

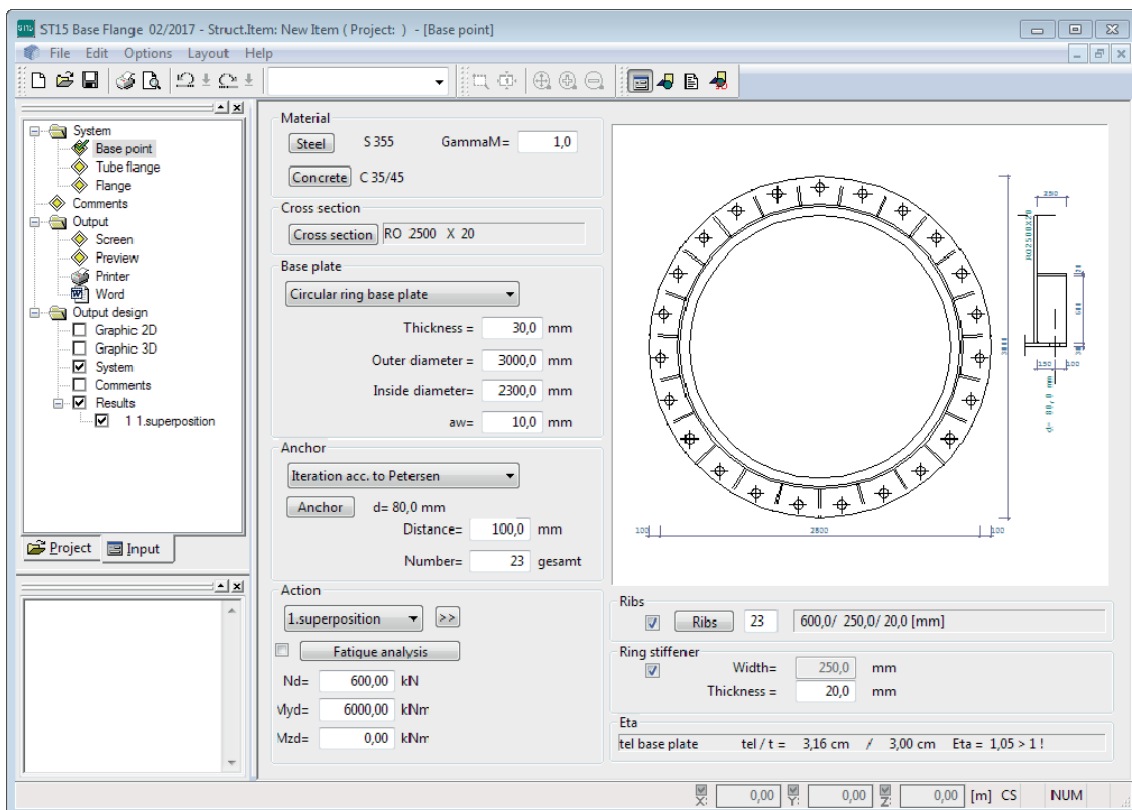
ST15 – Pipe Base & Flange

FRILO Software GmbH

www.friilo.com

info@friilo.eu

As of 23/06/2017



ST15 - Pipe Base & Flange

Contents

Application options	4
Basis of calculation	5
Settings for the calculation	7
Definition of the structural system	8
Steel	8
Shape selection	8
Pipe flange	9
Flange	11
Pipe base	12
Stiffeners	15
Annular stiffener	17
Jacket sheet	17
Tie rod (pipe base)	18
Superpositions for the pipe base	18
Service strength verification as per DIN 4133	19
Screws (pipe flange/flange)	19
Internal forces for the pipe flange connection	19
Output	20
Graphical representation	20
Reference literature	21

Further information and descriptions are available in the relevant documentations:

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 ST15 software is suitable for the calculation of pipe flange connections and pipe bases of annular components as well as single flange connections.

The design of the flange connections is performed in accordance with [1] Petersen Stahlbau, 2nd edition, p. 506 et seq. and p. 952 et seq.

The calculation is based on the analyses of the maximum tensile stress on the pipe and/or the tension plate.

Cross-section geometry

In the verifications of the pipe flange and base, only round pipes are considered.

Safety concept

The partial safety coefficient γ_M for steel can be edited; the internal forces, stresses (flange/pipe flange) and/or superpositions at the pipe base are entered with their γ_F -fold values.

In accordance with DIN 41337, Para. 7.1.1 The elastic limit internal forces may be increased by 10 % to take the higher load-bearing capacity in the plasticization state into account.

The utilization of plastic load-bearing capacities is not permissible.

The software application increases the permissible stresses by 10 % at this point, the static values (resistance moments) remain unaffected in the output.

Service strength verification as per DIN 4133

If the [service strength verification](#) is performed, the stress determined from the effects of actions is considered as an alternating stress and compared to the permissible values for the service strength.

$$\text{Max } \Delta\sigma \leq \Delta\sigma_R$$

The user can preset these values as a reference for the service strength.

$\Delta\sigma_A$ of the construction detail is determined in accordance with the notch class as per table 1 of DIN 4133 for screws, reinforcing steel, pipe base, flange, webs, pipe and annular stiffeners.

The factor n for the calculation of the service strength $\Delta\sigma_R$ is determined by the alternating stress values and the border conditions in accordance with DIN 4133, Annex B, Item 3 and should be preset.

$$\Delta\sigma_R = \Delta\sigma_A \cdot n \quad \text{eq. (B.3) DIN 4133}$$

For plate thicknesses $t > 25 \text{ mm}$, $\Delta\sigma_R$ can be reduced in accordance with DIN 4133, eq. (B.4) in DIN 4133.

Basis of calculation

1. Pipe base design

1.1 Anchor design

The design assumes unpretensioned anchors and can be based on the following methods.

1.1.1 Iteration in accordance with Petersen

Calculation of circular and annular base plates with bolt anchors as per reference [1] p. 960 with consideration of the equivalent bolt cross-section, that is determined by the relation of the moduli of elasticity of the anchor steel and the concrete.

The result of the iterative calculation is compressive edge stress and tensile edge stress.

The maximum tensile force of the anchor is calculated from the tensile edge stress.

1.1.2 Simple formula by Petersen

Calculation of the anchor forces as per reference [1], eq. 55, p. 957 and/or p. 963 (example)

r = radius of the bolt ring

1.1.3 Stahlbau Handbuch (Steel Construction Manual)

Determination of the anchor forces as per reference [2] eq. 39.9-19)

r = radius of the pipe

1.1.4 Design analogously to the reinforced concrete design

The design of the required steel surface is performed analogously to the design of reinforced concrete.

The anchor is not loaded with compression in this case.

1.2 Base plate design resulting from the anchor design

For the design of the base plate, the cantilever moment, which is calculated from the lever arm of the anchor distance and the maximum anchor force, is compared to the section modulus of the base plate.

A compression strip of the base plate with a width of 1 cm and the length of the base plate's projection is loaded with the calculated compressive concrete strain.

If there are stiffeners, the calculation is performed for a plate restrained between the stiffeners.

If the selected anchor verification only determines the tensile force acting on the anchor, the examination of the compression has to be performed separately.

The calculation of the base plate is performed in this simple way without considering carding moments or stiffness relationships between the pipe jacket and the base plate. This consideration would require an FEM calculation, which is currently not available for this type of model.

1.3 Stiffener design

The design of the stiffeners is performed in accordance with reference [3] p. 310 for a two-sided or, with annular stiffener, a three-sided stiffener. The loading is determined by the pipe tension and the spacing of the stiffeners.

1.4 Annular stiffener

The annular stiffener is calculated in accordance with reference [3] (36.9_1 to _17) p. 1091 et seq. If stiffeners were defined but not annular stiffener, the moment in the jacket sheeting and the interference tension in the circumferential direction are put out.

2. Flange design

The flange design is based on reference [1] p. 953 et seq., butt straps - butt flange joints, or p. 506 et seq., face plates and flange connectors.

Reference literature

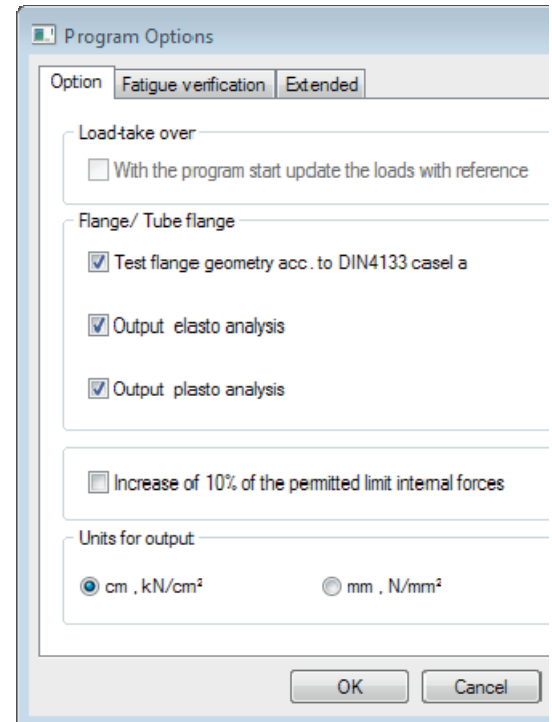
- [1] Petersen Stahlbau, second improved edition
- [2] Stahlbau Handbuch Band 2, second revised edition, Stahlbau-Verlagsgesellschaft 1985
- [3] Kahlmeyer

Settings for the calculation

Menu item Options >>Settings >>Options

The following options are available for selection:

- Check flange geometry in accordance with DIN 4133 case A
- Output options for the verifications
- Increase permissible limit internal forces by 10 %:
The limit stress is increased by 10 % in view of the available plastic reserves in accordance with DIN 4133 7.1.1.
- Select units to be put out.



Menu item 'Options >>Settings >>Service strength verification

Enter $\Delta\sigma_A$ for the service strength verification of the listed components (bolts, etc.)

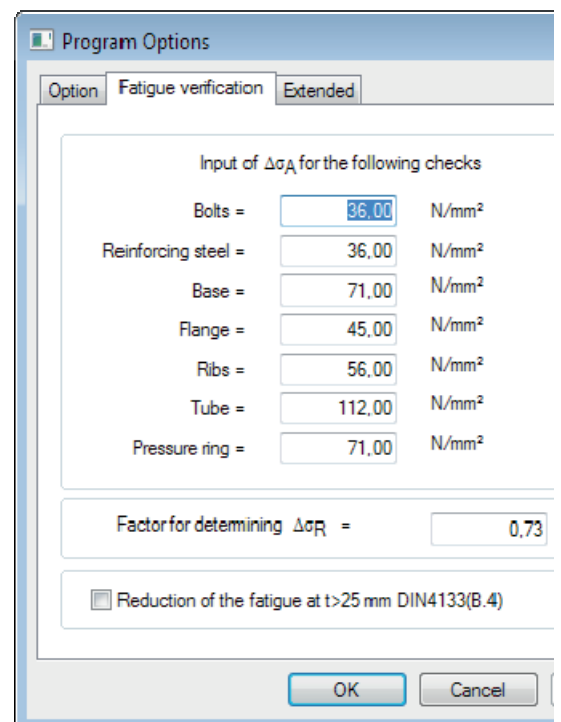
$\Delta\sigma_A$ is the reference value of the service strength in accordance with the notch class as per table B.1 in DIN 4133 (1991).

The service strength $\Delta\sigma_R$ is calculated with the reference value $\Delta\sigma_A$ specified by the user.

Also the factor n which is needed to determine $\Delta\sigma_R$ is specified by the user:

$\Delta\sigma_R = \Delta\sigma_A \cdot n$ as per Eq. (B.3) DIN 4133

For plate thicknesses $t > 25 \text{ mm}$, $\Delta\sigma_R$ can be reduced in accordance with eq. (B.4) in DIN 4133.



Definition of the structural system

Steel

When selecting a steel type (as per DIN 18800 and a steel grade as per DIN 4133, tables 1, 2, 3) from the list, the corresponding material parameters are set automatically. You can edit these values as desired.

For general structural steels, the permissible weld seam stresses are determined using **Alpha w**.

Values to define

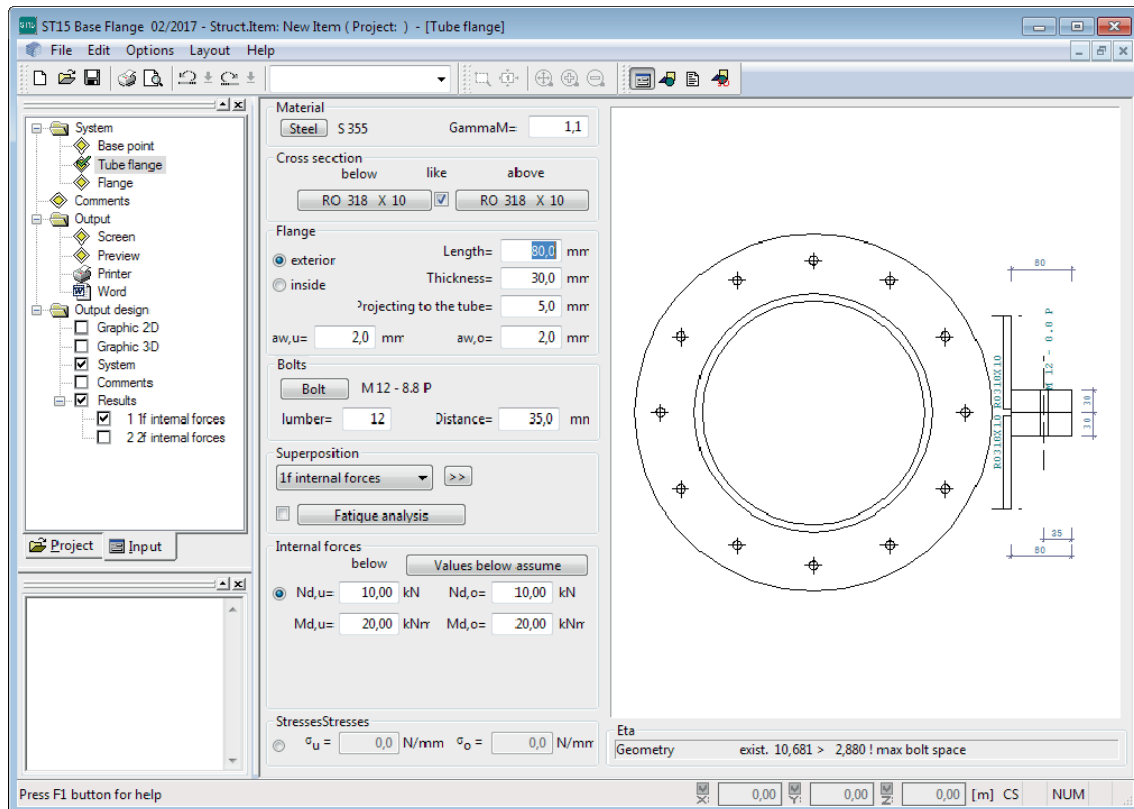
Operating temperature	the modulus of elasticity, f_{yk} and gamma depend on the operating temperature and are determined automatically.
Name	Code of the selected material. You can also edit this code.
Yield strength f_{yk}	characteristic value of the yield strength
Modulus of elasticity	characteristic value in [kN/cm ²] of the modulus of elasticity.
Alpha w	coefficient for the weld seam limit stress as per DIN 18800

Shape selection

You can either select the pipe shape from the Frilo profile selection file or specify user-defined dimensions.

General operating instructions for the Frilo profile selection file are available in the document [Select - edit cross section](#).

Pipe flange



Parameters to define

To define the connection, select the desired [Steel](#), specify γ_M (see [internal forces](#)), select the pipe shape ([Profile selection](#)) and define the flange via its dimensions.

The flange can be on the inside or the outside. It is defined via its minimum length, its thickness, the vertical projection as well as the weld seam thickness at the upper or the lower pipe cross-section.

The [screws](#) are distributed equally over the circumference, the distance to the outer edge of the flange is measured from the centre of the screw.

The software offers the possibility to handle several combinations of internal forces and/or stresses ([Internal forces for flanged pipe connections](#)).

Test minimum geometry:

You can verify the minimum geometry of the flange as per DIN 4133 , p. 22, case 'a':

- maximum distance to pipe jacket
- associated minimum distance to the outer edge of the flange
- minimum flange thickness
- minimum pipe thickness
- maximum screw diameter
- minimum screw diameter
- maximum screw spacing

Calculation

The design of the flange connections is performed in accordance with Petersen Stahlbau, 2nd edition, p. 506 et seq. or p. 952 et seq.

The calculation is based on the evaluation of the maximum tensile stress acting on the pipe. The screw spacing is used to determine the affected width c per screw.

The maximum tensile stress on the pipe is either specified by the user or calculated from the internal forces.

It is used to determine the forces in the tension spring = screw F_vS and in the compression spring F_vD for the existing tensile force Z . The existing tensile force is the maximum tensile stress in the pipe divided by the pipe thickness and the effective width c . The effective width is calculated with the help of the screw spacing referenced to the centre of gravity of the ring of screws.

For exterior flanges, the radius of the ring of screws r_s is assumed equal to the radius of the jacket centre line.

Flange spring:

The calculation is performed in accordance with Petersen [1] p. 508 9.7.4.3, 'Formeln für die Schrauben' and p. 510 'Flanschfedern.'

Calculated values:

- CS screw spring
- CD1 compression spring
- CD2 compression spring
- CD compression spring
- C total spring
- p distribution factor
- q distribution factor
- K torsion spring constant of jacket plate from rm or with L_s

(For the flange, the torsion spring constant K can also be determined via the length l_s of the tie rod, or via the average pipe diameter as for the pipe flange).

Flange force distribution:

The calculation is performed in accordance with Petersen [1] 'Kraftverteilung am Flansch' eq. 71 to 73 p. 508 or example on p. 955

- Calculation of the factors α , β , γ , δ , ε and the force F applying to the screw.

Elastic static analysis:

The calculation is based on the elastic static model by Petersen, 'Stahlbau', p. 510 and determines the moments on the flange and on the pipe (tension plate).

In this analysis, it is examined at which tensile force Z_{krit} the joint will gape. Pre-tensioning is considered.

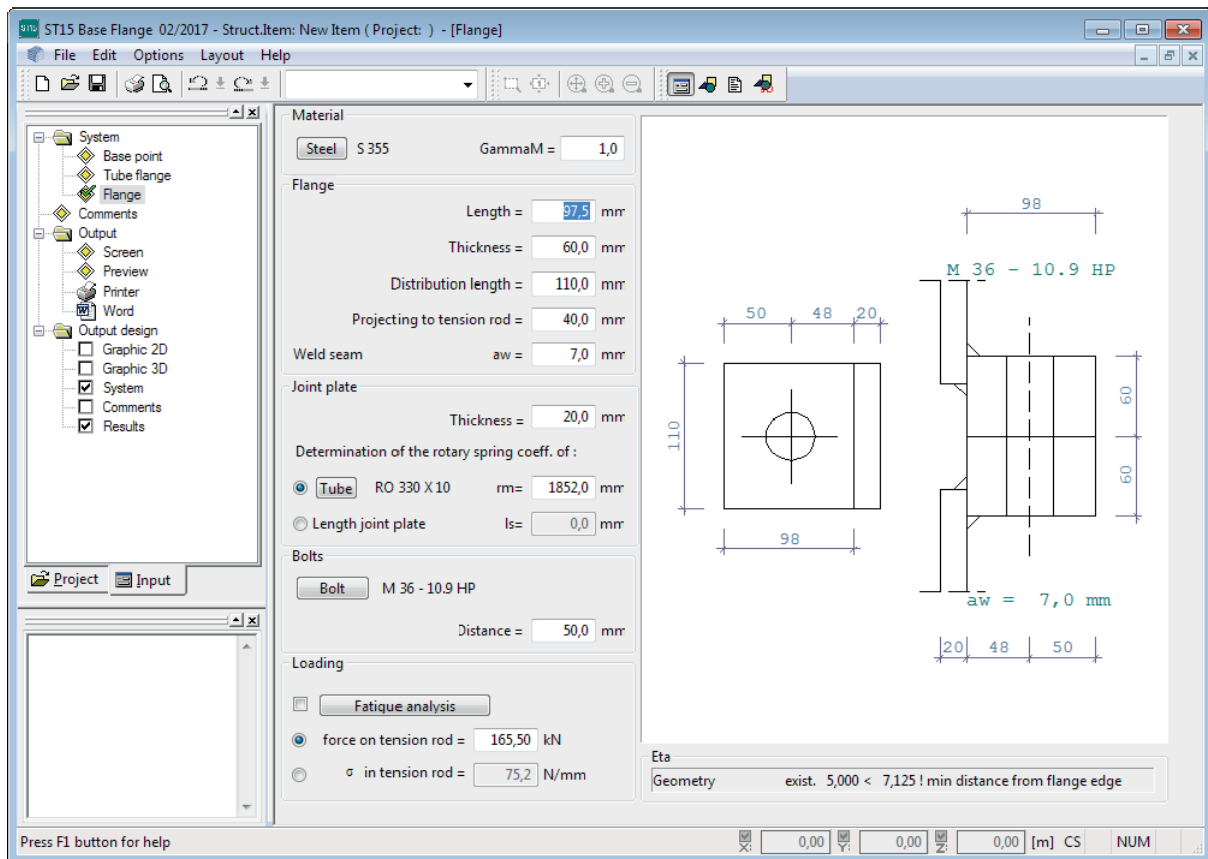
Plastic static analysis:

The calculation is based on the plastic static model by Petersen, 'Stahlbau', p. 511 and examines the three failure modes for the flange:

- failure mode A - screw failure
- failure mode B - plastic hinge, section 3, casing pipe
- failure mode C - plastic hinge, section 2, flange

If the option 'Increase permissible limit internal forces by 10 %' is enabled, the permissible resistance forces are increased by 10 % for the elastic static analysis; the plastic static analysis can be dispensed with.

Flange



Parameters to define

To define the connection, select the desired [Steel](#), specify γ_M (see [internal forces](#)) and define the flange and the tie member via their dimensions.

The flange is defined via its length, its thickness, the vertical projection at the tie member and the thickness of the weld seam. The user must specify the affected width c .

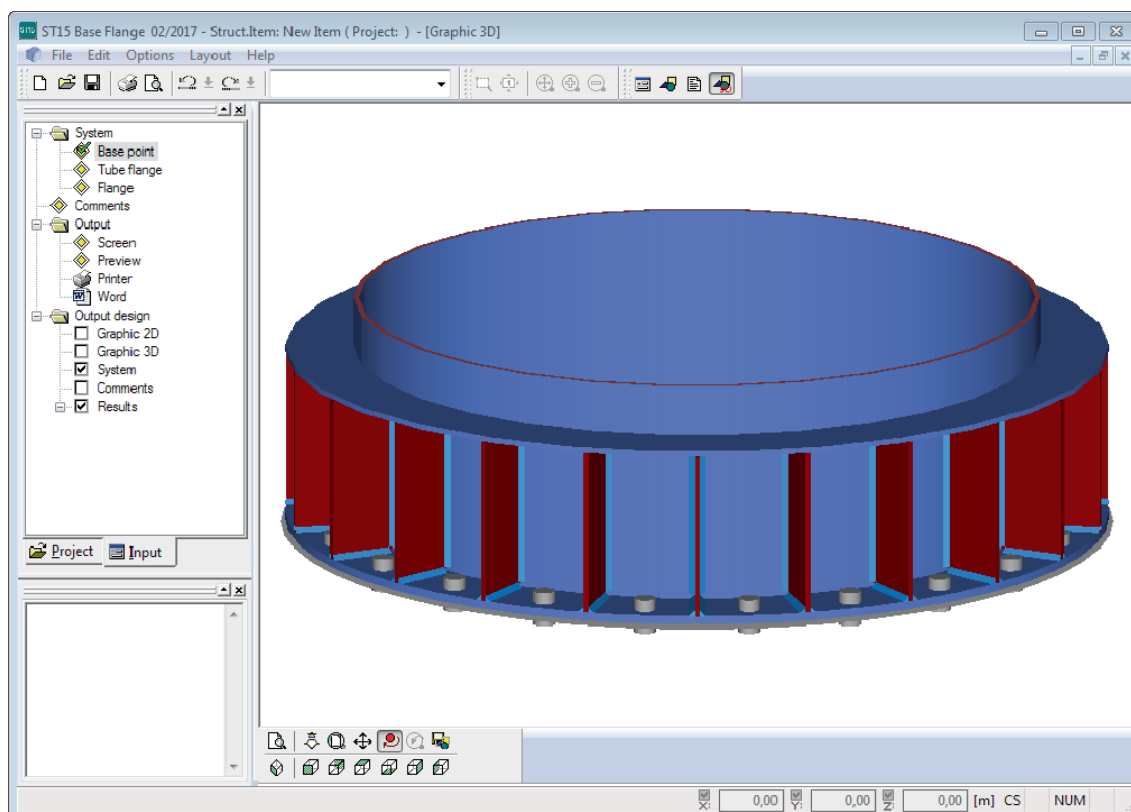
The distance of the [screw](#) is measured from the outer edge of the flange to the centre of the screw.

To define the loading, you can either specify a tensile force or the stress in the tie member.

The torsion spring constant K of the joint plate can be determined either via the mean pipe diameter (as with the pipe flange) or via the length l_s of the tie member.

The calculation is performed as described in the chapter [Pipe flange](#).

Pipe base



Parameters to define

To define the pipe base, select the desired [Steel](#), specify γ_M (see [internal forces](#)), select the concrete and the pipe shape ([Profile selection](#)) and define the base plate via its dimensions.

The pipe base can have as square, circular or annular base plate.

The weld seam between the pipe and the base plate is verified if no stiffeners are defined.

For the [tie rods](#), reinforcing steel, tee-head bolts or screws are available for selection.

The tie rods are distributed equally over the circumference, the distance to the outer edge of the flange is measured from the centre of the bar, bolt or screw. For square plates, specify the number of tie rods on one side; for other shapes, specify the total number of tie rods.

You have the possibility to handle multiple superpositions ([Superpositions for the pipe base](#)).

[Stiffeners](#) can have two sides or, in combination with a compression ring, three sides and are evenly distributed over the pipe cross section. Specify the number of stiffeners for the entire pipe.

The calculation of the loading on the stiffener is based on the stress distribution in the pipe per segment (load application area) of the stiffener.

Design of the tie rod at the base plate

You can select among four methods for the design of the tie rods on the base plate:

1. Calculation analogously to the design of reinforced concrete but without compression stresses applying to the steel, however.

The design is performed with the help of the FRILO Reinforcing Steel Design Library FLBemBn:

The design of the required steel surface (of the tie rods) is performed analogously to the design of reinforced concrete but without assuming any compression stresses acting on the steel.

The calculation is based on a reinforcement evenly distributed over the circumference of any base plate, no matter whether it is square, round or annular. For square base plates, this calculation method is used exclusively.

If reinforcing steel is selected for the tie rods, the values are determined in accordance with the reinforcing steel design library. If other types of tie rods are selected (screws), a maximum expansion of 5 per mil and the corresponding f_{yk} -value of strength are assigned.

(Gamma steel = 1.0, because γ is already included in f_{yk} - gamma reinforcing steel = 1.15)

Results of this calculation:

- the required total steel surface over the circumference as determined in the design
- the maximum stress acting on the steel
- the maximum concrete edge compression
- the surface of the compressive force
- the total compressive force
- the maximum tensile force per member
- the uniform compression on the concrete

2. Iteration in accordance with Petersen 'Stahl im Hochbau' [1]

The calculation is performed in accordance with Petersen 'Stahlbau' p. 960, para. 23.2.10.3, for anchors that are not pretensioned.

The equivalent screw cross-section t specified in table 23.3, case b is used in the calculation. It is determined by the difference between the moduli of elasticity of steel and concrete.

According to this table, design case 1, 2 or 3 applies; design case 2 (zero line inside the base plate opening) and 3 (zero line inside the annular ring) only occur with annular base plates.

Case 4 is a special case ($N = 0$).

Results of this calculation:

- the design case of the iteration
- the maximum tensile screw force determined by iteration
- the inclination angle of the neutral axis
- the maximum concrete compression
- die maximum tensile stress
- the equivalent screw cross-section
- the radius of the neutral axis run

3. Simple formula in accordance with Petersen 'Stahl im Hochbau' [1]

The maximum anchor tensile force is calculated using eq. 55 specified by Petersen.

$$F_s = N/n + 2/n \cdot M/r_s.$$

r_s = radius of the ring of screws

4. Calculation in accordance with 'Stahlbau Handbuch' [2] p. 1091 et seq.

The maximum tensile anchor force is calculated using eq. 55 specified by Petersen. 55

$$F_s = N/n + 2/n \cdot M/r_m.$$

r_m = mean pipe radius

If no stiffeners are defined, the flange moment is determined as per figure a, formula (36.7-9).

Calculation of the base plate

If no stiffeners are defined, the verification of the base plate is performed for a cantilever that is restrained at the pipe cross-section.

The loading consists of the uniform compression stress underneath the base plate and the maximum tensile force per anchor, which is distributed evenly over the affected width determined by the distance of the respective anchor.

If stiffeners are defined, the afore-mentioned loading is applied to a plate that is restrained on two sides by stiffeners.

If no loading by moments applies, the base plate is designed as a circular plate under uniform loading by axial force from the base plate area.

The **design of the base plate** is performed in accordance with the geometry of the pipe base:

With stiffeners:

Effects of actions on the outside of a plate restrained on two sides by stiffeners. The width of the plate corresponds to the stiffener thickness minus the snipe c and the length of the plate is the distance of the stiffeners in the screw axis.

Moment due to tension on the screw $M = Z / \text{width} \cdot \text{length} / 8$

Moment due to compressive stress $M = q \cdot \text{width} \cdot \text{length} / 12$

Without stiffeners:

The plate is calculated as a cantilever.

Moment due to tension on the screw: $M = Z / a / e$

a = distance of the screw from the pipe jacket

e = spacing of the screws referenced to the mean pipe diameter

Moment due to compressive stress: $M = q \cdot \text{cantilever}^2 / 2$

Loading by compressive force only:

Annular plate: Verification of the cantilever moment inwards, if the inwards oriented cantilever is greater.

No annulus: A circular plate enclosed by the pipe is calculated.

If stiffener have been defined or if a high cantilever moment occurs, the circular plate is calculated as being restrained, otherwise as being pinned.

Return values of the plate calculation:

- W_p resistance moment plastic
- W_e resistance moment elastic
- T_p plate thickness plastic
- T_e plate thickness elastic
- Moment due to compression (contact surface force for plate design)
- Moment due to tension (tensile force on the screw)
- span width of the plate restrained on two sides between stiffeners
- annular plate, inwards oriented cantilever
- M_f maximum span moment if only compression applies
- M_f maximum support moment if only compression applies
- maximum moment

Stiffeners

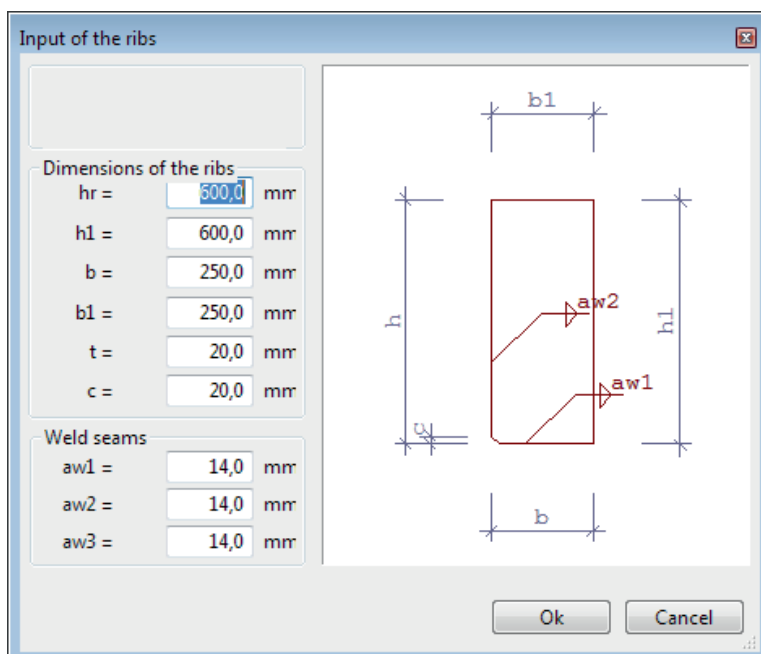
Stiffeners are evenly distributed over the pipe cross-section; the number of stiffeners corresponds to that of the tie rods or to half the number of stiffeners on the pipe.

The calculation of the loading on the stiffener is based on the stress distribution in the pipe per segment (loaded area) of the stiffener.

The design of the stiffeners is based on Kahlmeyer, 'Stahlbau nach DIN 18800' (11.9), para. 8, p. 308.

The maximally possible stiffener width is determined by the geometry of the pipe upstream and the base plate or the width of the compression ring. The stiffeners are designed as two-sided or, if a ring stiffener exists, as three-sided stiffeners.

F_1 is the load per stiffener (see also Petersen p. 550)



Results

- required thickness
- tension in the stiffener
- maximum weld seam stress

Two-sided stiffener:

- F2 force
- e1 lever arm
- e2 lever arm
- Aw1 associated weld seam surfaces
- Aw2 associated weld seam surfaces
- sigmaVw1 weld seam stress, equivalent stress
- sigmaVw2 weld seam stress, equivalent stress

Three-sided stiffener:

- F2 force
- e1 lever arm
- e2 lever arm
- Aw1 associated weld seam surfaces
- Aw2 associated weld seam surfaces
- Aw3 associated weld seam surfaces
- sigmaVw1 weld seam stress, equivalent stress
- tauw2 weld seam stress
- tauw3 weld seam stress

Force distribution on the stiffeners (example of a two-sided stiffener)

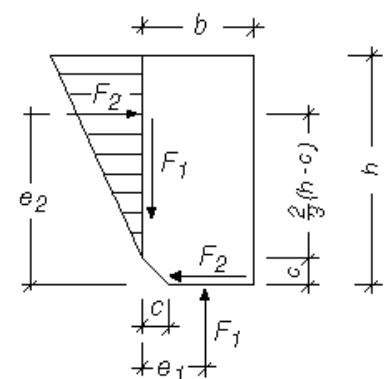
h - stiffener height

b - stiffener width

c - snipe on the stiffener where it meets the pipe or the base plate

The transfer of the forces to the stiffeners is based on the following assumptions:

- Even distribution of the applying vertical force F_1 over the length $(b - c)$.
- Therefore, the application point of the vertical force has the distance $e_1 = c) / 2$ to the pipe.
- The resulting moment $M = F_1 \cdot e_1$ is compensated by the force F_2 acting in the opposite direction.
- Triangular compression distribution in the area $(h - c)$ with the lever arm $e_2 = (2 \cdot h + c) / 3$



Annular stiffener

The **verification of the annular stiffener** is based on 'Stahlbau Handbuch'. P.1091 et seq.

The forces applying to the stiffener and to the annular stiffener are determined for the symmetric case and the antisymmetric case.

The verification of the annular stiffener is performed for the resulting bending moment.

Results

- Force applying to the stiffener along the pipe jacket, symmetric case, p. 1091 (36.9-3)
- Auxiliary quantity k , symmetric case, p. 1091 (36.9-5)
- Force applying to the stiffener along the pipe jacket, antisymmetric case, p. 1092 (36.9-7)
- Auxiliary quantity k , antisymmetric case, p. 1092 (36.9-9)
- Force applying to the stiffener in the compression ring, symmetric case, only N , p.1091 (36.9-4)
- Bending moment in the upper annular stiffener, symmetric case, p. 1092 (36.9-10)
- Force applying to the stiffener in the compression ring, antisymmetric case, p.1091 (36.9-8)
- Bending moment in the upper annular stiffener, antisymmetric case, p. 1092 (36.9-10)
- Section modulus annular stiffener
- Stress applying to the annular stiffener

Jacket sheet

Verification in accordance with 'Stahlbau Handbuch 2' with stiffeners and without annular stiffener

The structurally supporting width of the jacket sheeting and the interfering stress in the circumferential direction of the pipe jacket (p. 1092 (36.9-16)) are determined.

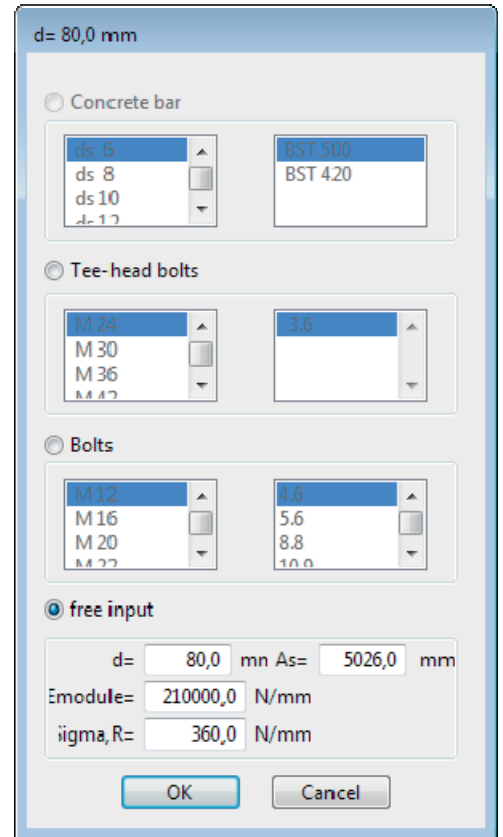
Results

- Force applying to the stiffener along the pipe jacket, symmetric case, p. 1091 (36.9-3)
- Auxiliary quantity k , symmetric case, p. 1091 (36.9-5)
- Force applying to the stiffener along the pipe jacket, antisymmetric case, p. 1092 (36.9-7)
- Auxiliary quantity k , antisymmetric case, p. 1092 (36.9-9)
- Auxiliary value b^* p. 1092 (36.9-9)
- Auxiliary value ζ (zeta) p. 1092 (36.9-12)
- Auxiliary value η (eta) p. 1092 (36.9-13)
- Structurally supporting width of the jacket sheeting B , p. 1092 (36.9-15)
- Moment on the pipe jacket, symmetric case, p. 1092 (36.9-16)
- Moment on the pipe jacket, antisymmetric case, p. 1092 (36.9-16)
- Interfering stress in circumferential direction, p. 1092 (36.9-17)

Tie rod (pipe base)

This window allows you to select the tie rods on the base plate.

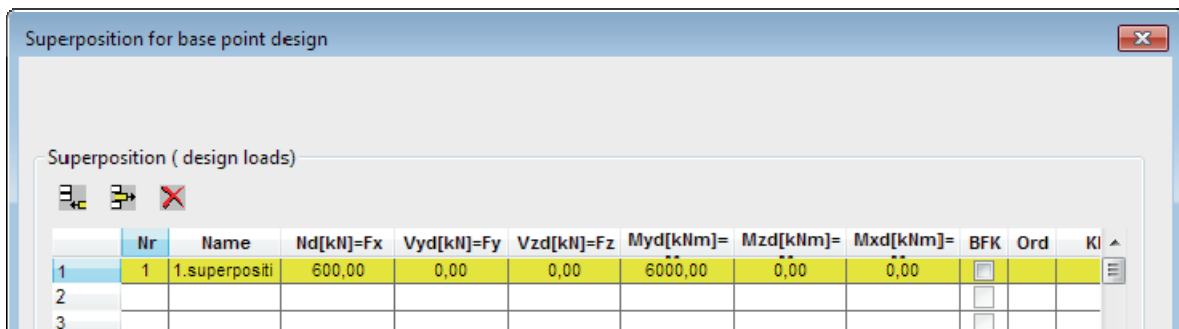
You can select among reinforcing steel, tee-head bolts, screws or specify user-defined dimensions and strength values for the tie rod.



Superpositions for the pipe base

This window allows you to handle multiple [superpositions](#) for the pipe base.

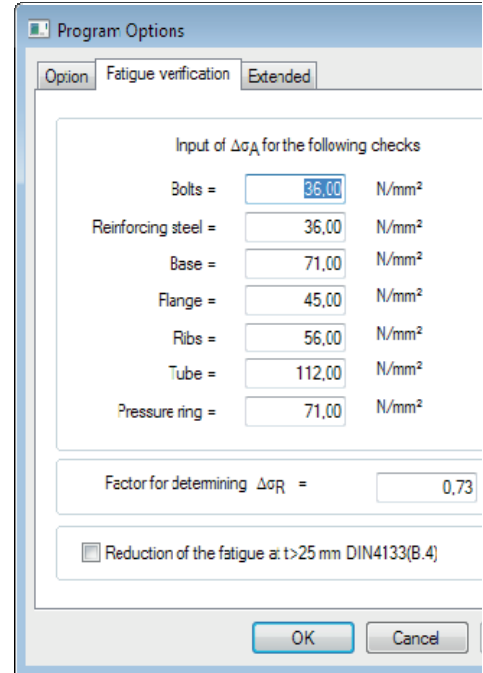
By checking the 'BFK' option, the data to be entered for the service strength verification are determined ([Service strength verification as per DIN 4133](#)), i.e. the stresses resulting from the Md and Nd values are compared to the service strength.



Service strength verification as per DIN 4133

Set the parameters for the service strength verification in the dialog >>Optionen >>Settings >>Service strength verification.

See also the chapter, settings for the calculation:
[Service strength verification as per DIN 4133](#)



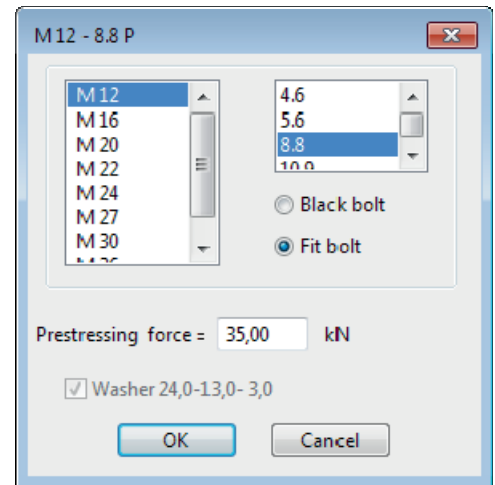
Screws (pipe flange/flange)

This window allows you to select the screws for the flange.

You can select the size, strength and pre-tensioning force for the screw.

For further information, refer to the chapters [Flange](#) / [Pipe flange](#).

The screws must be pre-tensioned for the flange connection to avoid a gapping joint.



Internal forces for the pipe flange connection

No	Name	Nd,u[kN]	Md,u[kNm]	Vd,u[kN]	Mxd,u[kNm]	Sigd,u[N/mm²]	Nd,o[kN]	Md,o[kNm]	Vd,o[kN]	Mxd,o[kNm]	Sigd,o[N/mm²]	SSA	Sigma
1	1f internal force	10,00	20,00	0,00	0,00	26,67	10,00	20,00	0,00	0,00	26,67	<input type="checkbox"/>	<input type="checkbox"/>
2	2f internal force	20,00	30,00	0,00	0,00	39,49	20,00	30,00	0,00	0,00	39,49	<input type="checkbox"/>	<input type="checkbox"/>
3												<input type="checkbox"/>	<input type="checkbox"/>

This window allows you to handle multiple [internal forces](#) or stress combinations for the pipe flange.

If you check the sigma option (Sig), you can define stress parameters. If you leave the option unchecked, the data-entry fields for the internal forces are enabled.

By checking the BFK options, the data to be entered for the service strength verification are determined ([Service strength verification as per DIN 4133](#))

Output

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

The 'Output' option in the main menu allows you to start the output on a printer or the screen. In some program versions, you will be required to enable the output functions by activating the 'Output' tab.

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


Output on the screen (text window)

The following options are available to access the text window:

- click on the text window icon 
- click on the menu item: Window → Output on the screen

In the text output on the screen all available data are displayed (system, loads, results) independent of the selected output scope.

Printing of the output on the screen

If the text window is active (e.g. by clicking in the window) you can print the contents by clicking on the printer icon  in the upper tool bar. Print options are also available via the context menu of the right mouse button.

Graphical representation

You can display the structural system in the graphic window.

The following options are available to access the graphic window:

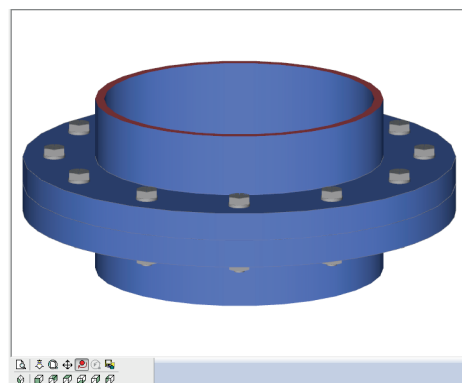


Click on the graphic window icon

You can print the displayed graphic by clicking on the printer icon in the upper toolbar.



Representation of the system in a 3-d graphic.



Reference literature

- [1] Petersen Stahlbau, second improved edition
- [2] Stahlbau Handbuch Band 2, second revised edition 1985
- [3] Kahlmeyer Stahlbau nach DIN 18800(11.9)