

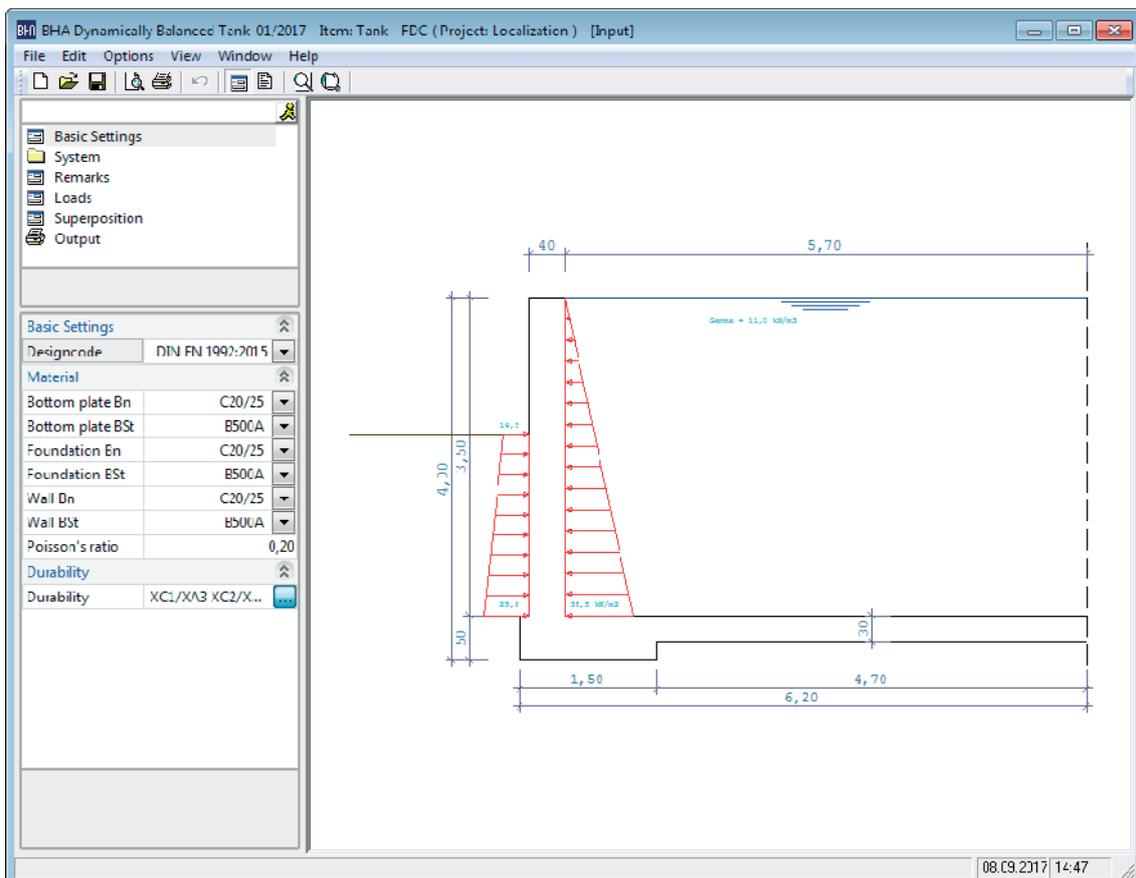
Dynamically Balanced Tank - BHA

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Dynamically Balanced Tank - BHA

Note: The present document describes the Eurocode-specific application. Documents referring to former standards are available in our document archive at www.friilo.eu >> Service >> Documentation >> Manuals.

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Further information and descriptions are available in the relevant documentations:

[Durability - Creep Coefficient and Shrinkage Strain.pdf](#)

[FDC – Basic Operating Instructions](#) General instructions for the manipulation of the user interface

[FDC – Menu Items](#) General description of the typical menu items of Frilo software applications

[FDC – Output and Printing](#) Output and printing

[FDC - Import and Export](#) Interfaces to other applications (ASCII, RTF, DXF ...)

[FCC](#) Frilo.Control.Center - the easy-to-use administration module for projects and items

[FDD](#) Frilo.Document.Designer - document management based on PDF

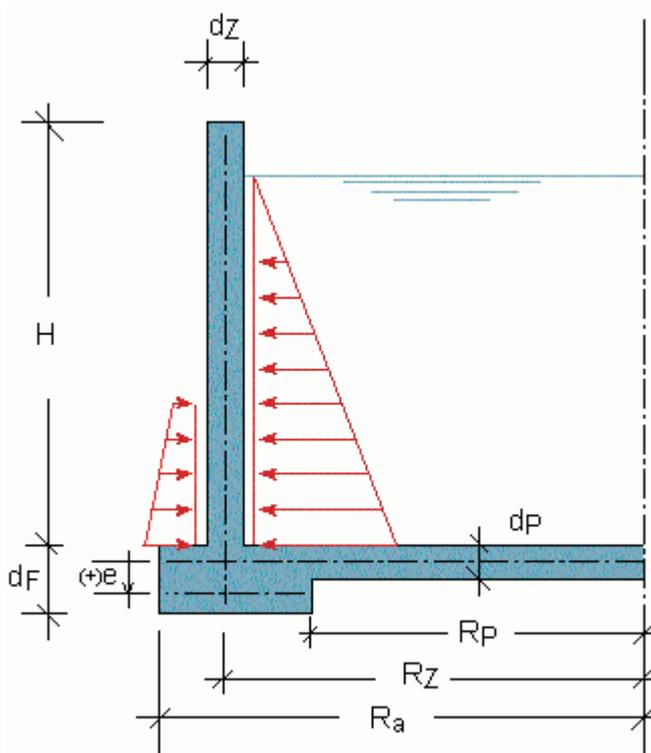
[Frilo.System.Next](#) Installation, configuration, network, database

Application options

The software allows the calculation of dynamically balanced tanks exposed to rotation-symmetric effects of actions.

Available standards:

- DIN EN 1992:2012/2015
- ÖNORM EN 1992:2011
- EN 1992:2010
- (DIN 1045 / DIN 1045-1)



- The wall thickness of the cylinder (tank) and the thicknesses of the foundation ring and the base slab are constant each.
- The supports of the cylinder walls must be inside the defined foundation ring. If you do not define a foundation ring and a base slab, only the cylinder is considered in combination with a vertically non-sway supporting system without foundation. The entered data concerning the geometry should be checked in the graphical representation of the structural system.
- The subgrade modulus is constant for the base slab and the foundation ring.
- Horizontal displacement and/or torsion of the cylinder head or base can be suppressed or coupled to the foundation.

Basis of calculation

The calculation is based on the method of exact solutions in accordance with the theory of elasticity for elastically supported circular slabs and circular cylinders. With the help of the corresponding displacement functions, stiffness matrices are produced for the slab and the cylinder that allow the application of the displacement method. We would like to draw your attention to some particularities of the bending function used in this software.

Elastically supported circular slab

Deflection w as a function of the dimensionless parameter $x = r/L$ is based on the following general equation: $w = C_1 \cdot be_r(x) + C_2 \cdot be_i(x) + C_3 \cdot ke_r(x) + C_4 \cdot ke_i(x) + q/c$.

The variables and constants are as follows:

- r** radius, i.e. distance of the considered point to the centre of the circular slab.
- L** elastic length of the slab (see below)
- C₁, C₂, C₃, C₄** are constants to map the border conditions.
- be_r, be_i, ke_r, ke_i** are the so-called Kelvin functions, i.e. special variants of the Bessel function ($r =$ real, $i =$ imaginary)
- q, c** area load and subgrade reaction modulus

For the application, the elastic length of the slab

$$L = \sqrt[4]{\frac{D}{C}} \quad \text{mit } D = \frac{E \cdot d^3}{12 \cdot (1 - \nu^2)} \quad (\text{with } E = \text{modulus of elasticity, } \nu = \text{Poisson's ratio})$$

is of importance. Increasing the x -argument causes the Kelvin functions to grow exponentially. This can cause numerical problems when L is much smaller than the slab radius. If the thickness d and the subgrade reaction modulus C assume realistic values no problems will occur.

Because users are always relatively uncertain about the subgrade reaction modulus, they often perform trial calculations with subgrade reaction moduli multiplied by 10, 100 or even 1,000. Rounding errors with very great values can distort the results completely. In most cases, the reason for numerical problems is that the user specifies the plate thickness d or the subgrade reaction modulus C in inappropriate dimensional units.

Circular cylinder

Deflection w as a function of the dimensionless parameter $x = r/L$ is based on the following general

$$\text{equation: } w = e^x \cdot C_1 \cdot \cos(x) + C_2 \cdot \sin(x) + e^{-x} \cdot C_3 \cdot \cos(x) + C_4 \cdot \sin(x) + \frac{q \cdot R}{E \cdot d}$$

The variables are as follows:

- z** height of the examined point
- R** radius of the cylinder
- E** modulus of elasticity

The following condition applies to the elastic length of the cylinder, which is of utmost importance also in this case:

$$L = \sqrt[4]{\frac{R^2 \cdot d^2}{3 \cdot (1 - \nu^2)}}$$

The elastic length L must not be considerably smaller than the height H of the cylinder if numerical problems should be avoided. In this calculation, problems are less likely to occur, however, because the subgrade reaction modulus is not considered. To date, no problems have been encountered in practice.

In this connection, you should note, however:

If the wall of the tank is very thin (e.g. steel tank) you can achieve a high accuracy by setting the constants C_1 and C_2 to zero and defining the remaining constants C_3 and C_4 exclusively via the border conditions at the base of the cylinder. Unfortunately, this approach is often used for reinforced concrete tanks too, because it facilitates the calculation extremely.

If the prerequisite of an infinitesimally small thickness in relation to the radius is not met, the calculation may produce extremely inaccurate results. Experience has shown that the results produced in this software can hardly be compared to the results obtained with other methods. It turned out that the reason for this was in most cases the inappropriate application of the approximation method described above. When comparing results, you should always make sure before that the theory underlying the calculation describes the construction sufficiently detailed.

Basic parameters

Standard

Select the desired standard – see also [Basis of Calculation](#).

Material

Depending on the selected standard, the following material properties can be defined in this section:

- Concrete qualities and reinforcing steel grades for the bottom slab, the foundation and the wall /cylinder
- Poisson's ratio ν in addition

Basic Settings	
Designcode	DIN EN 1992:2015
Material	
Bottom plate Bn	C20/25
Bottom plate BSt	B500A
Foundation Bn	C20/25
Foundation BSt	B500A
Wall Bn	C20/25
Wall BSt	B500A
Poisson's ratio	0,20
Durability	
Durability	XC1/XA3 XC2/X...

Durability

Attention: In the current version of this software, durability requirements are checked and adjusted in line with the specified concrete quality, the required concrete covers are simply indicated.

Access the dialog by activating the  button.

Durability can be ensured by complying with the required minimum concrete strength, the specified minimum concrete covers and the dimensional allowances as well as by setting additional parameters that result from the requirement class such as the permissible crack width.

See also the document [Durability, creep coefficient and shrinkage strain](#)).

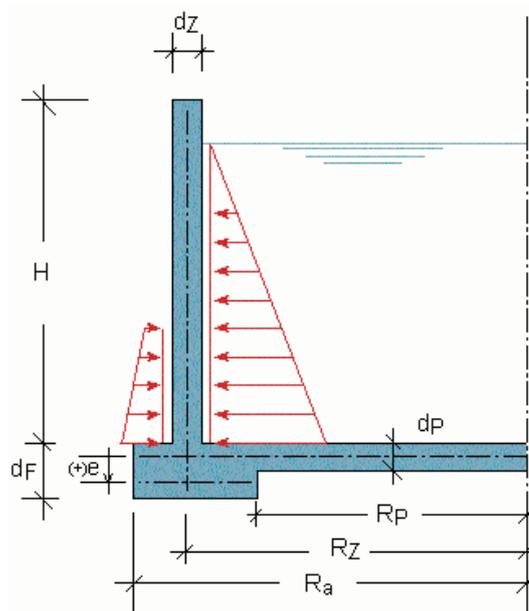
Definition of the structural system

The menu items referring to the structural system are accessible by double-clicking on the 'System' item in the [FDC Selection Area](#).

Geometry

If there is no bottom slab, enter *zero* for the plate thickness 'dP'. If there is no reinforced foundation strip you can set the foundation thickness 'dF' to *zero*. The cylinder height is measured from the slab axis. If the central lines of the foundation and of the bottom slab are at different height levels, the eccentricity is a positive value if the central line of the bottom slab is above that of the foundation. Check the plausibility of the selected dimensions in the system graph.

Bottom plate		
Dicke	dP [m]	0,30
Radius	RP [m]	4,70
Foundation		
Dicke	dP [m]	0,50
Radius	Ri [m]	4,70
Radius	Ra [m]	6,20
Cylinder		
Dicke	dZ [m]	0,40
Radius	RZ [m]	5,90
Height	H [m]	3,50
horizontal free	Kopf	<input checked="" type="checkbox"/>
Rotation free		<input checked="" type="checkbox"/>
horizontal free	Fuß	<input type="checkbox"/>
Rotation free		<input type="checkbox"/>
Input		
Eccentricity	e [m]	0,10
Bedding factor	C [kN/m ³]	000,00



Support conditions

The following support conditions are available for the cylinder base and top:

- horizontally free and
- free rotation

Subgrade reaction modulus

Specify the subgrade reaction modulus 'C' in [kN/m³].

Notes concerning the representation of the results

- Element division for slab, foundation and cylinder
- Design

→ See also the chapter [Output](#).

Reinforcement layers

Enter the reinforcement spacing (required concrete cover plus half of the reinforcement diameter).

In the design, you must check the reinforcement layers by considering the required concrete covers to ensure compliance with the durability requirements.

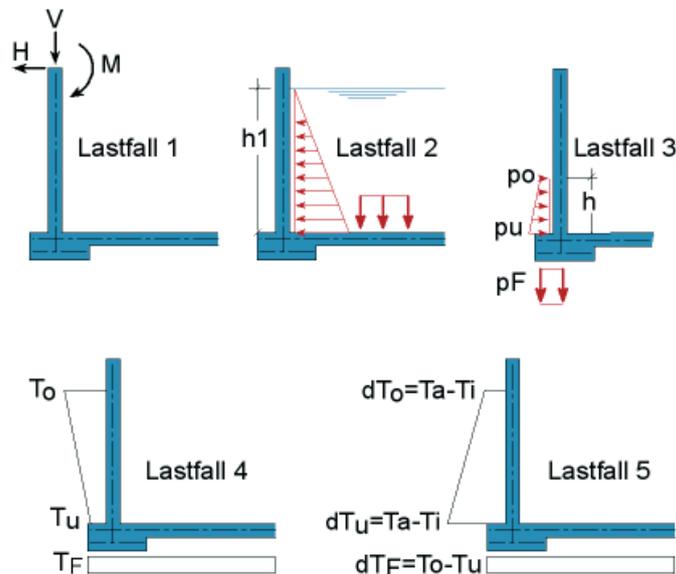
Bottom plate			
Ring inner	d	[cm]	3,00
Ring outer	d	[cm]	3,00
Radial top	d	[cm]	3,00
Radial bottom	d	[cm]	3,00
Foundation			
Ring inner	d	[cm]	3,00
Ring outer	d	[cm]	3,00
Radial top	d	[cm]	3,00
Radial bottom	d	[cm]	3,00
Cylinder			
Ring inner	d	[cm]	3,00
Ring outer	d	[cm]	3,00
Vertically inside	d	[cm]	3,00
Vertically outside	d	[cm]	3,00

Loads

The software calculates and combines the following load cases:

- Load case 1** self-weight + V, H and M at the cylinder top
- Load case 2** internal pressure due to the filling 'F'
Height h1 = filling height
Gamma F = Gamma of the filling
- Load case 3** external pressure
Height h, p top, p bottom, p foundation
- Load case 4** constant temperature
Height h, T top, T bottom, T foundation
- Load case 5** inconstant temperature
Height h, dT top, dT bottom, dT foundation

dead load + V,H and M on cylinder top		
gamma	g [kN/m3]	25,00
Actions Permanent loads		
Vertikal	V [kN/m]	10,00
Horizontal	H [kN/m]	5,00
Moment	M [kNm/m]	-2,00
Internal pressure due to filling F		
Height	h1 [m]	3,50
Actions Unusual live loads		
gamma	F [kN/m3]	11,00
Extern pressure		
Height	h	2,00
Actions Unusual live loads		
p top	[kN/m2]	14,30
p bottom	[kN/m2]	25,60
p foundation	[kN/m2]	30,00
regular temperature		
Height	h [m]	3,50
T top	[degree]	25,00
T bottom	[degree]	8,00
T foundation	[degree]	5,00
Irregular temperature		
Height	h [m]	3,50
T top	[degree]	25,00
T bottom	[degree]	8,00
T foundation	[degree]	5,00



Compliance with the following condition is imperative for the load height: load height > dz, otherwise, the load case will be disregarded.

Same temperature in the slab and the foundation (also in the projection).

For temperature load cases with a load height < hz, the internal forces 'N' in direction of the ring (continuous temperature) or 'M' in direction of the ring (inconstant temperature) are not constant. Therefore, two sections are put out for these load cases at the load height +/- 1 cm. Because of

organisational reasons, these sections cannot be considered in the superposition. If need be, these points of discontinuity must be checked in addition.

You can disable individual load cases by specifying a load height $h = 0$. These load cases are not considered in the calculation and are not put out.

You can simulate buoyancy via the internal pressure load case and the specification of a negative 'GammaF' value. You should do this in a separate calculation run, if possible. However, you should keep in mind that compression may only become negative in some points. Otherwise, highly falsified results will be obtained (the software assumes tensile springs in this case).

With inconstant temperatures, you should note that the signs of 'dT' inside the cylinder and of 'dT' in the bottom slab/foundation will be reversed under normal conditions (see the [load arrangement](#)).

For combinations as per EN 1990, you must specify the actions of the defined loads. The current superposition algorithm does not use the associated combination factors yet, however. To determine the design internal forces as per EN 1992, the load cases are merely combined with their partial safety factors ($\gamma_G = 1.35$ and $\gamma_Q = 1.50$), load case 1 includes only permanent actions, the remaining load cases include the variable actions such as internal/external pressure or temperature. You must specify the superpositions.

Superposition



These buttons allow you to add the current superposition. Activating the delete button will delete all superpositions.

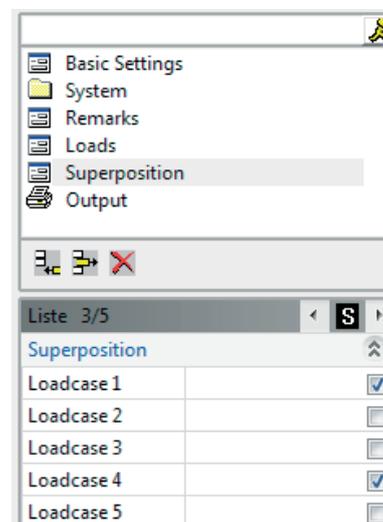
The number of existing superpositions and the currently active superposition are displayed in the form 'Lists n/m', n = currently active superposition, m = number of existing superpositions.

Activating the 'S' button displays the total list.

The arrow buttons (right/left) allow you to display the previous/next superposition.

To calculate the decisive design internal forces (m, n), the participating load cases must be checked in the desired load case superposition.

For the design as per EN 1992, the load cases are merely combined with their partial safety factors ($\gamma_G = 1.35$ and $\gamma_Q = 1.50$), load case 1 includes only permanent actions, the remaining load cases include the variable actions such as internal/external pressure or temperature.



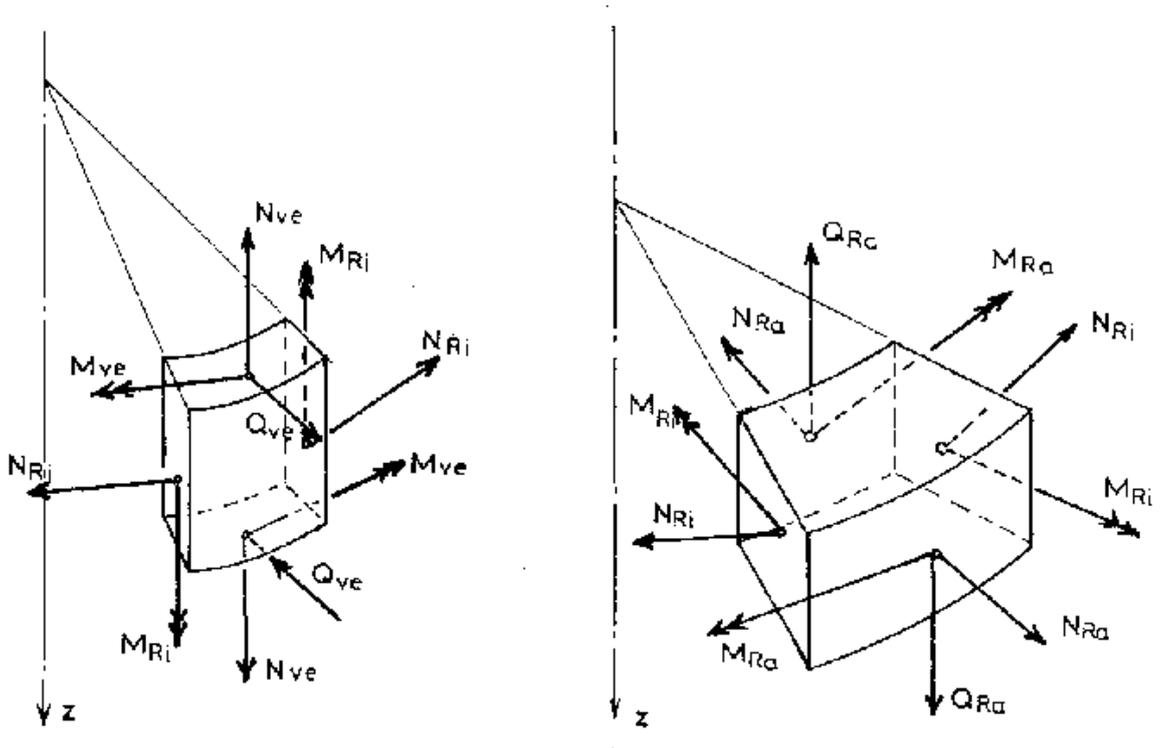


Fig.: Cylinder on the left, foundation/bottom slab on the right

Signs (as shown in the figure)

Axial forces N	tension is positive
Moments M	positive - generate tension on the outside or on the bottom
Shear forces Q	positive as shown in the figure
Torsion	positive, inwards rotation
Shift	positive, outwards displacement
Compression	positive, when the bottom is compressed; negative, when the component is lifted.

Attention: The z -coordinate for the description of the cylinder in the output is positive when the z -axis runs from the base to the top.

Output

Output of the system data, results and graphical representations on the screen or the printer.

Click on the corresponding button to launch the output.



- Word if installed on your computer, the text editor MS Word is launched and the data to be put out are transferred. You can edit them in Word as required.
- Screen displays the data in a text window on the screen
- Print starts the output on the printer

See also the document [Output and Printing - FDC](#)

See also 'Output using the [Frilo.Document.Designer](#)'.

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Project: Localization
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Actions:

No.	Cl Name	ψ0	ψ1	ψ2	γ
g	Permanent loads	1.00	1.00	1.00	1.35
L 5	Temperature (non-fire)	0.60	0.50	0.00	1.50
N 8	Unusual live loads	0.80	0.70	0.50	1.50

Dimensioning :DIN EN 1992-1-1/NA:2015-12
Minimum reinforcement in the cylinder acc.to EN2 9.5.2
reg. as = 3.0 cm2/m per page

Min. reinforcement in the foundation acc. to EN2 9.2.1.1 (9 1)
Min. moments fctm = 2.21 N/mm2
Mcr = 92.10 kNm/m erf as = 4.35 cm2/m

Min. reinforcement in the base plate acc. to EN2 9.2.1.1 (9 1)
Mcr = 33.16 kNm/m reg. as = 2.73 cm2/m

superposition: decisive for dimensioning is superposition no.

no.	l:	1	2
no. 1	l:	1	2
no. 2	l:	1	3
no. 3	l:	1	4
no. 4	l:	1	5
no. 5	l:	1	2 3 4 5

ground plate:

R (m)	radial direction				ring direction			
	Md (kNm/m)	Nd (kN/m)	as-ob (cm2/m)	as-un (cm2/m)	Md (kNm/m)	Nd (kN/m)	as-ob (cm2/m)	as-un (cm2/m)
0.00	-22.5	-43	2.7	0.0	-22.5	-43	2.7	0.0
0.47	-22.5	-43	2.7	0.0	-22.5	-43	2.7	0.0
0.94	-22.5	-43	2.7	0.0	-22.5	-43	2.7	0.0
1.41	-22.4	-43	2.7	0.0	-22.5	-43	2.7	0.0
1.88	-21.9	-43	2.7	0.0	-22.3	-43	2.7	0.0
2.35	-20.8	-43	2.7	0.0	-21.9	-43	2.7	0.0
2.82	-18.6	-43	2.7	0.0	-21.1	-43	2.7	0.0
3.29	12.1	-158	2.7	2.7	-19.7	-43	2.7	0.0
3.76	6.3	-104	2.7	2.7	-17.6	-43	2.7	0.0
4.23	10.6	-119	0.0	2.7	11.5	-158	2.7	2.7
4.70	19.6	-119	0.0	2.7	16.7	-158	2.7	2.7

foundation:

R (m)	radial direction				ring direction			
	Md (kNm/m)	Nd (kN/m)	as-ob (cm2/m)	as-un (cm2/m)	Md (kNm/m)	Nd (kN/m)	as-ob (cm2/m)	as-un (cm2/m)
4.70	25.6	-158	0.0	4.4	-55.1	204	7.6	4.4
4.85	10.8	-111	0.0	4.4	-52.2	197	7.5	4.4
5.00	14.1	-104	0.0	4.4	-49.3	190	7.4	4.4
5.15	17.8	-96	0.0	4.4	-46.4	184	7.3	4.4

Notes concerning the representation of the results

Element division for slab, foundation and cylinder

For the representation of the results, the components are divided into 10 elements. In the area where forces are directly transferred from the cylinder to the foundation, two cross-sections are verified which are at the left and the right of the force transfer point.

Design

The design as per EN 1992 is based on the 'kh' (kd) method and performed for each reinforcement side (bottom/top, inside/outside). If different combinations of internal forces are decisive for the resulting reinforcement (a_{s_in}/a_{s_out} or a_{s_top}/a_{s_bot}) at a specific design point, the internal forces of both combinations are indicated. The required minimum reinforcement in the components is displayed separately.