Hydro power

Machine bay design

TABLE OF CONTENT

1. GENERAL/MEASUREMENTS

1.1 STRUCTURAL TYPE

This reports handles the design of the concrete structure surrounding the power production unit. The structure is located deep below earth surface in excavated rock.

The structure is exposed to the loads mentioned bellow.

- Dead load (concrete structure / spiral case)
- Water load (runaway pressure)
- Head cover including water pressure
- Stator / rotor / upper bracket : upper cantilever
- Lower bracket : lower cantilever

1.2 PRODUCTION SCHEME

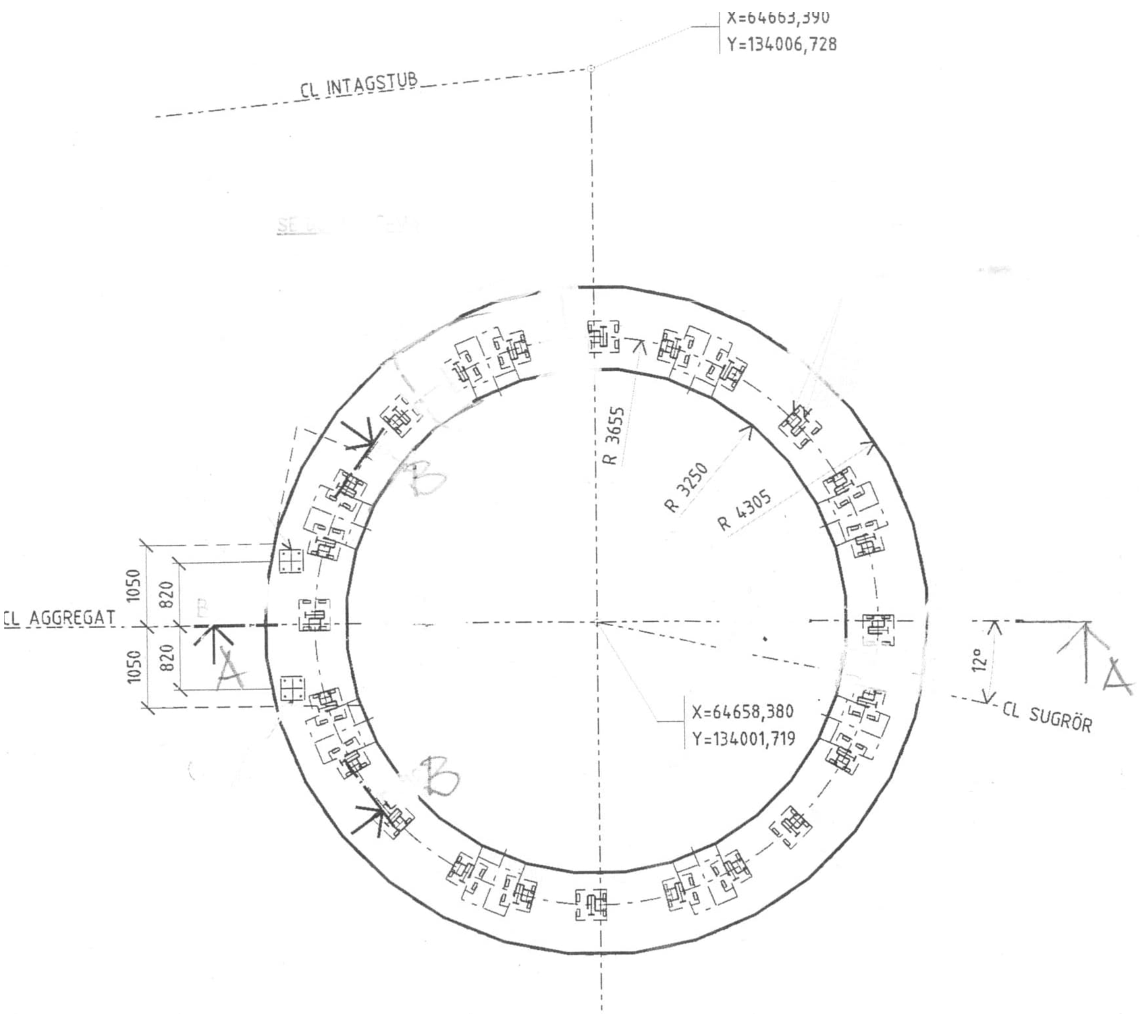
The production scheme assumes that the structure is cast-in situ.

1.3 TECHNICAL SPECIFICATION AND BUILDNING CODE

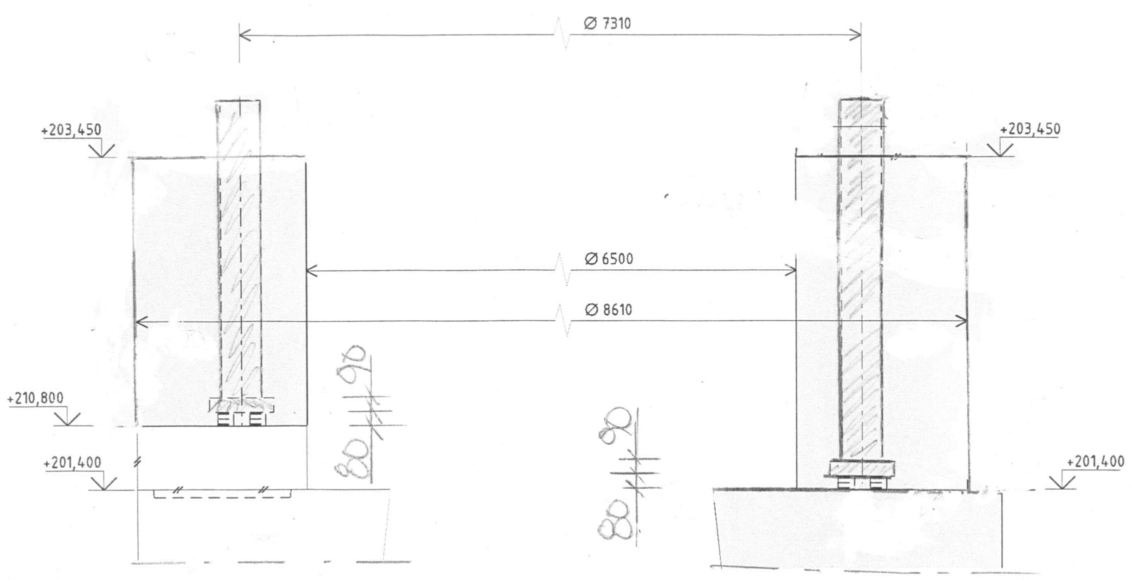
See sepeate specification.

1.4 MEASUREMENTS

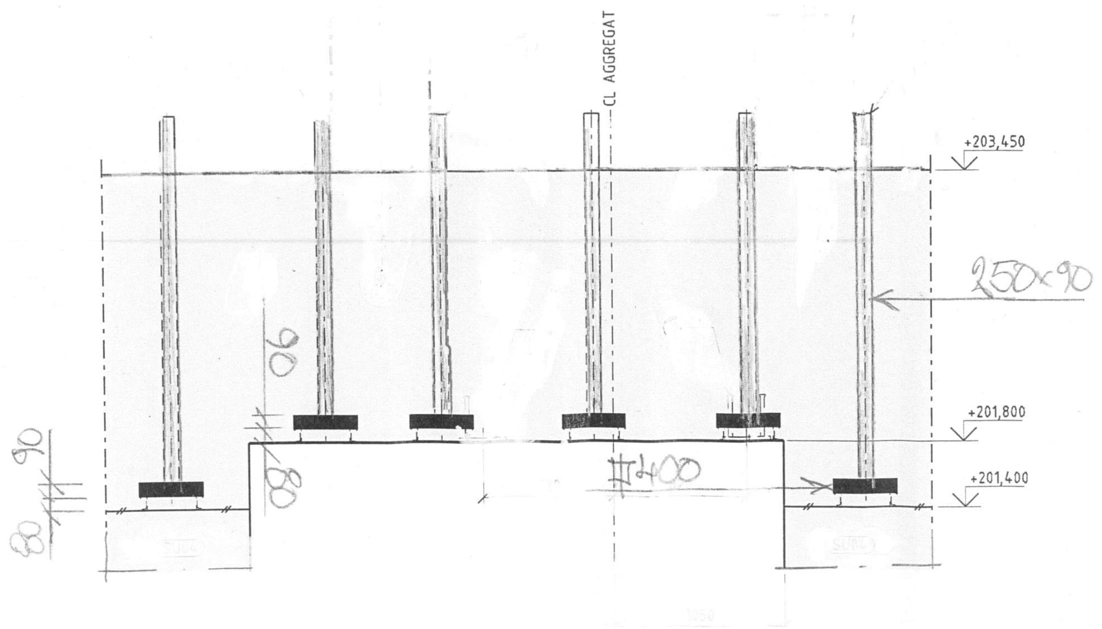
1.4.1 Concrete stay ring beam



PLAN

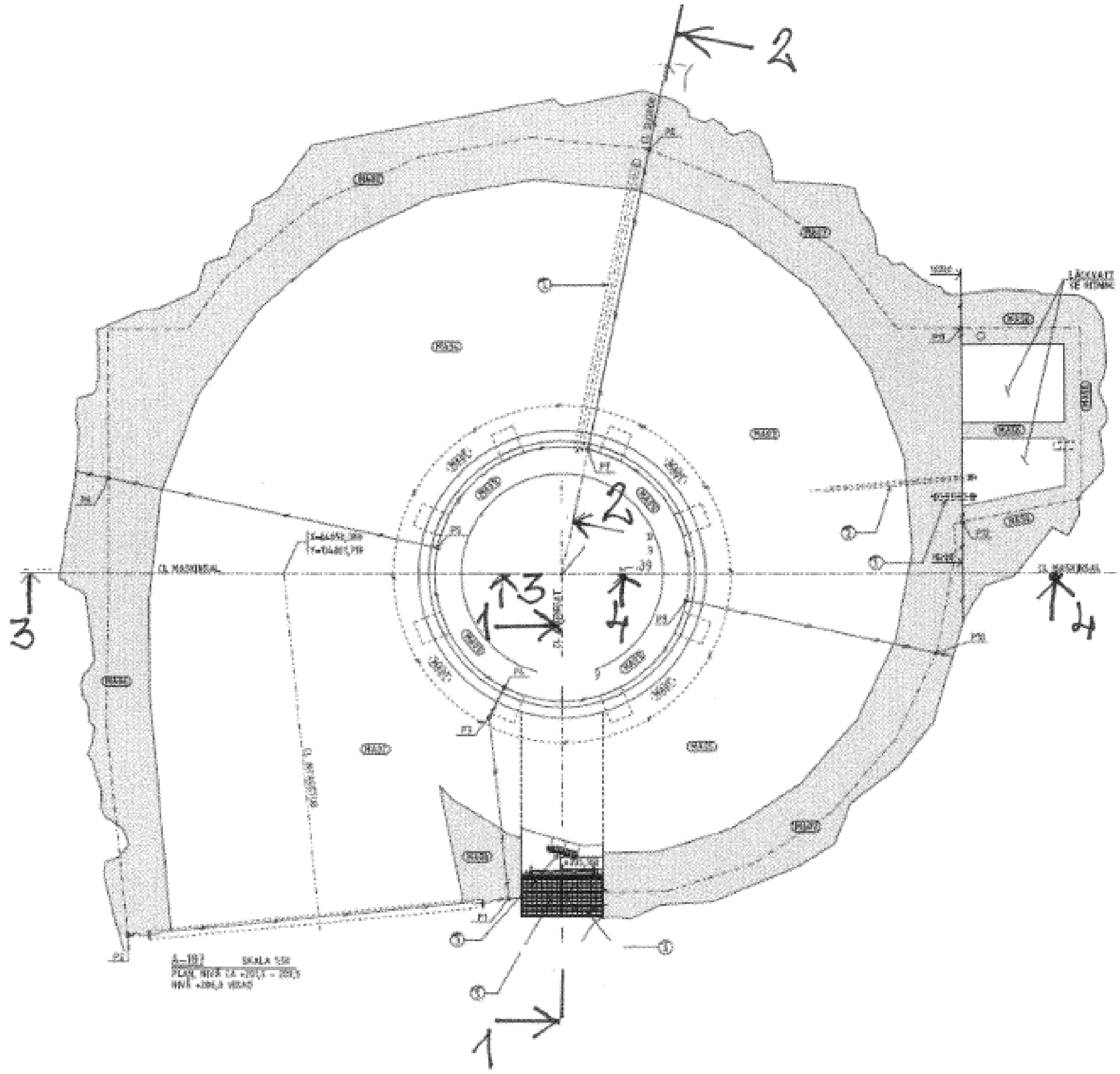


SECTION A-A
Radial direction

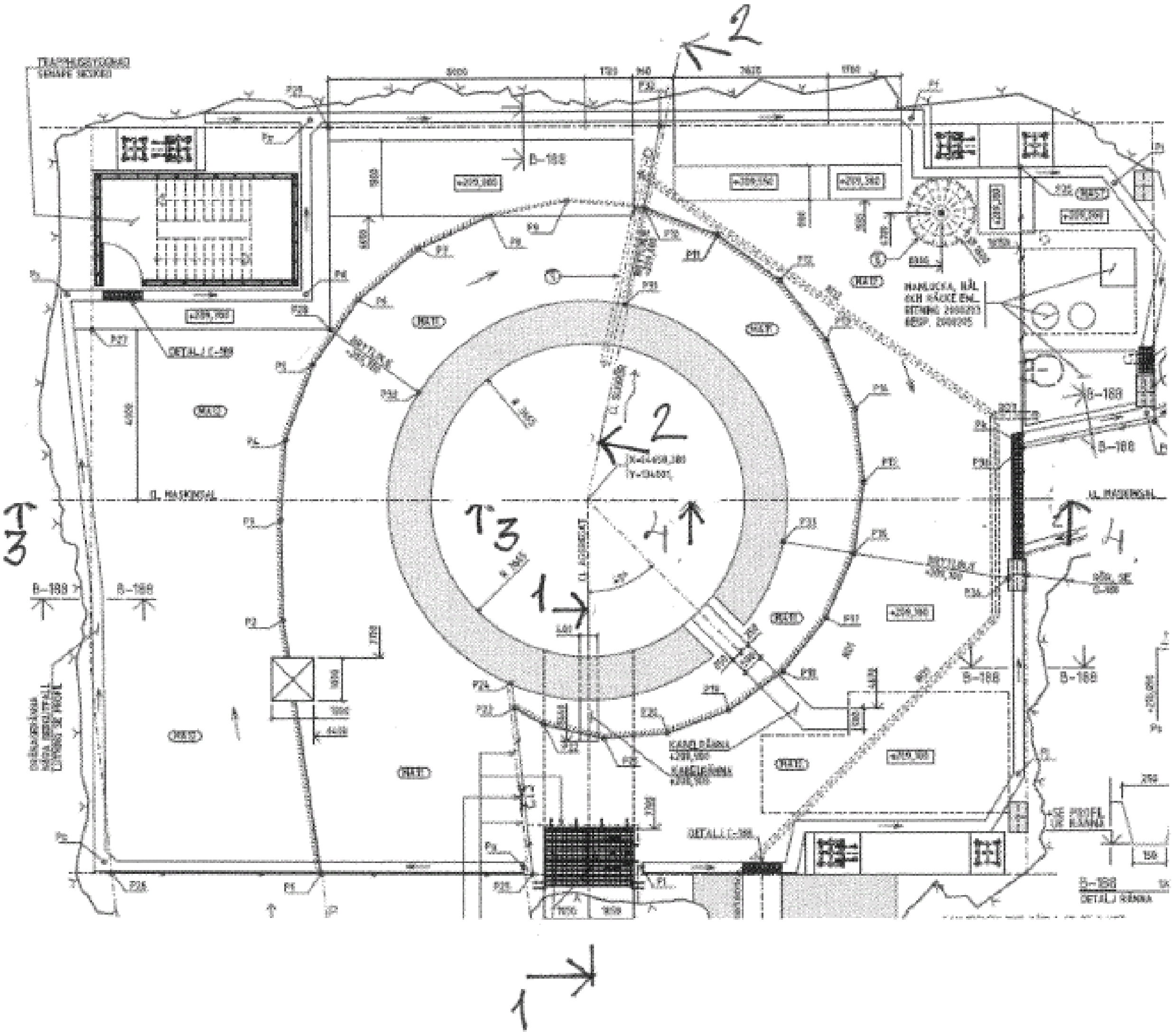


SECTION B-B
Tangential direction

1.4.2 Machine station



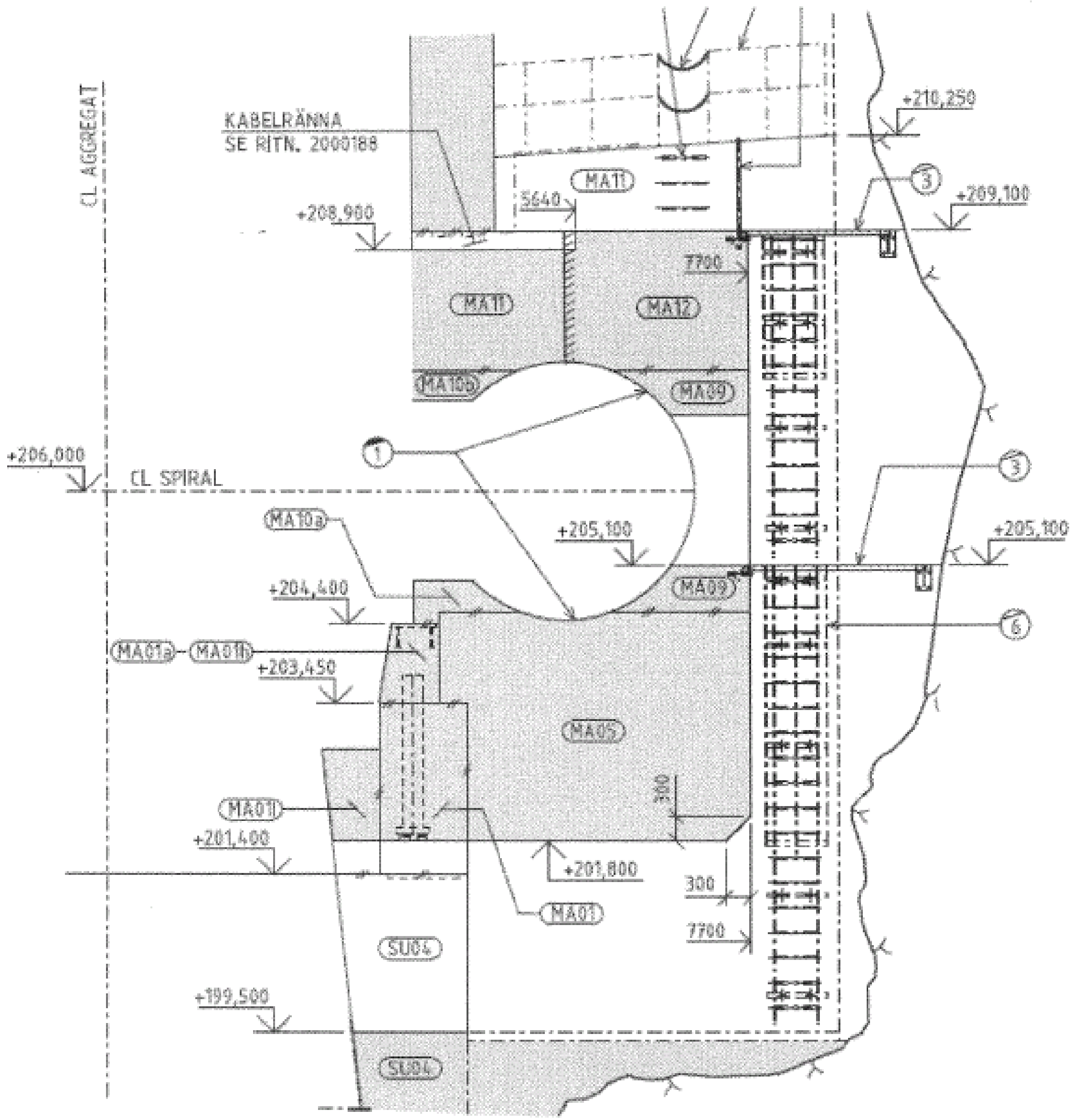
PLAN, LEVEL ~ +206



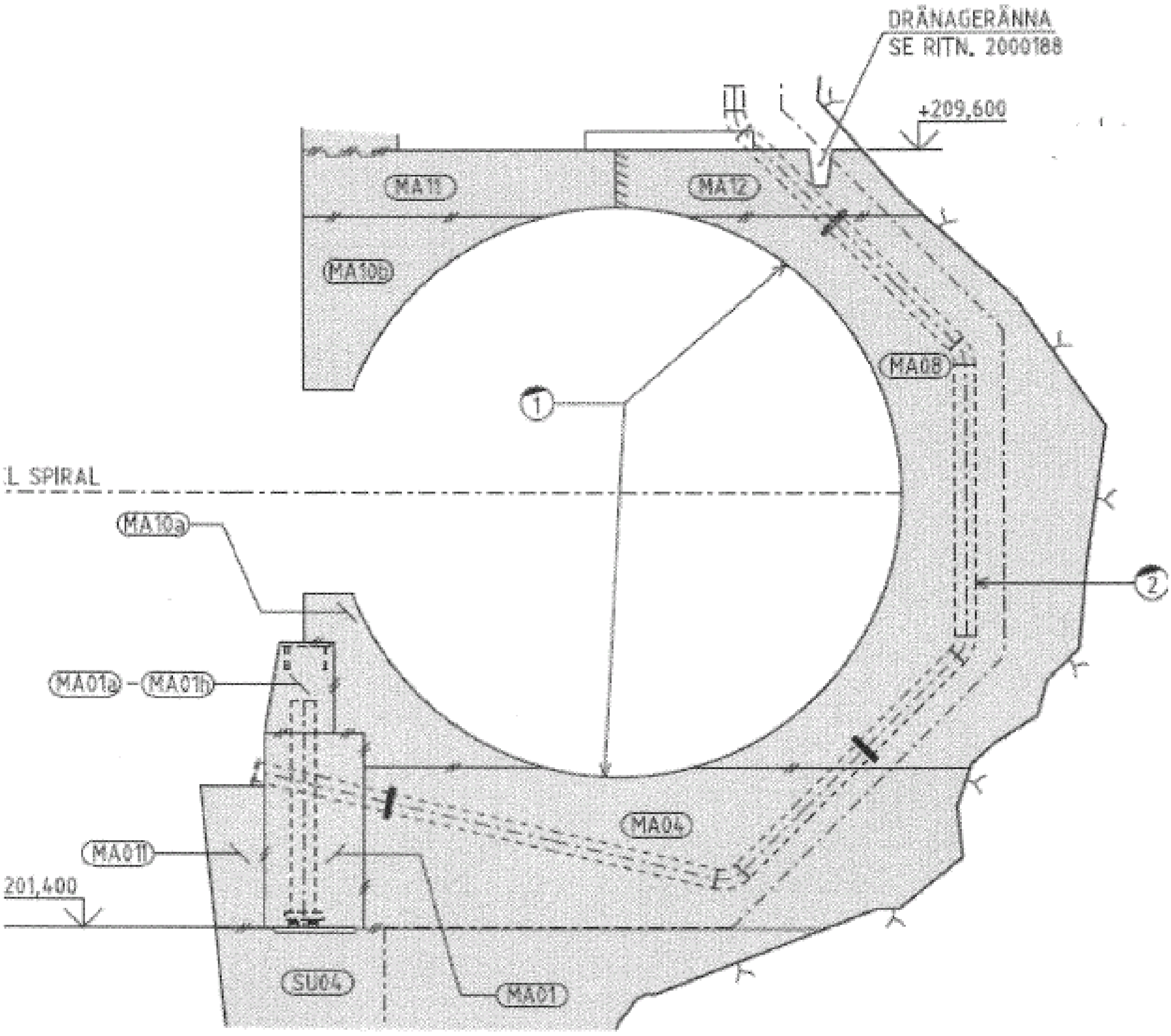
PLAN, LEVEL ~ +210.5

PUNKT NR	X-KOORD	Y-KOORD	HÖJD
P1	64668,984	133999,947	+210,250
P2	64665,404	134004,759	+209,995
P3	64663,769	134006,458	+209,895
P4	64662,361	134007,693	+209,815
P5	64660,665	134008,480	+209,737
P6	64658,835	134008,809	+209,690
P7	64656,990	134008,657	+209,665
P8	64655,260	134008,023	+209,645
P9	64653,744	134006,990	+209,625
P10	64652,569	134005,590	+209,600
P11	64651,818	134003,936	+209,500
P12	64651,546	134002,157	+209,400
P13	64651,771	134000,394	+209,300
P14	64652,454	133998,785	+209,195
P15	64653,519	133997,443	+209,095
P16	64654,868	133996,445	+209,100
P17	64656,396	133995,847	+209,100
P18	64657,993	133995,677	+209,100
P19	64659,535	133995,927	+209,100
P20	64660,932	133996,563	+209,100
P21	64662,070	133997,523	+209,100
P22	64662,840	133998,747	+209,100
P23	64663,045	133999,507	+209,100
P24	64662,694	133999,967	+210,057
P25	64665,498	133996,461	+210,250
P26	64672,413	134003,377	+210,250
P27	64663,697	134012,692	+209,700
P28	64659,795	134008,790	+209,700
P29	64656,435	134012,149	+209,668
P30	64659,380	134006,275	+209,700
P31	64654,504	134004,314	+209,600
P32	64650,947	134006,659	+209,600
P33	64655,842	133997,805	+209,100
P34	64652,750	133993,490	+209,100
P35	64645,723	134000,021	+209,350
P36	64650,361	133995,384	+209,095
P37	64647,775	133993,656	+209,445

TABLE

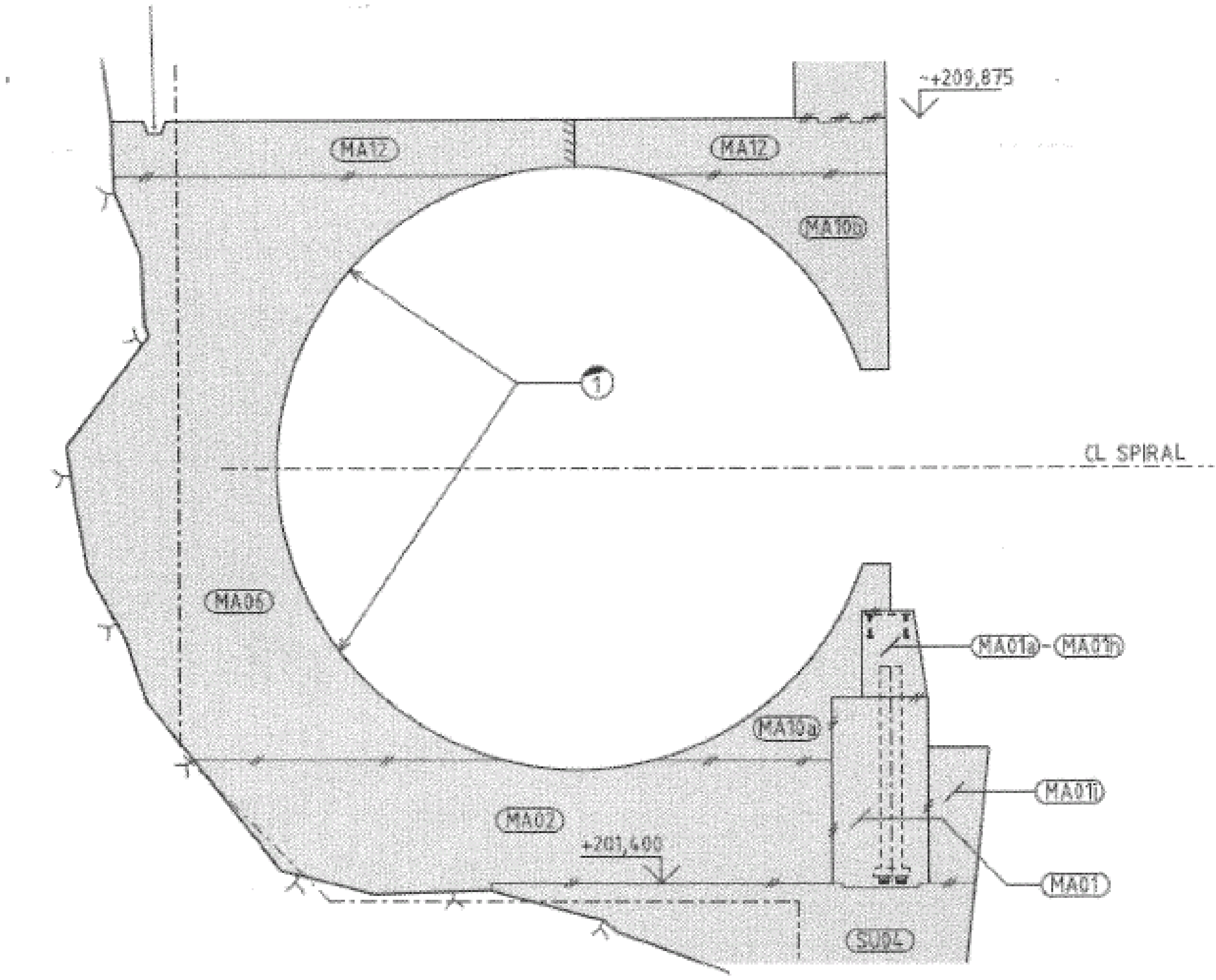

KABELRÄNNA
SE RITN. 2000188
CL AGGREGAT
+210,250
+209,100
+208,900
5640
MA11
7700
MA11
MA12
MA10b
MA09
+206,000
CL SPIRAL
MA10a
+205,100
+205,100
+204,400
MA09
MA01a
MA01b
+203,450
MA05
300
MA01
+201,400
+201,800
300
MA01
7700
SU04
+199,500
SU04

SECTION 1-1



DRÄNAGERÄNNA
SE RITN. 2000188
+209,600
MA11
MA12
MA10b
MA08
1
L SPIRAL
MA10a
2
MA01a - MA01h
MA04
MA01i
201,400
SU04
MA01

SECTION 2-2


+209,875
MA12
MA12
MA10b
1
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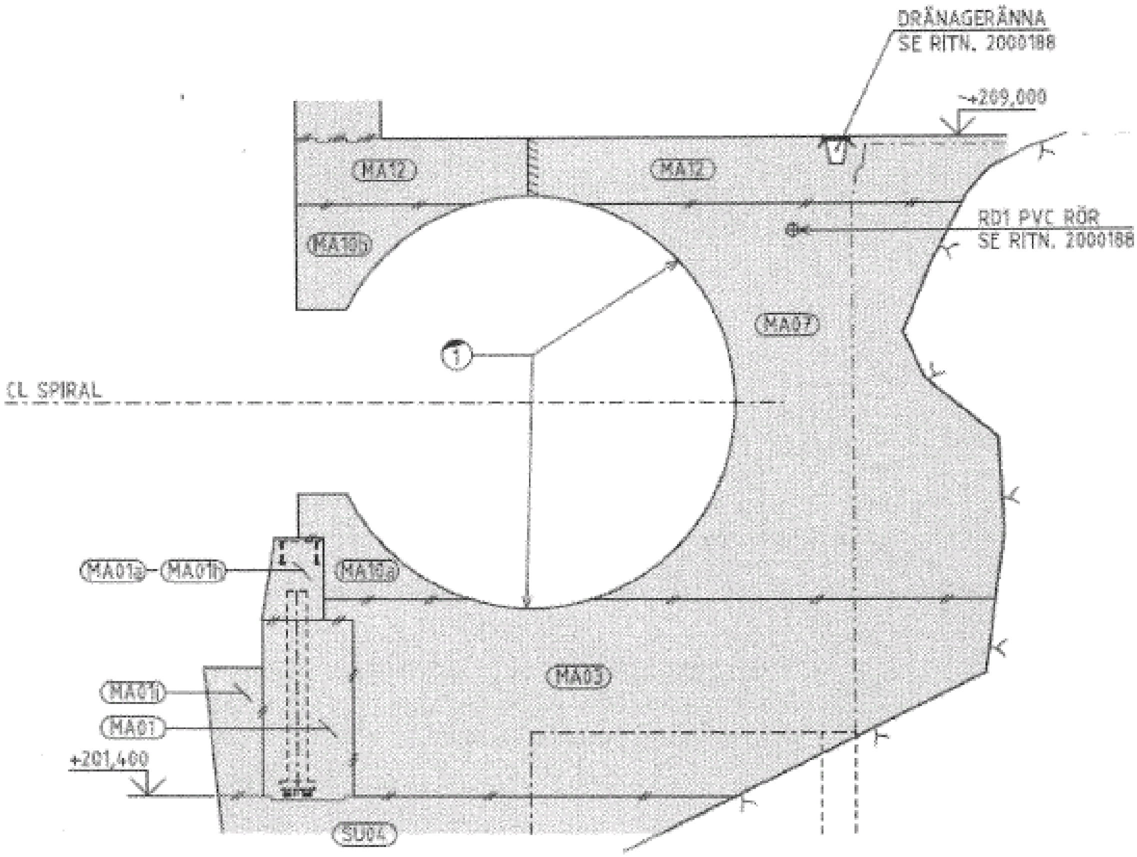
MA01a
MA01h
MA10a
MA01i
MA02
+201,400
MA01
SU04

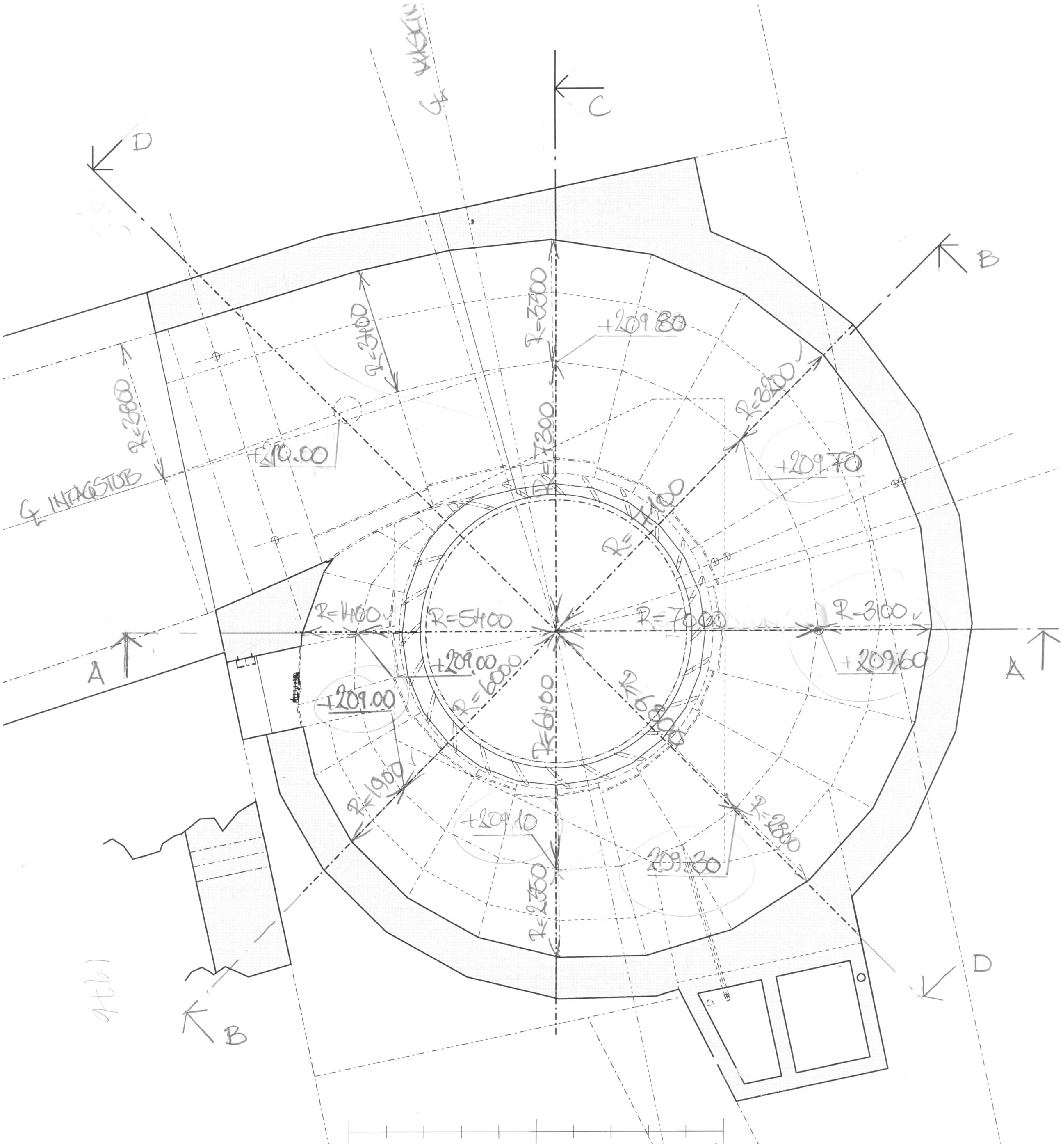
SECTION 3-3



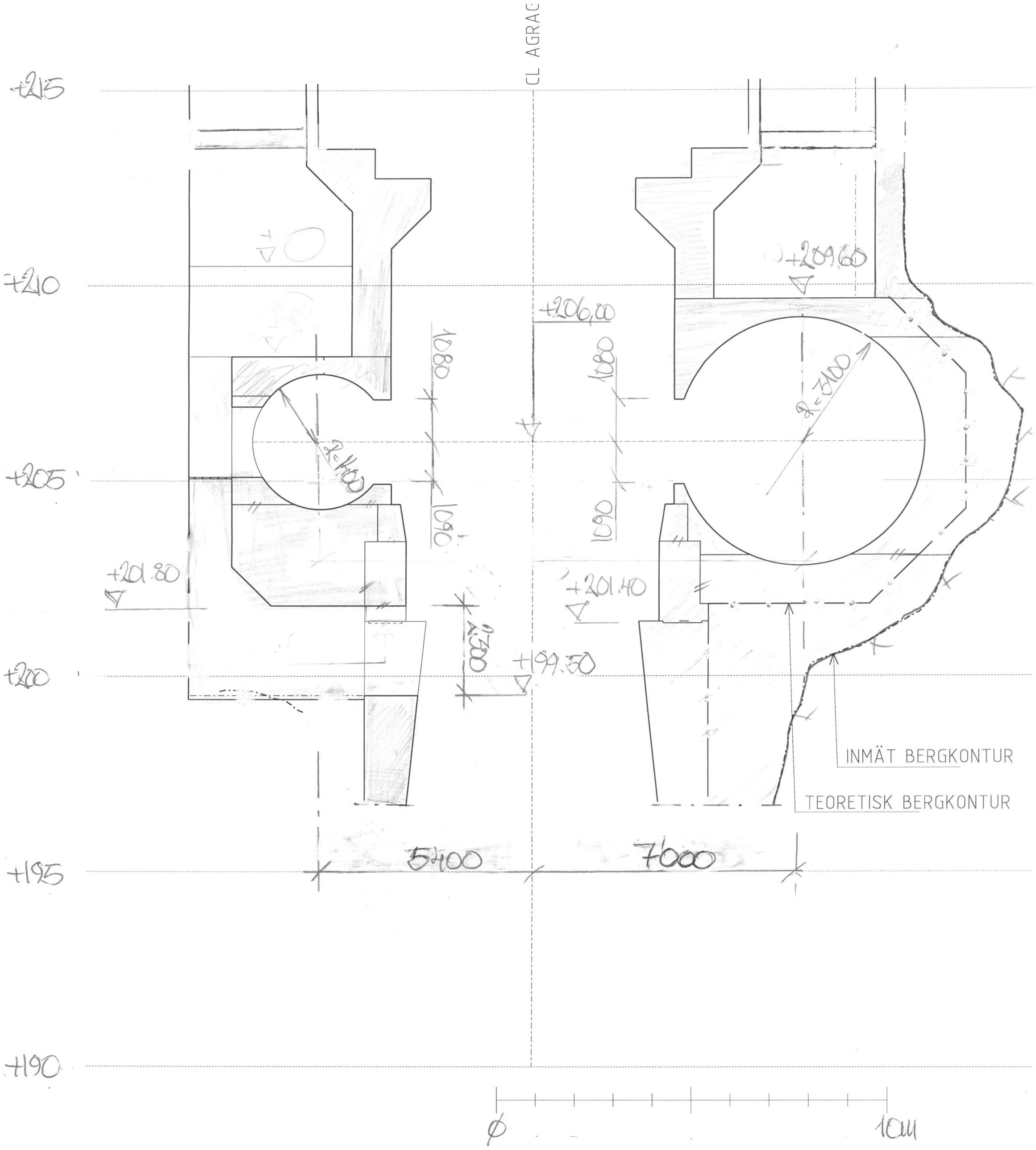
DRÄNAGERÄNNA
SE RITN. 2000188
+209,000
MA12
MA12
MA10b
RD1 PVC RÖR
SE RITN. 2000188
MA07
CL SPIRAL
MA01a
MA01b
MA10a
MA03
MA01i
MA01
+201,400
SU04

SECTION 4-4

Overview :

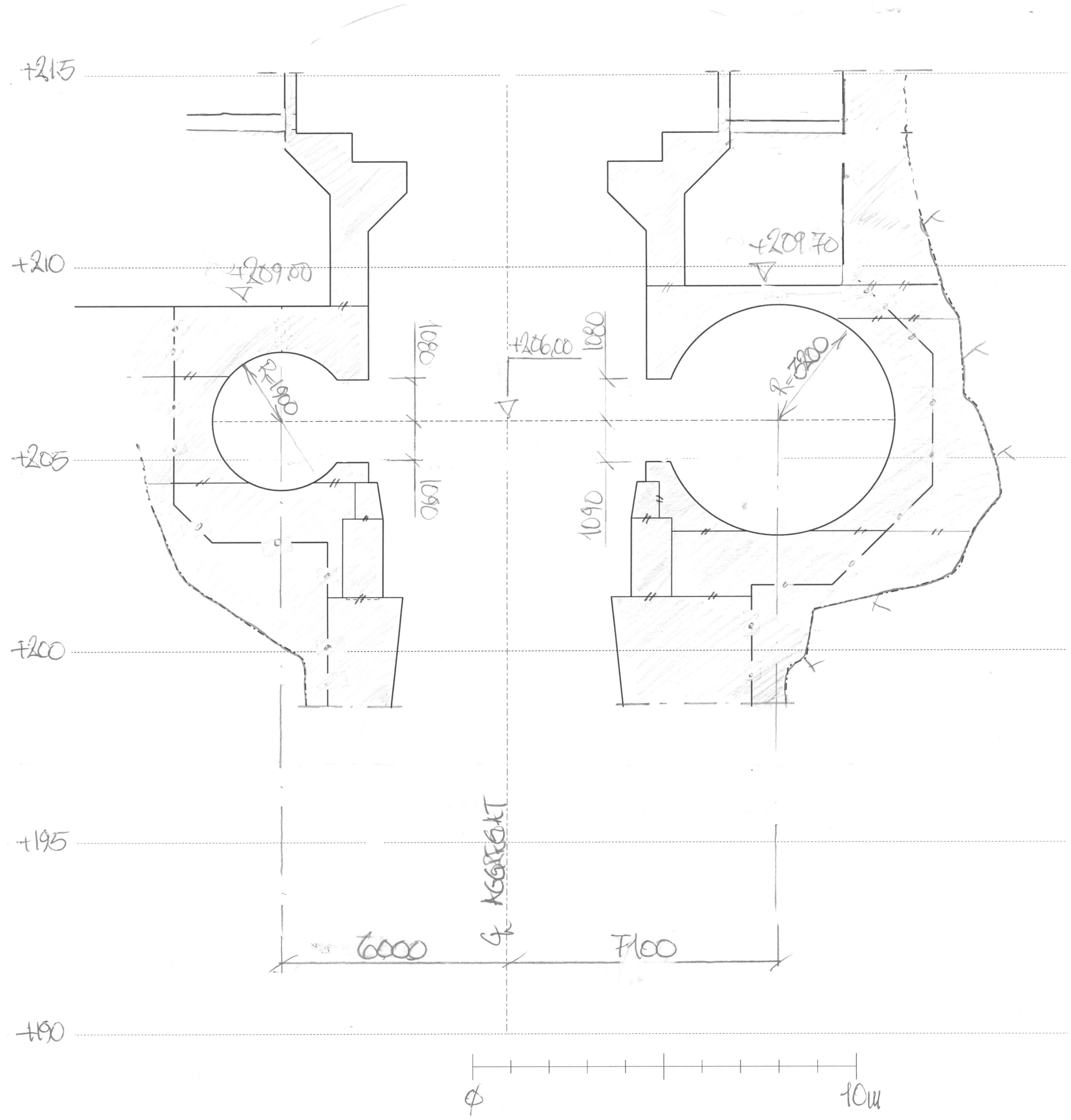


PLAN

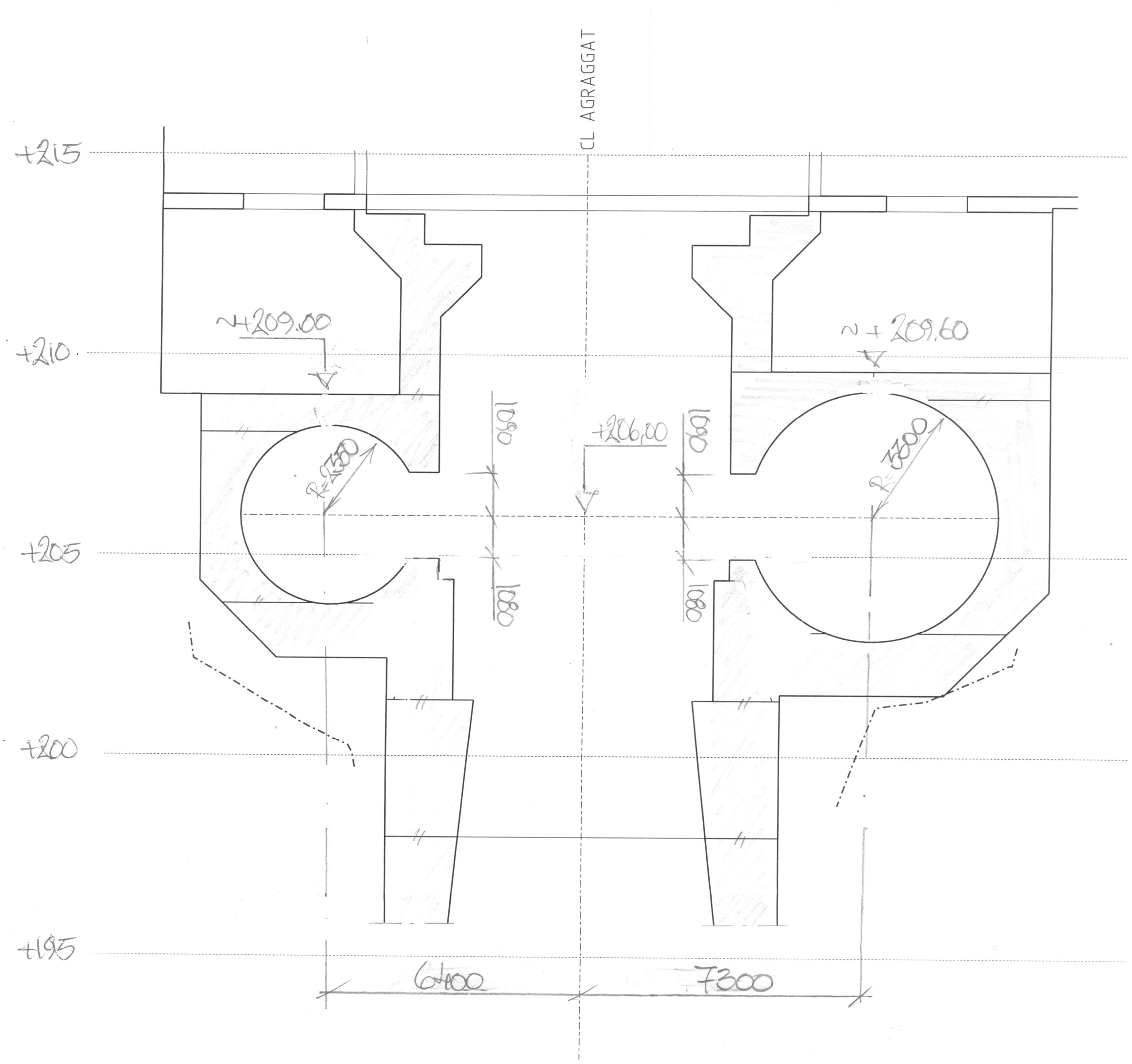


CL AGRAG
+215
+210
+205
+200
+195
+190
+209,60
+206,00
+201,80
+201,40
+199,50
1080
1090
2200
R=1400
R=3400
INMÄT BERGKONTUR
TEORETISK BERGKONTUR
5400
7000
0
10m

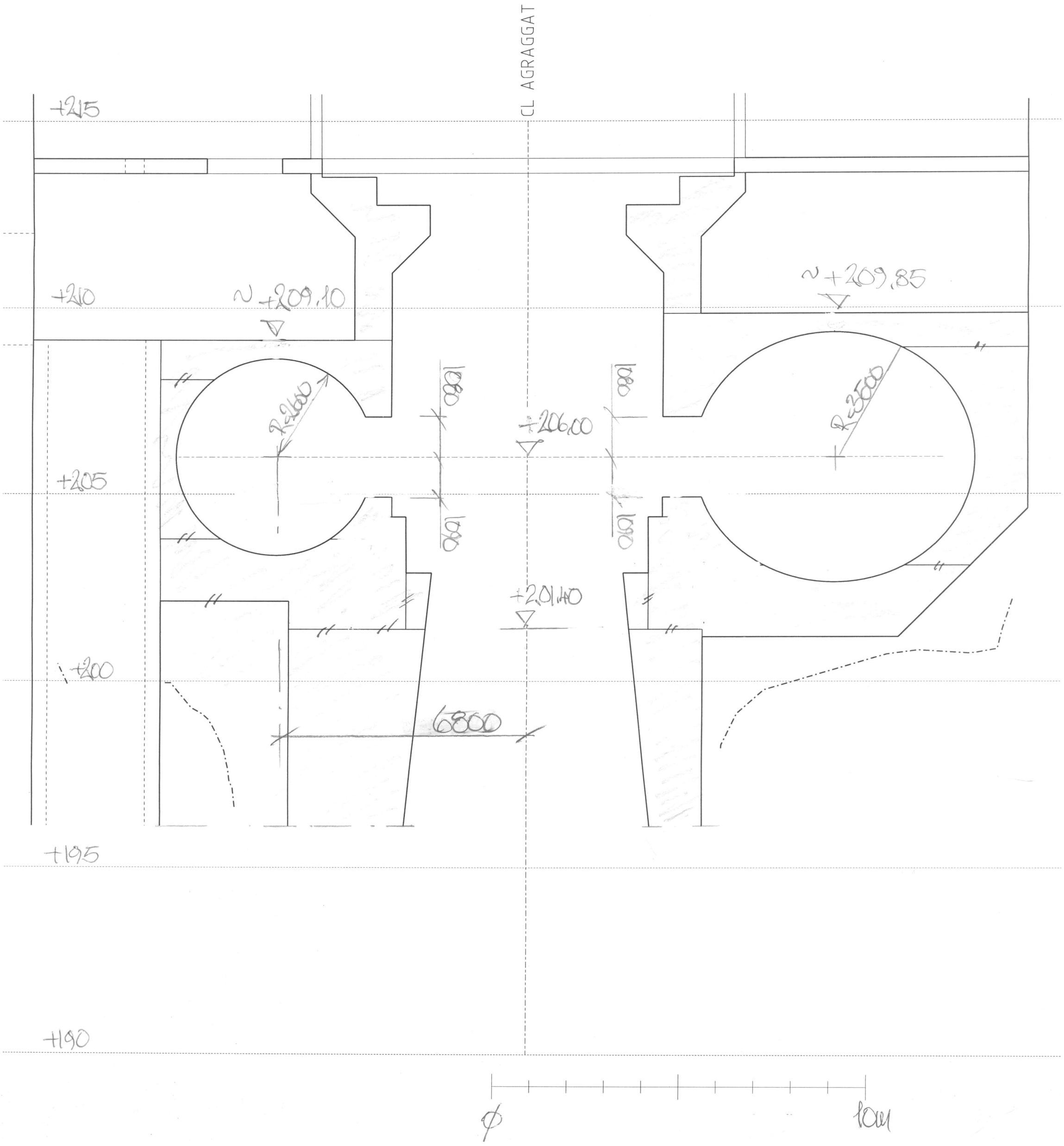
SECTION A-A



<u>SECTION B-B</u>


CL AGRAGGAT
+215
+210
+205
+200
+195
~+209.00
~+209.60
+206,00
R=2350
R=3300
1050
1050
1080
1080
6400
7300

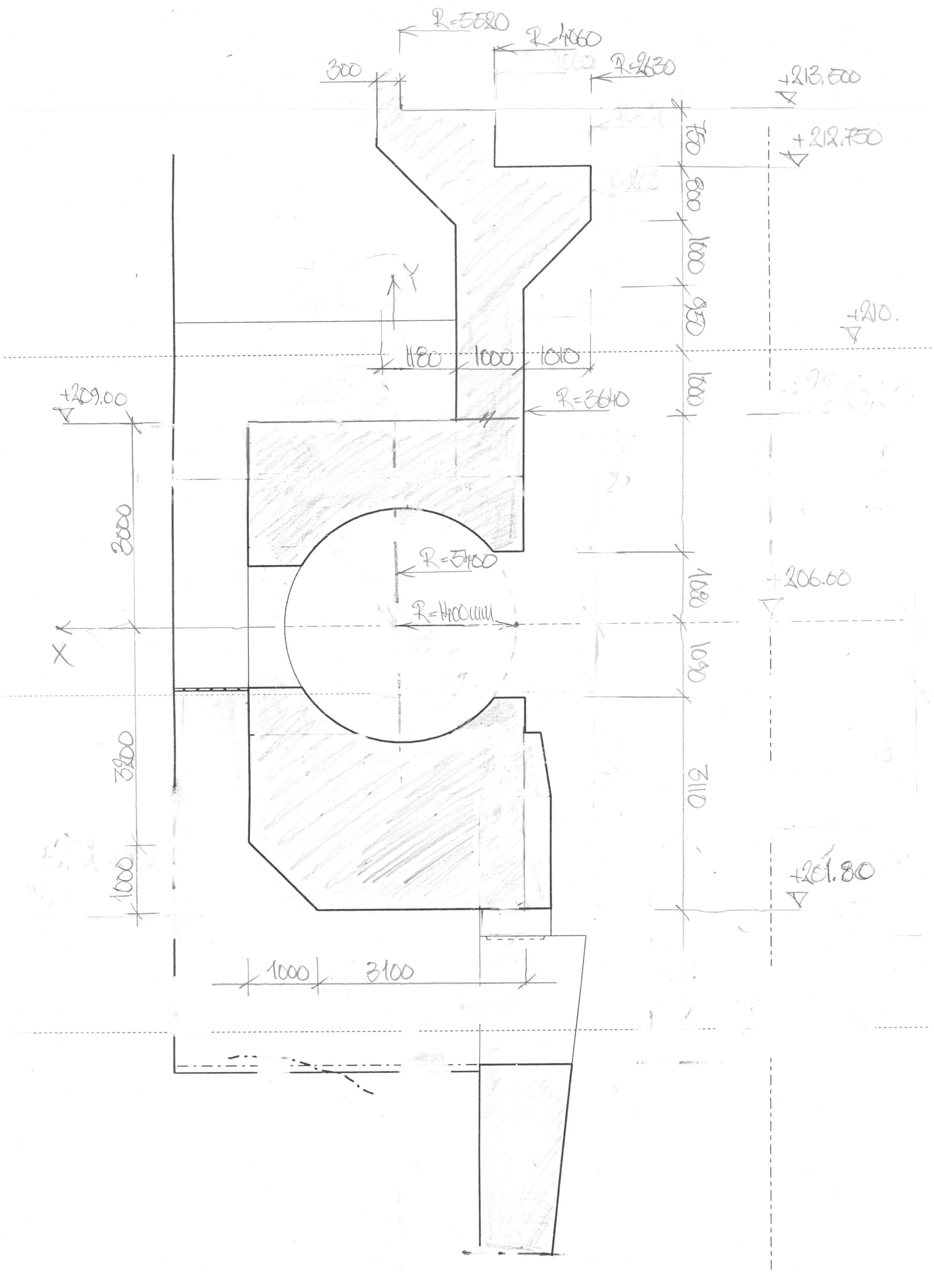
SECTION C-C



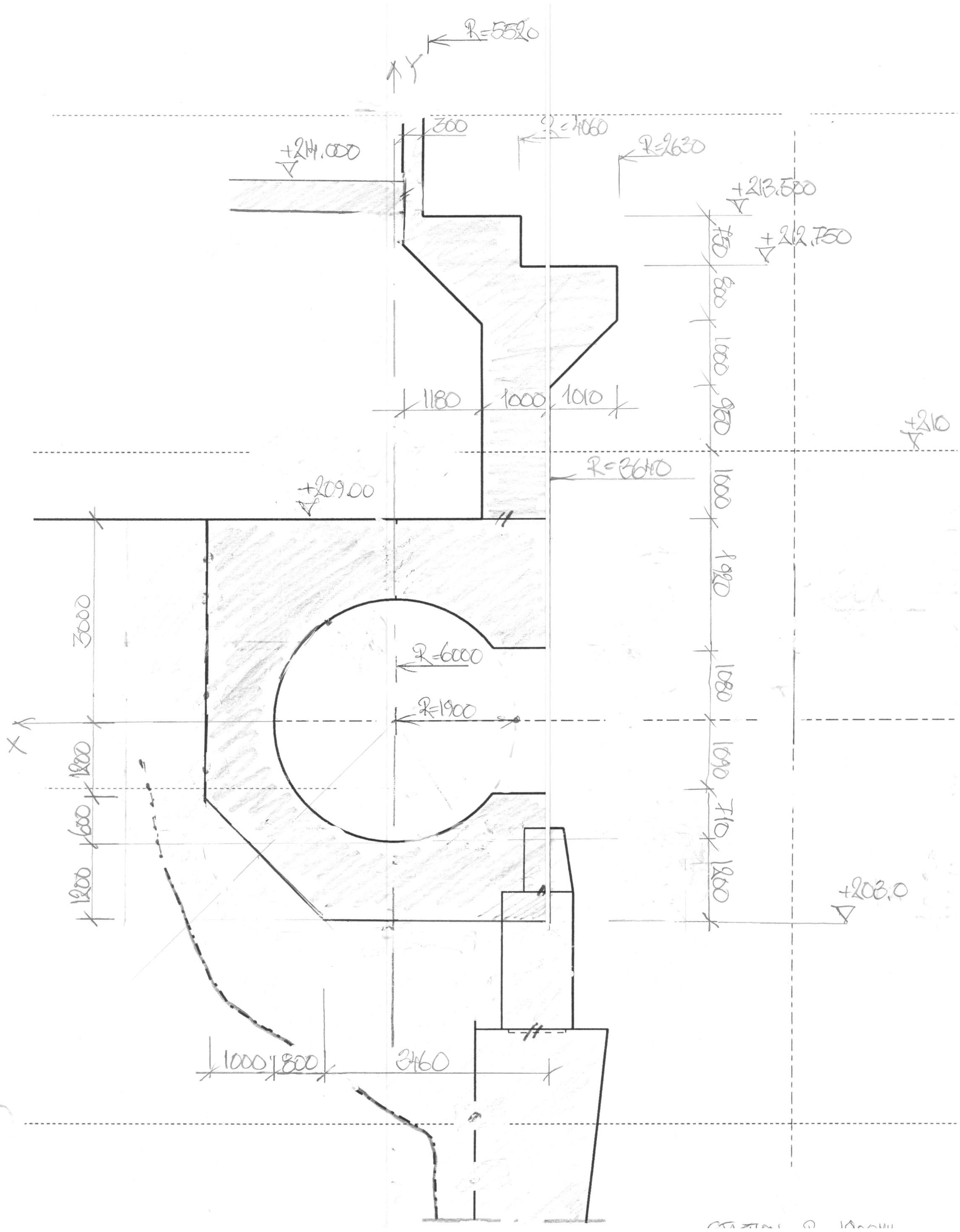
CL AGRAGGAT
+215
+210
~+209,10
~+209,85
R2600
R3500
+206,00
+205
+201,40
+200
6800
+195
+190
0
10m

SECTION D-D

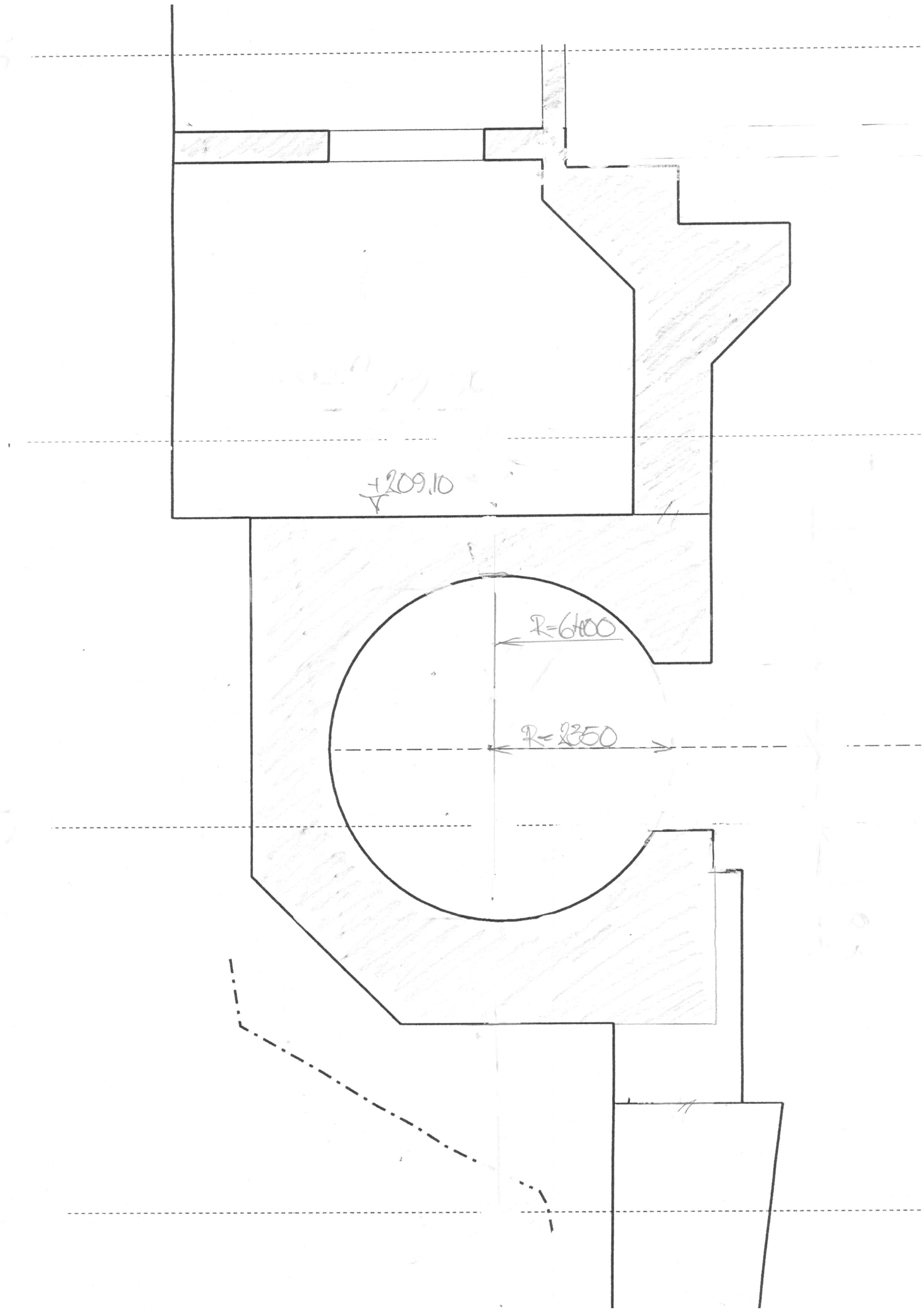
Details of various radial sections :



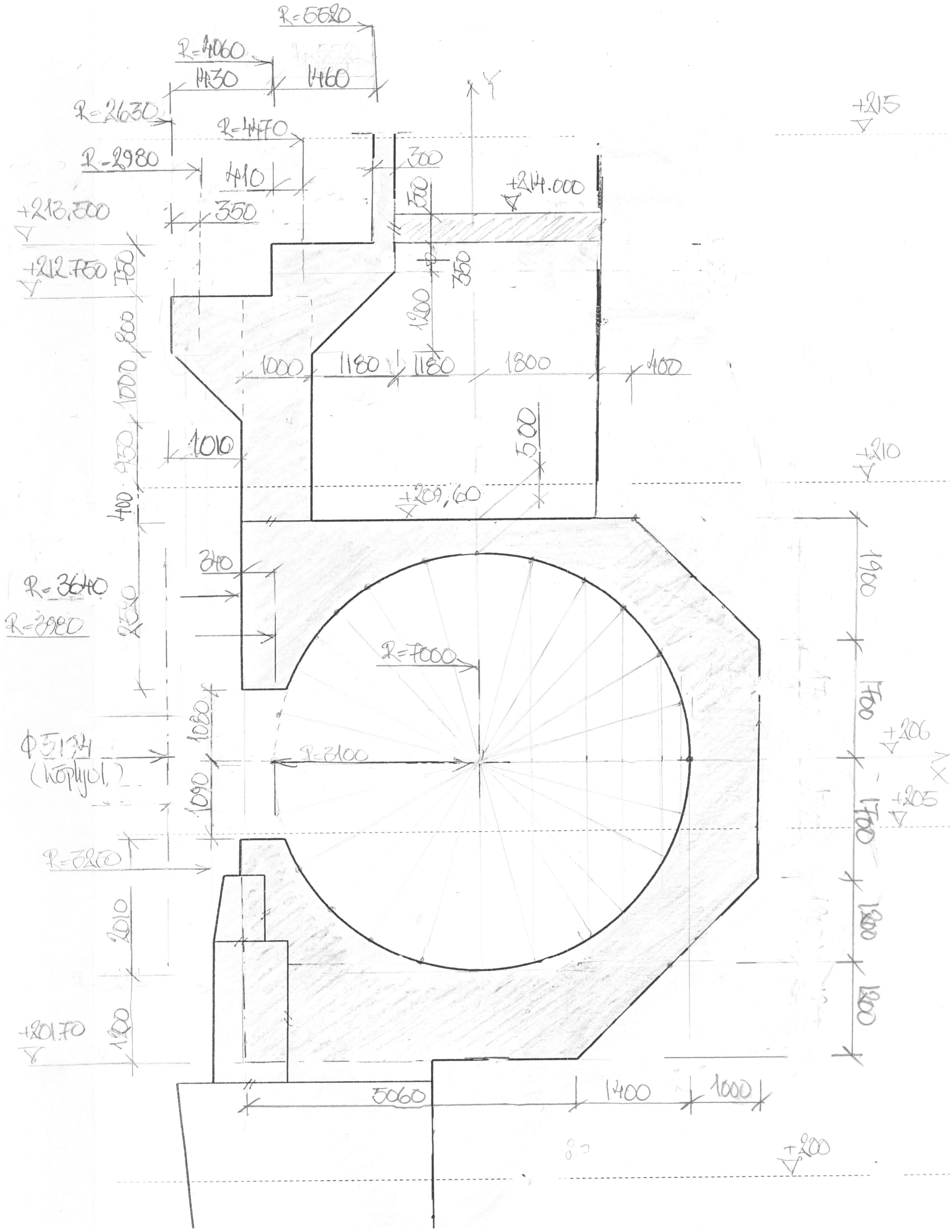
SECTION 1 – R = 1400 mm



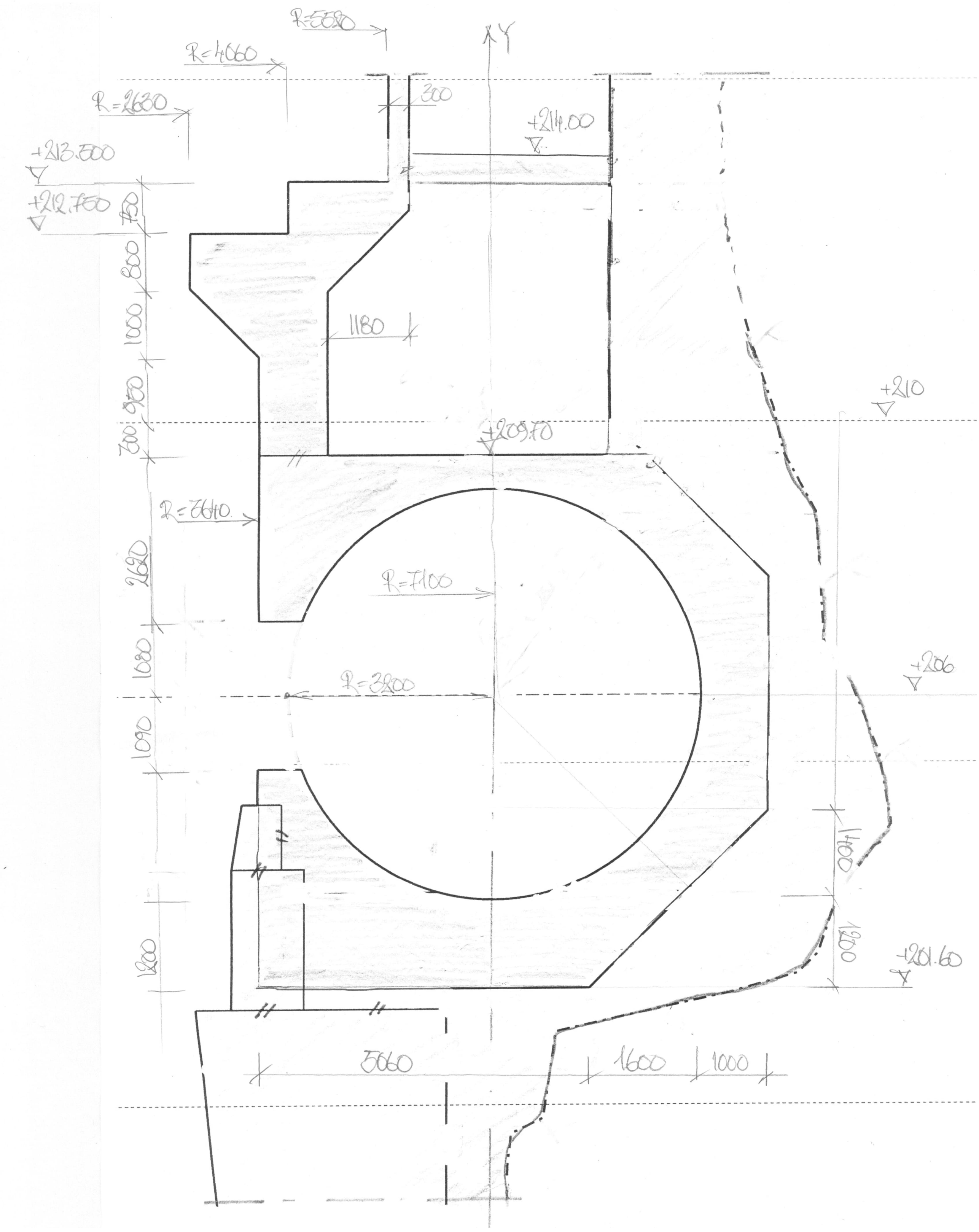
SECTION 2 – R = 1900 mm



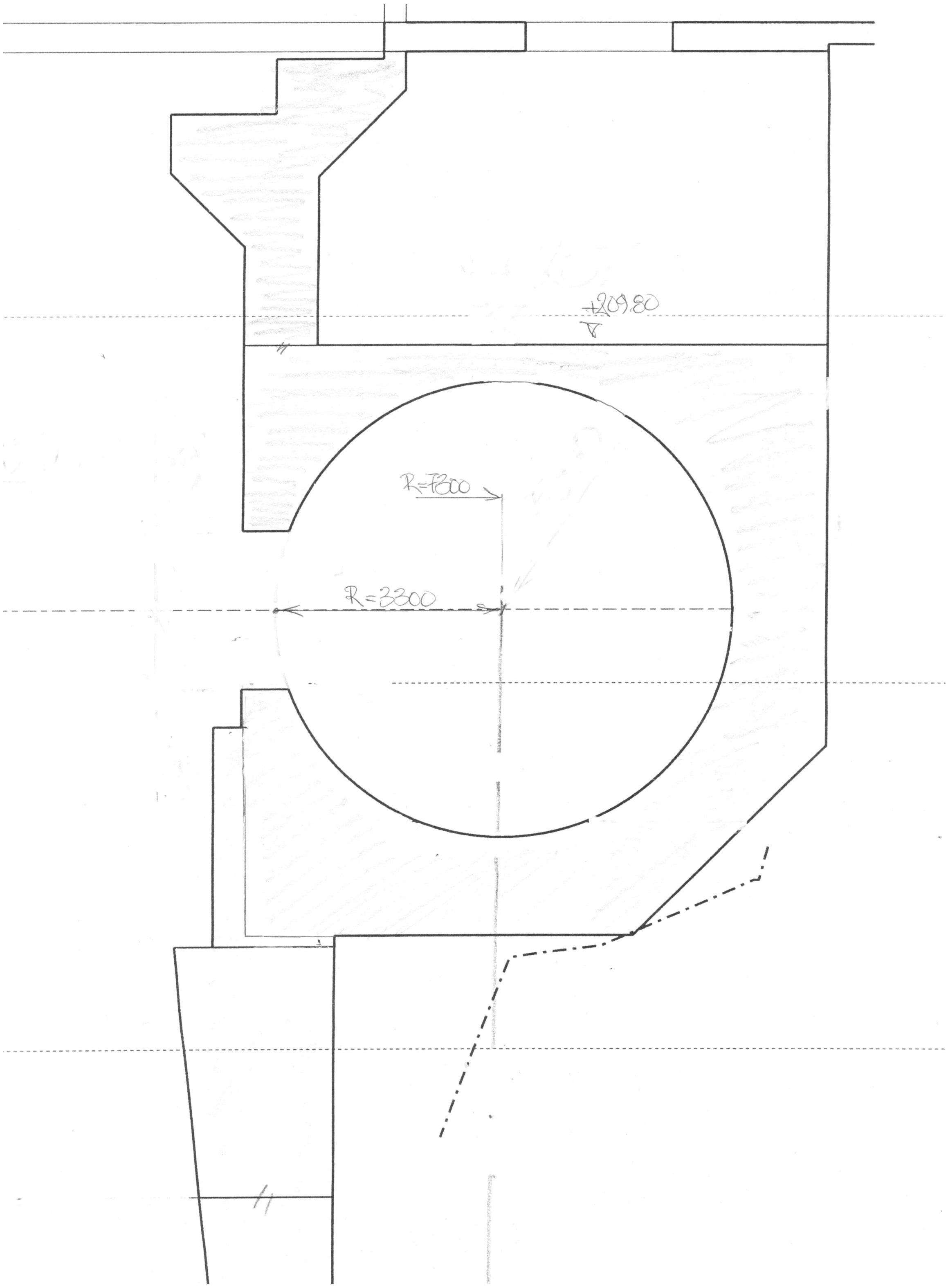
SECTION 3 – R = 2350 mm



SECTION 4 – R = 3100 mm

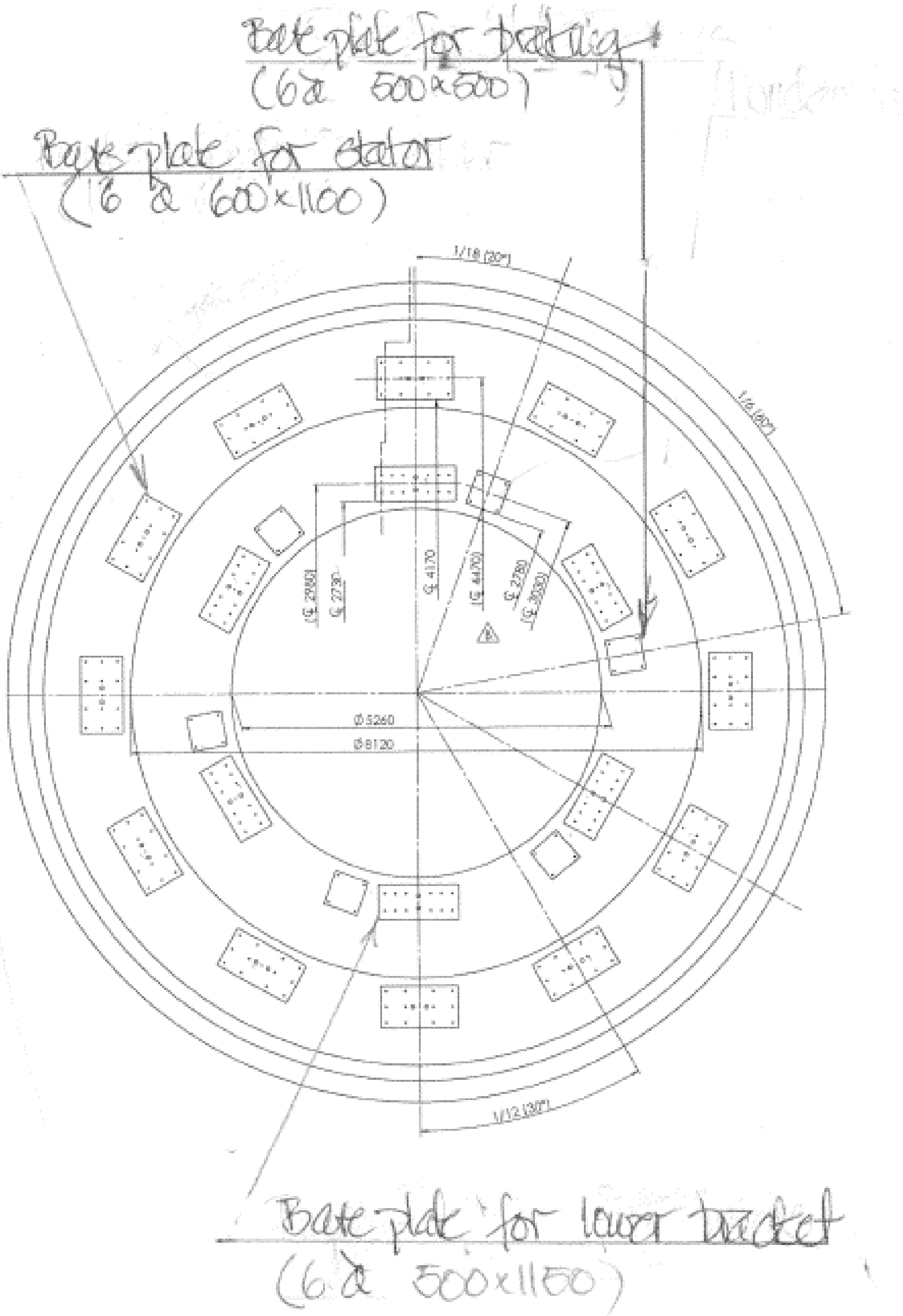


SECTION 5 – R = 3200 mm

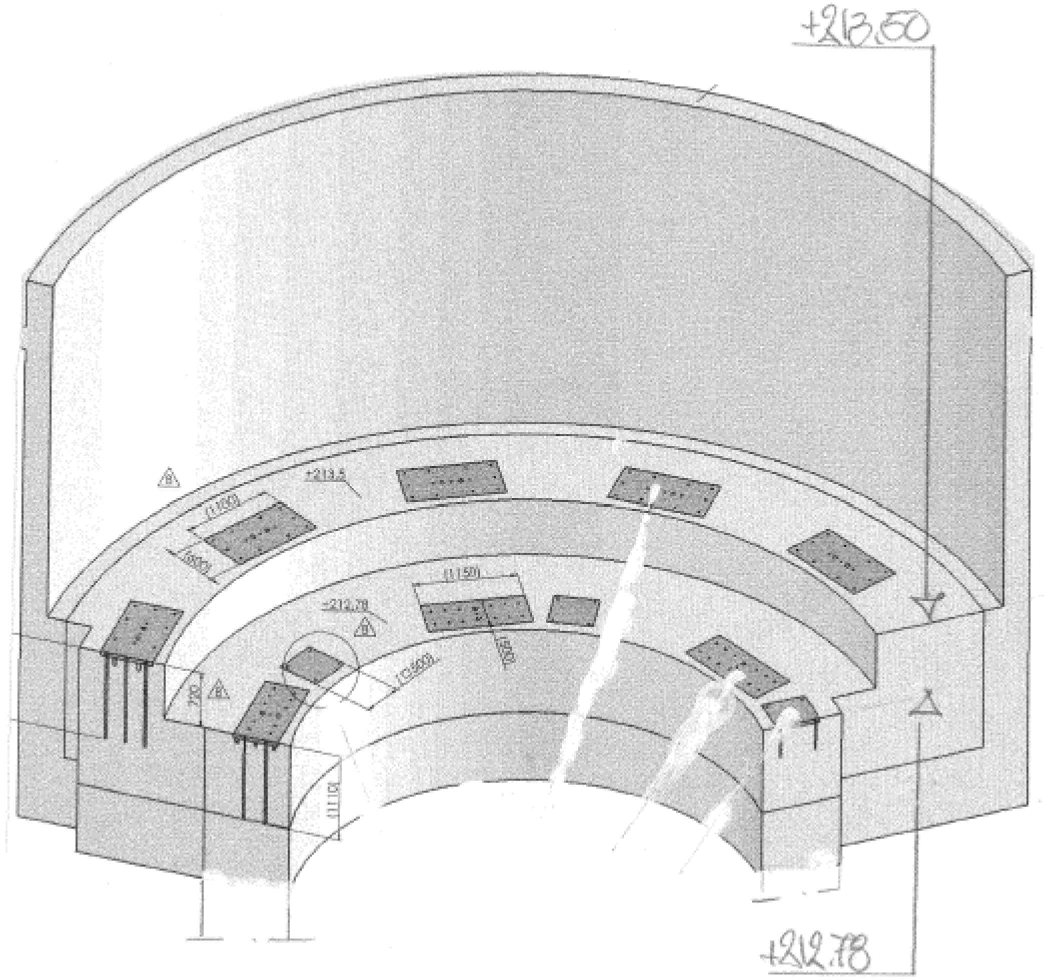


SECTION 6 – R = 3300 mm

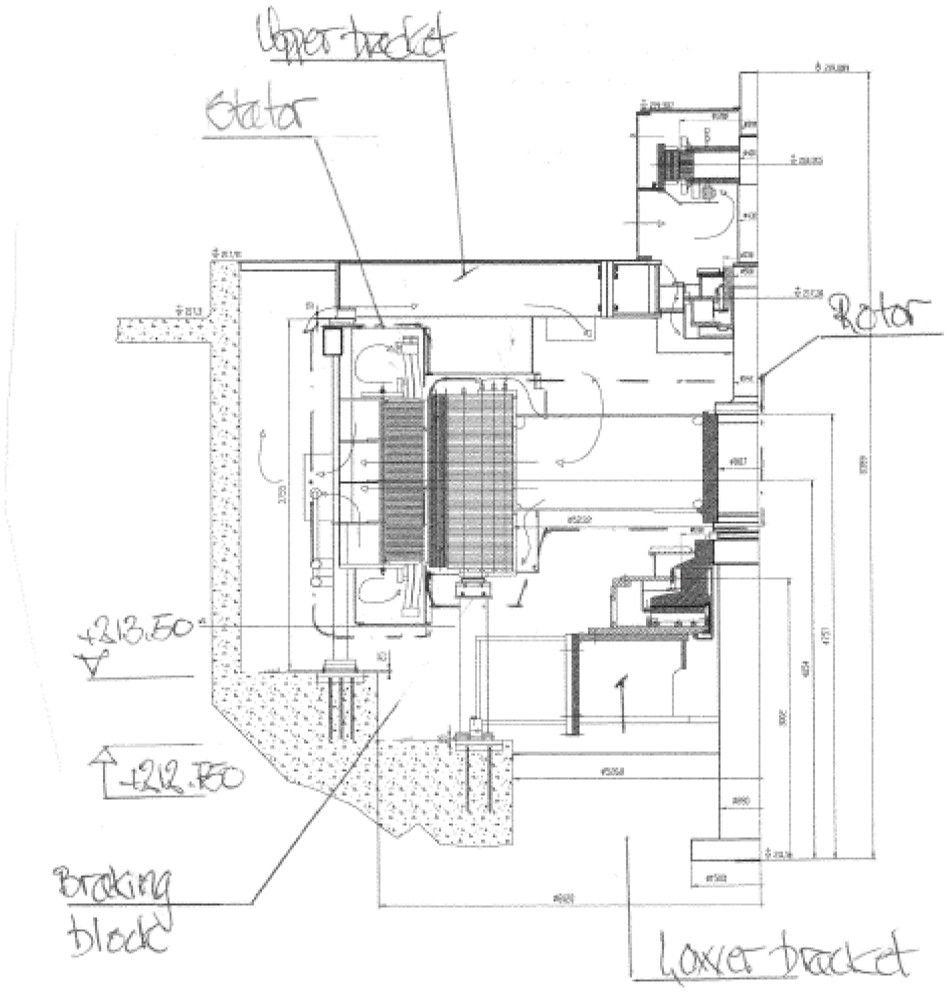
1.4.3 Generator foundation



PLAN

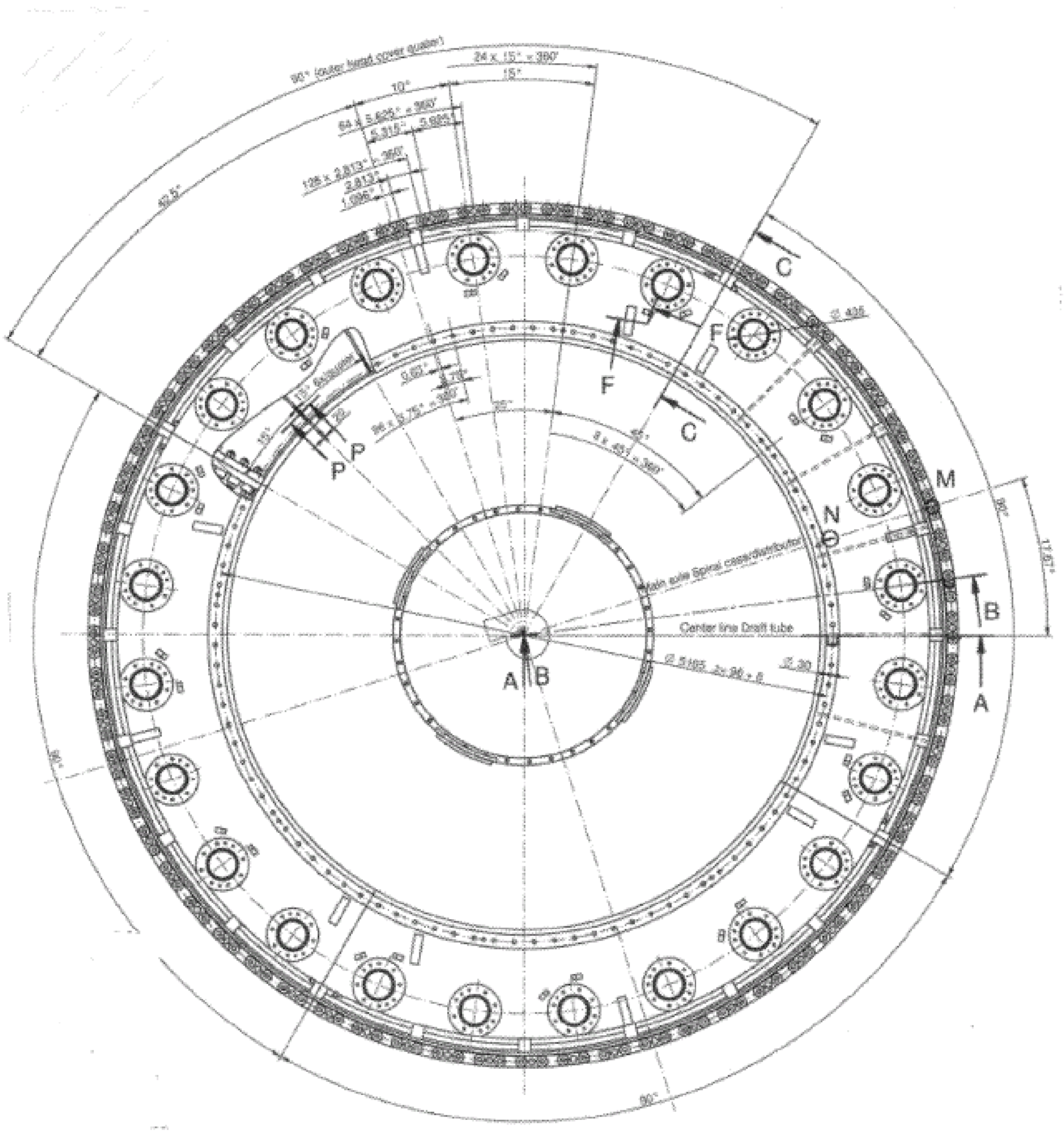


3D- VIEW

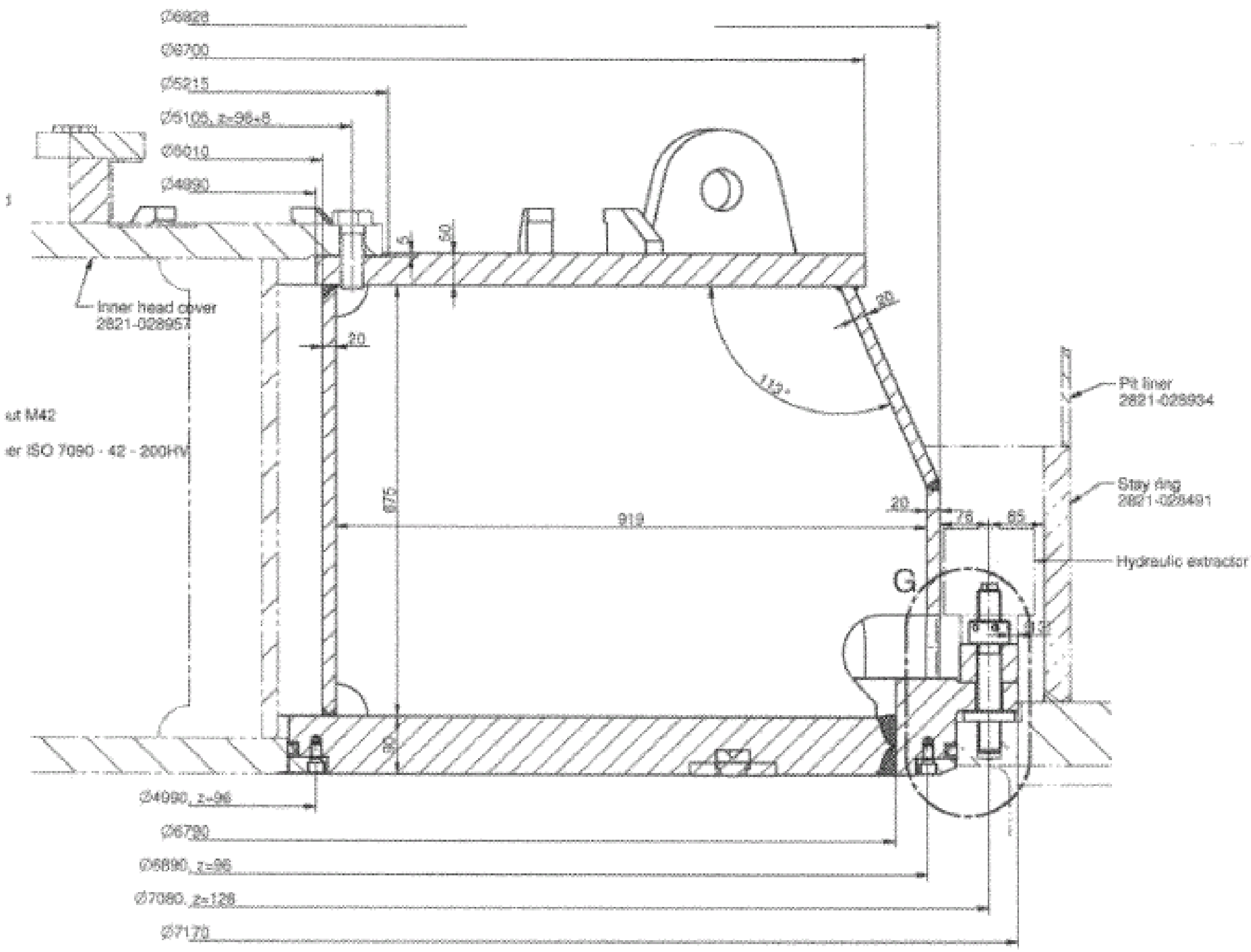


SECTION AXIAL

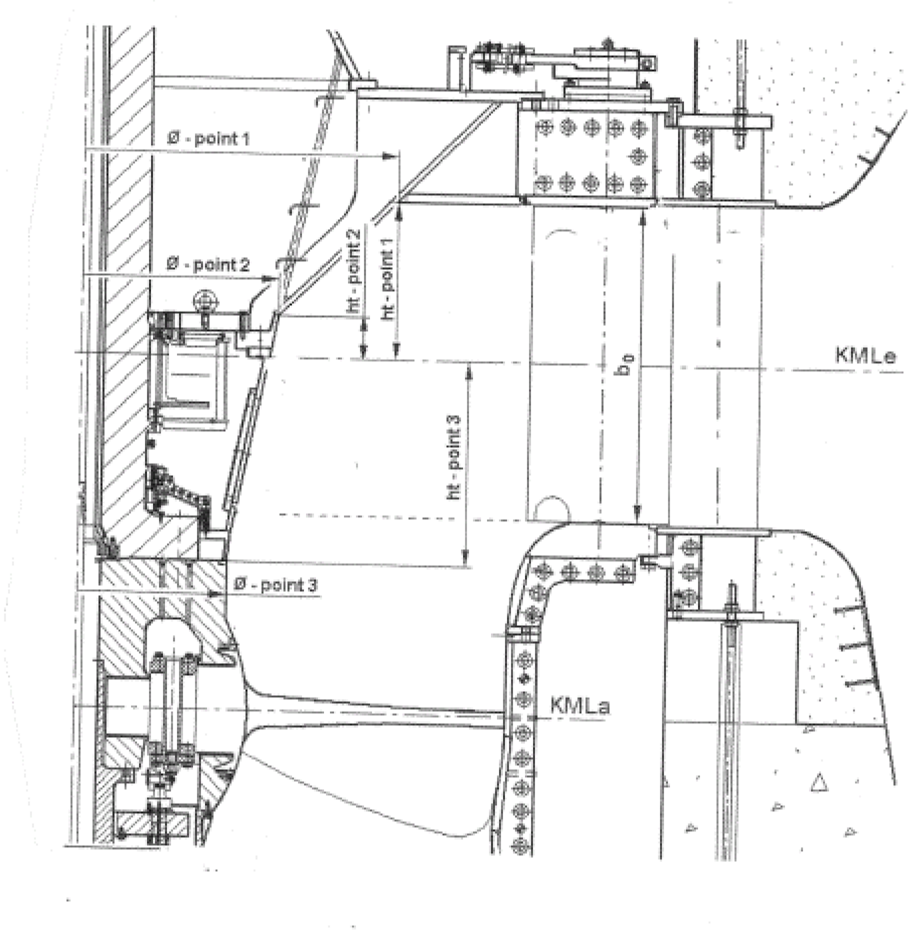
1.4.4 Head cover



PLAN

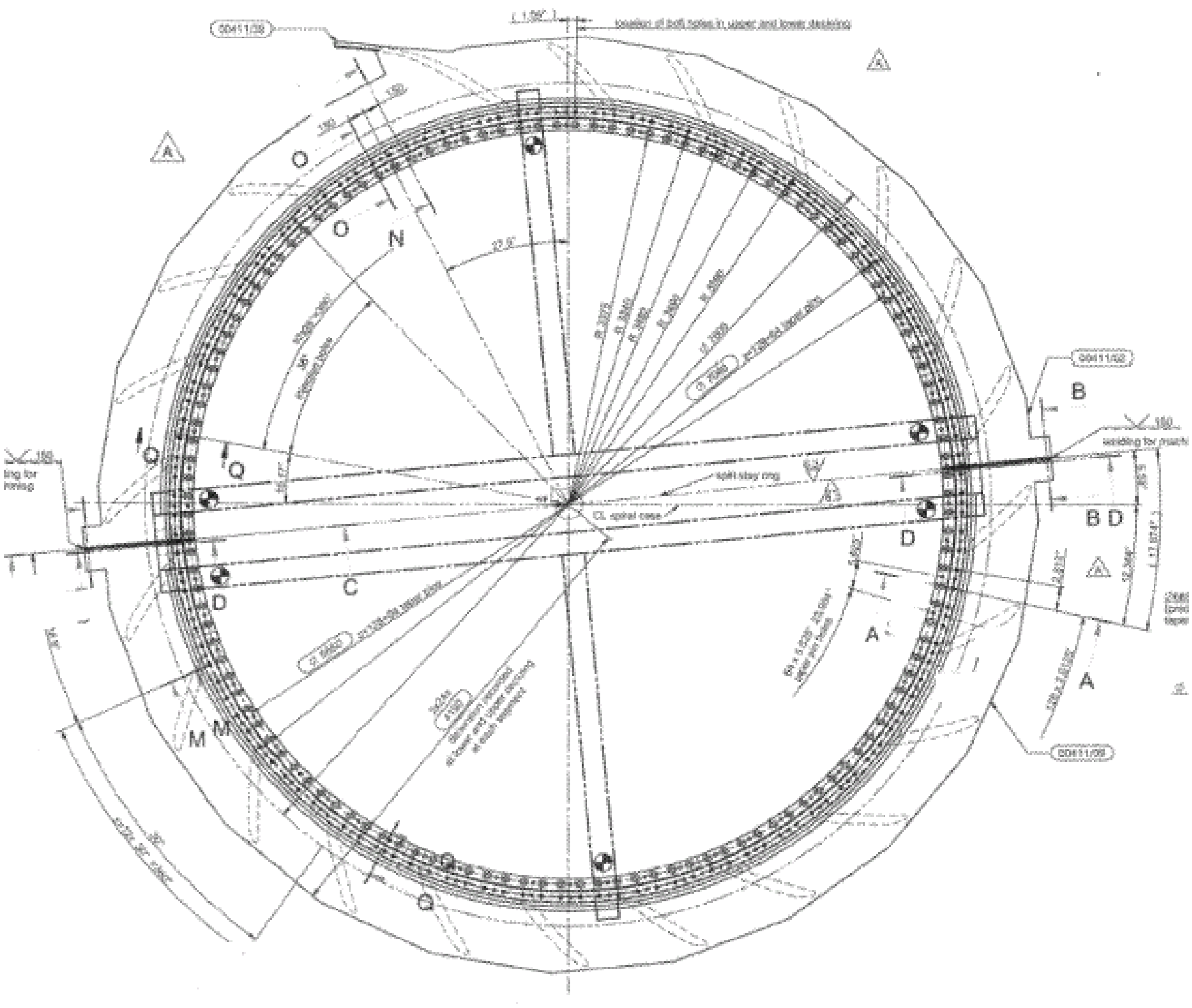

Ø6828
Ø6700
Ø5215
Ø5105, z=96+8
Ø5010
Ø4890
Inner head cover
2821-028957
ut M42
er ISO 7090 - 42 - 200HV
20
50
5
20
112°
Pit liner
2821-028934
Stay ring
2821-028491
Hydraulic extractor
20
78
65
919
875
G
Ø4990, z=96
Ø6790
Ø6890, z=96
Ø7080, z=128
Ø7170

SECTION A-A

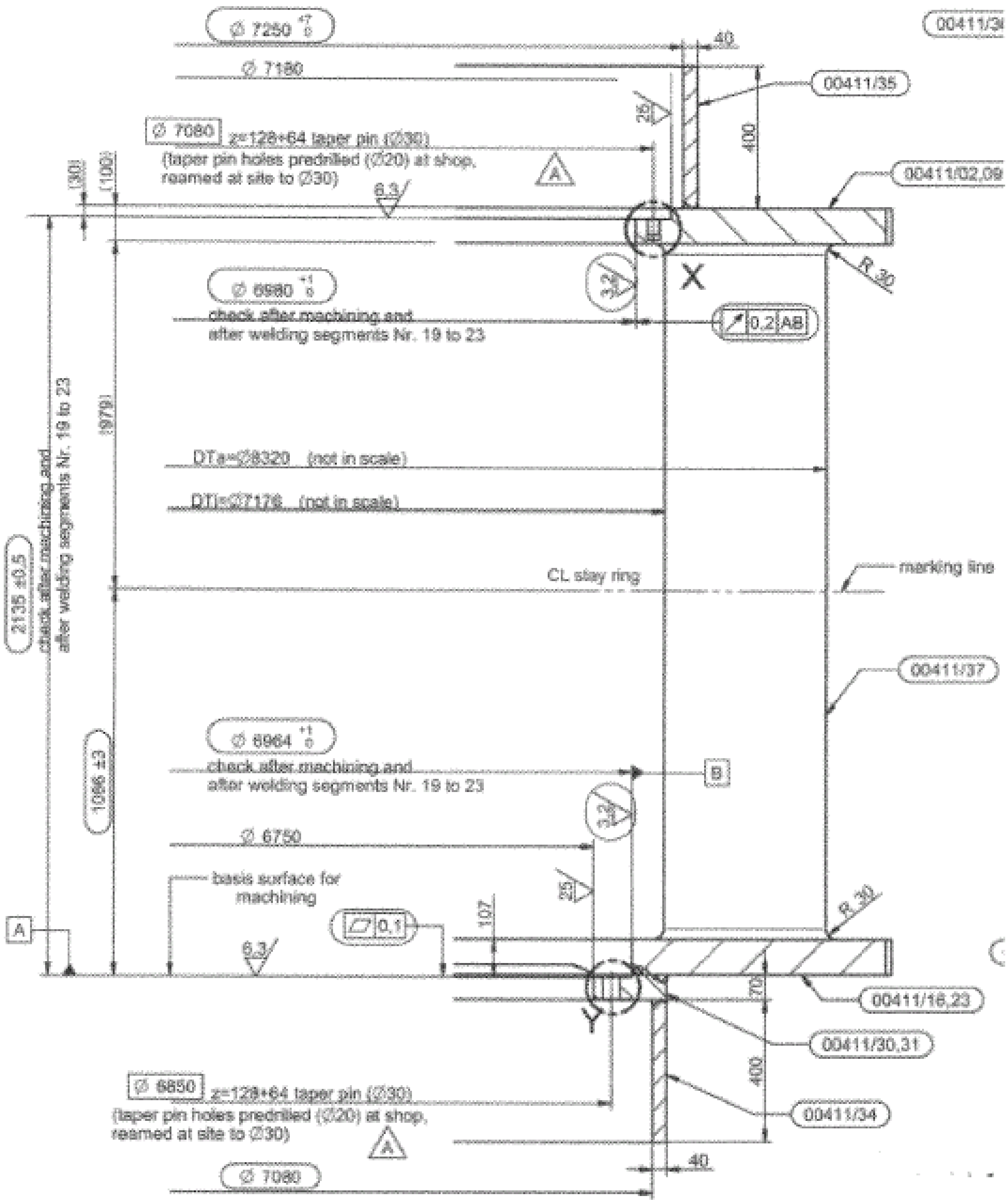


SECTION AXIAL

1.4.5 Steel stay ring

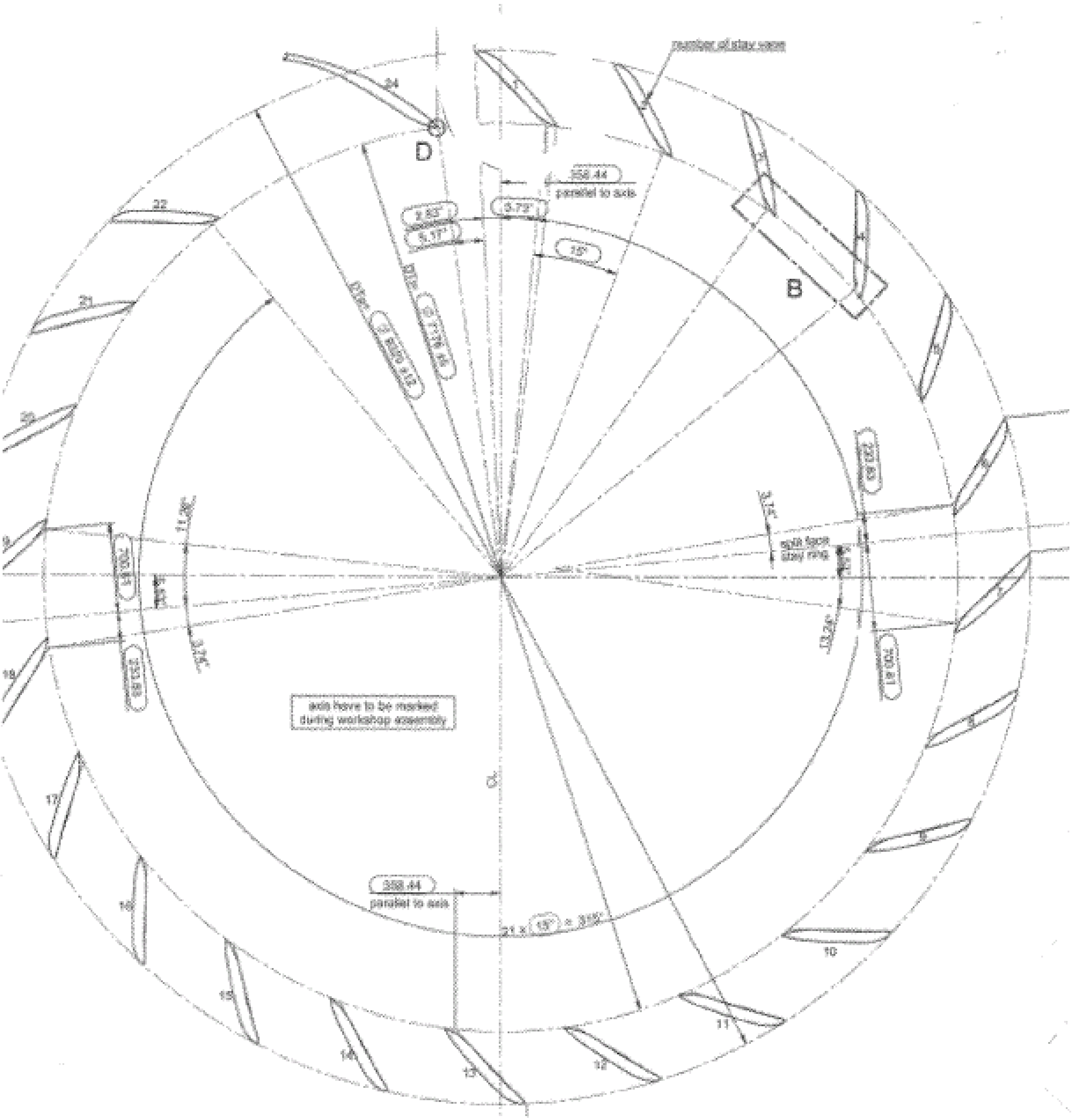


PLAN

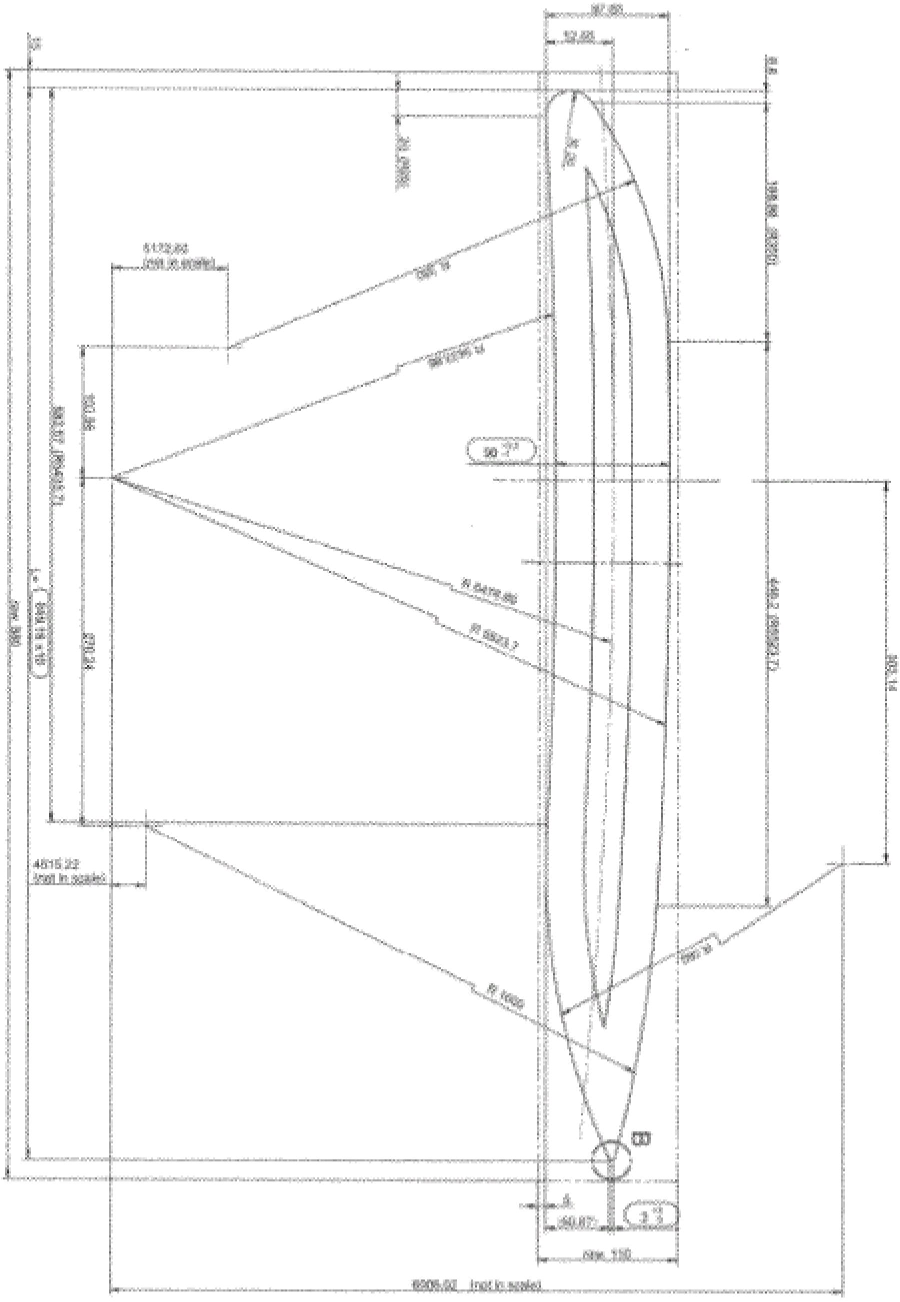

Ø 7250 +7 0
40
Ø 7180
00411/35
Ø 7080 z=128+64 taper pin (Ø30)
(taper pin holes predrilled (Ø20) at shop, reamed at site to Ø30)
400
00411/02,09
R 30
Ø 6980 +1 0
check after machining and after welding segments Nr. 19 to 23
0,2 AB
DTa=Ø8320 (not in scale)
DTi=Ø7178 (not in scale)
CL stay ring
marking line
2135 ±0,5
check after machining and after welding segments Nr. 19 to 23
00411/37
Ø 6964 +1 0
check after machining and after welding segments Nr. 19 to 23
B
1066 ±3
Ø 6750
basis surface for machining
0,1
107
R 30
00411/16,23
00411/30,31
Ø 6850 z=128+64 taper pin (Ø30)
(taper pin holes predrilled (Ø20) at shop, reamed at site to Ø30)
00411/34
40
Ø 7080

SECTION A-A

1.4.6 Steel stay vanes

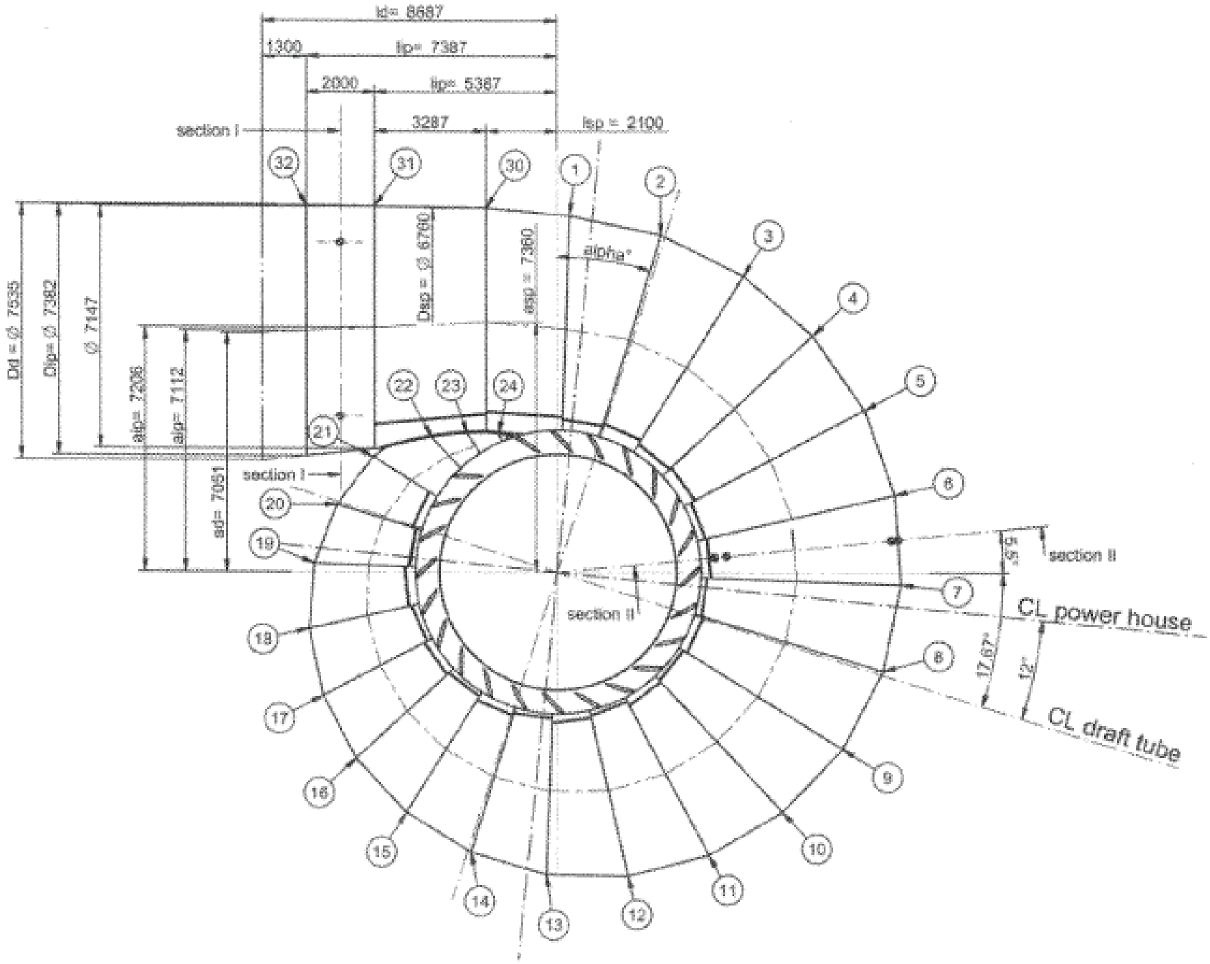


PLAN

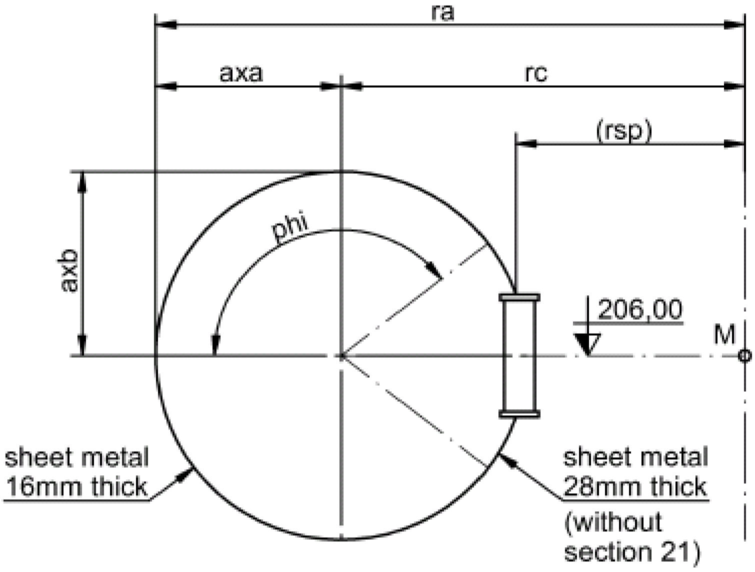


SECTION STAY VANE

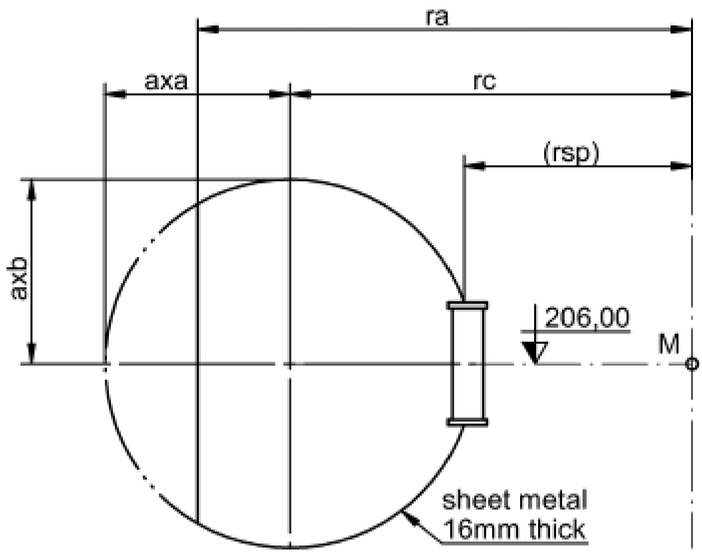
1.4.7 Steel spiral case



PLAN



SECTION 1-21



SECTION 22-24

Spiral Case Cross Sections							
Section	alpha	(rsp)	rc	ra	axa	axb	phi
[-]	[deg]	[mm]	[mm]	[mm]	[mm]	[mm]	[deg]
1	2.0	3997	7168	10517	3350	3350	140.0 / 141.6
2	17.0	3999	7110	10404	3293	3293	140.9 / 139.1
3	32.0	4001	7064	10313	3248	3248	138.4 / 142.0
4	47.0	4002	7031	10247	3216	3216	141.6 / 139.8
5	62.0	4003	7010	10206	3195	3195	139.5 / 143.1
6	77.0	4004	6986	10158	3172	3172	142.8 / 141.0
7	92.0	4005	6948	10083	3135	3135	140.4 / 144.1
8	107.0	4007	6901	9988	3088	3088	143.4 / 141.6
9	122.0	4010	6838	9866	3027	3027	140.7 / 144.5
10	137.0	4015	6747	9685	2938	2938	143.2 / 141.3
11	152.0	4020	6634	9462	2828	2828	139.5 / 143.6
12	167.0	4028	6508	9213	2705	2705	141.6 / 139.5
13	182.0	4037	6367	8936	2568	2568	136.9 / 141.5
14	197.0	4047	6222	8650	2428	2428	138.8 / 136.4
15	212.0	4059	6084	8378	2294	2294	133.3 / 138.5
16	227.0	4073	5938	8093	2155	2155	135.2 / 132.5
17	242.0	4090	5786	7797	2010	2010	130.5 / 134.3
18	257.0	4112	5627	7487	1860	1860	129.3 / 126.2
19	272.0	4118	5440	7147	1707	1707	122.3 / 127.2
20	287.0	4130	5240	6788	1548	1548	122.5 / 118.8
21	302.0	4142	5010	6395	1385	1385	111.9 / 0.0
22	317.0	4198	4780	5446	1226	1226	---
23	327.0	4206	4580	4888	1107	1107	---
24	337.0	4206	4316	4442	988	988	---

2. STATICAL SYSTEM

2.1 GENERAL

The structure considered is a steel spiral case surrounded by concrete and rock.

This report aims to analyse resistance of concrete structure.

The concrete surrounding the spiral case is modelled as *solid volume elements*.

The concrete wall carrying the upper bearings and lower bearings are modelled as *thick shell elements*. This with the objective of minimizing the size of the model.

The effect of steel spiral tube is neglected. This assumption is considered as on the safe side when studying stress in concrete structure. The effect of the steel stay ring and stay vanes are modelled using *thick shell elements*.

There are a total of 23 stay vanes distributed along the stay ring which are replaced with continuous shell elements. These shell elements have an equivalent thickness corresponding to the smeared cross section area of all stay vanes. Also this with the objective of minimizing the size of the model.

In order to verify results retrieved from the 3D-modell found in Appendix 1 several simplified 2D-modell analyses are performed in the radial direction.

The 2D-modells are taken from vertical sections in the radial direction of the spiral case.

Chapter A only contains the description of the 3D-modell.

Chapter E, F and G contains analysis of radiuses R = 3.30 m, R = 2.50 m and R = 3.10 m.

Each chapter contains a complete presentation of the 2D-modells.

Chapter H is used to verify results over the inspection shaft in the tangential direction.

2.2 STATICAL MODELL

2.2.1 Geometry

In order to describe the structures geometry first *POINTS* have to be defined. The high order geometry is determined as seen below.

LINES are generated from *POINTS*.
SURFACES are generated from *LINES*.
VOLUMES are generated from *SURFACES.*

Shell elements are applied to *SURFACES*.

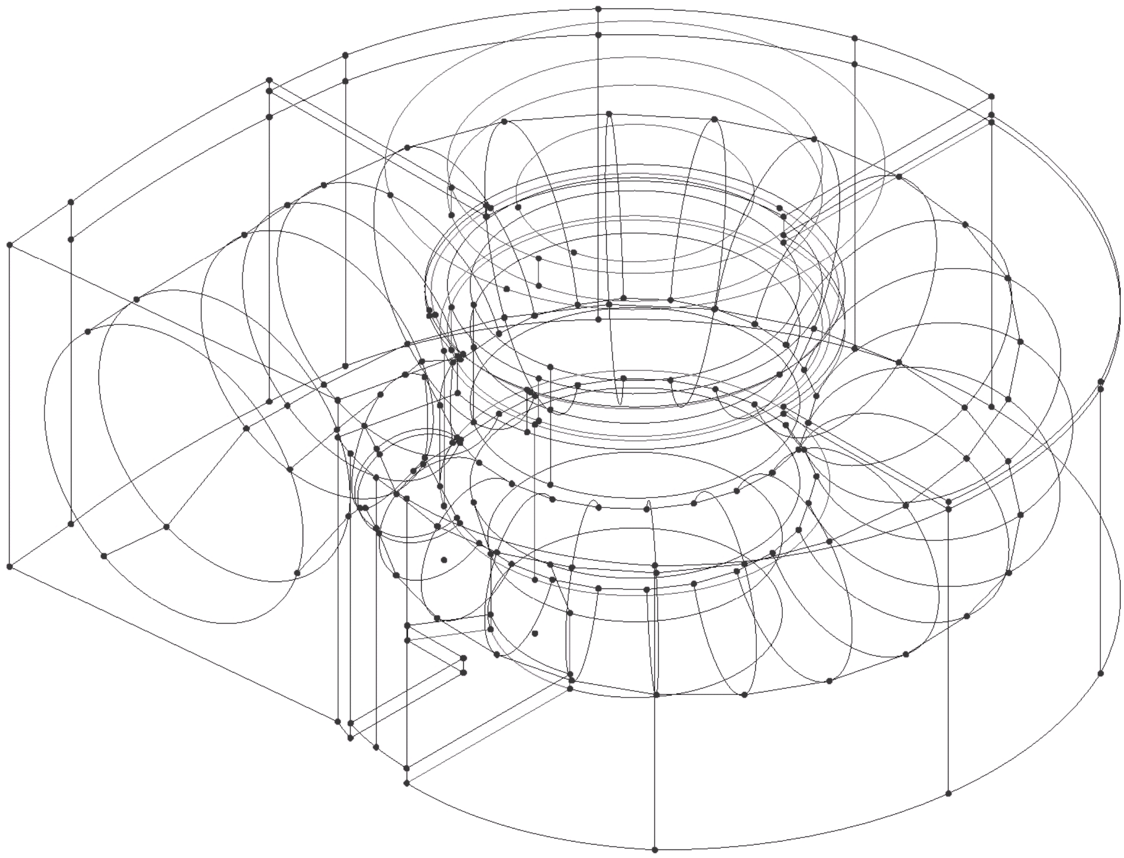
Volume elements are applied to *VOLUMES*.

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

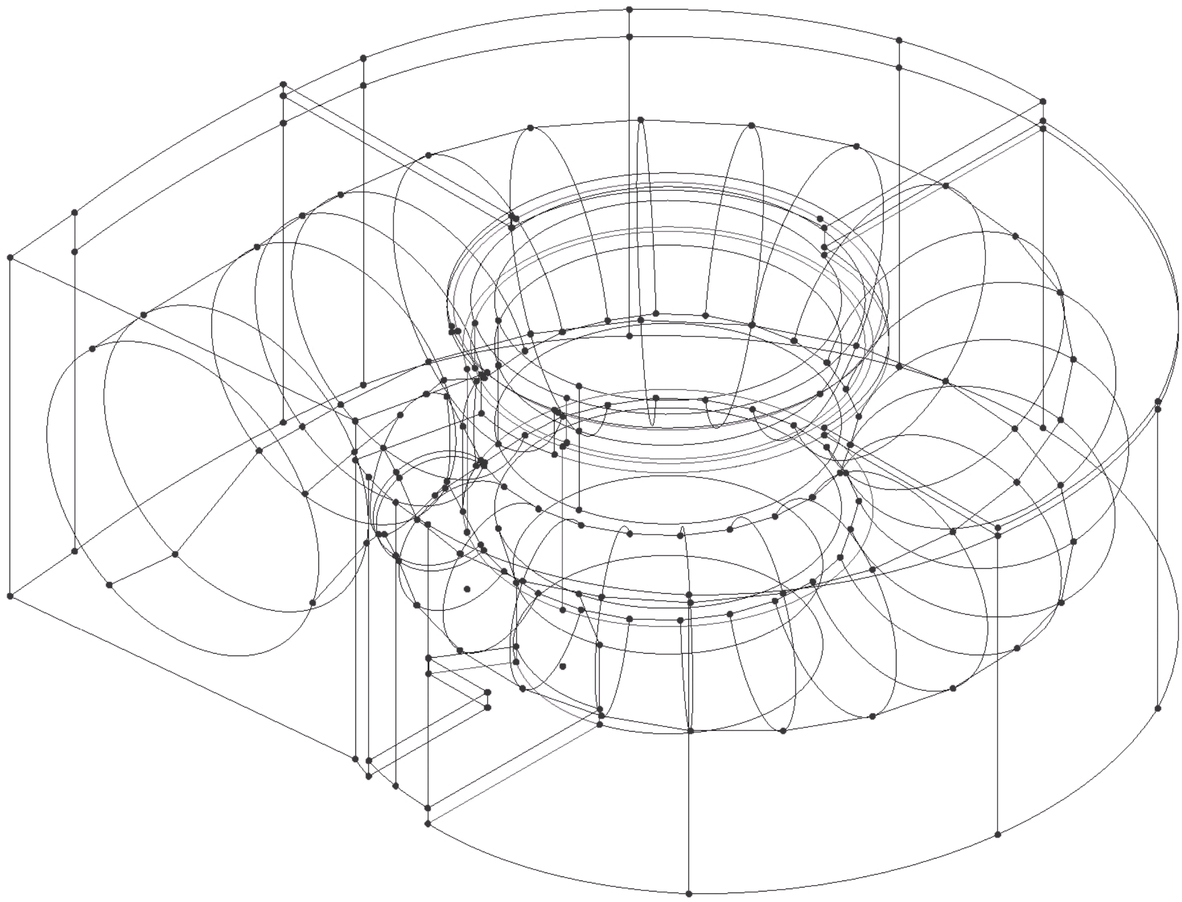
All *LINES* used to define *SURFACES* are presented in Appendix 1.

All *SURFACES* used to define *VOLUMES* are presented in Appendix 1.

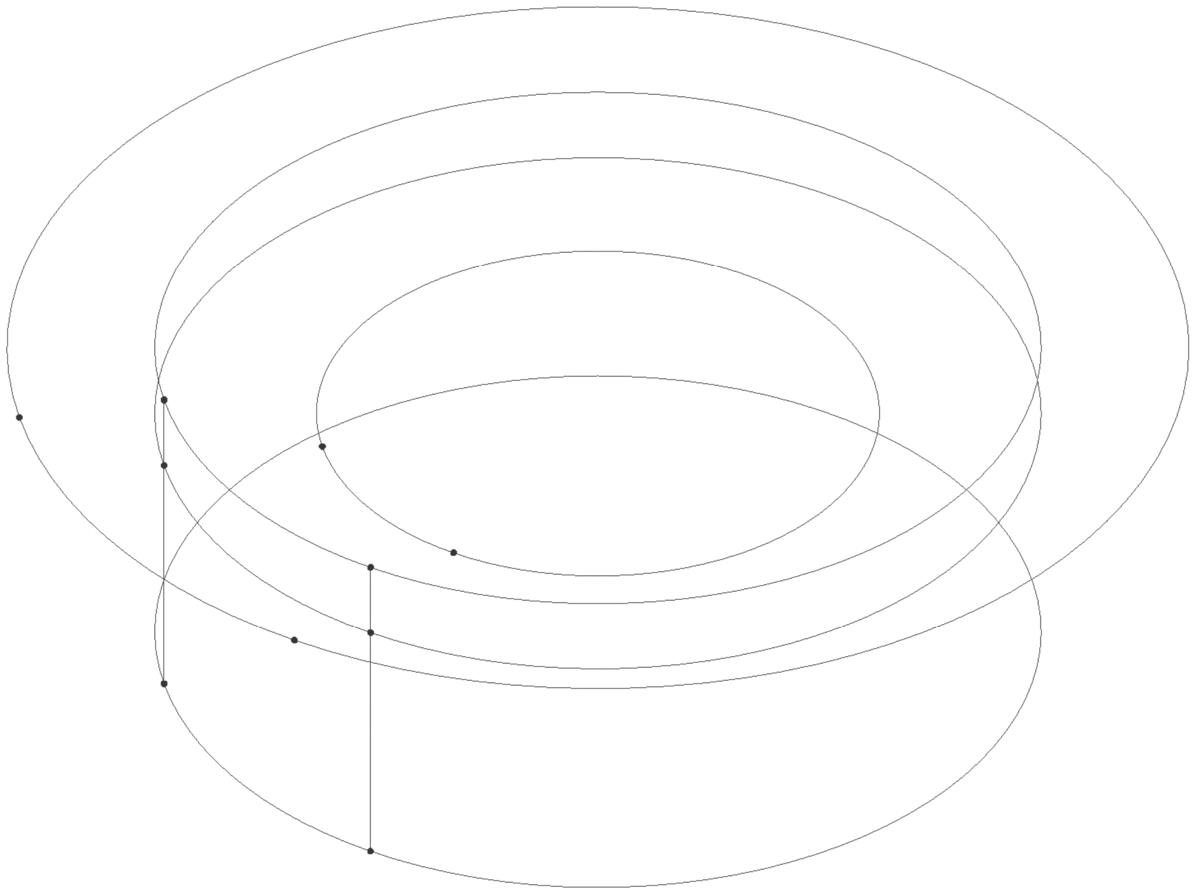
Overview :



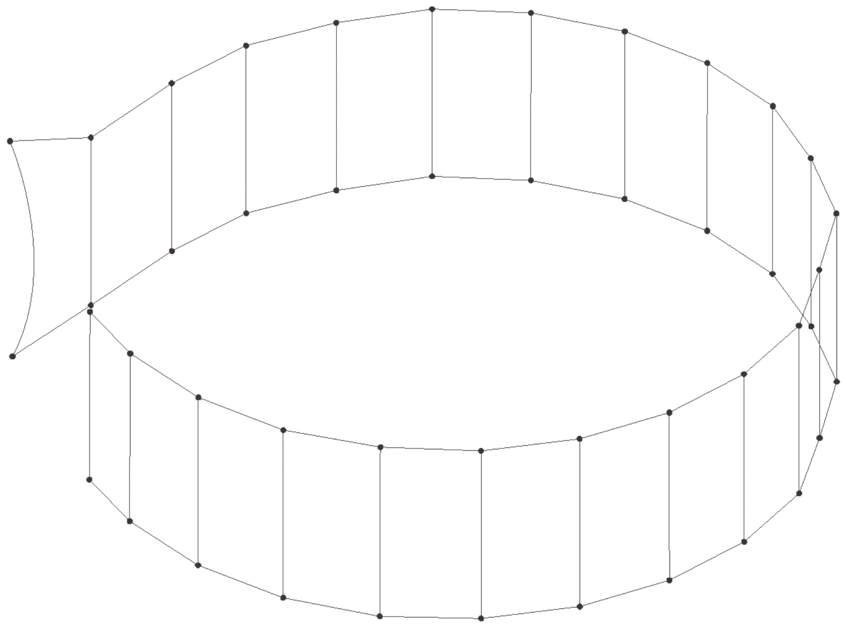
View – Concrete surrounding spiral case :



View – Concrete structure carrying bearings :

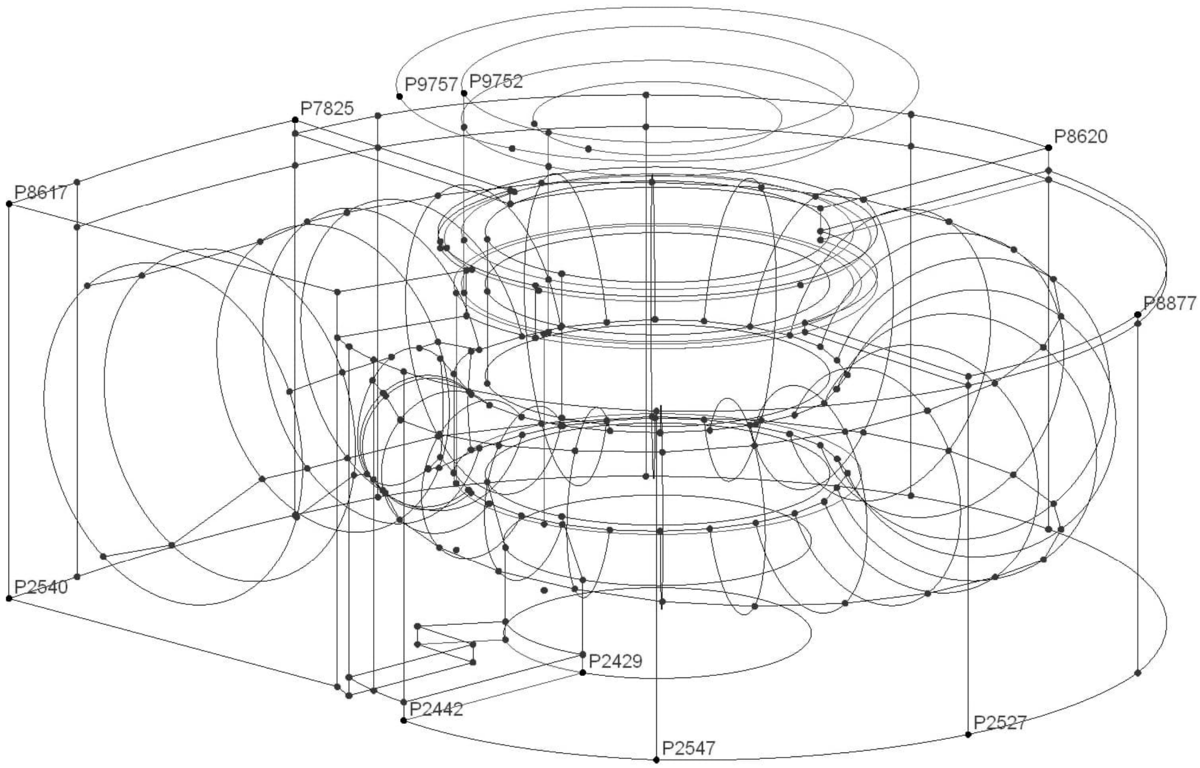


View – Equivalent stay vanes :



2.2.1.1 Geometry : POINTS

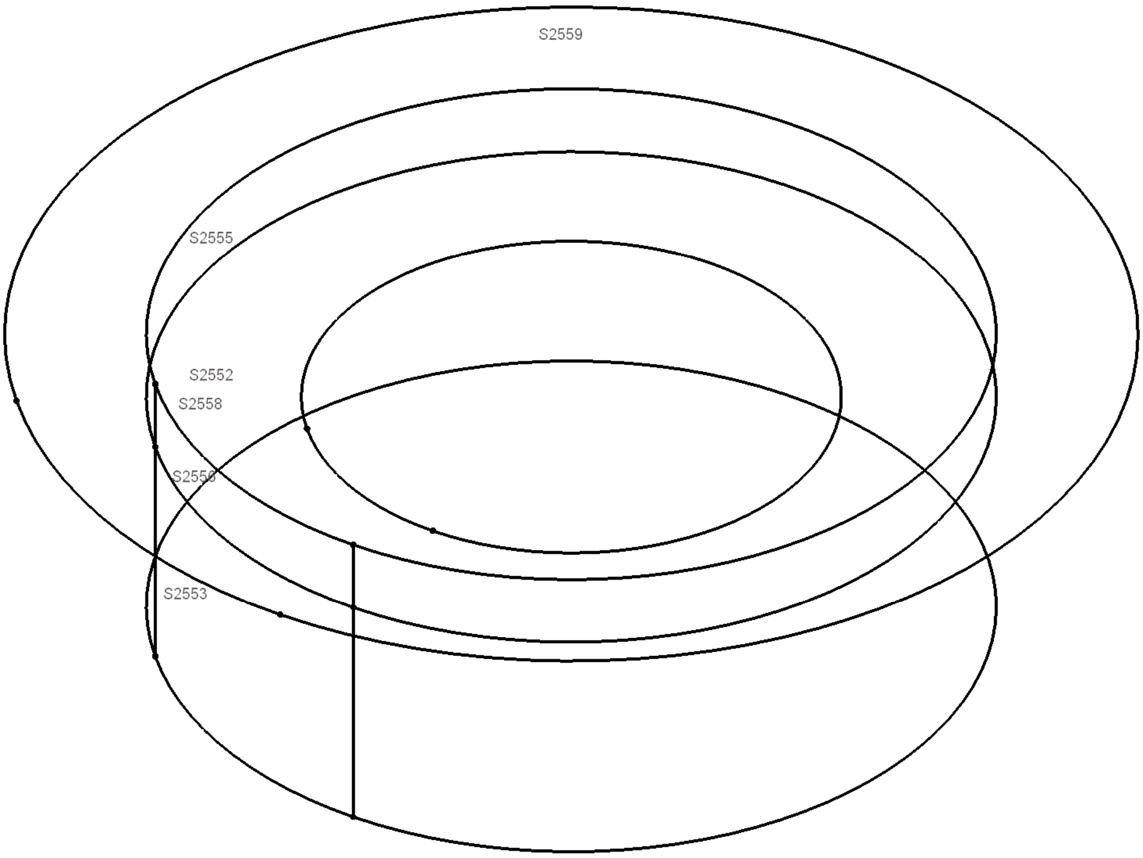
Overview :



Remark A great number of points are required to model the entire structure. All these points are marked with dots on picture above. Due the large number of points only a selection of all these points are labeled. The entire coordinate list of all occurring points are found in Appendix 1.

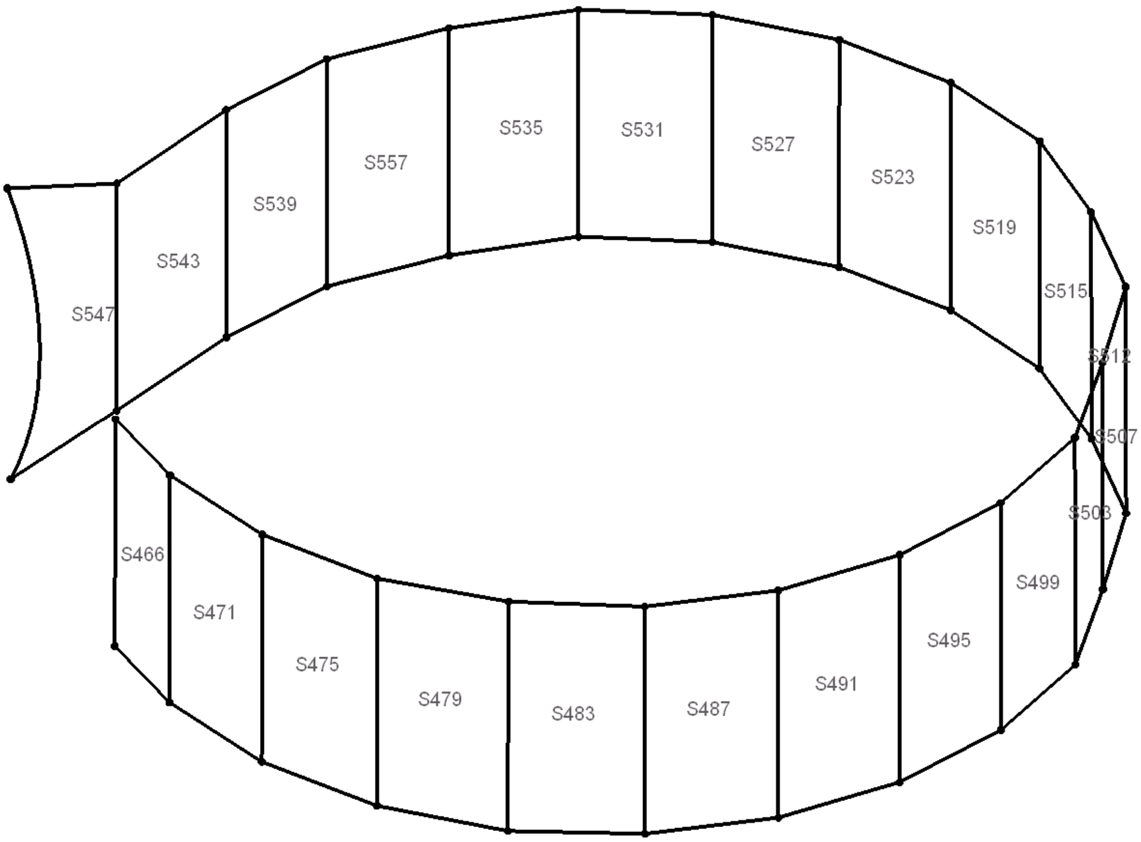
2.2.1.2 Geometry : SURFACES

View – Concrete structure carrying bearings :



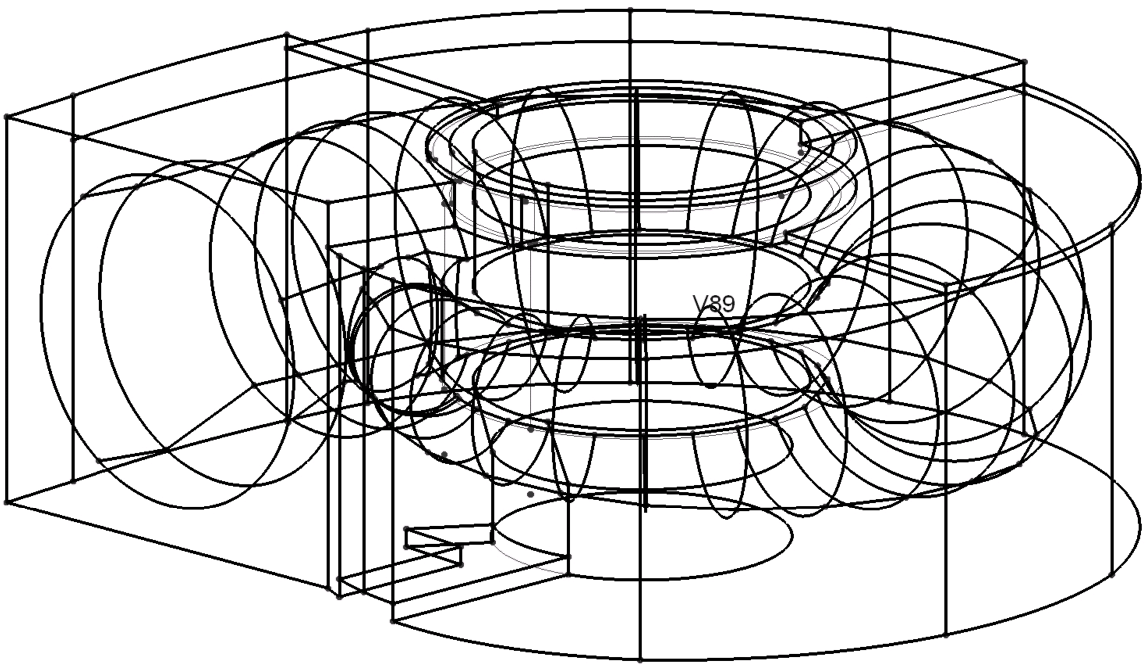
Remark The concrete structure is divided into four parts (Part I-IV).

View – Equivalent stay vanes :



2.2.1.3 Geometry : VOLUMES

Concrete surrounding spiral case :



Remark The entire concrete structure surrounding the spiral case is modeled as one volume. The volume is called V89 as seen in picture above.

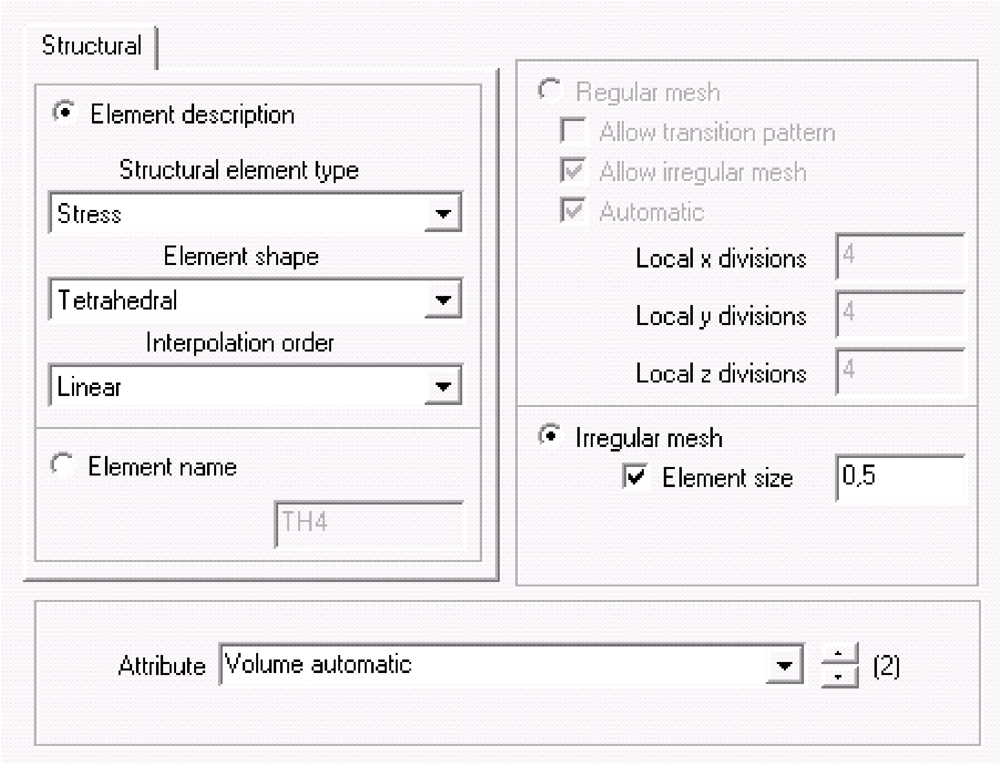
2.2.2 MESH

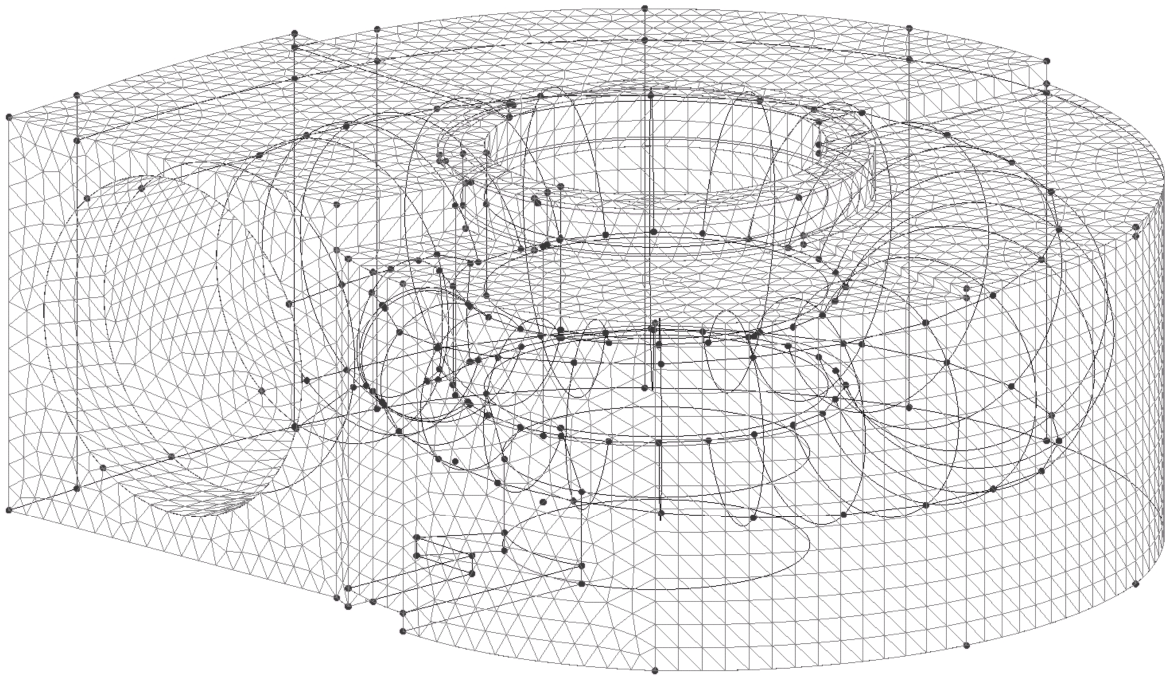
The previously defined *SURFACES* and *VOLUMES* are given attributes for generation of *MESH*.

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

2.2.2.1 Concrete surrounding spiral case

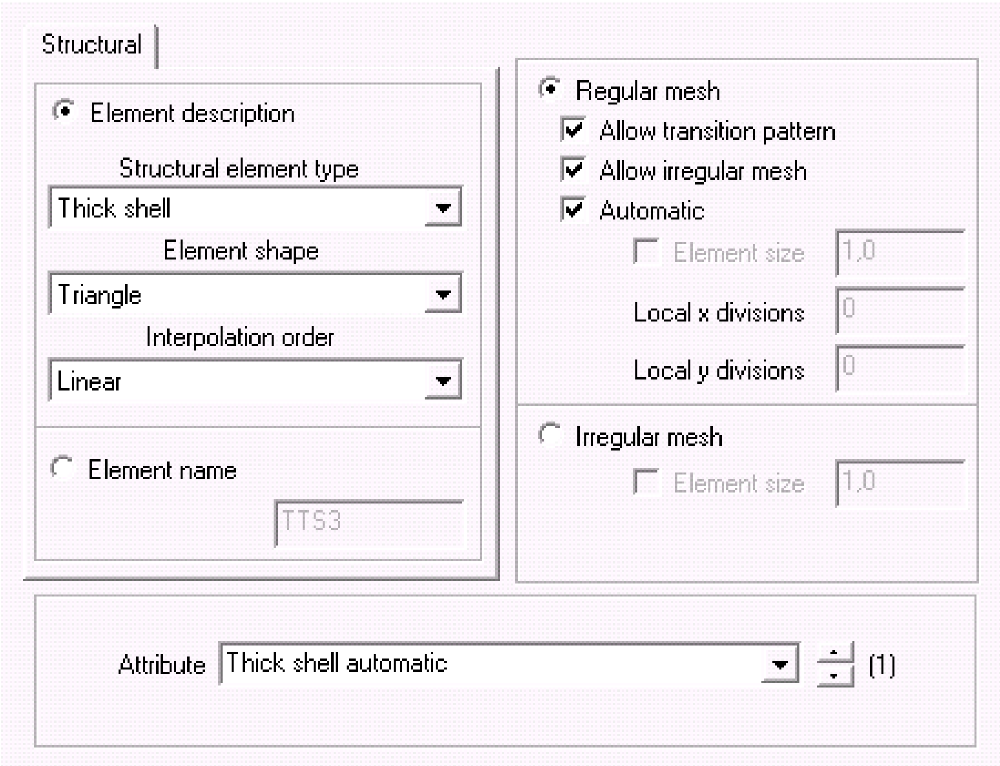
The concrete structure is modeled using 3D solid volume elements (“Volume elements” / TH4).

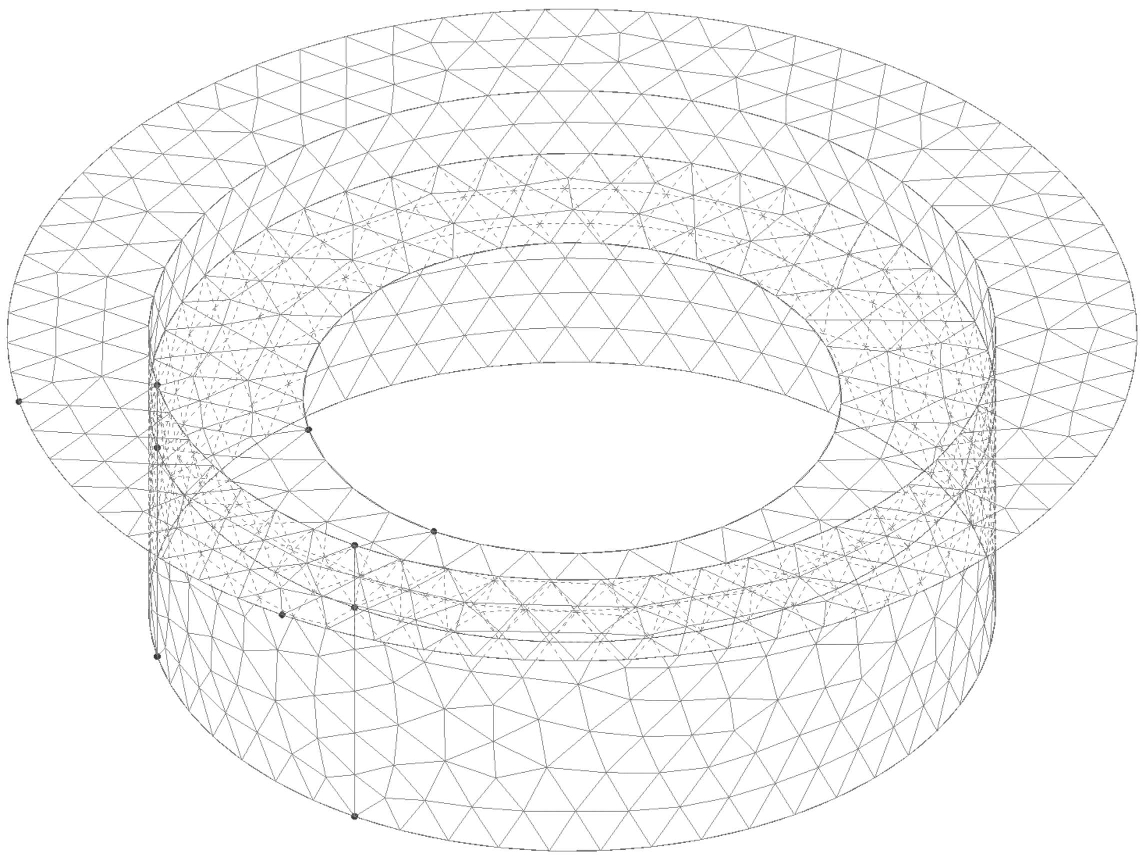




2.2.2.2 Concrete carrying bearings

The concrete structure is are modeled as shell elements (“Thick shell” / QTS4).

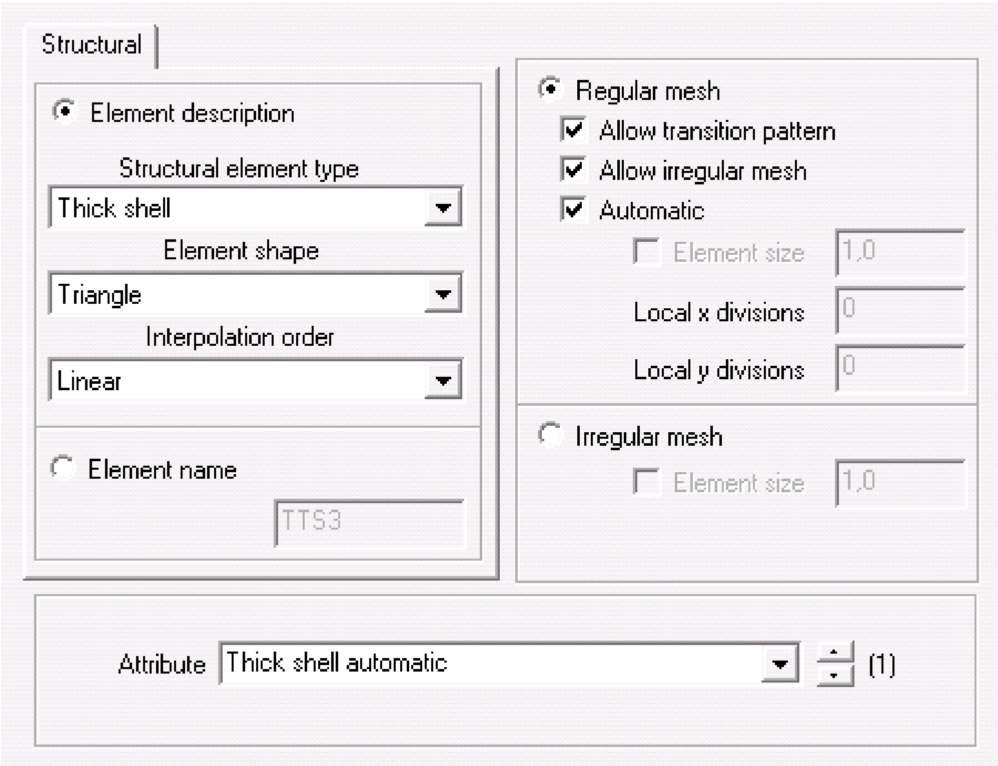




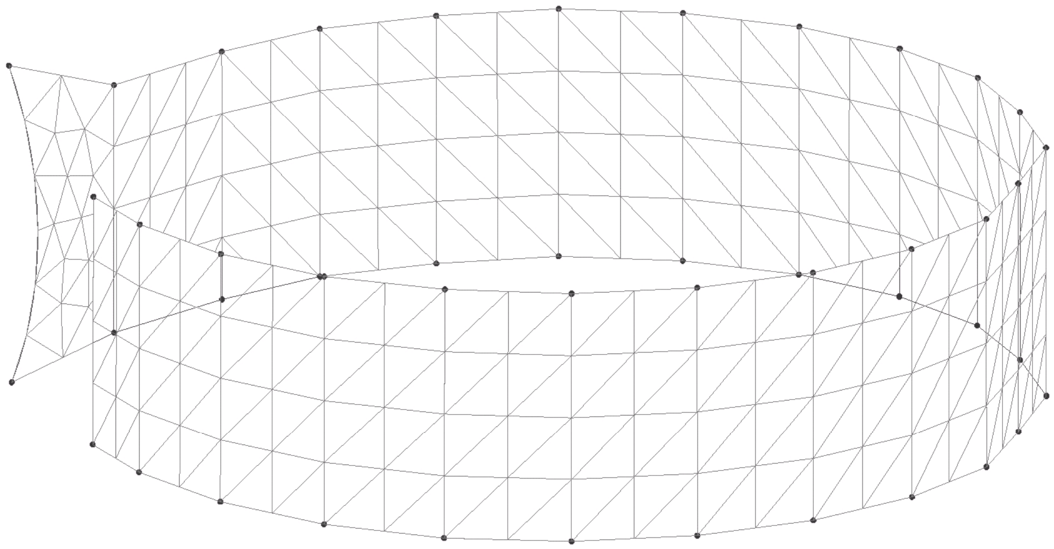
Remark The concrete structure is divided into four parts (Part I-IV)

2.2.2.3 Steel stay vanes

The steel stay vanes are modeled as equivalent shell elements (“Thick shell” / QTS4).

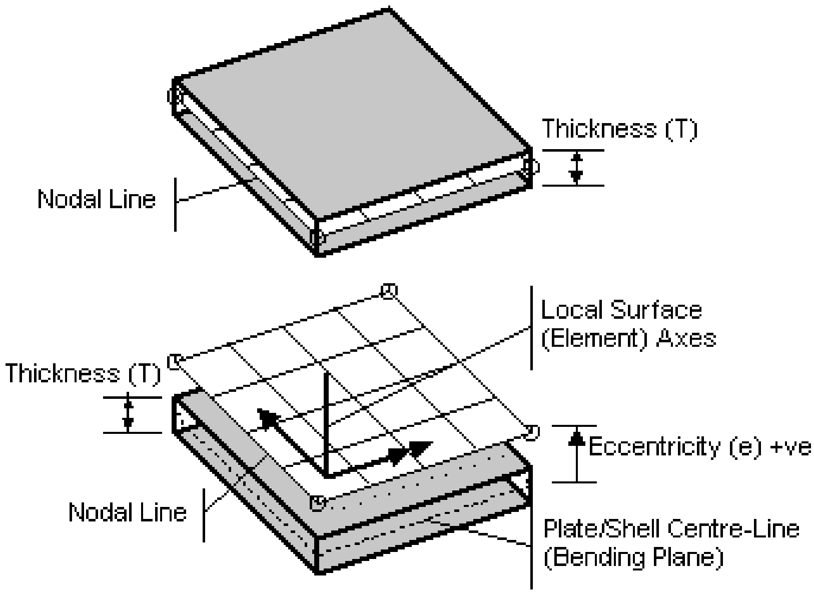


	Machine bay design	Status :	Page : A2:18
		Date :	Created :



2.3 CROSS SECTION PROPORTIES

The structure is modeled using either shell elements (“Thick shell” / TTS3) or volume element elements (”solid element” / TH4). By definition volume elements need no additional cross section properties.



Remark Definition of shell elements see picture above.

2.3.1 Steel shell elements (“Thick shell” / TTS3)

$DTa = 8320mm$: diameter of outer stay ring

$DTi = 7176mm$: diameter of inner stay ring

$\Rightarrow R = \frac{DTa + DTi}{2} \cdot \frac{1}{2} = 3874mm$: radius of stay vanes

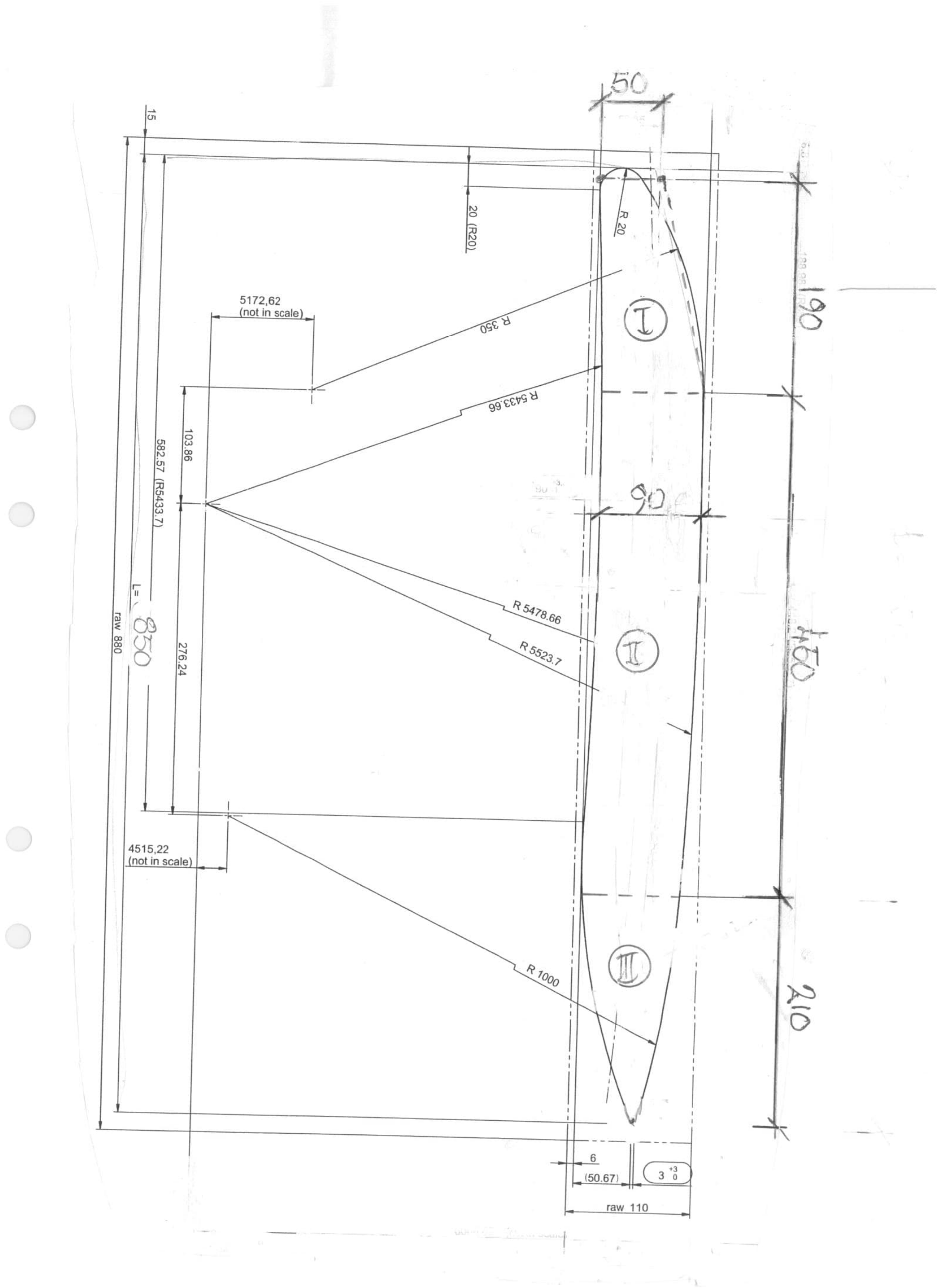
$\phi = 15°$: angle between stay vanes

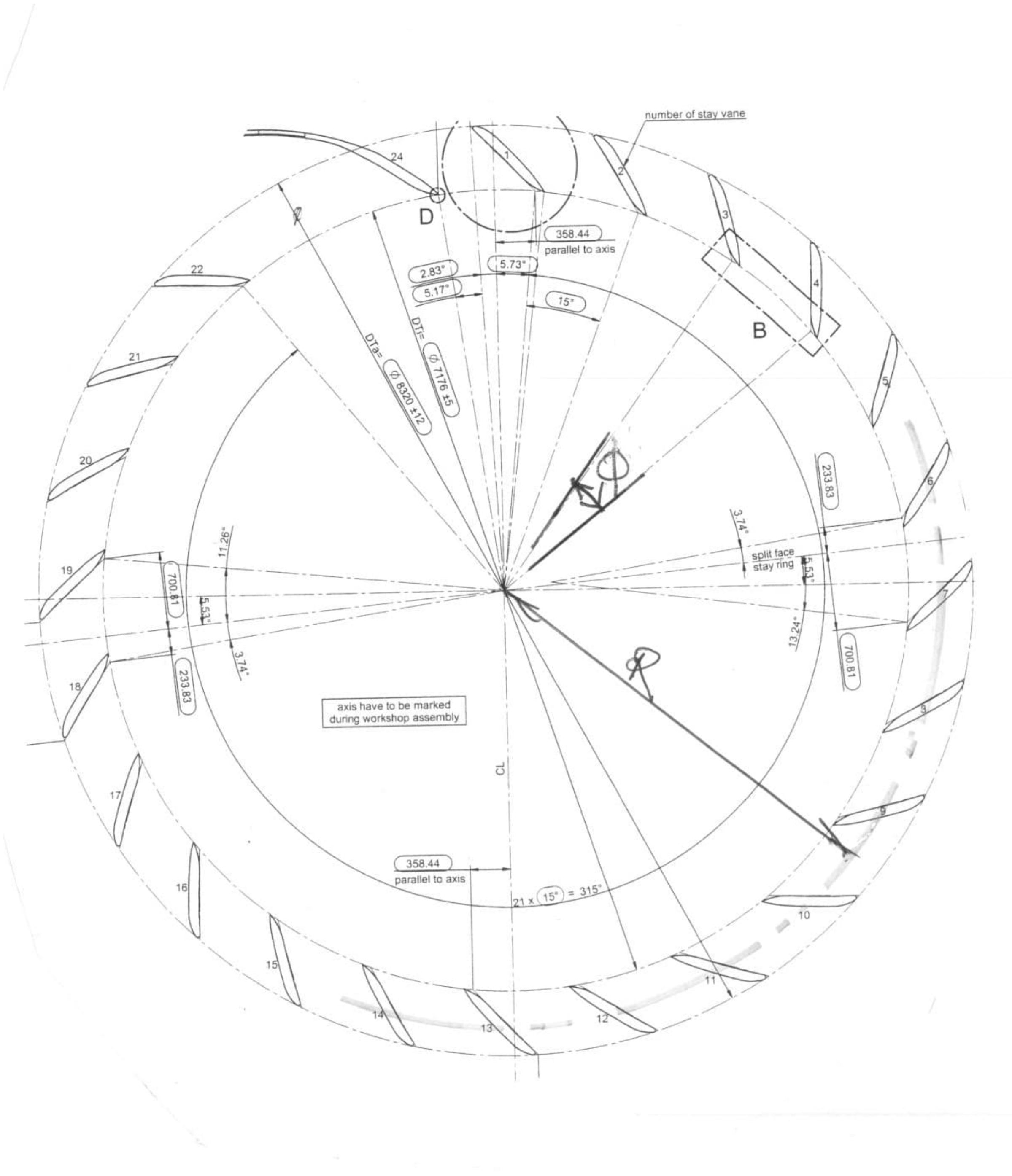
$$A_I = \frac{50mm + 90mm}{2} \cdot 190mm = 13300mm^2$$

$$A_{II} = 90mm \cdot 450mm = 40500mm^2$$

$$A_{III} = \frac{90mm \cdot 210mm}{2} = 18900mm^2$$

$A_{stayvane} = A_I + A_{II} + A_{III} = 72700mm^2 \therefore 86mm \cdot 850mm$: total area of one stay vane

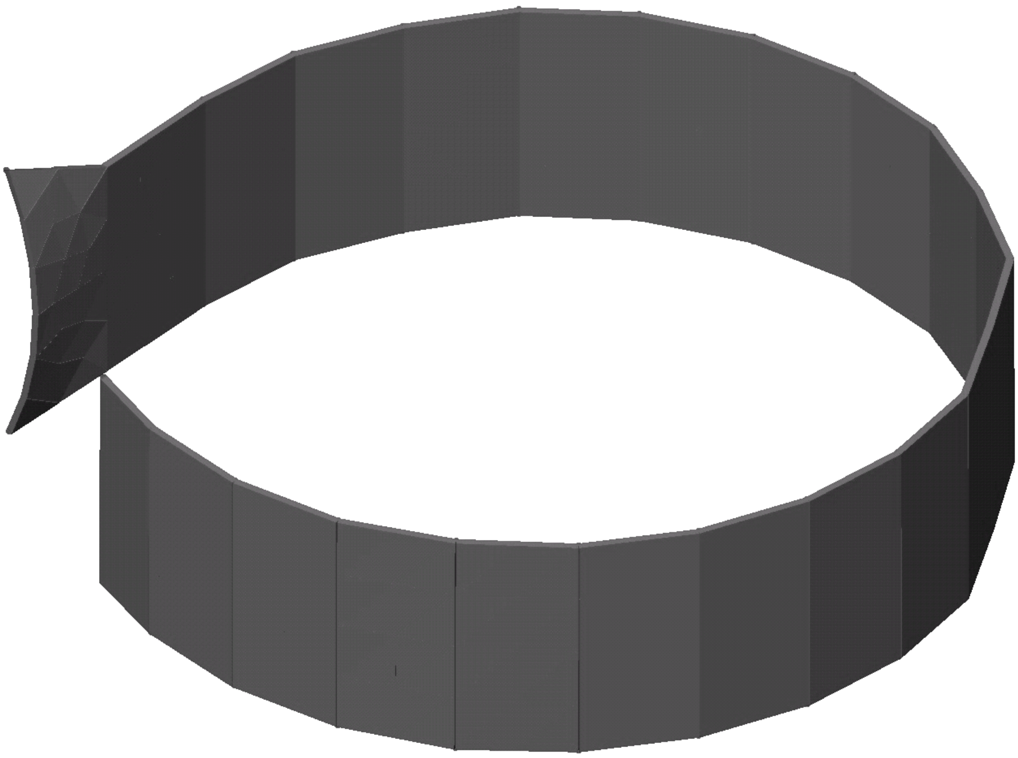

50
15
20 (R20)
R 20
5172,62
(not in scale)
R 350
R 5433.66
103.86
582.57 (R5433.7)
90
R 5478.66
R 5523.7
L= 830
raw 880
276.24
4515,22
(not in scale)
R 1000
190
450
210
I
II
III
6
(50.67)
3 +3 0
raw 110


number of stay vane
D
B
358.44
parallel to axis
2.83°
5.73°
5.17°
15°
DTa= ∅ 8320 ±12
DTi= ∅ 7176 ±5
233.83
3.74°
split face
stay ring
5.53°
13.24°
700.81
11.26°
700.81
5.53°
3.74°
233.83
axis have to be marked
during workshop assembly
CL
358.44
parallel to axis
21 x 15° = 315°

$$2\pi \cdot R \cdot t_{eqivalent} \equiv \frac{360°}{\phi} \cdot A_{stayvane} \Rightarrow t_{eqivalent} = \frac{360°}{\phi} \cdot A_{stayvane} \cdot \frac{1}{2\pi \cdot R} = 70mm$$

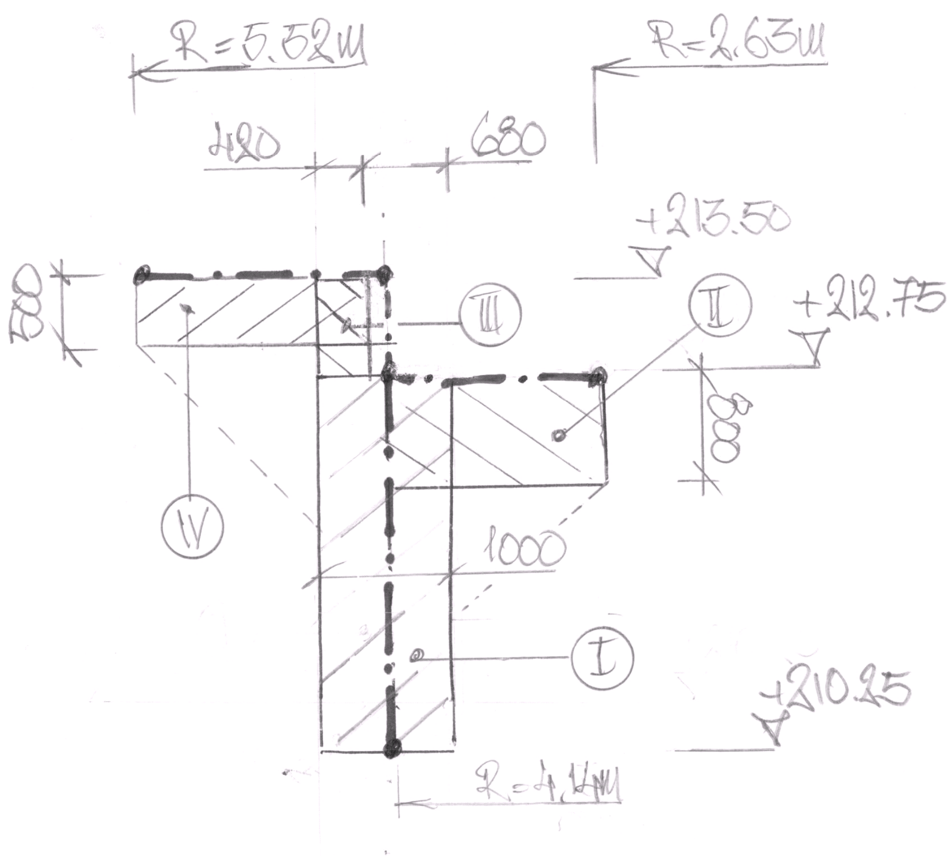
Geometry	t	e_z	Material
t = 0.07 m	0.07	0	Steel
-	m	m	-

View – Equivalent stay vanes (t = 0.07 m) :



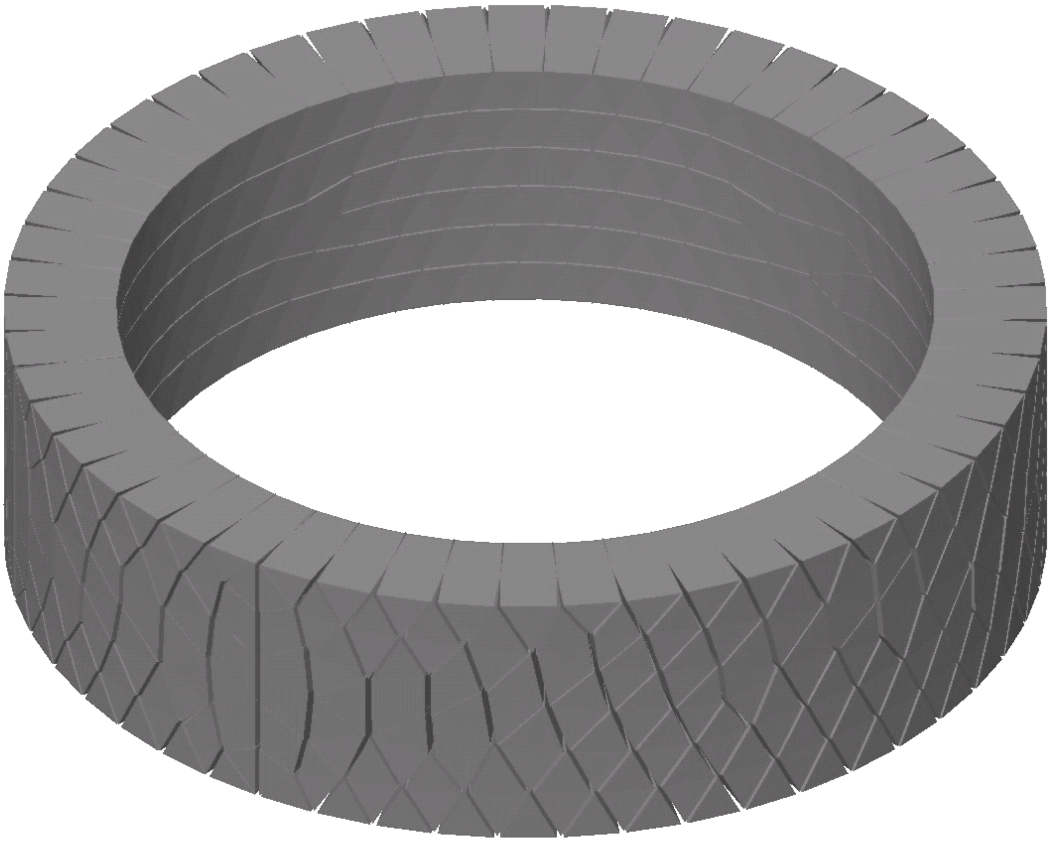
2.3.2 Concrete shell elements (“Thick shell” / TTS3)

The concrete structure that supports the bearings is divided into four parts (Part I-IV) as seen below. The cross section properties are simplified using constant thickness. This assumption is negligible.

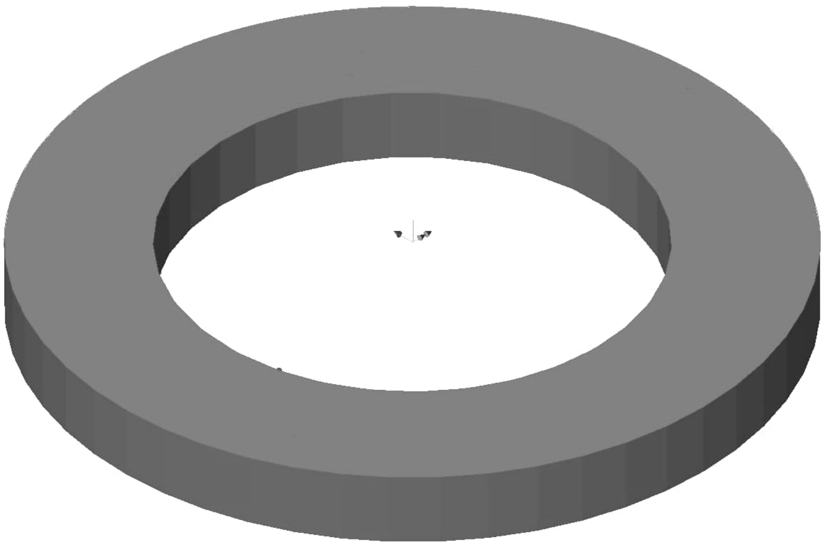


Geometry	t	e_z	Material	Remark
t = 1.00 m	1.00	0	Concrete	Part I
t = 0.80 m	0.80	0.40	Concrete	Part II
t = 0.42 m	0.42	-0.25	Concrete	Part III
t = 0.50 m	0.50	0.25	Concrete	Part IV
-	m	m	-	

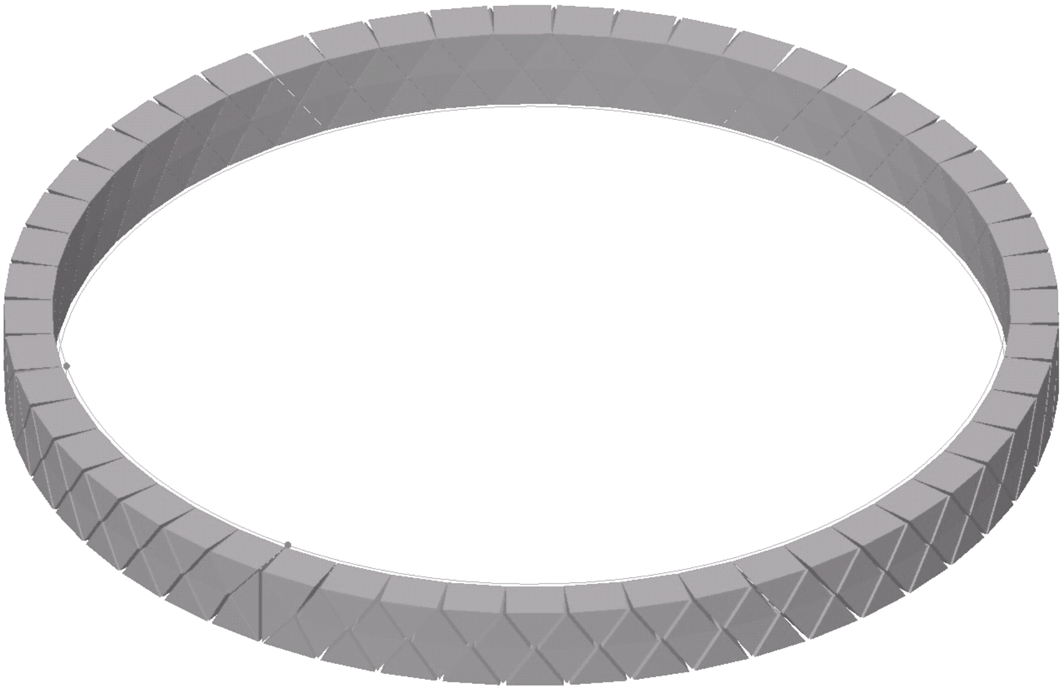
View – Part I (t = 1.00 m) :



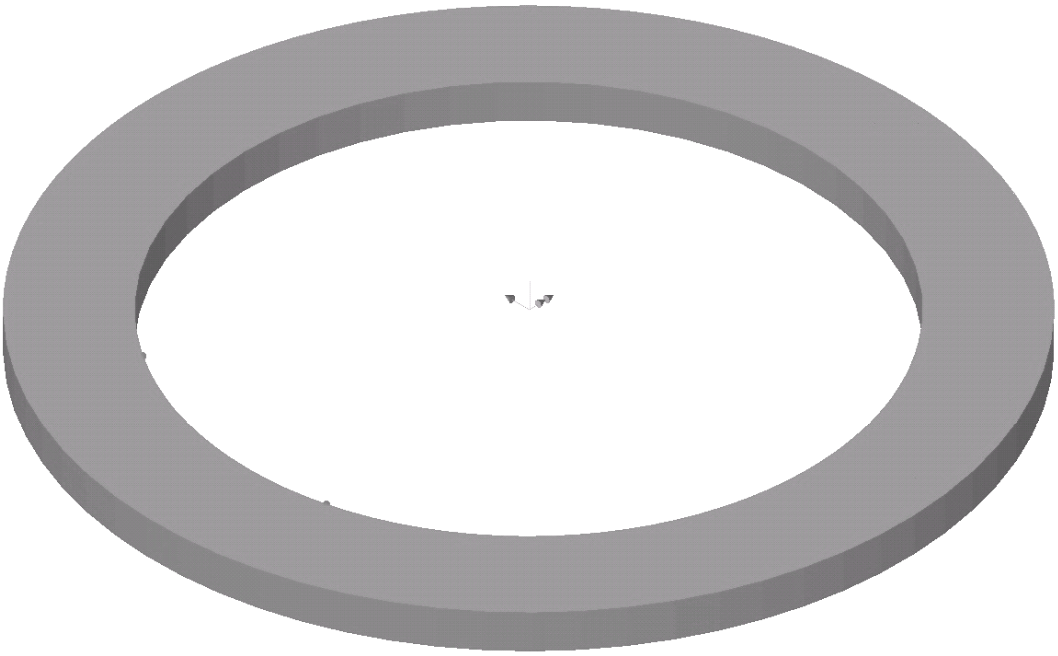
View – Part II (t = 0.80 m) :



View – Part III (t = 0.42 m) :



View – Part IV (t = 0.50 m) :



2.4 MATERIAL

The structure has two types of materials (steel and concrete).

2.4.1 Steel : elastic

$$G_s = \frac{E_s}{2(1+\nu)} \rightarrow \nu = \frac{E_s}{2G_s} - 1 = \frac{210GPa}{2 \cdot 81GPa} - 1 = 0.3$$

Properties	Value
E_s	$210 \cdot 10^6$ kPa
ν	0.3
ρ_s	7700 kg/m^3

2.4.2 Reinforced concrete : elastic

Properties	Value
E_c	$33 \cdot 10^6$ kPa
ν	0.2
ρ_c	2500 kg/m^3

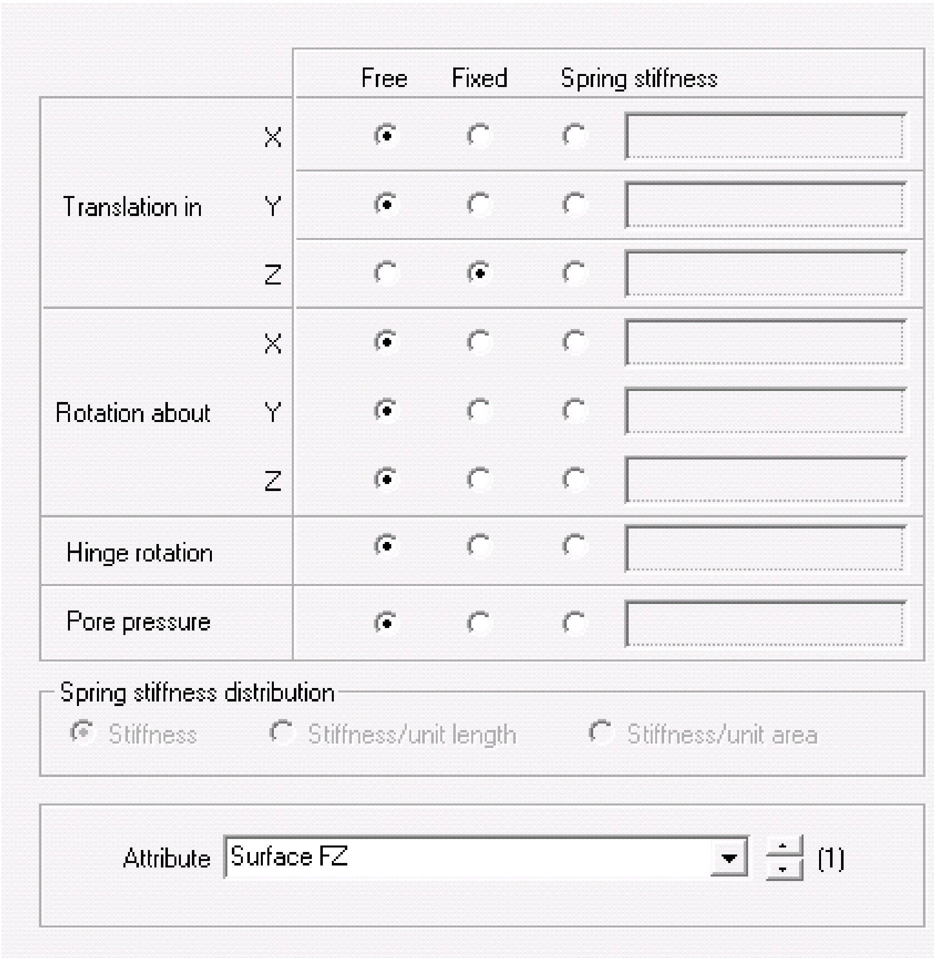
Remark Due to bending the concrete is considered cracked. Creep value at time t_2 is assumed critical.

2.5 BOUNDARY CONDITIONS

The structure is modeled with 2 different boundary conditions. The shell structure uses a line support while the volume structure uses a surfaces support.

2.5.1 Boundary condition : Surface FZ

All rock surfaces acting against the volume elements in the concrete structure are modeled with fixed supports. The supports act against translation normal to each surface.

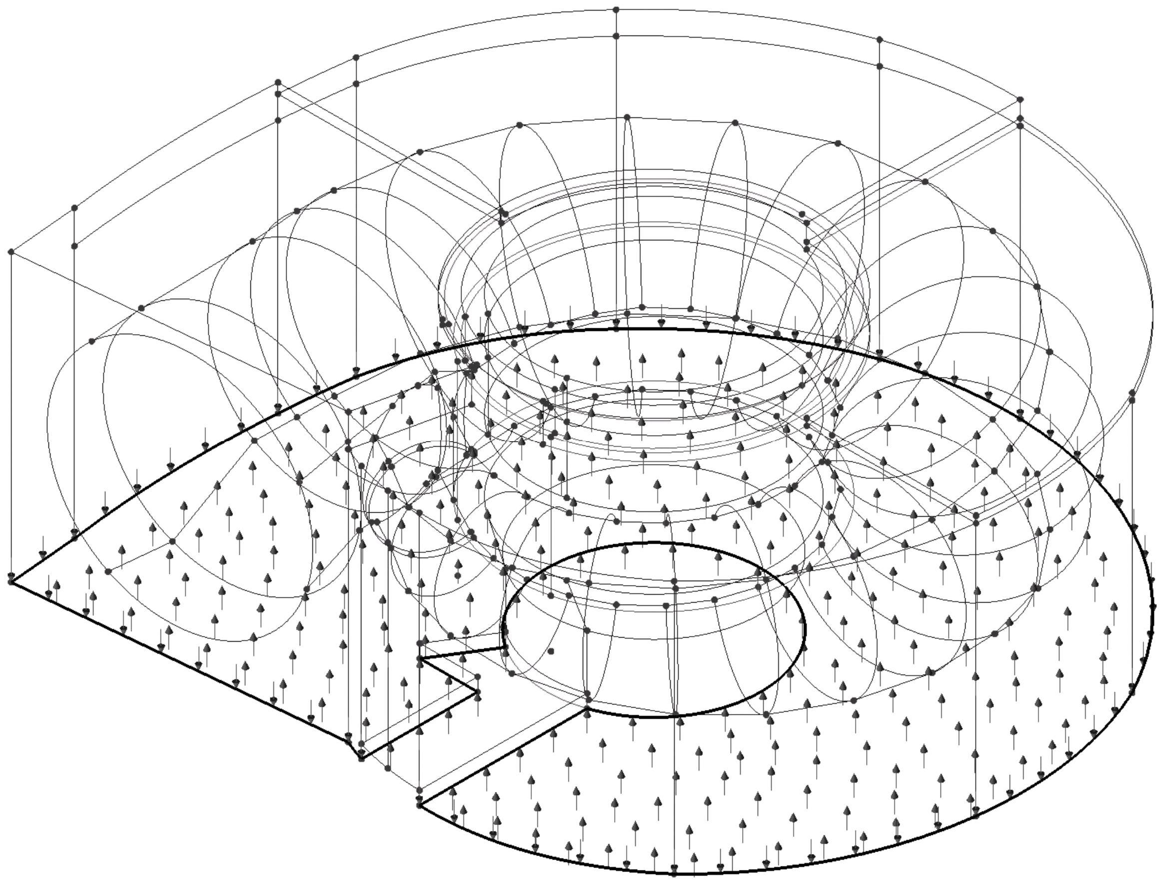


-

<u>Remark</u> A local coordinate system of type “surface” is introduced to achieve this effect.

2.5.1.1 Horizontal rock surfaces

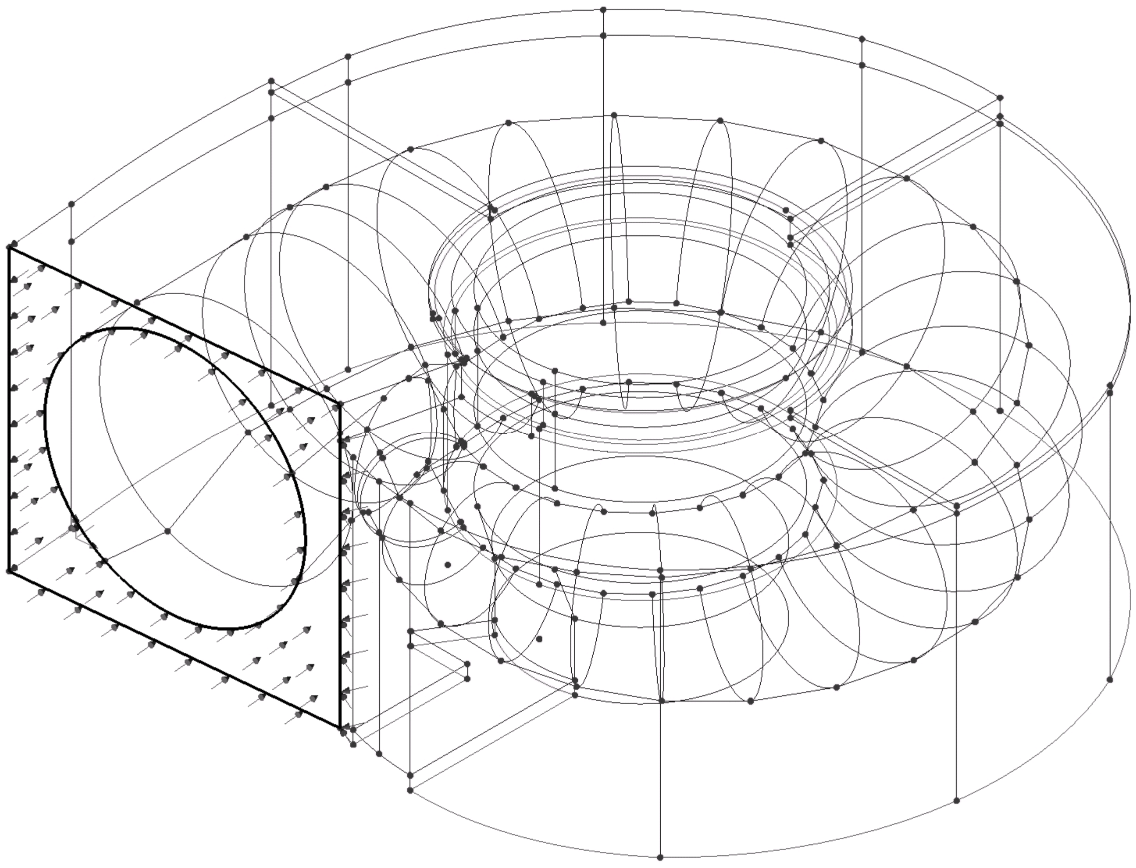
Only one horizontal rock surface exists. This surface is found at level +201.40 as seen below.



2.5.1.2 Vertical rock surfaces

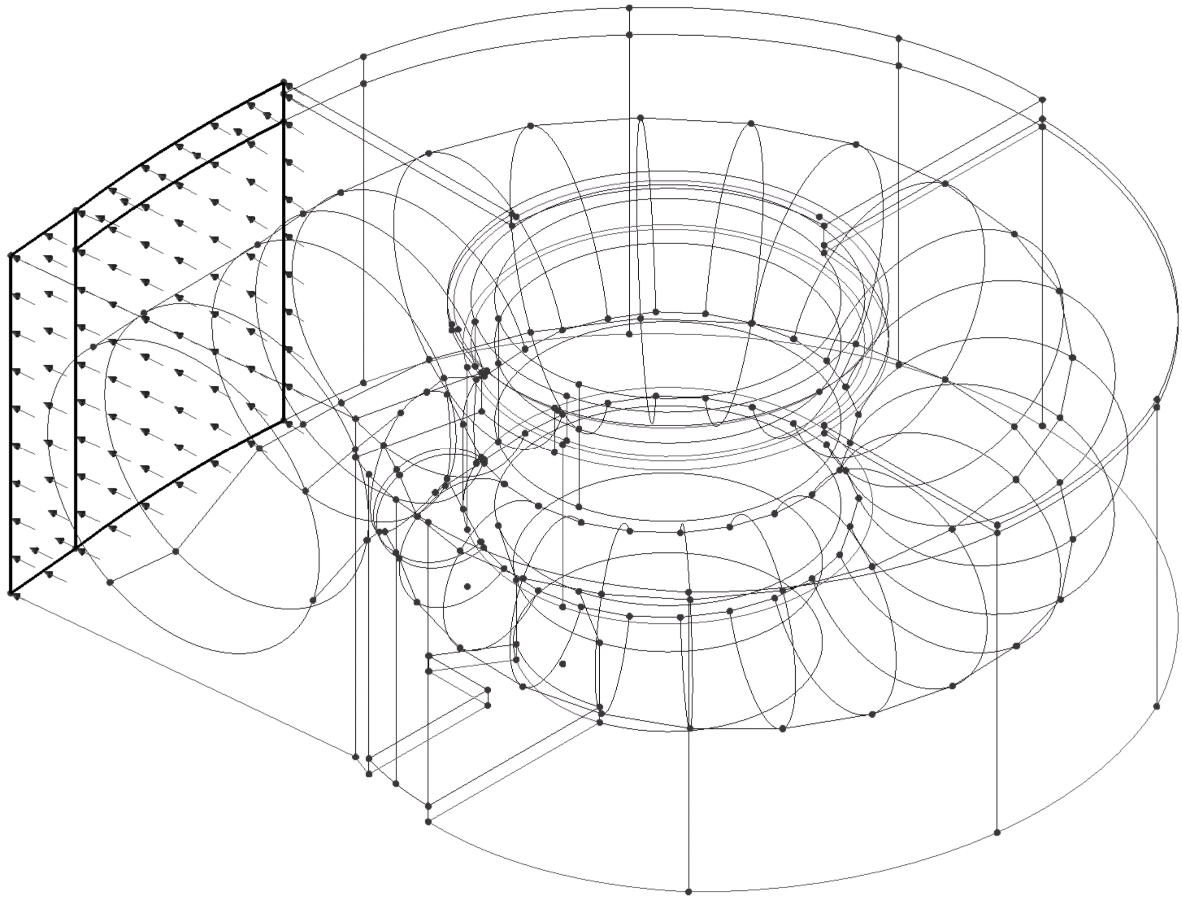
The vertical rock surfaces found between level +201.40 and 210.10 are divided into 7 rock surfaces as seen on the following pages.

View - rock surface 1 :



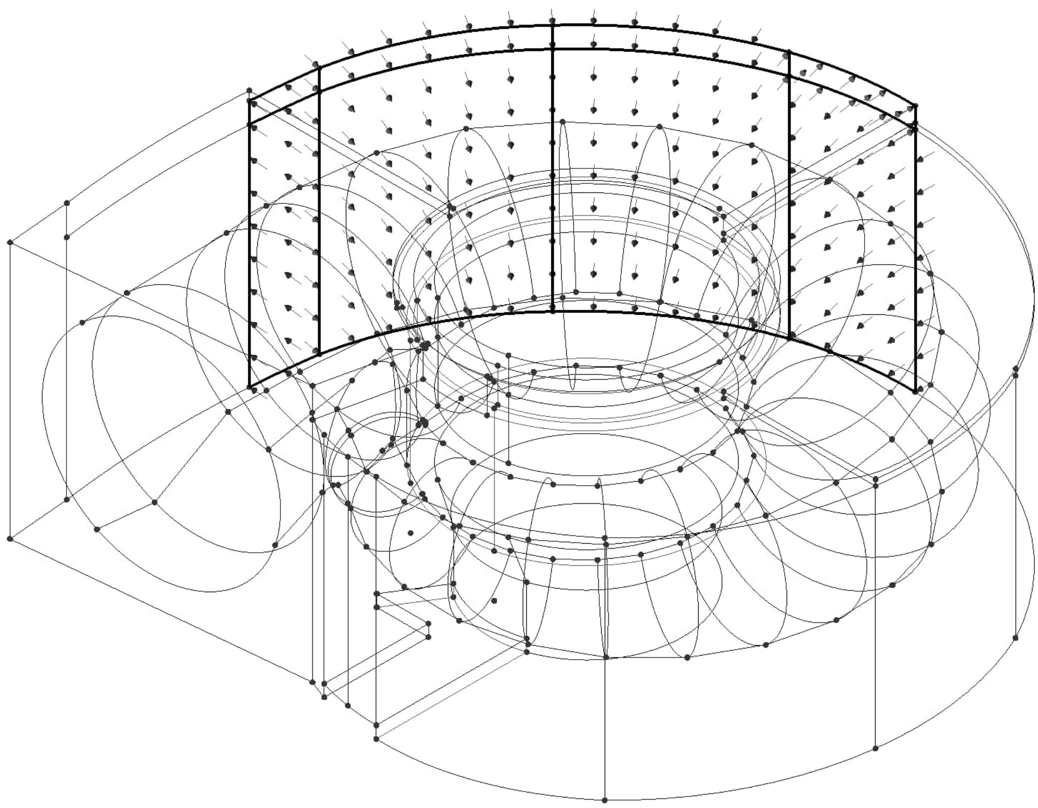
Remark Support acts between level +210.1 and +210.4

View - rock surface 2 :



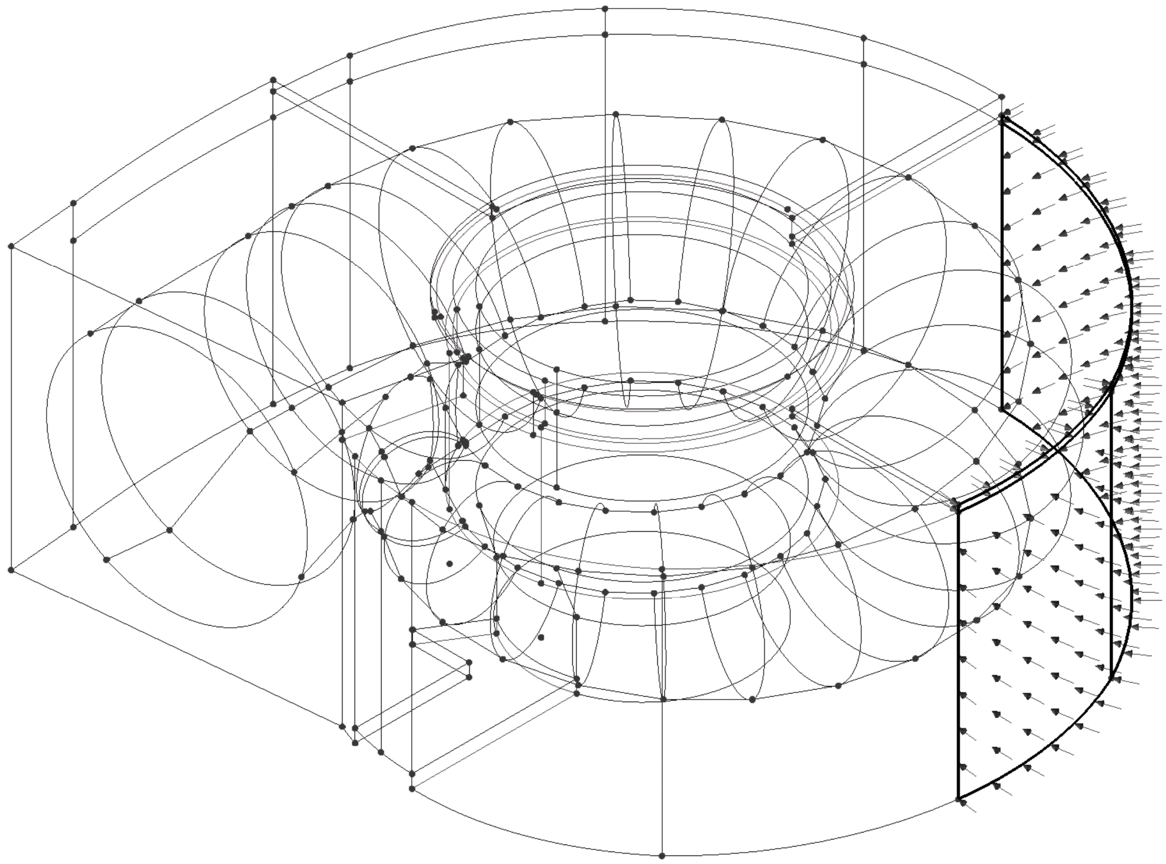
Remark Support acts between level +210.1 and +210.4

View - rock surface 3 :



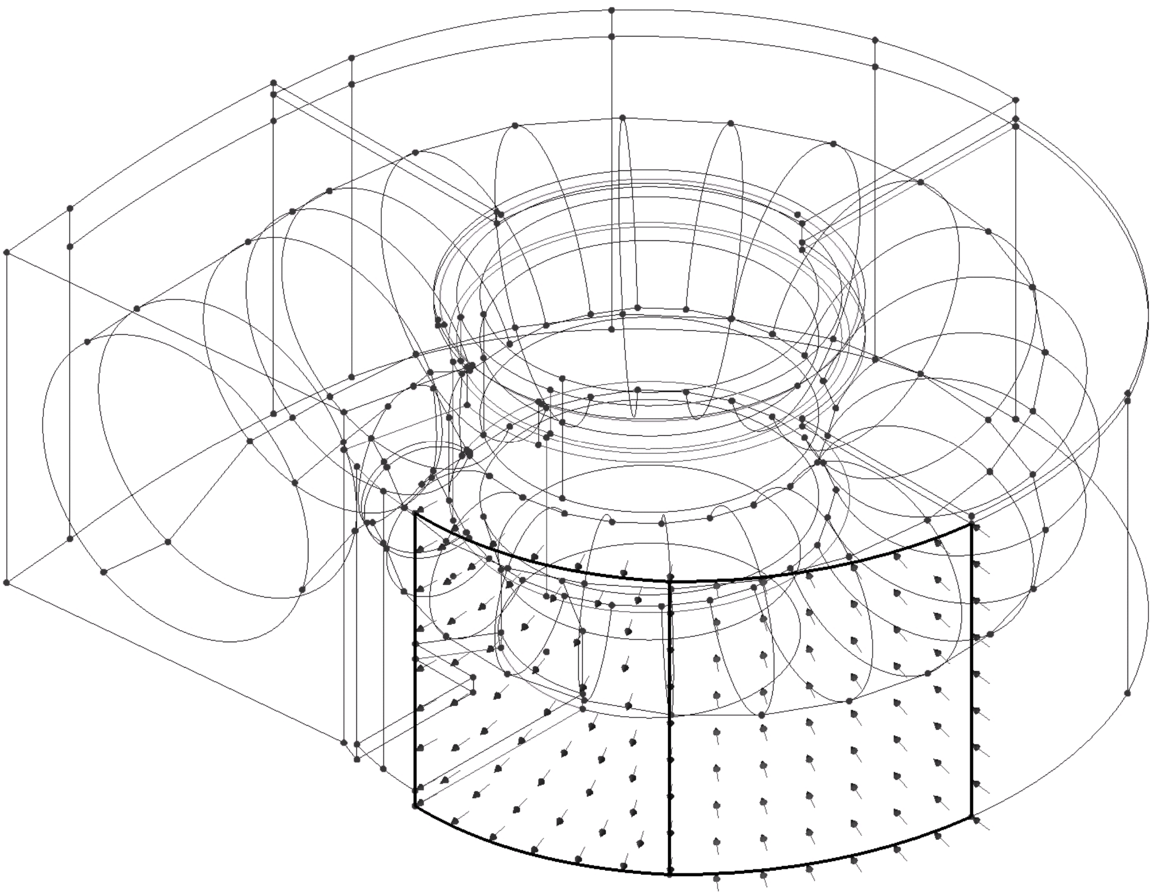
Remark Support acts between level +210.1 and +209.8

<u>View - rock surface 4 :</u>



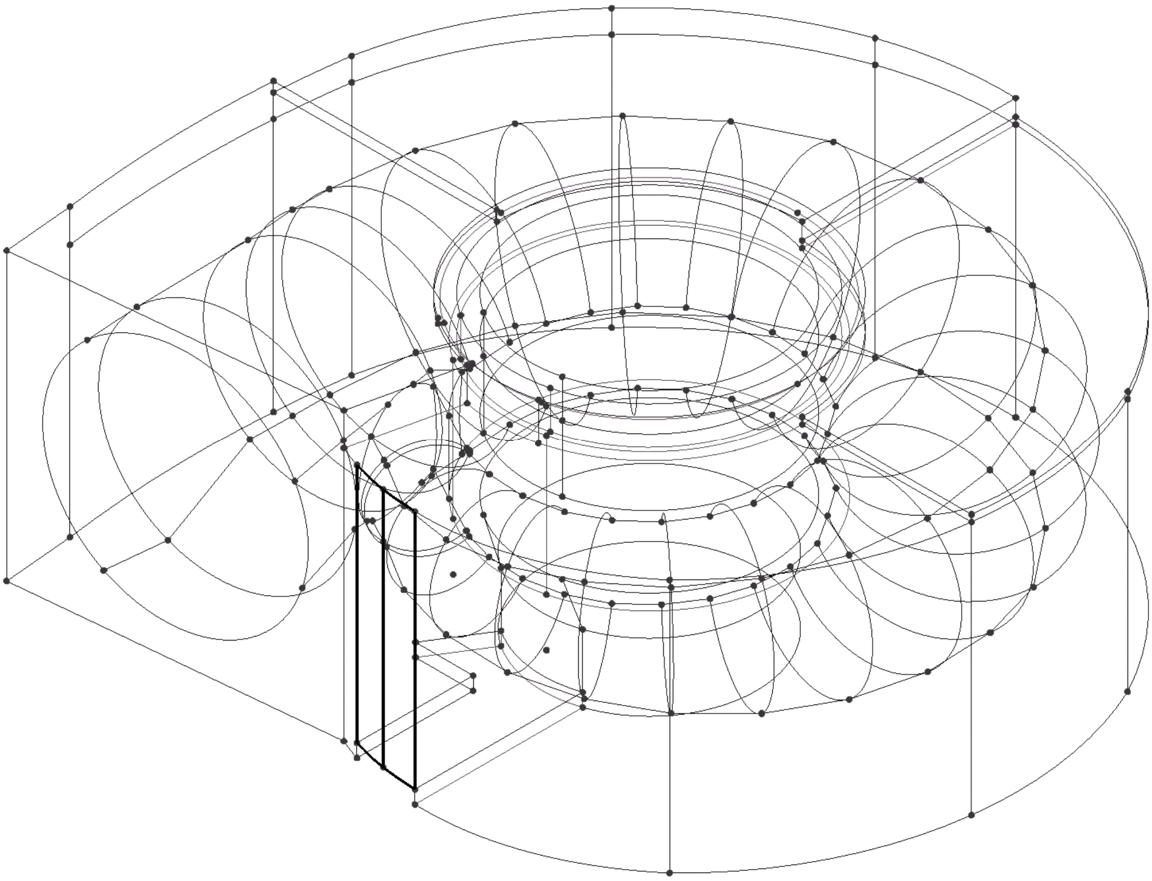
<u>Remark</u> Support acts between level +210.1 and +209.3

View - rock surface 5 :



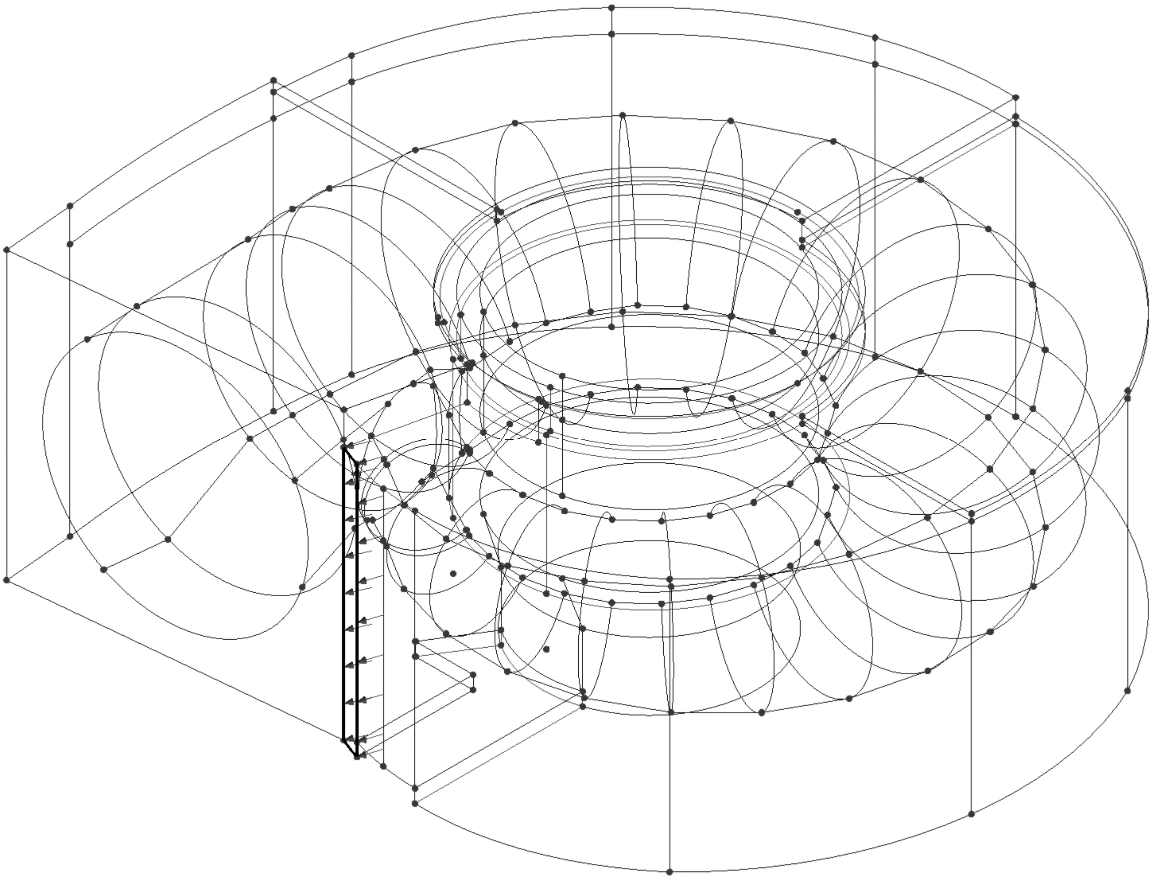
Remark Support acts between level +210.1 and +209.1.

View - rock surface 6 :



Remark No support acts due to vertical passage acting along this surface.

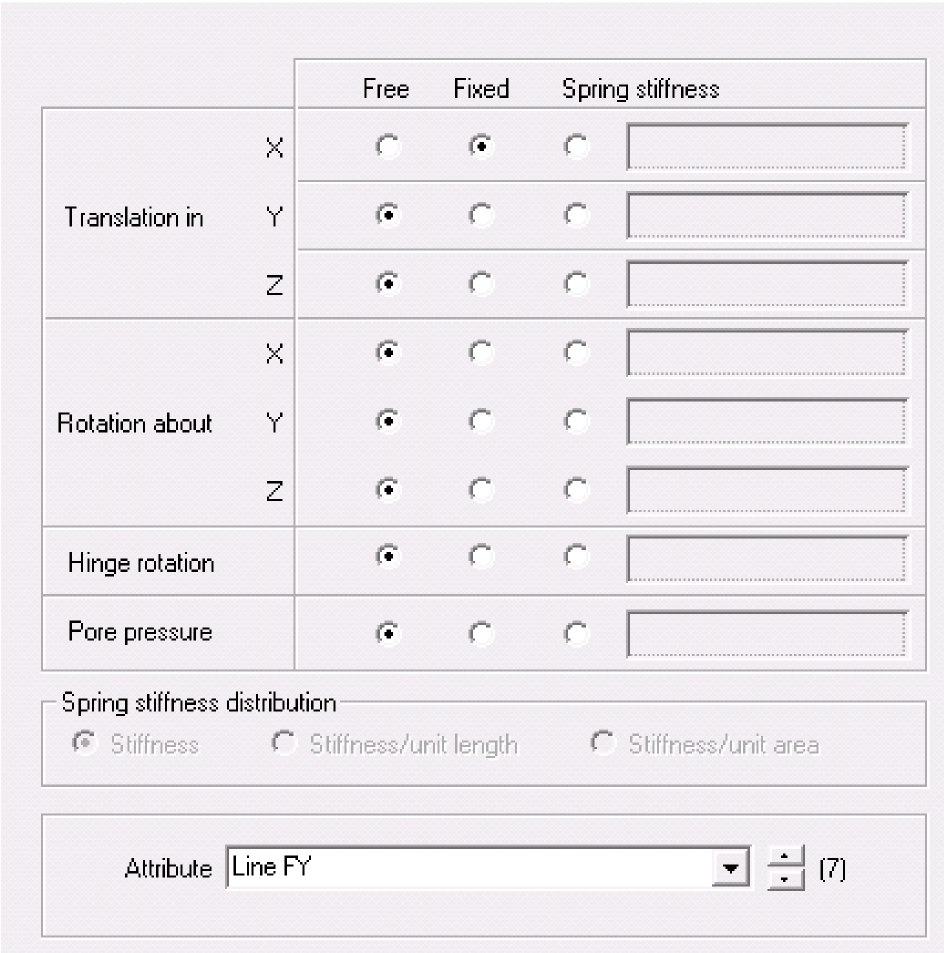
View - rock surface 7 :



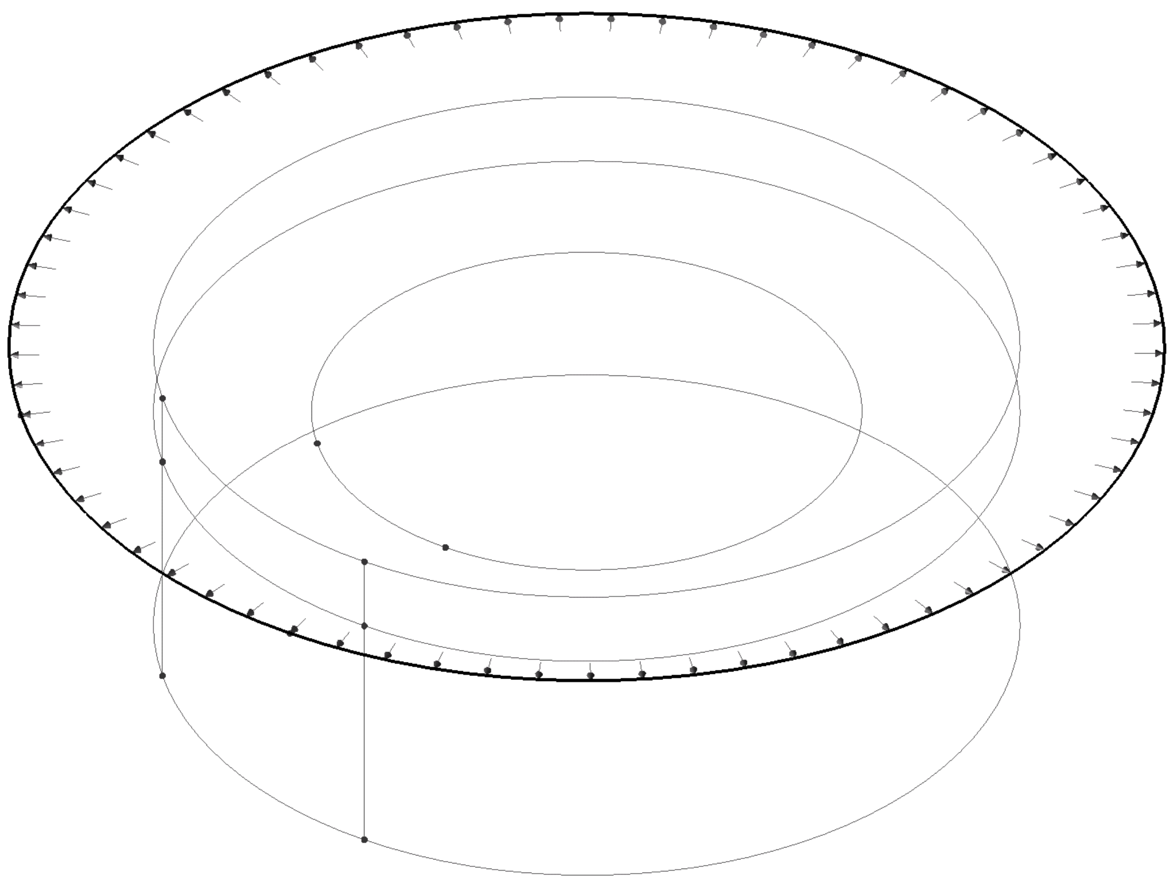
Remark Support acts between level +210.1 and +209.1.

2.5.2 Boundary condition : Line FY

At level of upper bearing support (∴ +213.5) a line support is introduced. The support is fixed against translation in the radial direction as seen below.



Remark A local coordinate system of type “cylindrical” is introduced to achieve this effect.



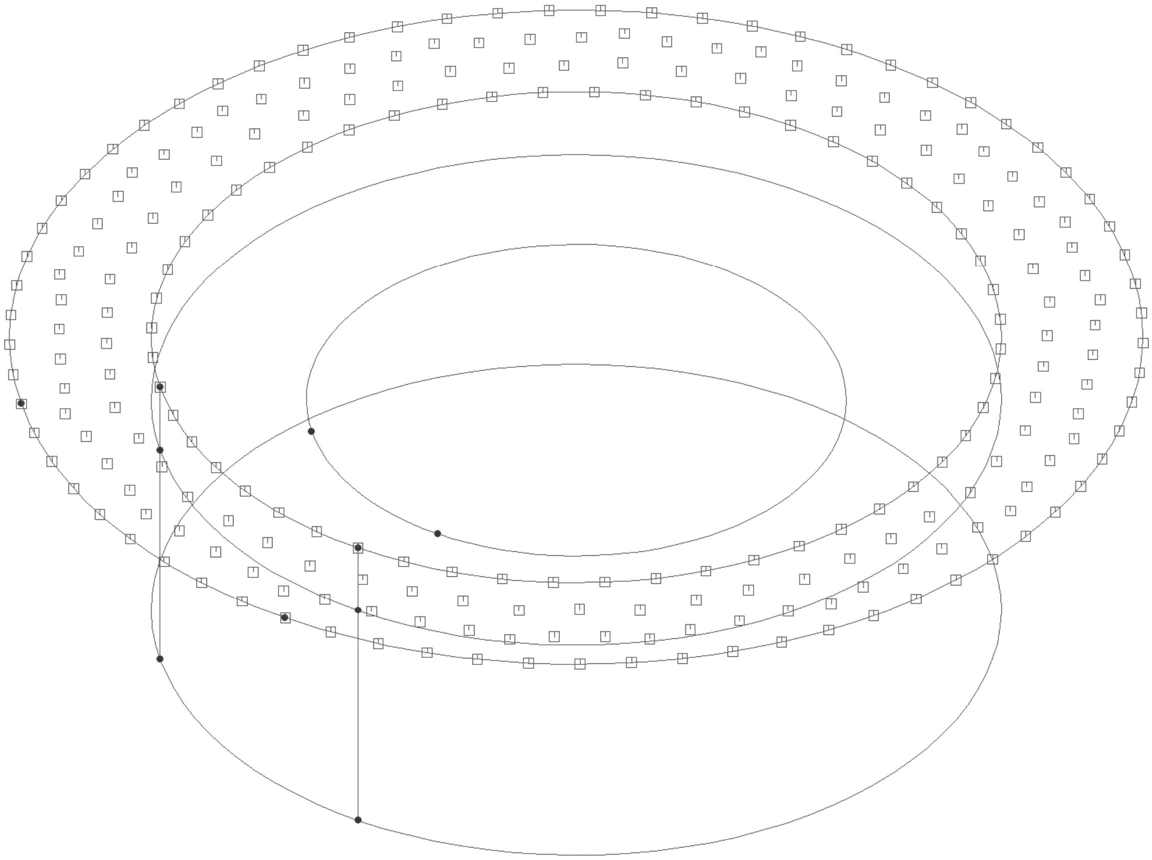
2.6 SEARCH AREA

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

For the analysis two *Search Area*´s are defined.

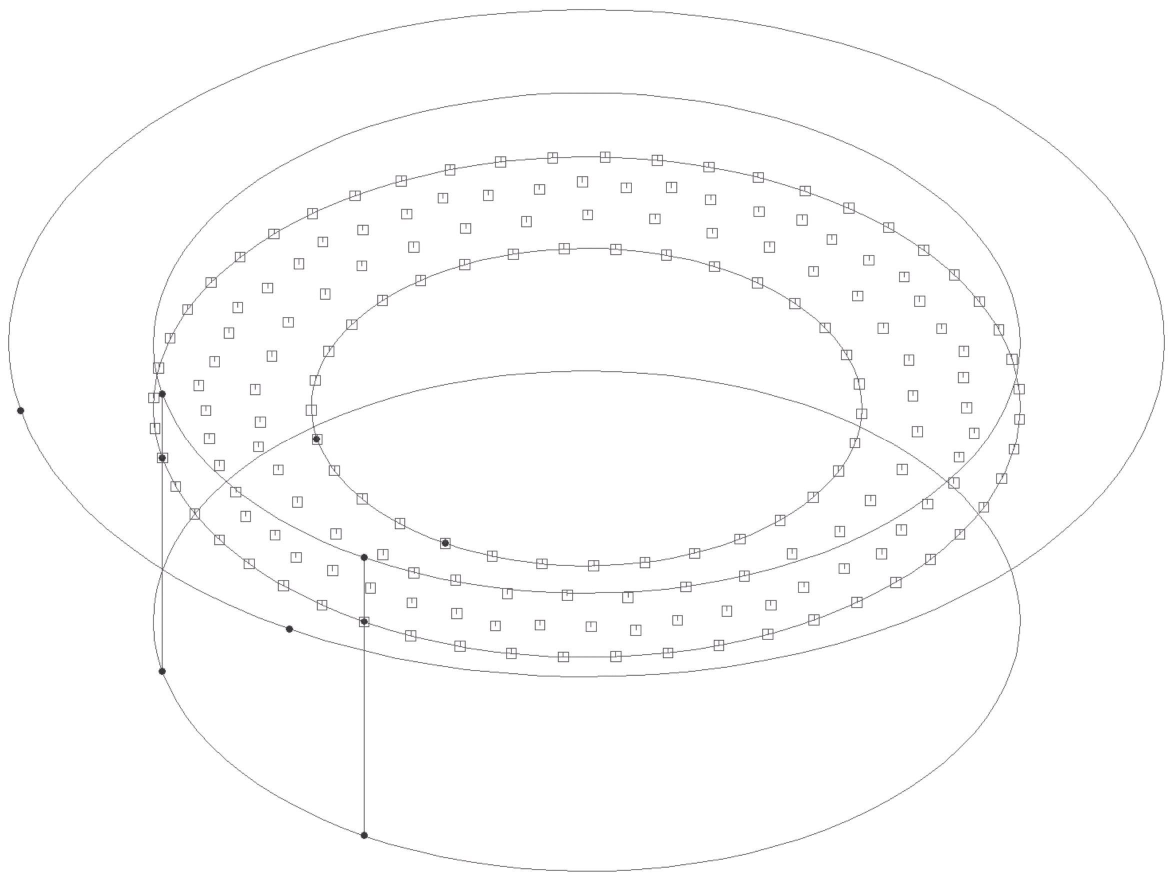
2.6.1 Search area : Upper cantilever

Structural elements : Part IV



2.6.2 Search area : Lower cantilever

Structural elements : Part II



3. LOADS

3.1 DEAD WEIGHT

Only the load from the concrete structure is considered. The effect of the steel material in spiral case, stay vanes and stay ring is negligible when studying stress in concrete structure.

3.1.1 Reinforced concrete

$\gamma_c = 25 \ \frac{kN}{m^3}$

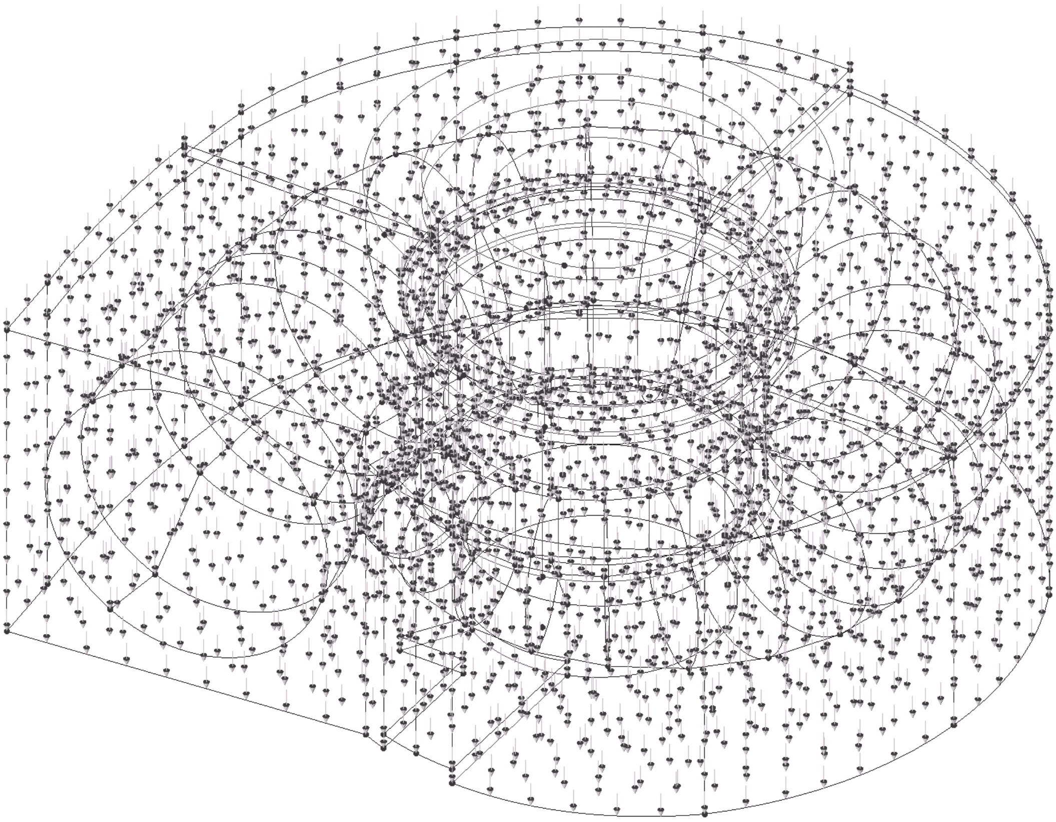
Loadcase : Concrete

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 Deadweight (1)



Remark Load intensity is determined by applying the acceleration a_z to the density of the concrete structure.

3.2 WATER LOAD

The water load corresponds to a runaway pressure as seen below.

$q_w = 594 kPa$: total water pressure

Loadcase : Water pressure qw

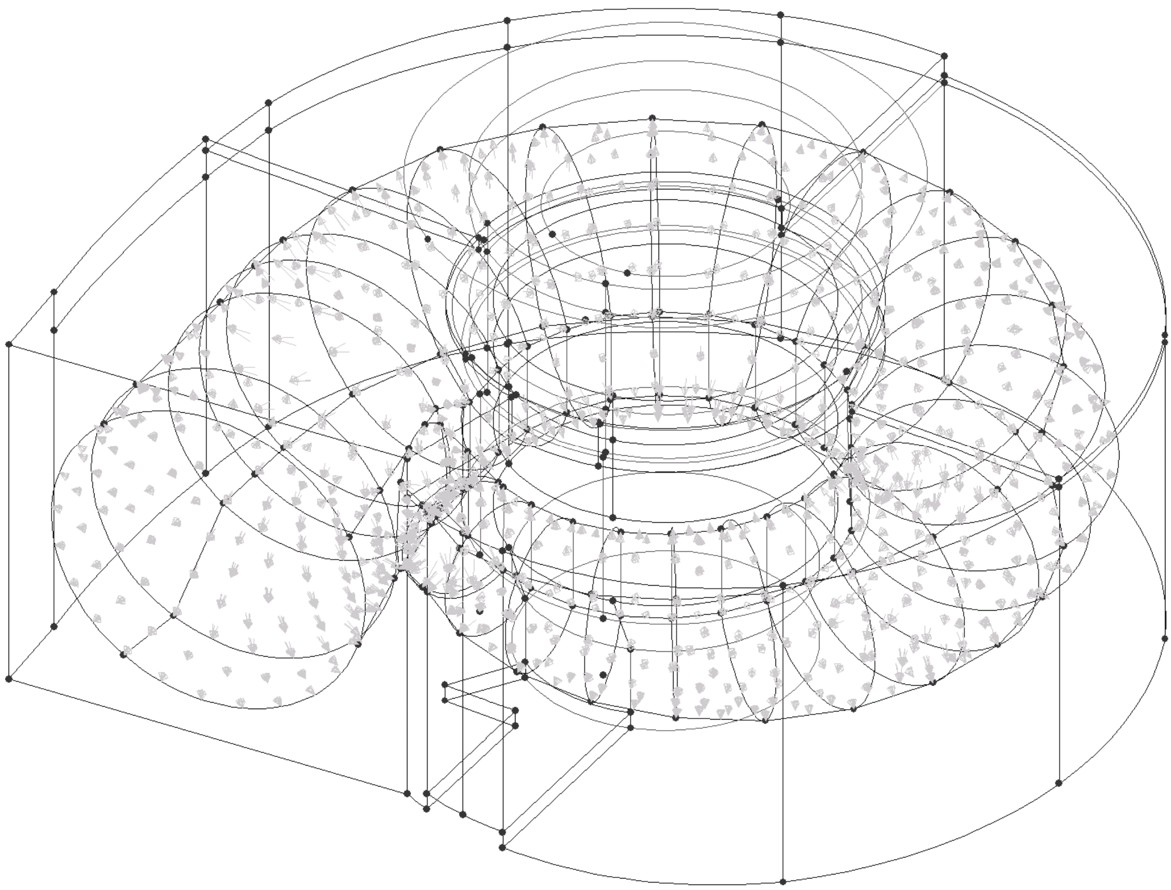
Structural loading : Structural

Force type : Face load

Component z direction along local element : -594 kPa

Component	Value
x Direction	0,0
y Direction	0,0
z Direction	-594,0

Attribute qw = 594 kPa (4)



3.3 HEAD COVER

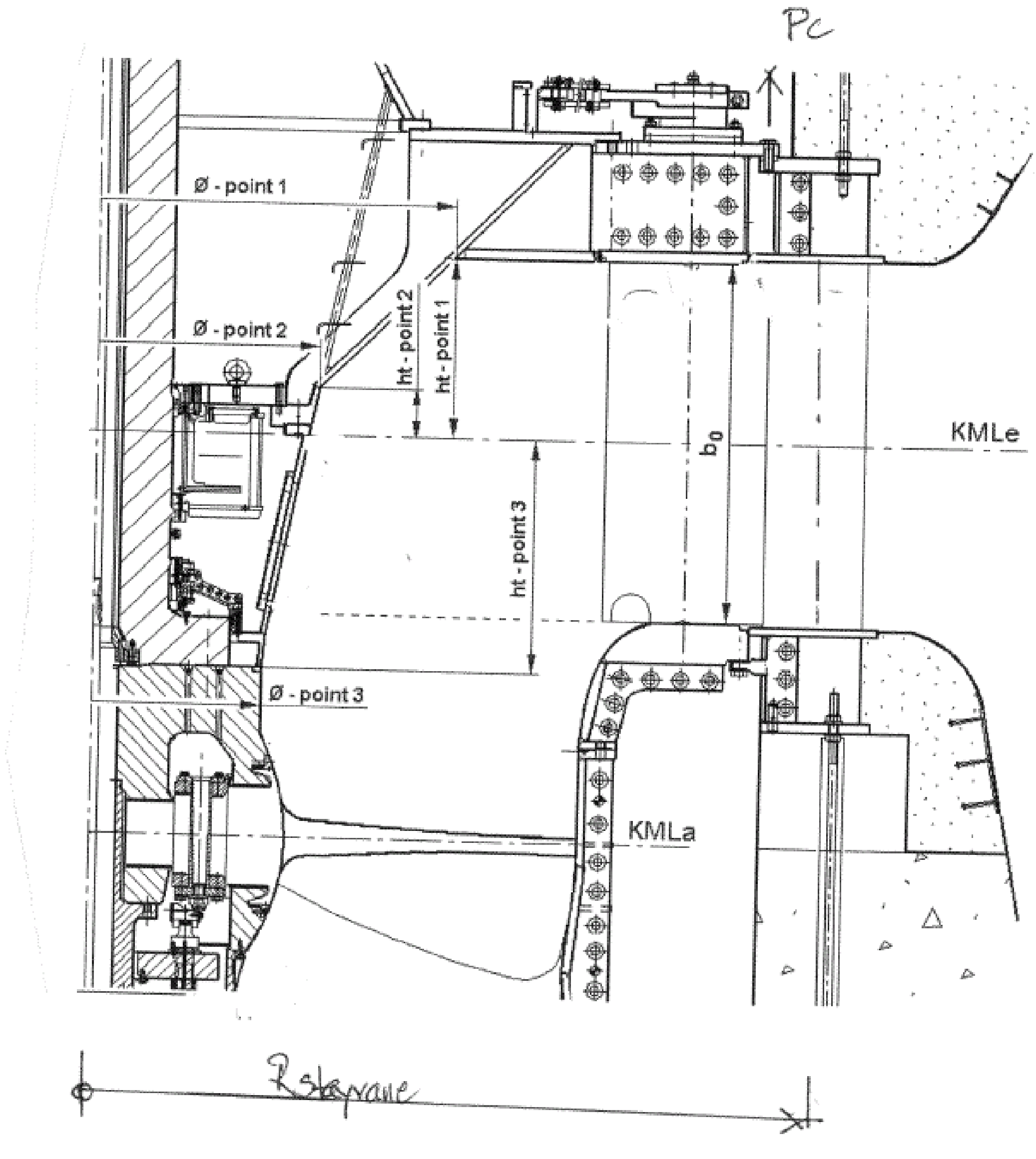
The weight of the head cover including upward acting water pressure is introduced as a circular load line load. The total load is termed P_C.

$$P_C = 16466kN$$

$R_{stayvane} = 4.1m$: radius of the equivalent stay vane

$l = 2\pi \cdot R_{stayvane} = 25.7m$: equivalent load length

$p_C = \frac{P_C}{l} = \frac{16466kN}{25.7m} = 640\frac{kN}{m}$: equivalent load introduced into structure



Loadcase : pc

Structural loading : Structural

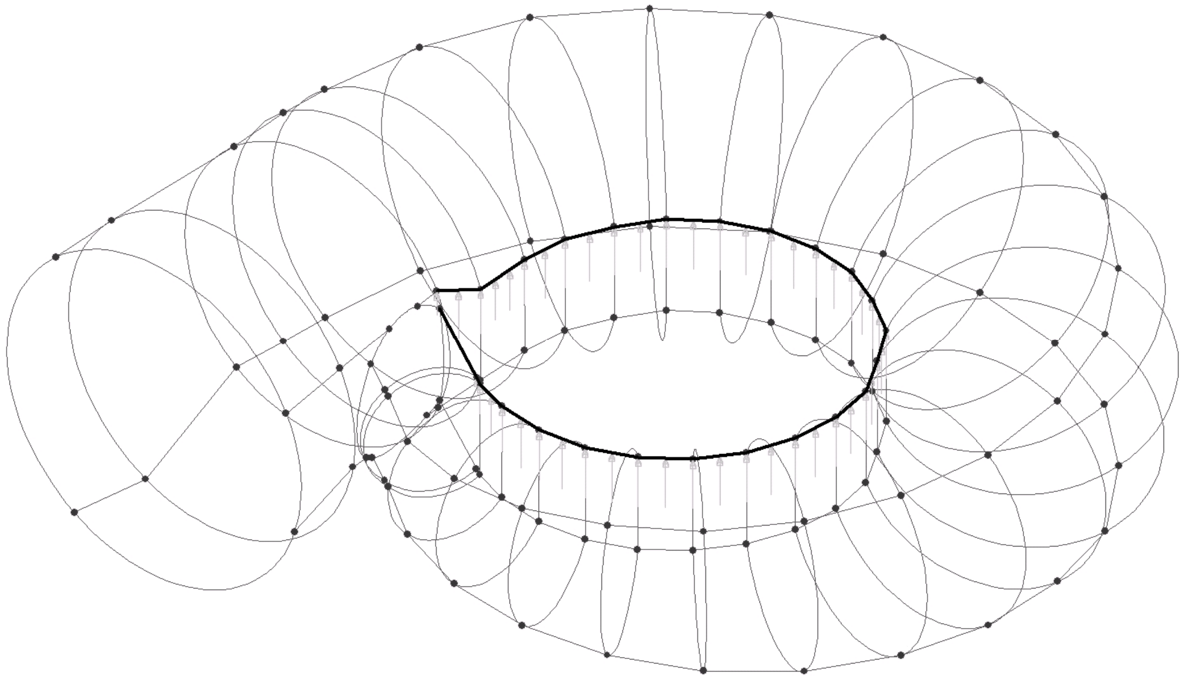
Force type : Line load

Component z direction : 640 kN/m

Total   Per unit length   Per unit area

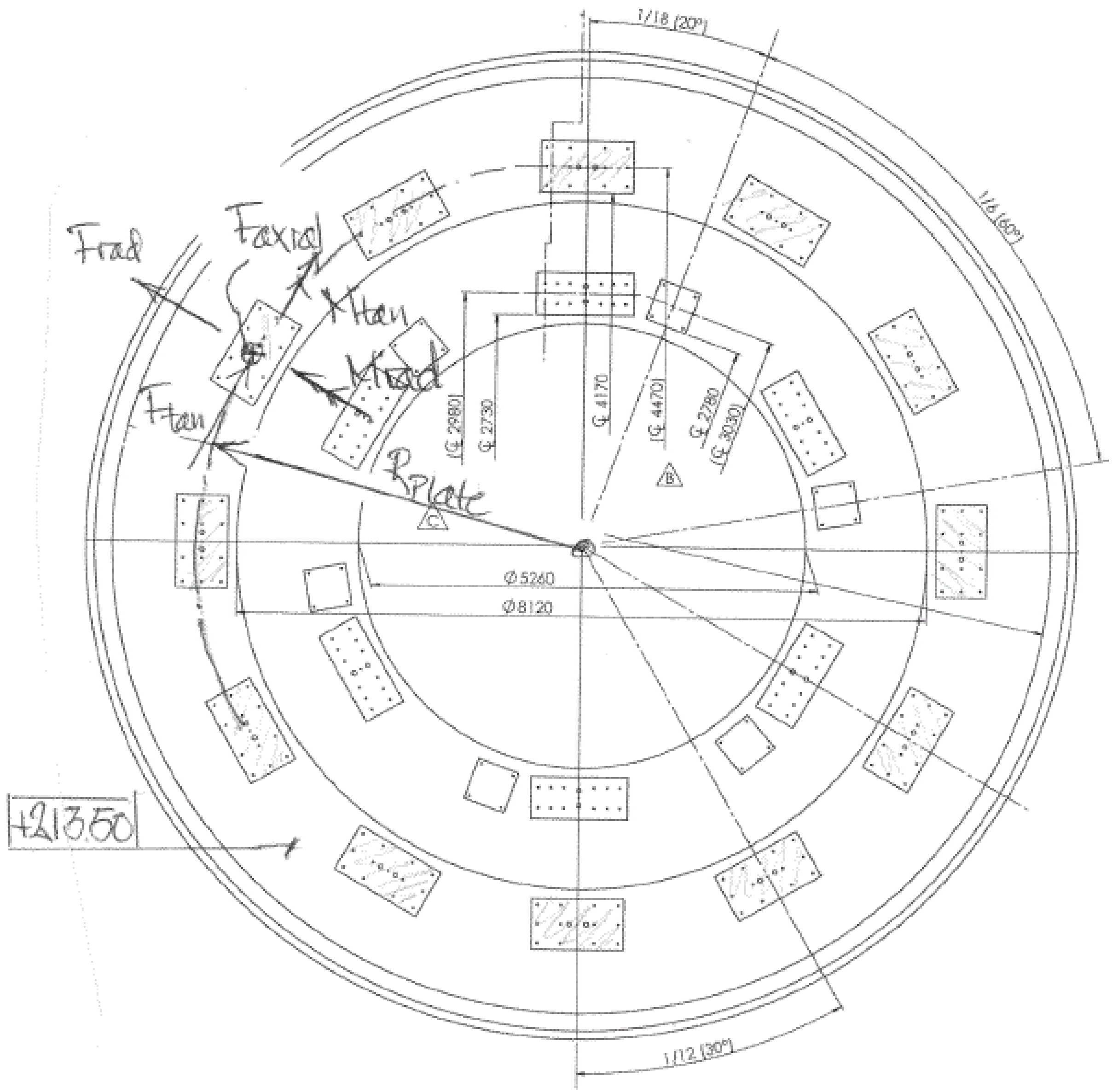
Component	Value
X Direction	0,0
Y Direction	0,0
Z Direction	640,0
Moment about X axis	0,0
Moment about Y axis	0,0
Moment about Z axis	0,0
Moment about hinge nodes	0,0

Attribute pc (5)



3.4 STATOR : UPPER CANTILIVER

At level +213.50 the stator applies load through twelve base plates. The reaction forces are as seen below.

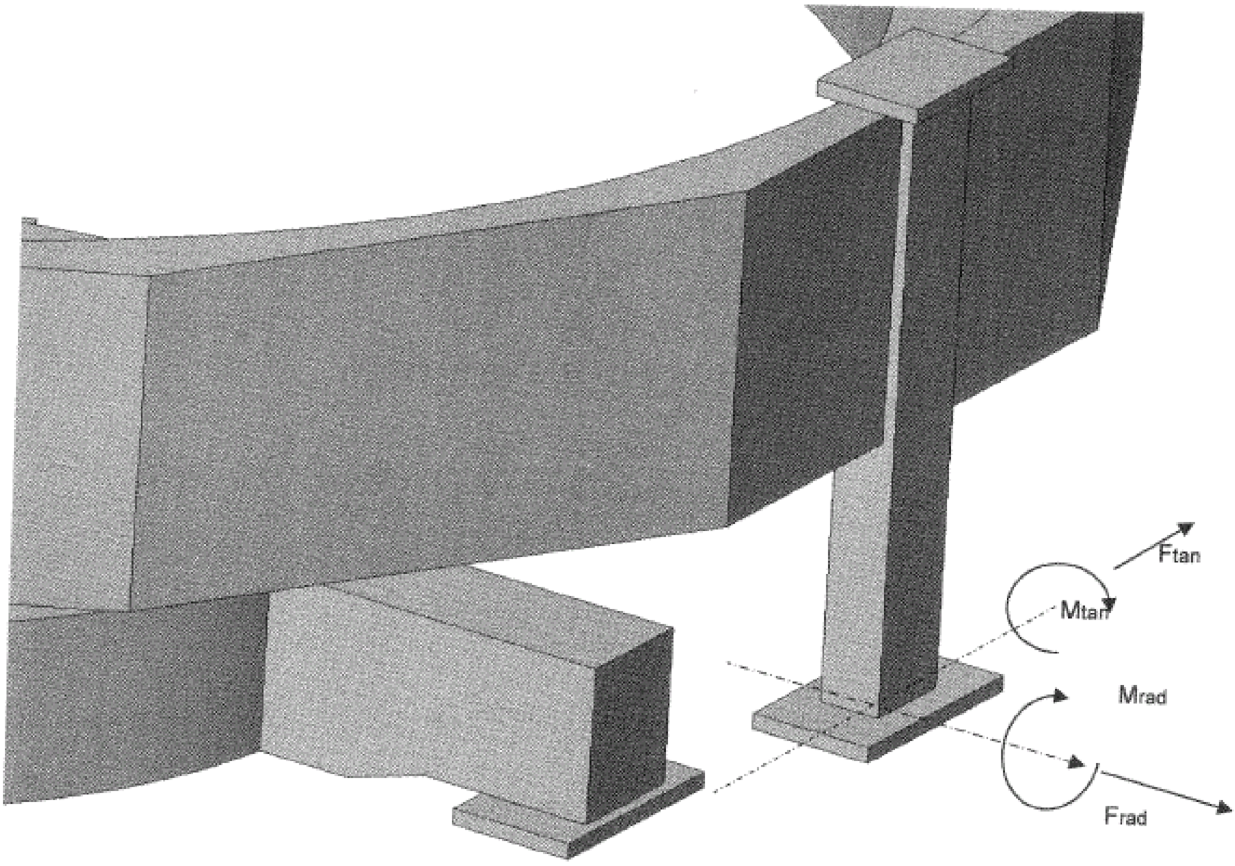


$F_{rad}^{Temp} = \pm 152kN$: radial reaction force due to temperature expansion
$M_{\tan}^{Temp} = \pm 91kNm$: tangential reaction moment due to temperature expansion

$F_{rad}^{Twist} = \pm 68kN$: radial reaction force due to operational twisting
$F_{\tan}^{Twist} = \pm 86kN$: tangential reaction force due to operational twisting
$M_{rad}^{Twist} = \pm 52kNm$: radial reaction moment due to operational twisting

$F_{\tan}^{Short} = \pm 482kN$: tangential reaction force due to electric short circuit
$M_{rad}^{Short} = \pm 291kNm$: radial reaction moment due to electric short circuit ¨

$F_{axial} = 143kN$: vertical reaction force from stator and upper bracket



3.4.1 Vertical reaction load

The vertical load is modelled as twelve discrete point loads.

Each load corresponds to $F_{axial} = 143kN$.

Loadcase : Upper cantilever – Pz :

Load type : Discrete

Search area : Upper cantilever

Discrete point load : UC – Pz

Options for load outside search area : Exclude All loads

Arbitrary

Grid x 0 y 0

Untransformed load direction

X Z

Y Surface normal

Projection vector

Project in load direction

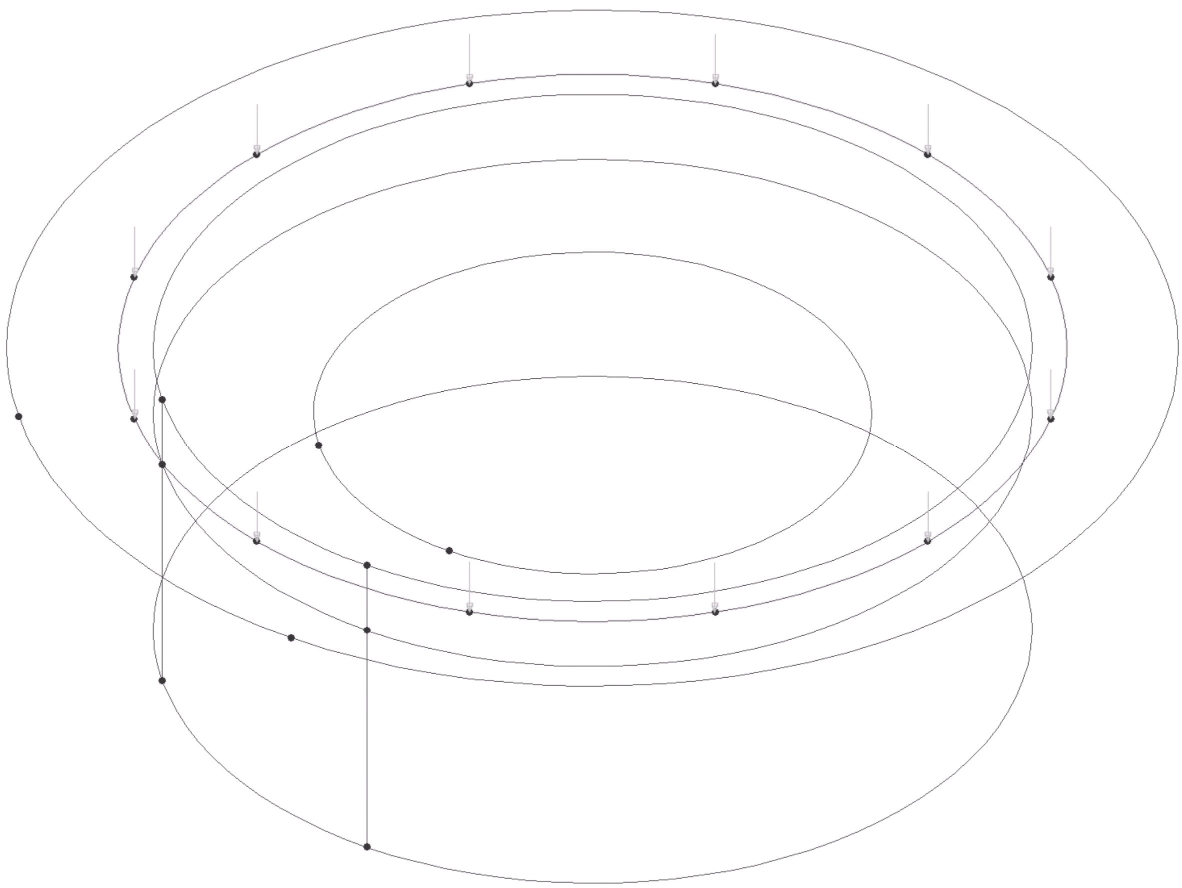
X component 0,0

Y component 0,0

Z component 1,0

	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-4,47	0,0	213,5	-143,0
2	-3,87	-2,23	213,5	-143,0
3	-2,24	-3,87	213,5	-143,0
4	0,0	-4,47	213,5	-143,0
5	2,23	-3,87	213,5	-143,0
6	3,871	-2,23	213,5	-143,0
7	4,47	0,0	213,5	-143,0
8	3,87	2,23	213,5	-143,0
9	2,23	3,87	213,5	-143,0
10	-3,87	2,23	213,5	-143,0
11	-2,23	3,87	213,5	-143,0
12	0,0	4,47	213,5	-143,0

Attribute UC - Pz [18]



3.4.2 Radial reaction load

There are twelve radial reaction loads acting on twelve base plates. The loads arise due to temperature expansion and operational twist. On the safe side they are considered to act simultaneously.

$F_{rad}^{Temp} = \pm 152kN$: radial reaction force due to temperature expansion

$F_{rad}^{Twist} = \pm 68kN$: radial reaction force due to operational twisting

$\Rightarrow \; F_{rad} = F_{rad}^{Temp} + F_{rad}^{Twist} \pm 220kN$: total radial reaction force on each base plate

At level +213.50 the total radial reaction force $12F_{rad} = \pm 2640kN$ is distributed as a structural line load as seen below. The simplified as assumption is considered negligible.

$R_{Load} = 5.52m$: radius of the load line

$l = 2\pi \cdot R_{Load} = 34.7m$: load length

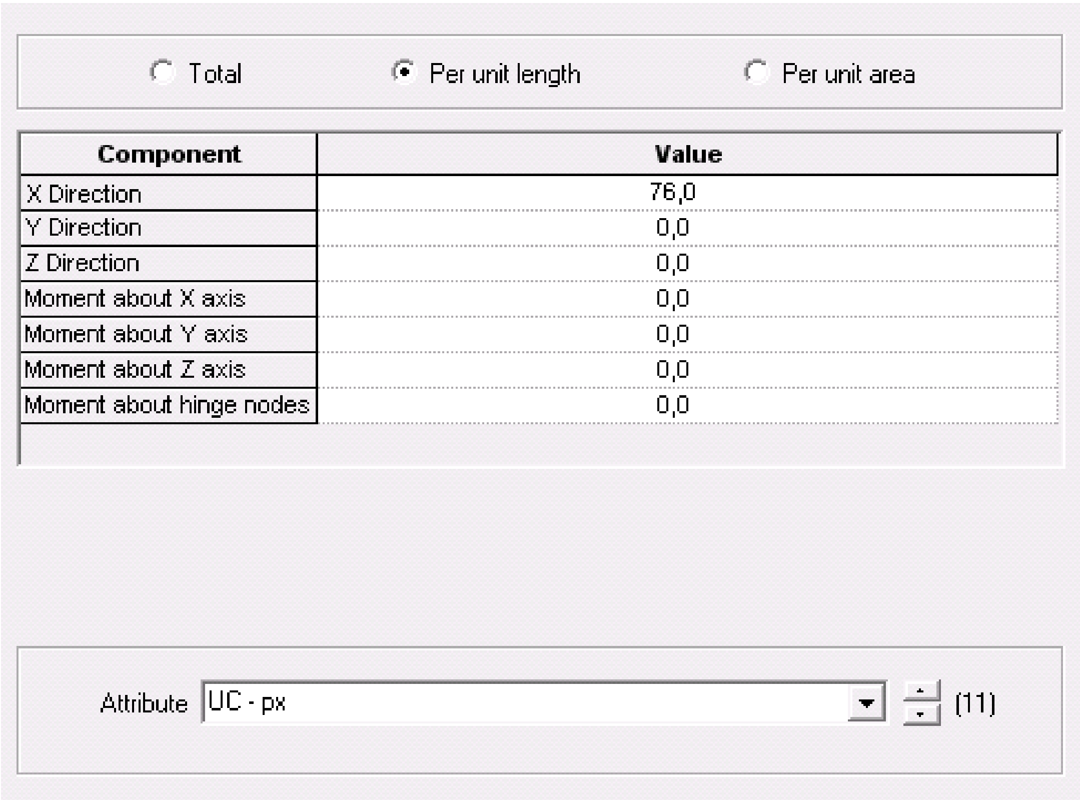
$p_x^{UC} = \frac{12F_{rad}}{l} = \frac{2640kN}{34.7m} = 76\frac{kN}{m}$: load introduced into structure

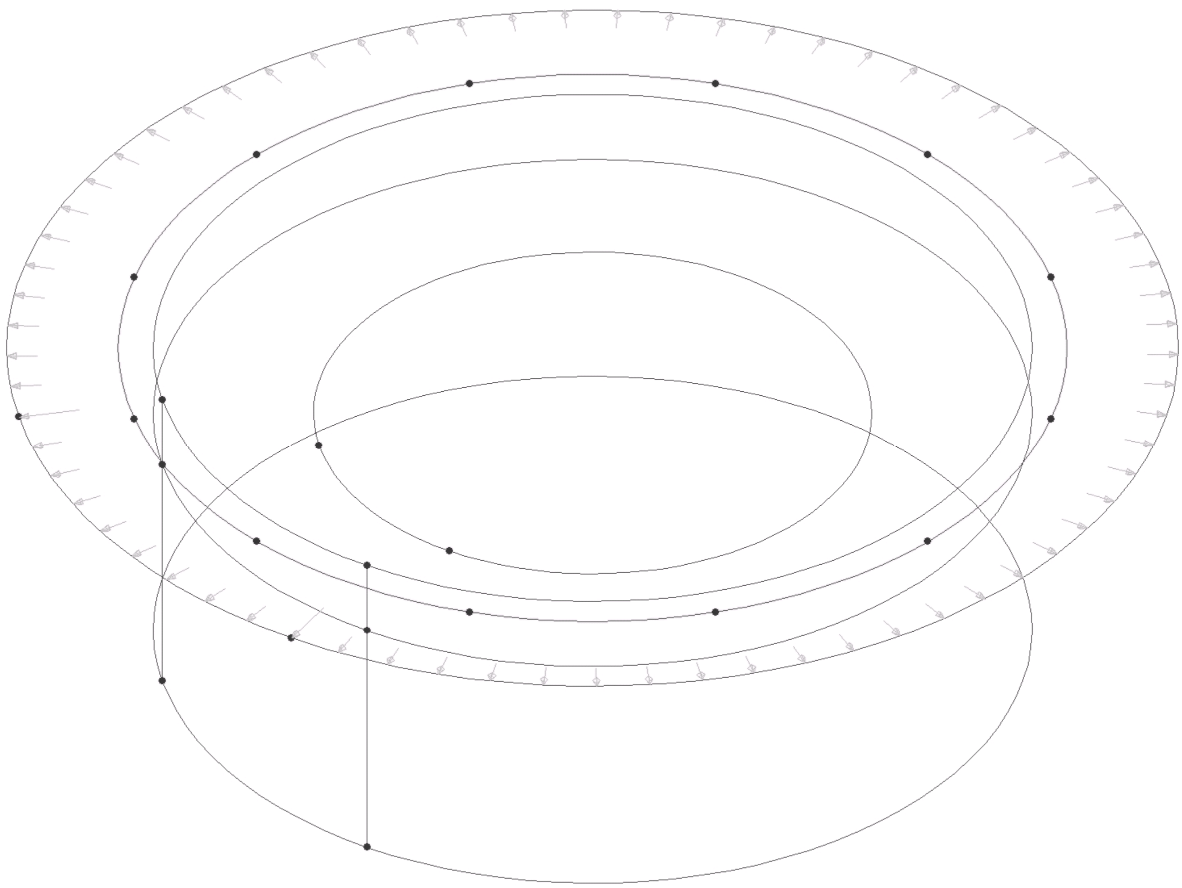
Loadcase : Upper cantilever – Px :

Load type : Structural / global distributed

Line load : UC – px

Component in local x direction : 76 kN/m





3.4.3 Tangential reaction load

There are twelve tangential reaction loads acting on twelve base plates. The loads arise due to operational twisting and electric short circuiting. They are not considered to act simultaneously.

$F_{\tan}^{Twist} = \pm 86kN$: tangential reaction force due to operational twisting

$F_{\tan}^{Short} = \pm 482kN$: tangential reaction force due to electric short circuit

$\Rightarrow \; F_{\tan} = \left\{ F_{\tan}^{Twust} ; F_{\tan}^{Short} \right\}^{\max} = \pm 482kN$: maximum tangential reaction force on each base plate

At level +213.50 the total radial reaction force $12F_{\tan} = \pm 5784kN$ is distributed as a structural line load as seen below. The simplified as assumption is considered negligible.

$R_{Load} = 5.52m$: radius of the load line
$R_{Plate} = 4.47m$: radius to centre of base plate

$l = 2\pi \cdot R_{Load} = 34.7m$: load length

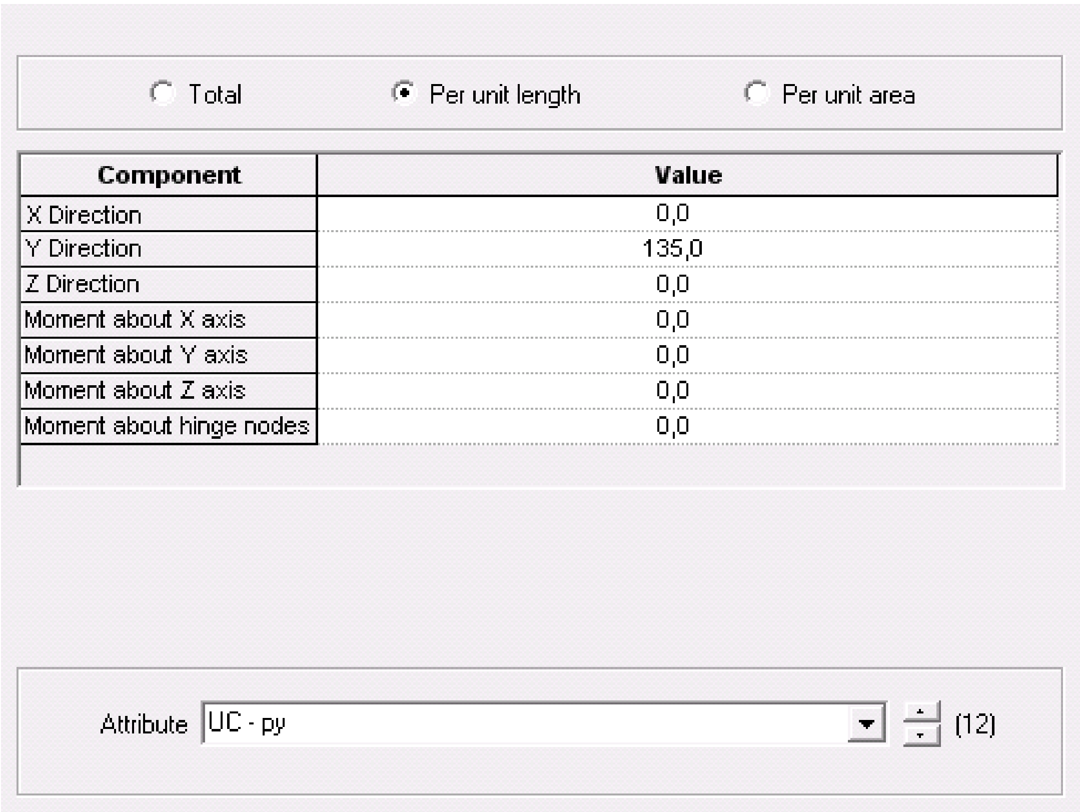
$$(p_y^{UC} \cdot l) \cdot R_{load} \equiv 12F_{\tan} \cdot R_{Plate} \Rightarrow p_y^{UC} = \frac{12F_{\tan} \cdot R_{Plate}}{l \cdot R_{Load}} = \pm \frac{5784kN \cdot 4.47m}{34.7m \cdot 5.52m} = \pm 135\frac{kN}{m}$$

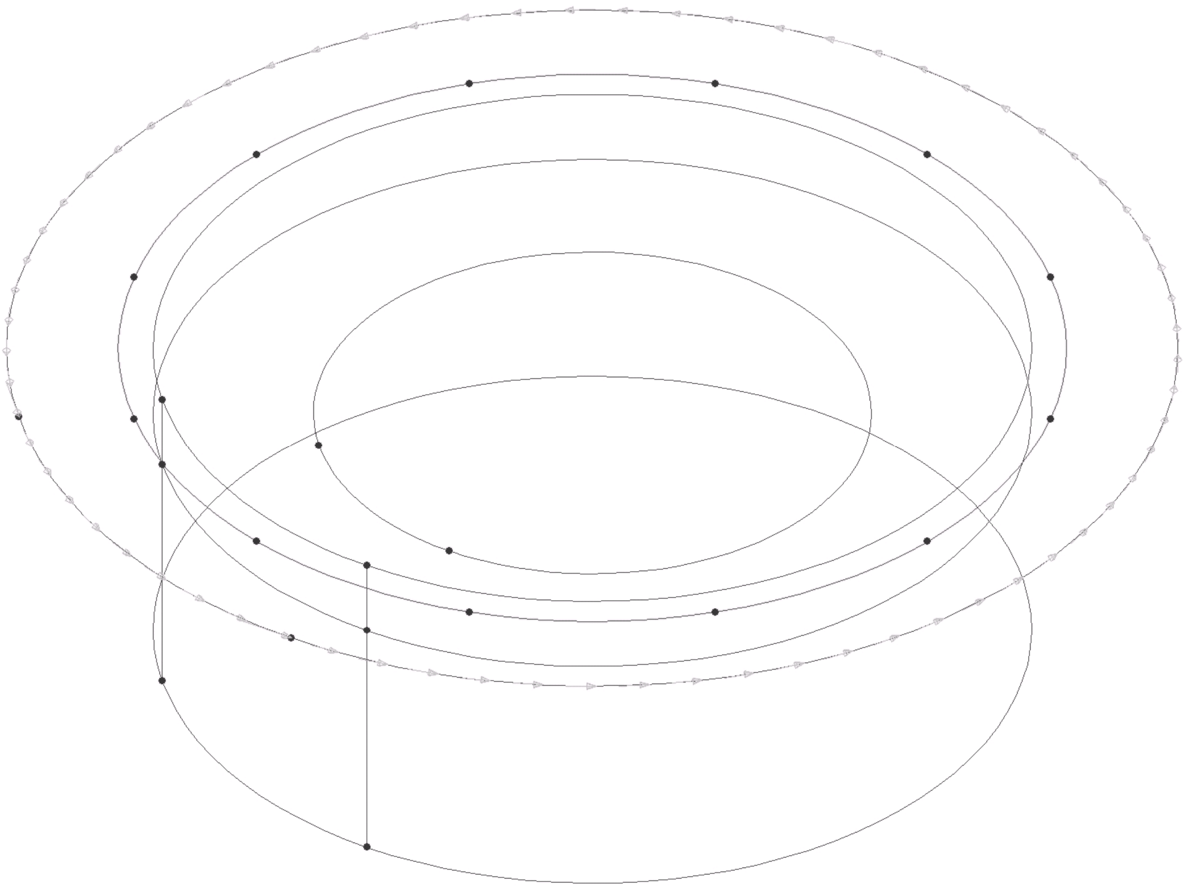
Loadcase : Upper cantilever – Py :

Load type : Structural / global distributed

Line load : UC – py

Component in local y direction : 135 kN/m





3.4.4 Tangential moment load

There are twelve tangential reaction moments acting on twelve base plates. The loads arise due to temperature expansion.

$M_{\tan}^{Temp} = \pm 91 kNm$: tangential reaction moment due to temperature expansion

At level +213.50 the total tangential reaction moment $12 M_{\tan}^{Temp} = \pm 1092 kNm$ is distributed as a structural line load as seen below. The simplified as assumption is considered negligible.

$R_{Load} = 4.14 m$: radius of the load line

$l = 2\pi \cdot R_{Load} = 26.0 m$: load length

$m_y^{UC} = \dfrac{12 M_{\tan}^{Temp}}{l} = \dfrac{1092 kNm}{26.0 m} = 42 \dfrac{kNm}{m}$: load introduced into structure

Loadcase : Upper cantilever – My :

Load type : Structural / global distributed

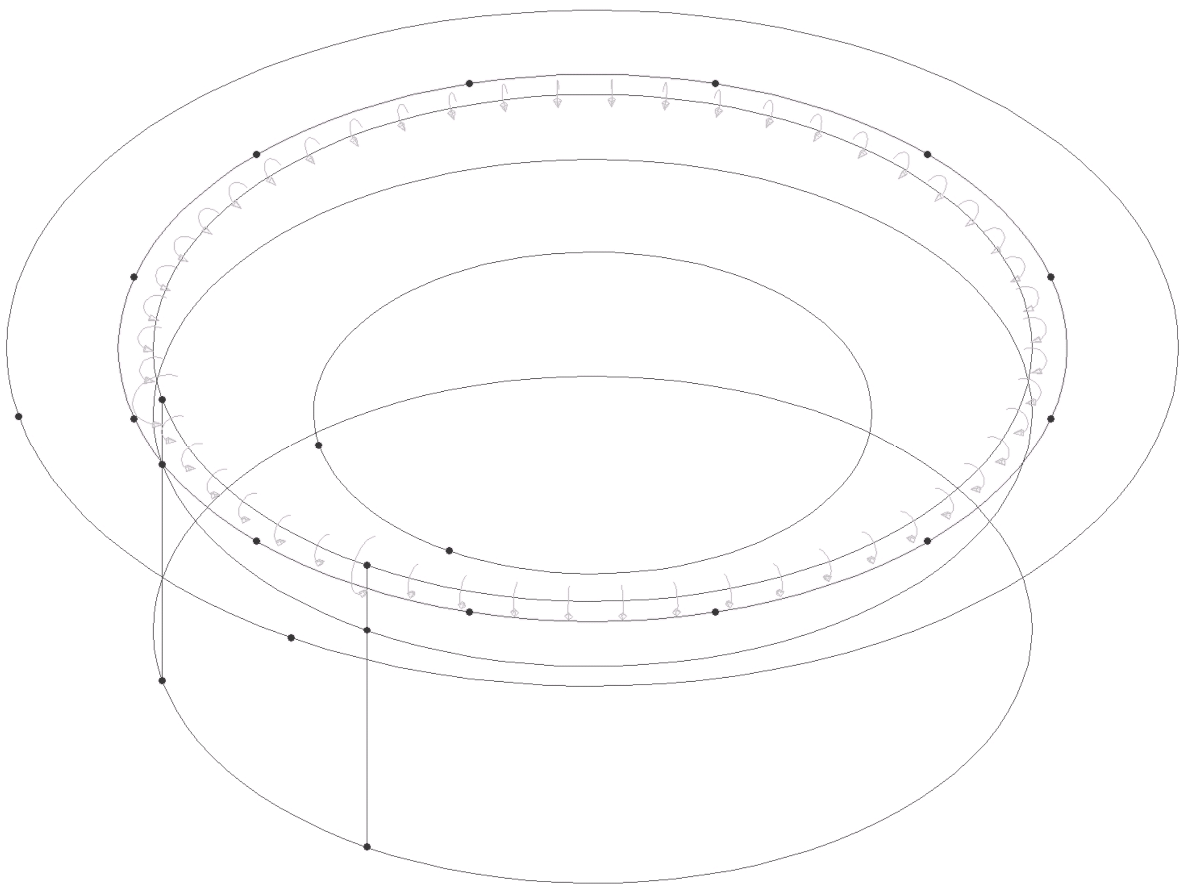
Line load : UC – my

Component around local y direction : 42 kNm/m

Total   Per unit length   Per unit area

Component	Value
X Direction	0,0
Y Direction	0,0
Z Direction	0,0
Moment about X axis	0,0
Moment about Y axis	42,0
Moment about Z axis	0,0
Moment about hinge nodes	0,0

Attribute UC - my (2)



3.4.5 Radial moment load

There are twelve radial reaction moments acting on twelve base plates. The loads arise due to temperature expansion.

$M_{\tan}^{Temp} = \pm 91 kNm$: tangential reaction moment due to temperature expansion

. The loads arise due to operational twisting and electric short circuiting. They are not considered to act simultaneously.

$M_{rad}^{Twist} = \pm 52 kNm$: radial reaction moment due to operational twisting

$M_{rad}^{Short} = \pm 291 kNm$: radial reaction moment due to electric short circuit ¨

$\Rightarrow \quad M_{rad} = \left\{ M_{rad}^{Twust} ; M_{rad}^{Short} \right\}^{\max} = \pm 291 kNm$: maximum tangential reaction force on each base plate

At level +213.50 the total tangential reaction moment $12 M_{rad} = \pm 3492 kNm$ is distributed as a structural line load as seen below. The simplified as assumption is considered negligible.

$R_{Load} = 4.14 m$: radius of the load line

$l = 2\pi \cdot R_{Load} = 26.0 m$: load length

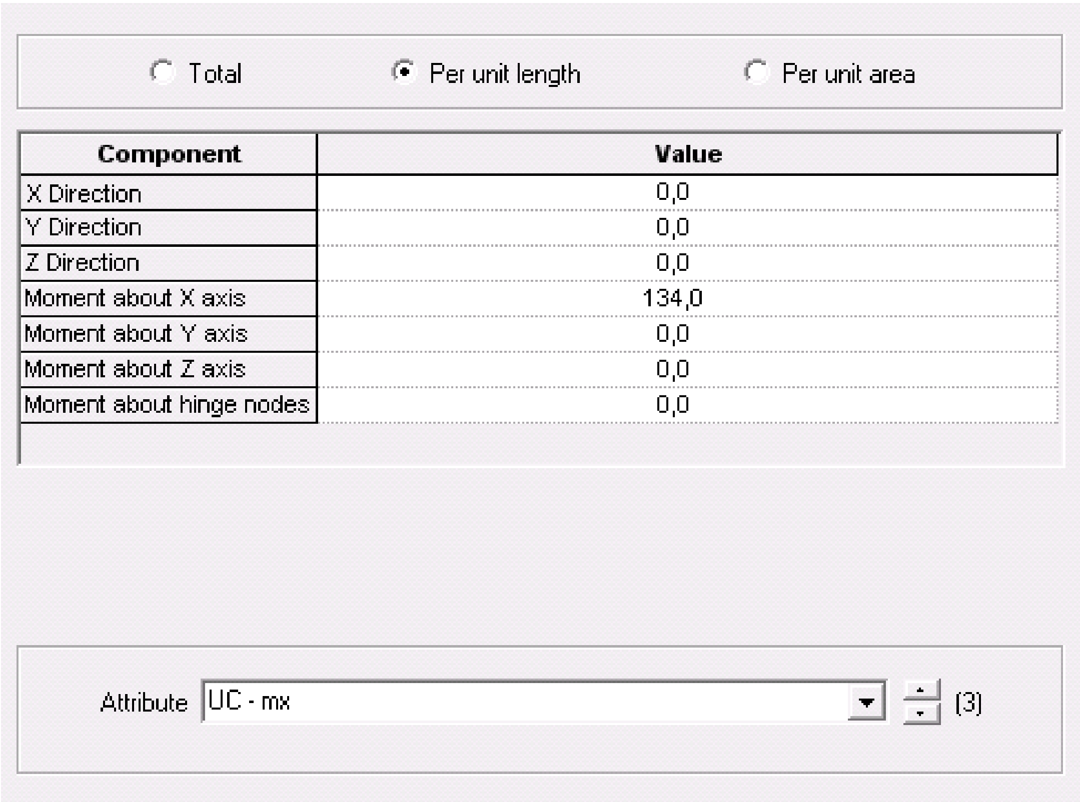
$m_x^{UC} = \dfrac{12 M_{rad}}{l} = \dfrac{3492 Nm}{26.0 m} = 134 \dfrac{kNm}{m}$: load introduced into structure

Loadcase : Upper cantilever – Mx :

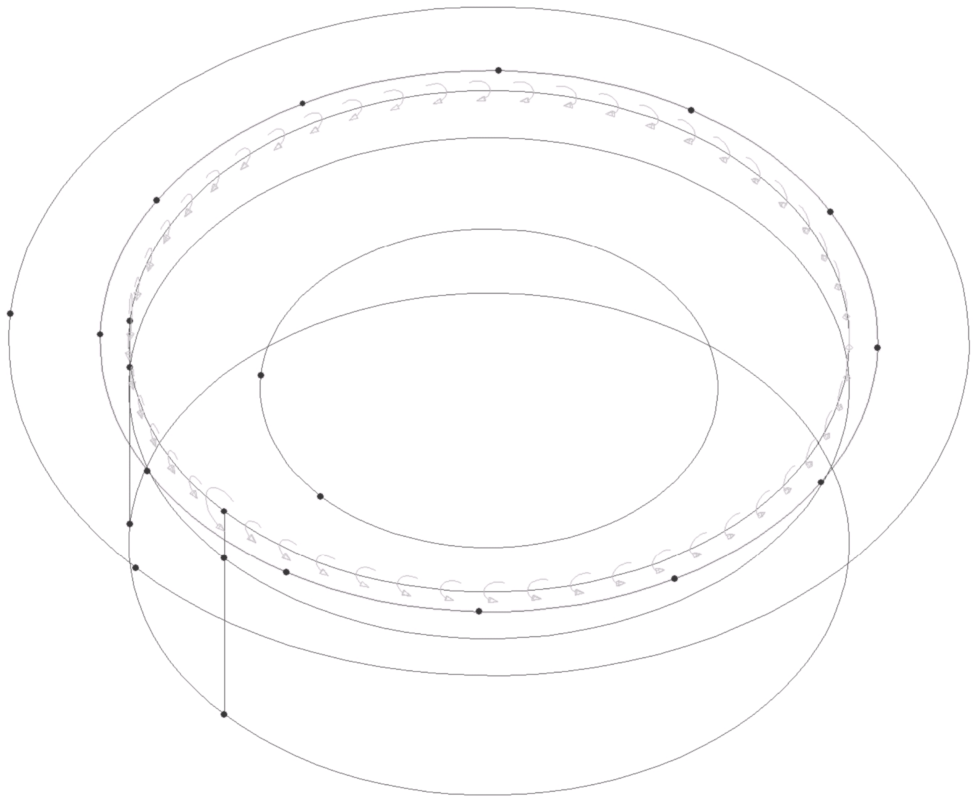
Load type : Structural / global distributed

Line load : UC – mx

Component around local x direction : 134 kNm/m



Component	Value
X Direction	0,0
Y Direction	0,0
Z Direction	0,0
Moment about X axis	134,0
Moment about Y axis	0,0
Moment about Z axis	0,0
Moment about hinge nodes	0,0



3.4.6 Load combination : Upper cantilever

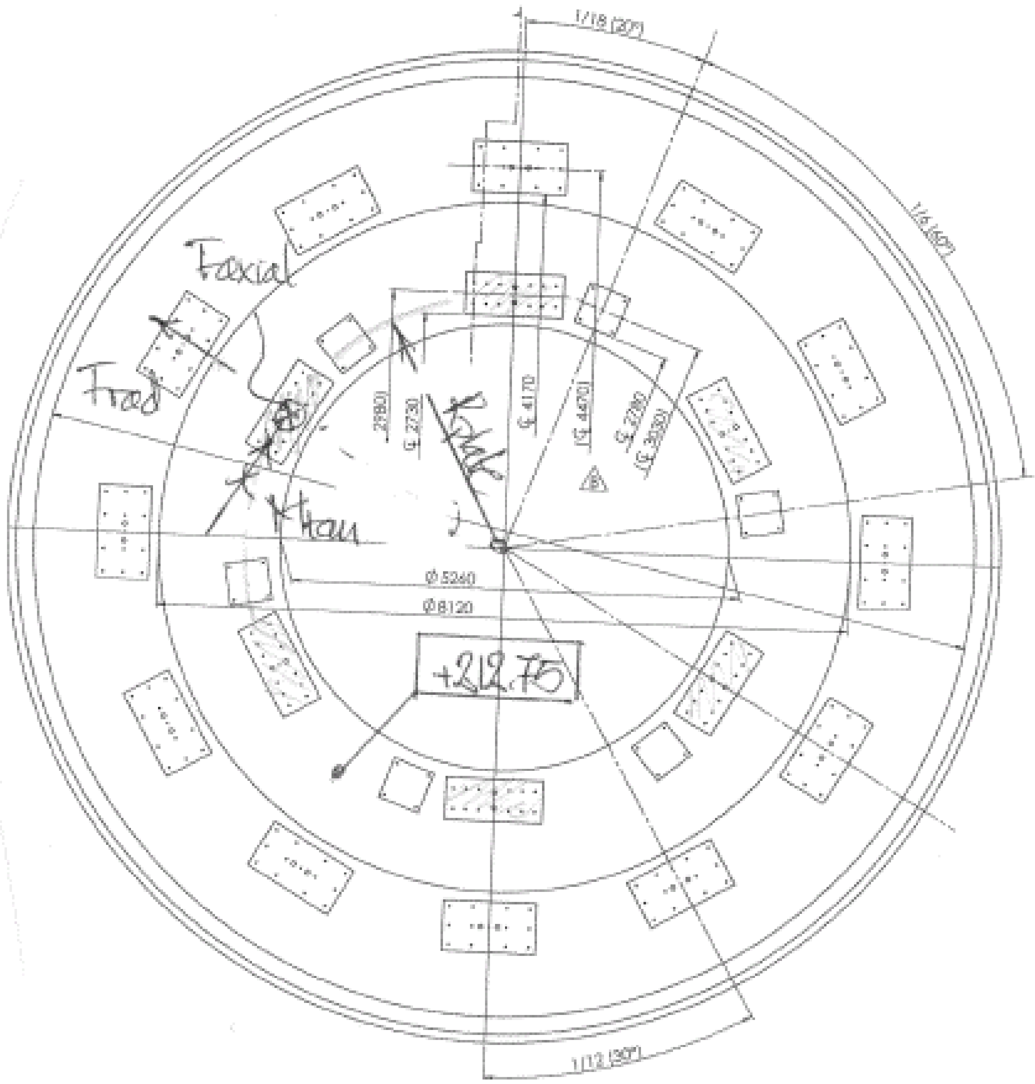
On the safe side all loads except UC-Pz is considered to act independently and with alternating direction.

Smart load combination : Upper cantilever

Load case	Permanent factor	Variable factor
Upper cantilever – Pz	0	1
Upper cantilever - Px	0	1
Upper cantilever - Px	0	-1
Upper cantilever – Py	0	1
Upper cantilever - Py	0	-1
Upper cantilever – Mx	0	1
Upper cantilever - Mx	0	-1
Upper cantilever – My	0	1
Upper cantilever – My	0	-1

3.5 LOWER BRACKET : LOWER CANTILIVER

At level +212.75 there are six base plates. The reaction forces are as seen below.



$F_{rad}^{Temp} = \pm 1420kN$: radial reaction force due to temperature expansion

$M_{\tan}^{Temp} = \pm 140kNm$: tangential reaction moment due to temperature expansion

$F_{axial} = 2031kN$: vertical reaction force from rotating part, lower bracket and water load

3.5.1 Vertical reaction load

The vertical load is modelled as six discrete point loads.

Each load corresponds to $F_{axial} = 2031 kN$.

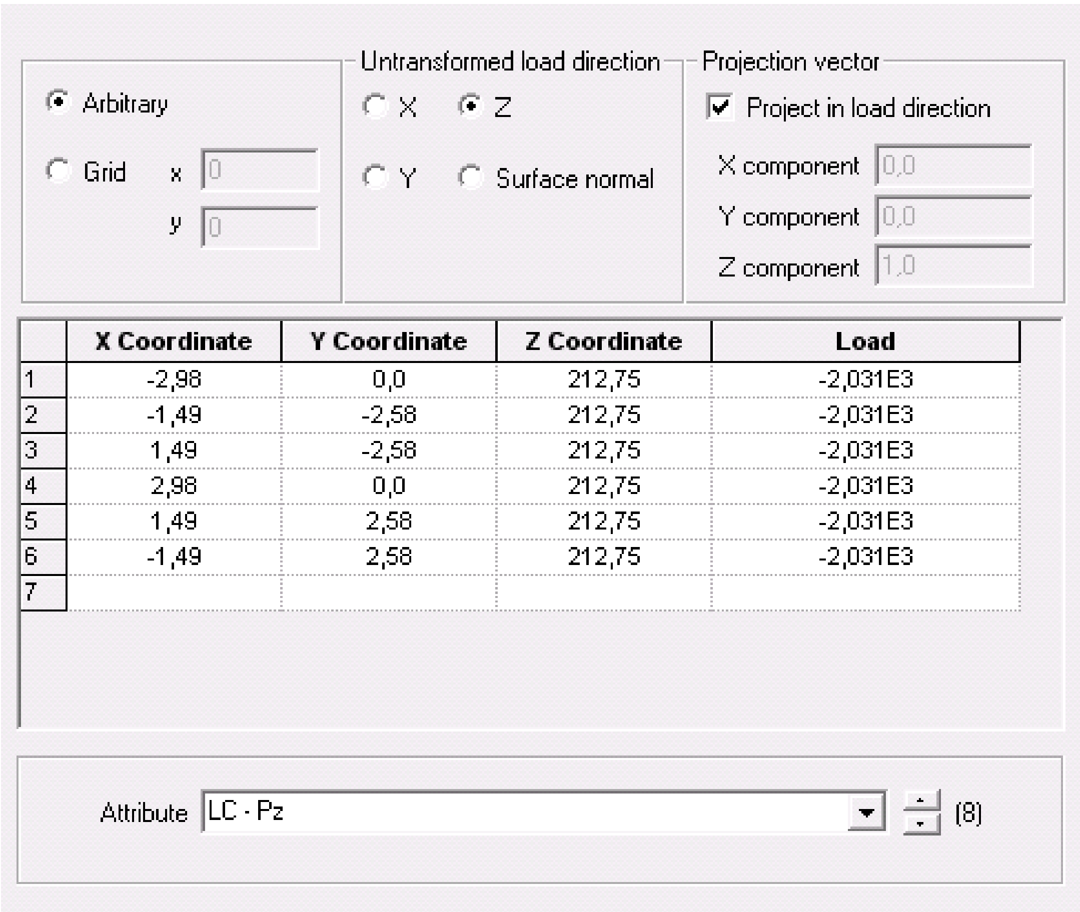
Loadcase : Lower cantilever – Pz :

Load type : Discrete

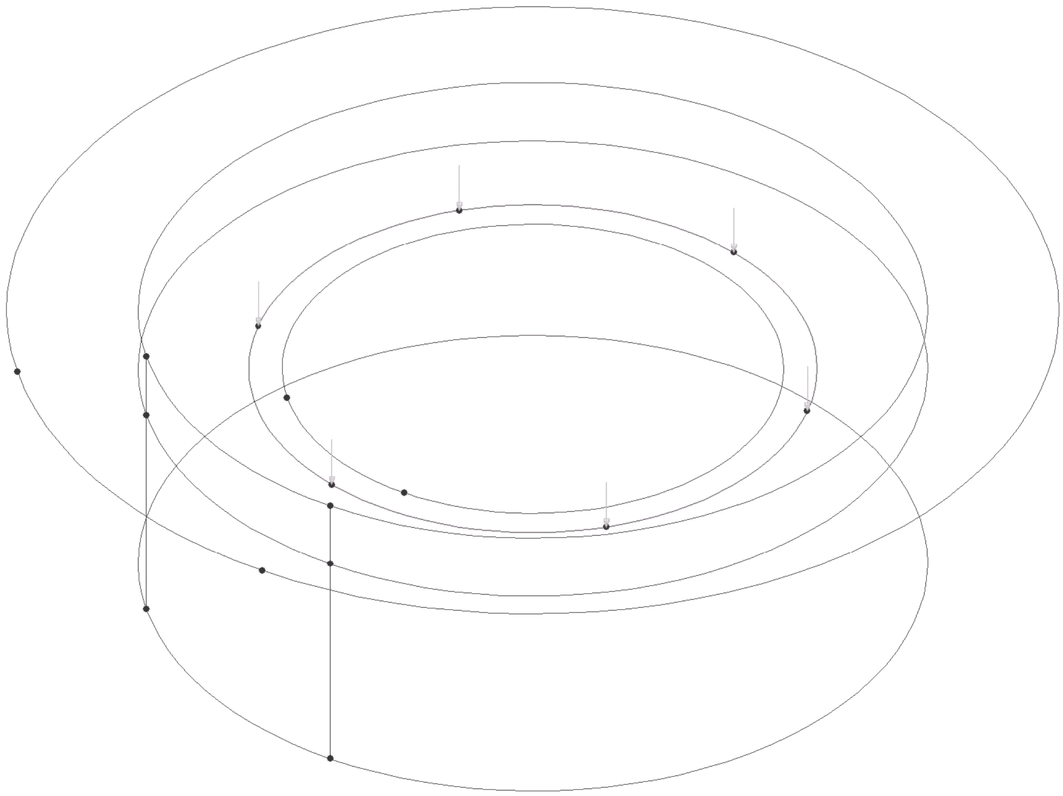
Search area : Lower cantilever

Discrete point load : LC – Pz

Options for load outside search area : Exclude All loads



	X Coordinate	Y Coordinate	Z Coordinate	Load
1	-2,98	0,0	212,75	-2,031E3
2	-1,49	-2,58	212,75	-2,031E3
3	1,49	-2,58	212,75	-2,031E3
4	2,98	0,0	212,75	-2,031E3
5	1,49	2,58	212,75	-2,031E3
6	-1,49	2,58	212,75	-2,031E3
7				



3.5.2 Radial reaction load

There are six radial reaction loads acting on six base plates. The loads arise due to temperature expansion.

$F_{rad}^{Temp} = \pm 1420kN$: radial reaction force due to temperature expansion

At level +212.75 the total radial reaction force $6F_{rad}^{temp} = \pm 8520kN$ is distributed as a structural line load as seen below. The simplified as assumption is considered negligible.

$R_{Load} = 2.63m$: radius of the load line

$l = 2\pi \cdot R_{Load} = 16.5m$: load length

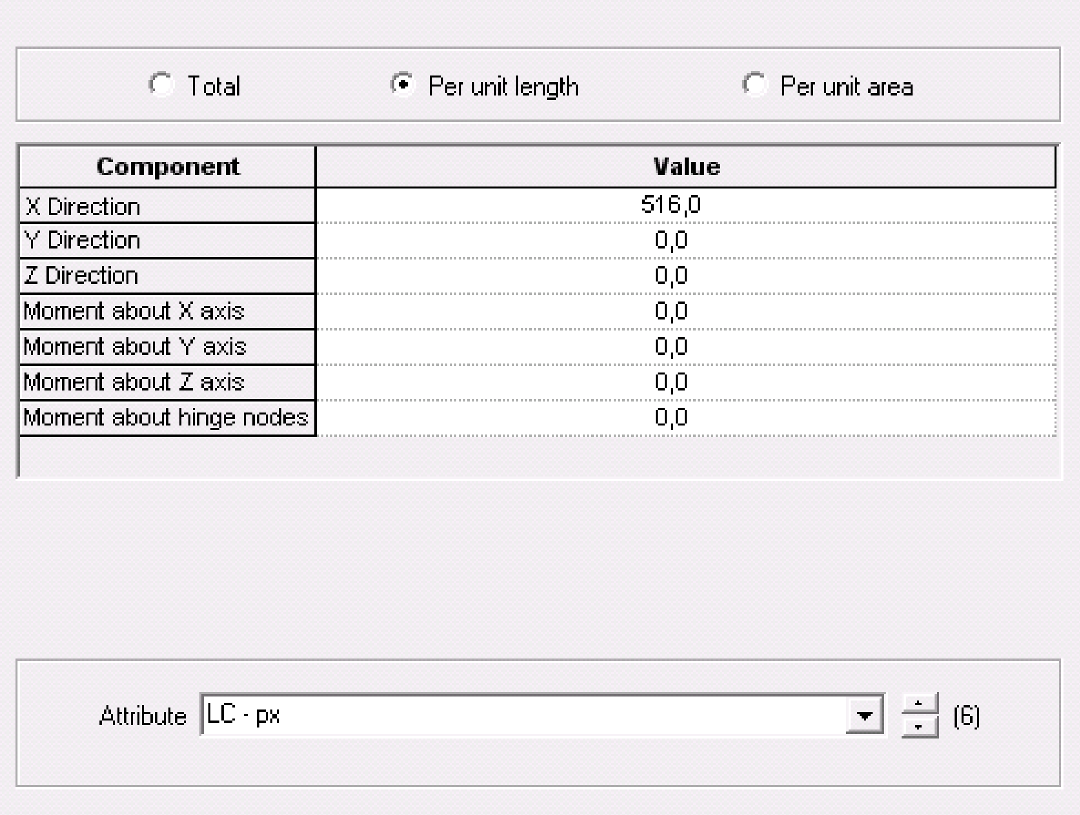
$p_x^{LC} = \dfrac{12F_{rad}}{l} = \dfrac{8520kN}{16.5m} = 516\dfrac{kN}{m}$: load introduced into structure

Loadcase : Lower cantilever – Px :

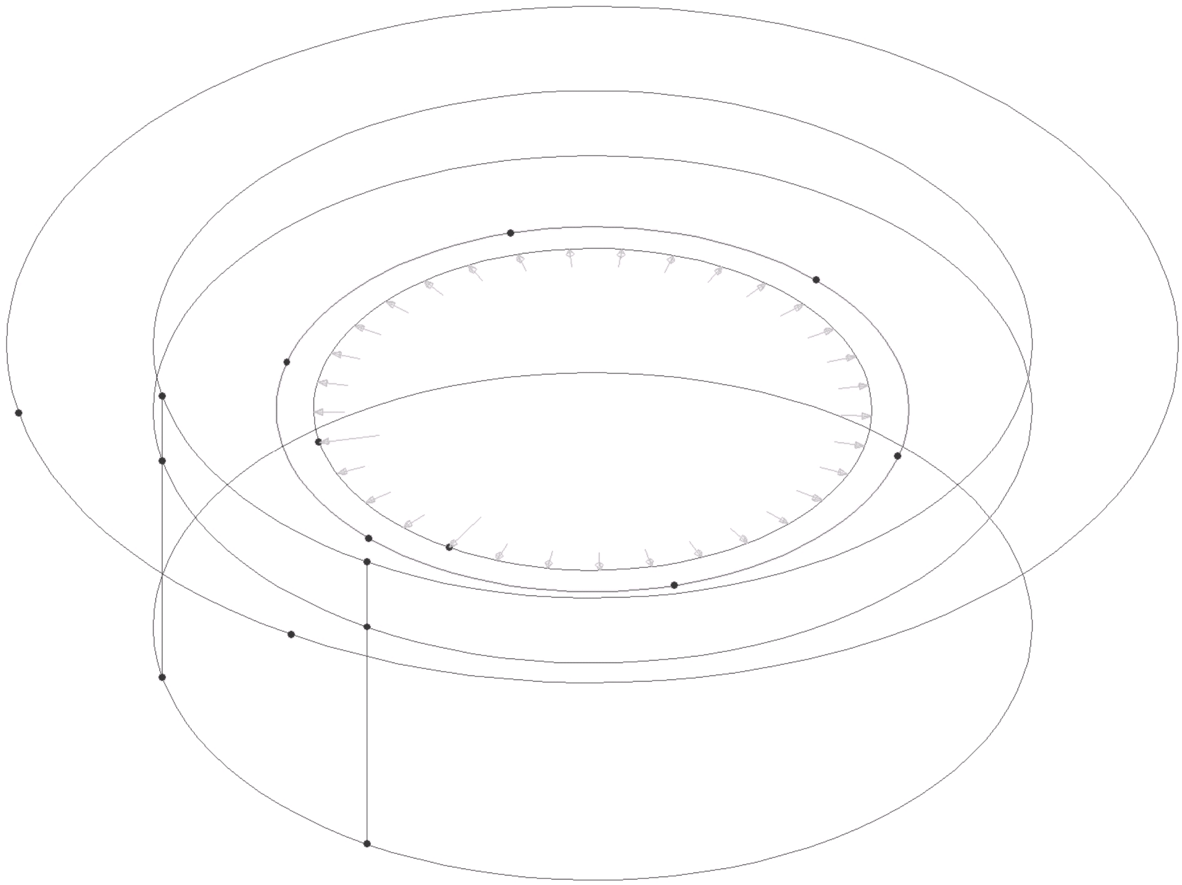
Load type : Structural / global distributed

Line load : LC – px

Component in local x direction : 516 kN/m



Component	Value
X Direction	516,0
Y Direction	0,0
Z Direction	0,0
Moment about X axis	0,0
Moment about Y axis	0,0
Moment about Z axis	0,0
Moment about hinge nodes	0,0



3.5.3 Tangential moment load

There are six tangential reaction moments acting on six base plates. The loads arise due to temperature expansion.

$M_{\tan}^{Temp} = \pm 140kNm$: tangential reaction moment due to temperature expansion

At level +212.75 the total tangential reaction moment $6M_{\tan}^{Temp} = \pm 840kNm$ is distributed as a structural line load as seen below. The simplified as assumption is considered negligible.

$R_{Load} = 2.63m$: radius of the load line

$l = 2\pi \cdot R_{Load} = 16.5m$: load length

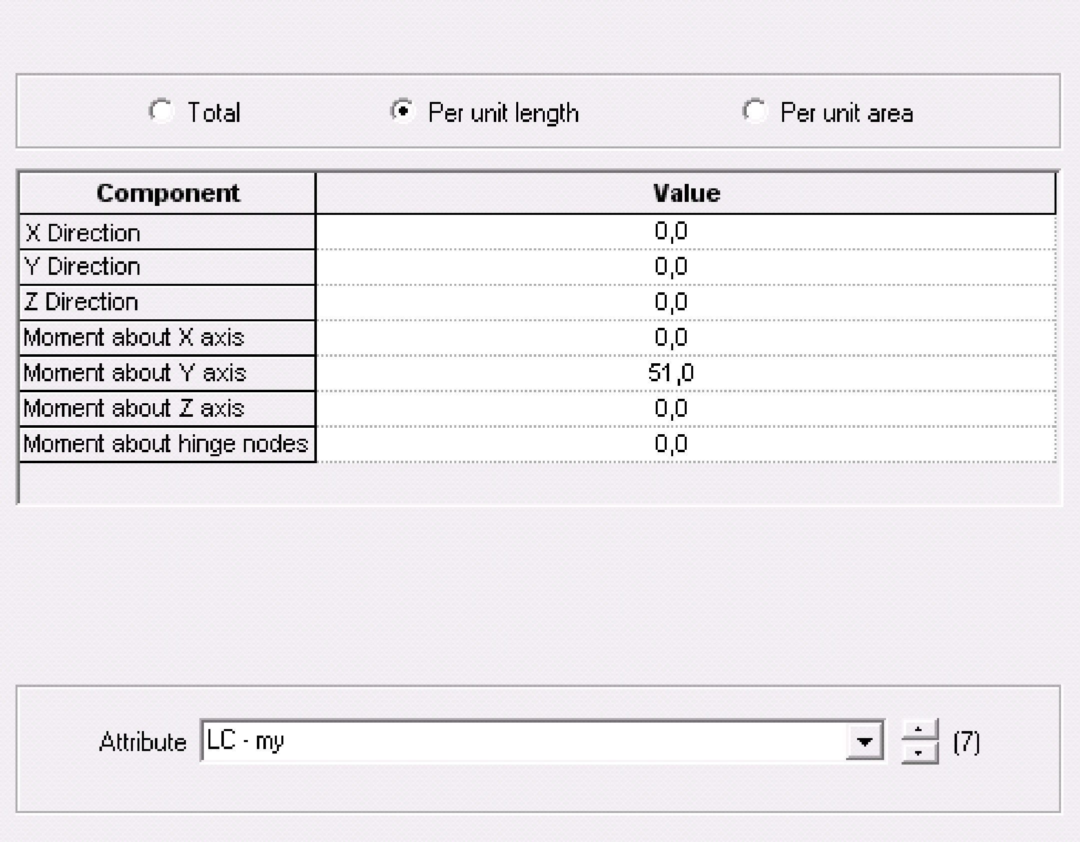
$m_y^{LC} = \frac{6M_{\tan}^{Temp}}{l} = \frac{840kNm}{16.5m} = 51\frac{kNm}{m}$: load introduced into structure

Loadcase : Lower cantilever – My :

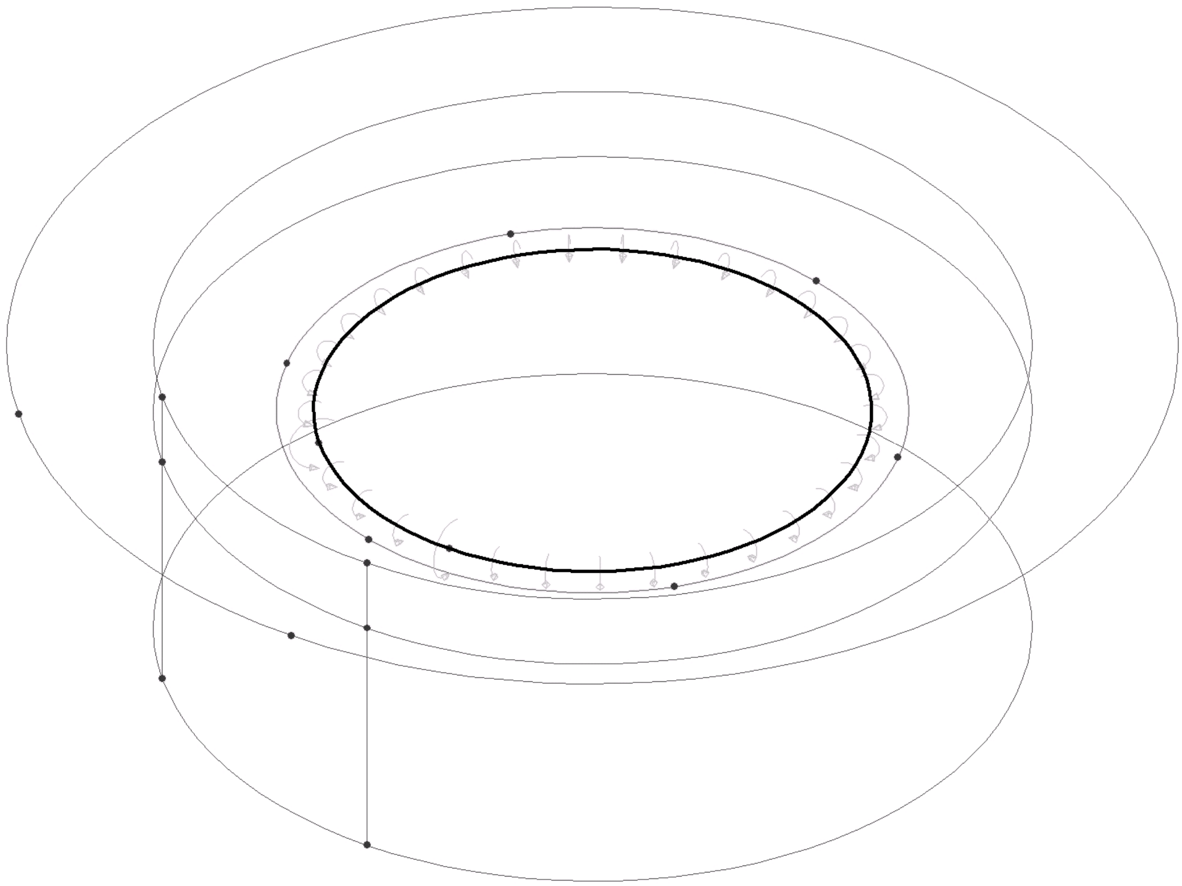
Load type : Structural / global distributed

Line load : LC – my

Component around local y direction : 51 kNm/m



Component	Value
X Direction	0,0
Y Direction	0,0
Z Direction	0,0
Moment about X axis	0,0
Moment about Y axis	51,0
Moment about Z axis	0,0
Moment about hinge nodes	0,0



3.5.4 Load combination : Lower cantilever

On the safe side all loads except LC-Pz is considered to act independently and with alternating direction.

Smart load combination : Lower cantilever

Load case	Permanent factor	Variable factor
Lower cantilever – Pz	0	1
Lower cantilever - Px	0	1
Lower cantilever - Px	0	-1
Lower cantilever – My	0	1
Lower cantilever – My	0	-1

3.6 LOAD COMBINATIONS

Both basic and smart load combinations are used.

The basic load combinations are used for volume element in order to retrieve equivalent design forces by integrating stresses

The smart load combinations are used to retrieve stress in foundation and retrieve design forces from shell structures.

3.6.1 Basic load combinations

Basic load combination : Ultimate 1

Loadcase	Factor
Deadweight	1.1
Water pressure qw	0
Head cover pc	0
Upper cantilever -Pz	1.3
Upper cantilever – Px	0
Upper cantilever – Py	0
Upper cantilever –Mx	0
Upper cantilever – My	0
Lower cantilever – Pz	1.3
Lowe cantilever –Px	0
Lower cantilever – My	0

Basic load combination : Ultimate 2

Loadcase	Factor
Deadweight	0.9
Water pressure qw	1.1
Head cover pc	1.1
Upper cantilever -Pz	0.9
Upper cantilever – Px	0
Upper cantilever – Py	0
Upper cantilever –Mx	0
Upper cantilever – My	0
Lower cantilever – Pz	0.9
Lower cantilever –Px	0
Lower cantilever – My	0

3.6.2 Smart load combinations

Smart load combination : Upper cantilever

Loadcase	Permanent factor	Variable factor
Upper cantilever - Pz	1.0	0
Upper cantilever – Px	0	-1.0
Upper cantilever – Px	0	+1.0
Upper cantilever – Py	0	-1.0
Upper cantilever – Py	0	+1.0
Upper cantilever – Mx	0	-1.0
Upper cantilever – Mx	0	+1.0
Upper cantilever – My	0	-1.0
Upper cantilever - My	0	+1.0

Smart load combination : Lower cantilever

Loadcase	Permanent factor	Variable factor
Lower cantilever - Pz	1.0	0
Lower cantilever – Px	0	-1.0
Lower cantilever – Px	0	+1.0
Lower cantilever – My	0	-1.0
Lower cantilever - My	0	+1.0

Smart load combination : Ultimate state

Loadcase	Permanent factor	Variable factor
Deadweight	0.90	0.20
Water pressure qw	0	1.10
Head cover pc	0	1.10
Upper cantilever	0	1.30
Lower cantilever	0	1.30