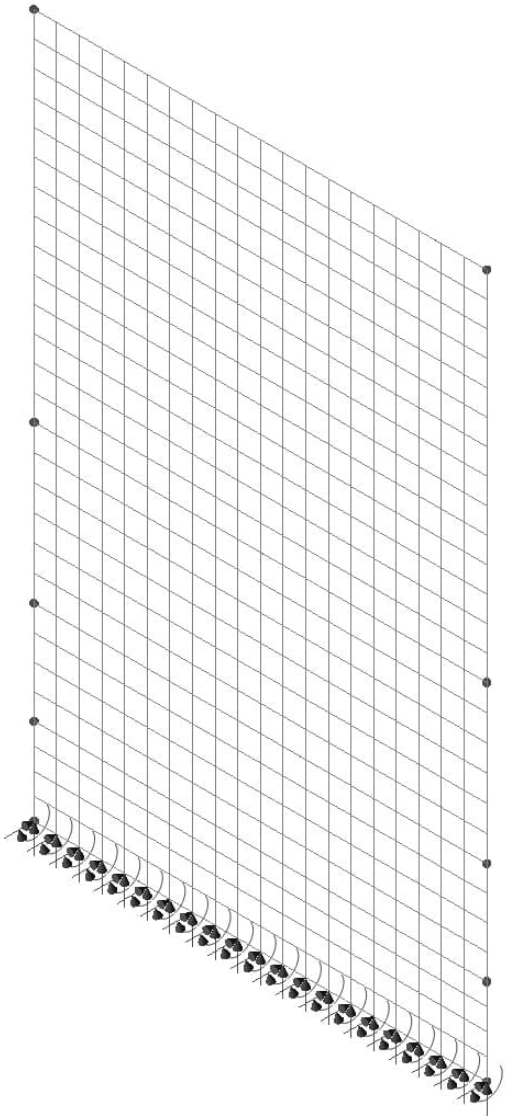
2.5.2.3 Boundary at foundation of wall 3 : “Line support – wall 3 : Clamped”





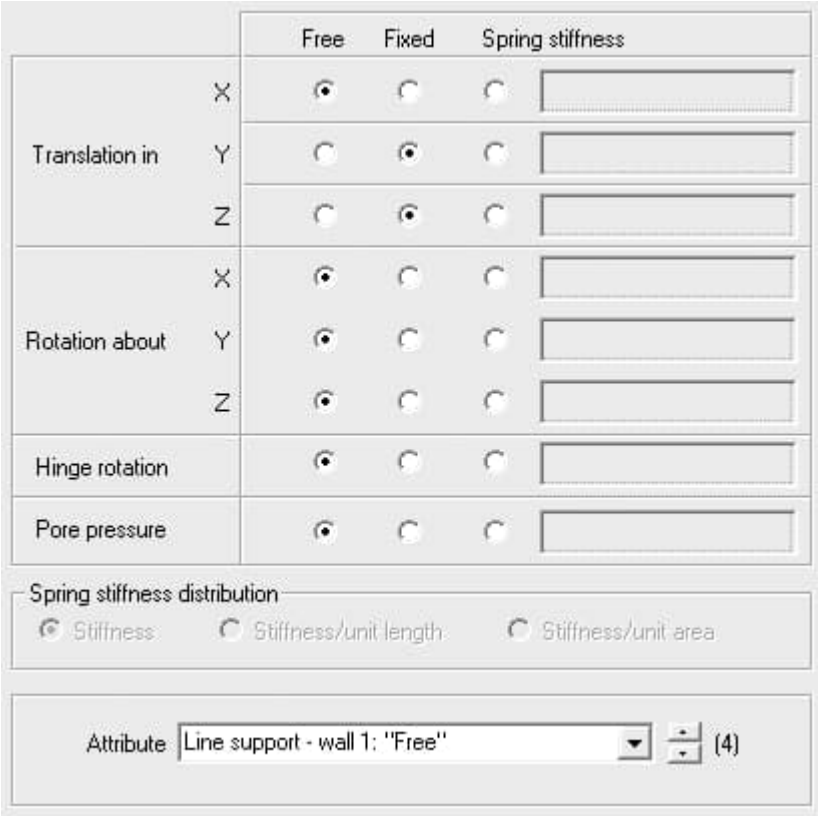
2.5.2.4 Boundary at foundation of wall 4 : “Line support – wall 4 : Clamped”

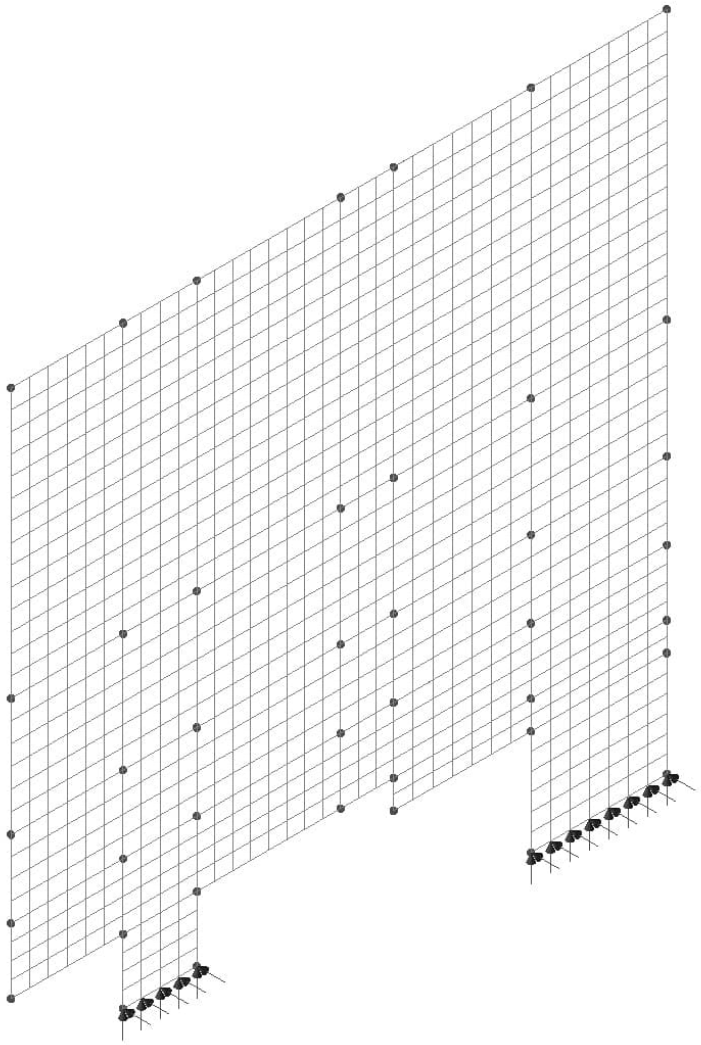




2.5.2.5 Boundary at foundation of wall 1 : “Line support – wall 1 : Free”

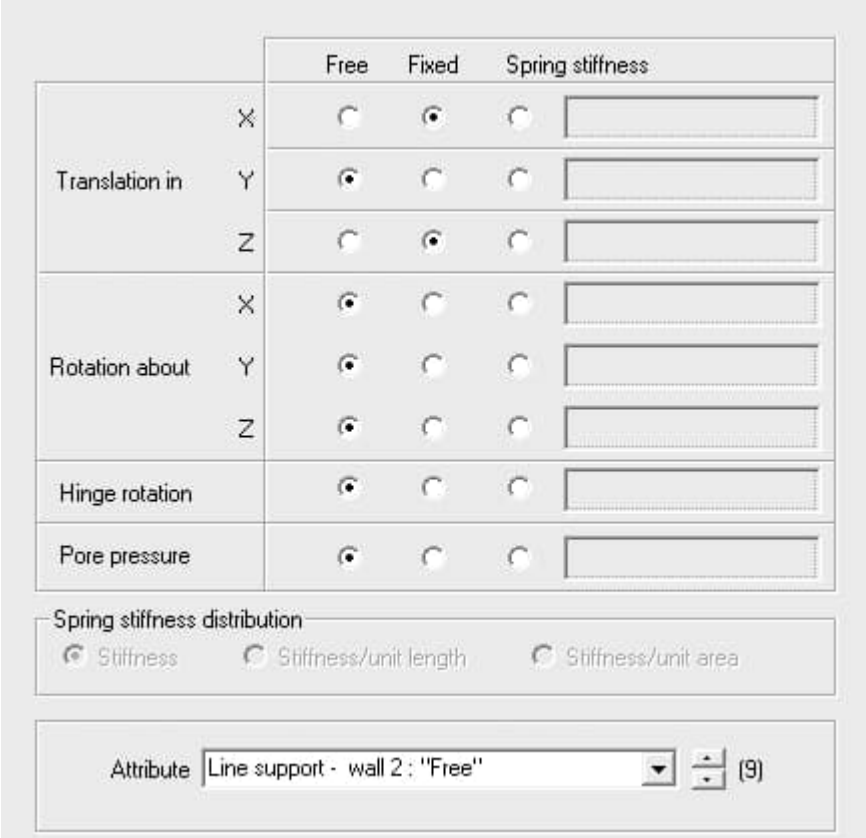
Simulates horizontal boundary conditions at pits.

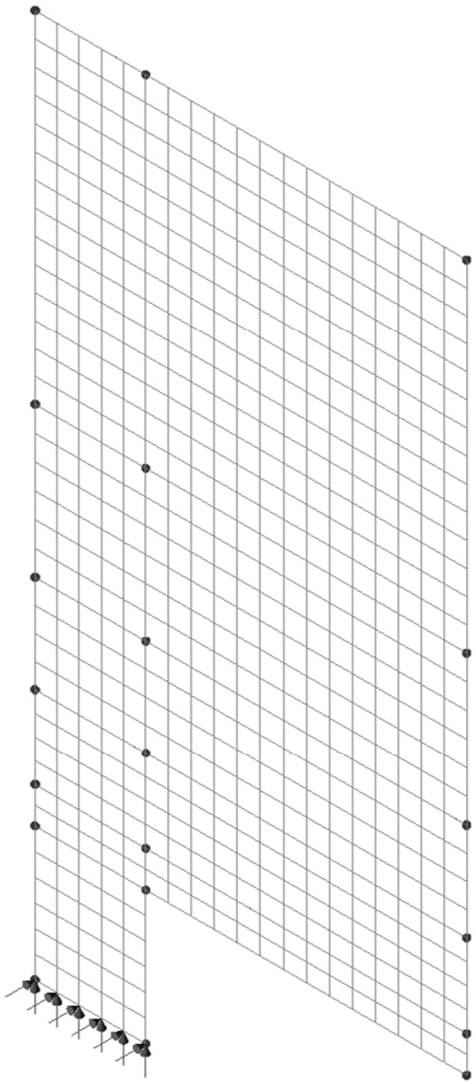




2.5.2.6 Boundary at foundation of wall 2 : “Line support – wall 2 : Free”

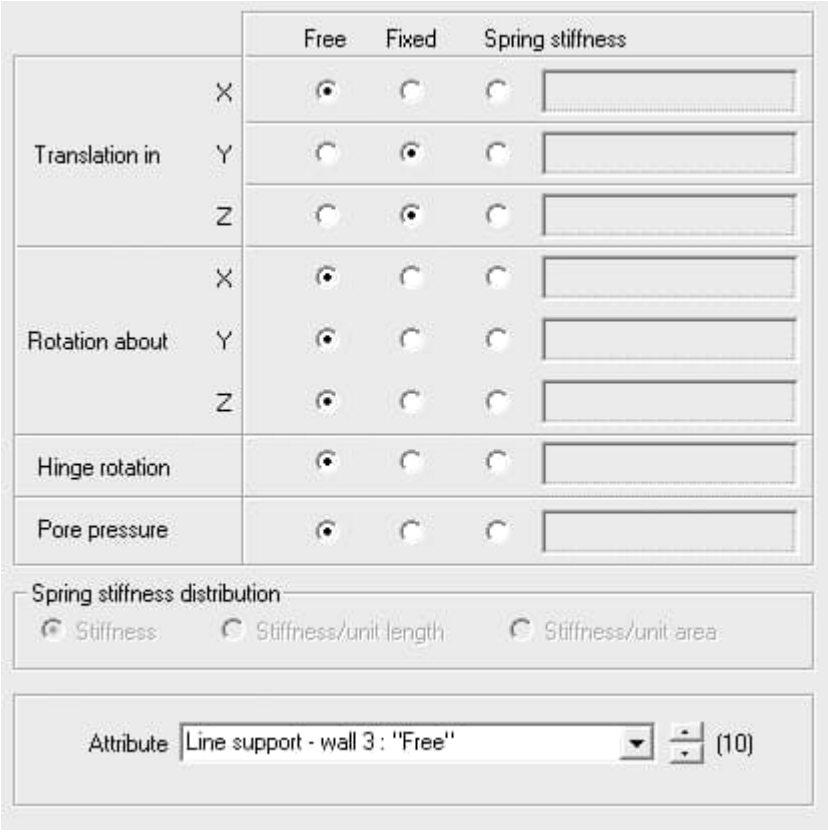
Simulates horizontal boundary conditions at pits.





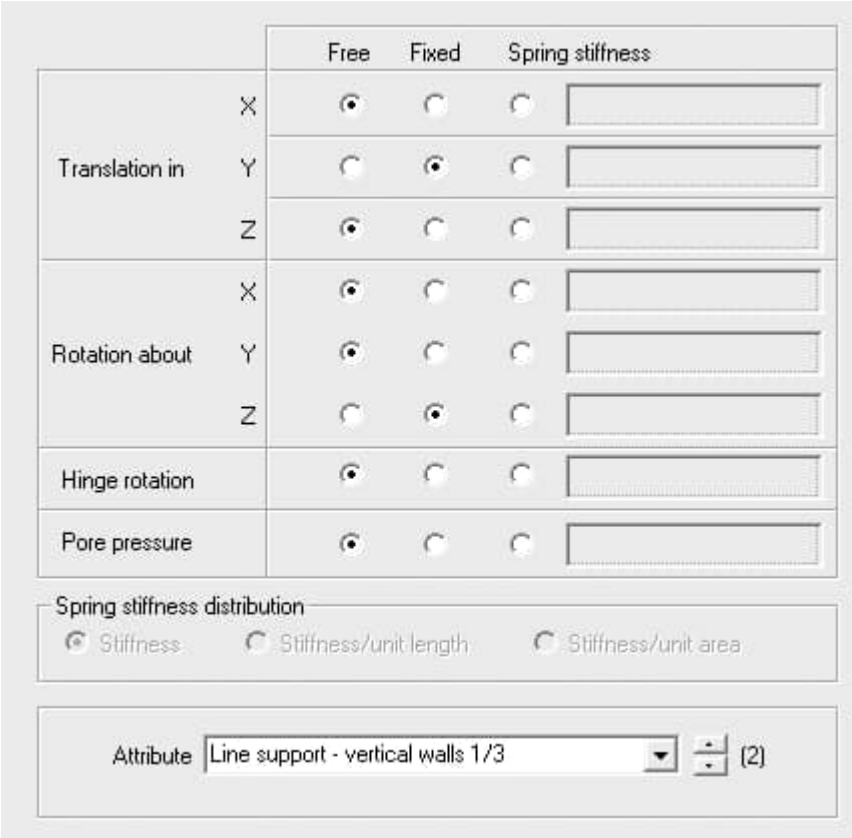
2.5.2.7 Boundary at foundation of wall 2 : “Line support – wall 2 : Free”

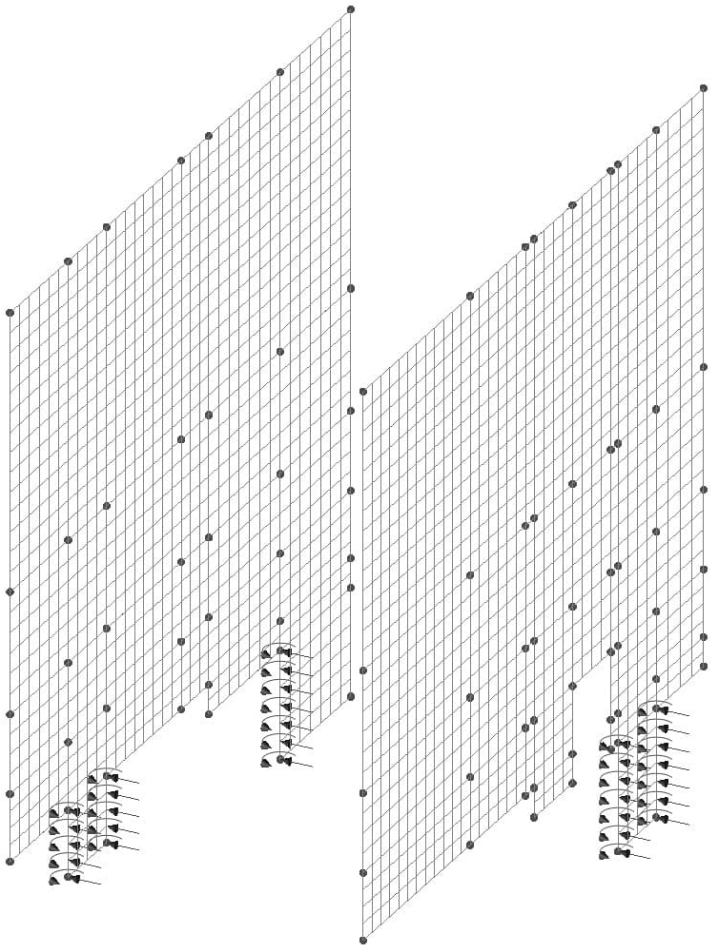
Simulates horizontal boundary conditions at pits.



2.5.2.8 Boundary at foundation of wall 1/3 : “Line support vertical 1/3”

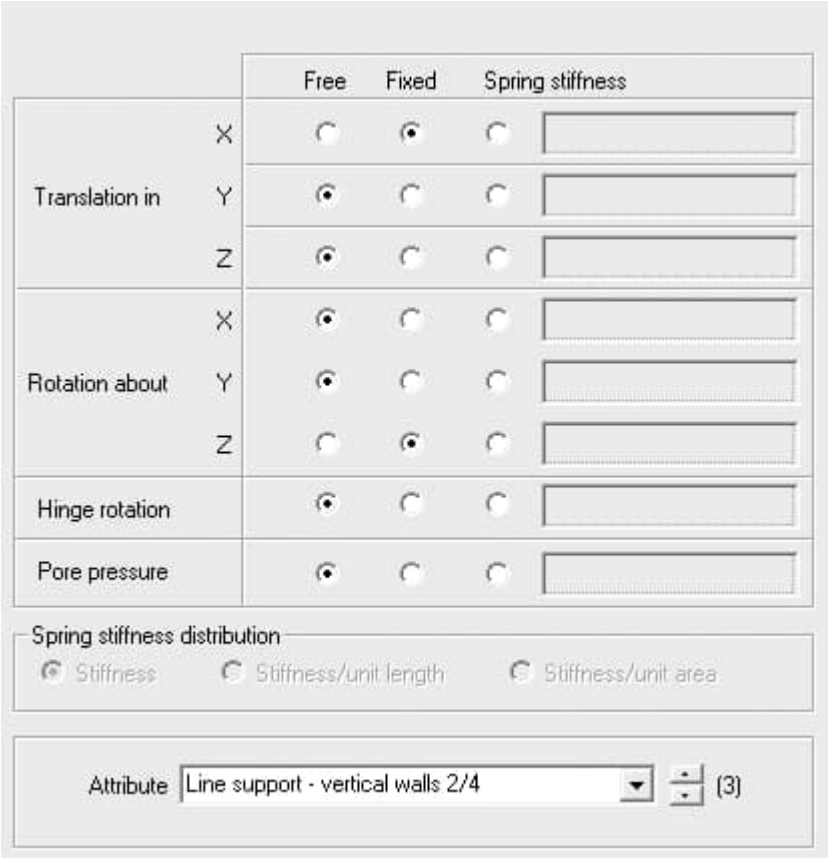
Simulates horizontal boundary conditions at pits.

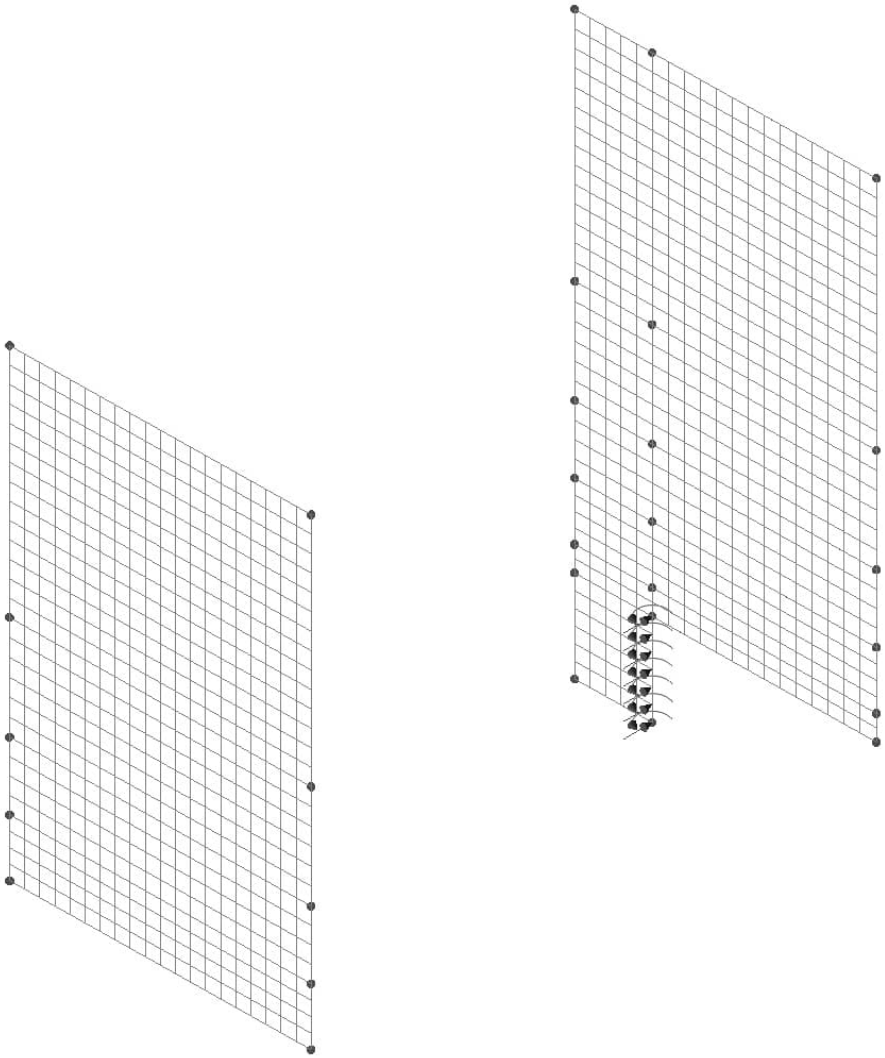




2.5.2.9 Boundary at foundation of wall 2/4 : “Line support vertical 2/4”

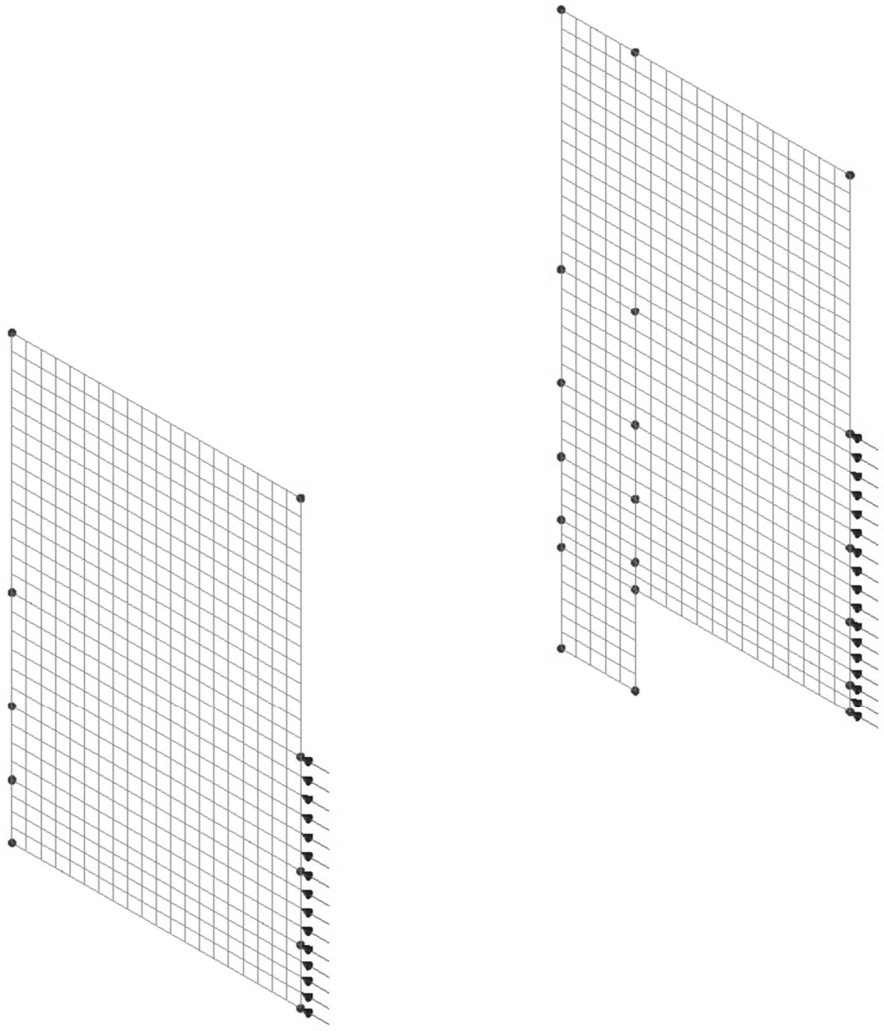
Simulates horizontal boundary conditions at pits.





2.5.2.10 Boundary at foundation of wall 2/4 : “Line support horizontal 2/4”

Simulates edge beams acting between level +67.0 and to +81.0 along base line1 and base line 4.

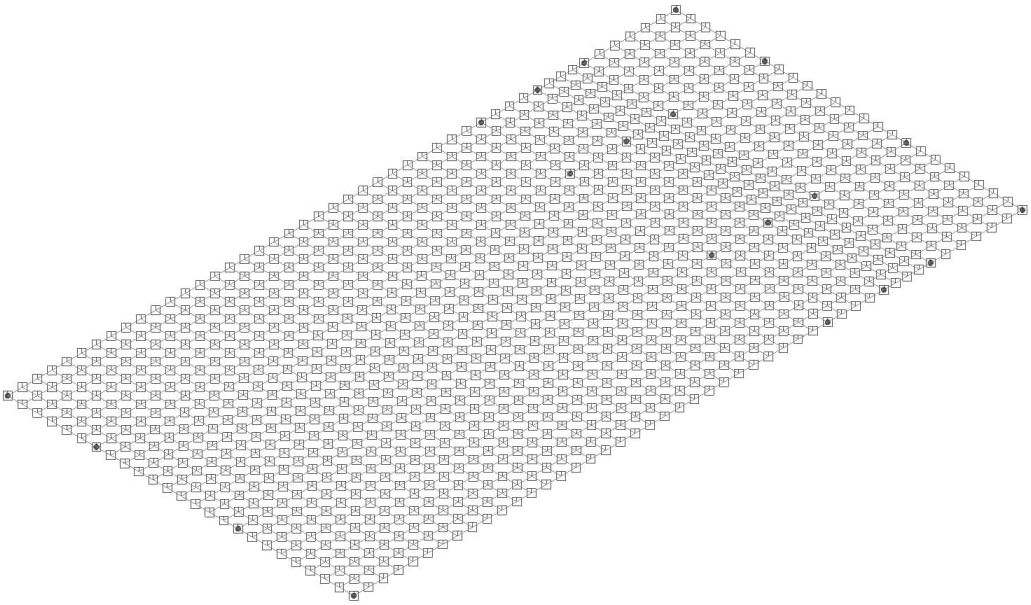


2.6 SEARCH AREA

Discrete loads are applied to various load areas. These are termed *Search Area*.

2.6.1 Model : Part I (Bottom slab)

For the analysis 1 *Search Area´*s are defined consisting om structural elements.

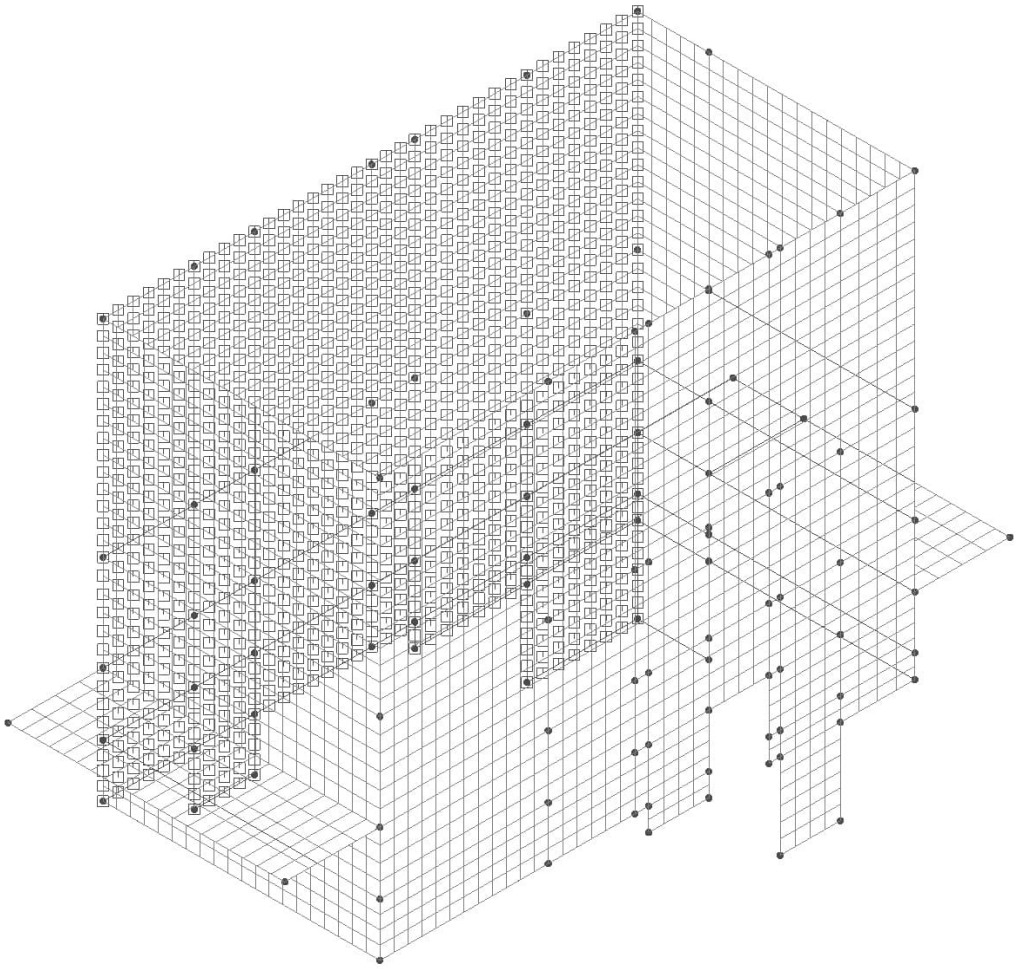


2.6.2 Model : Part II (Walls)

For the analysis 4 *Search Area´*s are defined consisting om structural elements.

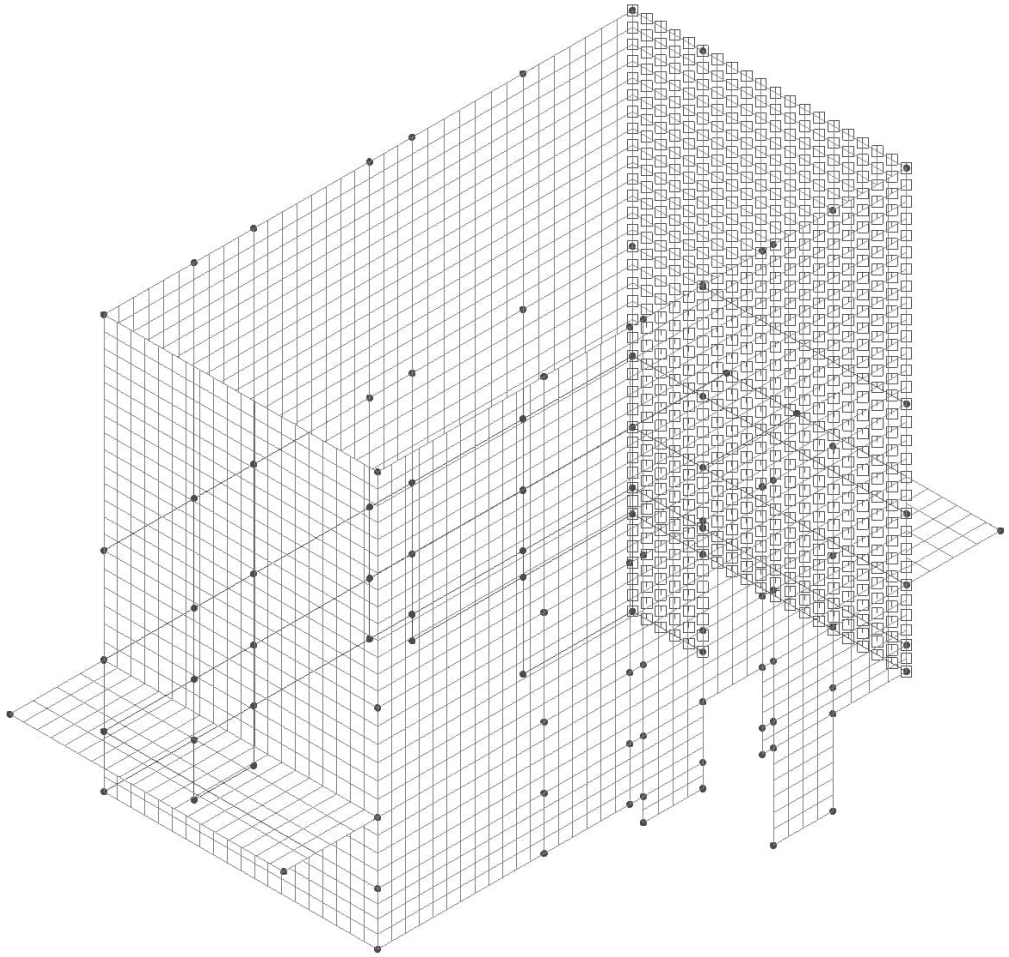
2.6.2.1 *Search* area : *Wall 1*

Structural elements : Wall 1



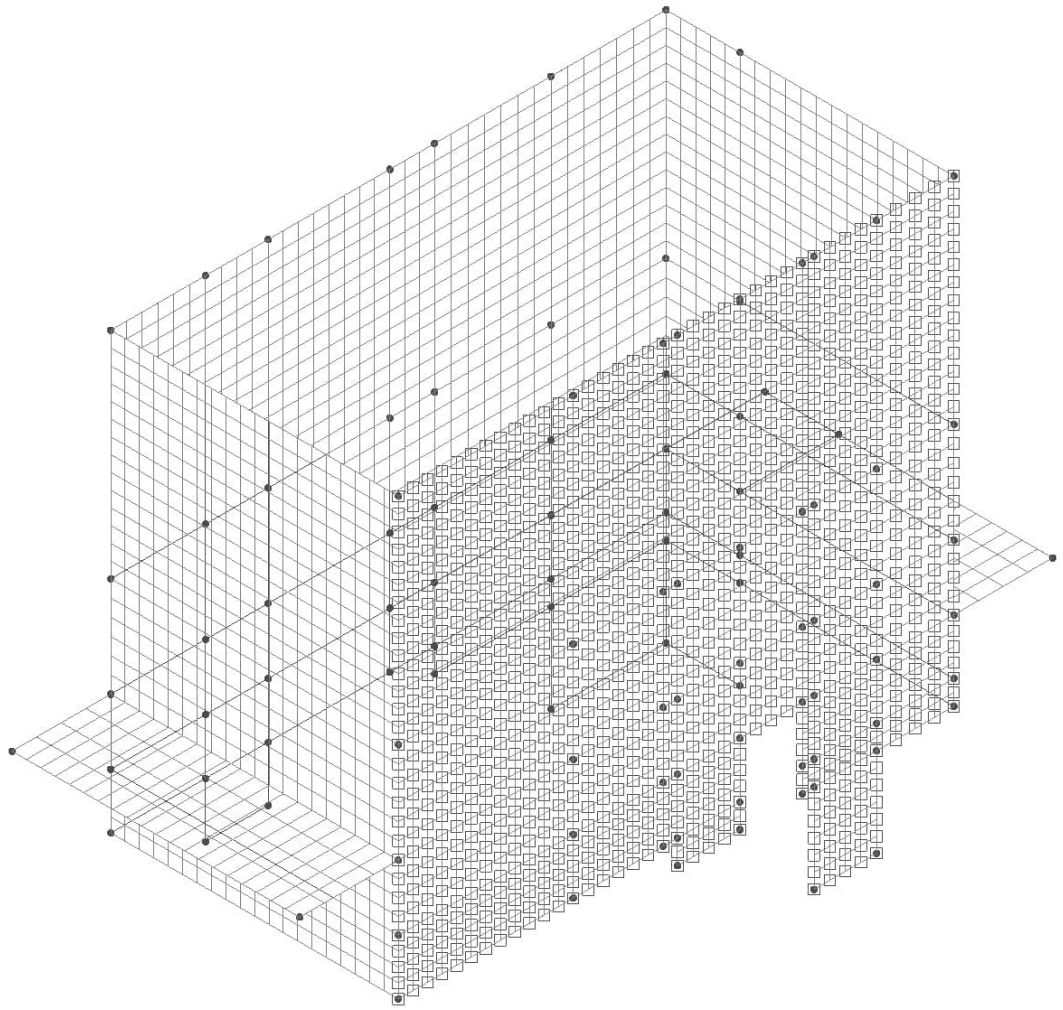
2.6.2.2 *Search* area : *Wall 2*

Structural elements : Wall 2



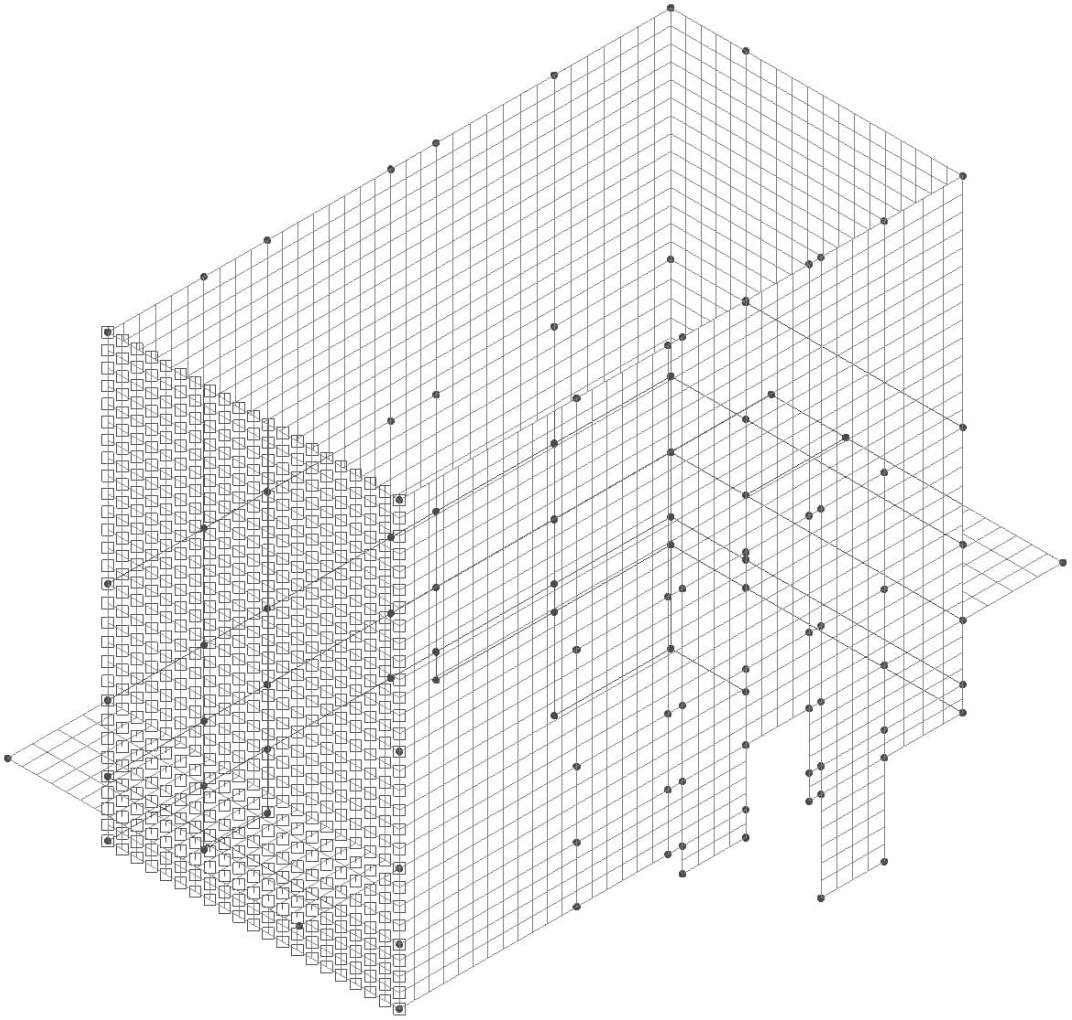
2.6.2.3 *Search* area : *Wall 3*

Structural elements : Wall 3



2.6.2.4 *Search* area : *Wall 4*

Structural elements : Wall 4



3. LOADS

Remark This section describes load effect of Model: Part II (Walls).

Loads applied to Model :Part I (Slab) consists of ground pressure and is described separately in chapter C.

3.1 DEAD WEIGHT (DC)

3.1.1 Reinforced concrete (DC 1)

$\gamma_c = 24 \ \frac{kN}{m^3}$

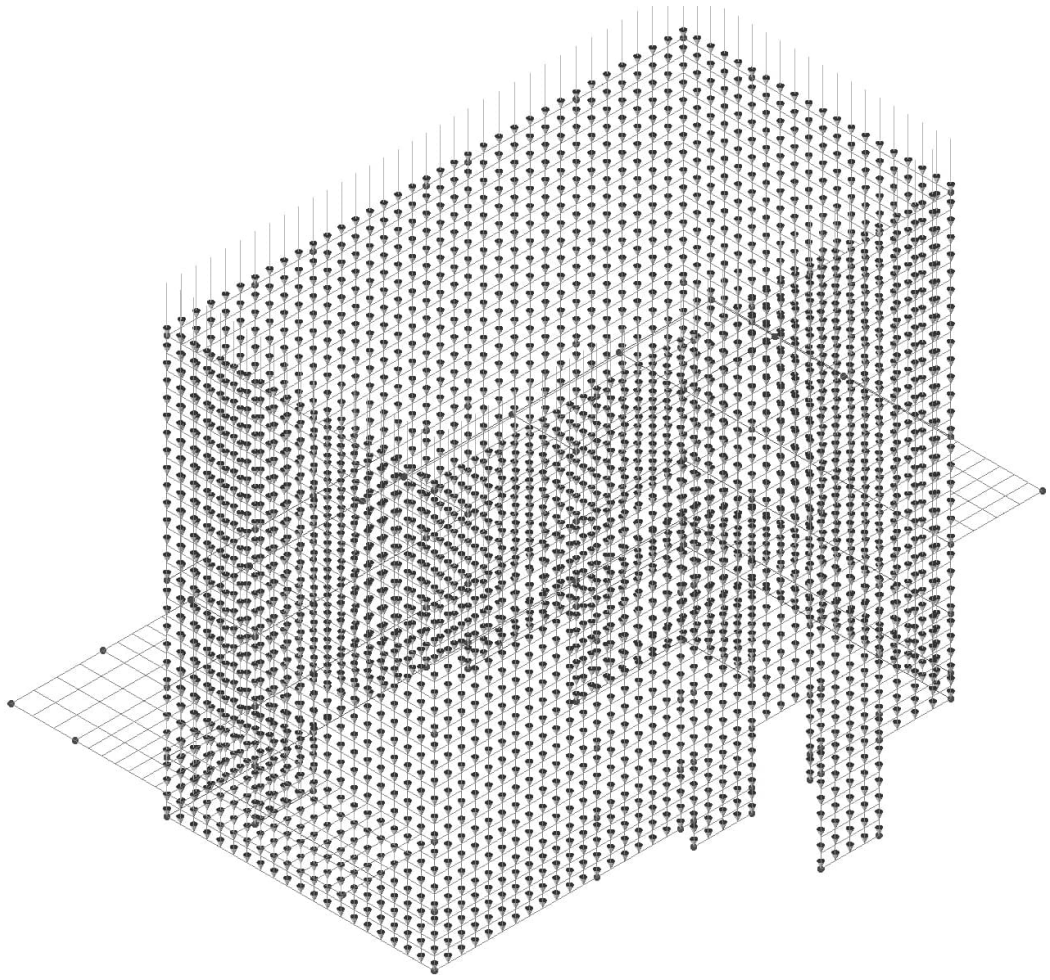
Loadcase : DC 1

Structural loading : Body force

Acceleration in z direction (a_z) : -10 $\frac{m}{s^2}$

Component	Value
Linear acceleration in X	0,0
Linear acceleration in Y	0,0
Linear acceleration in Z	-10,0
Angular velocity about X axis	0,0
Angular velocity about Y axis	0,0
Angular velocity about Z axis	0,0
Angular acceleration about X axis	0,0
Angular acceleration about Y axis	0,0
Angular acceleration about Z axis	0,0

Attribute DC 1 (3)



Shell elements : $q = a_z \cdot t \cdot \rho_c$

Remark Load intensity is found by applying density and geometric properties to all SURFACES. Load on slabs at level +77.0 is not included.

3.1.2 Roof structure (DC 2)

The loadcase includes roof (equivalent load 1 kPa) and upper wall (level > 90.11).

The load intensity of roof is distributed along concrete walls at level +90.11.

Roof :

$A_{roof} = 23.7m \cdot 13.0m = 310m^2$: area of roof

$P_{roof.1} = 310m^2 \cdot 1kPa = 308kN$

Upper wall :

$l_{wall} = 2 \cdot (23.7m + 13.0m) = 73m$: length of upper wall

$t_{wall} = 0.3m$: thickness of upper wall

$h_{wall} = 1.5m$: height of upper wall

$P_{roof.2} = 73m \cdot 0.3m \cdot 1.5m \cdot 24\frac{kN}{m^3} = 790kN$

Total :

$P_{roof} = 310kN + 790kN = 1100kN$

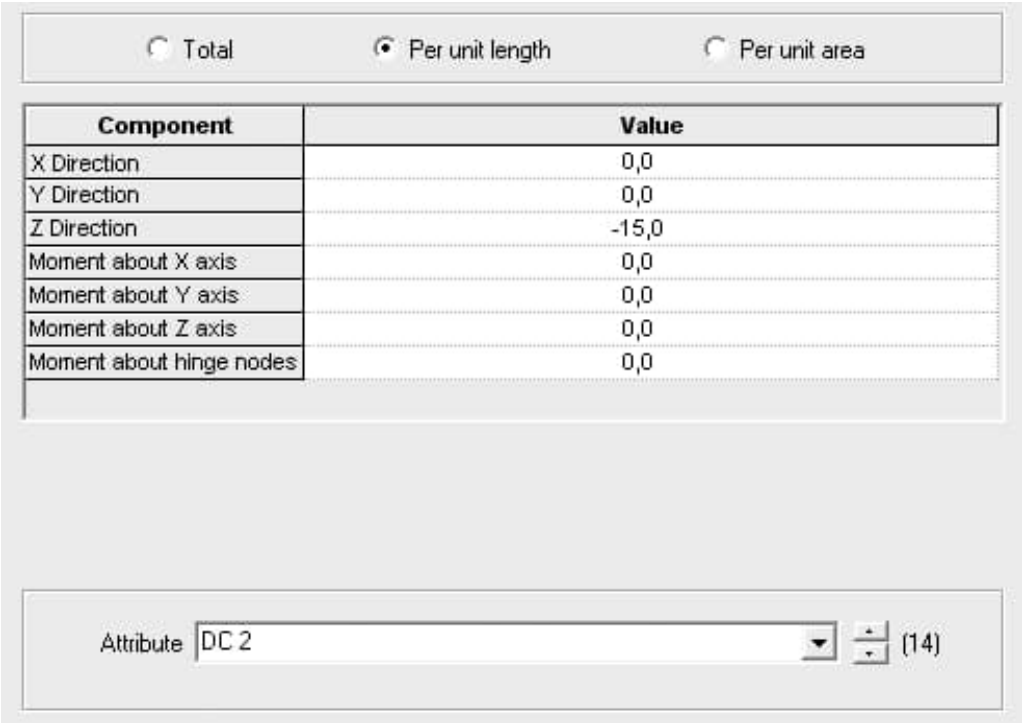
$p_{roof} = \frac{P_{roof}}{l_{wall}} = \frac{1100kN}{73m} = 15\frac{kN}{m}$

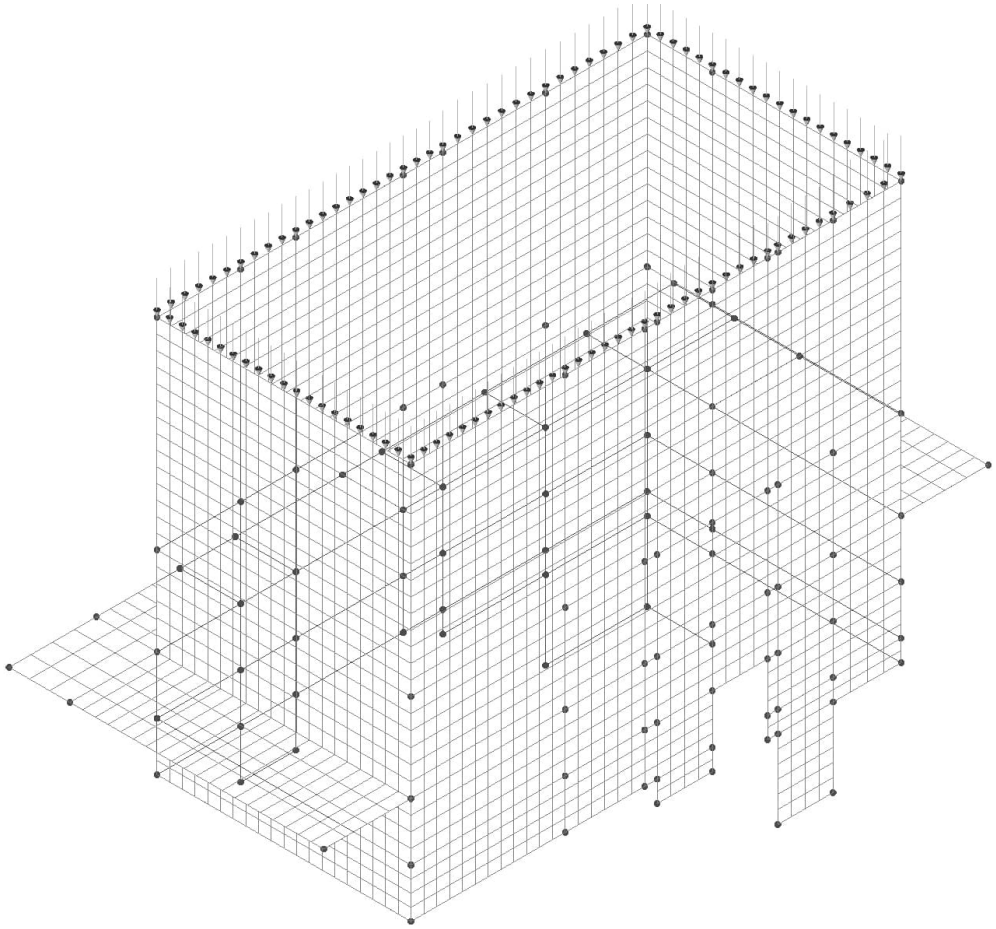
Loadcase : DC 2

Structural loading : Global distributed

Force type : Per unit length

Component z direction : -15 $\frac{kN}{m}$





3.1.3 Earth filling

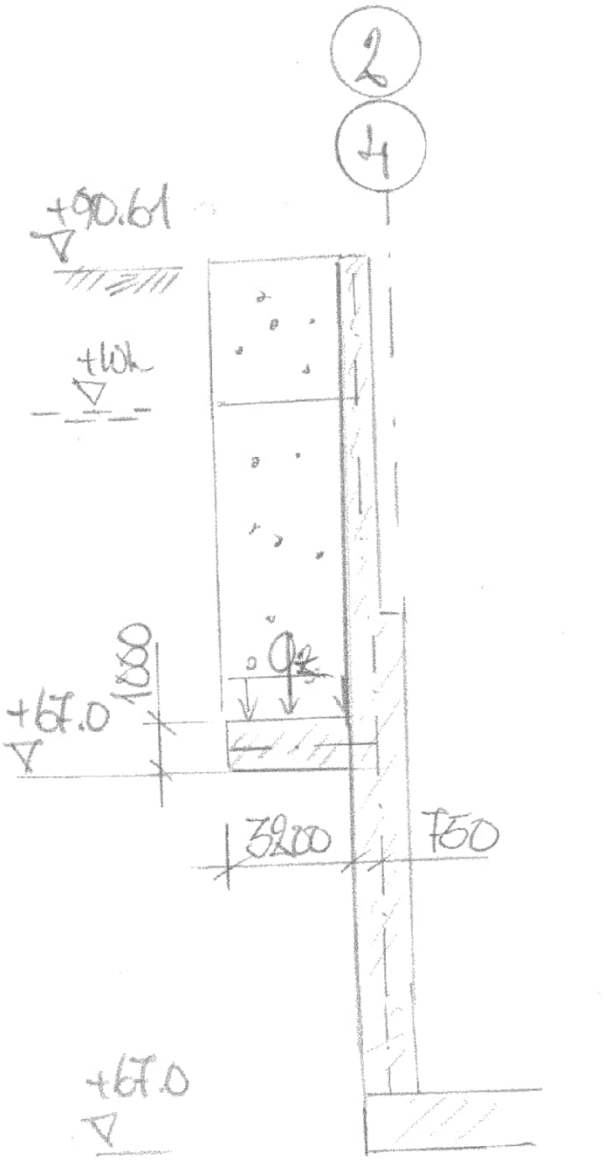
Load is introduced at level +77.50 due the effect of horizontal slab along base line 2, 4 and A. The effect of these parts is studied at levels H0, H1, H2 and H3.

Densities :

$\gamma_e = 18 \frac{kN}{m^3}$; $\gamma'_e = 11 \frac{kN}{m^3}$ - Earth filling

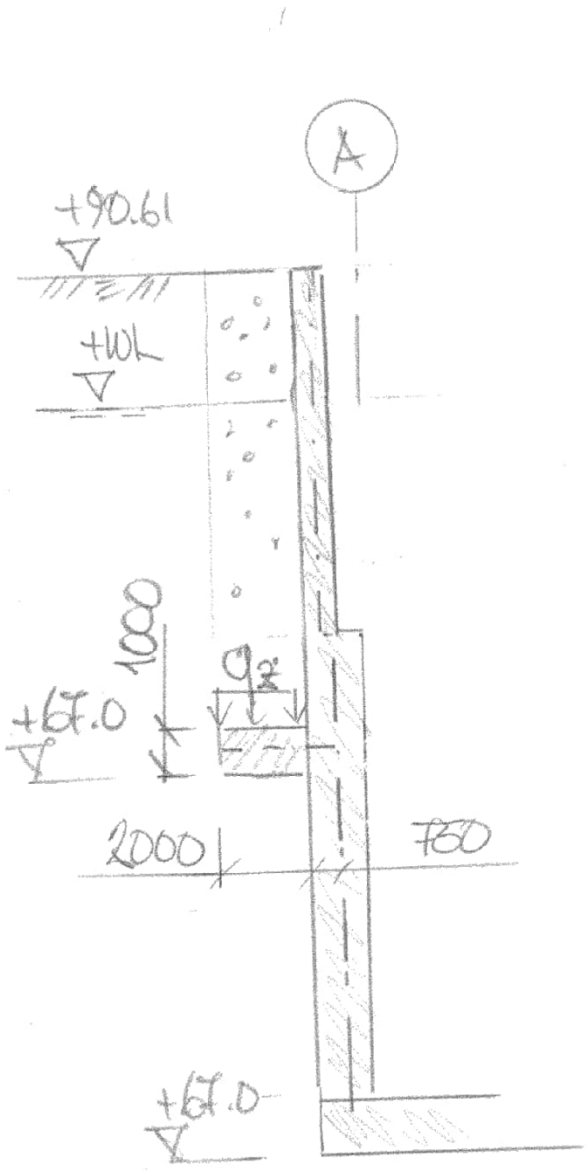
$\gamma_c = 24 \frac{kN}{m^3}$; $\gamma'_c = 14 \frac{kN}{m^3}$ - Concrete

Load on wall 2:2 and 4:2 :



Fictious loadarea : $A'_{tot} = (3.2m + 0.75m) \cdot 11.5m = 45.4m^2$

Load on wall 1:4 :



Fictious loadarea : $A'_{tot} = (2.0m + 0.75m) \cdot 30.1m = 82.8m^2$

3.1.3.1 Water level H0

Water level H0 : WL = +67.0

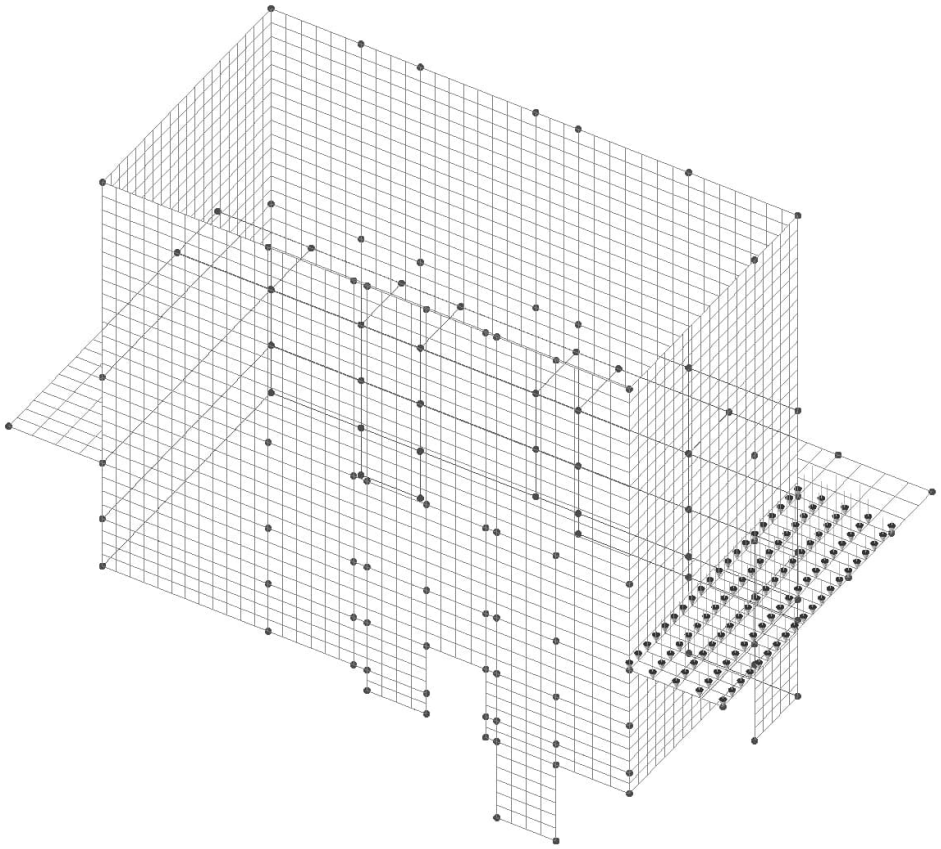
Load on Wall 2:2 (Load case DC 3_1 – H0)

- Concrete : $P_{wall} = \gamma_c \cdot b \cdot l = 24\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 883kN$

- Earth filling : $P_{earth} = (90.61m - 78.00m) \cdot 18\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m = 8352kN$

$$\Rightarrow \qquad P_{total} = 9236kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{9236kN}{45.4m^2} = 203kPa$$

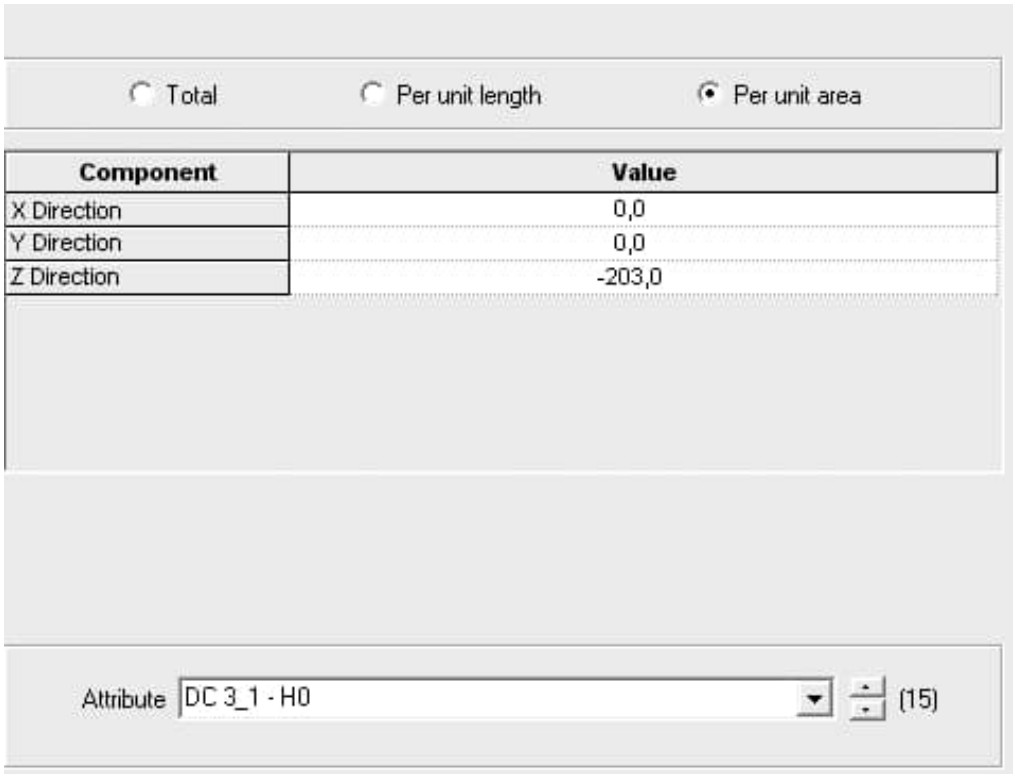


Loadcase : DC 3_1 – H0

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -203 $\frac{kN}{m^2}$


Total
Per unit length
Per unit area
Component
Value
X Direction
0,0
Y Direction
0,0
Z Direction
-203,0
Attribute
DC 3_1 - H0
(15)

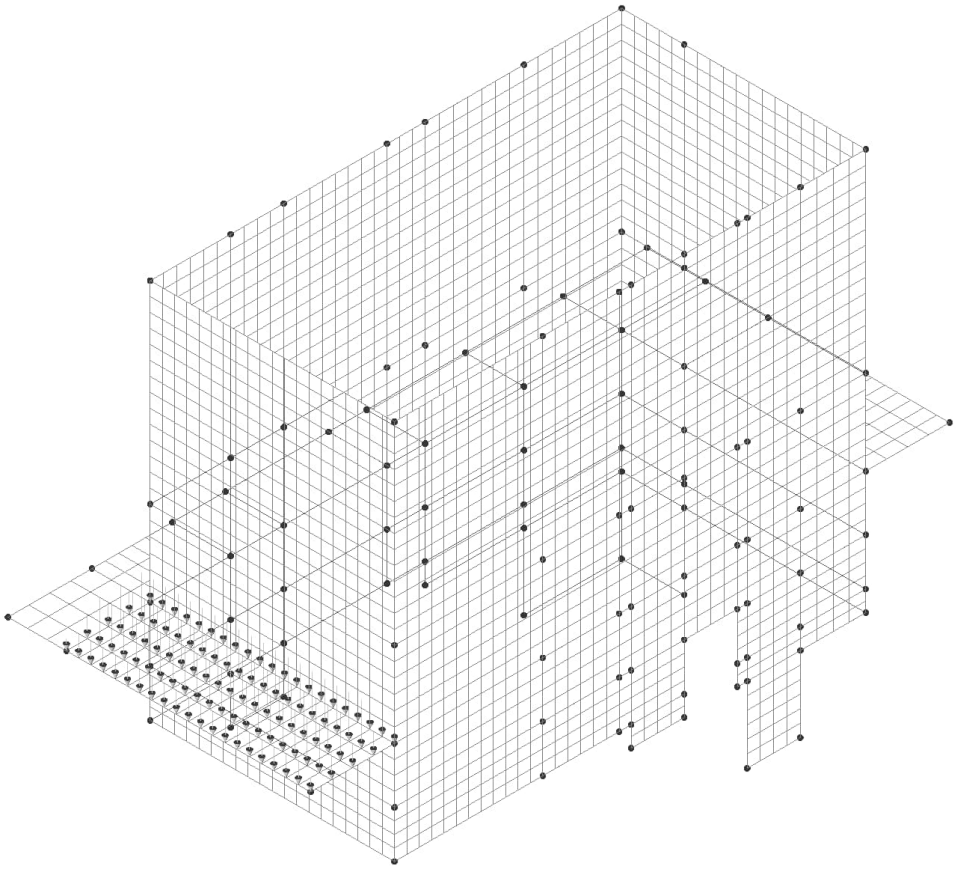
Load on Wall 4:2 (Load case DC 3_2 – H0)

• Concrete : $P_{wall} = \gamma_c \cdot b \cdot l = 24\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 883kN$

• Earth filling : $P_{earth} = (90.61m - 78.00m) \cdot 18\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m = 8352kN$

$$\Rightarrow \qquad P_{total} = 9236kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{9236kN}{45.4m^2} = 203kPa$$

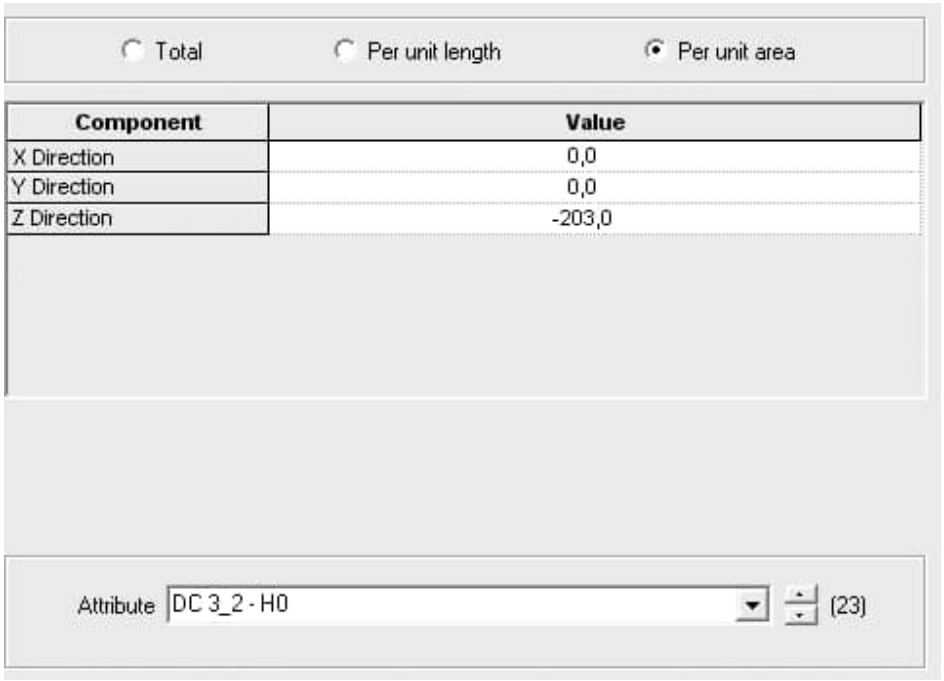


Loadcase : DC 3_2 – H0

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -203 $\frac{kN}{m^2}$



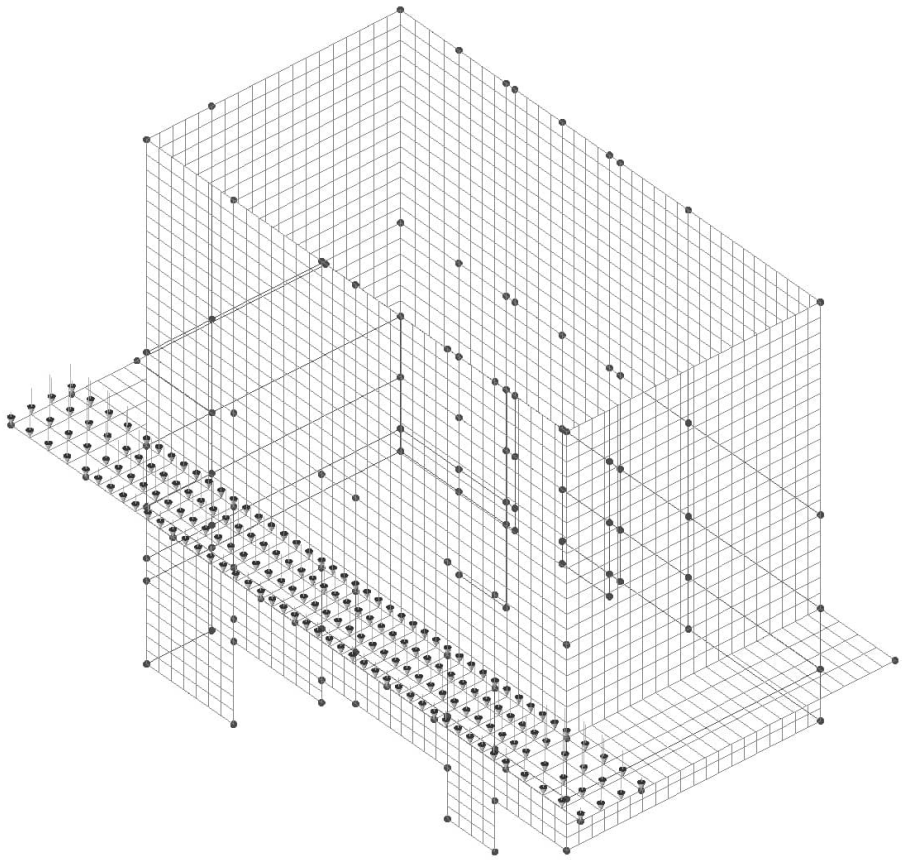
Load on Wall 1:4 (Load case DC 3_3 – H0)

- Concrete : $P_{wall} = \gamma_c \cdot b \cdot l = 24\frac{kN}{m^3} \cdot 2.0m \cdot 30.1m \cdot 1.0m = 1448kN$

- Earth filling : $P_{earth} = (90.61m - 78.00m) \cdot 18\frac{kN}{m^3} \cdot 2.0m \cdot 30.1m = 13364kN$

$$\Rightarrow \qquad P_{total} = 14812kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{14812kN}{82.8m^2} = 178kPa$$

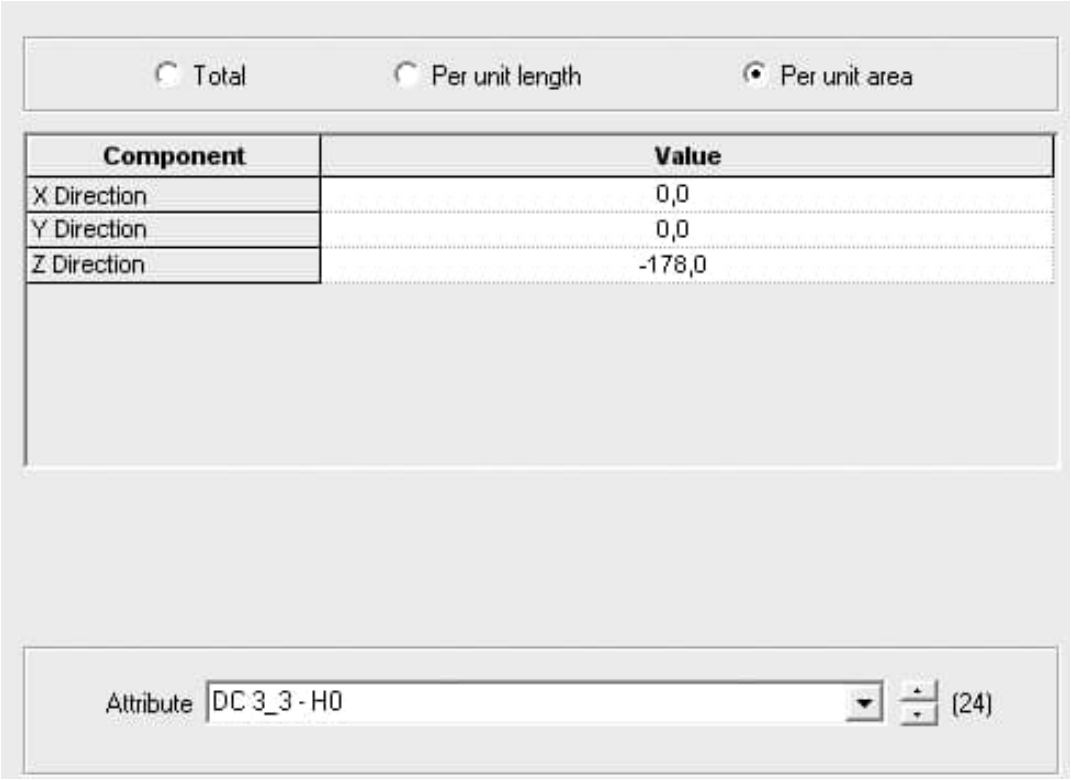


Loadcase : DC 3_3 – H0

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -178 $\frac{kN}{m^2}$



3.1.3.2 Water level H1

Water level H1 : WL = +78.65

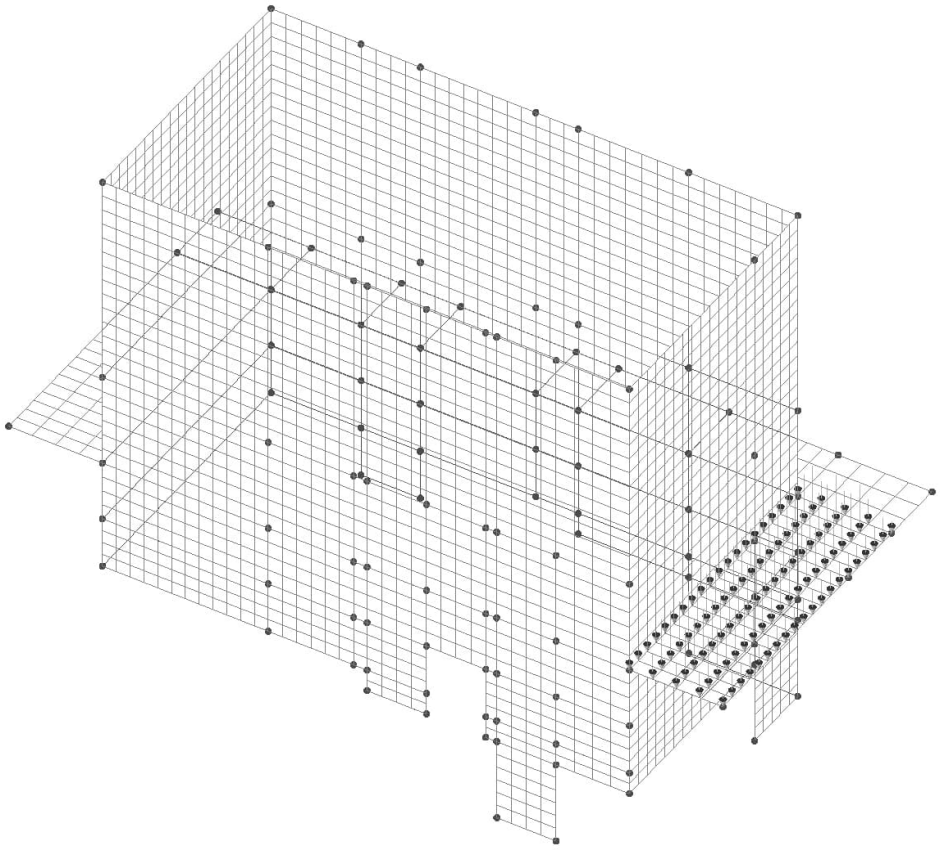
Load on Wall 2:2 (Load case DC 3_1 – H1)

• Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 515kN$

• Earth filling : $P_{earth} = ((90.61m - 78.65m) \cdot 18\frac{kN}{m^3} + (78.65m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 3.2m \cdot 11.5m = 8185kN$

$$\Rightarrow \qquad P_{total} = 9236kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{8700kN}{45.4m^2} = 192kPa$$

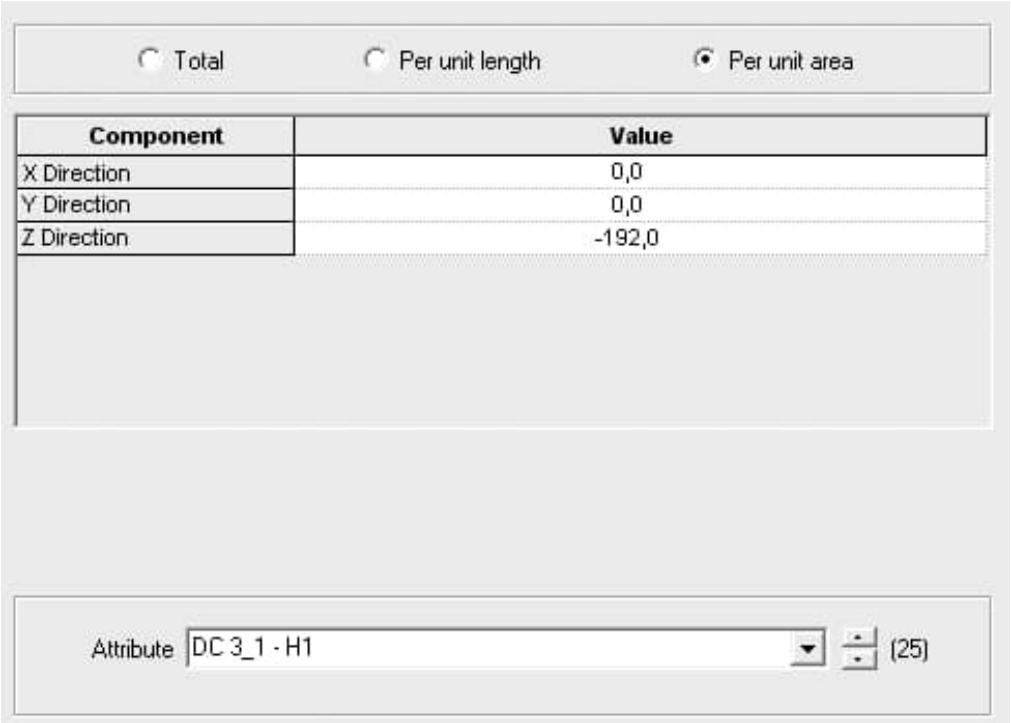


Loadcase : DC 3_1 – H1

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -192 $\frac{kN}{m^2}$


Total
Per unit length
Per unit area
Component
Value
X Direction
0,0
Y Direction
0,0
Z Direction
-192,0
Attribute
DC 3_1 - H1
(25)

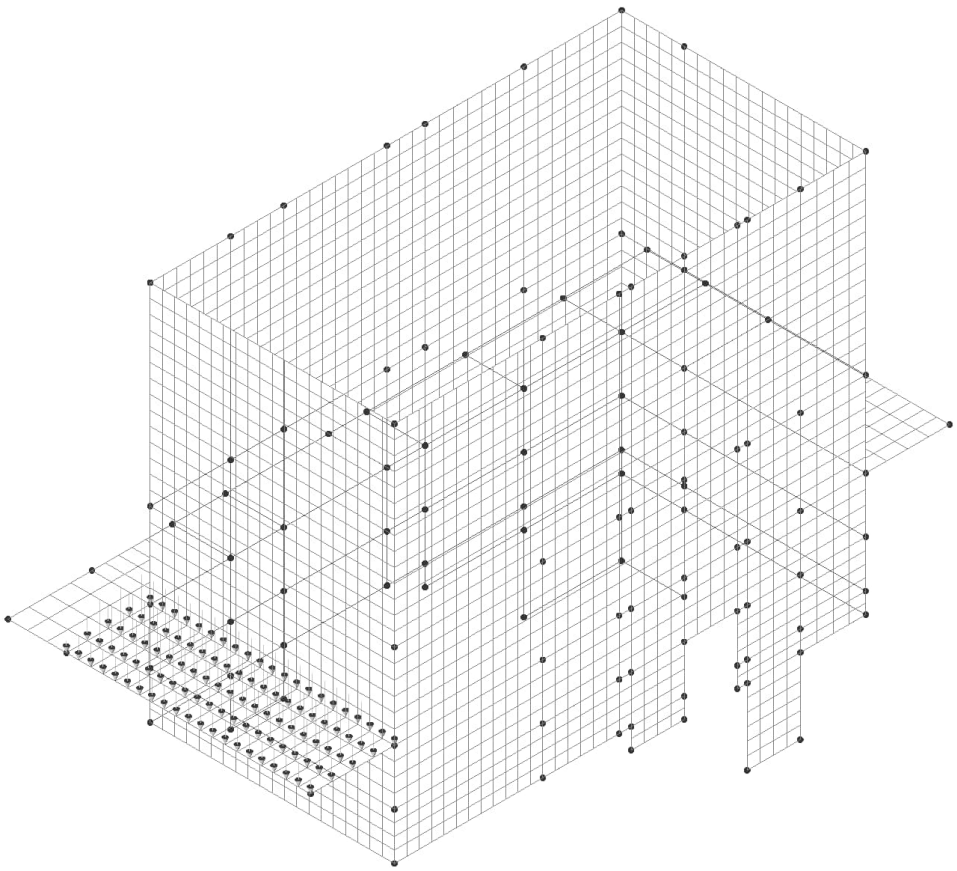
Load on Wall 4:2 (Load case DC 3_2 – H1)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 515kN$

- Earth filling : $P_{earth} = ((90.61m - 78.65m) \cdot 18\frac{kN}{m^3} + (78.65m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 3.2m \cdot 11.5m = 8185kN$

$$\Rightarrow \qquad P_{total} = 9236kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{8700kN}{45.4m^2} = 192kPa$$

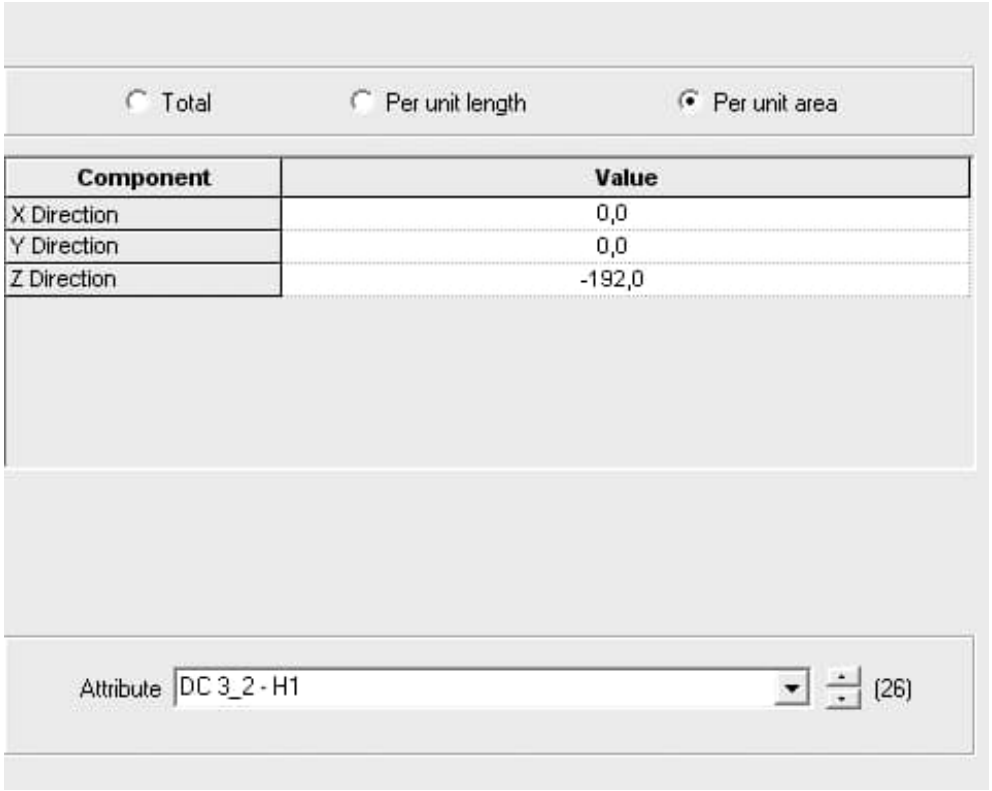


Loadcase : DC 3_2 – H1

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -192 $\frac{kN}{m^2}$



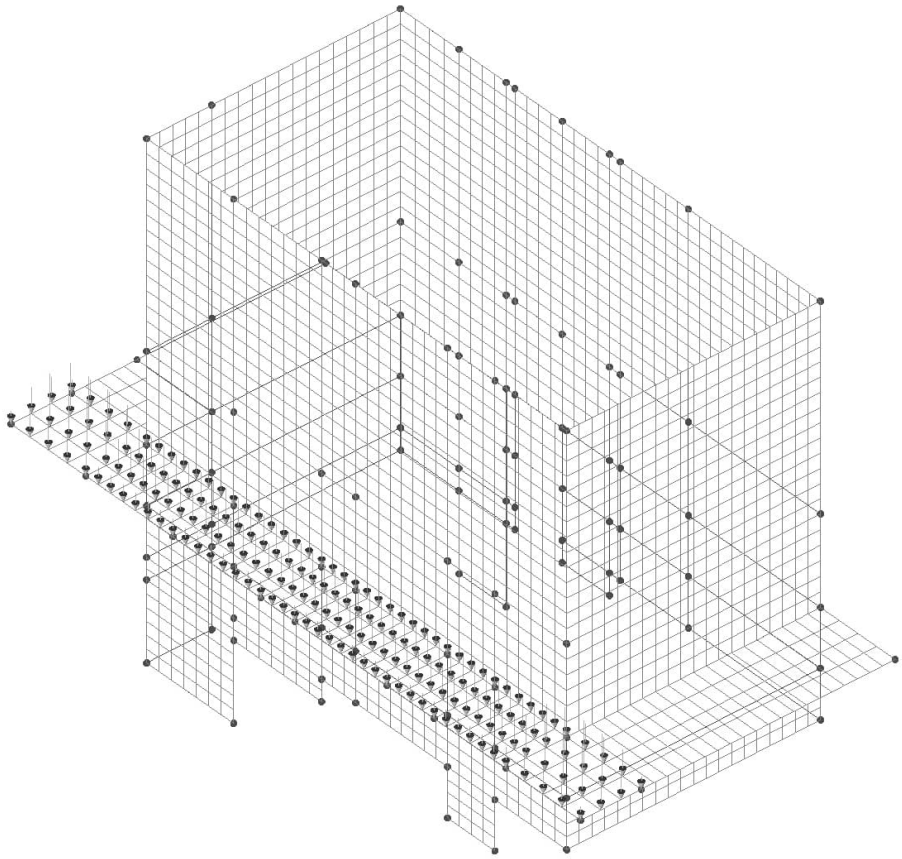
Load on Wall 1:4 (Load case DC 3_3 – H1)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 2.0m \cdot 30.1m \cdot 1.0m = 843kN$

- Earth filling : $P_{earth} = ((90.61m - 78.65m) \cdot 18\frac{kN}{m^3} + (78.65m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 2.0m \cdot 30.1m = 13390kN$

$$\Rightarrow \qquad P_{total} = 14333kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{14333kN}{82.8m^2} = 173kPa$$

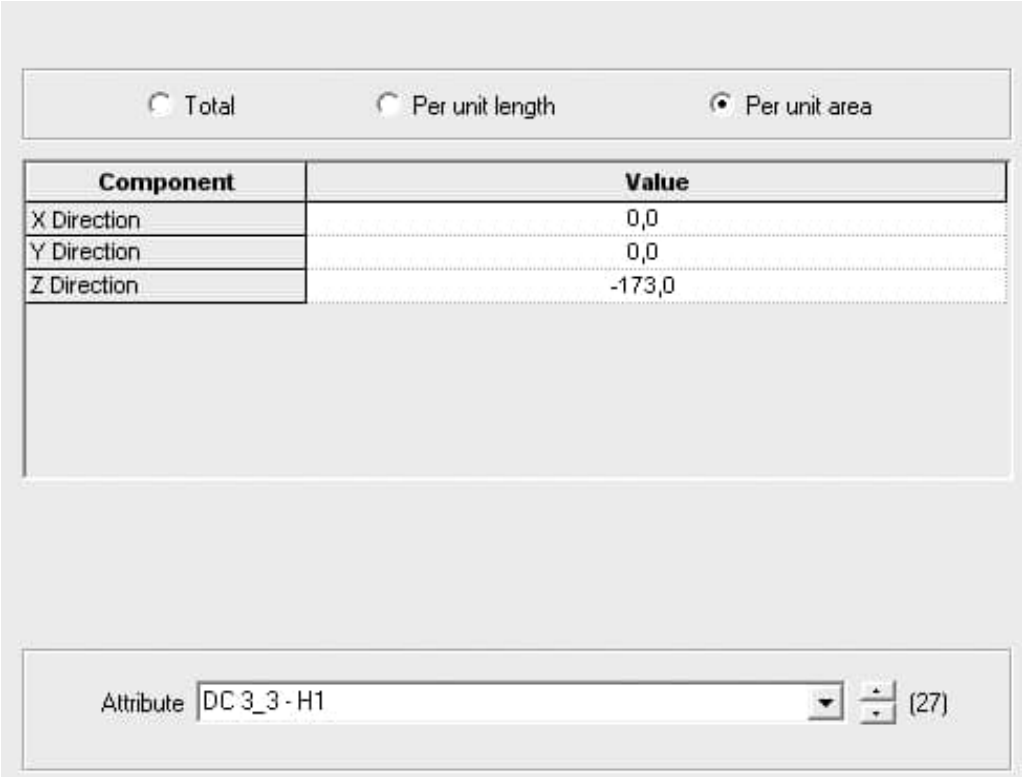


Loadcase : DC 3_3 – H1

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -173 $\frac{kN}{m^2}$



3.1.3.3 Water level H2

Water level H2 : WL = +79.65

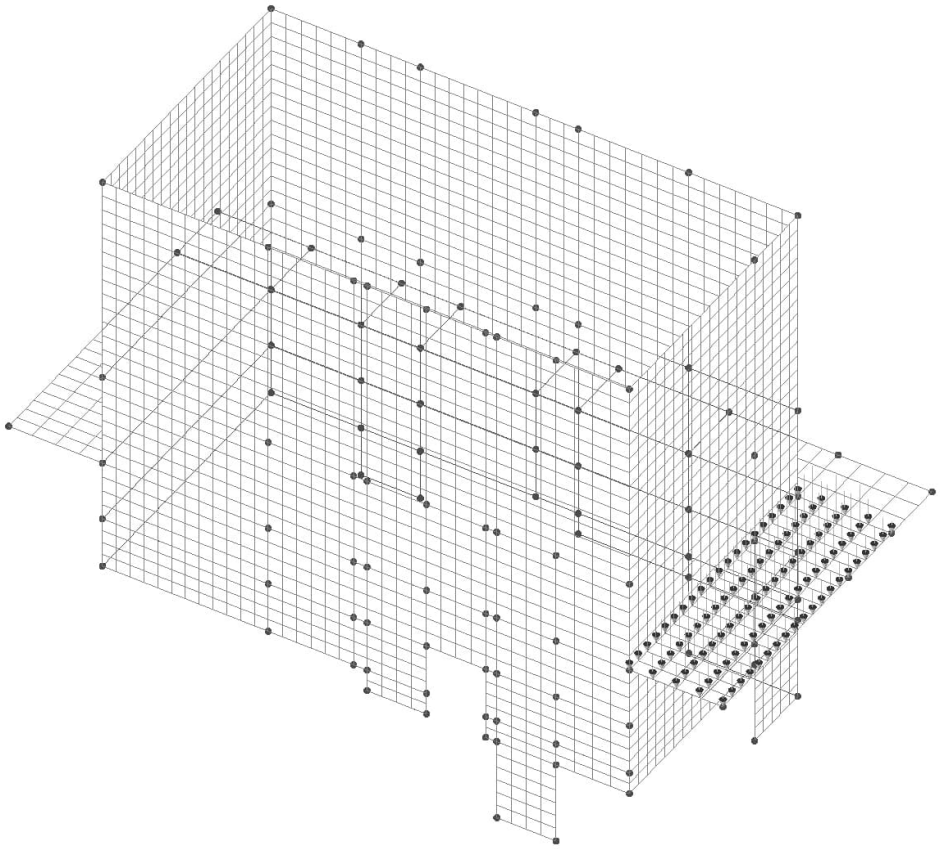
Load on Wall 2:2 (Load case DC 3_1 – H2)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 515kN$

- Earth filling : $P_{earth} = ((90.61m - 79.65m) \cdot 18\frac{kN}{m^3} + (79.65m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 3.2m \cdot 11.5m = 7927kN$

$$\Rightarrow \qquad P_{total} = 8442kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{8442kN}{45.4m^2} = 186kPa$$

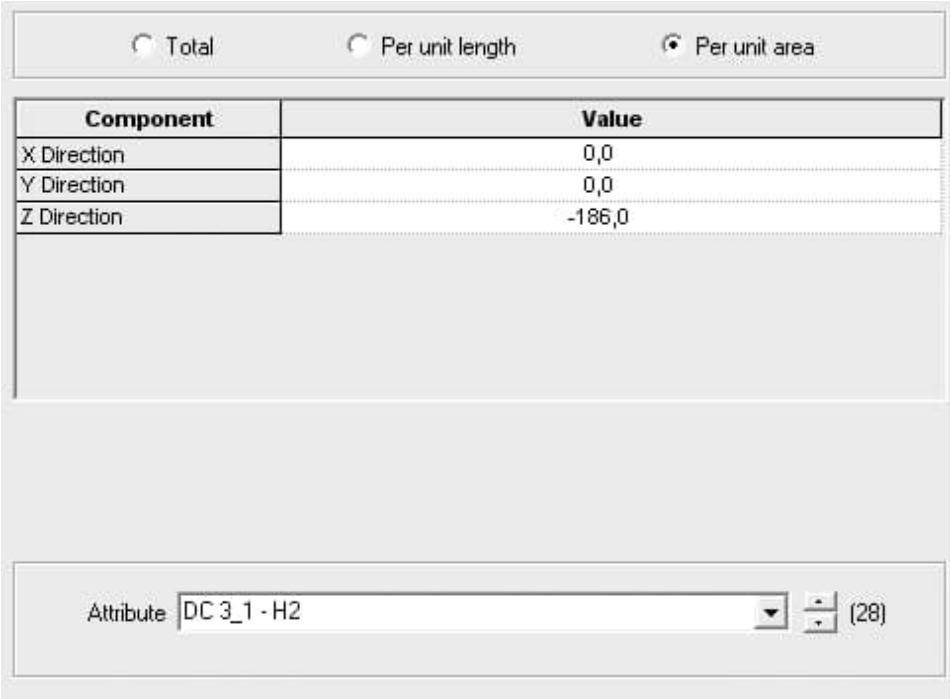


Loadcase : DC 3_1 – H2

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -186 $\frac{kN}{m^2}$


Total
Per unit length
Per unit area
Component
Value
X Direction
0,0
Y Direction
0,0
Z Direction
-186,0
Attribute
DC 3_1 - H2
(28)

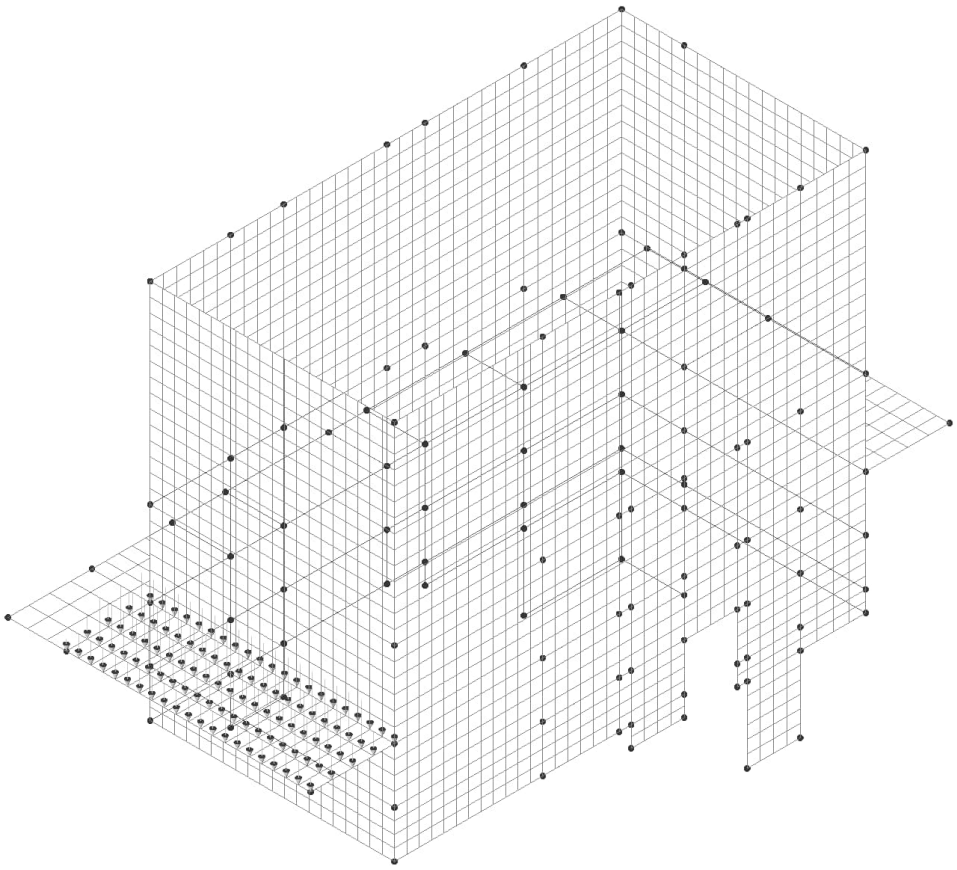
Load on Wall 4:2 (Load case DC 3_2 – H2)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 515kN$

- Earth filling : $P_{earth} = ((90.61m - 79.65m) \cdot 18\frac{kN}{m^3} + (79.65m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 3.2m \cdot 11.5m = 7927kN$

$$\Rightarrow \qquad P_{total} = 8442kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{8442kN}{45.4m^2} = 186kPa$$

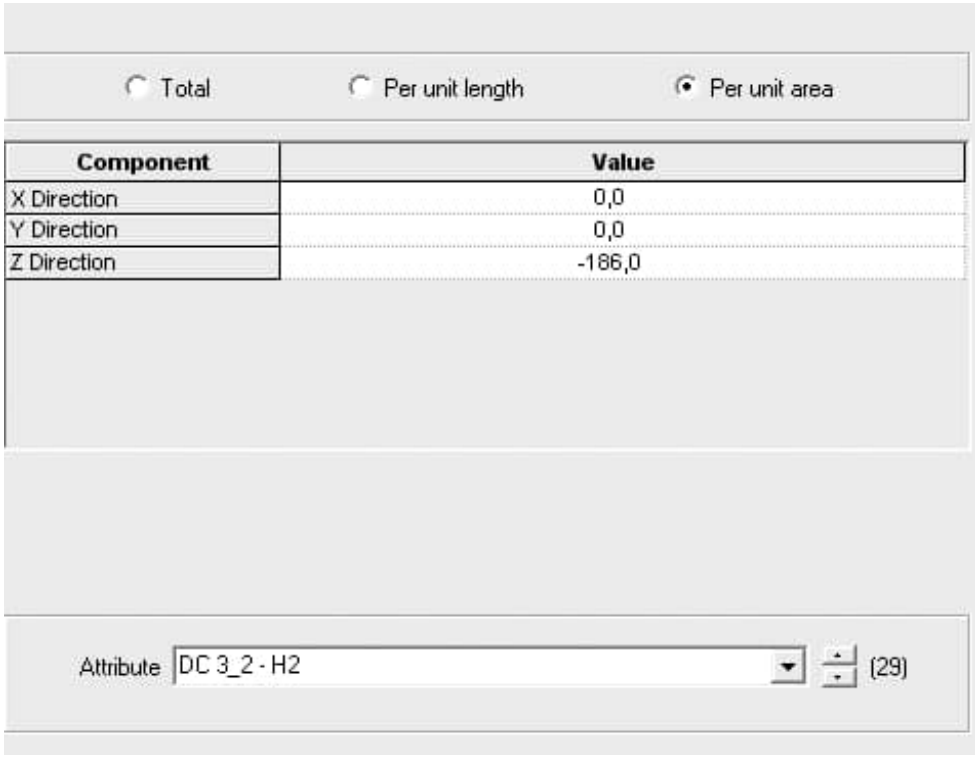


Loadcase : DC 3_2 – H2

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -186 $\frac{kN}{m^2}$



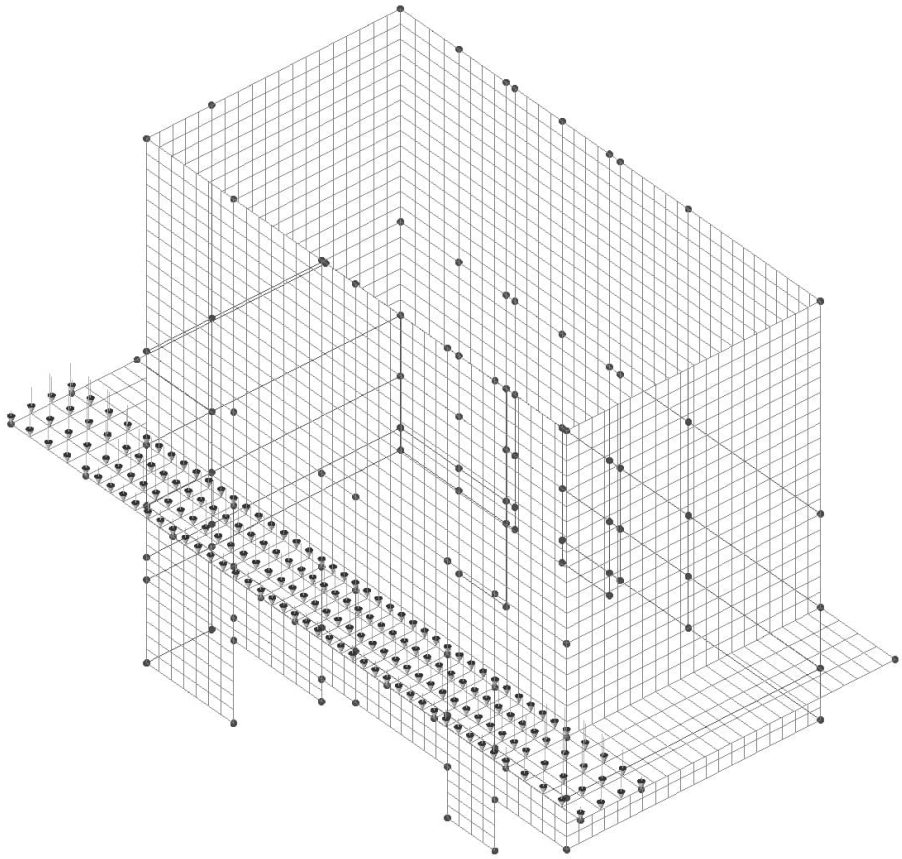
Load on Wall 1:4 (Load case DC 3_3 – H2)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 2.0m \cdot 30.1m \cdot 1.0m = 843kN$

- Earth filling : $P_{earth} = ((90.61m - 79.65m) \cdot 18\frac{kN}{m^3} + (79.65m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 2.0m \cdot 30.1m = 12969kN$

$$\Rightarrow \qquad P_{total} = 13811kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{13811kN}{82.8m^2} = 167kPa$$

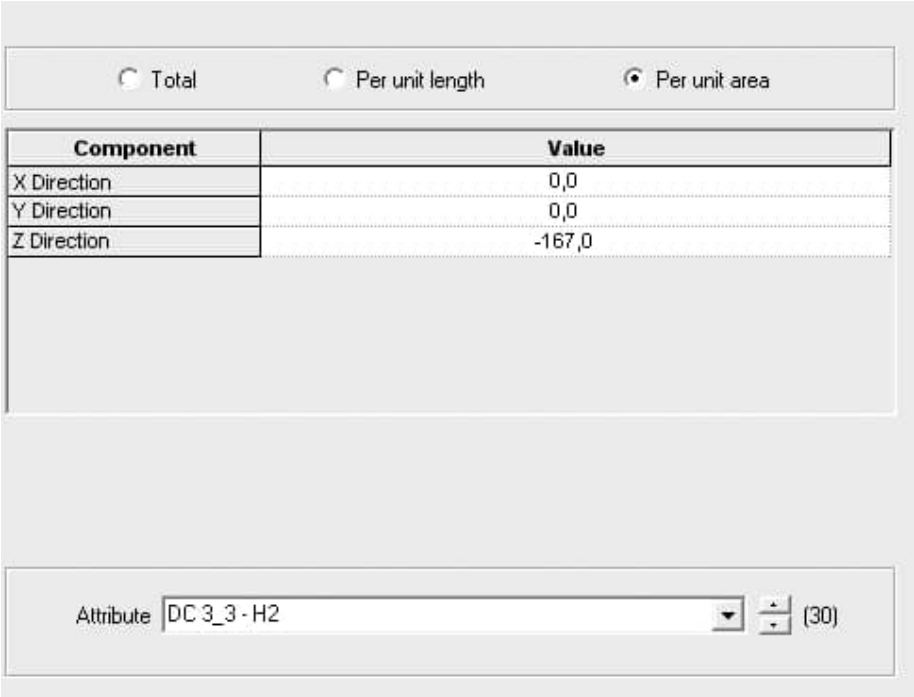


Loadcase : DC 3_3 – H2

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -167 $\frac{kN}{m^2}$



3.1.3.4 Water level H3

Water level H3 : WL = +90.61

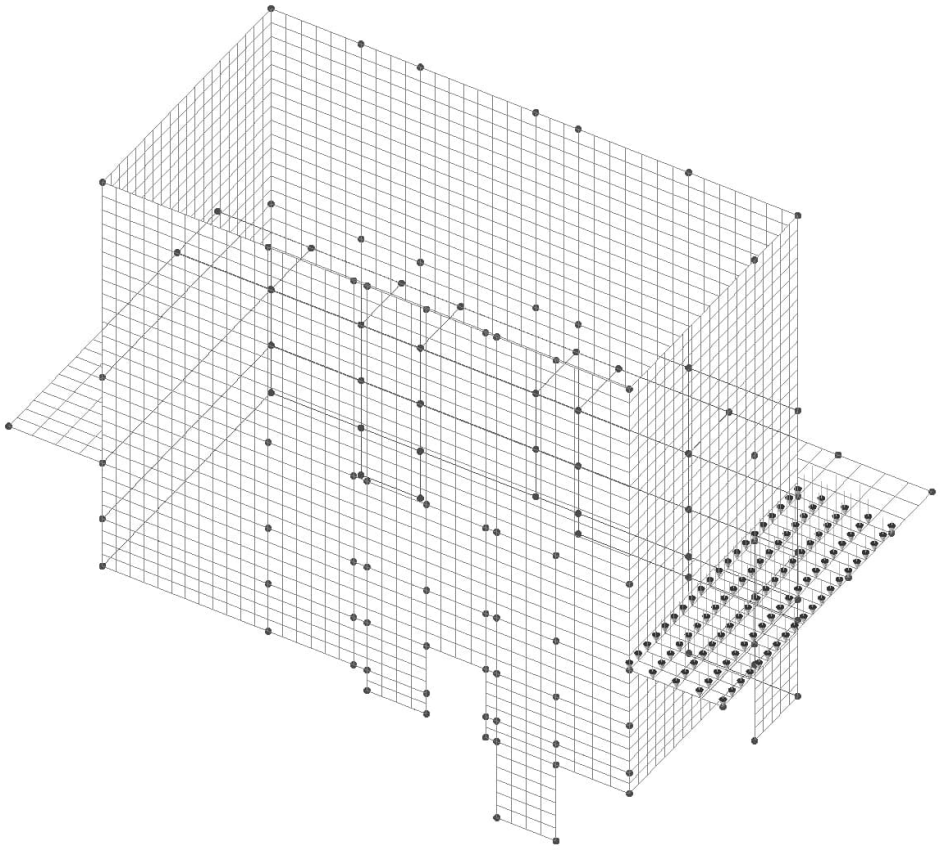
Load on Wall 2:2 (Load case DC 3_1 – H3)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 515kN$

- Earth filling : $P_{earth} = ((90.61m - 90.60m) \cdot 18\frac{kN}{m^3} + (90.60m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 3.2m \cdot 11.5m = 5107kN$

$$\Rightarrow \qquad P_{total} = 5622kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{5662kN}{45.4m^2} = 124kPa$$

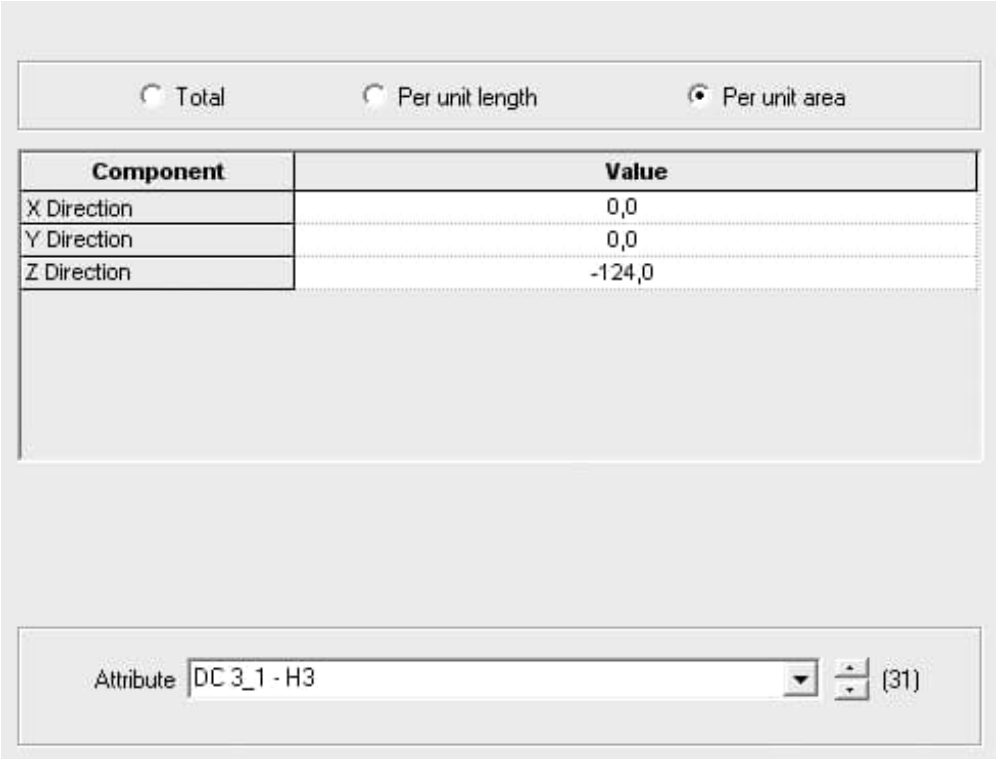


Loadcase : DC 3_1 – H3

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -124 $\frac{kN}{m^2}$


Total
Per unit length
Per unit area
Component
Value
X Direction
0,0
Y Direction
0,0
Z Direction
-124,0
Attribute
DC 3_1 - H3
(31)

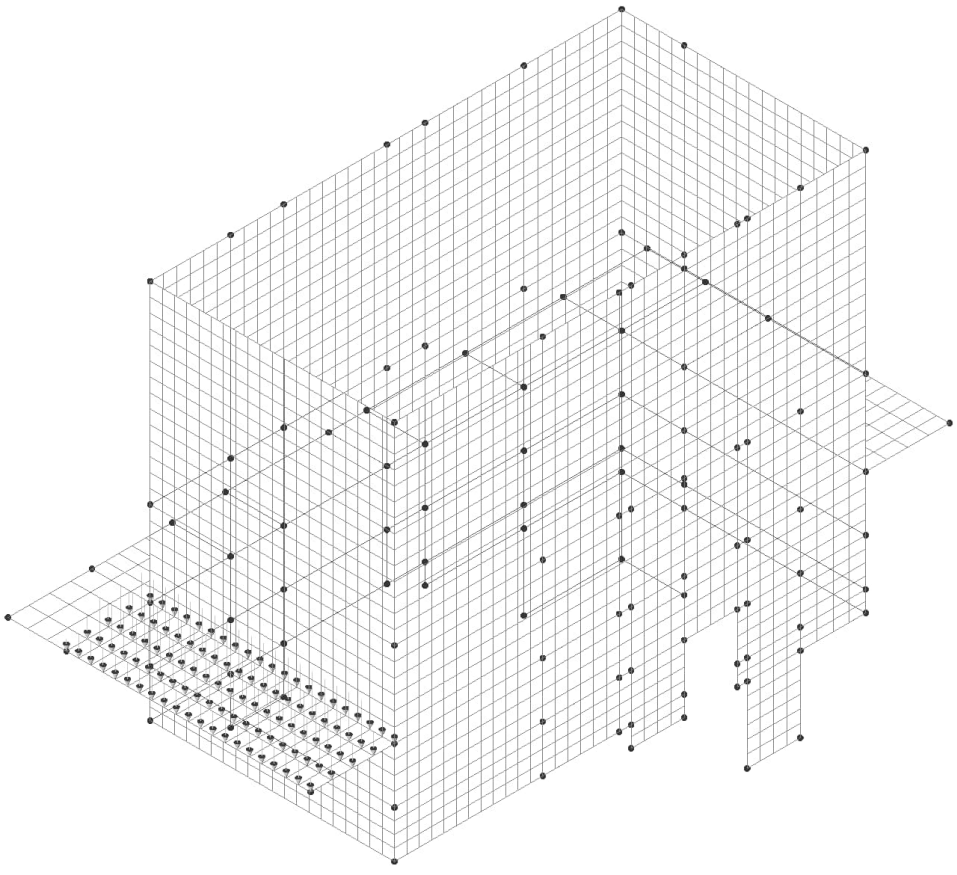
Load on Wall 4:2 (Load case DC 3_2 – H3)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 3.2m \cdot 11.5m \cdot 1.0m = 515kN$

- Earth filling : $P_{earth} = ((90.61m - 90.60m) \cdot 18\frac{kN}{m^3} + (90.60m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 3.2m \cdot 11.5m = 5107kN$

$$\Rightarrow \qquad P_{total} = 5622kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{5662kN}{45.4m^2} = 124kPa$$

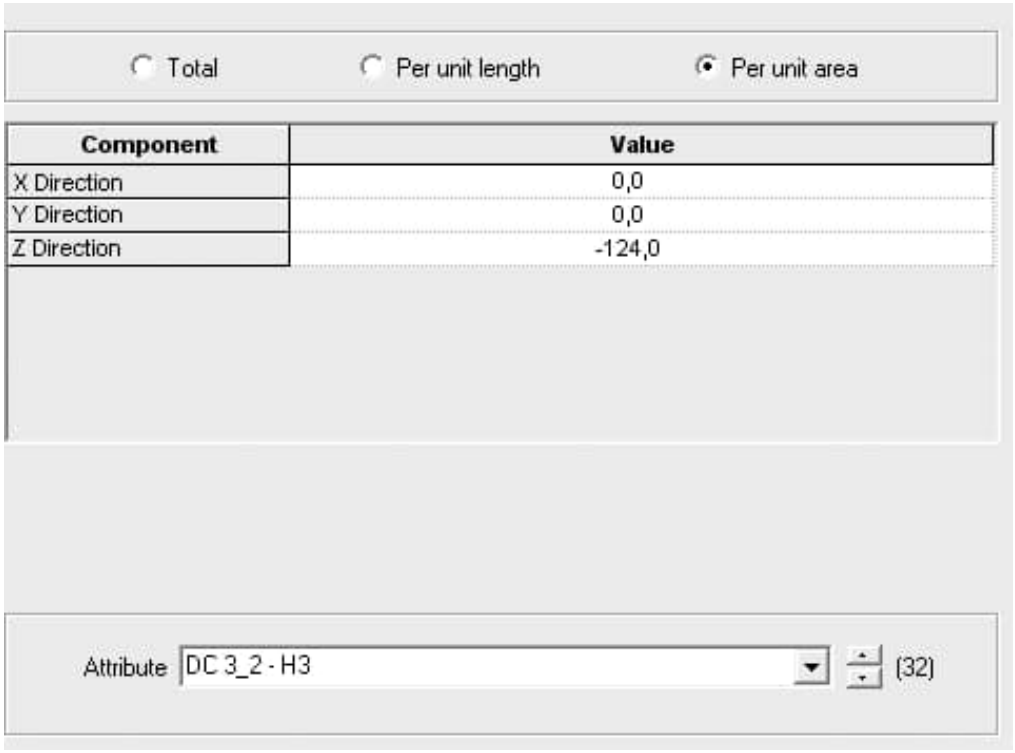


Loadcase : DC 3_2 – H3

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -124 $\frac{kN}{m^2}$



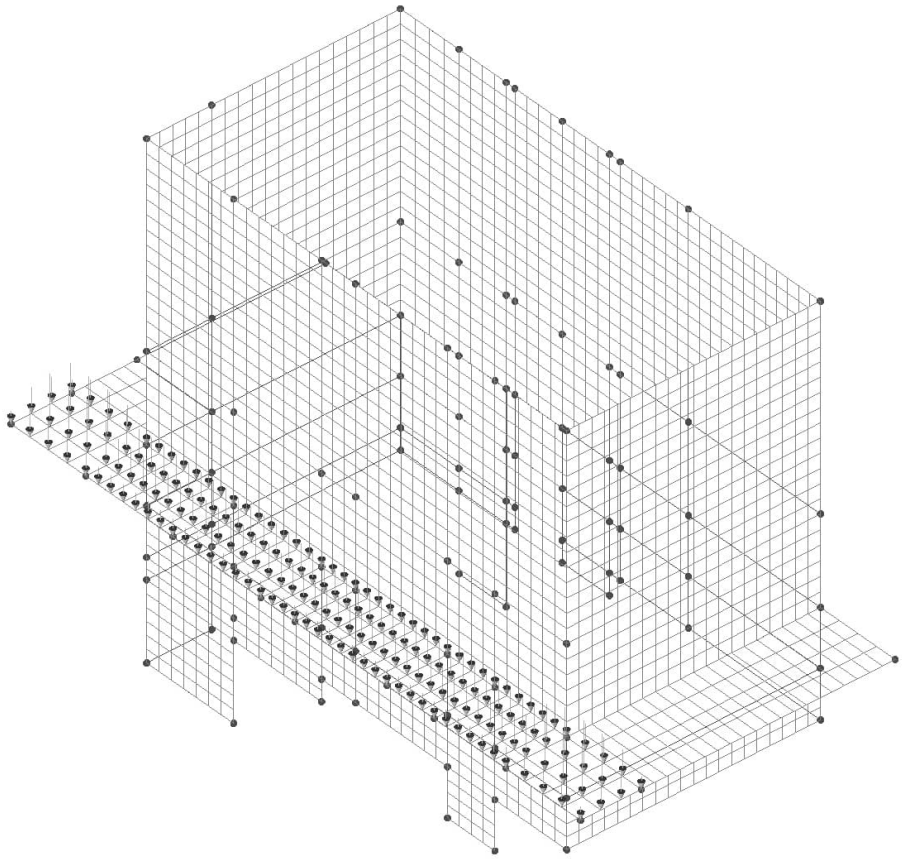
Load on Wall 1:4 (Load case DC 3_3 – H3)

- Concrete : $P_{wall} = \gamma'_c \cdot b \cdot l = 14\frac{kN}{m^3} \cdot 2.0m \cdot 30.1m \cdot 1.0m = 843kN$

- Earth filling : $P_{earth} = ((90.61m - 90.6m) \cdot 18\frac{kN}{m^3} + (90.6m - 78.00m) \cdot 11\frac{kN}{m^3}) \cdot 2.0m \cdot 30.1m = 8355kN$

$$\Rightarrow \qquad P_{total} = 9197kN$$

$$q_z = \frac{P_{total}}{A_{total}} = \frac{9197kN}{82.8m^2} = 111kPa$$

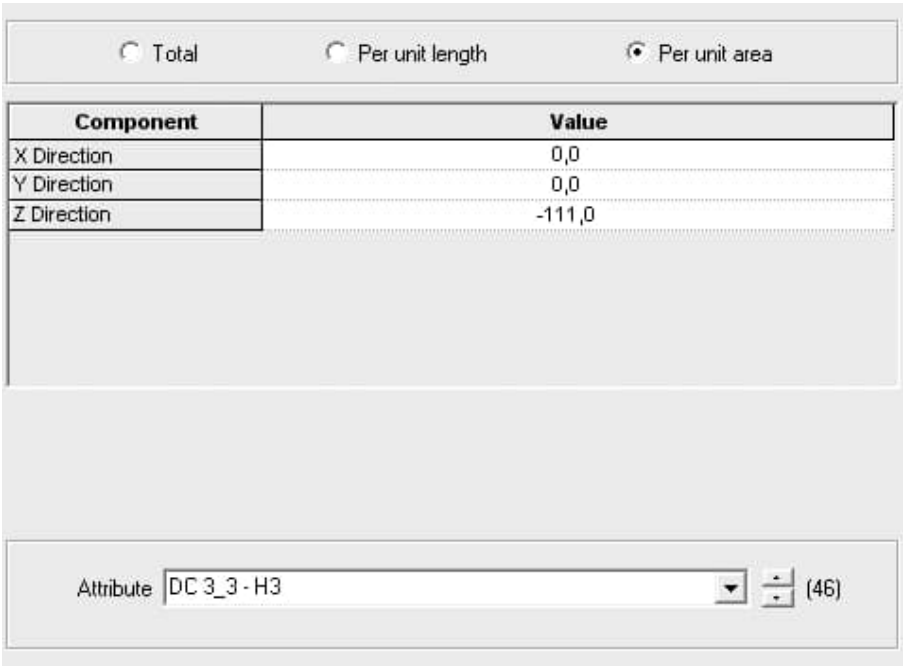


Loadcase : DC 3_3 – H3

Structural loading : Global distributed

Force type : Per unit area

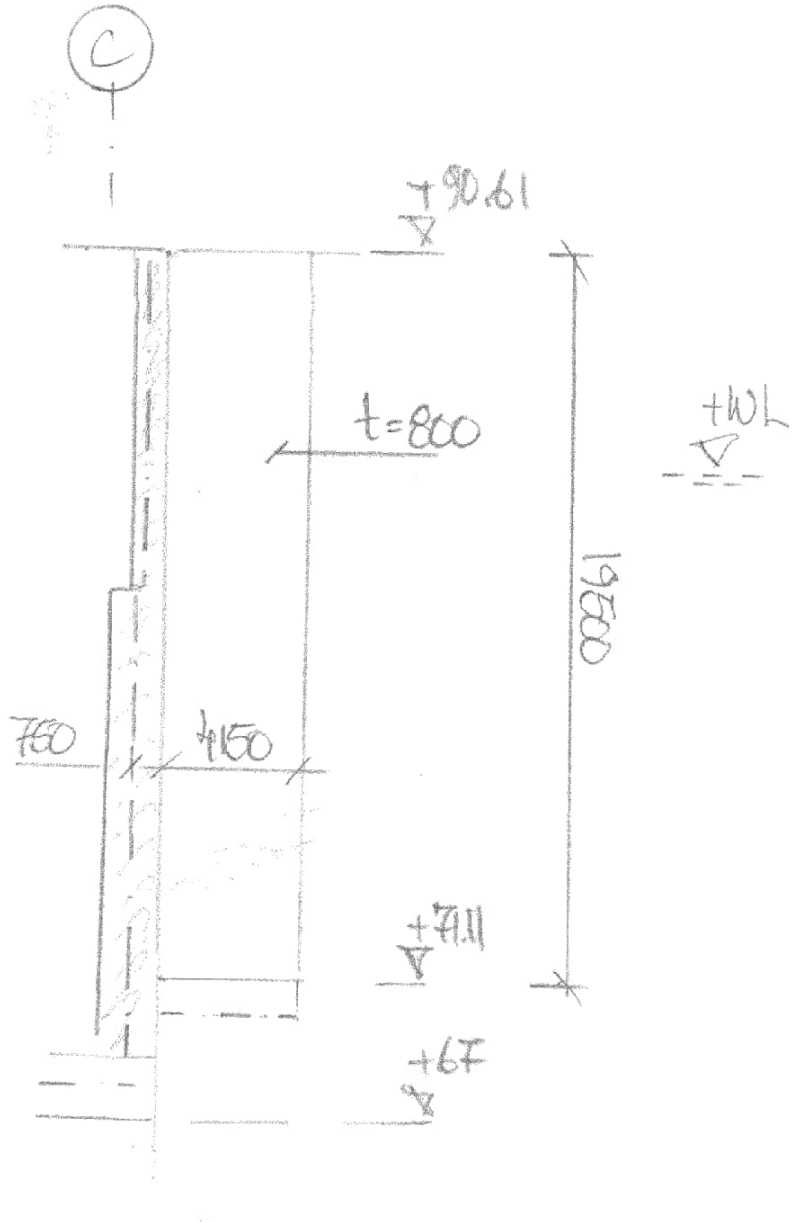
Component z direction : -111 $\frac{kN}{m^2}$



3.1.4 Concrete structure outside walls

The following parts describe load effect from parts Wall 3_4, Wall 3_5 and Wall 3_6.

The effect of these parts are studied at levels H0, H1, H2 and H3.



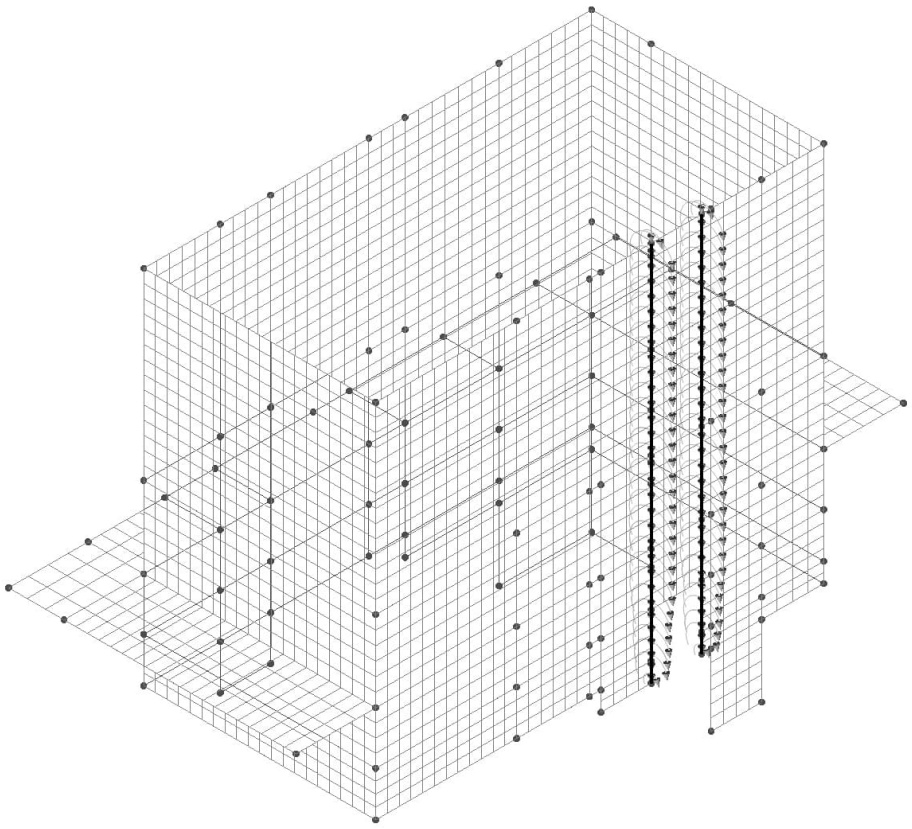
3.1.4.1 Water level H0 (Load case DC_4 – H0)

Water level H0 : WL = +67.0

$$P_c = \gamma_c \cdot V = 24\frac{kN}{m^3} \cdot (19.5m \cdot 4.15m \cdot 0.8m) = 1554kN$$

$$p_z = \frac{P_c}{l} = \frac{1554kN}{18.88m} = 82\frac{kN}{m}$$

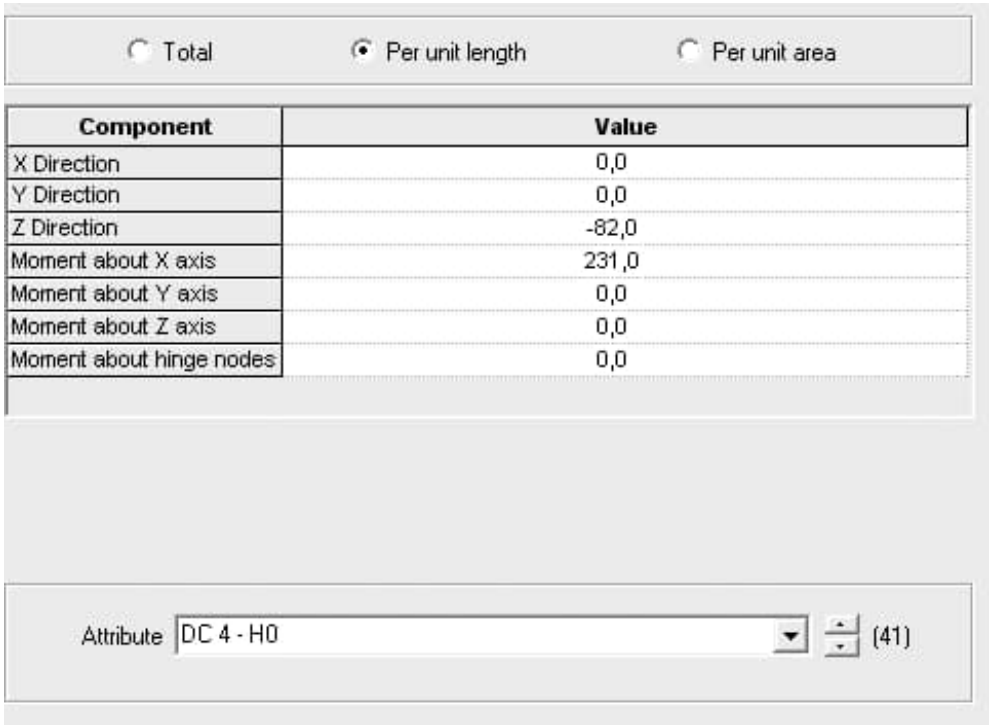
$$m_x = p_z \cdot e = 82\frac{kN}{m} \cdot (0.75m + \frac{4.15m}{2}) = 231\frac{kNm}{m}$$



Loading : DC 4 – H0

Structural loading : Global distributed

Force type : Per unit length



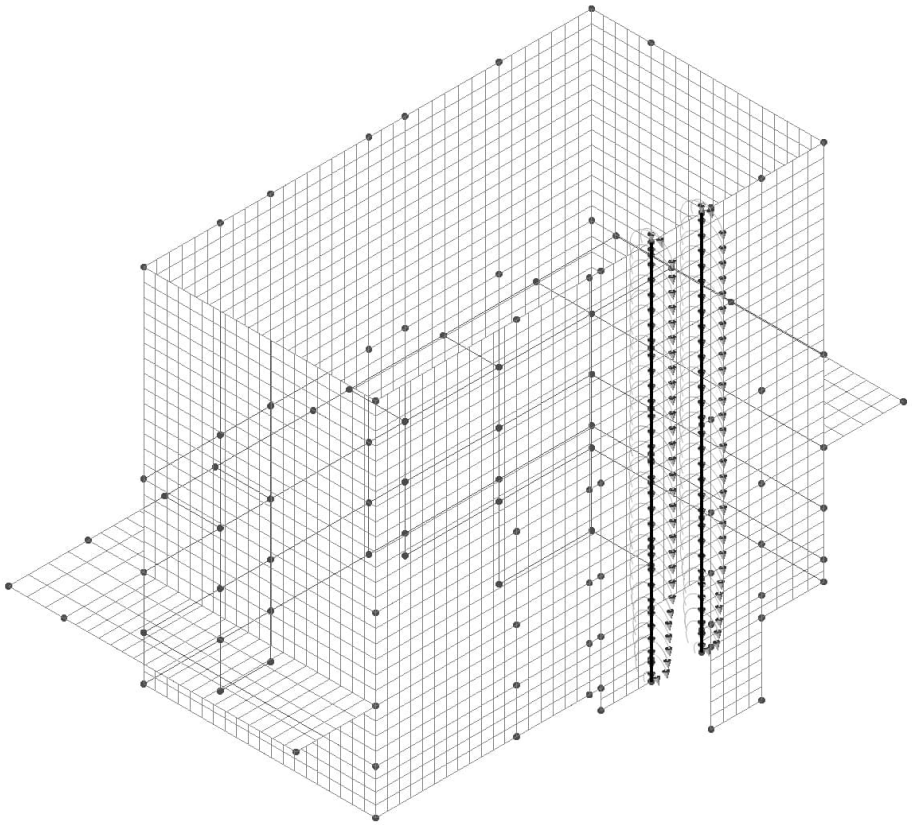
3.1.4.2 Water level H1 (Load case DC_4 – H1)

Water level H1 : WL = +78.65

$$P_c = (24\frac{kN}{m^3} \cdot (90.61m - 78.65m) + (78.65m - 71.11m) \cdot 14\frac{kN}{m^3}) \cdot 4.15m \cdot 0.8m = 1303kN$$

$$p_z = \frac{P_c}{l} = \frac{1303kN}{18.88m} = 69\frac{kN}{m}$$

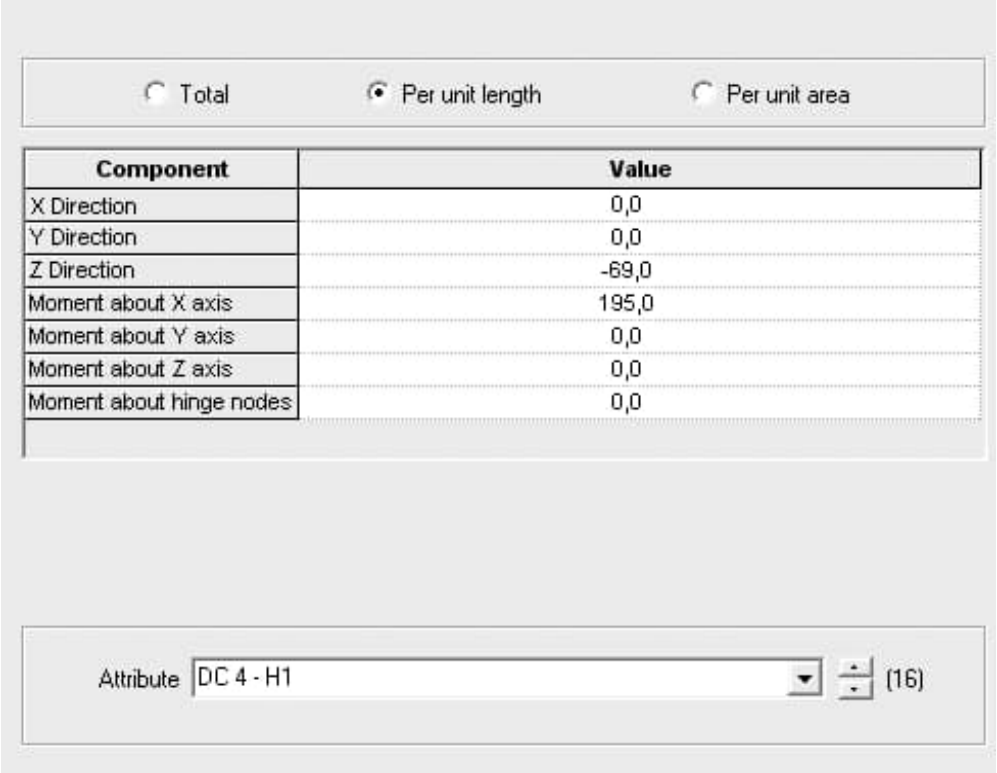
$$m_x = p_z \cdot e = 69\frac{kN}{m} \cdot (0.75m + \frac{4.15m}{2}) = 195\frac{kNm}{m}$$



Loading : DC 4 – H1

Structural loading : Global distributed

Force type : Per unit length



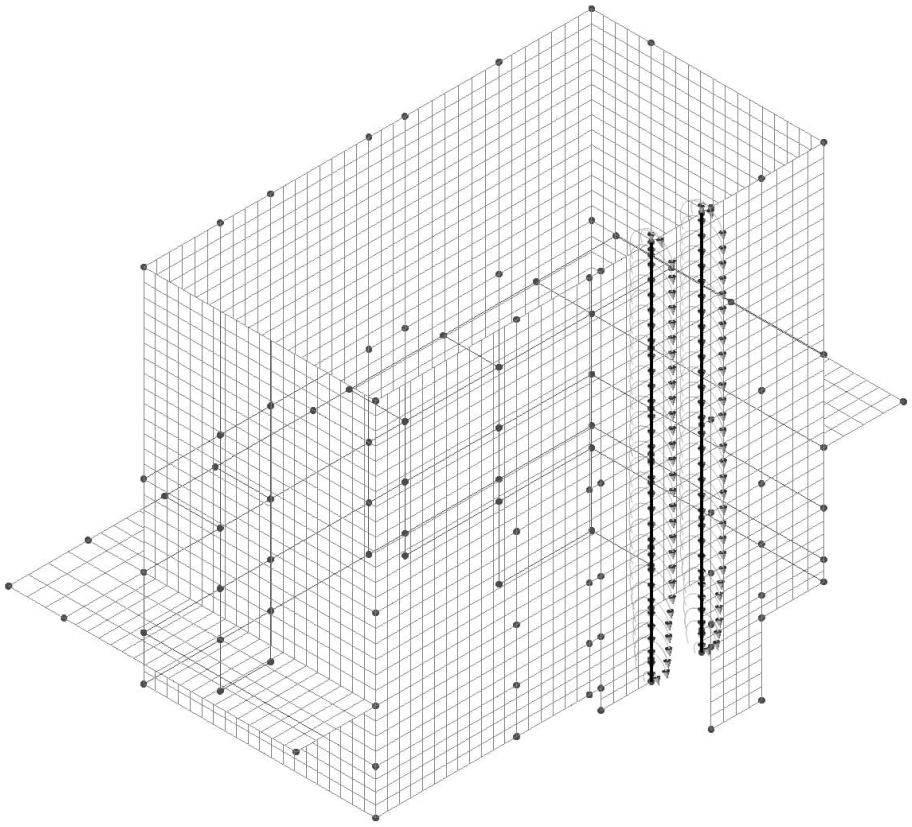
3.1.4.3 Water level H2 (Load case DC_4 – H2)

Water level H2 : WL = +79.65

$$P_c = (24\frac{kN}{m^3} \cdot (90.61m - 79.65m) + (79.65m - 71.11m) \cdot 14\frac{kN}{m^3}) \cdot 4.15m \cdot 0.8m = 1270kN$$

$$p_z = \frac{P_c}{l} = \frac{1270kN}{18.88m} = 67\frac{kN}{m}$$

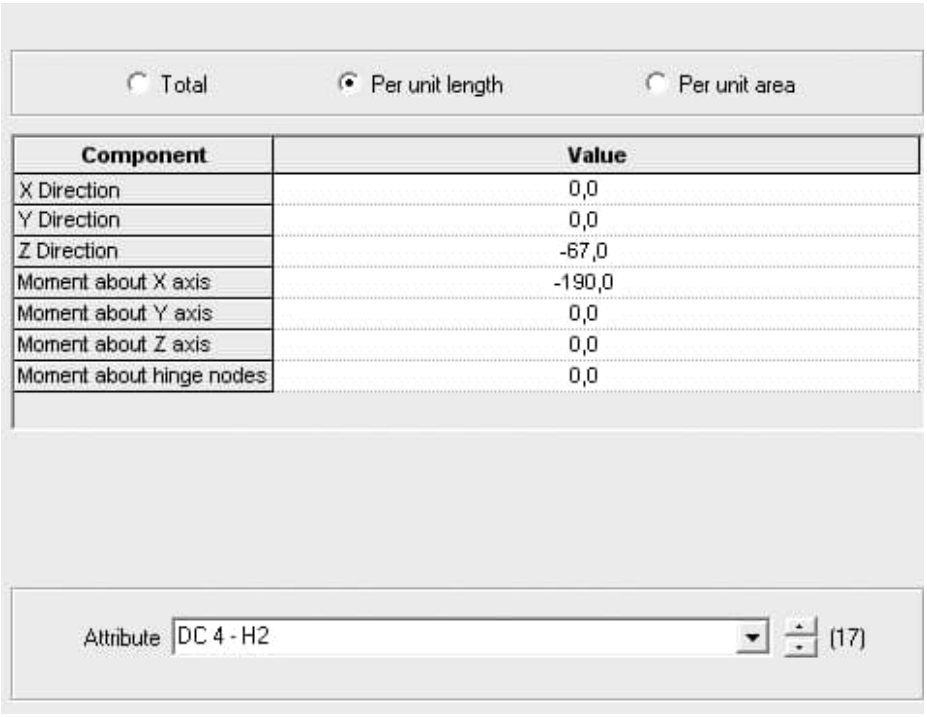
$$m_x = p_z \cdot e = 67\frac{kN}{m} \cdot (0.75m + \frac{4.15m}{2}) = 190\frac{kNm}{m}$$



Loading : DC 4 – H2

Structural loading : Global distributed

Force type : Per unit length



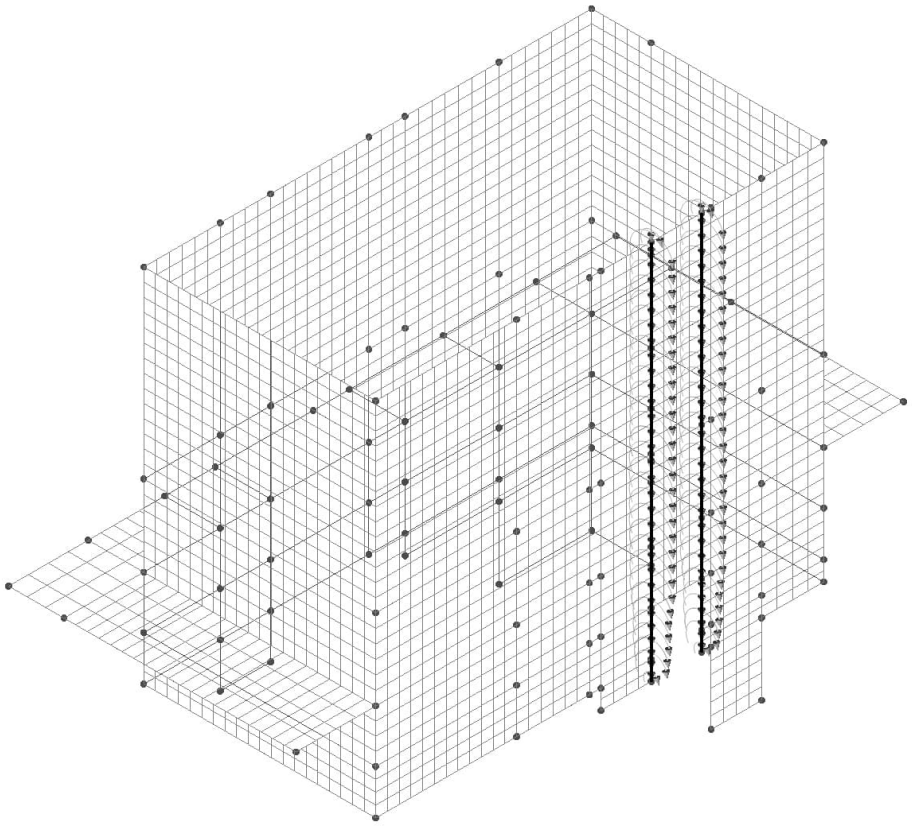
3.1.4.4 Water level H3 (Load case DC_4 – H3)

Water level H3 : WL = +90.60

$$P_c = (24\frac{kN}{m^3} \cdot (90.61m - 90.60m) + (90.60m - 71.11m) \cdot 14\frac{kN}{m^3}) \cdot 4.15m \cdot 0.8m = 907kN$$

$$p_z = \frac{P_c}{l} = \frac{907kN}{18.88m} = 48\frac{kN}{m}$$

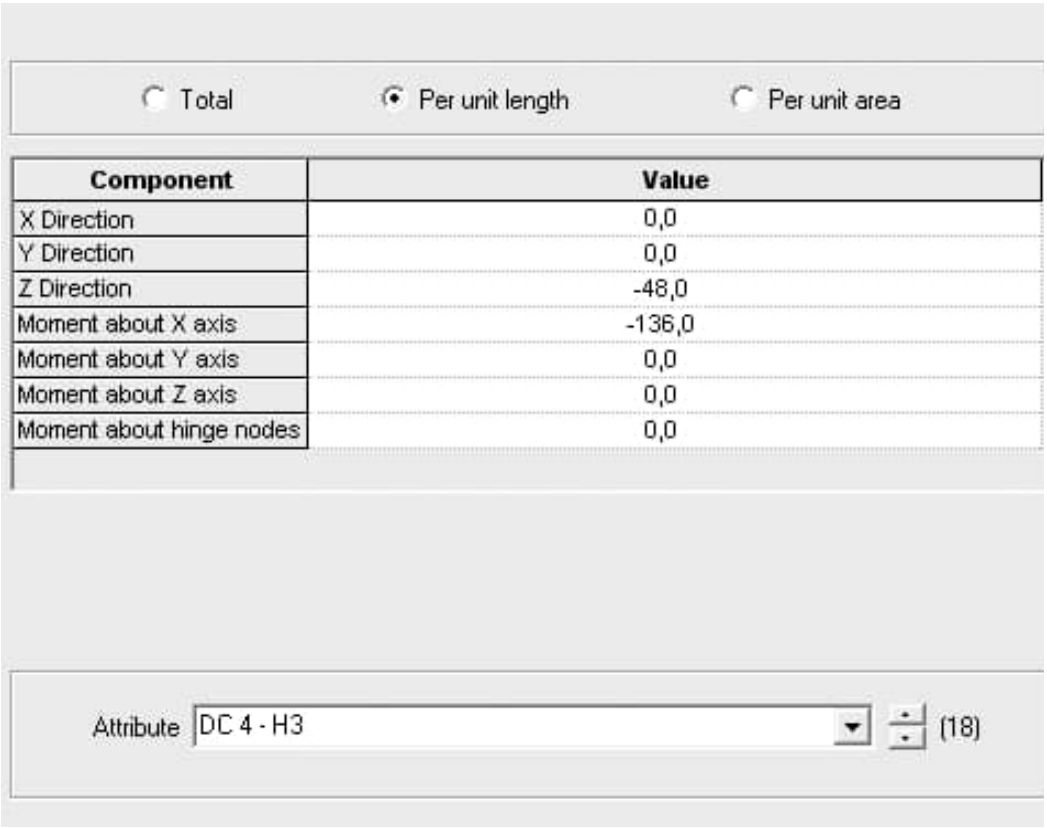
$$m_x = p_z \cdot e = 67\frac{kN}{m} \cdot (0.75m + \frac{4.15m}{2}) = 136\frac{kNm}{m}$$



Loading : DC 4 – H3

Structural loading : Global distributed

Force type : Per unit length



3.1.5 Load combinations

Loadcombination basic : DC – H0

Loadcase	Factor
DC 1	1.00
DC 2	1.00
DC 3_1 – H0	1.00
DC 3_2 – H0	1.00
DC 3_3 – H0	1.00
DC 4 – H0	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	DC 1	152	1	-1	1
2	DC 2	30	1	-1	1
3	DC 3_1 - H0	128	1	-1	1
4	DC 3_2 - H0	129	1	-1	1
5	DC 3_3 - H0	130	1	-1	1
6	DC 4 - H0	140	1	-1	1

Loadcombination basic : DC – H1

Loadcase	Factor
DC 1	1.00
DC 2	1.00
DC 3_1 – H1	1.00
DC 3_2 – H1	1.00
DC 3_3 – H1	1.00
DC 4 – H1	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	DC 1	152	1	-1	1
2	DC 2	30	1	-1	1
3	DC 3_1 - H1	131	1	-1	1
4	DC 3_2 - H1	132	1	-1	1
5	DC 3_3 - H1	133	1	-1	1
6	DC 4 - H1	141	1	-1	1

Loadcombination basic : DC – H2

Loadcase	Factor
DC 1	1.00
DC 2	1.00
DC 3_1 – H2	1.00
DC 3_2 – H2	1.00
DC 3_3 – H2	1.00
DC 4 – H2	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	DC 1	152	1	-1	1
2	DC 2	30	1	-1	1
3	DC 3_3 - H1	133	1	-1	1
4	DC 3_1 - H2	134	1	-1	1
5	DC 3_2 - H2	135	1	-1	1
6	DC 4 - H2	142	1	-1	1

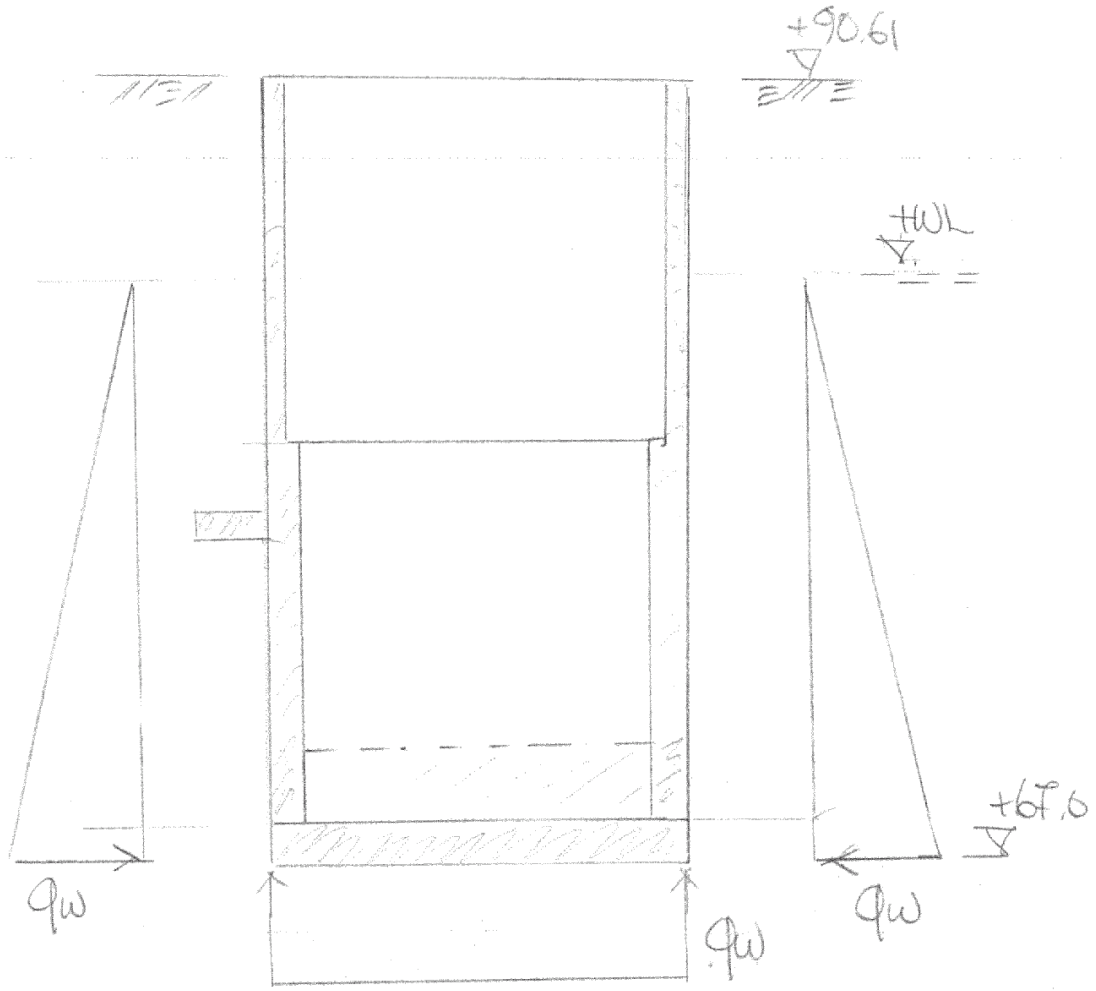
Loadcombination basic : DC – H3

Loadcase	Factor
DC 1	1.00
DC 2	1.00
DC 3_1 – H3	1.00
DC 3_2 – H3	1.00
DC 3_3 – H3	1.00
DC 4 – H3	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	DC 1	152	1	-1	1
2	DC 2	30	1	-1	1
3	DC 3_1 - H3	137	1	-1	1
4	DC 3_2 - H3	138	1	-1	1
5	DC 3_3 - H3	139	1	-1	1
6	DC 4 - H3	143	1	-1	1

3.2 WATER LOAD (WA)

Due to varying water flow level the following levels are studied levels H0, H1, H2 and H3.



3.2.1 Water level H0

Water level H0 : WL = +67.0

⇒ No water pressure acting !

3.2.2 Water level H1

Water level H1 : WL = +78.65

$$q_w = (78.65m - 67.0m) \cdot 1.0 \cdot 10 \frac{kN}{m^3} = 117kPa$$

3.2.2.1 Load at water level H1 against Wall 1

Loadcase : WA Wall 1 – H1

Structural loading : Discrete patch load

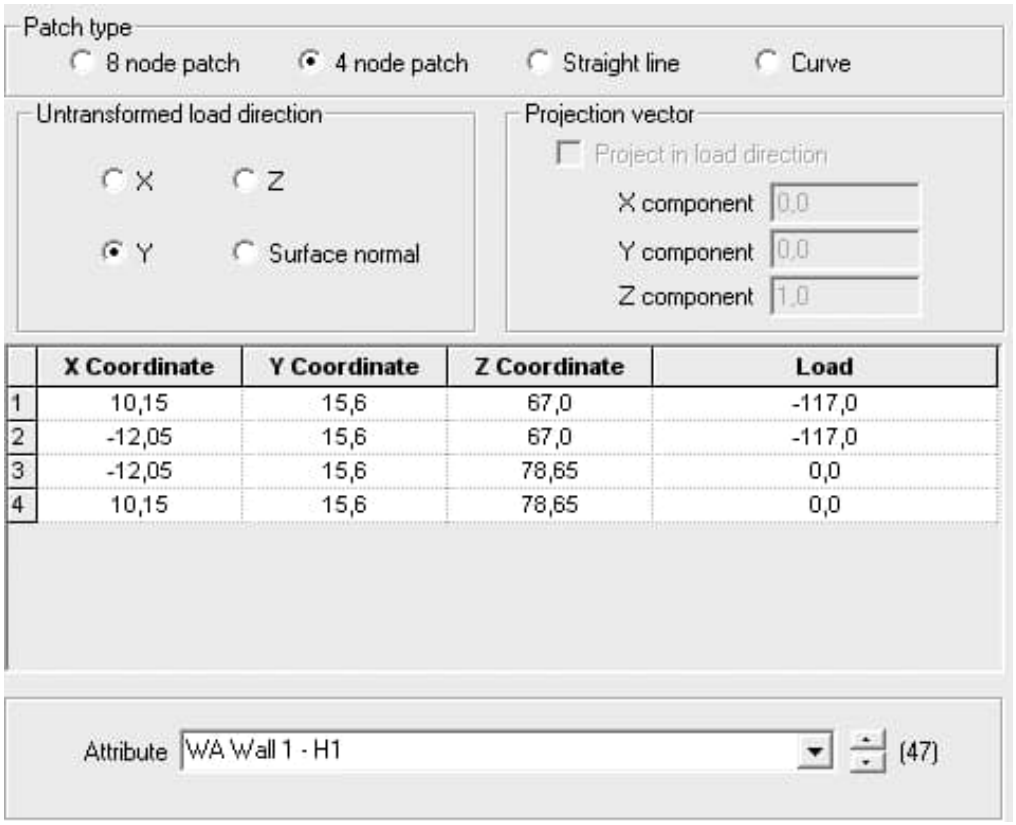
Search area : Wall 1

Force type : Per unit area

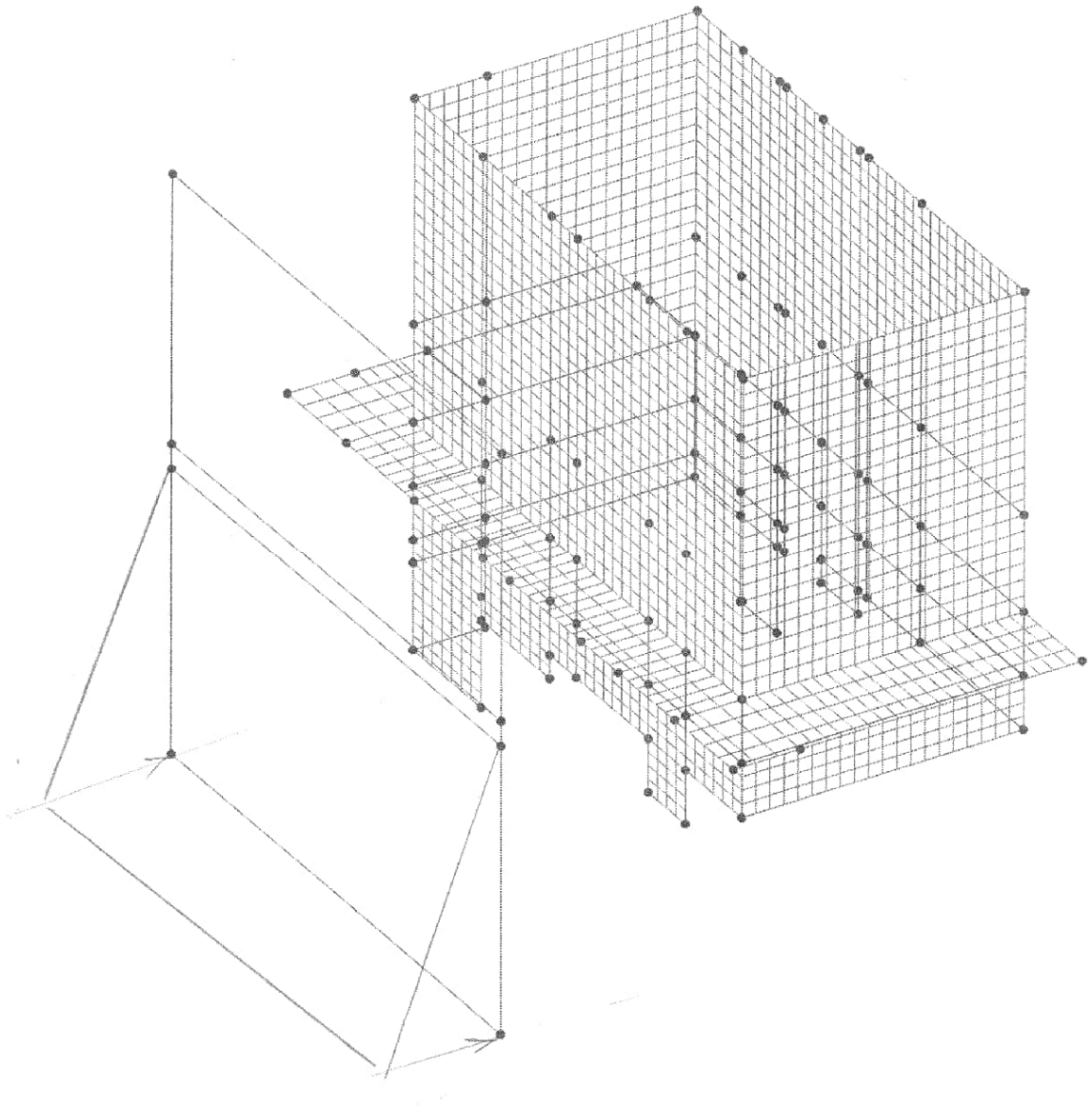
Component y direction : -117 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	10,15	15,6	67,0	-117,0
2	-12,05	15,6	67,0	-117,0
3	-12,05	15,6	78,65	0,0
4	10,15	15,6	78,65	0,0



3.2.2.2 Load at water level H1 against Wall 2

Loadcase : WA Wall 2 – H1

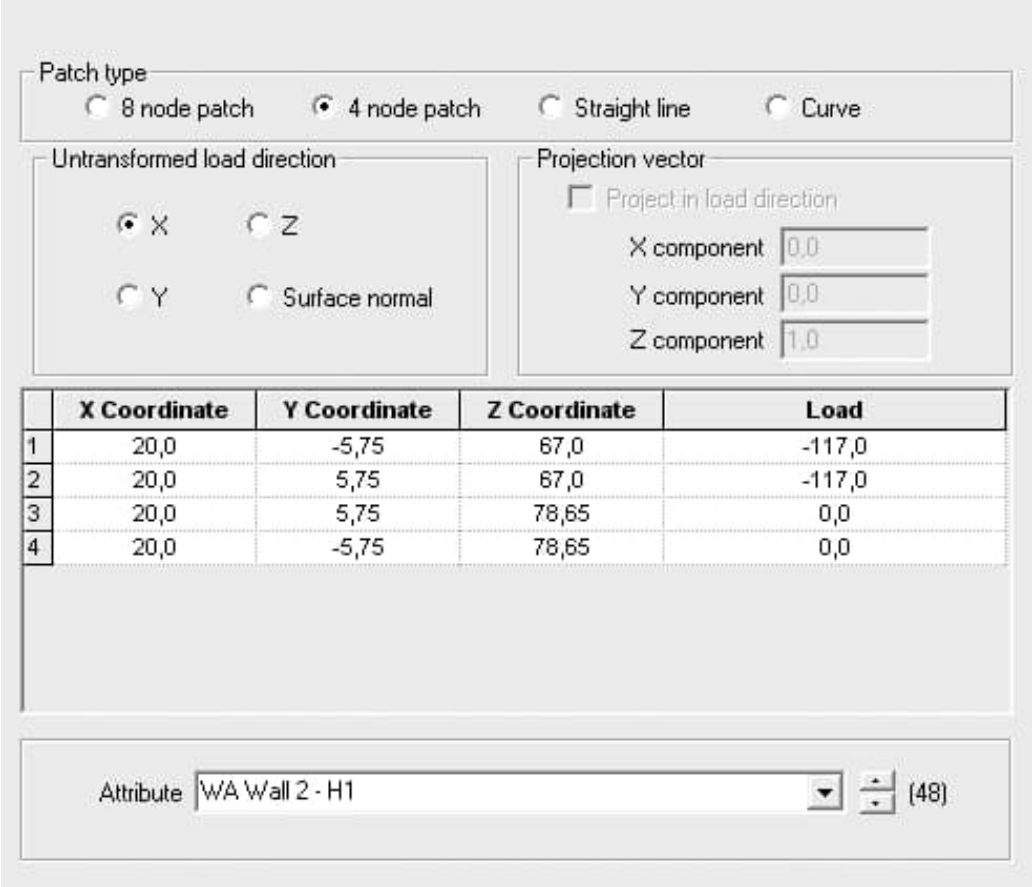
Search area : Wall 2

Force type : Per unit area

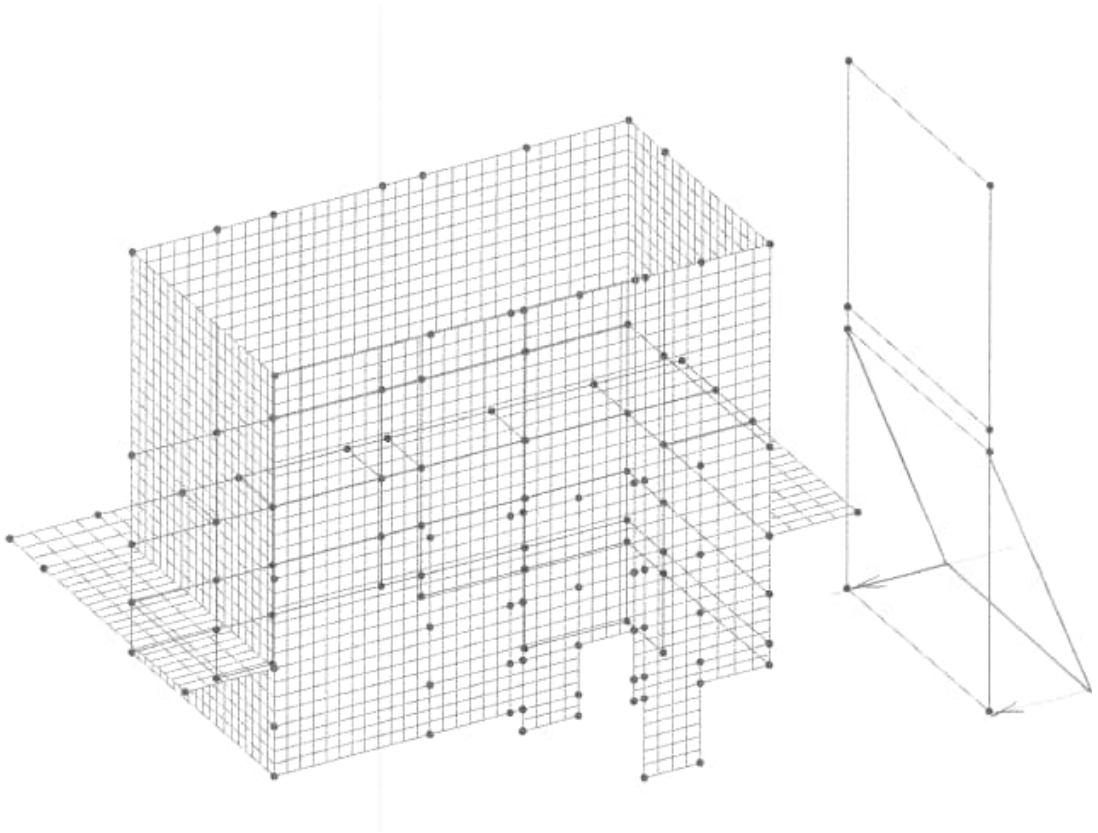
Component x direction : -117 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	20,0	-5,75	67,0	-117,0
2	20,0	5,75	67,0	-117,0
3	20,0	5,75	78,65	0,0
4	20,0	-5,75	78,65	0,0



3.2.2.3 Load at water level H1 against Wall 3

Loadcase : WA Wall 3 – H1

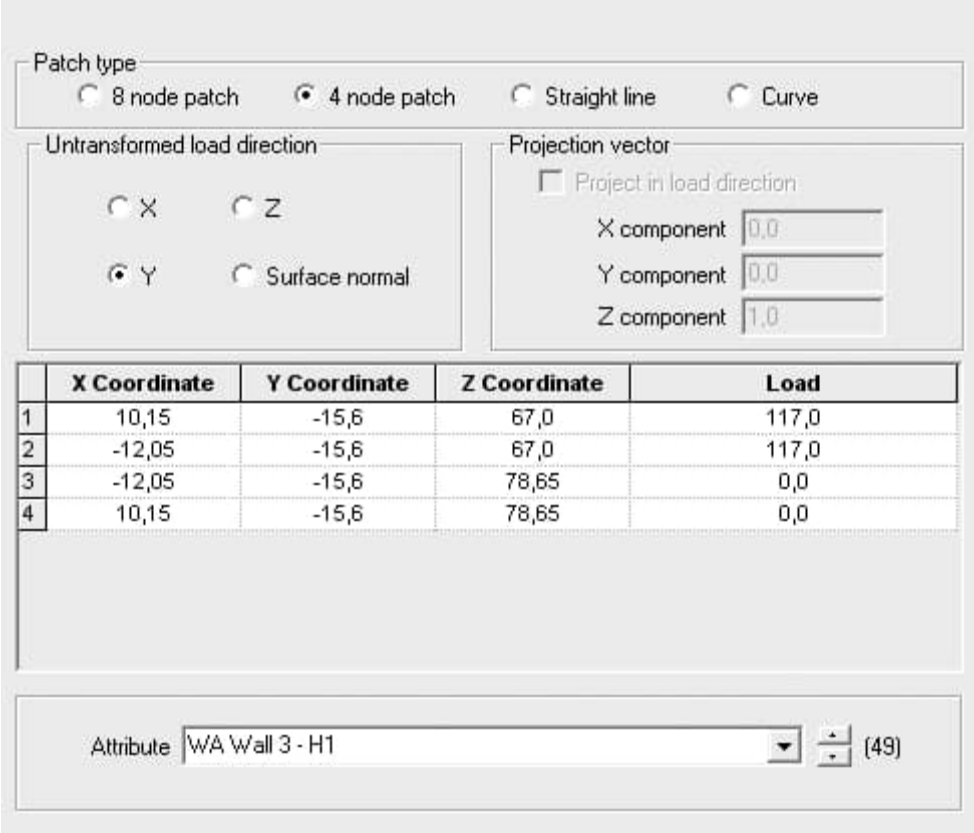
Search area : Wall 3

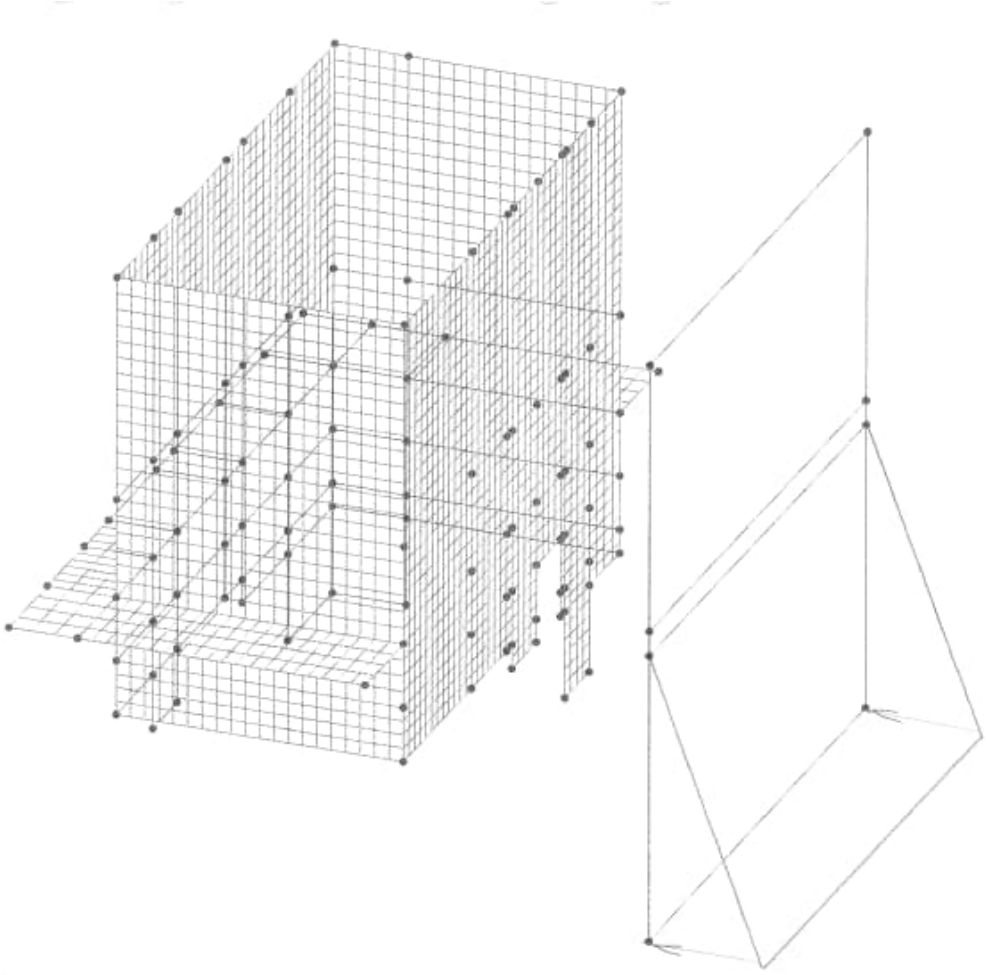
Force type : Per unit area

Component y direction : 117 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20





3.2.2.4 Load at water level H1 against Wall 4

Loadcase : WA Wall 4 – H1

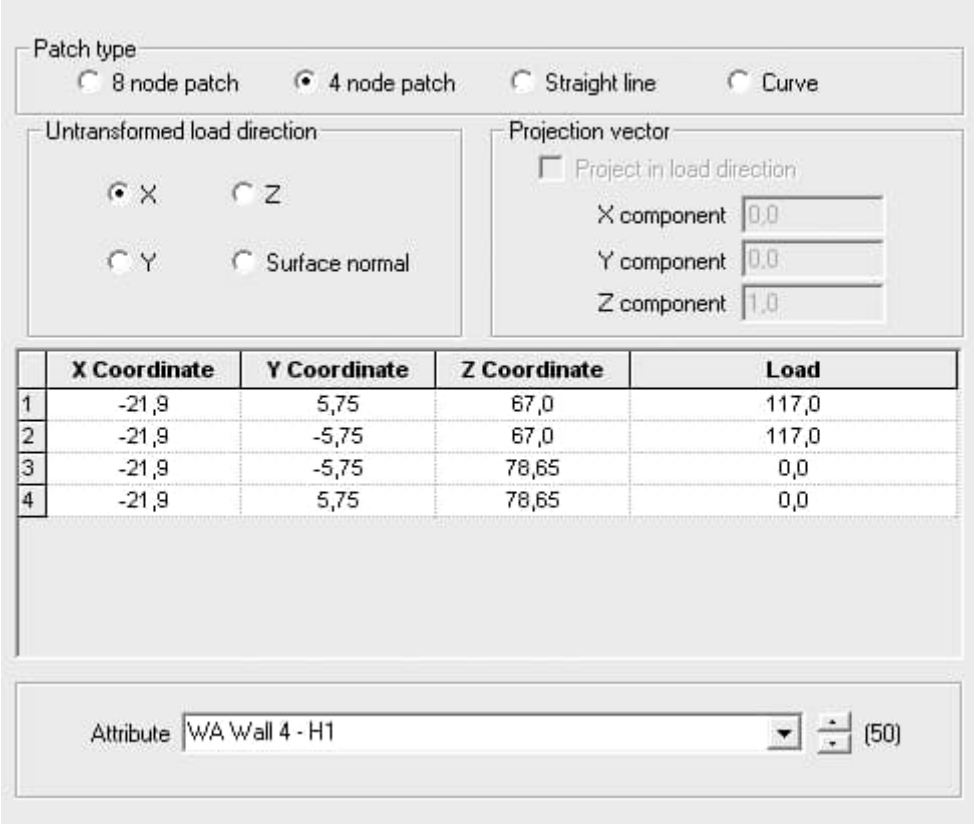
Search area : Wall 4

Force type : Per unit area

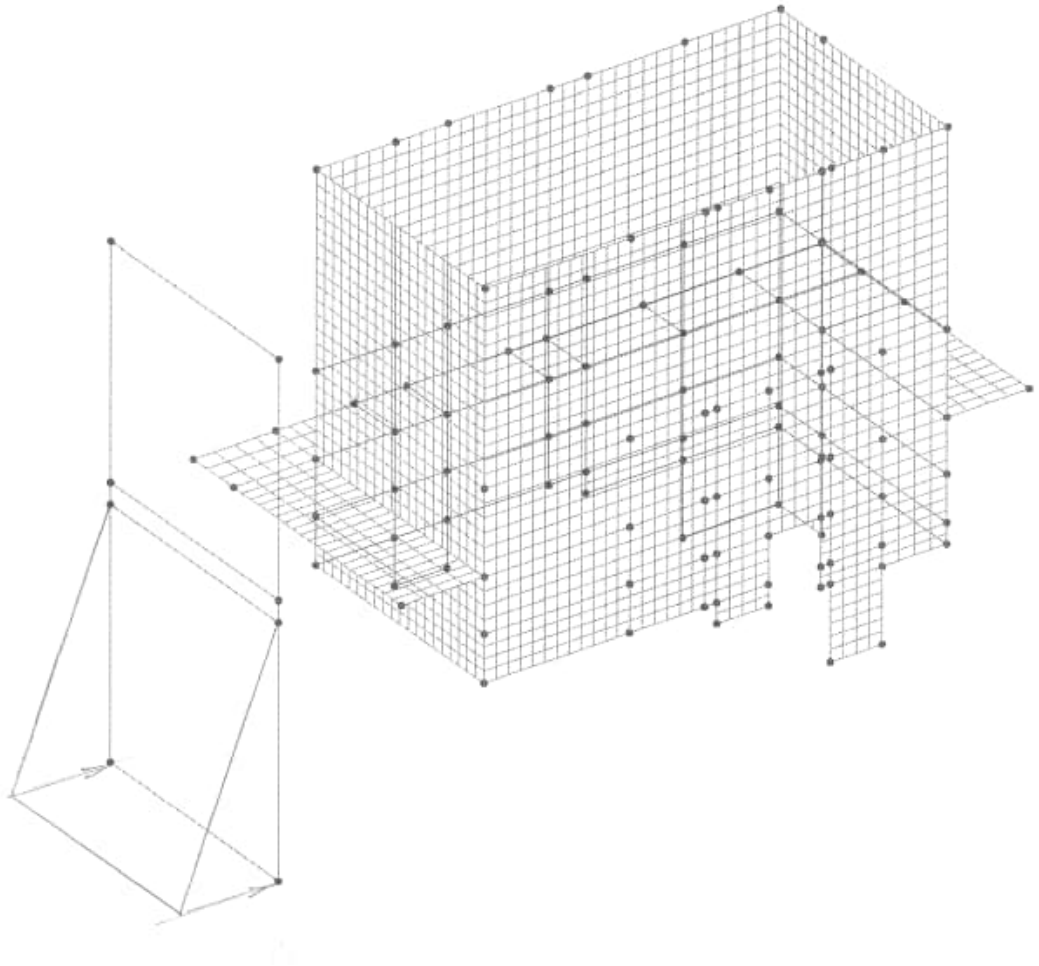
Component x direction : 117 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	67,0	117,0
2	-21,9	-5,75	67,0	117,0
3	-21,9	-5,75	78,65	0,0
4	-21,9	5,75	78,65	0,0



3.2.3 Water level H2

Water level H2 : WL = +79.65

$$q_w = (79.65m - 67.0m) \cdot 1.0 \cdot 10 \frac{kN}{m^3} = 127kPa$$

3.2.3.1 Load at water level H2 against Wall 1

Loadcase : WA Wall 1 – H2

Structural loading : Discrete patch load

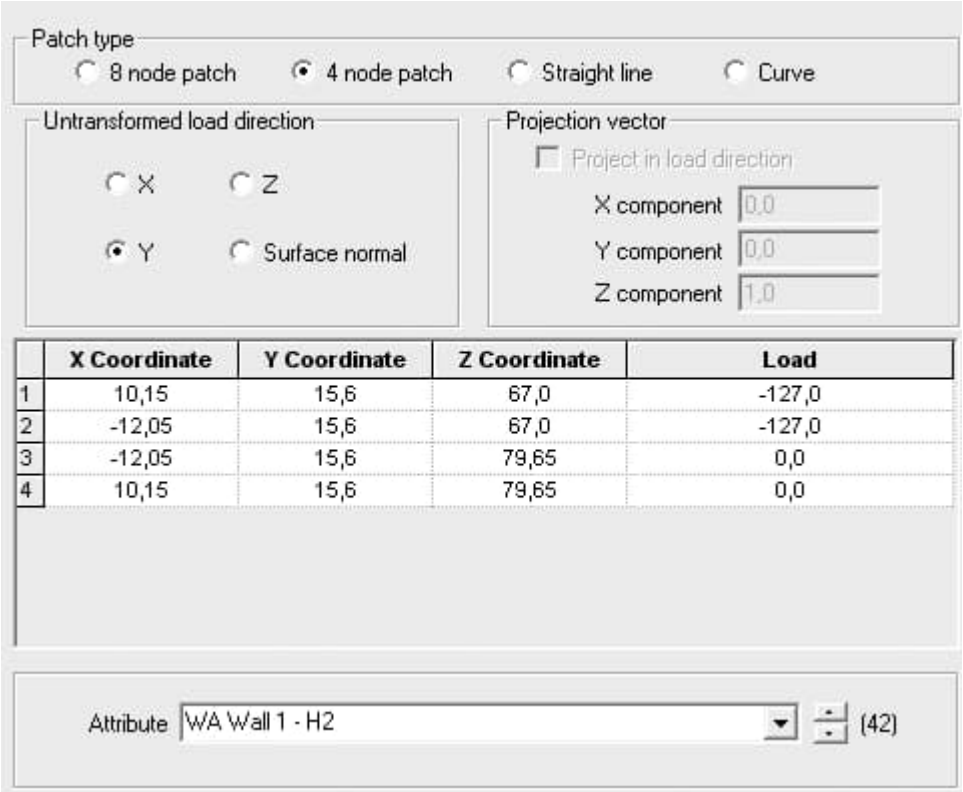
Search area : Wall 1

Force type : Per unit area

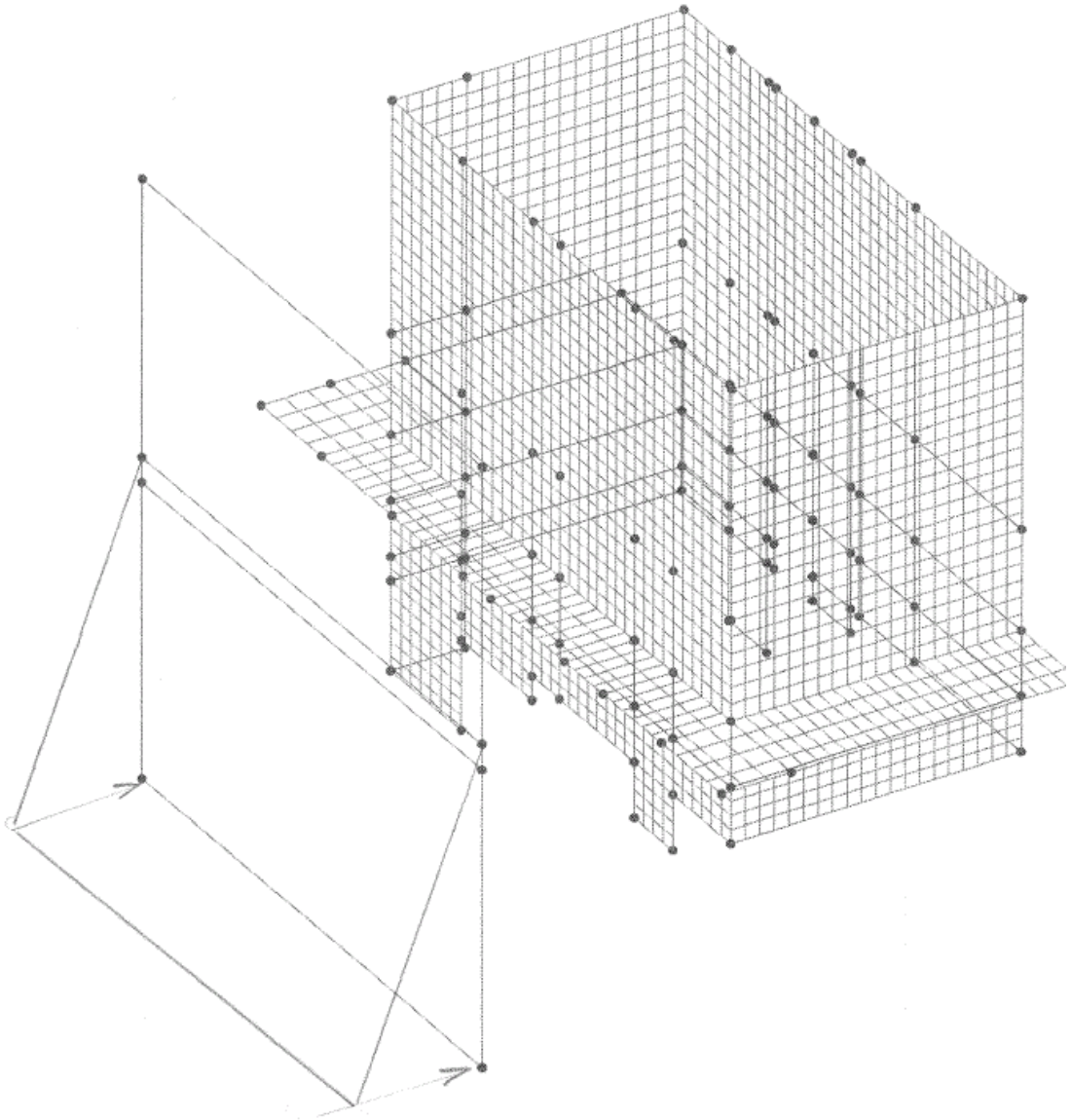
Component y direction : -127 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	10,15	15,6	67,0	-127,0
2	-12,05	15,6	67,0	-127,0
3	-12,05	15,6	79,65	0,0
4	10,15	15,6	79,65	0,0



3.2.3.2 Load at water level H2 against Wall 2

Loadcase : WA Wall 2 – H2

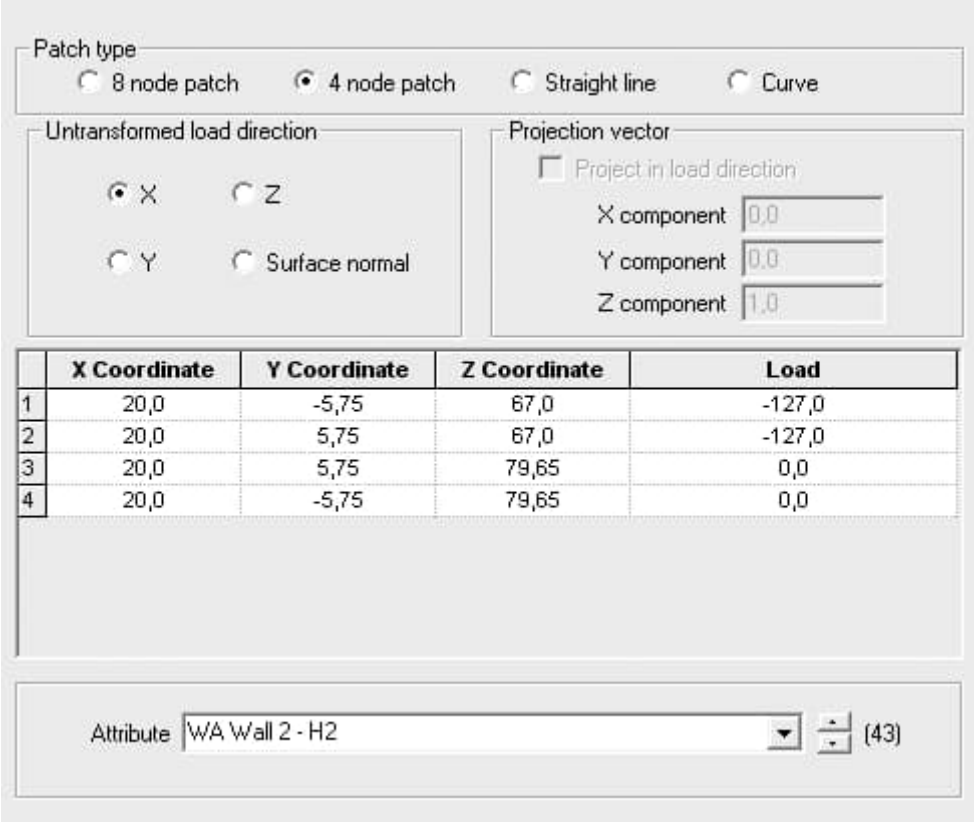
Search area : Wall 2

Force type : Per unit area

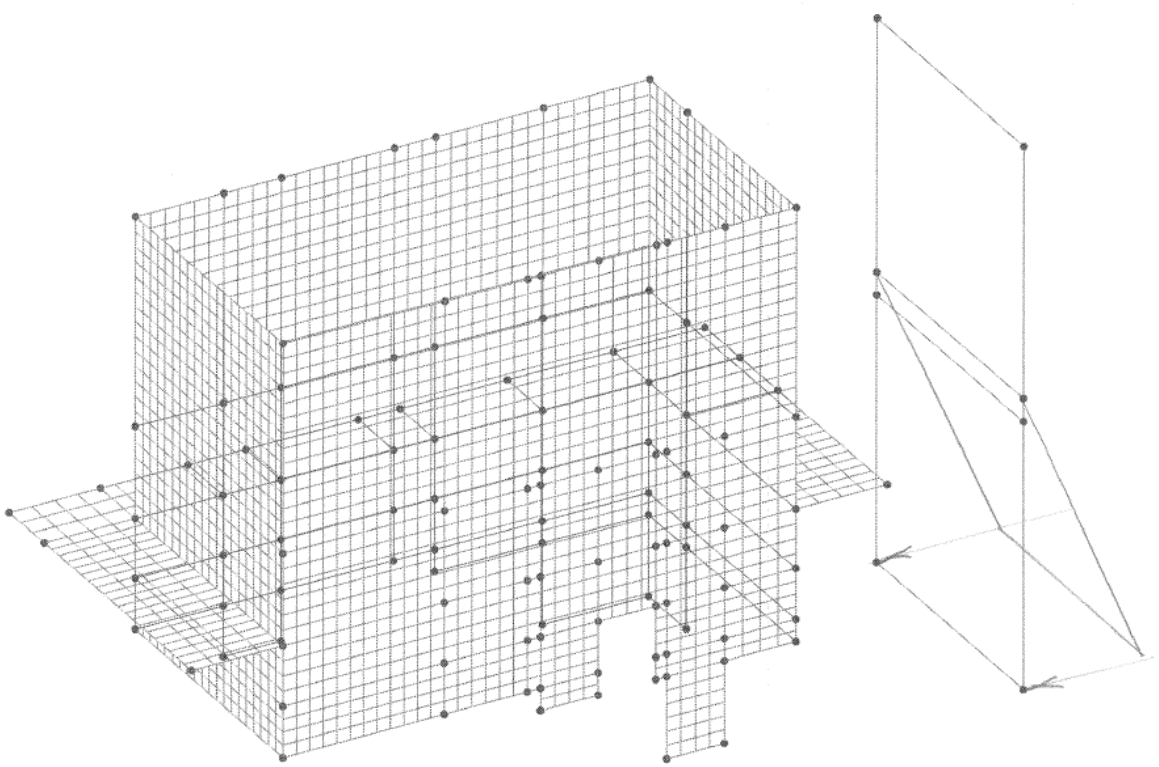
Component x direction : -127 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	20,0	-5,75	67,0	-127,0
2	20,0	5,75	67,0	-127,0
3	20,0	5,75	79,65	0,0
4	20,0	-5,75	79,65	0,0



3.2.3.3 Load at water level H2 against Wall 3

Loadcase : WA Wall 3 – H2

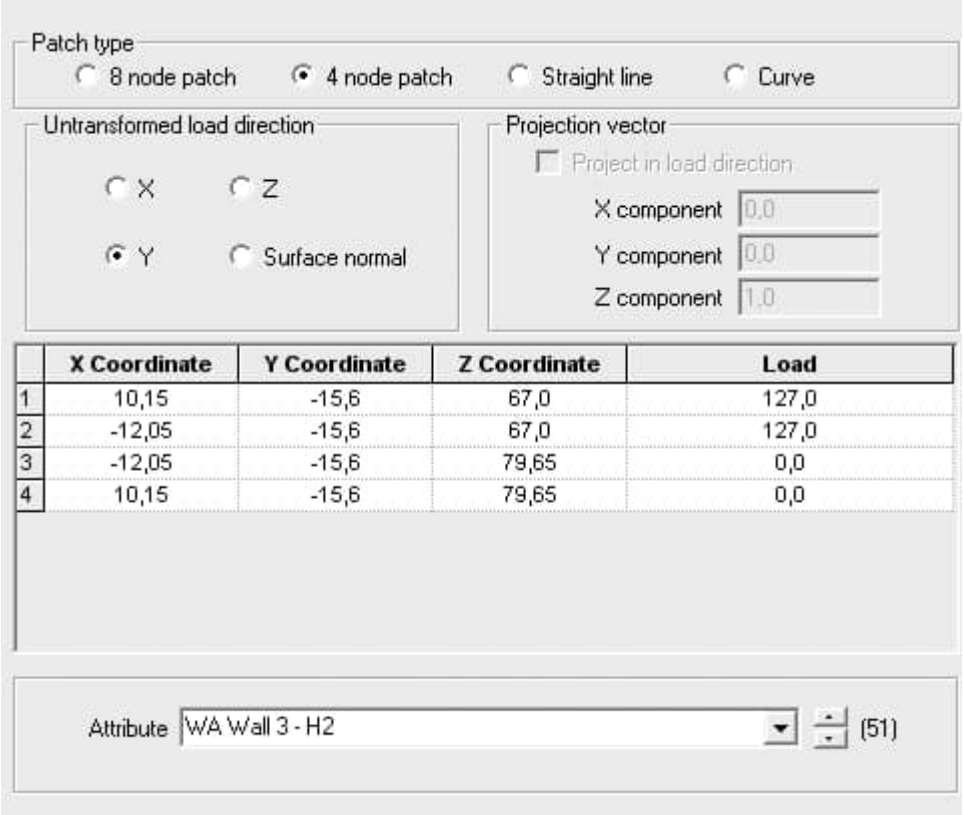
Search area : Wall 3

Force type : Per unit area

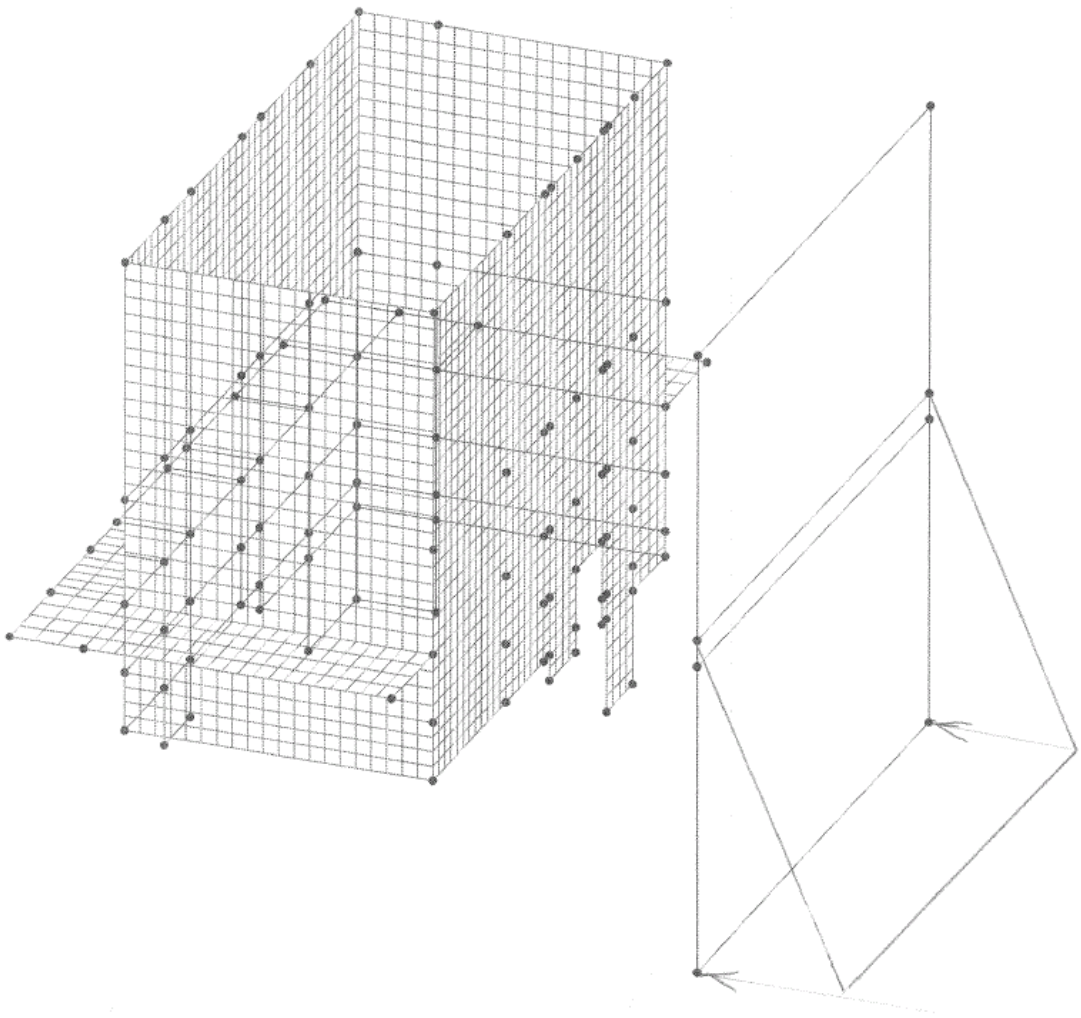
Component y direction : 127 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	10,15	-15,6	67,0	127,0
2	-12,05	-15,6	67,0	127,0
3	-12,05	-15,6	79,65	0,0
4	10,15	-15,6	79,65	0,0



3.2.3.4 Load at water level H2 against Wall 4

Loadcase : WA Wall 4 – H2

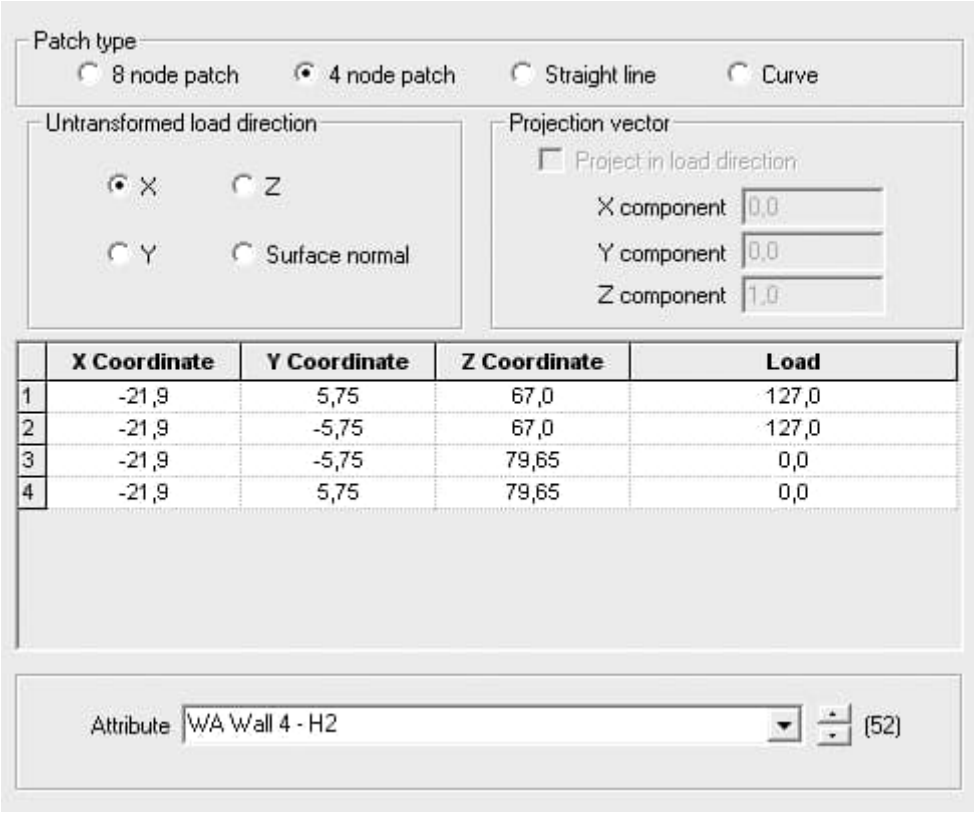
Search area : Wall 4

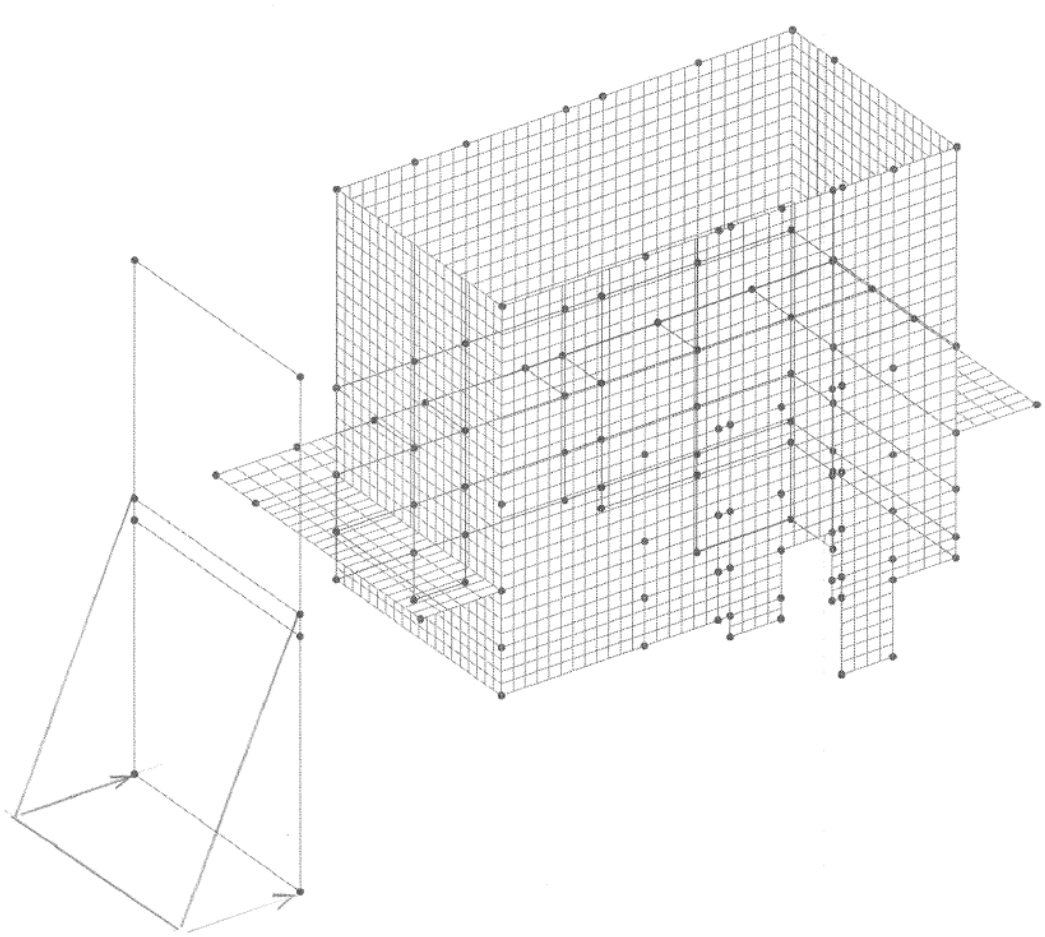
Force type : Per unit area

Component x direction : 127 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10





3.2.4 Water level H3

Water level H3 : WL = +90.60

$$q_w = (90.6m - 67.0m) \cdot 1.0 \cdot 10 \frac{kN}{m^3} = 236kPa$$

3.2.4.1 Load at water level H3 against Wall 1

Loadcase : WA Wall 1 – H3

Structural loading : Discrete patch load

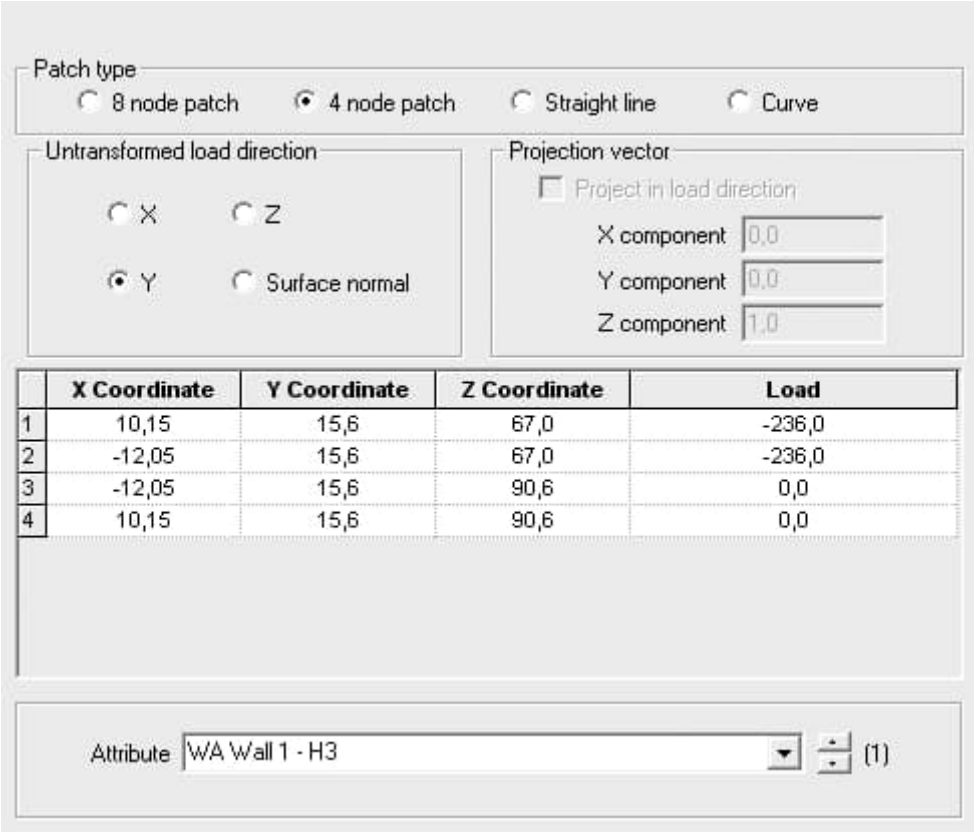
Search area : Wall 1

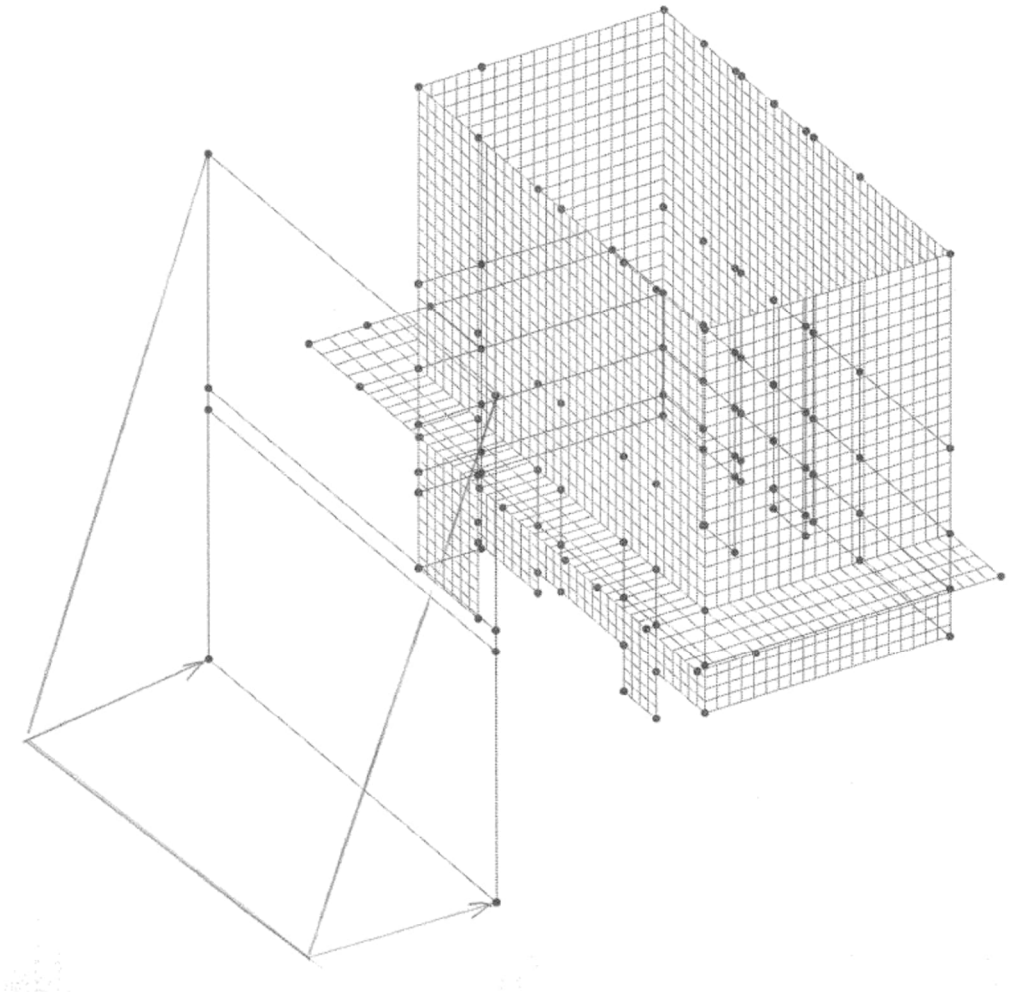
Force type : Per unit area

Component y direction : -236 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20





3.2.4.2 Load at water level H3 against Wall 2

Loadcase : WA Wall 2 – H3

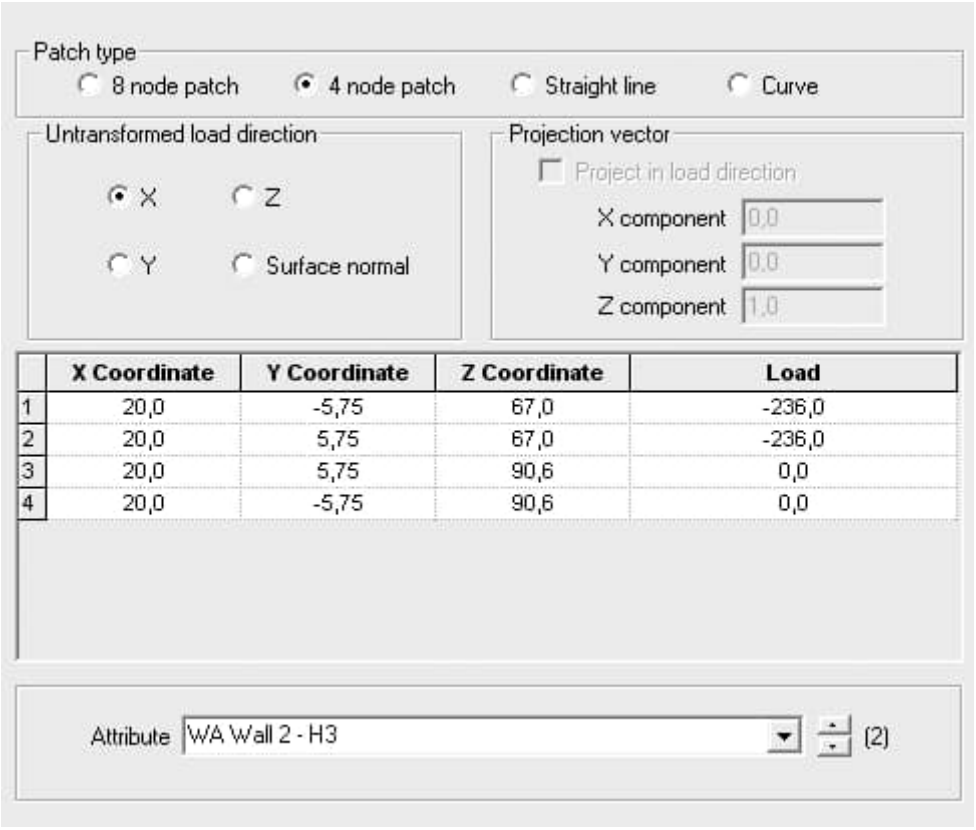
Search area : Wall 2

Force type : Per unit area

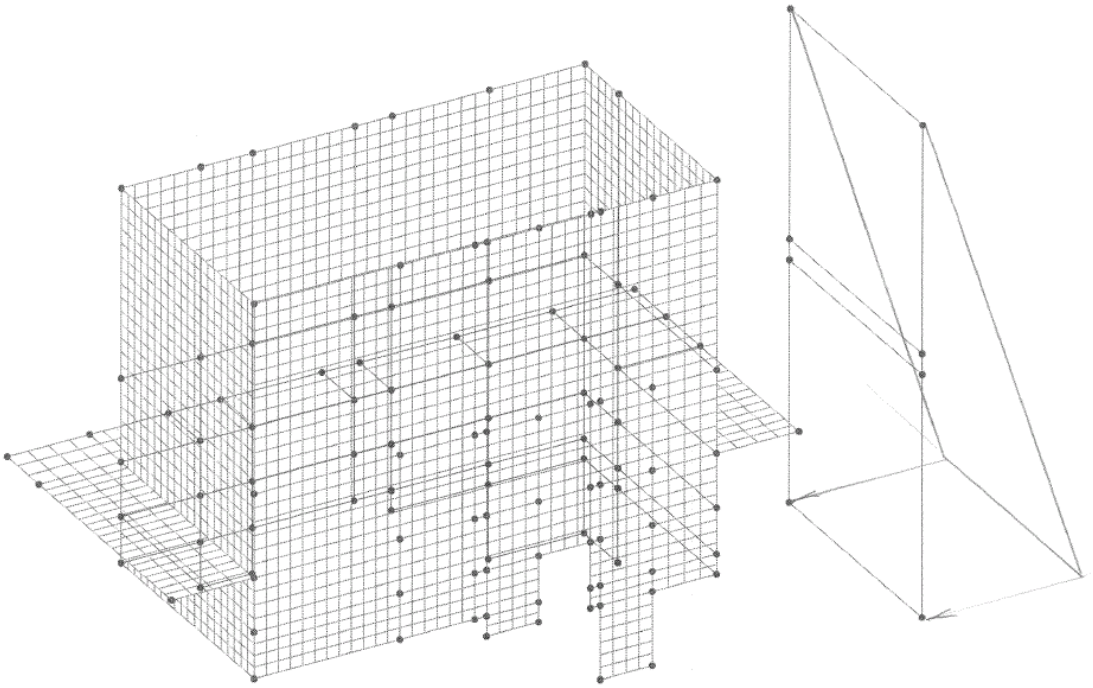
Component x direction : -236 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	20,0	-5,75	67,0	-236,0
2	20,0	5,75	67,0	-236,0
3	20,0	5,75	90,6	0,0
4	20,0	-5,75	90,6	0,0



3.2.4.3 Load at water level H3 against Wall 3

Loadcase : WA Wall 3 – H3

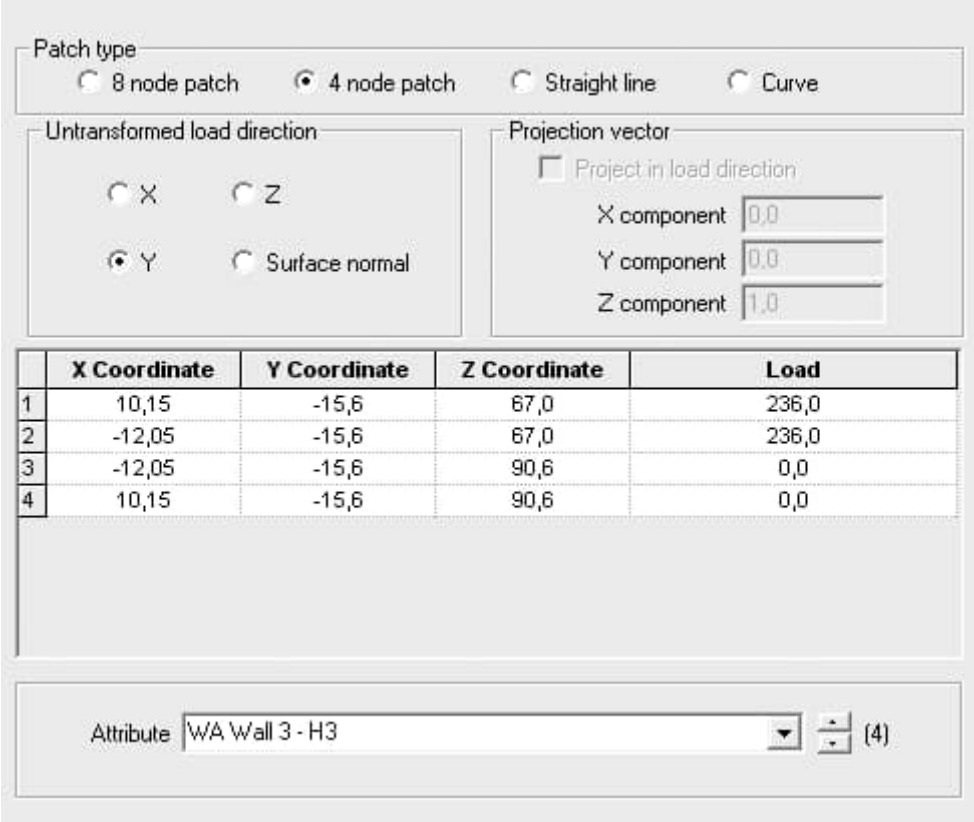
Search area : Wall 3

Force type : Per unit area

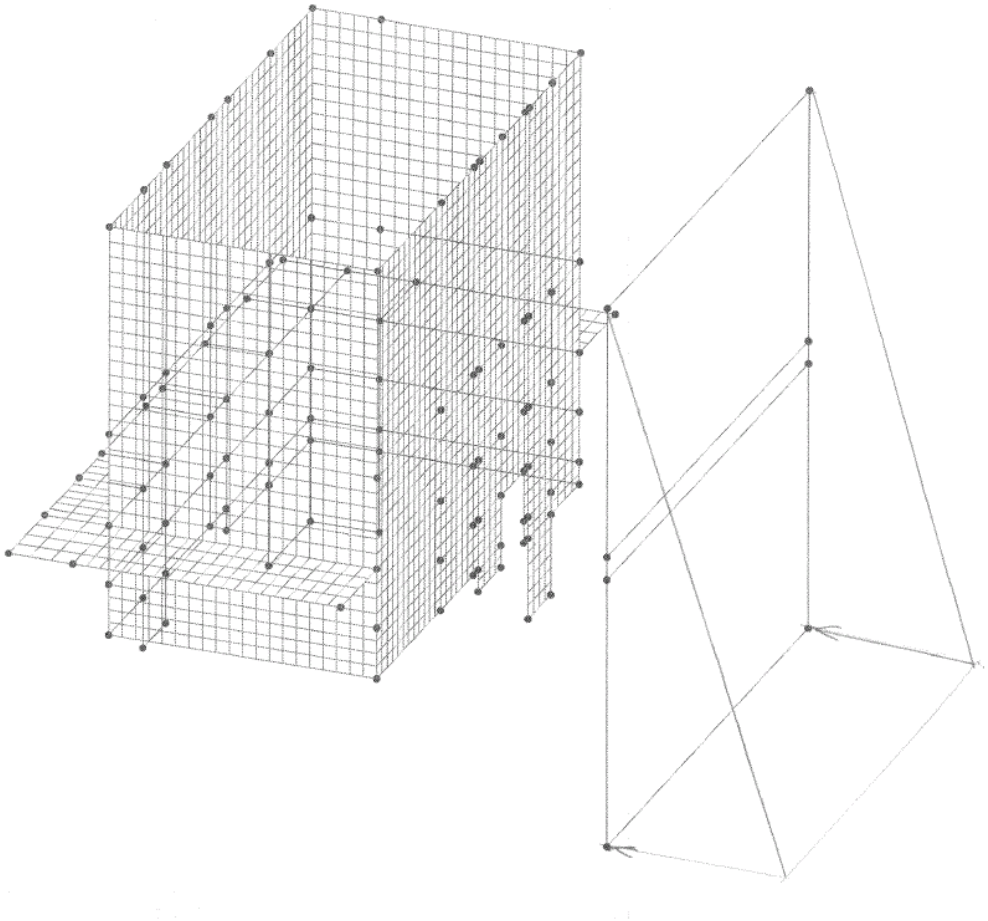
Component y direction : 236 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	10,15	-15,6	67,0	236,0
2	-12,05	-15,6	67,0	236,0
3	-12,05	-15,6	90,6	0,0
4	10,15	-15,6	90,6	0,0



3.2.4.4 Load at water level H3 against Wall 4

Loadcase : WA Wall 4 – H3

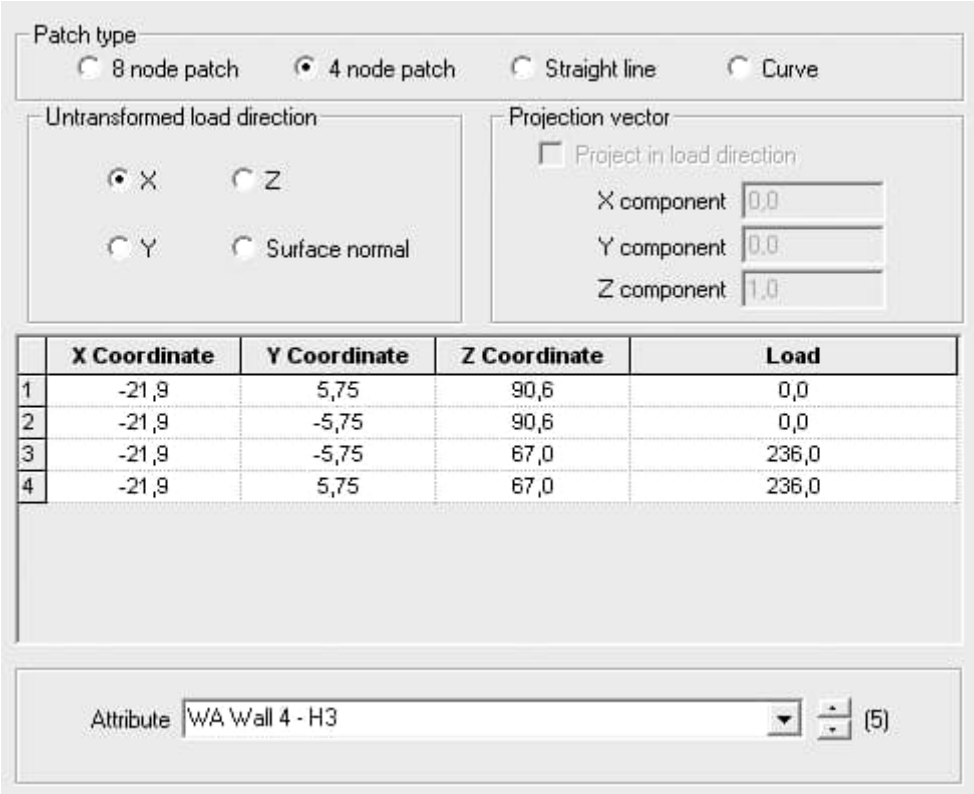
Search area : Wall 4

Force type : Per unit area

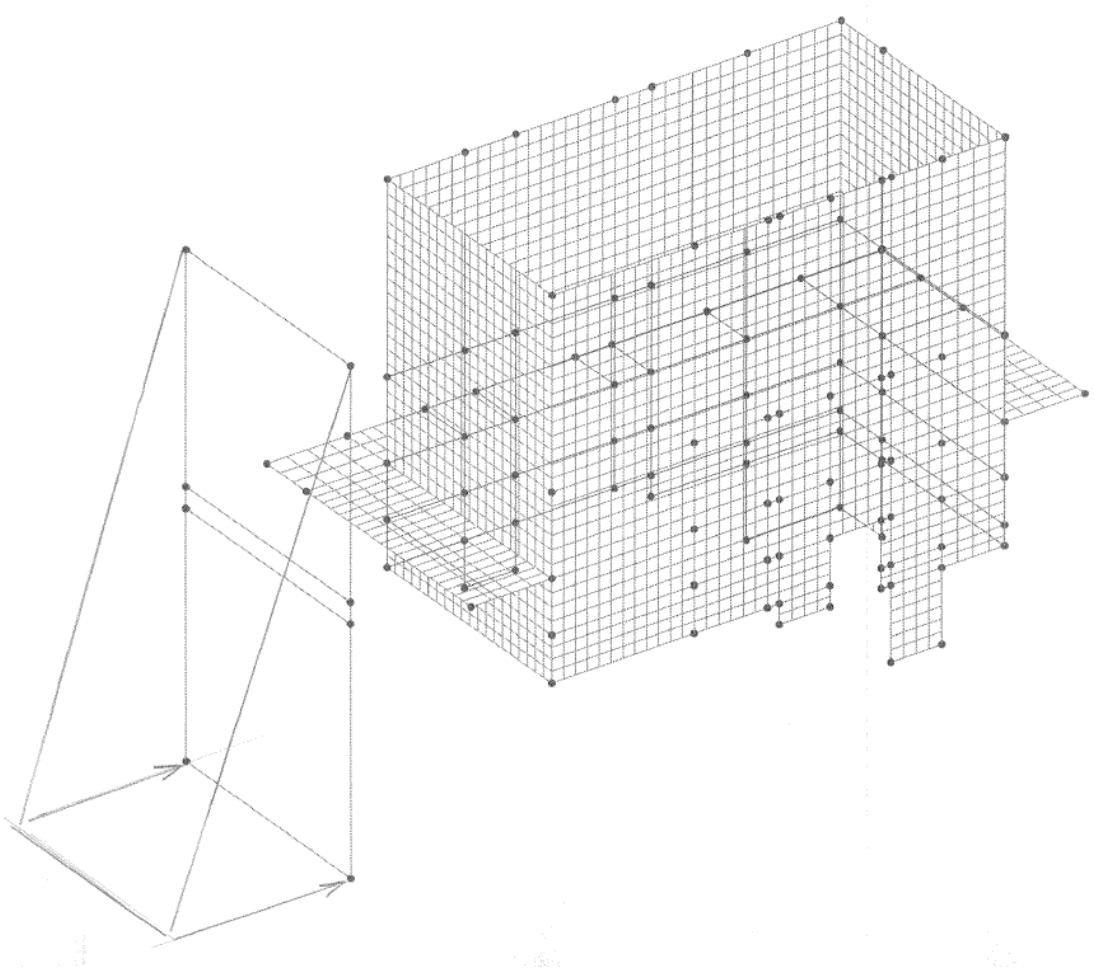
Component x direction : 236 kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	90,6	0,0
2	-21,9	-5,75	90,6	0,0
3	-21,9	-5,75	67,0	236,0
4	-21,9	5,75	67,0	236,0



3.2.5 Load combinations

Loadcombination basic : WA – H1

Loadcase	Factor
WA Wall 1 – H1	1.00
WA Wall 2 – H1	1.00
WA Wall 3 – H1	1.00
WA Wall 4 – H1	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	WA Wall 1 - H1	148	1	-1	1
2	WA Wall 2 - H1	149	1	-1	1
3	WA Wall 3 - H1	150	1	-1	1
4	WA Wall 4 - H1	151	1	-1	1

Loadcombination basic : WA – H2

Loadcase	Factor
WA Wall 1 – H2	1.00
WA Wall 2 – H2	1.00
WA Wall 3 – H2	1.00
WA Wall 4 – H2	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	WA Wall 1 - H2	156	1	-1	1
2	WA Wall 2 - H2	157	1	-1	1
3	WA Wall 3 - H2	158	1	-1	1
4	WA Wall 4 - H2	159	1	-1	1

Loadcombination basic : WA – H3

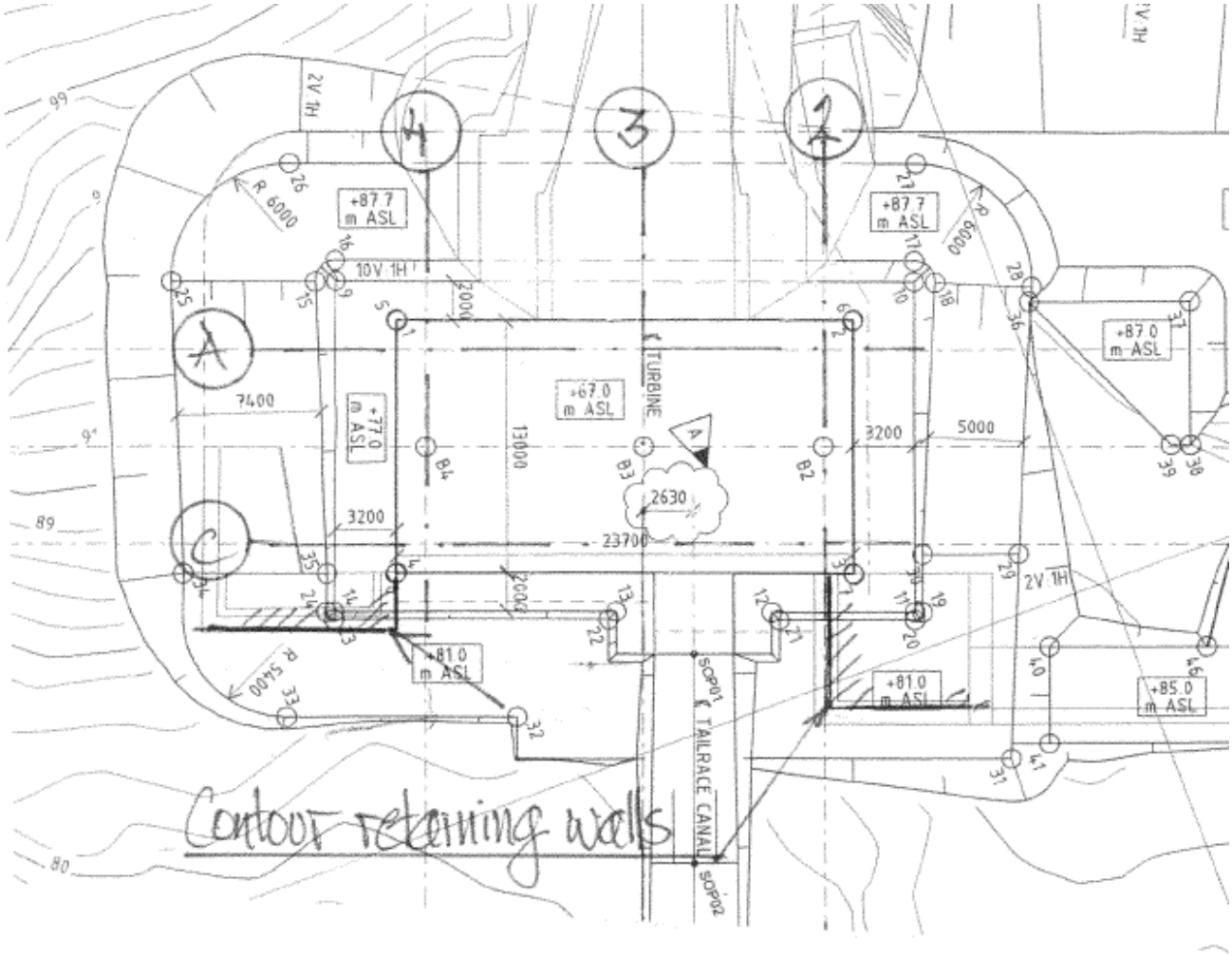
Loadcase	Factor
WA Wall 1 – H3	1.00
WA Wall 2 – H3	1.00
WA Wall 3 – H3	1.00
WA Wall 4 – H3	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	WA Wall 1 - H3	35	1	-1	1
2	WA Wall 2 - H3	118	1	-1	1
3	WA Wall 3 - H3	153	1	-1	1
4	WA Wall 4 - H3	120	1	-1	1

3.3 EARTH PRESSURE

Due to varying water flow level the following levels are studied levels H0, H1, H2 and H3.

Earth pressure is applied to structure between level +77.0 and +90.61 against wall 1.
Against wall 2 and 4 earth pressure is applied to structure between level +78.0 and +90.61.
Against 3 no earth pressure is applied due to connecting retaining walls, see sketch below.



Earth properties :

$K_0 = 1 - \sin 38^o = 0.38$

$\gamma_e = 18 \frac{kN}{m^3}$

$\gamma_e' = 11 \frac{kN}{m^3}$

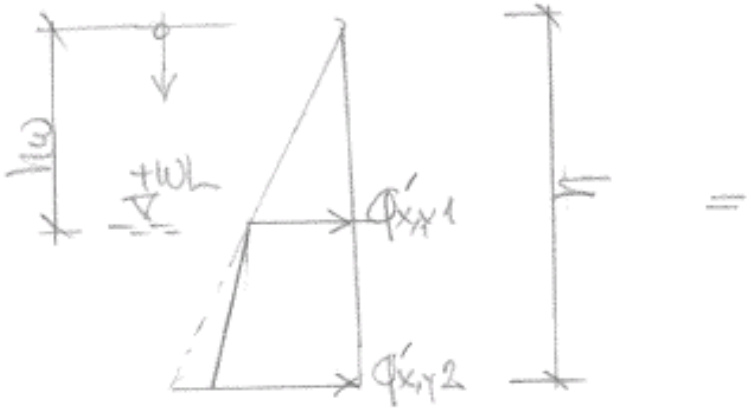
Earth pessure :

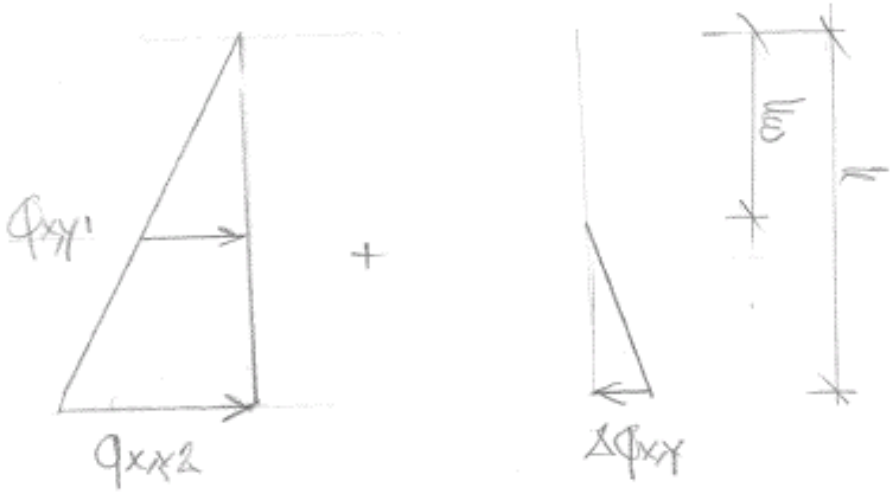
$q'_{x,y}(s) = K_0 \cdot s \cdot \gamma$: s ≤ hw

$q'_{x,y}(s) = K_0 \cdot (h_w \cdot \gamma + (s - h_w) \cdot \gamma')$: s > hw

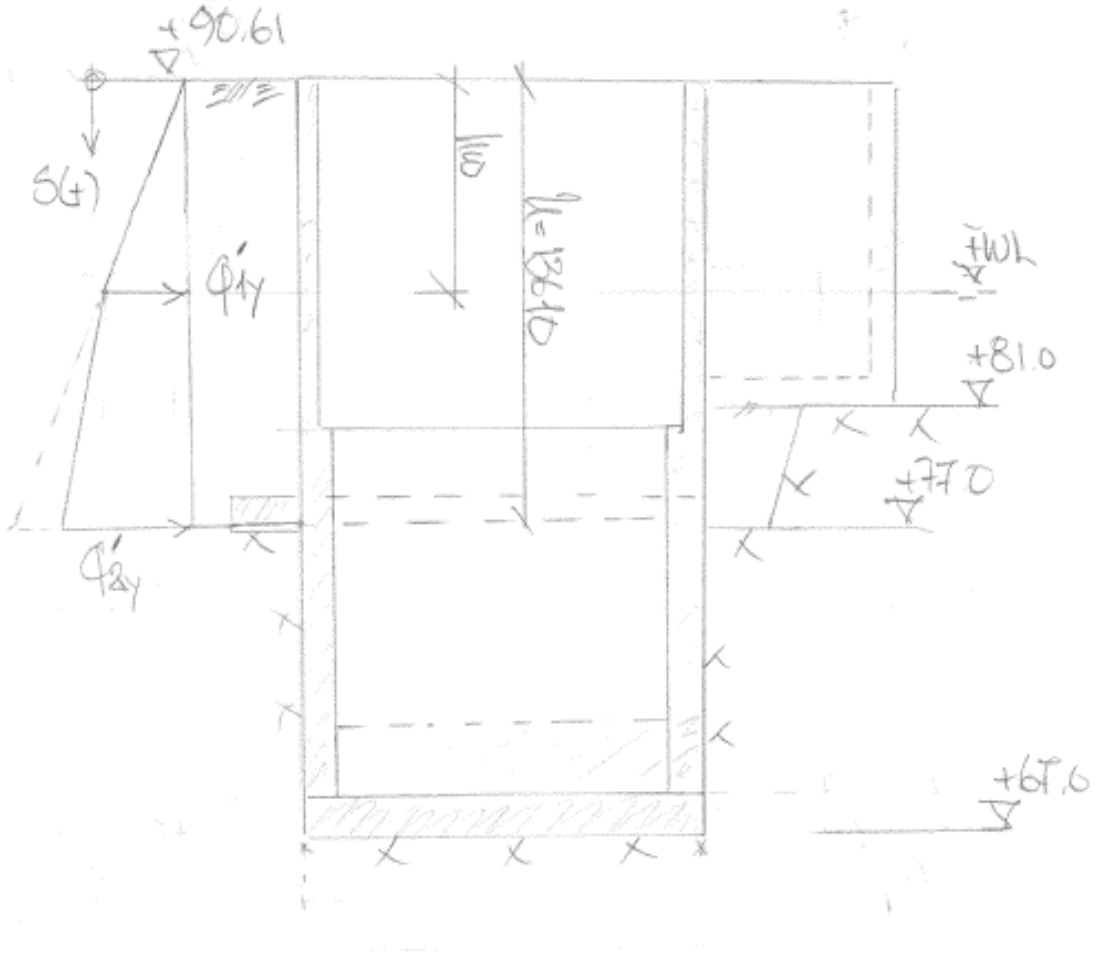
When studying the effect of varying water levels load is devided into two parts as seen below.

$q'_{x,y}(s) = q_{x,y}(s) - \Delta q_{x,y}(s)$

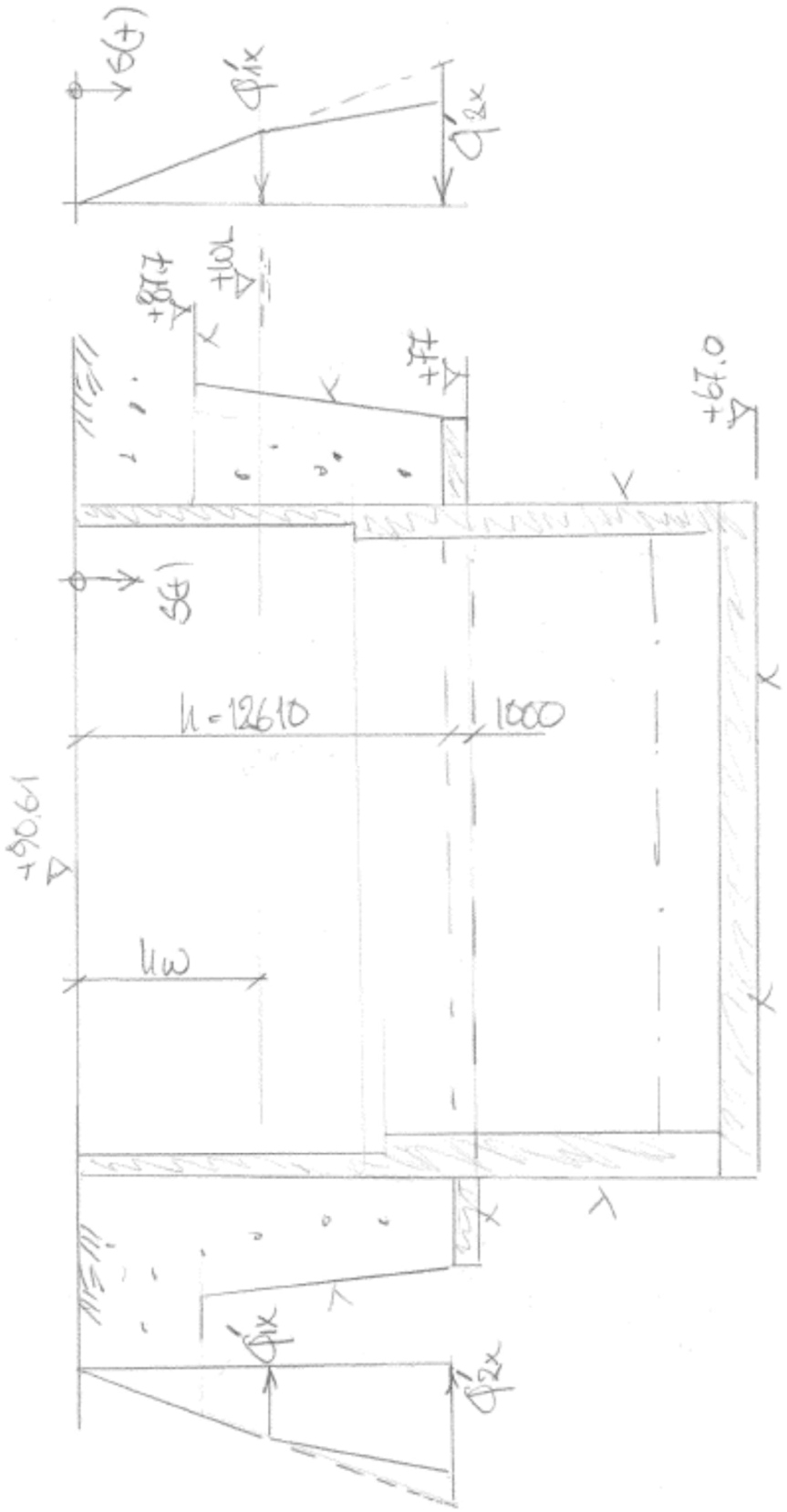




Sketch of earth pressure against Wall 1 :



Sketch of earth pressure against Wall 2 and 4 :



3.3.1 Water level H0

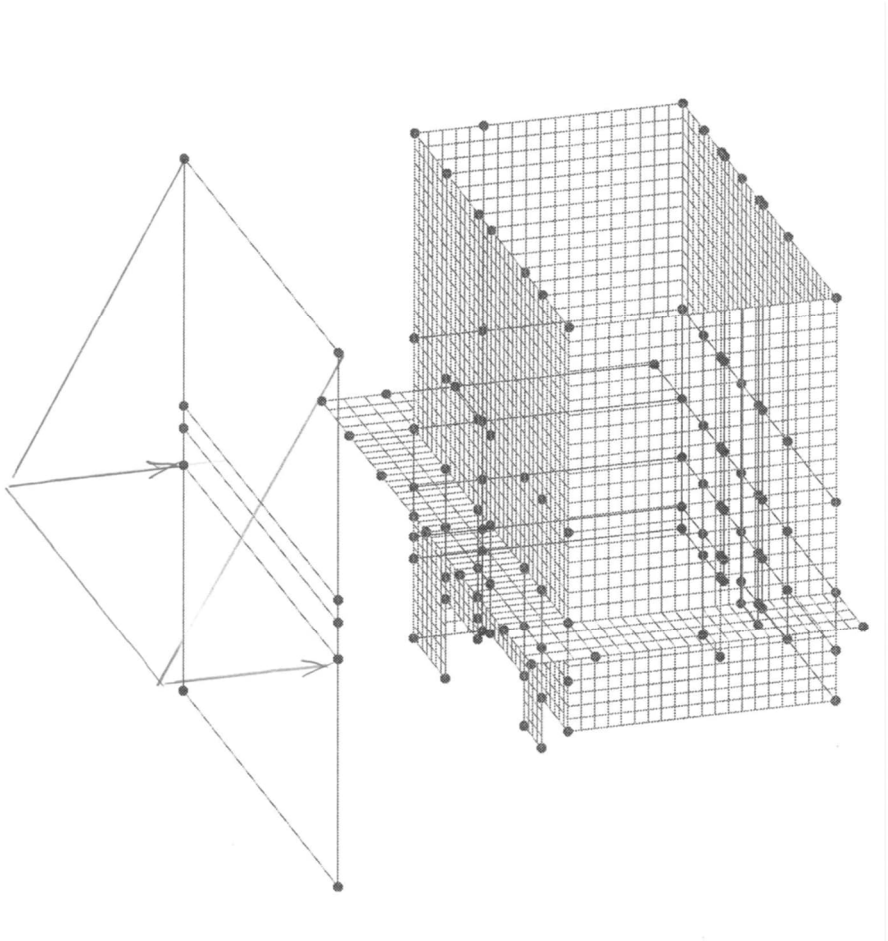
Water level H0 : +67.0

3.3.1.1 Load against wall 1

$$q_y(s = 0m) = 0kPa$$

$$q_{y1} = q_y(s = 13.61m) = (90.61m - 77.0m) \cdot 0.38 \cdot 18\frac{kN}{m^3} = 93kPa$$

$$q_{y2} = q_y(s = 13.61m) = (90.61m - 77.0m) \cdot 0.38 \cdot 18\frac{kN}{m^3} = 93kPa$$



.....

Loadcase : EH Wall 1- H0

Structural loading : Discrete patch load

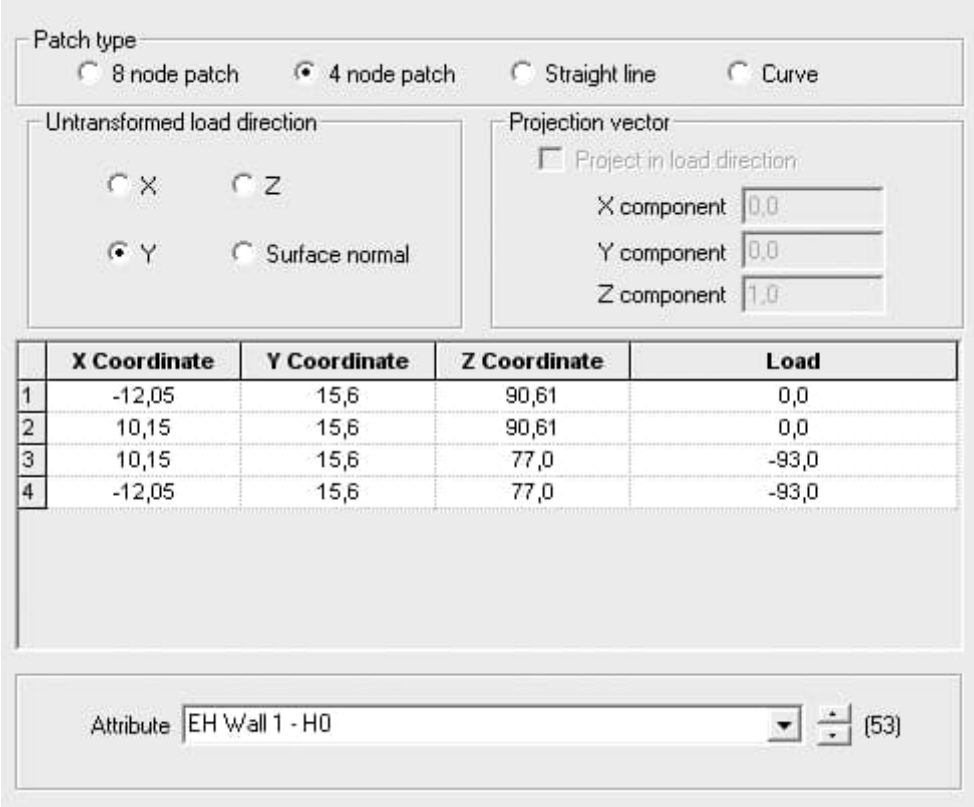
Search area : Wall 1

Force type : Per unit area

Component y direction : { 0 -93 } kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in x-direction : 20



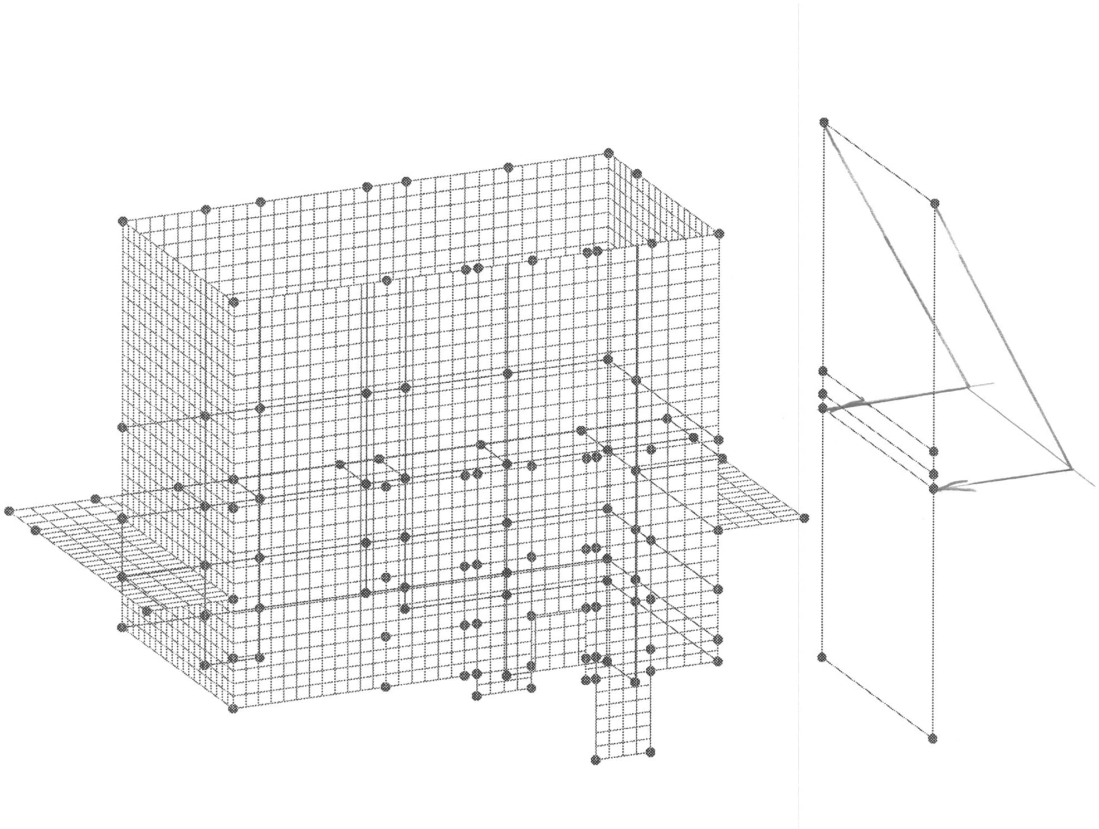
	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-12,05	15,6	90,61	0,0
2	10,15	15,6	90,61	0,0
3	10,15	15,6	77,0	-93,0
4	-12,05	15,6	77,0	-93,0

3.3.1.2 Load against wall 2

$$q_x(s = 0m) = 0kPa$$

$$q_{x1} = q_x(s = 12.61m) = (90.61m - 78.0m) \cdot 0.38 \cdot 18\frac{kN}{m^3} = 86kPa$$

$$q_{x1} = q_x(s = 12.61m) = (90.61m - 78.0m) \cdot 0.38 \cdot 18\frac{kN}{m^3} = 86kPa$$



Loadcase : EH Wall 2- H0

Structural loading : Discrete patch load

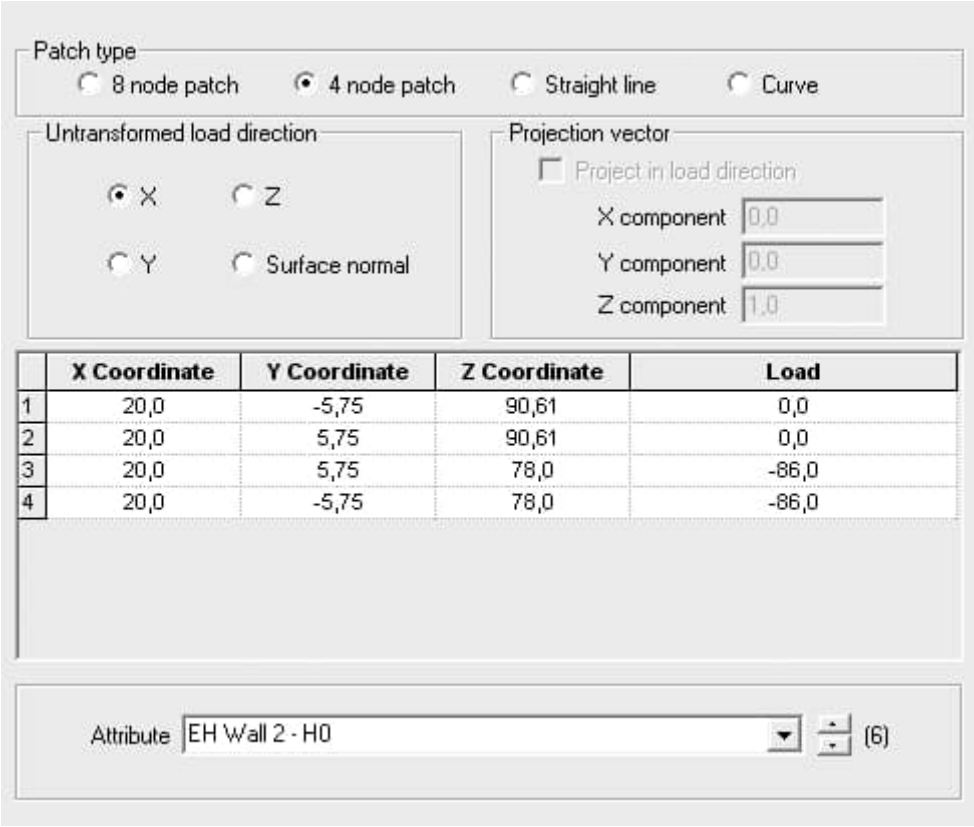
Search area : Wall 2

Force type : Per unit area

Component x direction : { 0 -86 } kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



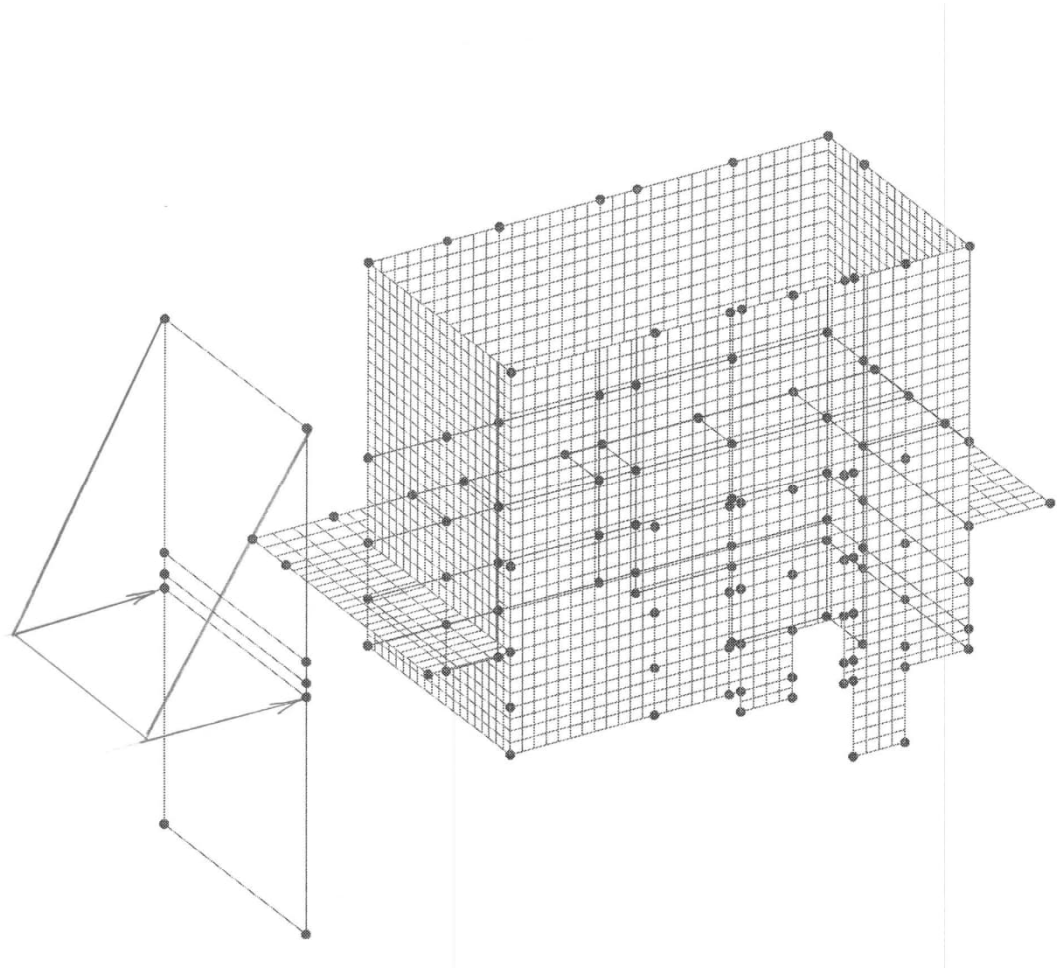
	X Coordinate	Y Coordinate	Z Coordinate	Load
1	20,0	-5,75	90,61	0,0
2	20,0	5,75	90,61	0,0
3	20,0	5,75	78,0	-86,0
4	20,0	-5,75	78,0	-86,0

3.3.1.3 Load against wall 4

$$q_x(s = 0m) = 0kPa$$

$$q_{x1} = q_x(s = 12.61m) = (90.61m - 78.0m) \cdot 0.38 \cdot 18\frac{kN}{m^3} = 86kPa$$

$$q_{x1} = q_x(s = 12.61m) = (90.61m - 78.0m) \cdot 0.38 \cdot 18\frac{kN}{m^3} = 86kPa$$



Loadcase : EH Wall 4- H0

Structural loading : Discrete patch load

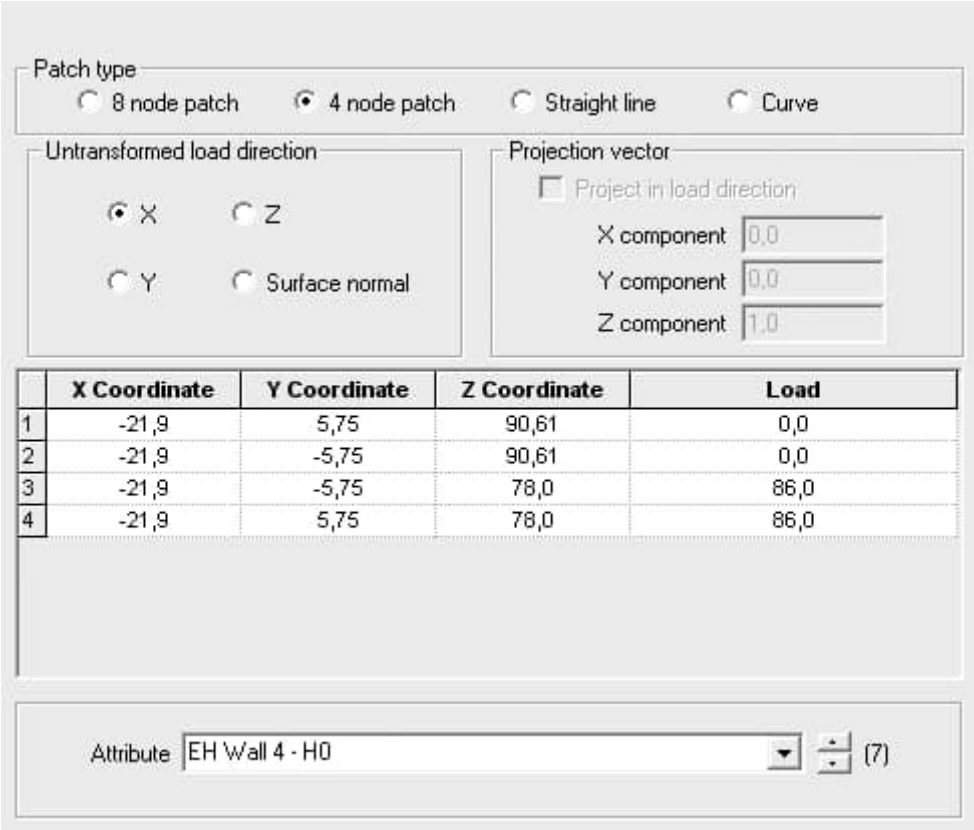
Search area : Wall 4

Force type : Per unit area

Component x direction : { 0 86 } kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	90,61	0,0
2	-21,9	-5,75	90,61	0,0
3	-21,9	-5,75	78,0	86,0
4	-21,9	5,75	78,0	86,0

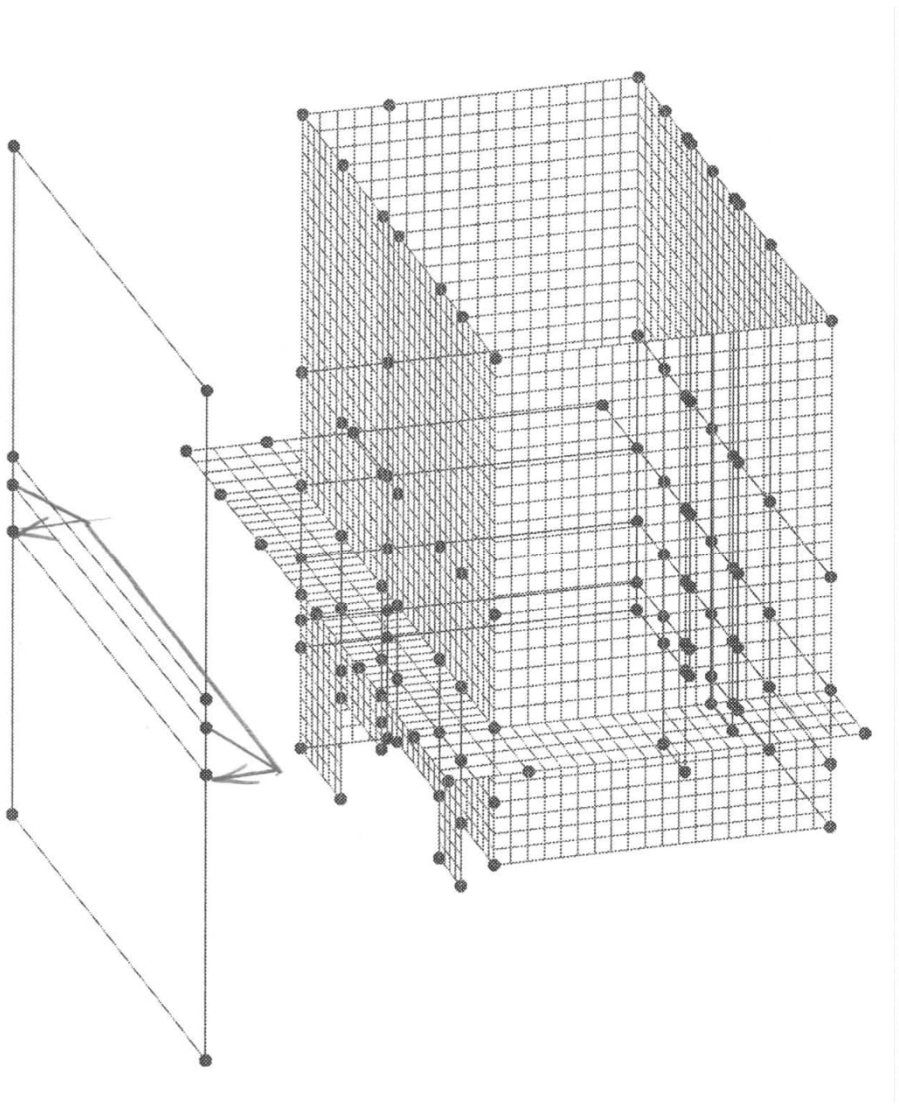
3.3.2 Water level H1

Water level H1 : +78.65

The defined load below correspond $\Delta q_{x,y}$. The total load effect is reached when applying $q_{x,y}(s)$ determined at water level H0.

3.3.2.1 Load against wall 1

$$\Delta q_y = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (78.65m - 77.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 4kPa$$



Loadcase : EH Wall 1- H1

Structural loading : Discrete patch load

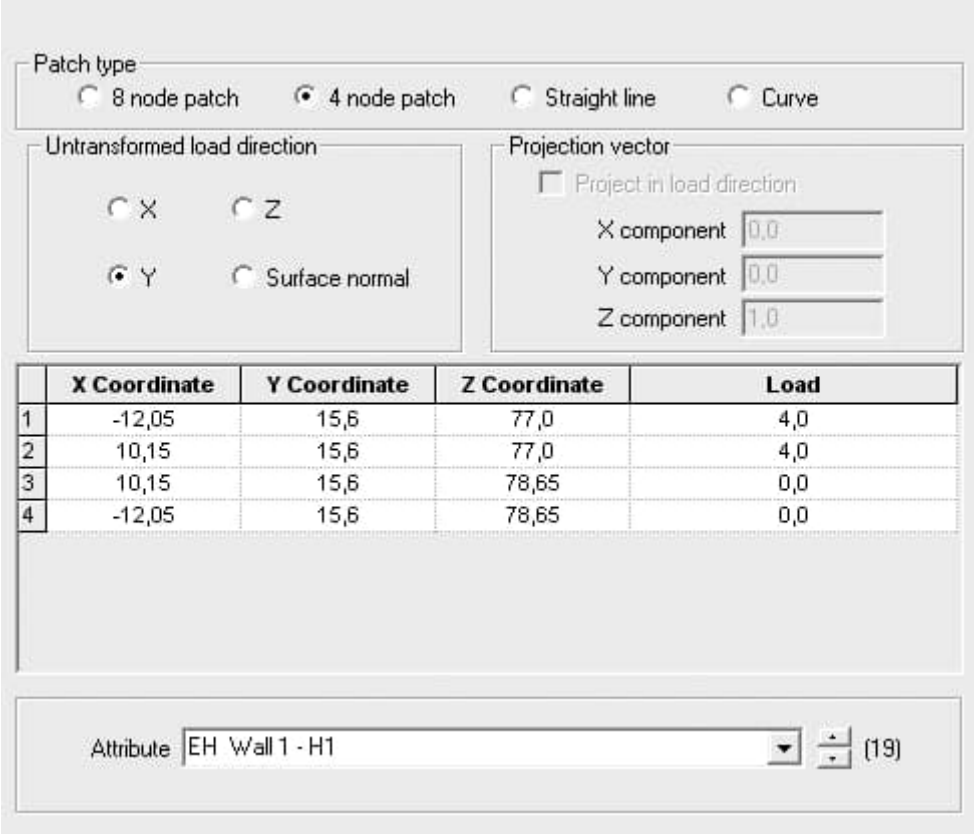
Search area : Wall 1

Force type : Per unit area

Component y direction : { 0 +4 } kPa

Options for load outside search area : Exclude All Load

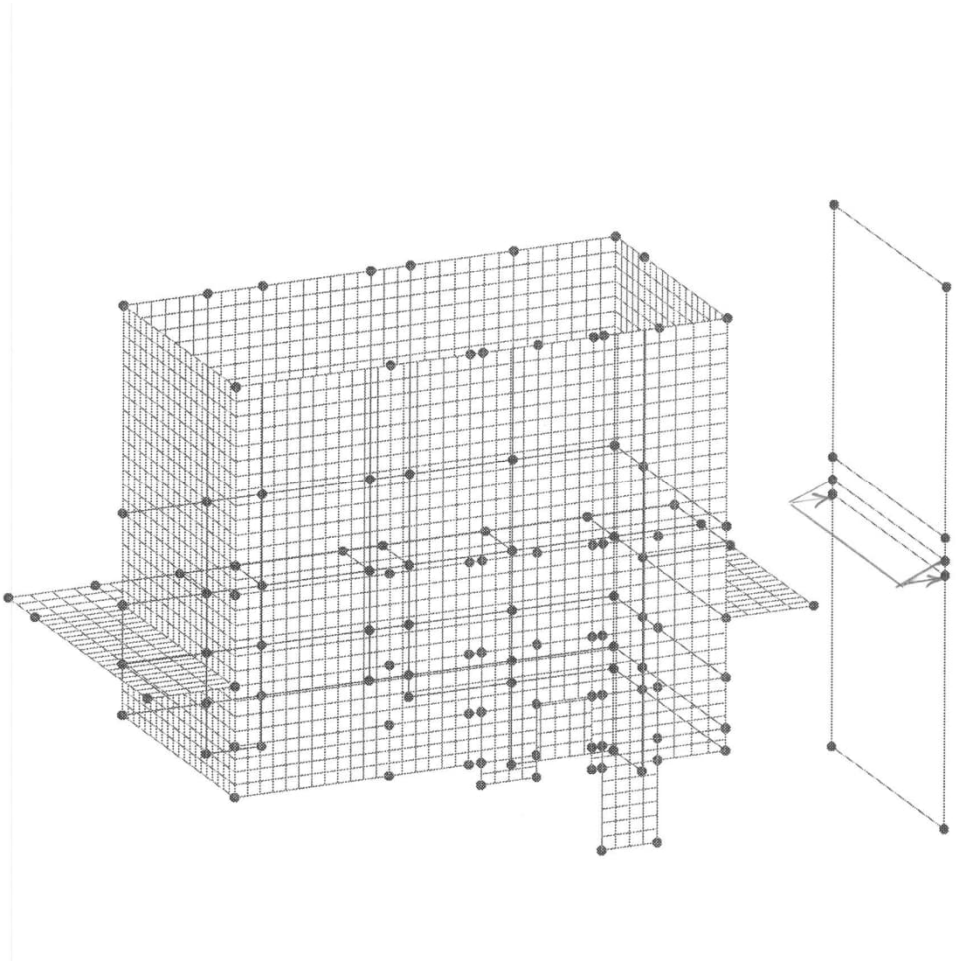
Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-12,05	15,6	77,0	4,0
2	10,15	15,6	77,0	4,0
3	10,15	15,6	78,65	0,0
4	-12,05	15,6	78,65	0,0

3.3.2.2 Load against wall 2

$$\Delta q_x = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (78.65m - 78.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 2kPa$$



Loadcase : EH Wall 2- H1

Structural loading : Discrete patch load

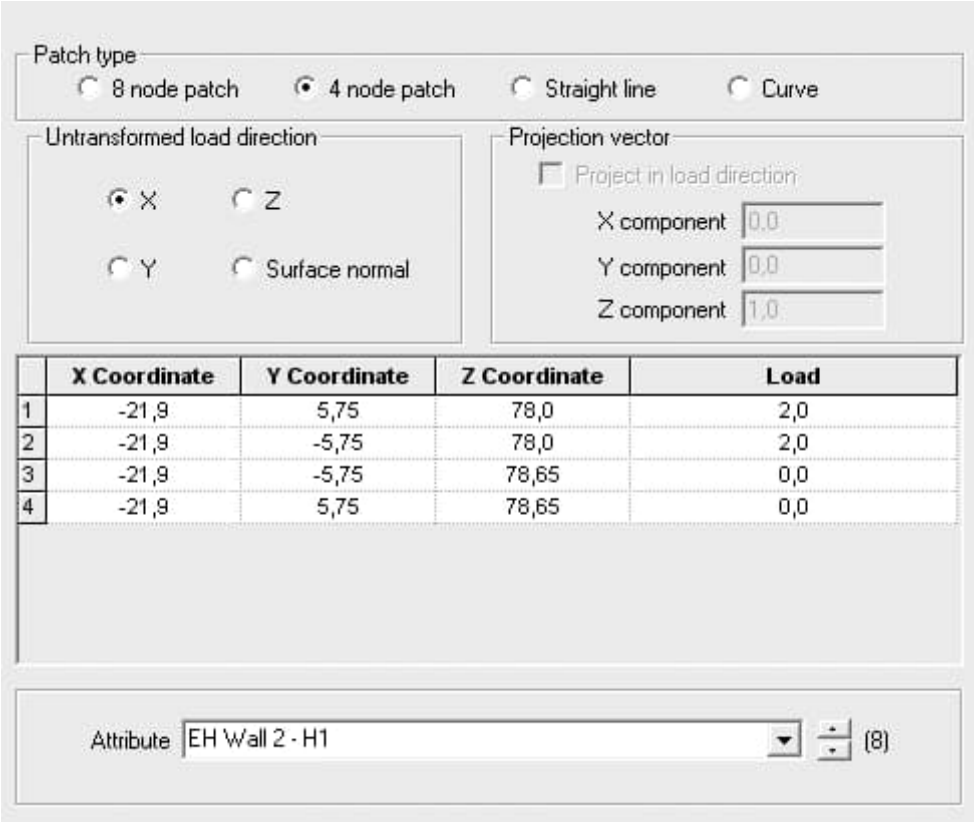
Search area : Wall 2

Force type : Per unit area

Component x direction : { 0 2 } kPa

Options for load outside search area : Exclude All Load

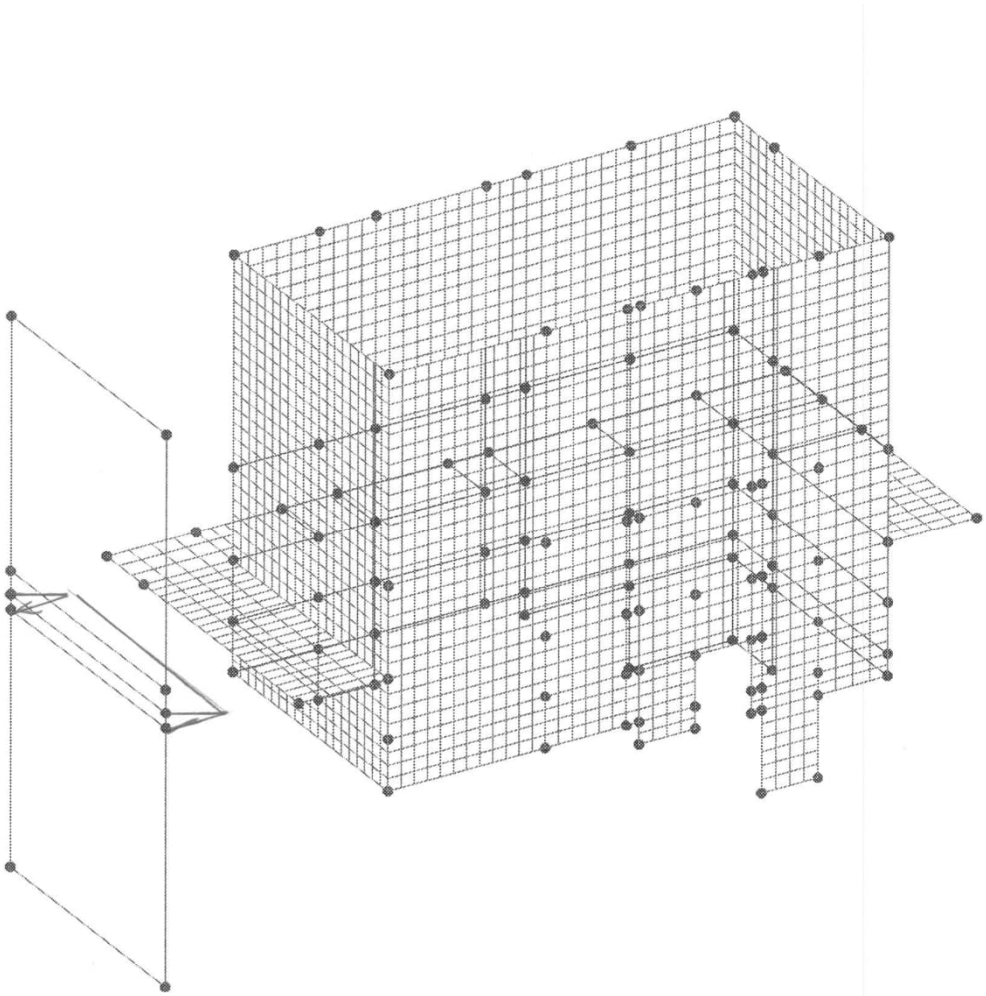
Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	78,0	2,0
2	-21,9	-5,75	78,0	2,0
3	-21,9	-5,75	78,65	0,0
4	-21,9	5,75	78,65	0,0

3.3.2.3 Load against wall 4

$$\Delta q_x = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (78.65m - 78.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 2kPa$$



Loadcase : EH Wall 4 - H0

Structural loading : Discrete patch load

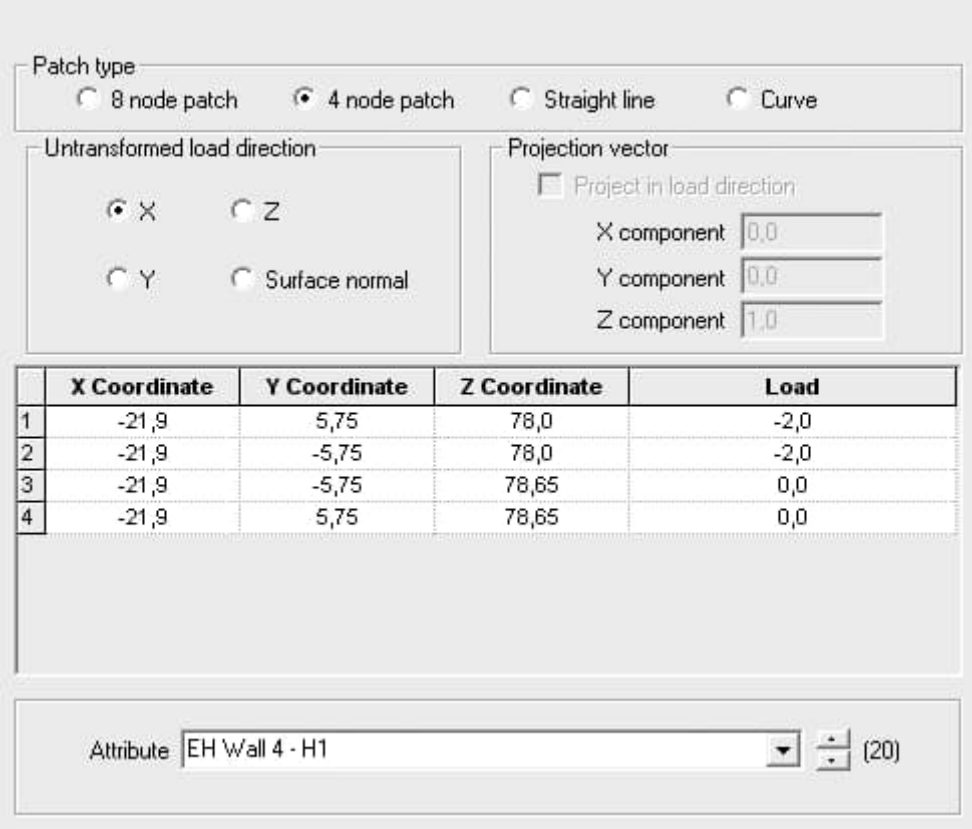
Search area : Wall 4

Force type : Per unit area

Component x direction : { 0 -2 } kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	78,0	-2,0
2	-21,9	-5,75	78,0	-2,0
3	-21,9	-5,75	78,65	0,0
4	-21,9	5,75	78,65	0,0

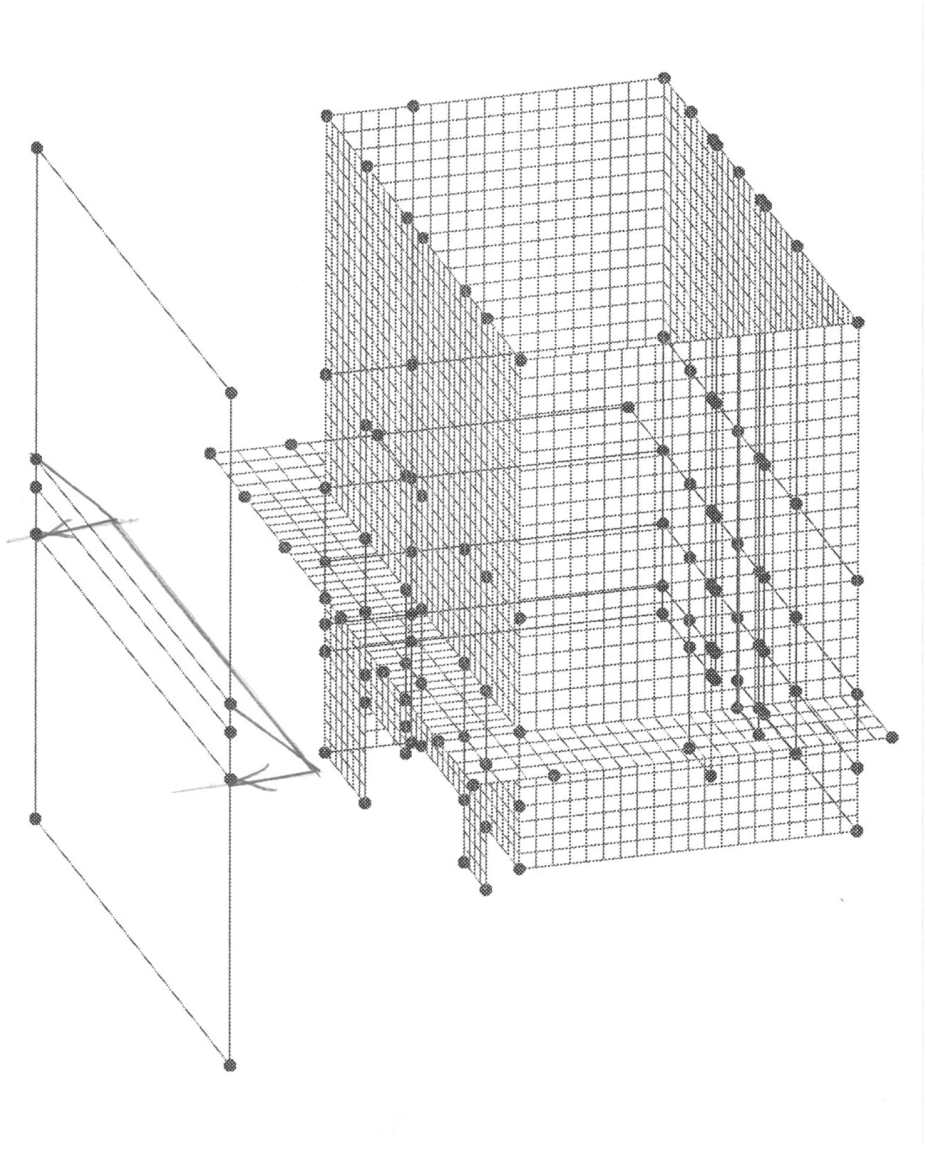
3.3.3 Water level H2

Water level H2 : +79.65

The defined load below correspond $\Delta q_{x,y}$. The total load effect is reached when applying $q_{x,y}(s)$ determined at water level H0.

3.3.3.1 Load against wall 1

$$\Delta q_y = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (79.65m - 77.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 7kPa$$



Loadcase : EH Wall 1- H2

Structural loading : Discrete patch load

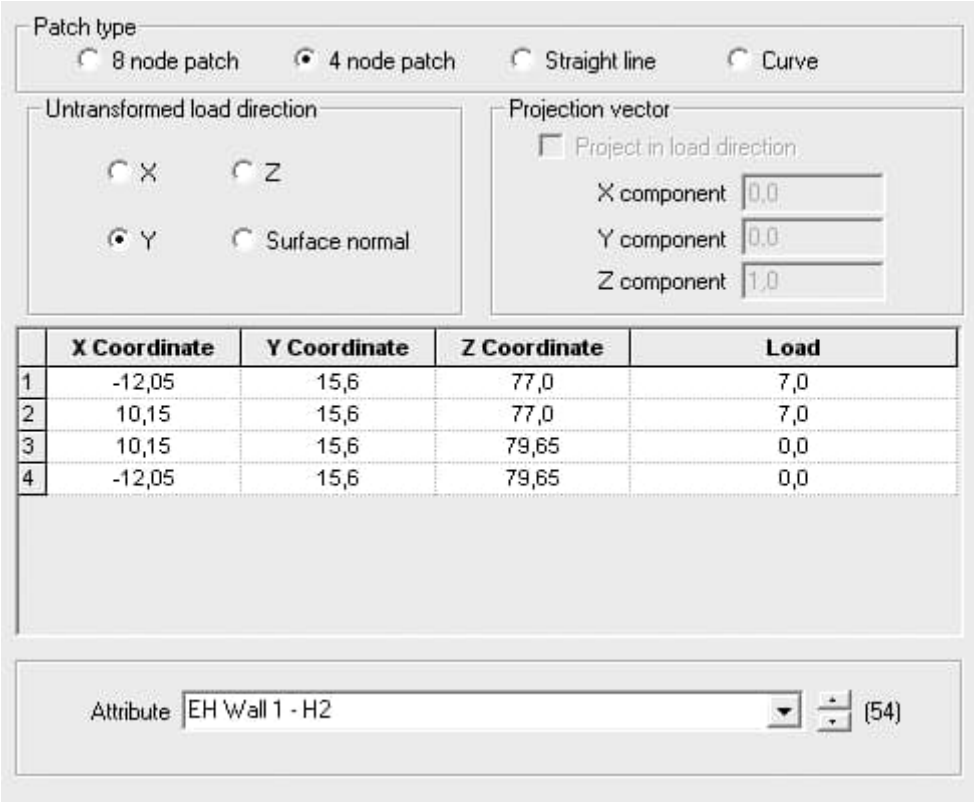
Search area : Wall 1

Force type : Per unit area

Component y direction : { 0 +7 } kPa

Options for load outside search area : Exclude All Load

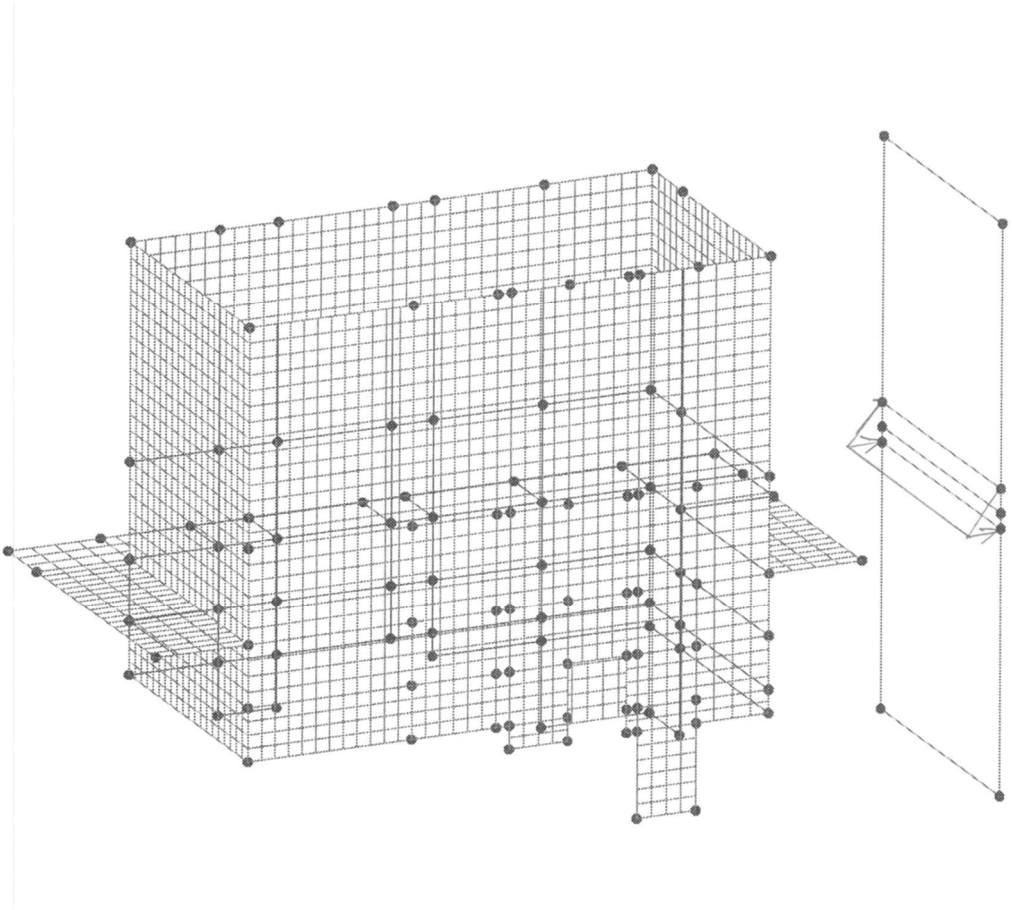
Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-12,05	15,6	77,0	7,0
2	10,15	15,6	77,0	7,0
3	10,15	15,6	79,65	0,0
4	-12,05	15,6	79,65	0,0

3.3.3.2 Load against wall 2

$$\Delta q_x = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (79.65m - 78.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 4kPa$$



Loadcase : EH Wall 2- H2

Structural loading : Discrete patch load

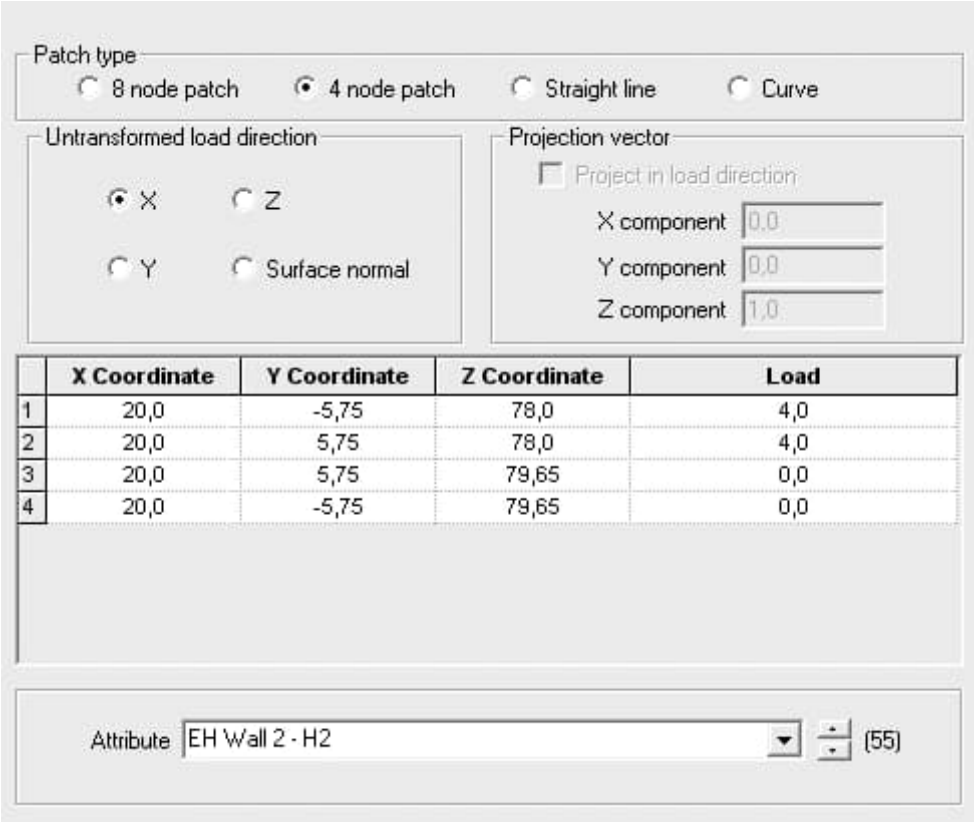
Search area : Wall 2

Force type : Per unit area

Component x direction : { 0 4 } kPa

Options for load outside search area : Exclude All Load

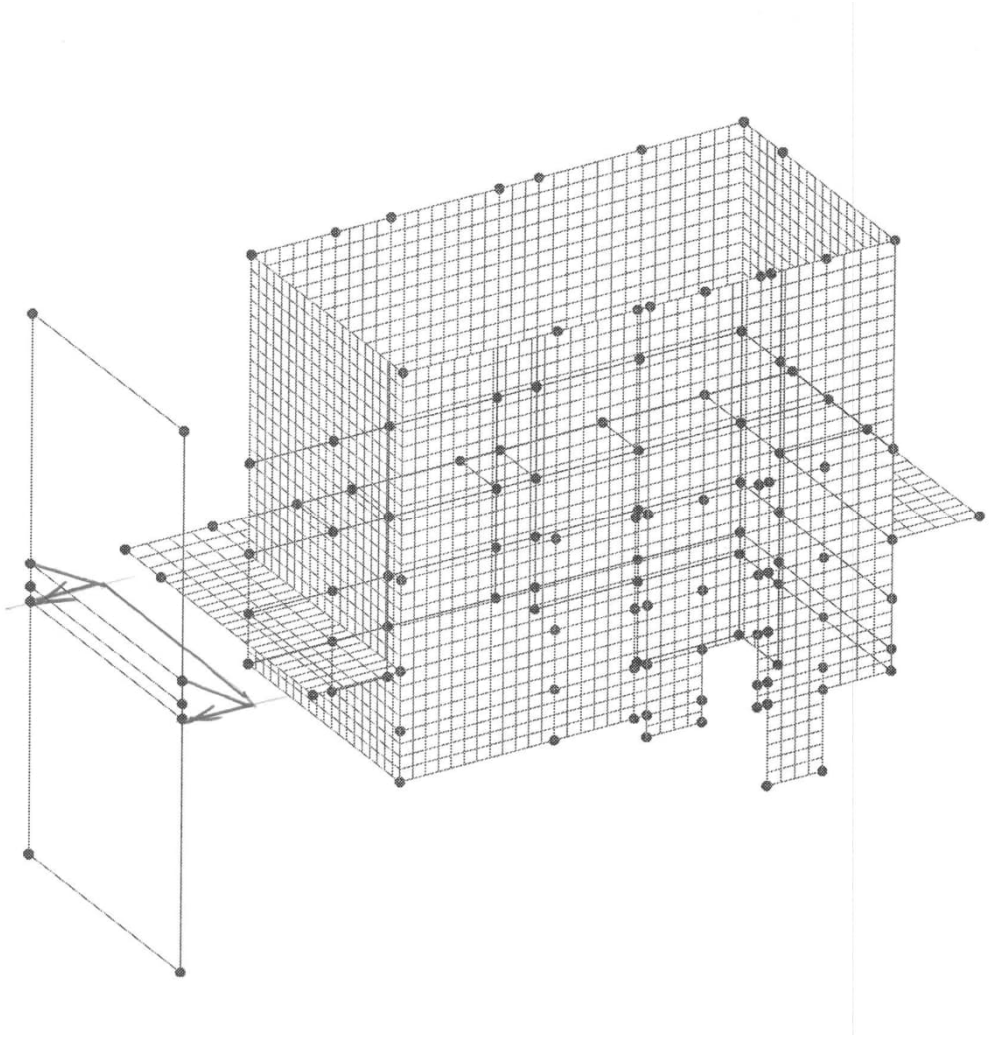
Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	20,0	-5,75	78,0	4,0
2	20,0	5,75	78,0	4,0
3	20,0	5,75	79,65	0,0
4	20,0	-5,75	79,65	0,0

3.3.3.3 Load against wall 4

$$\Delta q_x = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (79.65m - 78.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 4kPa$$



Loadcase : EH Wall 4 – H2

Structural loading : Discrete patch load

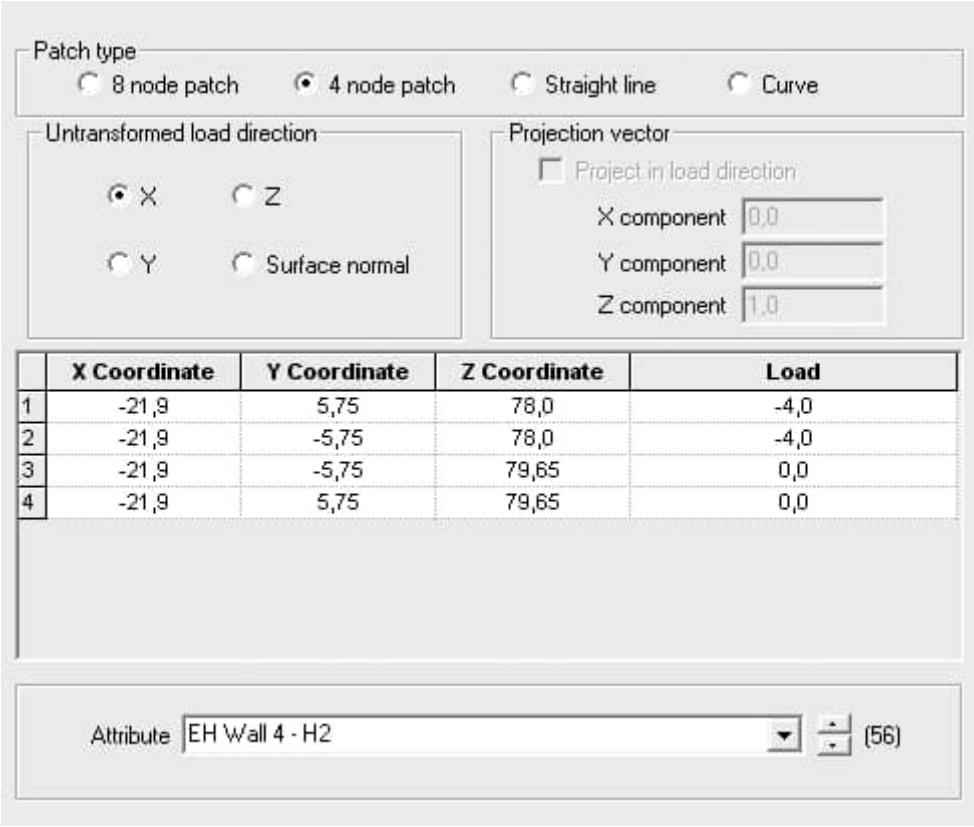
Search area : Wall 4

Force type : Per unit area

Component x direction : { 0 -4 } kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	78,0	-4,0
2	-21,9	-5,75	78,0	-4,0
3	-21,9	-5,75	79,65	0,0
4	-21,9	5,75	79,65	0,0

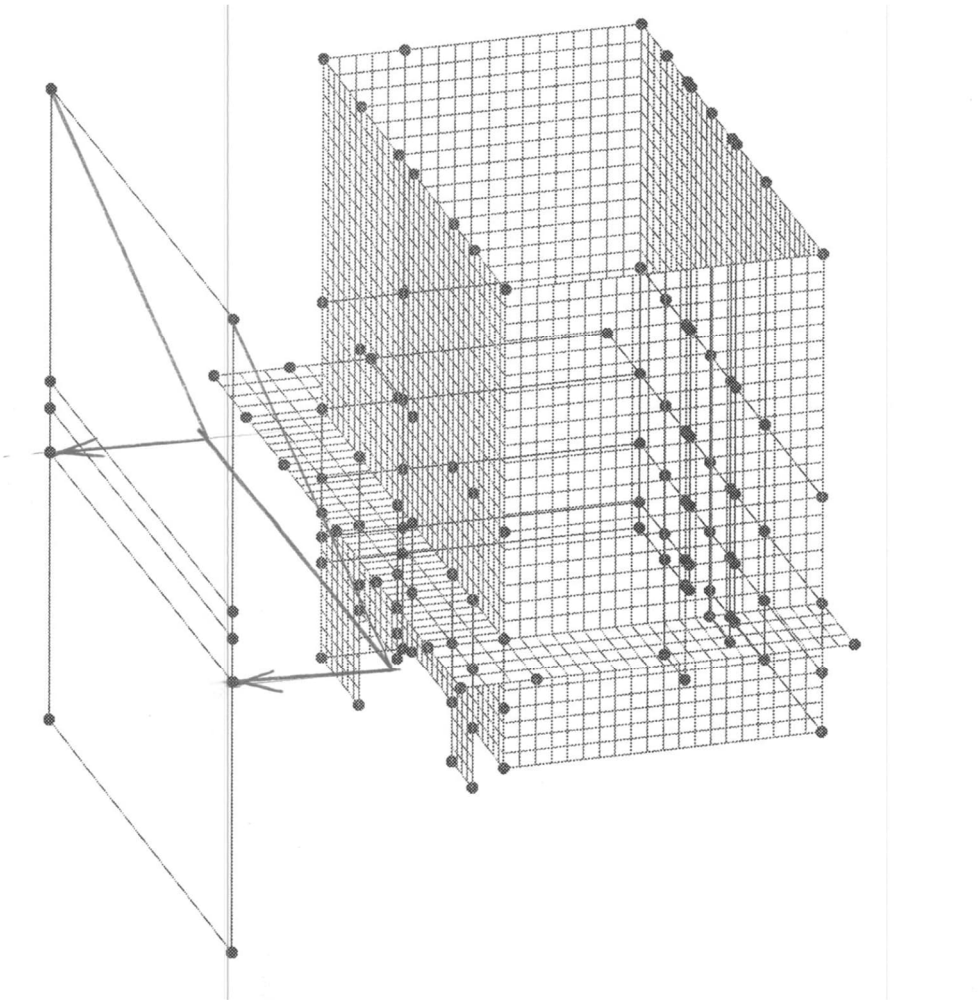
3.3.4 Water level H3

Water level H3 : +90.60

The defined load below correspond $\Delta q_{x,y}$. The total load effect is reached when applying $q_{x,y}(s)$ determined at water level H0.

3.3.4.1 Load against wall 1

$$\Delta q_y = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (90.6m - 77.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 36kPa$$



Loadcase : EH Wall 1- H3

Structural loading : Discrete patch load

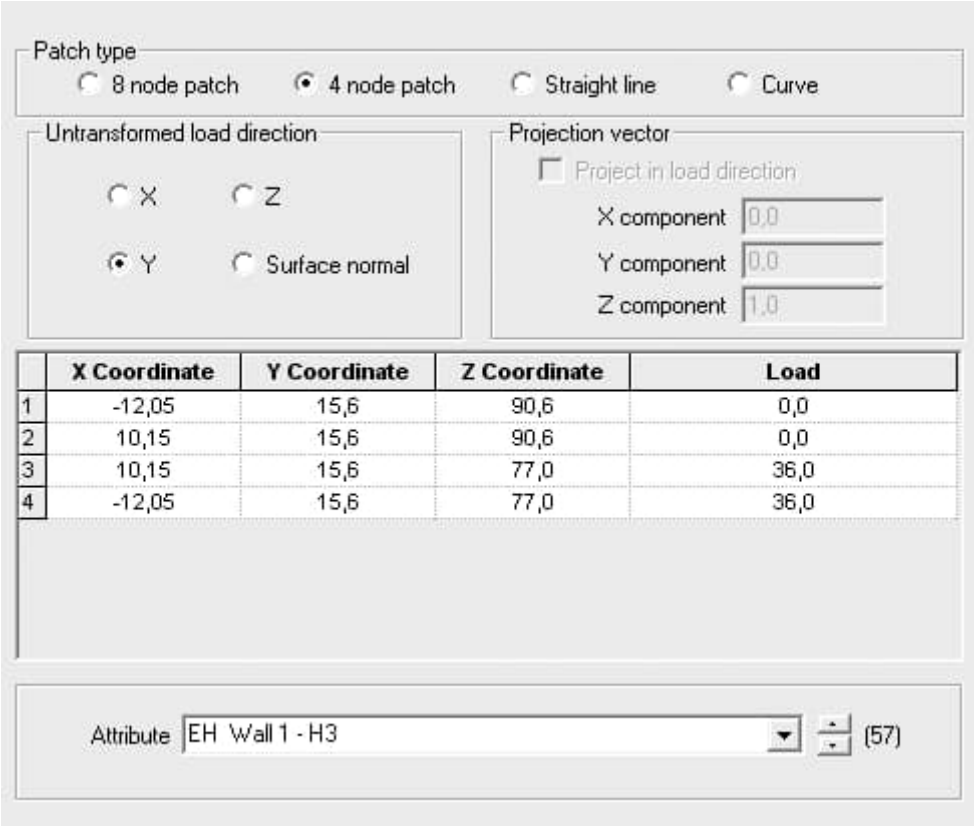
Search area : Wall 1

Force type : Per unit area

Component y direction : { 0 +36 } kPa

Options for load outside search area : Exclude All Load

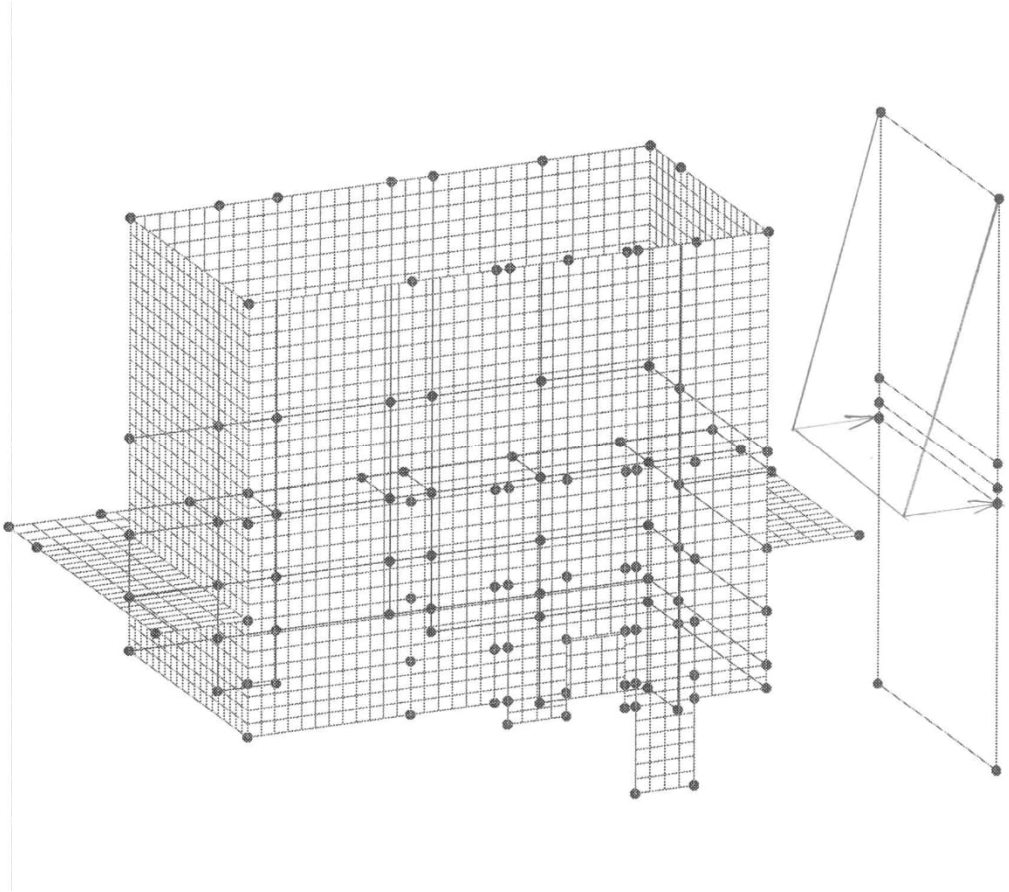
Divisions of patch load in x-direction : 20



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-12,05	15,6	90,6	0,0
2	10,15	15,6	90,6	0,0
3	10,15	15,6	77,0	36,0
4	-12,05	15,6	77,0	36,0

3.3.4.2 Load against wall 2

$$\Delta q_x = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (90.6m - 78.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 35kPa$$



Loadcase : EH Wall 2- H3

Structural loading : Discrete patch load

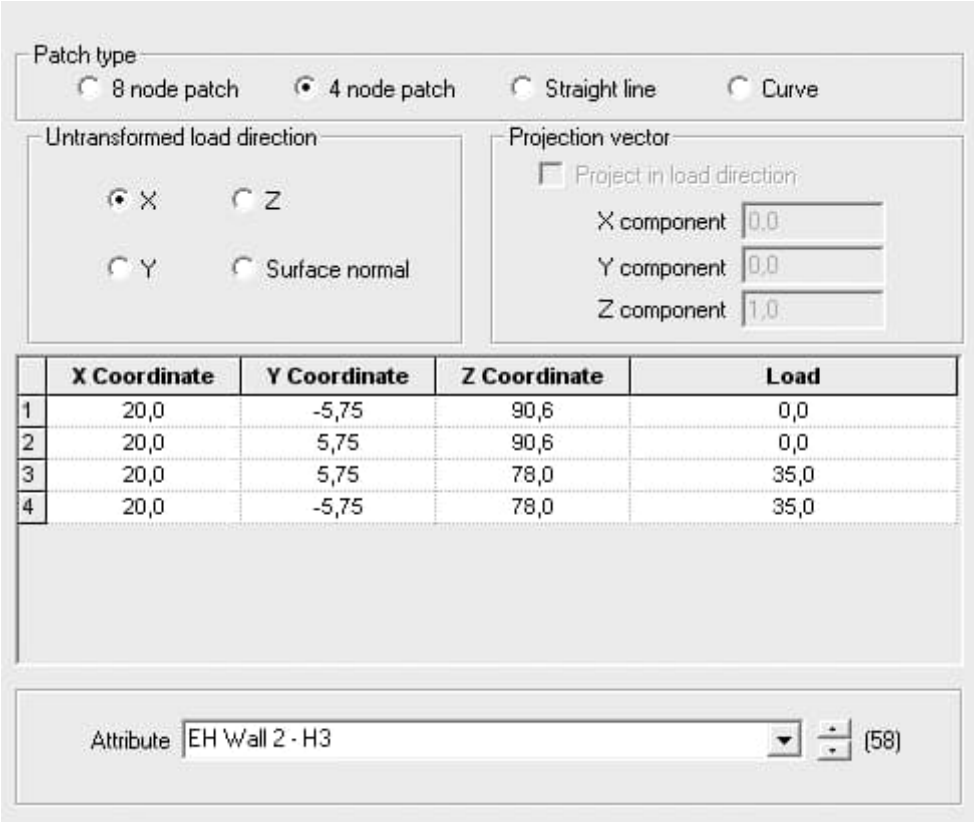
Search area : Wall 2

Force type : Per unit area

Component x direction : { 0 35 } kPa

Options for load outside search area : Exclude All Load

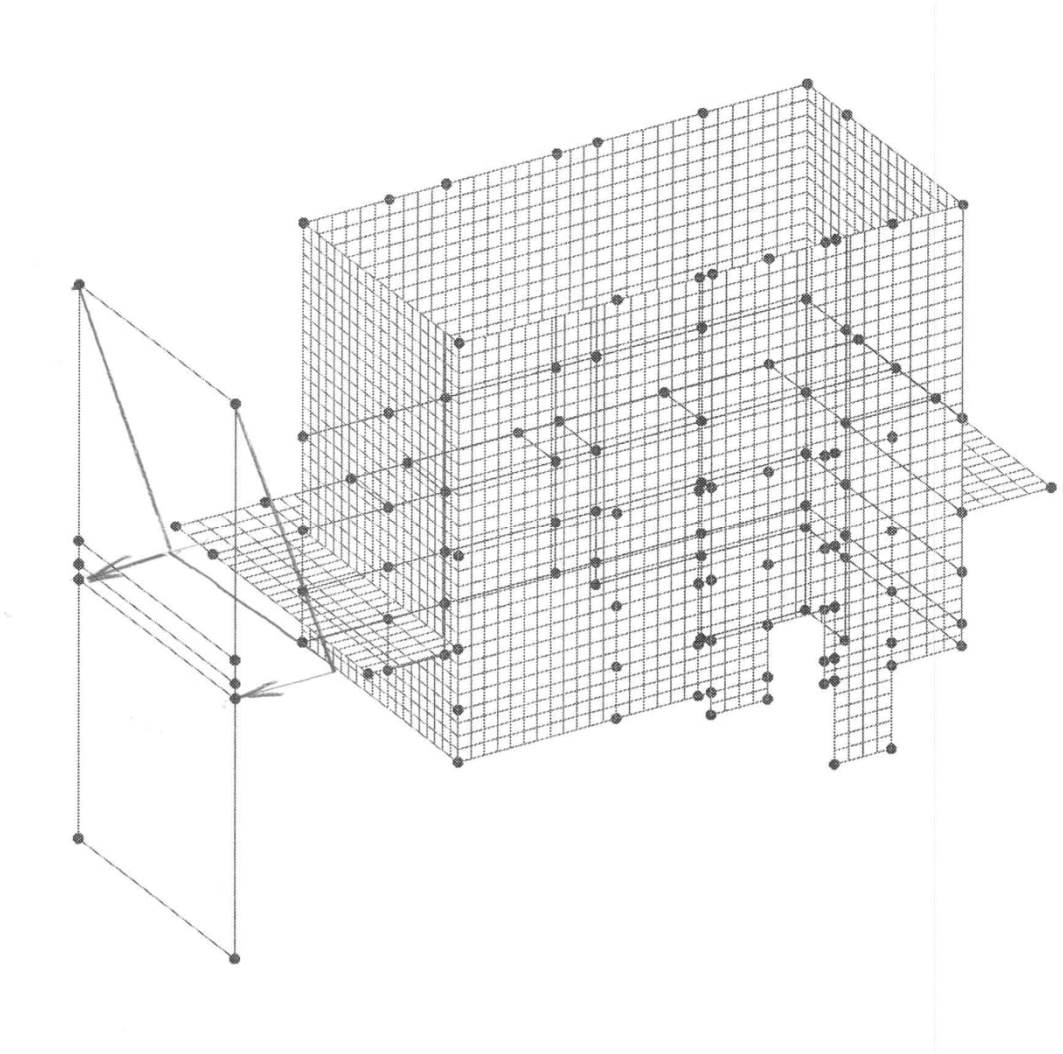
Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	20,0	-5,75	90,6	0,0
2	20,0	5,75	90,6	0,0
3	20,0	5,75	78,0	35,0
4	20,0	-5,75	78,0	35,0

3.3.4.3 Load against wall 4

$$\Delta q_x = (h - h_w) \cdot K_0 \cdot (\gamma_e - \gamma'_e) = (90.6m - 78.0m) \cdot 0.38 \cdot (18\frac{kN}{m^3} - 11\frac{kN}{m^3}) = 35kPa$$



Loadcase : EH Wall 4 – H3

Structural loading : Discrete patch load

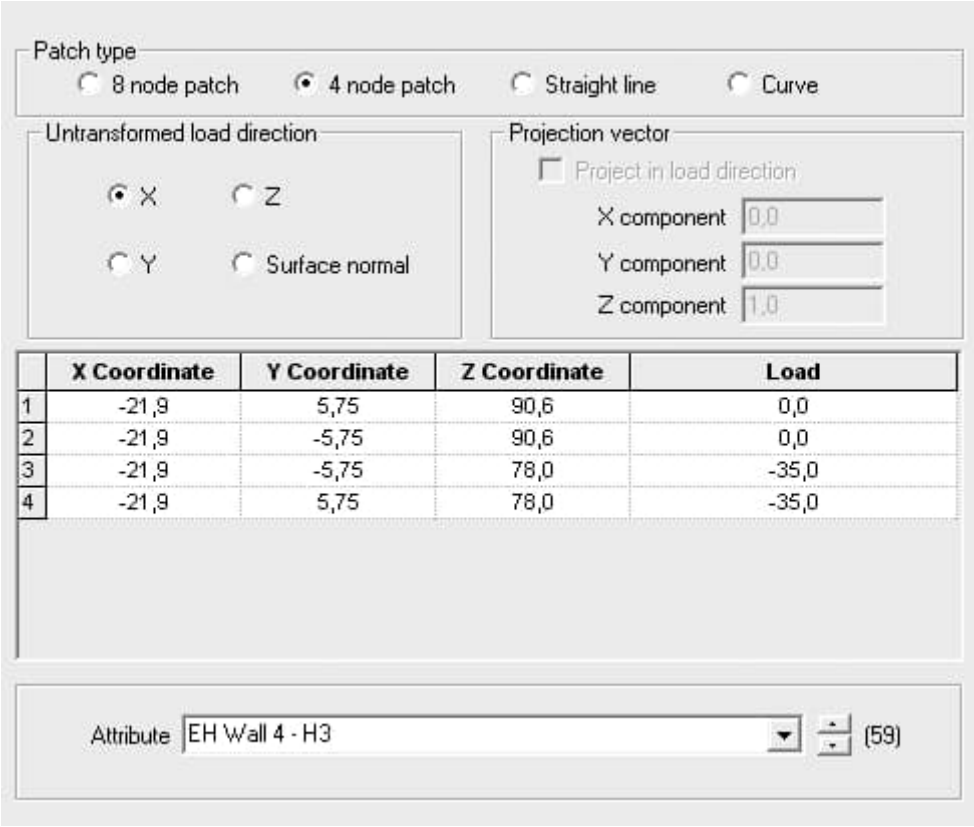
Search area : Wall 4

Force type : Per unit area

Component x direction : { 0 -35 } kPa

Options for load outside search area : Exclude All Load

Divisions of patch load in y-direction : 10



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	90,6	0,0
2	-21,9	-5,75	90,6	0,0
3	-21,9	-5,75	78,0	-35,0
4	-21,9	5,75	78,0	-35,0

3.3.5 Load combinations

Load combination basic : EH - H0

Loadcase	Factor
EH Wall 1- H0	1.00
EH Wall 2- H0	1.00
EH Wall 4 –H0	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	EH Wall 1 - H0	161	1	-1	1
2	EH Wall 2 - H0	163	1	-1	1
3	EH Wall 4 - H0	164	1	-1	1

Load combination basic : EH – H1

Loadcase	Factor
EH Wall 1- H0	1.00
EH Wall 2- H0	1.00
EH Wall 4 –H0	1.00
EH Wall 1- H1	1.00
EH Wall 2- H1	1.00
EH Wall 4 -H1	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	EH Wall 1 - H0	161	1	-1	1
2	EH Wall 2 - H0	163	1	-1	1
3	EH Wall 4 - H0	164	1	-1	1
4	EH Wall 1 - H1	165	1	-1	1
5	EH Wall 2 - H1	166	1	-1	1
6	EH Wall 4 - H1	167	1	-1	1

Load combination basic : EH – H2

Loadcase	Factor
EH Wall 1- H0	1.00
EH Wall 2- H0	1.00
EH Wall 4 –H0	1.00
EH Wall 1- H2	1.00
EH Wall 2- H2	1.00
EH Wall 4 –H2	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	EH Wall 1 - H0	161	1	-1	1
2	EH Wall 2 - H0	163	1	-1	1
3	EH Wall 4 - H0	164	1	-1	1
4	EH Wall 1 - H2	168	1	-1	1
5	EH Wall 2 - H2	169	1	-1	1
6	EH Wall 4 - H2	170	1	-1	1

Load combination basic : EH – H3

Loadcase	Factor
EH Wall 1- H0	1.00
EH Wall 2- H0	1.00
EH Wall 4 –H0	1.00
EH Wall 1- H3	1.00
EH Wall 2- H3	1.00
EH Wall 4 –H3	1.00

	Name	Loadcase	Results File	Eigenvalue	Factor
1	EH Wall 1 - H0	161	1	-1	1
2	EH Wall 2 - H0	163	1	-1	1
3	EH Wall 4 - H0	164	1	-1	1
4	EH Wall 1 - H3	171	1	-1	1
5	EH Wall 2 - H3	172	1	-1	1
6	EH Wall 4 - H3	173	1	-1	1

3.4 SURCHARGE

Surcharge is applied to structure between level +77.00 and +90.61 against wall 1.
Against wall 2 and 4 surcharge is applied to structure between level +78.00 and +90.61.
Against wall 3 no surcharge is applied due to connecting retaining walls (compare with load earth pressure).

Surcharges is applied continuously along all sides but independently. The assumption is as considered as on the safe side with regard to stressed in wall structure.

Load properties :

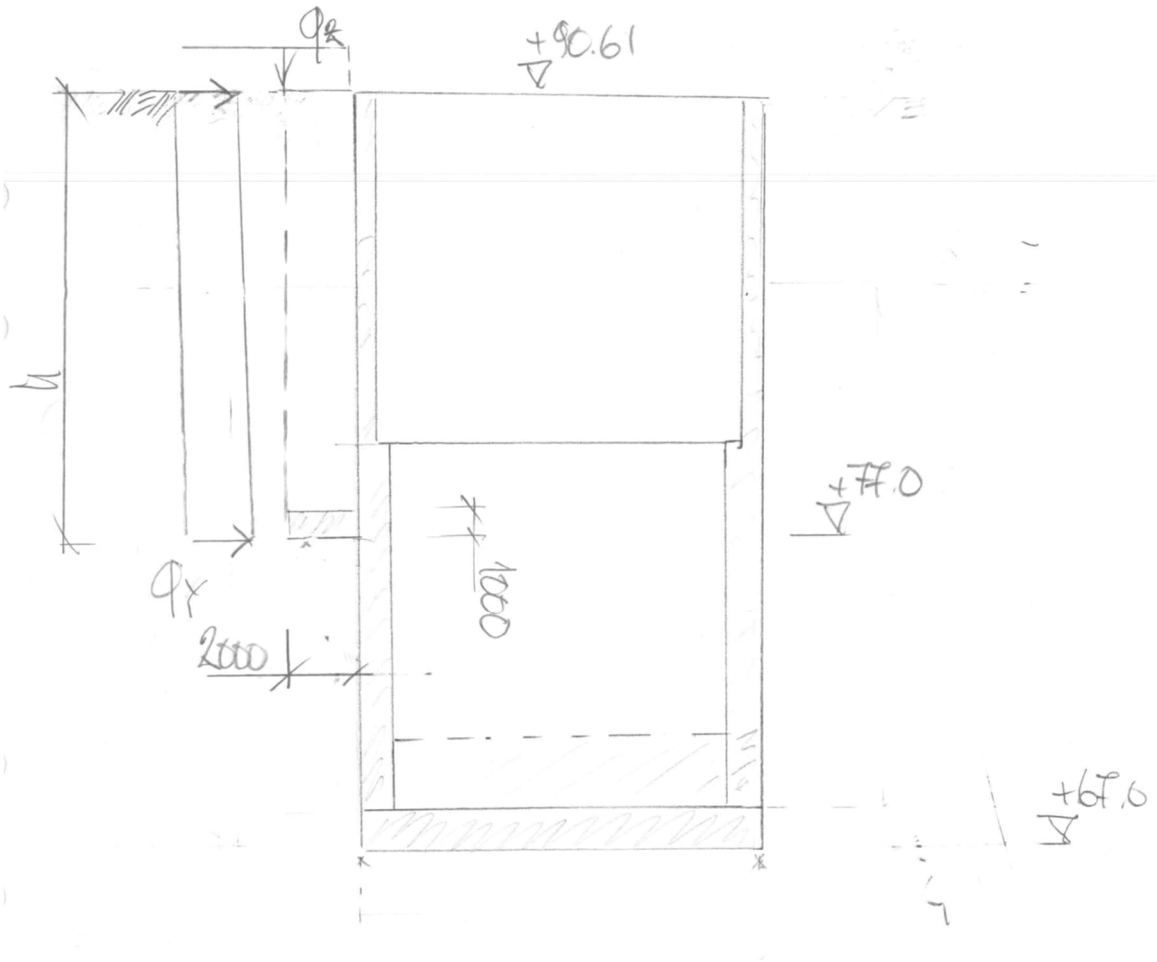
$K_0 = 0.38$

$q_{surcharge} = 10kPa$

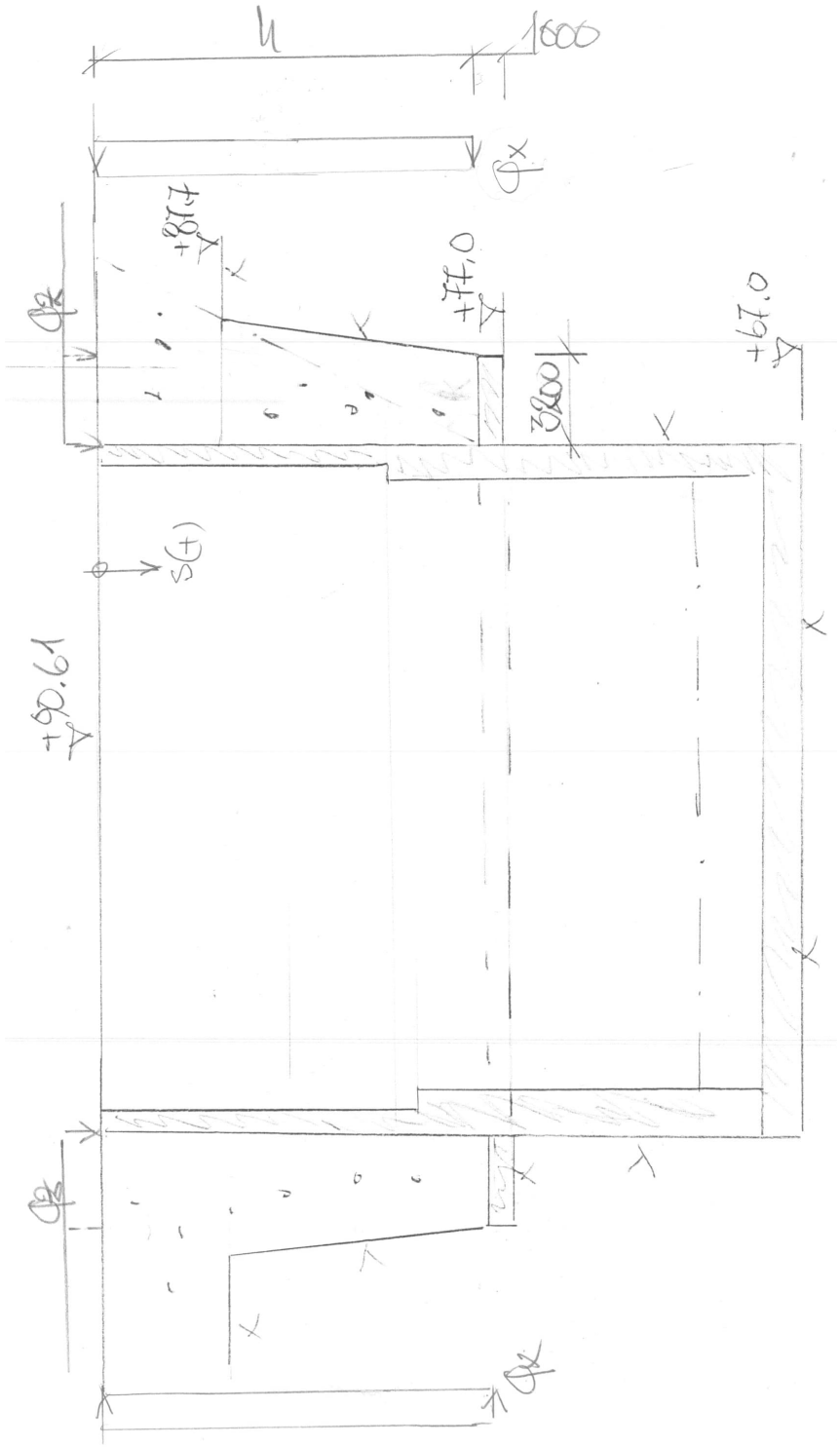
$q_{x,y} = K_0 \cdot q_{surcharge} = 3.8kPa$

$q_z = 10kPa$

Sketch of earth pressure against Wall 1 :



Sketch of earth pressure against Wall 2 and 4 :



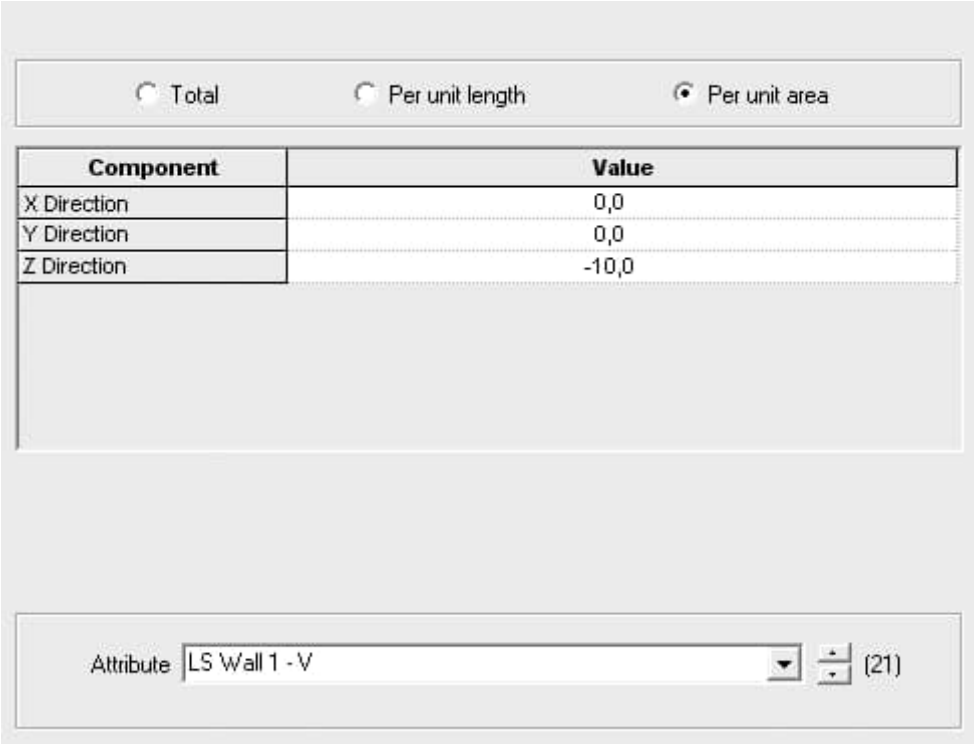
3.4.1 Vertical contribution

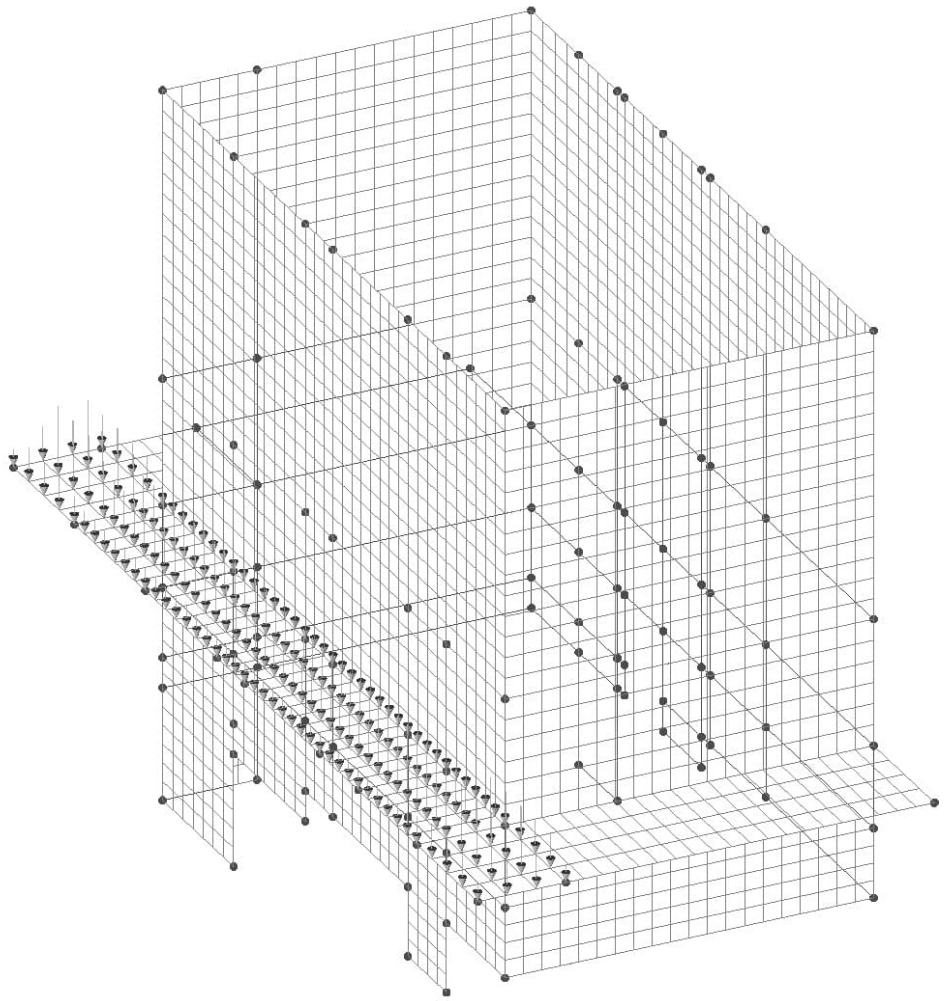
3.4.1.1 Load against wall 1 (Load case LS Wall 1 – V)

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -10 $\frac{kN}{m^2}$



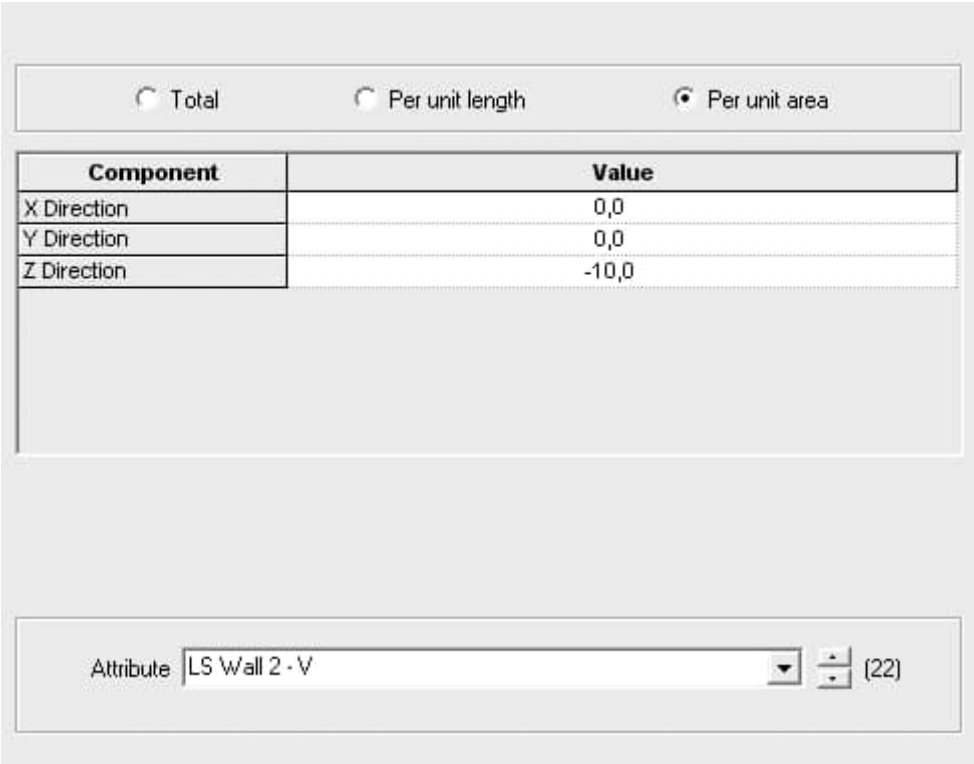


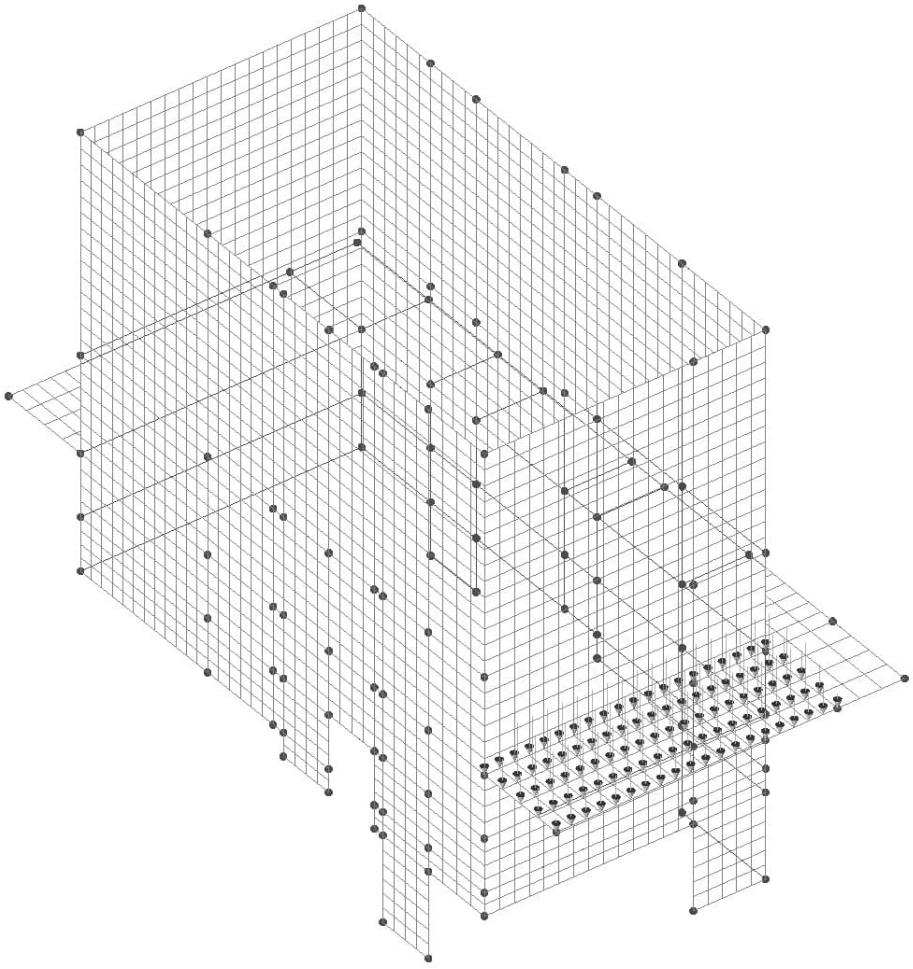
3.4.1.2 Load against wall 2 (Load case LS Wall 2 – V)

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -10 $\frac{kN}{m^2}$



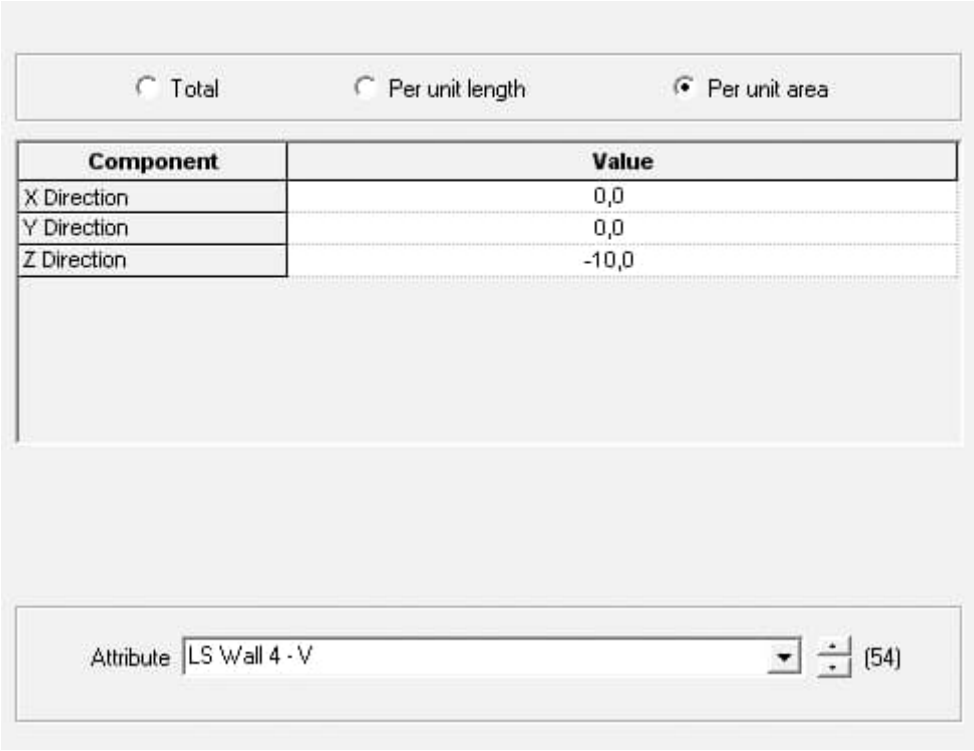


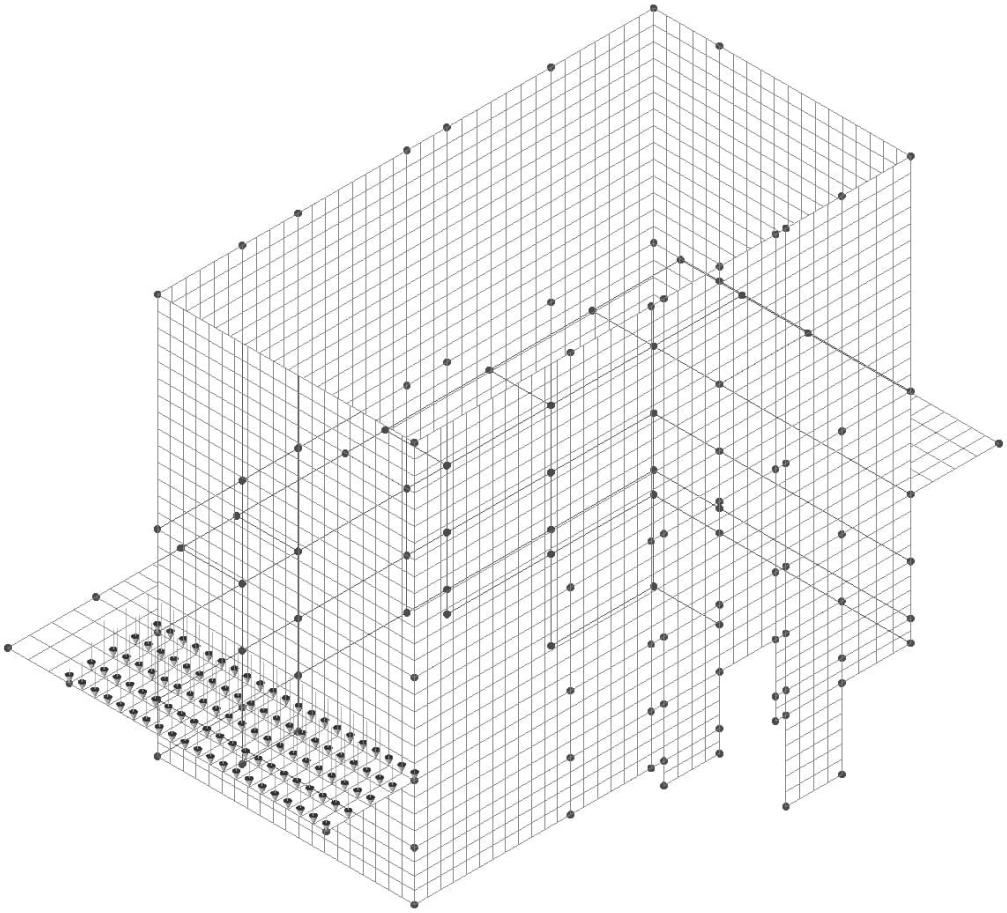
3.4.1.3 Load against wall 4 (Load case LS Wall 4 – V)

Structural loading : Global distributed

Force type : Per unit area

Component z direction : -10 $\frac{kN}{m^2}$





3.4.2 Horizontal contribution

3.4.2.1 Load against wall 1 (Load case LS Wall 1 – H)

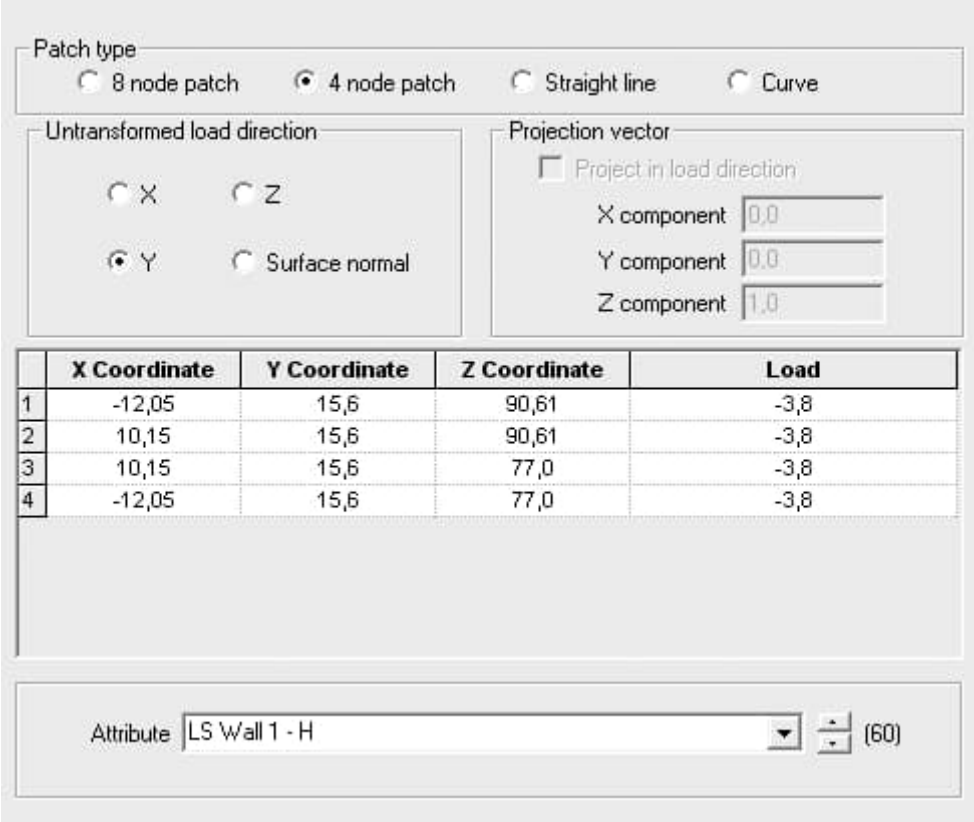
Structural loading : Discrete patch load

Search area : Exterior wall 1

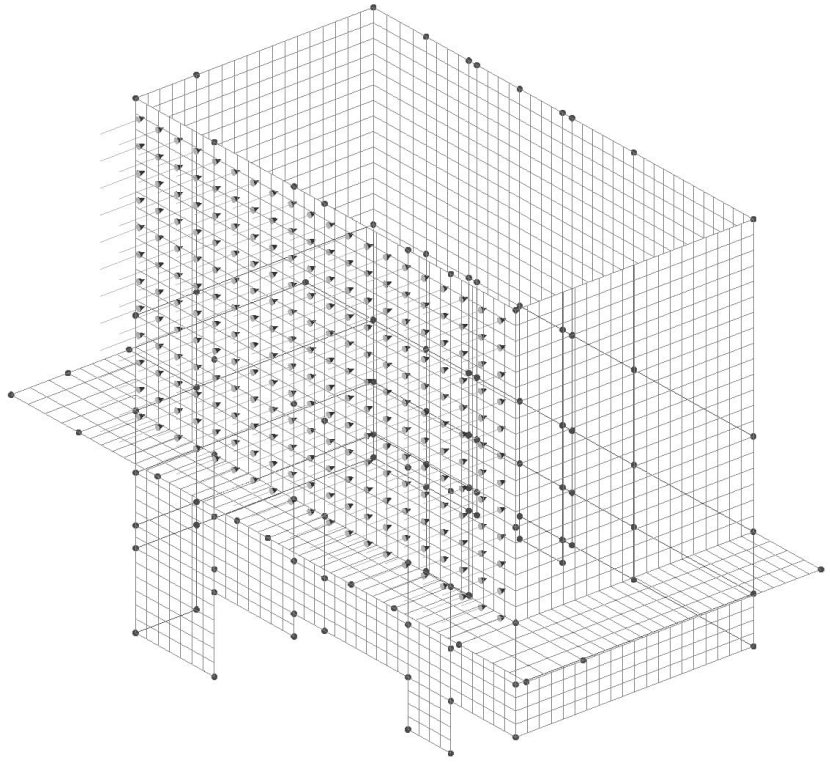
Force type : Per unit area

Component y direction : -3.8 kPa

Options for load outside search area : Exclude All Load



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-12,05	15,6	90,61	-3,8
2	10,15	15,6	90,61	-3,8
3	10,15	15,6	77,0	-3,8
4	-12,05	15,6	77,0	-3,8



3.4.2.2 Load against wall 2 (Load case LS Wall 2 – H)

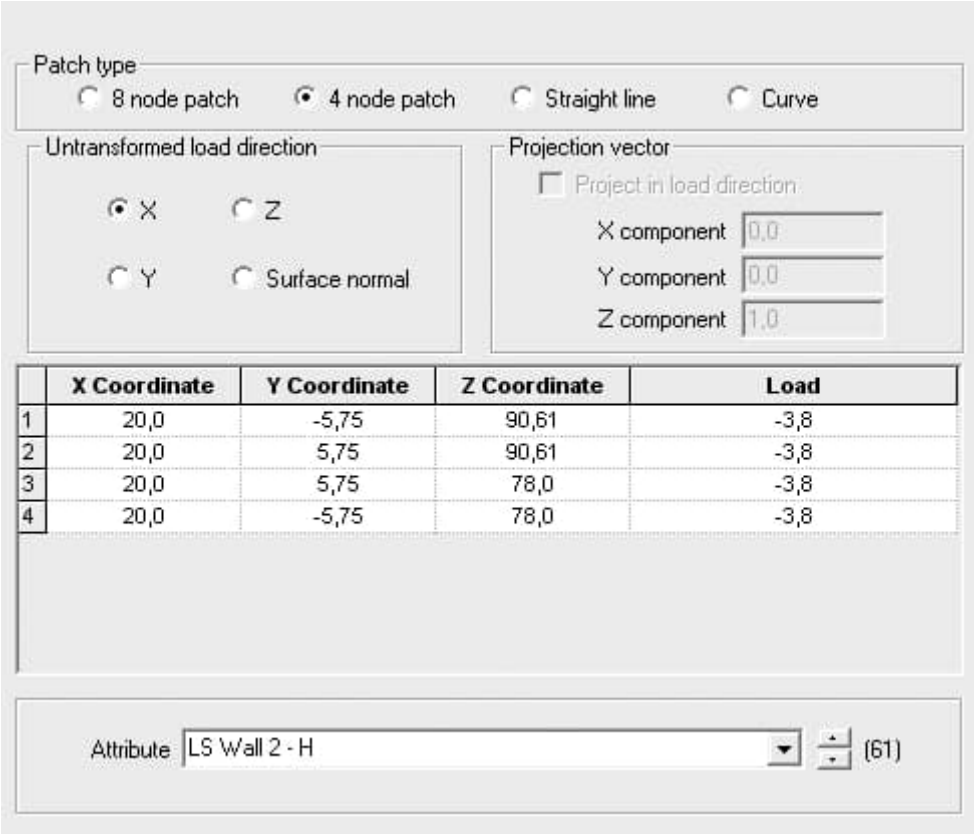
Structural loading : Discrete patch load

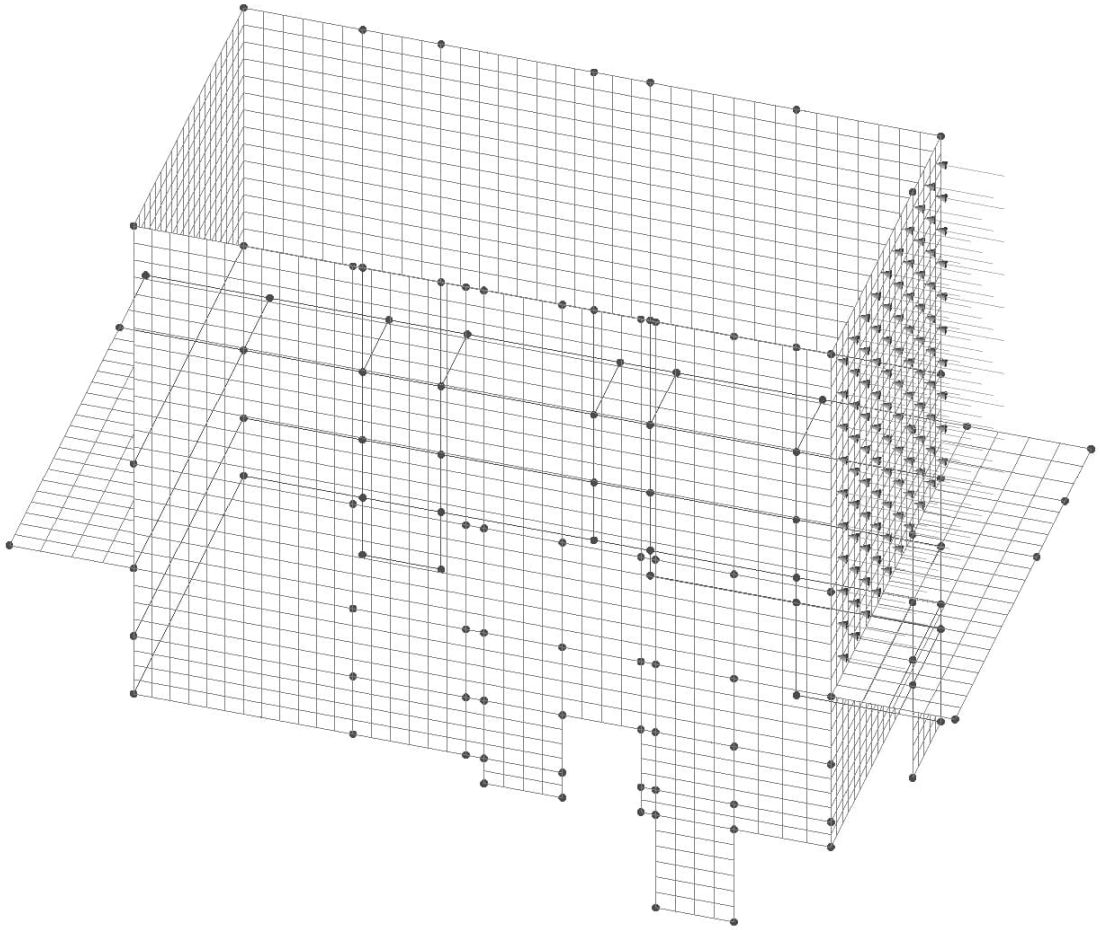
Search area : Exterior wall 2

Force type : Per unit area

Component x direction : -3.8 kPa

Options for load outside search area : Exclude All Load





3.4.2.3 Load against wall 4 (Load case LS Wall 4 – H)

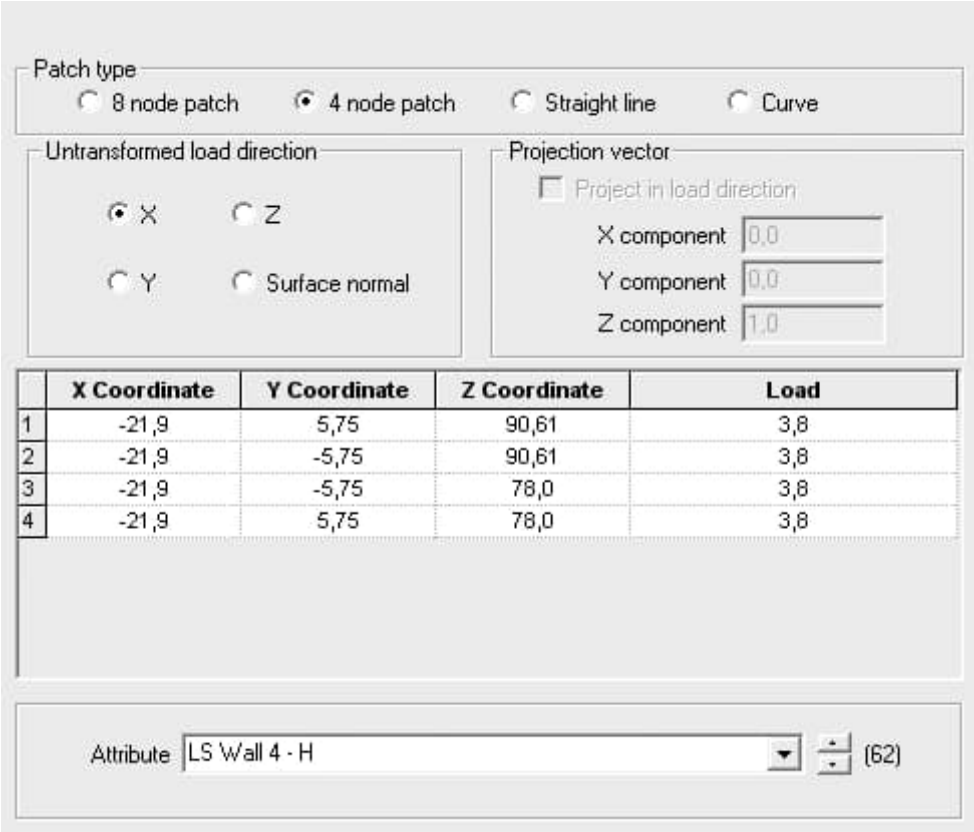
Structural loading : Discrete patch load

Search area : Exterior wall 4

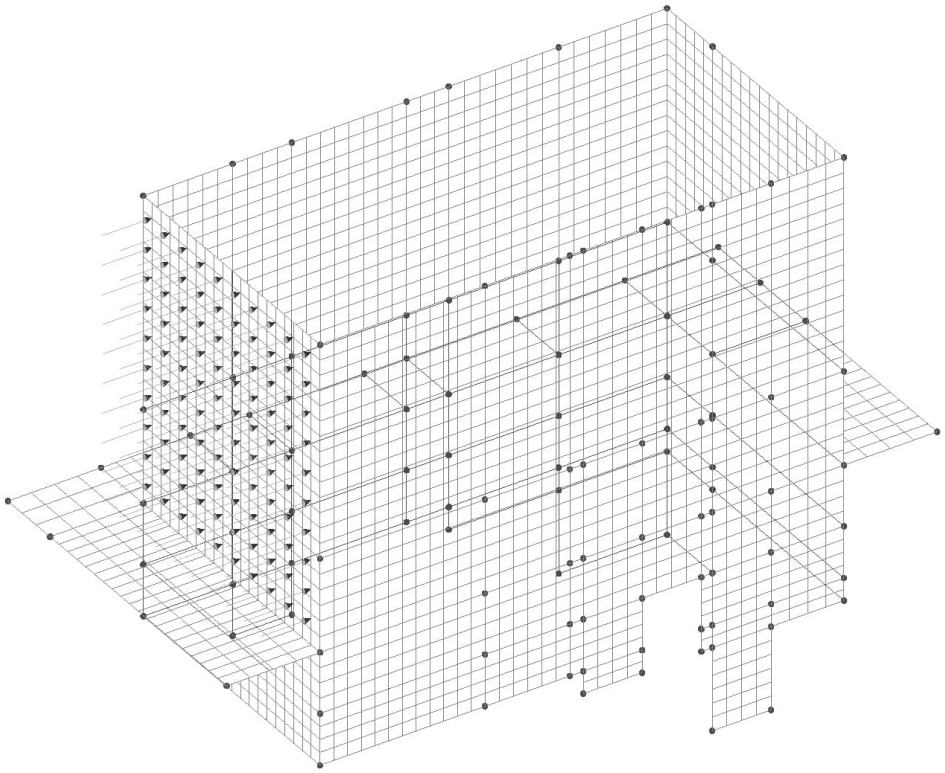
Force type : Per unit area

Component x direction : 3.8 kPa

Options for load outside search area : Exclude All Load



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-21,9	5,75	90,61	3,8
2	-21,9	-5,75	90,61	3,8
3	-21,9	-5,75	78,0	3,8
4	-21,9	5,75	78,0	3,8



3.4.3 Load combinations

Load combination smart : *LS*

Loadcase	Permanent factor	Variable factor
LS Wall 1 - V	0	1.00
LS Wall 2 – V	0	1.00
LS Wall 4 – V	0	1.00
LS Wall 1 – H	0	1.00
LS Wall 2 – H	0	1.00
LS Wall 4 – H	0	1.00

3.5 EARTHQUAKE LOADS

The effect of earthquake is considered by using at simplified method. The method increases the effect of dead weight as seen below (see also OTR 5.6.4).

In order to apply load to structure it is necessary to divide it into several load cases. A total of 8(16) load cases are required.

3.5.1 Unusual loading (UE)

The effect is considered by increasing load case dead weight in both vertical and horizontal directions. But in the evaluation of walls only the horizontal effect is considered.

The load case UE is divided into smaller load cases depending on which wall is considered as seen below.

Basic load cases :

Loadcase	Load	Load factor
UE Wall 1+	UE Wall 1	+1
UE Wall 1-	UE Wall 1	-1
UE Wall 2+	UE Wall 2	+1
UE Wall 2-	UE Wall 2	-1
UE Wall 3+	UE Wall 3	+1
UE Wall 3-	UE Wall 3	-1
UE Wall 4+	UE Wall 4	+1
UE Wall 4-	UE Wall 4	-1

Loadcombination smart : *UE*

Loadcase	Permanent factor	Variable factor
UE: Wall 1+	0	1.0
UE: Wall 1-	0	1.0
UE: Wall 2+	0	1.0
UE: Wall 2-	0	1.0
UE : Wall 3+	0	1.0
UE : Wall 3-	0	1.0
UE : Wall 4+	0	1.0
UE : Wall 4-	0	1.0

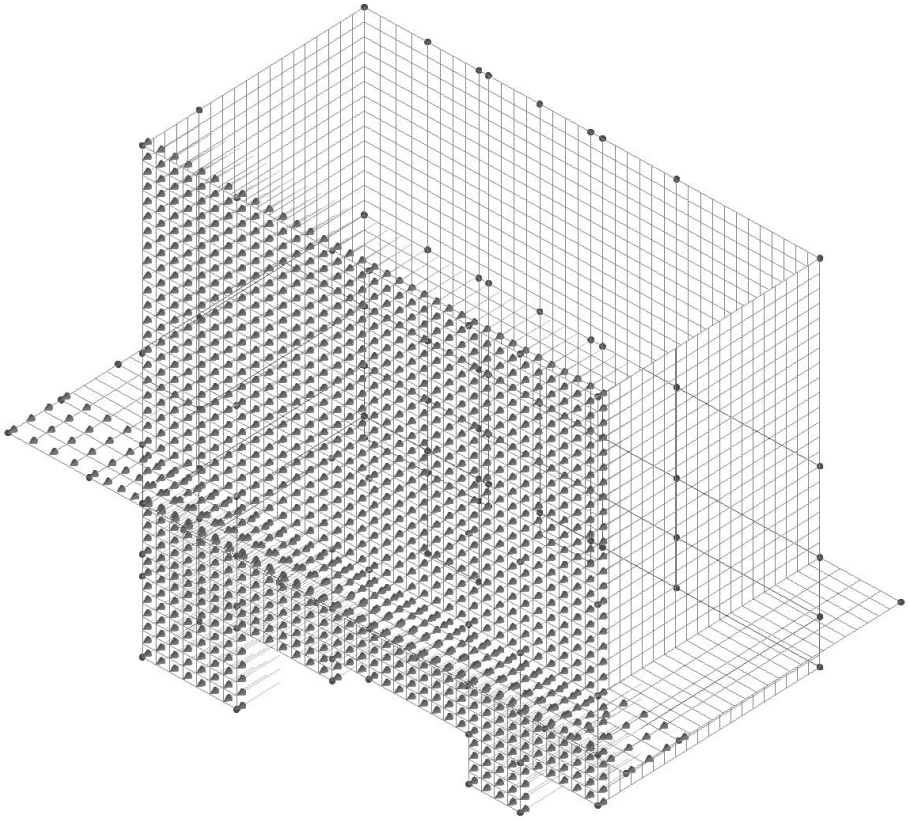
3.5.1.1 Load acting on wall 1 (Load : UE Wall 1)

Structural loading : Body force

Acceleration in y direction (a_y) : 1 $\frac{m}{s^2}$

Component	Value
Linear acceleration in X	0,0
Linear acceleration in Y	1,0
Linear acceleration in Z	0,0
Angular velocity about X axis	0,0
Angular velocity about Y axis	0,0
Angular velocity about Z axis	0,0
Angular acceleration about X axis	0,0
Angular acceleration about Y axis	0,0
Angular acceleration about Z axis	0,0

Attribute UE Wall 1 (9)



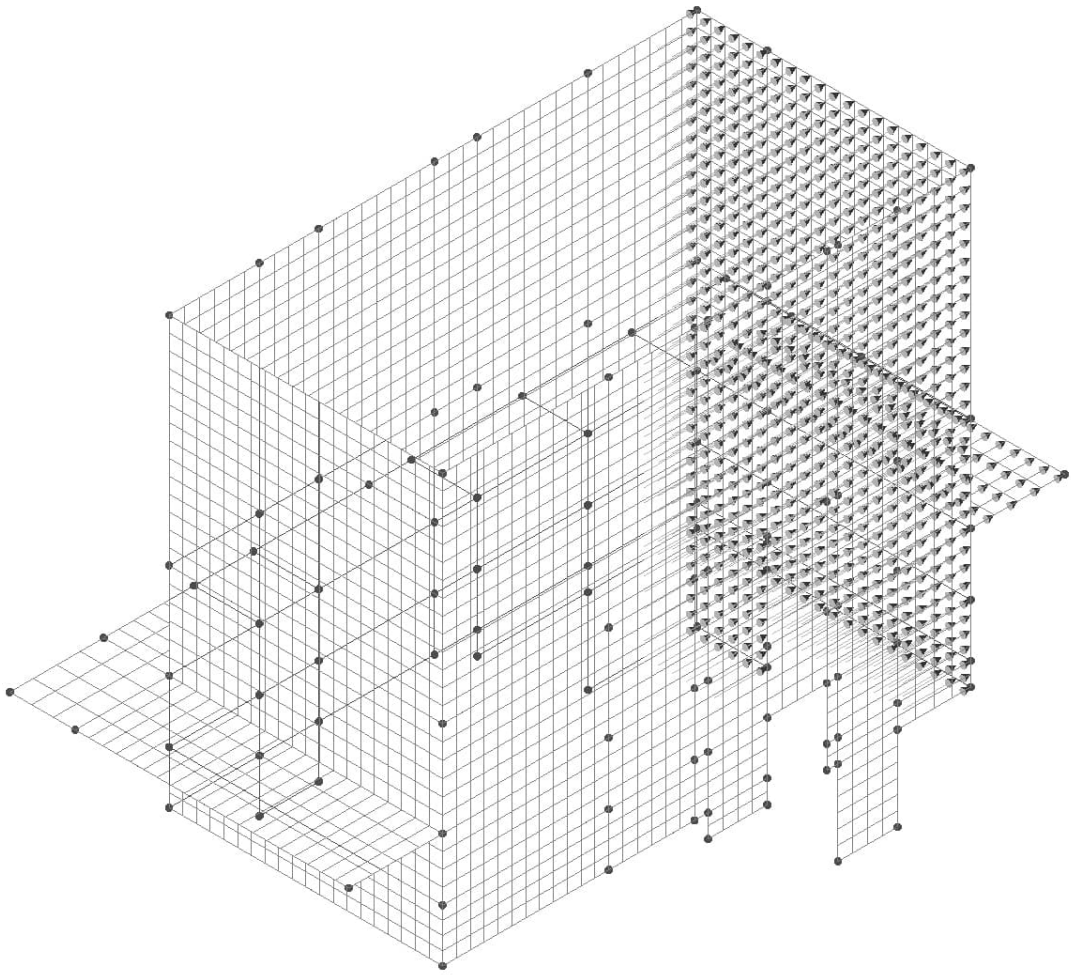
3.5.1.2 Load acting on wall 2 (Load : UE Wall 2)

Structural loading : Body force

Acceleration in x direction (a_x) : 1 $\frac{m}{s^2}$

Component	Value
Linear acceleration in X	1,0
Linear acceleration in Y	0,0
Linear acceleration in Z	0,0
Angular velocity about X axis	0,0
Angular velocity about Y axis	0,0
Angular velocity about Z axis	0,0
Angular acceleration about X axis	0,0
Angular acceleration about Y axis	0,0
Angular acceleration about Z axis	0,0

Attribute UE Wall 2 (10)



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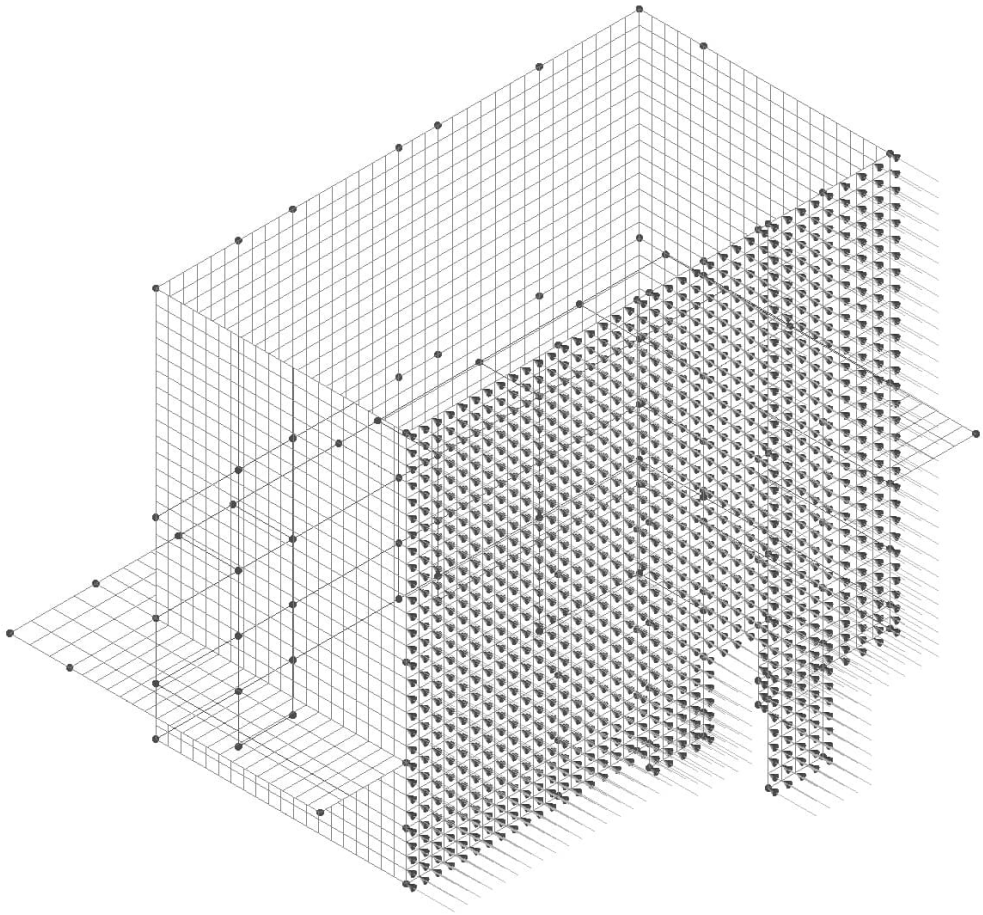
3.5.1.3 Load acting on wall 3 (Load : UE Wall 3)

Structural loading : Body force

Acceleration in y direction (a_y) : 1 $\frac{m}{s^2}$

Component	Value
Linear acceleration in X	0,0
Linear acceleration in Y	1,0
Linear acceleration in Z	0,0
Angular velocity about X axis	0,0
Angular velocity about Y axis	0,0
Angular velocity about Z axis	0,0
Angular acceleration about X axis	0,0
Angular acceleration about Y axis	0,0
Angular acceleration about Z axis	0,0

Attribute UE Wall 3 (11)



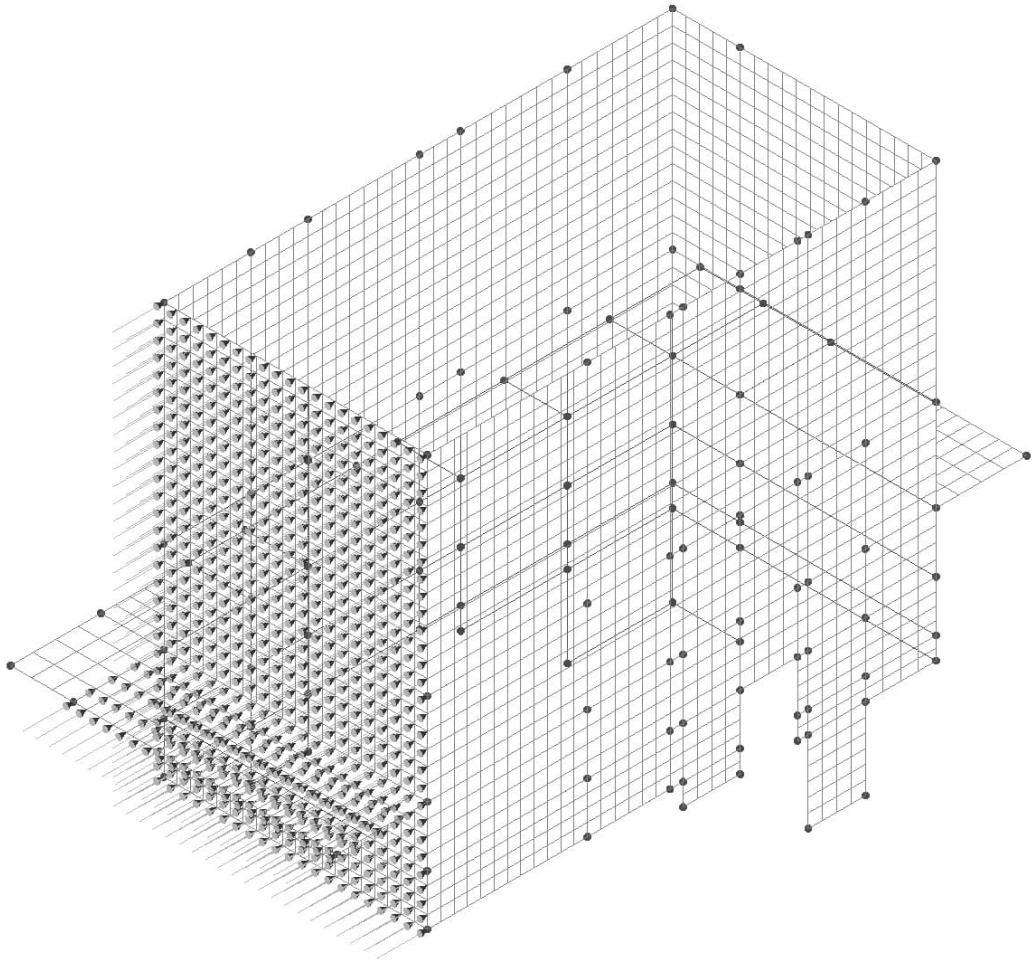
3.5.1.4 Load acting on wall 4 (Load : UE Wall 4)

Structural loading : Body force

Acceleration in x direction (a_x) : 1 $\frac{m}{s^2}$

Component	Value
Linear acceleration in X	1,0
Linear acceleration in Y	0,0
Linear acceleration in Z	0,0
Angular velocity about X axis	0,0
Angular velocity about Y axis	0,0
Angular velocity about Z axis	0,0
Angular acceleration about X axis	0,0
Angular acceleration about Y axis	0,0
Angular acceleration about Z axis	0,0

Attribute UE Wall 2 (10)



3.5.2 Extreme loading (EE)

The effect is considered by increasing load case dead weight by 15 % in both vertical and horizontal directions. But in the evaluation of walls only the horizontal effect is considered.

Since EE is identical with UE apart from load intensity it stresses is retrieved by scaling results with a factor of 1.5 as seen below.

Loadcombination smart : *EE*

Loadcase	Permanent factor	Variable factor
UE (Max)	0	1.5
UE (Min)	0	1.5

3.6 LOAD COMBINATIONS

Load combinations below are considered.

LC:I Ultimate limit state
LC :II Service limit state with the objective crack control
LC:III Extreme limit state (operational basis earthquake / OBE)
LC:IV Extreme limit state (maximum credible earthquake / MCE)
LC:V Extreme limit state (10 000 year flood earthquake / MCE)

3.6.1 LC:I Ultimate limit state

The load combination has varying water levels. The water level is either at level H0 or H2. Due to this table below has to be adapted using an envelope of the different water levels.

Load case	Load factor	Remark
DC	1.17 / 2.21	Dead weight
EH	1.17 / 2.21	Horizontal earth pressure
WA	0 / 2.21	Water loads
LS	0 / 2.21	Surcharge

Loadcombination smart *LC:I – H0 :*

Loadcase	Permanent factor	Variable factor
DC – H0	1.17	1.04
EH – H0	1.17	1.04
LS	0	2.21

Loadcombination smart *LC:I – H2 :*

Loadcase	Permanent factor	Variable factor
DC – H2	1.17	1.04
EH – H2	1.17	1.04
WA – H2	1.17	1.04
LS	0	2.21

Envelope *LC:I :*

Loadcombination
LC:I – H0
LC:I – H2

3.6.2 LC:II Service limit state

The load combination has varying water levels. The water level is either at level H0 or H1. Due to this table below has to be adapted using an envelope of the different water levels.

Load case	Load factor	Remark
DC	1.0	Dead weight
EH	1.0	Horizontal earth pressure
WA	0 / 1.0	Water loads

.

Loadcombination basic *LC:II – H0 :*

Loadcase	Factor
DC – H0	1.00
EH – H0	1.00

Loadcombination basic *LC:II – H1 :*

Loadcase	Factor
DC – H1	1.00
EH – H1	1.00
WA – H1	1.00

Envelope *LC:II :*

Loadcombination
LC:II – H0
LC:II – H1

3.6.3 LC:III Extreme limit state / OBE

The load combination has varying water levels. The water level is either at level H0 or H1. Due to this table below has to be adapted using an envelope of the different water levels.

Load case	Load factor	Remark
DC	1.17 / 2.21	Dead weight
EH	1.17 / 2.21	Horizontal earth pressure
WA	0 / 2.21	Water loads
UE	0 / 1.90	Earthquake OBE
LS	0 / 2.21	Surcharge

Loadcombination smart *LC:III – H0* :

Loadcase	Permanent factor	Variable factor
DC – H0	1.17	1.04
EH – H0	1.17	1.04
LS	0	2.21
UE	0	1.90

Loadcombination smart *LC:III – H1*:

Loadcase	Permanent factor	Variable factor
DC – H1	1.17	1.04
EH – H1	1.17	1.04
WA – H1	1.17	1.04
LS	0	2.21
UE	0	1.90

Envelope *LC:III*

Loadcombination
LC:III –H0
LC:III – H1

3.6.4 LC:IV Extreme limit state / MCE

The load combination has varying water levels. The water level is either at level H0 or H1. Due to this table below has to be adapted using an envelope of the different water levels.

Load case	Load factor	Remark
DC	1.17 / 1.43	Dead weight
EH	1.17 / 1.43	Horizontal earth pressure
WA	0 / 1.43	Water loads
EE	0 / 1.25	Earthquake MCE
LS	0 / 1.43	Surcharge

Loadcombination smart *LC:IV- H0 :*

Loadcase	Permanent factor	Variable factor
DC – H0	1.17	0.26
EH – H0	1.17	0.26
LS	0	1.43
EE	0	1.25

Loadcombination smart *LC:IV – H1:*

Loadcase	Permanent factor	Variable factor
DC – H1	1.17	0.26
EH – H1	1.17	0.26
WA – H1	1.17	0.26
LS	0	1.43
EE	0	1.25

Envelope *LC:IV*

Loadcombination
LC:IV –H0
LC:IV – H1

3.6.5 LC:V Extreme limit state / 10000 year flood

The load combination has only one water level termed H3.

Load case	Load factor	Remark
DC	1.17 / 1.43	Dead weight
EH	1.17 / 1.43	Horizontal earth pressure
WA	0 / 1.43	Water loads

Loadcombination smart *LC:V :*

Loadcase	Permanent factor	Variable factor
DC – H3	1.17	0.26
EH – H3	1.17	0.26
WA – H3	0	1.43