tnxFoundation

Version 1.0 General Reference

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March 29, 2024

Contents

Overview

Introduction

tnxFoundation is a standalone Windows application for foundation analysis and design.

Key features include:

- Multiple foundation types
    - Pad and Pier
    - Pad
    - Caisson
    - Pad with Piles
    - Pad and Pier with Piles
    - Mat and Piers
    - Mat
    - Mat with Piles
    - Mat and Piers with Piles
- Material and geometry type definitions
- Soil layer definitions
- Multiple load combinations and load cases
- Design parameter selection
- Foundation stability verification
- Foundation geometry optimization
- Required reinforcement determination
- Reports with calculation results

Licensing

tnxFoundation software is licensed as a subscription on a yearly renewal basis.

Access to the software is controlled by an Internet license server. The user has the option of checking out the license for a specified length of time. In such a case, the license is transferred to the user's workstation for the duration of the checkout, and no Internet access is required for the program to operate.

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5. MAINTENANCE AND SUPPORT. Tower shall provide You with maintenance and support services ("**Support**") as part of your paid Subscription. Support consists of patches and upgrades for the SOFTWARE as they are released to Our customer base and response to service inquiries and problem reports within a reasonable time by telephone, email or fax.

6. PROTECTION; PRIVACY. We use a third party Internet service (the "**Authorization Vendor**") to manage Your use of the SOFTWARE so that it does not exceed the scope of rights You have purchased.

6.1 *Disclosing All Usage*. You are specifically prohibited from attempting to bypass these Internet controls by any means. If these controls become broken or inoperable, or if You defeat or tamper with them, You will fully disclose to Tower all actual usage of the SOFTWARE by You and Your Users and will permit Tower or its designee to physically inspect the sites and systems where You use the SOFTWARE to audit and correctly compute Your actual usage and to charge You for it at Our highest applicable fee schedule.

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7.1. *Fees.* Upon execution of this AGREEMENT, You shall pay the Annual Subscription Fee (as quoted by Us in writing) for the Initial Term. If You wish to renew Your Subscription, You shall pay additional Annual Subscription Fees (as quoted by Us in writing) per annual Renewal Term, which amount may be increased by Tower at any time upon at least sixty (60) days advanced notice. Should You fail to pay Your Annual Subscription Fee prior to the termination of the then current annual term, the Subscription shall expire at the end of the then current term, unless earlier terminated. Any fees or other amounts due and payable hereunder which are not paid on or before each due date will bear interest at the rate of one percent (1%) per month (or the highest rate permitted by applicable law, if less). You are responsible and liable for any fees, including reasonable attorney and collection fees, that Tower may incur in its efforts to collect any remaining overdue balances from You.

7.2. *Invoicing and Payment*. All fees shall be due and payable within thirty (30) days of receipt of Tower's invoice. You are responsible for providing complete and accurate billing and contact information to Tower and notifying Tower of any changes.

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7.5. *Future Functionality*. You agree that Your purchases are not contingent on the delivery of any future functionality or features, or dependent on any oral or written public comments made by Tower regarding future functionality or features.

8. TERMINATION. This AGREEMENT commences on the Effective Date and continues until the Subscription has expired or has been terminated in accordance with the terms hereof.

8.1. Tower may terminate Your Subscription and right to use the SOFTWARE if You fail to comply with any terms or conditions of this AGREEMENT and fail to correct such failure within ten (10) days of notice from Tower. In such event You must delete and destroy any copies of the SOFTWARE in Your possession or control and promptly return the associated documentation to Tower.

8.2. You may also elect to terminate Your Subscription at any time, by notice thereof to Tower. In neither case 8.1 or 8.2 will You be entitled to a refund.

8.3. Tower may terminate Your Subscription at any time, in its sole discretion. If such termination is not due to Your breach or misconduct, Tower will refund a portion of the Subscription fee paid by You, prorated for the period that follows termination.

9. EXPORT CONTROLS. You agree to comply with all export and import laws and restrictions and regulations of the United States or any foreign nation, and not to export, re-export or import the SOFTWARE in violation of any such restrictions, laws or regulations.

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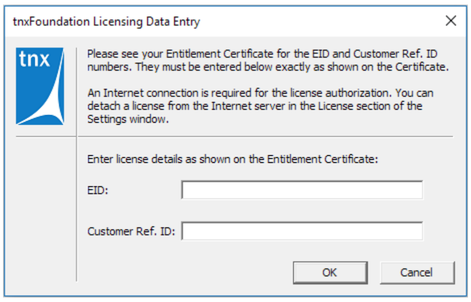
Configuring tnxFoundation

When the program starts for the first time, you will need to enter license entitlement information. This information is normally included in the Entitlement Certificate email that you will receive from TNX.

Licensing Data Entry



Entitlement ID and Customer Ref. ID

Enter the EID number from the Entitlement Certificate. The EID number uniquely identifies your entitlement. The entitlement may include a license for one or multiple concurrent users. If the program is installed on multiple PCs within your organization, the same EID will be used in all instances.

Enter the Customer Ref. ID from the Entitlement Certificate.

Important: The EID and Customer Ref. ID numbers must be entered exactly as printed out in the Entitlement Certificate.

User Interface

Menu Bar

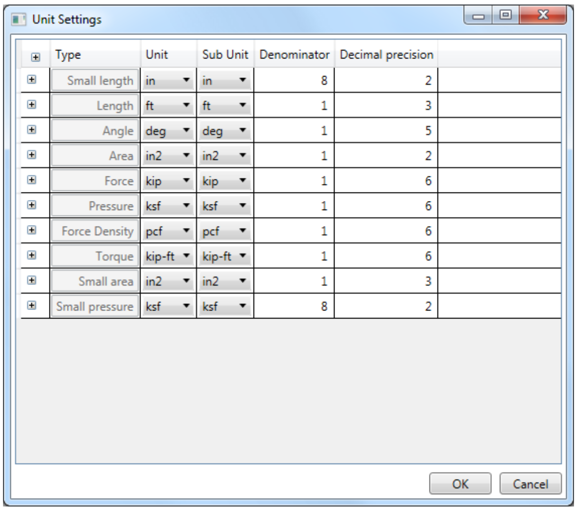
File

- **New** – Opens the initial application window with the New Project tab active. The user can choose to start a new project or open an existing project by selecting the appropriate tab.
- **Open** – Opens the initial application window with the Open Existing Project tab active. The user can choose to start a new project or open an existing project by selecting the appropriate tab.
- **Close** – Closes the current project. The user will be prompted to save the project if there are unsaved changes.
- **Save** – Saves the current project file. If the file has not been previously saved, a dialog will prompt for the file name.
- **Save A**s – Saves the current project file, always prompting for a file name.
- **Exit** – Exits the program.

Settings

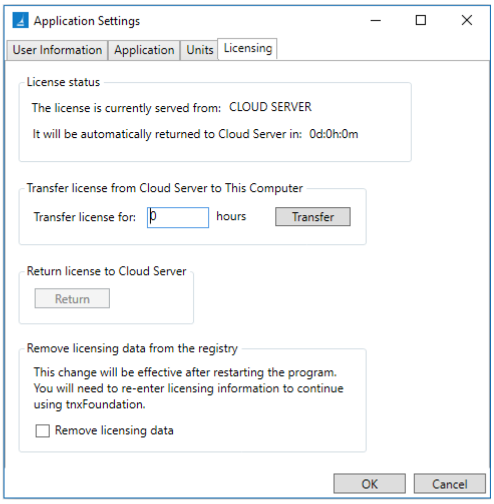
- **Application Settings –** Opens the Application Settings window with three tabs.
  - **User Information –** This tab is used to define user information data to be used in the documentation header.
  - **Application –** This tab is used to define default project and database file locations. The database directory is the directory in which the program will search database files in the first instance.
  - **Units –** This tab is used to set the units used within the program.
    - **Database system of units –** Sets the units to either US Customary or Metric. This setting changes both the interface and database units.
    - **Numerical data format** – For US Customary units you can select the numerical data format to be Architectural or Decimal notation. If Architectural notation is selected, length units are displayed in feet and inches.

- **Unit Settings –** Opens the Unit Settings window allowing the user to determine what type of units to use and how many decimal places (precision) to use.



Type	Unit	Sub Unit	Denominator	Decimal precision
Small length	in	in	8	2
Length	ft	ft	1	3
Angle	deg	deg	1	5
Area	in2	in2	1	2
Force	kip	kip	1	6
Pressure	ksf	ksf	1	6
Force Density	pcf	pcf	1	6
Torque	kip-ft	kip-ft	1	6
Small area	in2	in2	1	3
Small pressure	ksf	ksf	8	2

- **Licensing**



On the Licensing page the user can manage the authorization mode for the software and reset the license data.

License status. The program requires a license to run. It obtains this license when it starts, and then periodically checks the license status during its execution. The license can be served from either the TNX Cloud Server, or from the local machine.

By default, all licenses for all users are obtained from the Cloud Server. tnxTower operating in this mode requires that an Internet connection be available.

The user may transfer the license to the local machine for a specified length of time. After the license is transferred it is served from the user's machine and no Internet connection is required to facilitate it. The license can be transferred back to the Cloud Server at any time.

Once the time for which the license was transferred to the local machine elapses, the license expires on the local machine and becomes available on the Cloud Server. If at that point the machine using the license has a running instance of tnxTower, it will automatically switch to the Cloud Server licensing mode. Otherwise, the license becomes available to any machine using the associated license entitlement.

The currently active license server is indicated in the "The license is currently served from:" field as CLOUD SERVER or THIS COMPUTER.

If the license is currently served from the local machine, the remaining time until it expires is shown.

Transfer license from the Cloud Server to This Computer. Enter the number of hours for the license checkout period and press the Transfer License button. Once the license is transferred to the local machine, it will be consumed from the local server. No Internet connectivity will be required until the expiration of the license checkout.

This option is inactive (grayed out) if the license is currently served from the local machine.

Return License to the Cloud Server. Click the Return License button to switch to the Cloud Server licensing mode. This operation requires that the machine is connected to the Internet. Once the Cloud Server mode is established, the program will immediately consume a license from the Cloud Server.

This option is inactive (grayed out) if the license is currently served from the Cloud Server.

Remove licensing data from the Registry. The license entitlement details are entered once and stored in the Windows Registry. The Registry records are used by tnxTower to get the licensing parameters each time the program starts. If you wish to discontinue using your current license entitlement and/or to switch to a different one, select this checkbox.

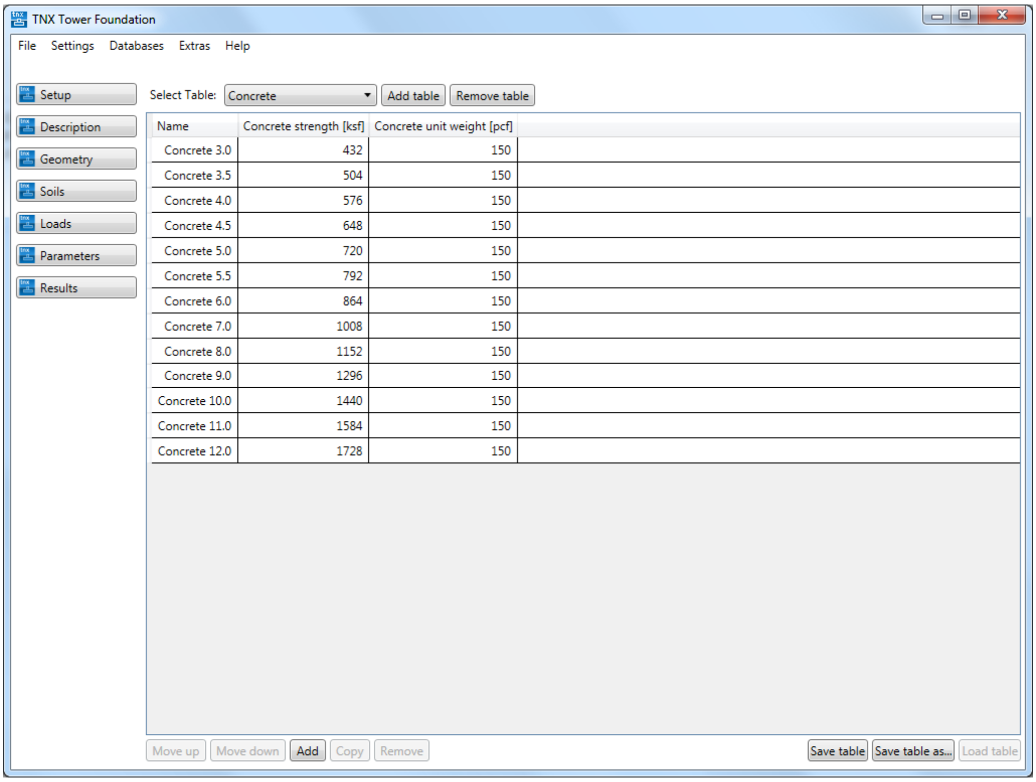
This option is inactive (grayed out) if the license is currently served from the local machine.

Databases

There are four database types available to edit:

- **Concrete**
- **Soil**
- **Steel**
- **Steel Pile**

Tables may be added or removed from the database types. Rows may be added, copied or removed from each table. Once edits are completed for a table, they can be saved using the **Save table** or **Save table as** buttons in the lower right corner of the window. The current table for each database type will be used to populate the applicable drop down lists.



Extras - Anchor analysis

Opens a window for conducting the analysis of post-installed anchors.

New Project/Open Existing Project

In the initial application window, the user can choose to start a new project or open an existing project by selecting the appropriate tab.

New Project

The New Project tab gives the user two choices to start a project:

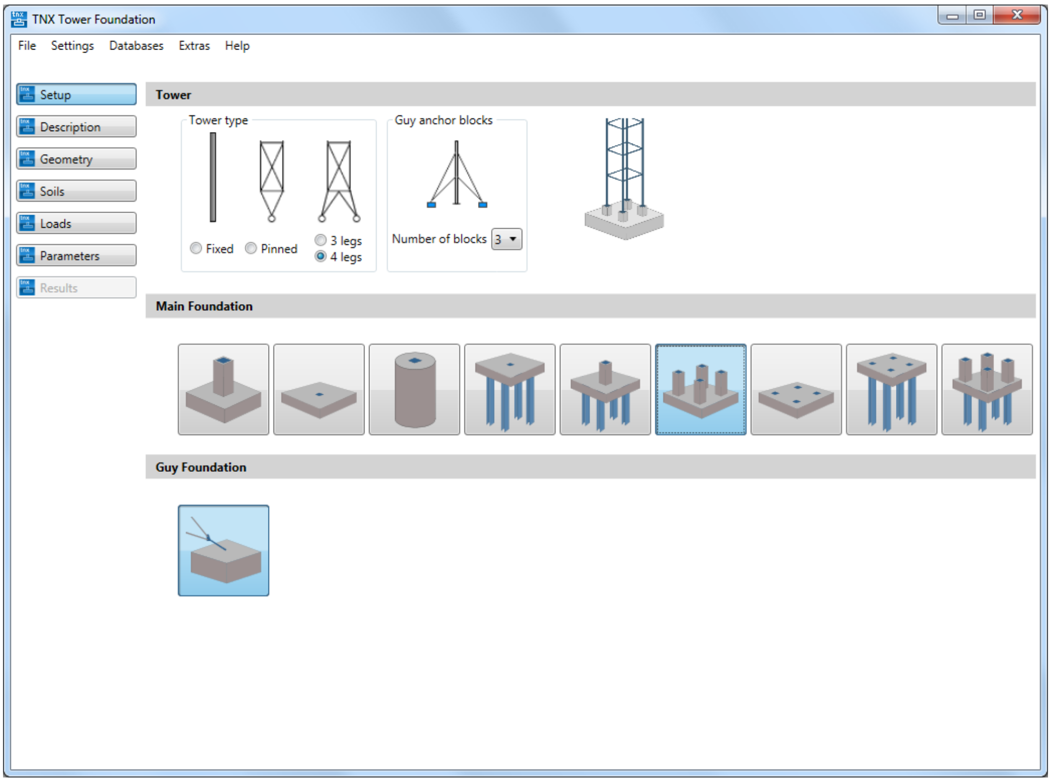
- **Create New Project – Create New Project** will start a new project where the user will enter all of the data manually.
- **Open – Open** will allow the user to import the data from a tnxTower analysis into the project. The data import will automatically fill out the **Tower type** and **Guy anchor blocks** sections in the **Setup** window.

Open Existing Project

The **Open Existing Project** tab allows the user to select a recent project file and open it.

Setup

In this window, the user can define the tower type, quantity of guy anchor blocks and foundation type.



Tower type

This section allows the user to select the tower type. If the data has been imported from a tnxTower analysis, the tower type will be automatically set. Otherwise, all tower types will be available. The foundation types available in the **Main Foundation** section will vary based on the tower type.

Tower types:

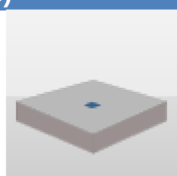
- Fixed – monopole
- Pinned – monopole or tapered lattice tower
- 3 Legs – lattice tower with 3 legs
- 4 Legs – lattice tower with 4 legs

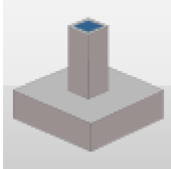
Guy Anchor Blocks

This section allows the user to select the number of guy anchor blocks. If the data has been imported from a txnTower analysis, the quantity will be automatically set. Otherwise, all quantities will be available. An additional **Setup** section, **Guy Foundation**, will be visible if the quantity of guy anchor blocks is greater than 0.

Main Foundation/Guy Foundation

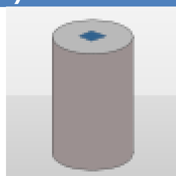
In this section, the user can select the foundation type for the tower. Each foundation type contains different data ranges and calculation types. These data ranges and calculations have been broken out in the table below.

Pad, Pad and Pier	Icon(s)
Geometry • one support point • square in plan • pier definition [Pad and Pier]	

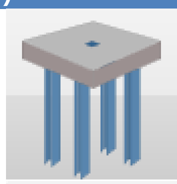
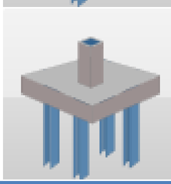


Calculations

- soil bearing
- sliding
- uplift
- overturning
- reinforcement check:
  - ➢ pad one-way shear verification
  - ➢ pad punching shear verification
  - ➢ pad flexural reinforcement verification
  - ➢ pad flexural reinforcement development length verification
  - ➢ pier shear verification [Pad and Pier]
  - ➢ pier flexural verification [Pad and Pier]
- geometry optimization (pad width and depth resizing)

Caisson	Icon(s)
Geometry • one support point • round section shape • two caisson shape types: straight and bell	

Calculations
• uplift
• compression
• lateral verification
  ➢ Broms' method
  ➢ p-y method
• reinforcement check:
  ➢ caisson flexural reinforcement verification
• geometry optimization (caisson diameter and length resizing)	

Pad with Piles, Pad and Pier with Piles	Icon(s)
Geometry • one support point • square in plan • definition of number and types of steel piles • pier definition [Pad and Pier with Piles]	 

Calculations
• calculation of load on each pile
• single pile compression
• single pile tension
• pile group compression
• pile group tension
• pile axial structural capacity
• reinforcement check:
  ➢ pad one-way shear verification
  ➢ pile punching shear verification	

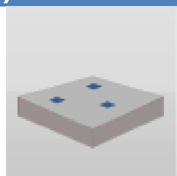
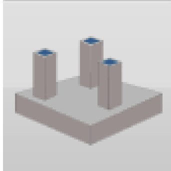
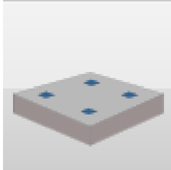
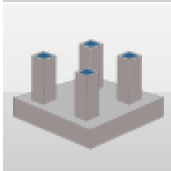
- pier punching shear verification
- pad top flexural reinforcement verification
- pad bottom flexural reinforcement verification
- pier shear verification [Pad and Pier with Piles]

- geometry optimization (pad depth resizing, number of piles)

Mat, Mat and Piers | **Icon(s)**

Geometry

- three or four support points
- square in plan
- pier definition [Mat and Piers]

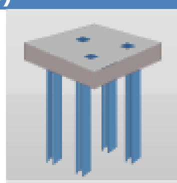
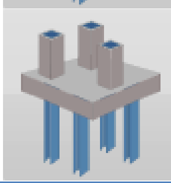
Calculations

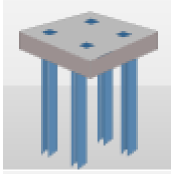
- soil bearing
- sliding
- uplift
- overturning
- reinforcement check:
  - mat one-way shear verification
  - mat punching shear verification
  - mat top flexural reinforcement verification
  - mat bottom flexural reinforcement verification
  - mat flexural reinforcement development length verification
  - pier shear verification [Mat and Pier]
  - pier flexural verification [Mat and Pier]
- geometry optimization (mat width and depth resizing)

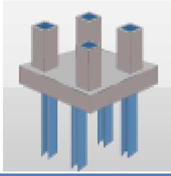
Mat with Piles, Mat and Piers with Piles | **Icon(s)**

Geometry

- three or four support points
- square in plan
- definition of number and types of steel piles
- pier definition [Mat and Piers with Piles]





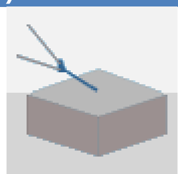
Calculations

- calculation of load on each pile
- single pile compression
- single pile tension
- pile group compression
- pile group tension
- pile axial structural capacity
- reinforcement check:
  - ➢ mat one-way shear verification
  - ➢ pile punching shear verification
  - ➢ pier punching shear verification
  - ➢ mat top flexural reinforcement verification
  - ➢ mat bottom flexural reinforcement verification
  - ➢ pier shear verification [Mat and Piers with Piles]
- geometry optimization (mat depth resizing, number of piles)

Guy Anchor Block	Icon(s)

Geometry

- one support point
- rectangular in plan
- local x axis is parallel to the direction of resultant force



Calculations

- uplift
- sliding
- reinforcement check:
  - ➢ top flexural reinforcement verification
  - ➢ front flexural reinforcement verification
- geometry optimization (block resizing)

Analysis of Post-Installed Anchors [Extras module]	Icon(s)

Data

- external (tension) load
- anchor geometry
- anchor parameters
- material

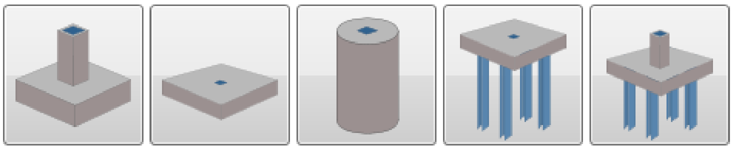
Calculations

- post-installed anchor tension capacity (ACI 318-11)
- concrete breakout capacity (concrete/rock mass failure)
- anchor pullout capacity (contact failure)
- development length check

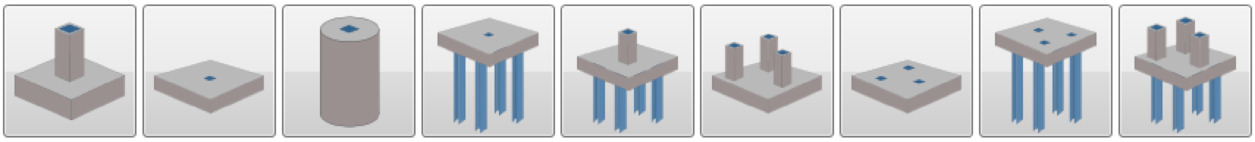
The combinations of tower types and foundation types are shown below.

Tower Type	Foundation Type
Monopole - fixed	1 foundation: Pad and Pier
Monopole or tapered lattice tower - pinned	1 foundation: Pad

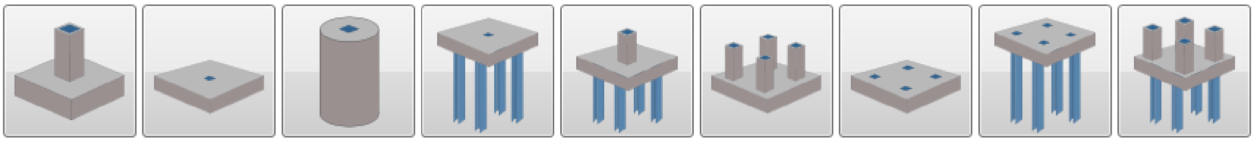
	1 foundation: Caisson 1 foundation: Pad with Piles 1 foundation: Pad and Pier with Piles



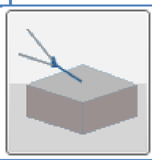
Tower Type	Foundation Type
Lattice tower - 3 sided, 3 support points	3 isolated foundations: Pad and Pier 3 isolated foundations: Pad 3 isolated foundations: Caisson 3 isolated foundations: Pad with Piles 3 isolated foundations: Pad and Pier with Piles 1 common foundation: Mat and Piers 1 common foundation: Mat 1 common foundation: Mat with Piles 1 common foundation: Mat and Piers with Piles



Tower Type	Foundation Type
Lattice tower - 4 sided, 4 support points	4 isolated foundations: Pad and Pier 4 isolated foundations: Pad 4 isolated foundations: Caisson 4 isolated foundations: Pad with Piles 4 isolated foundations: Pad and Pier with Piles 1 common foundation: Mat and Piers 1 common foundation: Mat 1 common foundation: Mat with Piles 1 common foundation: Mat and Piers with Piles



Tower Type	Foundation Type
Monopole - fixed **Monopole or tapered lattice tower - pinned** **Lattice tower - 3 sided, 3 support points** **Lattice tower - 4 sided, 4 support points**	3-12 foundations: Guy Anchor Block

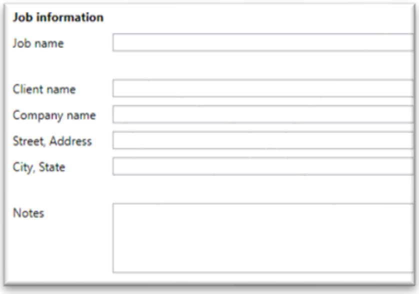


Description

Job specific information is entered in this window. This data will be shown on the report generated in the **Results** window once it has been printed or exported as a PDF or Word document.

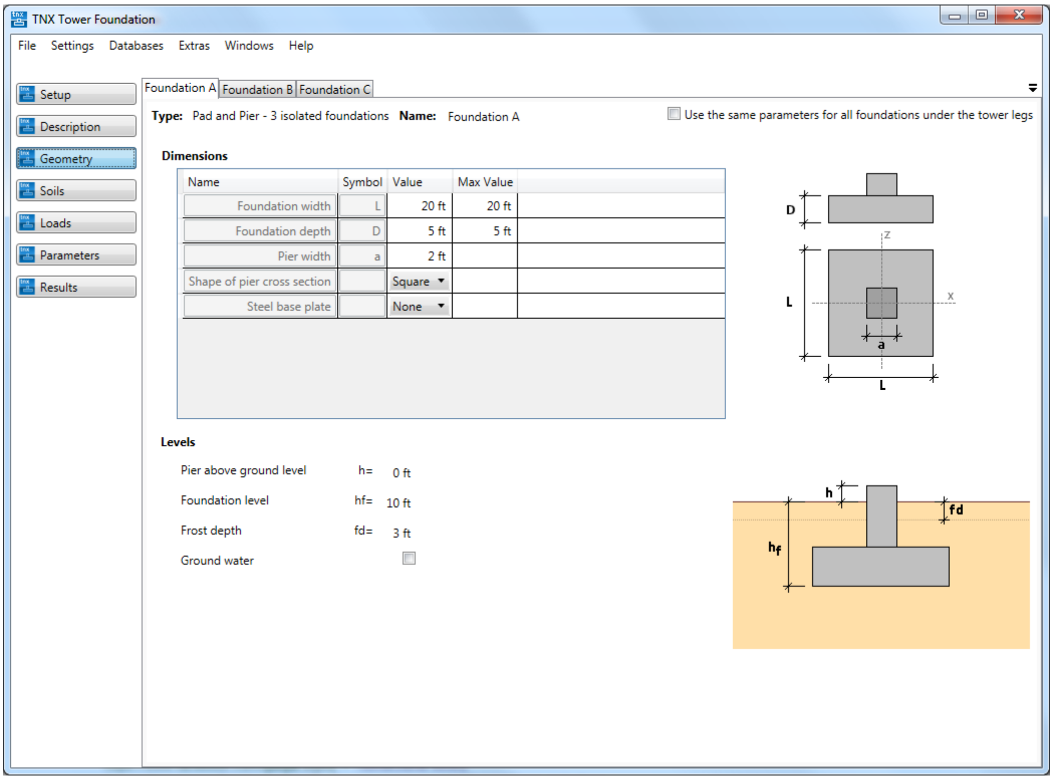
Job information:

- **Job name**
- **Client name**
- **Company name**
- **Street, Address**
- **City, State**
- **Notes**



Geometry

The **Geometry** window contains one tab for each main foundation or guy anchor block.



Type

This section tells the user the type of main foundation or guy anchor block to be defined on the active tab.

Name

The **Name** section is editable and can be updated to the user's preferred name for the main foundation or guy anchor block. The name is maintained even if the checkbox has been selected to use the same parameters.

Use the same parameters for all foundations/guy foundations

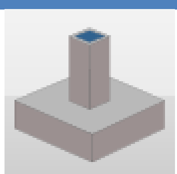
If the tower has more than one main foundation or guy anchor blocks, an additional section with a checkbox is visible.

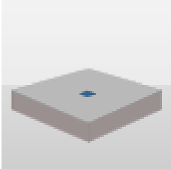
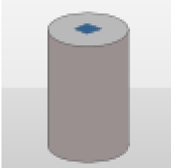
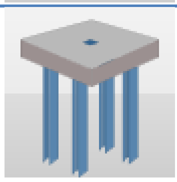
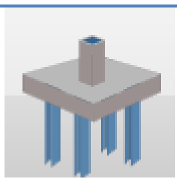
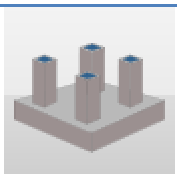
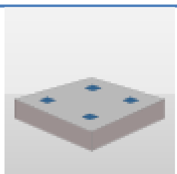
- **Use the same parameters for all foundations under the tower legs (main foundation)**
- **Use the same parameters for all guy foundations (guy anchor blocks)**

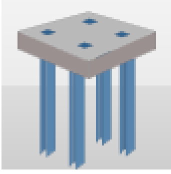
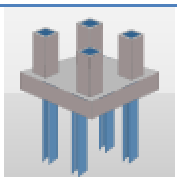
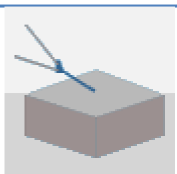
If the checkbox is selected, only the checked tab for the main foundation and/or guy anchor block is shown. The user defined geometry will be same for all main foundations and/or guy anchor blocks. (Note: The checkboxes for the main foundations and guy anchor blocks are independent of each other. A user can define the main foundations to use the same parameters and keep the guy anchor blocks unique or vice versa.)

Dimensions

The geometry of the main foundation or guy anchor block is defined in the **Dimensions** section.

#	Foundation type	Graph	symbol	description
1	Pad and Pier		L	Foundation width (square)
			D	Foundation depth
			A	Width of pier
			Square / Round	Shape of pier cross section
			Exist / None	Steel base plate

<table>
<tr><td></td><td></td><td></td><td><table><tr><td>Ap</td><td>Width of base plate</td></tr></table></td></tr>
<tr><td>2</td><td>Pad</td><td></td><td><table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Foundation width (square)</td></tr>
<tr><td>D</td><td>Foundation depth</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
</table></td></tr>
<tr><td>3</td><td>Caisson</td><td></td><td><table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>D</td><td>Diameter</td></tr>
<tr><td>Exist / None</td><td>Bell</td></tr>
<tr><td>Db</td><td>Bell diameter</td></tr>
<tr><td>Hb</td><td>Bell height</td></tr>
</table></td></tr>
<tr><td>4</td><td>Pad with Piles</td><td></td><td><table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Width of foundation (pad) (square)</td></tr>
<tr><td>D</td><td>Depth of foundation (pad)</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
<tr><td>Emb</td><td>Pile pad embedment (depth that the pile is embedded in the pad)</td></tr>
<tr><td>Edg</td><td>Pile edge distance (distance from the center of pile to the edge of pad)</td></tr>
<tr><td>Pile</td><td>Pile type</td></tr>
<tr><td>C</td><td>Pile diameter</td></tr>
<tr><td>N</td><td>Number of piles in a row (the same number in X and Z directions)</td></tr>
<tr><td>Dp</td><td>Depth (height) of piles</td></tr>
</table></td></tr>
<tr><td>5</td><td>Pad and Pier with Piles</td><td></td><td><table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Width of foundation (pad) (square)</td></tr>
<tr><td>D</td><td>Depth of foundation (pad)</td></tr>
<tr><td>A</td><td>Width of pier</td></tr>
<tr><td>Square / Round</td><td>Shape of pier cross section</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
<tr><td>Emb</td><td>Pile pad embedment (depth that the pile is embedded in the pad)</td></tr>
<tr><td>Edg</td><td>Pile edge distance (distance from the center of pile to the edge of pad)</td></tr>
<tr><td>Pile</td><td>Pile type</td></tr>
<tr><td>C</td><td>Pile diameter</td></tr>
<tr><td>N</td><td>Number of piles in a row (the same number in X and Z directions)</td></tr>
<tr><td>Dp</td><td>Depth (height) of piles</td></tr>
</table></td></tr>
<tr><td>6</td><td>Mat with Piers (3 or 4 legs)</td><td></td><td><table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Width of foundation (square)</td></tr>
<tr><td>D</td><td>Depth of foundation</td></tr>
<tr><td>W</td><td>Tower width (axial distance between tower legs)</td></tr>
<tr><td>A</td><td>Width of pier</td></tr>
<tr><td>Square / Round</td><td>Shape of pier cross section</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
</table></td></tr>
<tr><td>7</td><td>Mat (3 or 4 legs)</td><td></td><td><table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Width of foundation (square)</td></tr>
<tr><td>D</td><td>Depth of foundation</td></tr>
<tr><td>W</td><td>Tower width (axial distance between tower legs)</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
</table></td></tr>
</table>

<table>
<tr><td>8</td><td>Mat with Piles (3 or 4 legs)</td><td></td><td>
<table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Width of foundation (mat) (square)</td></tr>
<tr><td>D</td><td>Depth of foundation (mat)</td></tr>
<tr><td>W</td><td>Tower width (axial distance between tower legs)</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
<tr><td>Emb</td><td>Pile mat embedment (depth that the pile is embedded in the mat)</td></tr>
<tr><td>Edg</td><td>Pile edge distance (distance from the center of pile to the edge of mat)</td></tr>
<tr><td>Pile</td><td>Pile type</td></tr>
<tr><td>C</td><td>Pile diameter</td></tr>
<tr><td>N</td><td>Number of piles in a row (the same number in X and Z directions)</td></tr>
<tr><td>Dp</td><td>Depth (height) of piles</td></tr>
</table>
</td></tr>
<tr><td>9</td><td>Mat with Piers and Piles (3 or 4 legs)</td><td></td><td>
<table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Width of foundation (mat) (square)</td></tr>
<tr><td>D</td><td>Depth of foundation (mat)</td></tr>
<tr><td>W</td><td>Tower width (axial distance between tower legs)</td></tr>
<tr><td>A</td><td>Width of pier</td></tr>
<tr><td>Square / Round</td><td>Shape of pier cross section</td></tr>
<tr><td>Exist / None</td><td>Steel base plate</td></tr>
<tr><td>Ap</td><td>Width of base plate</td></tr>
<tr><td>Emb</td><td>Pile mat embedment (depth that the pile is embedded in the mat)</td></tr>
<tr><td>Edg</td><td>Pile edge distance (distance from the center of pile to the edge of mat)</td></tr>
<tr><td>Pile</td><td>Pile type</td></tr>
<tr><td>C</td><td>Pile diameter</td></tr>
<tr><td>N</td><td>Number of piles in a row (the same number in X and Z directions)</td></tr>
<tr><td>Dp</td><td>Depth (height) of piles</td></tr>
</table>
</td></tr>
<tr><td>10</td><td>Guy anchor block</td><td></td><td>
<table>
<tr><th>symbol</th><th>description</th></tr>
<tr><td>L</td><td>Length</td></tr>
<tr><td>A</td><td>Distance to anchor</td></tr>
<tr><td>B</td><td>Width</td></tr>
<tr><td>D</td><td>Depth</td></tr>
</table>
</td></tr>
</table>

For select parameters such as foundation width, there is an additional maximum value. These values are used during automatic optimization of the foundation.

Levels

The **Levels** section shows additional editable geometry parameters:

- **hf** = **Foundation level** or **Bottom Level**, distance from ground level to bottom of the foundation/pad/mat/guy anchor block
- **hw** = **Ground water level** (displays if the **Ground water** checkbox is checked), distance from ground to the ground water depth
- **fd** = **Frost depth**, distance from ground to the frost depth

Depending on the type of foundation, there can be some additional parameters:

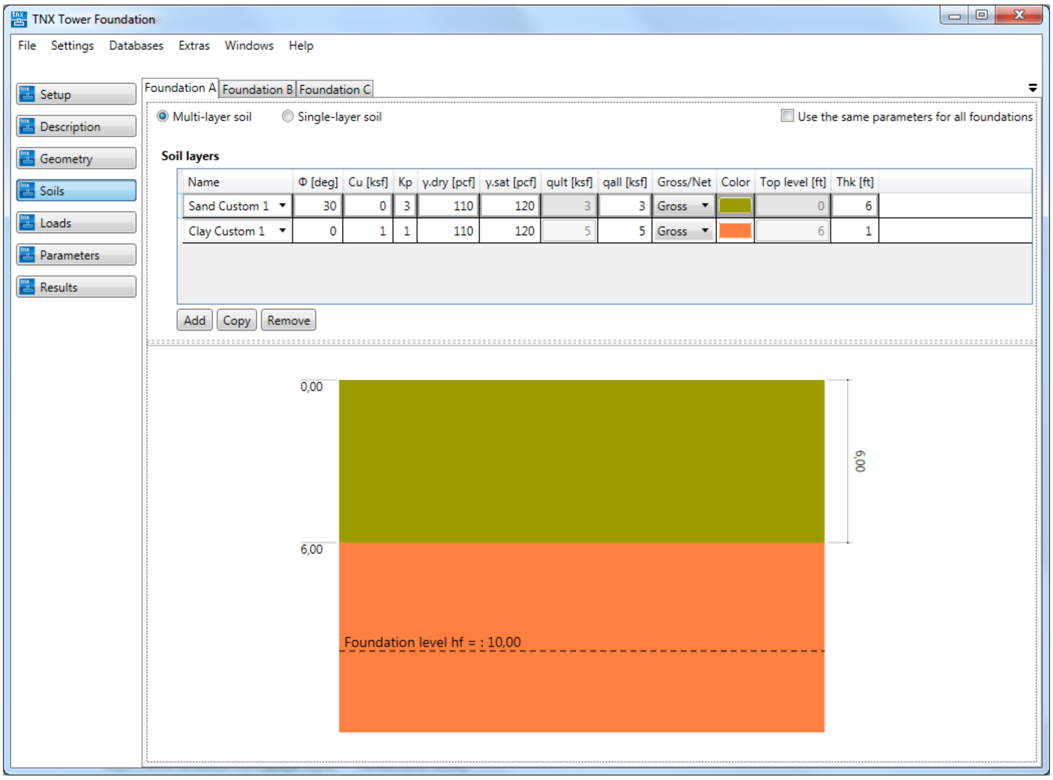
- **h** = Pier above ground level or caisson above the ground level

The pier height is calculated automatically as pier height = hf + h – D.

The caisson height is calculated automatically as caisson height = hf + h.

Soils

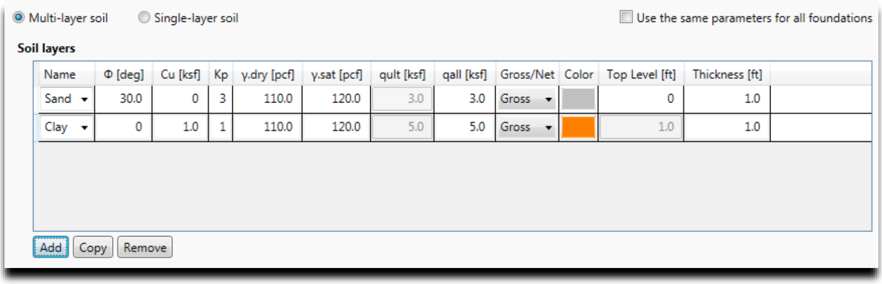
The **Soils** window contains one tab for each main foundation or guy anchor block.



Soil layers

The **Soil layer** section is a table containing rows that represent soil layers. At least one soil layer has to be defined.

The soil layers can be defined either as **Multi-layer soil** or **Single-layer soil**. For multi-layer soil you can add, copy or remove soil layers.



The number of soil parameters depends on the type of foundation. The soil parameters are defined in the table below.

Symbol	Soil Parameter
ϕ	Friction angle of soil
Cu	Cohesion of soil
Kp	Coefficient of passive resistance of soil for sliding check

γs.dry	Dry soil density
γs.sat	Saturated soil density
q_{ult}	Ultimate Bearing Capacity
q_{all}	Allowable Bearing Capacity
Gross/Net	Allowable Soil Bearing is Gross or Net
Top level	Top level of soil layer
Thk	Thickness of soil layer
Color	Color to display on screen
Fs	Pile or caisson external skin friction
Qb	Pile or caisson end bearing stress
δ	Friction angle between the soil and the pile or caisson
α	Adhesion factor for skin friction calculation
Kt	Coefficient for lateral earth pressure for skin friction calculation
Nc	Pile or caisson bearing capacity factor Nc for end bearing calculation
Nq	Pile or caisson bearing capacity factor Nq for end bearing calculation
ε50	Strain corresponding to one-half of the maximum principal stress difference for p-y method
K	Initial soil stiffness for p-y method

p-y curve model	Selection of p-y curve model for soil layer

If the **Defined value for Soil Bearing Capacity** is set as **Ultimate** on the **Calculation Parameters** tab in the **Parameters** window, **qult** is available to edit, and **qall** is calculated as qall = $\varphi * $ qult. Otherwise if **Allowable** is selected in the **Parameters** window, **qall** is available to edit, and **qult** is unable to be edited. The value of φ can be defined on the **Calculations Factors** tab of the **Parameters** window.

Use the same parameters for all foundations

If the tower has more than one main foundation or guy anchor blocks, an additional section with a checkbox is visible.

- **Use the same parameters for all foundations**
- **Use the same parameters for all guy foundations**

If the checkbox is selected, only the checked tab for the main foundation and/or guy anchor block is shown. The user defined geometry will be same for all main foundations and/or guy anchor blocks. (Note: The checkboxes for the main foundations and guy anchor blocks are independent of each other. A user can define the main foundations to use the same parameters and keep the guy anchor blocks unique or vice versa.)

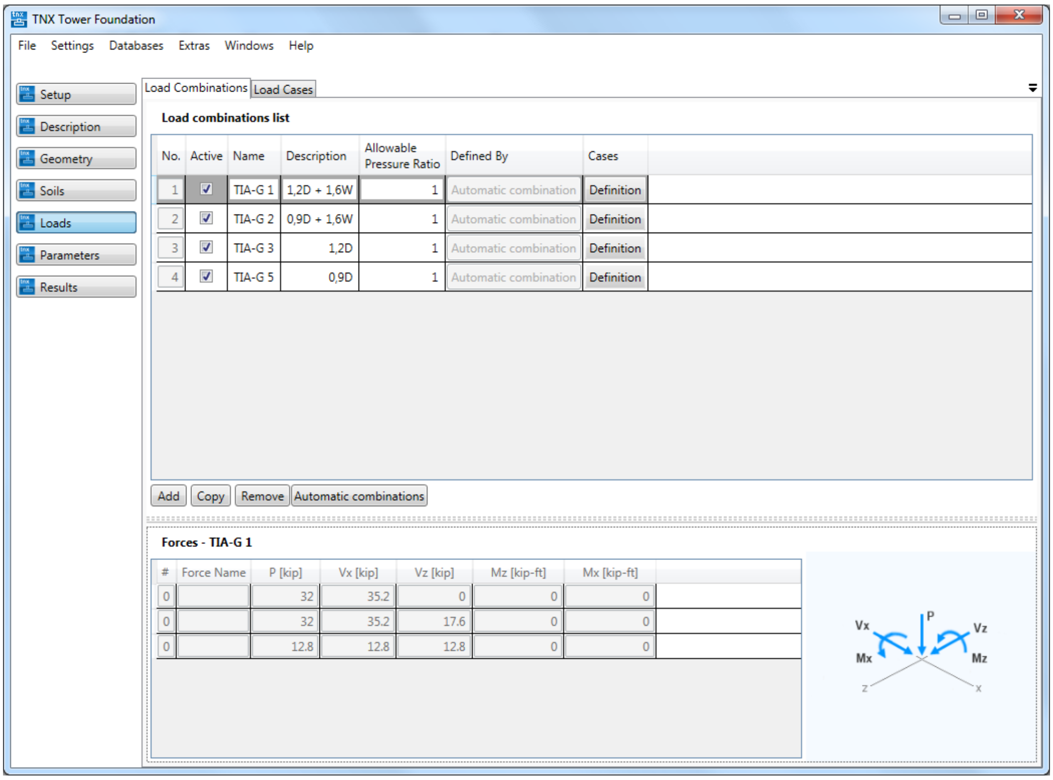
Loads

The **Loads** window contains the **Load Combinations** and **Load Cases** tabs.

General Information

- The analysis is carried out independently for each combination.
- Each combination contains one set of loads for each point of support (leg or guy anchor).
- There are a three methods for defining a load combination:
    1. The load combination can be directly defined by selecting **Direct Input** under **Defined By** in the **Load combinations list** section on the **Load Combinations** tab. The forces for each support will then be entered in the **Forces** section below the **Load combinations list**.
    2. Use a manual combination of load cases.
        - Step 1: Define the load cases in the **Load cases list** section and applicable forces in the **Forces** section on the **Load Cases** tab.
        - Step 2: Create a load combination on the **Load Combinations** tab by setting the **Defined By** option to **Combining load cases**. The **Definition** under **Cases** is used to define what load cases and load factors are used for the load combination.
    3. Use an automatic combination of load cases.
        - Step 1: Define the load cases in the **Load cases list** section and applicable forces in the **Forces** section on the **Load Cases** tab.
        - Step 2: Select the **Automatic combinations** button in the **Load combinations list** section on the **Load Combinations** tab.

Load Combinations



Load combinations list

This section allows the user to define load case combinations to use in the analysis or design of the foundation. Each row is a load combination. Rows can be added, copied or removed. When using the **Automatic combinations** button, combinations appropriate for the **Code** selected in the **Parameters** window will be added. However all of the applicable load cases must be defined in the **Load Cases** tab prior to selecting **Automatic combinations**. **Automatic load combinations** with load cases not defined, will not be displayed.

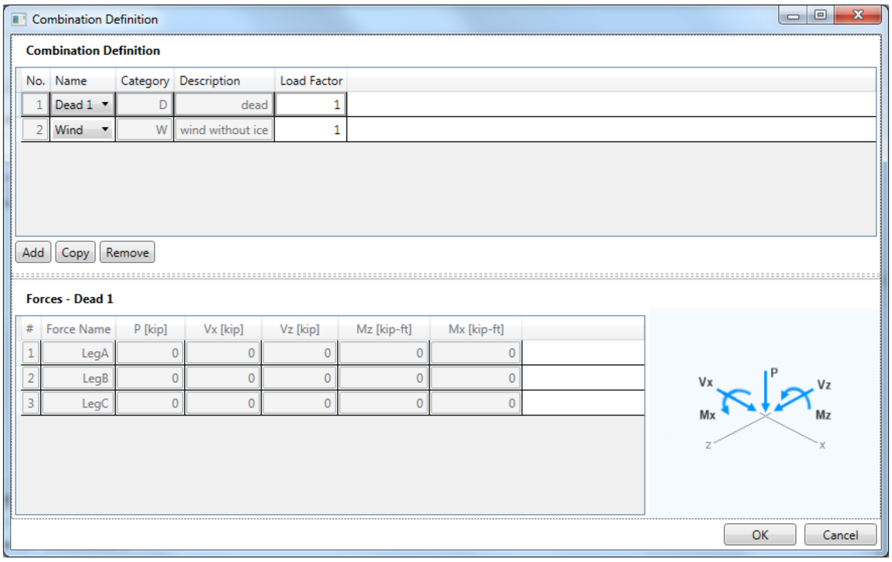
- **Active** – allows turning individual load combinations on and off. No design or analysis will be done for inactive load combinations.
- **Name** – editable name for the load combination.
- **Description** – extended name that can be defined by the user or is created automatically when a load case combination is defined.
- **Allowable Pressure Ratio** – factor to multiple all inputted loads.
- **Defined By** – indicates whether reaction forces for a given load combination were entered directly in the program or calculated based on load case reactions.
    - **Direct Input** – reactions for each load combination are entered directly in the **Forces** section, directly below the **Load combinations list**. This entry mode will also apply if the reactions are imported from a tnxTower analysis.
    - **Combining Load Cases** – reactions for each load combination are calculated from load cases entered in the **Load Cases** tab and applicable load factors.
- **Cases –** is available when either **Defined By** is **Combining load cases** or the **Automatic combinations** button has been seleted. The **Definition** button will make the **Combination Definition** input window visible.

Forces

The **Forces** section below the **Load combinations list** contains fields for entering reactions for each support point. Reactions may be defined for each load combination depending on the **Defined By** selection. The number of rows depends on the number of support points.

Combination Definition

The **Combination Definition** is an input window that is visible when the user selects the **Definition** button under **Cases** in the **Load combinations list** section of the **Load Combinations** tab.



Combination Definition

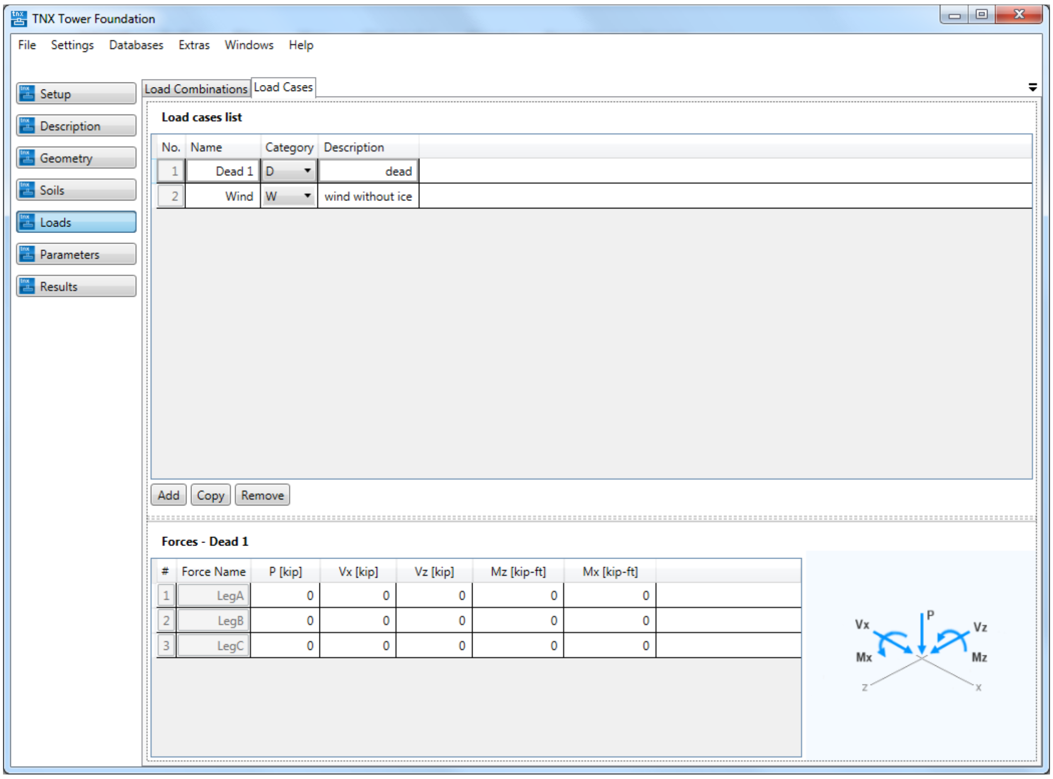
This section allows the user to select what load cases define the load combination and the appropriate load factor to use. Rows can be added, copied or removed. If the load combination is an automatic combination, the user can only view the combination definition.

- **Name –** A list containing all of the names from the **Load cases list** section on the **Load Cases** tab.
- **Category –** The category for the load case selected above.
- **Description –** The description of the load case selected above.
- **Load Factor –** The load factor to be used for the load case in load combination. For automatic combinations, this value cannot be edited

Forces

The **Forces** section below the **Combination Definition** shows the reactions for each support point corresponding to the load case selected under **Name** in the **Combination Definition**. The number of rows depends on the number of support points. This section cannot be edited.

Load Cases



Load cases list

This window is used to define load cases. The **Forces** section below the **Load cases list** contains fields for entering reactions for each support point. Reactions are defined for each load case. The number of rows depends on the number of support points.

- **Name –** editable name for the load case.
- **Category –** This list contains the categories of loads used for automatic load combinations and defining load combinations. Only categories applicable to the **Code** selected in the **Parameters** window will be used for automatic load combination generation.

TIA	ASCE	Load Description
D	D	dead
Dg	Dg	guy
Di	Di	ice
E	E	earthquake
Ti	Ti	temperature
W	W	wind without ice
Wi	Wi	wind with ice
	L	live
	S	snow
	R	rain
	H	earth

- **Description –** editable description for the load case. The default description will be the one shown in the category list table above.

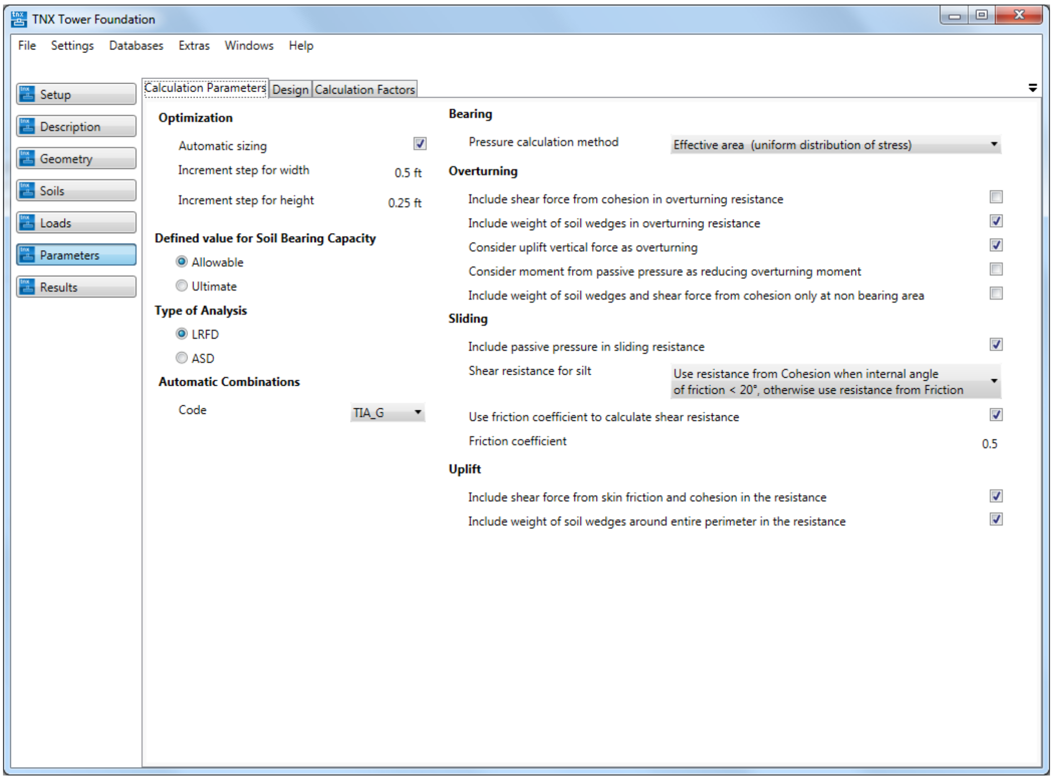
Forces

The **Forces** section below the **Load cases list** contains fields for entering reactions for each support point. Reactions may be defined for each load case. The number of rows depends on the number of support points.

Parameters

Calculation Parameters

Calculation parameters available to set are based on the foundation type selected in the **Setup** window.



- **Optimization**
  - **Automatic sizing –** This option determines whether to perform automatic optimization of the foundation. The width and/or height of the foundation can be incrementally increased, so the maximum ratio value is not exceeded for all applicable checks.
  - **Increment step for diameter / width / length / height –** Editable values used during optimization to incrementally increase the foundation dimensions.
  - **Maximum length of caisson –** Editable value to define the maximum caisson length.

- **Defined value for Soil Bearing Capacity**
  - **Allowable –** When selected, the **qall** value in the **Soil layer** section of the **Soils** window is available to be edited.
  - **Ultimate –** When selected, the **qult** value in the **Soil layer** section of the **Soils** window is available to be edited.

- **Type of Analysis**
  - **ASD (Allowable Stress Design) –** The calculations are based on the allowable stresses. Unfactored (service loads) are used.
  - **LRFD (Limit States Design, Load and Resistance Factor Design) –** Calculations are based on factored resistances. Factored loads are used.

- **Automatic Combinations**
  - **Code –** Option to select the code or standard. Automatic load combinations are generated based on this selection.
    - TIA_G – Load combinations according to ANSI/TIA-222-G.
    - TIA_F – Load combinations according to ANSI/TIA-222-F.
    - ASCE_ASD – Load combinations using ASD according to ASCE 7.
    - ASCE_LRFD – Load combinations using LRFD according to ASCE 7.

- Load cases and load factors based on the code selected.

TIA- G

Name	D	Dg	W	Wi	Di	Ti	E	L	R	S	H
TIA-G 1	1.2	1	1.6								
TIA-G 2	0.9	1	1.6								
TIA-G 3	1.2	1		1	1	1					
TIA-G 4	1.2	1					1				
TIA-G 5	0.9	1					1				

TIA- F

Name	D	Dg	W	Wi	Di	Ti	E	L	R	S	H
TIA-F 1	1	1									
TIA-F 2	1	1	1								
TIA-F 3	1	1			1	1					
TIA-F 4	1	1		0.75	1	1					

ASCE ASD

Name	D	Dg	W	Wi	Di	Ti	E	L	R	S	H
ASCE ASD 1	1										
ASCE ASD 2a	1							1			1
ASCE ASD 2b	1				0.7			1			1
ASCE ASD 3a	1									1	1
ASCE ASD 3b	1								1		1
ASCE ASD 3c	1			0.7	0.7					1	1
ASCE ASD 4a	1							0.75		0.75	1
ASCE ASD 4b	1							0.75	0.75		1
ASCE ASD 5a	1		1								1
ASCE ASD 5b	1		-1								1
ASCE ASD 5c	1						0.7				1
ASCE ASD 5d	1						-0.7				1
ASCE ASD 6a	1		0.75					0.75		0.75	1
ASCE ASD 6b	1		0.75					0.75	0.75		1
ASCE ASD 6c	1		-0.75					0.75		0.75	1
ASCE ASD 6d	1		-0.75					0.75	0.75		1
ASCE	1						0.525	0.75		0.75	1

ASD 6e											
ASCE ASD 6f	1						0.525	0.75	0.75		1
ASCE ASD 6g	1						-0.525	0.75		0.75	1
ASCE ASD 6h	1						-0.525	0.75	0.75		1
ASCE ASD 7a	0.6		1								1
ASCE ASD 7b	0.6		-1								1
ASCE ASD 7c	0.6			0.7	0.7						1
ASCE ASD 8a	0.6						0.7				1
ASCE ASD 8b	0.6						-0.7				1

ASCE LRFD

Name	D	Dg	W	Wi	Di	Ti	E	L	R	S	H
ASCE LRFD 1	1.4										
ASCE LRFD 2a	1.2							1.6		0.5	1.6
ASCE LRFD 2b	1.2							1.6	0.5		1.6
ASCE LRFD 2c	1.2				0.2			1.6		0.5	1.6
ASCE LRFD 3a	1.2							0.5		1.6	
ASCE LRFD 3b	1.2		0.8							1.6	
ASCE LRFD 3c	1.2							0.5	1.6		
ASCE LRFD 3d	1.2		0.8						1.6		
ASCE LRFD 4a	1.2		1.6					0.5		0.5	
ASCE LRFD 4b	1.2		1.6					0.5	0.5		
ASCE LRFD 4c	1.2			1	1			0.5	0.5		
ASCE LRFD 5a	1.2						1	0.5		0.2	
ASCE LRFD 5b	1.2						-1	0.5		0.2	
ASCE LRFD 6a	0.9		1.6								1.6
ASCE LRFD 6b	0.9		-1.6								1.6
ASCE LRFD 6c	0.9			1	1						1.6
ASCE LRFD 7a	0.9						1				1.6
ASCE LRFD 7b	0.9						-1				1.6

- **Bearing**
  - **Pressure calculation method –** Option to choose how to calculate the maximum pressure under pad and mat foundations.

Effective area (uniform distribution of stress)
The maximum soil pressure is calculated using the reduced effective footing area A'. [AASHTO]

Effective Area:
A' = B' * L'
Effective Foundation Dimensions:
B' = B – 2 * |ez|
L' = L – 2 * |ex|
Maximum Pressure = Load / A'

Variable distribution of stress for one-way eccentricity, and effective area for two-way eccentricity
Method of determining the forces depends on the position of the load.

- Trapezoidal distribution of pressure for eccentricities less than L / 6 (load in kern):
  (6 * |ex| / L + 6 * |ez| / B) < 1 [100% of pad is compressed]
- Triangular distribution of pressure for one way eccentricity to value L / 3:
  L / 3 > |ex| >= L / 6 and ez = 0
  B / 3 > |ez| >= L / 6 and ex = 0
- Rectangular distribution of pressure for one way eccentricity to value L / 2:
  L / 2 > |ex| >= L / 3 and ez = 0
  B / 2 > |ez| >= L / 3 and ex = 0
- Effective uniform distribution of pressure for two way eccentricity:
  (6 * |ex| / L + 6 * |ez| / B) >= 1 and |ex| > 0, |ez| > 0, |ex| < L / 2, |ez| < B / 2

Variable distribution of stress
Detailed calculation method for two-way eccentricity that determines the tension at the four corners of the foundation taking into account the stress redistribution in the presence of a partial detachment of the foundation.

Load eccentricities, ex and ez
ex = (Mz + Hx * (hf + h)) / V
ez = (Mx - Hz * (hf + h)) / V

Where:
Mx, Mz = Bending moments
Hx, Hy = Horizontal loads
V = Total vertical load
hf + h = Distance from Foundation level to top of the pier

- **Overturning**
  - **Include shear force from cohesion in overturning resistance –** Use this option to choose whether the shear force from cohesion at the non-bearing length vertical plane of the foundation perimeter is added to the overturning resistance.
  - **Include weight of soil wedges in the resistance –** Use this option to choose whether the weight of soil wedges is added to the overturning resistance.
  - **Consider uplift vertical force as overturning –** Use this option to choose whether the moment from the uplift vertical force is treated as overturning.
  - **Consider moment from passive pressure as reducing overturning moment –** Use this option to choose whether the moment from the passive pressure is taken into account in overturning. It will cause a reduction in the overturning moment.
  - **Include weight of soil wedges and shear force from cohesion only at non-bearing area –** Use this option to choose whether the weight of soil wedges and the shear force from cohesion are calculated only at the non-bearing length vertical plane of the foundation perimeter.

- **Sliding**
  - **Include passive pressure in sliding resistance –** Use this option to choose whether sliding resistance is to be calculated with the passive resistance.
  - **Shear resistance for silt –** Use this option to choose how to calculate the shear resistance between footing and foundation for silt in sliding. This choice is used only when the shear resistance in sliding is calculated without the definition of friction coefficient.

<u>Use resistance from cohesion when internal angle of friction < 20°, otherwise use resistance from friction</u>

Shear Resistance = tan(ϕ) * V for ϕ >= 20deg [silt] or cu = 0 [cohesionless soil]
Shear Resistance = cu * Ac for ϕ < 20deg [silt] or ϕ = 0 [cohesive soil]

Where:

ϕ = internal friction angle of the soil at the formation level
V = vertical load from the weight of the foundation and the soil above
cu = soil cohesion
Ac = foundation-soil contact area

<u>Use the smaller of resistance from cohesion or friction</u>

Minimum of:

Shear Resistance = tan(ϕ) * V
Shear Resistance = cu * Ac

Where:

ϕ = internal friction angle of the soil at the formation level
V = vertical load from the weight of the foundation and the soil above
cu = soil cohesion
Ac = foundation-soil contact area

<u>Use sum of resistances from cohesion and friction</u>

Shear Resistance = tan(ϕ) * V + cu * Ac

Where:

ϕ = internal friction angle of the soil at the formation level
V = vertical load from the weight of the foundation and the soil above
cu = soil cohesion
Ac = foundation-soil contact area

- **Use friction coefficient to calculate shear resistance –** Use this option to choose how to calculate shear resistance between footing and foundation. If this option is selected, the shear resistance is the vertical load from the weight of the foundation and the soil above multiplied by the friction coefficient.
- **Friction coefficient –** editable value. The coefficient of friction between the base of the footing and the soil.
- **Include friction acting on the inclined plane of front wedge –** Use this option for anchor block foundations to choose whether the sliding resistance is to be calculated with the friction force from the front wedge soil. It is calculated only for cohesionless soil.

- **Uplift**
  - **Include shear force from skin friction and cohesion in the resistance –** Use this option on pad or mat foundations to include the cohesion shear force around the entire perimeter of foundation as resistance to uplift.
  - **Include weight of soil wedges around entire perimeter in the resistance –** Use this option to include the weight of the soil wedges around the entire perimeter of the foundation as resistance to uplift.

- **Steel**
  - **Grade – piles –** The steel grade for the piles can be selected from the list. The available values are defined in the database.
  - **Strength fy –** The steel yield strength is defaulted to the value in the database corresponding to the grade selected above. This value is available to edit.

- **Group of piles**
  - **Calculate capacity of pile group as –** Use this option to choose how to calculate tension and compression capacity of the pile group.
    - **a reduced sum of individual piles capacity –** Capacity is calculated as a sum of single pile capacities multiplied by a group reduction factor.
    - **one rigid pile capacity –** The pile group capacity is considered as a block. It is calculated as a single pile, but with pile dimensions equal to external dimensions of the group.

    - **the lesser of a reduced sum of individual piles capacity and one rigid pile capacity –** Capacity is taken as the smaller value from the two above methods.
  - **Reduction factor for a sum of piles capacity – bearing –** Editable factor used to reduce the capacity of the pile group calculated as a sum of individual pile capacities.
  - **Reduction factor for a sum of piles capacity – tension –** Editable factor used to reduce the capacity of the pile group calculated as a sum of individual pile capacities.

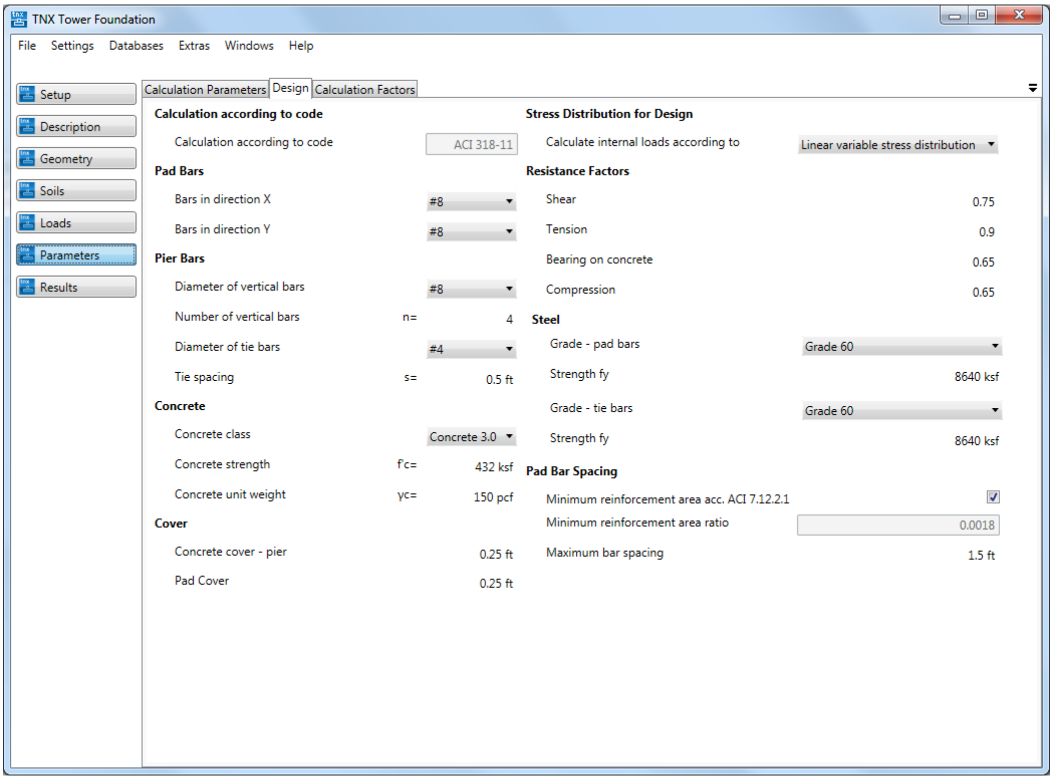
- **Piles capacity**
  - **Calculate bearing and tension capacity of the pile –** Use this option to choose whether to calculate single pile tension and compression capacities. If not selected, these values are entered by the user.
  - **Pile bearing capacity –** The user entered single pile bearing capacity.
  - **Pile tension capacity –** The user entered single pile tension capacity.
  - **Calculate unit skin friction (fs) and unit end bearing (qb) –** Use this option to choose whether to calculate the unit skin friction and unit end bearing for a single pile. If not selected, these values are entered by the user. User values of **fs** and **qb** can be entered in the **Soils** window, separately for each soil layer. This option is only available when the bearing and tension capacity of the pile is calculated as well.
  - **Calculate end bearing capacity factors (Nc and Nq) –** Use this option to choose whether to calculate end bearing capacity factors for a single pile. If not selected, these values are entered by the user. User values of **Nc** and **Nq** can be entered in the **Soils** window, separately for each soil layer. This option is only available when the bearing capacity, tension capacity, unit skin friction and unit end bearing of the pile is calculated as well.

- **Caisson parameters**
  - **Calculate unit skin friction (fs) and unit end bearing (qb) –** Use this option to choose whether to calculate the unit skin friction and unit end bearing. If not selected, these values are entered by the user. User values of **fs** and **qb** can be entered in the **Soils** window, separately for each soil layer.
  - **Calculate end bearing capacity factors (Nc and Nq) –** Use this option to choose whether to calculate the end bearing capacity factors. If not selected, these values are entered by the user. User values of **Nc** and **Nq** can be entered in the **Soils** window, separately for each soil layer. This option is available when the unit skin friction and unit end bearing is calculated as well.
  - **Lateral capacity –** Use this option to choose one of two available methods of lateral capacity analysis.
    - **Broms' method –** Selecting this option means that the analysis of the lateral capacity of the caisson will be done according to Broms' method. Only one soil layer may be defined with this method.
    - **p-y method –** Selecting this option means that the analysis of the lateral capacity of the caisson will be done according to the p-y method. Multiple soil layers can be defined. For each soil layer, additional parameters dedicated to the p-y analysis must be entered.

- **P-Y Analysis Settings**
  - **Number of caisson increments –** This value sets the number of increments along the caisson. It is set to 100 as the default. The accuracy of the solution is proportional to the increment length.
  - **Number of layers in results' table –** This value will set the number of layers displayed in the results table.
  - **Maximum number of iterations –** This value sets the maximum number of iterations allowed.
  - **Convergence precision –** This value sets the convergence tolerance for solution. It is used to determine when the iterative solution is acceptably accurate.
  - **Initial stiffness is calculated –** Use this option to choose whether to calculate soil initial stiffness, **k**, otherwise it is taken from the soil parameters.
  - **Loading type is Static –** Use this option to choose the type of loading to be analyzed. If the loading is not specified as static then cyclic p-y curve criteria is used.
  - **Number of cycles of loading –** It sets the number of cycles of loading for the p-y curve. This entry field is active if cyclic loading is specified.

Design

Design parameters available to set are based on the foundation type selected in the **Setup** window.



- **Calculation according to code**
  - **Calculation according to code –** Design calculations are performed according to ACI. This setting cannot be changed.

- **Pad Bars / Anchor Block Bars**
  - **Bars in direction X –** Select the diameter of the bars in the x direction for the pad or mat.
  - **Bars in direction Y –** Select the diameter of the bars in the y direction for the pad or mat.
  - **Diameter of bars –** Select the diameter of the bars in the x and y directions for the anchor block.

US Customary		SI	
Bar:	ϕ [in]	Bar:	ϕ [cm]
#3	0.375	10	9.50
#4	0.500	13	12.7
#5	0.625	16	15.9
#6	0.750	19	19.1
#7	0.875	22	22.2
#8	1.000	25	25.2
#9	1.128	29	28.7
#10	1.270	32	32.3
#11	1.410	36	35.8
#14	1.693	43	43.0
#18	2.257	57	57.3

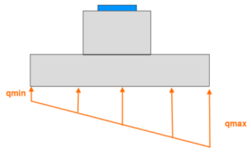
- **Pier Bars**
  - **Diameter of vertical bars –** Select the diameter of the vertical bars from the list.
  - **Number of vertical bars –** Enter the number of vertical bars.
  - **Diameter of tie bars –** Select the diameter of the tie bars from the list.
  - **Tie spacing –** Enter the tie spacing.

- **Caisson bars**
  - **Diameter of vertical bars –** Select the diameter of the vertical bars from the list.
  - **Number of vertical bars –** Enter the number of vertical bars.

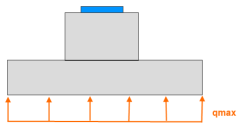
- **Concrete**
  - **Concrete class –** The concrete class can be selected from the list. The list values are defined in the database.
  - **Concrete strength –** The concrete strength is automatically populated by the selection of the concrete class. However it can be edited to a custom value.
  - **Concrete unit weight –** The concrete unit weight is automatically populated by the selection of the concrete class. However it can be edited to a custom value.

- **Cover**
  - **Concrete cover – pier –** The pier concrete cover for a mat or pad foundation. The minimum input value is 3 in (75 mm) per ACI 318-11, 7.7.1.
  - **Pad Cover –** The pad concrete cover for a mat or pad foundation. The minimum input value is 3 in (75 mm) per ACI 318-11, 7.7.1.
  - **Concrete cover –** The concrete cover for a caisson or anchor block foundation. The minimum input value is 3 in (75 mm) per ACI 318-11, 7.7.1.
  - **Transverse reinforcement diameter –** The transverse reinforcement diameter for a caisson foundation.

- **Stress Distribution for Design**
  - **Calculate internal loads according to** – Use this option to choose the type of stress distribution to calculate the shear and bending moments for a pad or mat foundation.
    - **Linear variable stress distribution –** Linear variable stress from minimum to maximum stress values.



    - **Uniform maximum stress distribution –** Uniform maximum stress value.



- **Resistance Factors –** The list of strength reduction factors. The default values are according to ACI 318-11, C.9.3.2.
  - **Shear,** φ.s = 0.75
  - **Tension,** φ.t = 0.90
  - **Bearing on concrete,** φ.bc = 0.65
  - **Compression,** φ.c = 0.65

- **Steel**
  - **Grade – pad bars –** The grade can be selected from the list. The list values are defined in the database.
  - **Grade – tie bars –** The grade can be selected from the list. The list values are defined in the database.
  - **Grade –** The grade can be selected from the list. The list values are defined in the database.
  - **Grade – vertical bars –** The grade can be selected from the list. The list values are defined in the database.
  - **Strength fy –** The strength is automatically populated by the selection of the grade. However it can be edited to a custom value.

- **Minimal reinforcement**
  - **Minimum Vertical Reinforcement Ratio –** Editable value to set the minimum vertical reinforcement ratio for a caisson foundation.

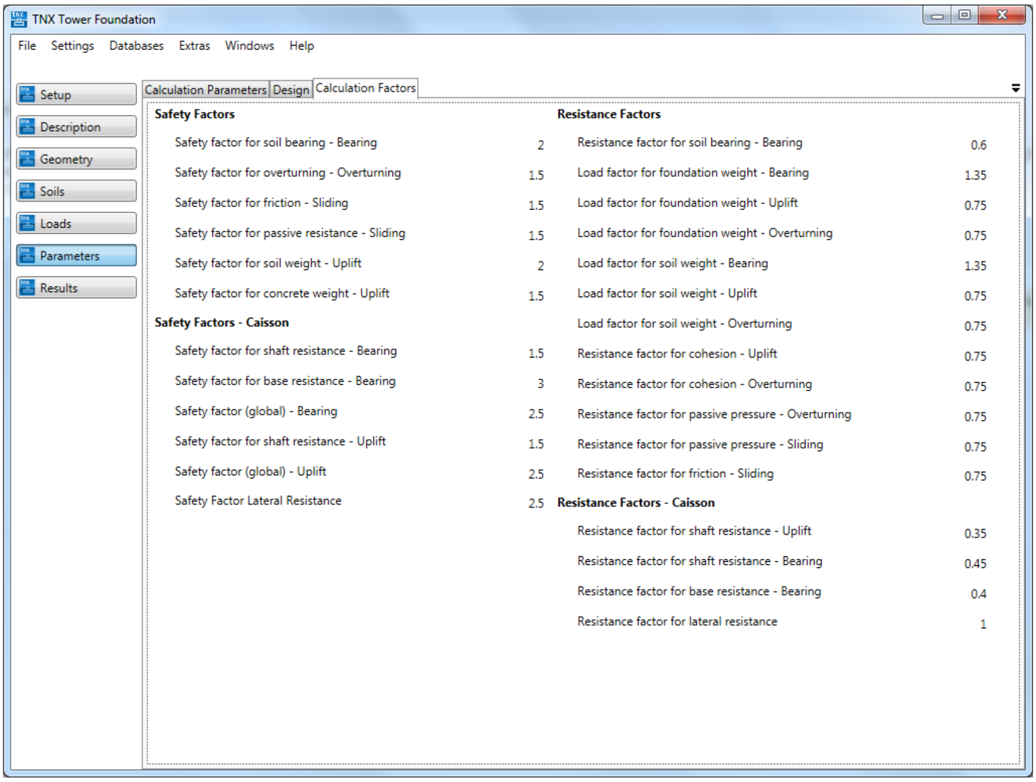
- **Pad Bar Spacing**
  - ➢ **Minimum reinforcement area per ACI 318-11, 7.12.2.1 –** When selected, the minimum reinforcement area ratio is calculated according to ACI 318-11, 7.12.2.1. Otherwise the user can edit the ratio to a custom value.
  - ➢ **Minimum reinforcement area ratio –** This ratio is editable if the minimum reinforcement area has not been selected to be calculated. If it is calculated, the value is dependent on steel strength.

US Customary:	$\rho min = 0.0018$	for steel grade 60
	$\rho min = 0.0020$	for steel grade 40
(steel fy in [ksi])	$\rho min = 0.0018 * 60000 / fy$	for steel grade > 60
SI:	$\rho min = 0.0018$	for steel grade 280-530
	$\rho min = 0.0020$	for steel grade 420
(steel fy in [Mpa])	$\rho min = 0.0018 * 420 / fy$	for steel grade > 420

  - ➢ **Maximum bar spacing –** Maximum spacing of the reinforcing bars.

- **Anchor Block Bar Spacing**
  - ➢ **Minimum reinforcement area ratio –** Minimum reinforcement area ratio.
  - ➢ **Maximum bar spacing –** Maximum spacing of the reinforcing bars.

Calculation Factors



- **Safety Factors –** Used when the **Type of Analysis** on the **Calculations Parameters** tab is set to **ASD**. The default values are according to TIA_F but can be edited to custom values.

Safety factor for soil bearing – Bearing	2.0
Safety factor for soil overturning - Overturning	1.5
Safety factor for friction – Sliding	1.5
Safety factor for passive resistance - Sliding	1.5
Safety factor for soil weight – Uplift	2.0

Safety factor for concrete weight - Uplift	1.5

- **Safety Factors – Piles –** Used when the **Type of Analysis** on the **Calculations Parameters** tab is set to **ASD**. The default values are according to TIA_F but can be edited to custom values.

Safety factor for shaft resistance – Bearing	1.5
Safety factor for base resistance - Bearing	3.0
Safety factor (global) – Bearing	2.5
Safety factor for shaft resistance – Uplift	1.5
Safety factor (global) – Uplift	2.5

- **Safety Factors – Caisson –** Used when the **Type of Analysis** on the **Calculations Parameters** tab is set to **ASD**. The default values are according to TIA_F but can be edited to custom values.

Safety factor for shaft resistance – Bearing	1.5
Safety factor for base resistance - Bearing	3.0
Safety factor (global) – Bearing	2.5
Safety factor for shaft resistance – Uplift	1.5
Safety factor (global) – Uplift	2.5
Safety factor for lateral resistance	2.5

- **Resistance Factors –** Used when the **Type of Analysis** on the **Calculations Parameters** tab is set to **LRFD**. The default values are according to TIA_G but can be edited to custom values.

Resistance factor for soil bearing - Bearing	0.60
Load factor for foundation weight - Bearing	1.35
Load factor for foundation weight - Uplift	0.75
Load factor for foundation weight - Overturning	0.75
Load factor for soil weight - Bearing	1.35
Load factor for soil weight – Uplift	0.75
Load factor for soil weight - Overturning	0.75
Resistance factor for soil cohesion - Uplift	0.75
Resistance factor for soil cohesion - Overturning	0.75
Resistance factor for passive pressure - Overturning	0.75
Resistance factor for passive pressure - Sliding	0.75
Resistance factor for friction – Sliding	0.75

- **Resistance Factors – Piles –** Used when the **Type of Analysis** on the **Calculations Parameters** tab is set to **LRFD**. The default values are according to TIA_G but can be edited to custom values.

Resistance factor for shaft resistance - Uplift	0.40
Resistance factor for shaft resistance - Bearing	0.35
Resistance factor for base resistance - Bearing	0.40
Resistance factor for axial structural resistance	0.60

- **Resistance Factors – Caisson –** Used when the **Type of Analysis** on the **Calculations Parameters** tab is set to **LRFD**. The default values are according to TIA_G but can be edited to custom values.

Resistance factor for shaft resistance - Uplift	0.35
Resistance factor for shaft resistance - Bearing	0.45
Resistance factor for base resistance - Bearing	0.40
Resistance factor for axial structural resistance	1.00

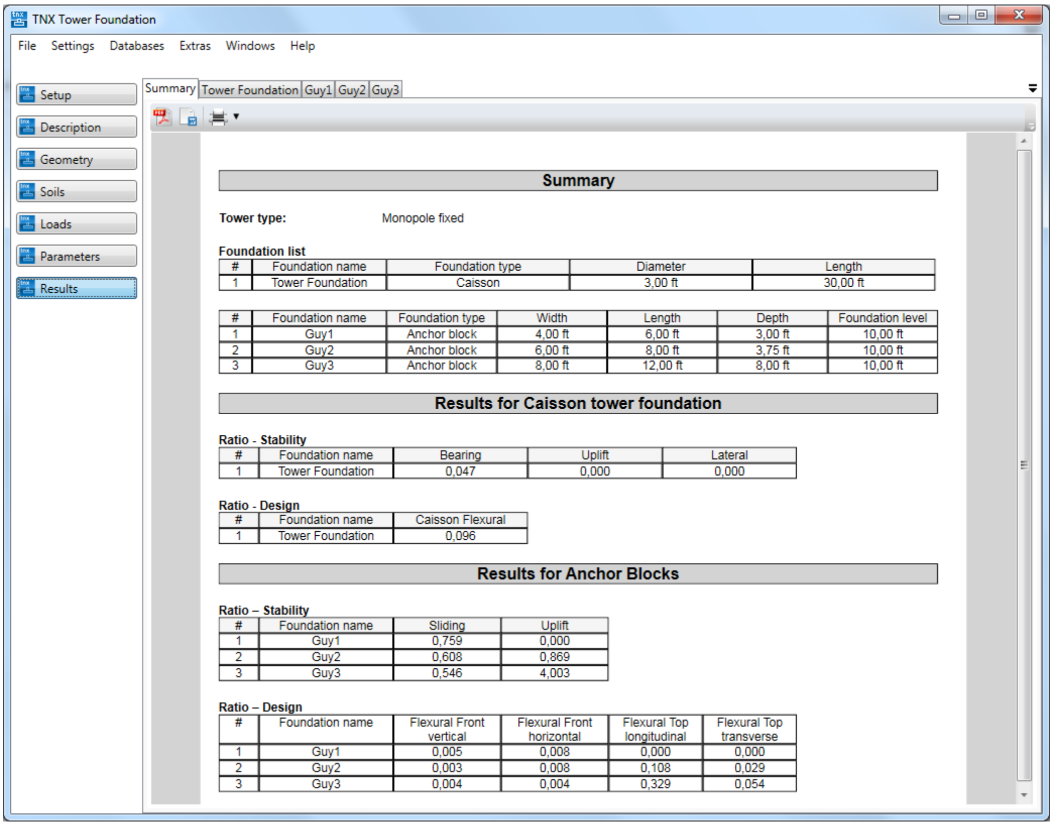
Results

Summary

The summary results for all foundations are displayed in this tab. Theses results can be saved as a PDF Document, Word Document or printed using the icons displayed beneath the tab name.

The summary results are broken down into two sections. The displayed ratios are the maximum ratios from all calculated load combinations.

- **Summary** – This section contains a table with the basic foundation geometery parameters and foundation names.
- **Results for Main foundations –** This section contains two tables.
  - **Ratio – Stability –** Contains a table with the maximum ratio for stability checks.
  - **Ratio – Design –** Contains a table with the maximum ratio for design checks.



Summary

Tower type: Monopole fixed

Foundation list

#	Foundation name	Foundation type	Diameter	Length
1	Tower Foundation	Caisson	3,00 ft	30,00 ft

#	Foundation name	Foundation type	Width	Length	Depth	Foundation level
1	Guy1	Anchor block	4,00 ft	6,00 ft	3,00 ft	10,00 ft
2	Guy2	Anchor block	6,00 ft	8,00 ft	3,75 ft	10,00 ft
3	Guy3	Anchor block	8,00 ft	12,00 ft	8,00 ft	10,00 ft

Results for Caisson tower foundation

Ratio - Stability

#	Foundation name	Bearing	Uplift	Lateral
1	Tower Foundation	0,047	0,000	0,000

Ratio - Design

#	Foundation name	Caisson Flexural
1	Tower Foundation	0,096

Results for Anchor Blocks

Ratio – Stability

#	Foundation name	Sliding	Uplift
1	Guy1	0,759	0,000
2	Guy2	0,608	0,869
3	Guy3	0,546	4,003

Ratio – Design

#	Foundation name	Flexural Front vertical	Flexural Front horizontal	Flexural Top longitudinal	Flexural Top transverse
1	Guy1	0,005	0,008	0,000	0,000
2	Guy2	0,003	0,008	0,108	0,029
3	Guy3	0,004	0,004	0,329	0,054

Detailed Results

The detailed results for each foundation or guy anchor block are displayed in tabs following the **Summary** tab. The tab name will correspond with the name entered in the **Geometry** window for each foundation or guy anchor block. These results can be saved as a PDF Document, Word Document or printed using the icons displayed beneath the tab name.

The detailed results displayed will vary with type.

Calculations

Main Analysis Types

Analysis Type	Description
Soil bearing capacity	Check the pressure under the foundation vs. the bearing resistance of soil to vertical loads and moments.
Overturning	Check the stability for rotation vs. the resistance to overturning forces.
Uplift	Check the foundation uplift vs. the resistance to uplift forces.
Sliding	Check the stability for sliding vs. the sliding resistance to lateral loads.
Design	Check the wide beam shear, punching shear, flexural reinforcement, pier shear and pier force transfer.

With the exception of reinforcement design, the analyses are conducted based on the principles of LRFD or ASD. The user selects of **Type of analysis**, **LRFD** or **ASD**, in the **Parameters** window.

Main Algorithm

Note: The following procedure may vary depending on the type of foundation.

1. Collect Data.
    - Base type, foundation type, number of foundations
    - Geometry for each foundation
    - Soil definition
    - Loads
    - Parameters
2. Calculate foundation and soil weight.
3. Calculate total vertical load as the sum of the vertical load, weight of the foundation and soil above.
4. Calculate the load eccentricity, common loads from all legs and loads acting on each pile.
5. Perform stability verifications.
    - Soil bearing capacity
    - Sliding
    - Overturning
    - Uplift / Compression
    - Caisson lateral capacity
6. Perform structural design.
    - One-Way (wide beam) shear
    - Punching (two-way) shear
    - Pad flexural reinforcement
    - Development length of bars
    - Pier shear
    - Pier force transfer
    - Axial and flexural pier capacity

Soil Bearing Capacity [Pad and Mat foundations]

Bearing capacity of the soil is a core limit state of foundation design and cannot be turned off during the design or analysis of a foundation.

The soil bearing ratio is calculated as a maximum pressure divided by the bearing capacity.

Ratio = Maximum Pressure / Bearing Capacity

Bearing Capacity

The bearing capacity is defined in 2 ways:

- Defined directly as **qall** (allowable bearing capacity) on the **Soils** window.
- Calculated on the basis of **qult** (ultimate bearing capacity).

The method of calculation depends on the type of analysis:

LRFD

qall = φ.b * qult

Where:

qall = Factored Bearing Resistance
qult = Nominal Bearing Capacity
φ.b = Resistance Factor for Soil Bearing

ASD

qall = qult / FS.b

Where:

qall = Allowable Bearing Capacity
qult = Ultimate Bearing Capacity
FS.b = Factor of Safety for Bearing

When the type of analysis is set to ASD, the loads should not be factored. The allowable bearing capacity (qall) is defined directly or by using the ultimate bearing capacity (qult) and the safety factor (SF).

When the type of analysis is set to LRFD, the loads should be factored. The allowable bearing capacity (qall) is defined directly as a factored value or by using the nominal bearing capacity (qult) and the resistance factor for soil bearing (φ.b).

If the type of analysis is set to LRFD and the user has been supplied an allowable bearing capacity (qall), the nominal bearing capacity (qult) should be qult = qall * SF.

Gross/Net

The allowable bearing capacity is typically supplied by the Geotechnical Engineer as either a gross or net allowable value. In the **Soils** window under each foundation tab, it can be defined by the user as **Gross** or **Net**.

When a gross soil pressure is specified, the load is compared directly against the allowable bearing (user entered value):

Allowable Bearing Capacity = qall (Gross)

When a net soil pressure is specified, the load is compared against a modified soil capacity. It is a sum of the allowable bearing (user-entered value) and the pressure from the soil weight at the foundation level divided by safety factor.

Allowable Bearing Capacity = qall (Net) + Soil Pressure / FS

Maximum Pressure

The maximum pressure is the maximum stress under the foundation (gross soil pressure). A linear model, not allowing for tensile stresses in the soil, is applied.

Stresses under the foundation are based on the total vertical load. This is the sum of the external loads, the weight of the foundation, and the overlying soils.

Vertical Loads

V = Vz + φ.bc * Foundation Weight + φ.bs * Soil Weight

Where:

Vz = Vertical load from the load combination. It is a load passing through the center of gravity of the foundation and is applied at the level of the support point.
Foundation Weight = The weight of the foundation. It is the sum of the weight of the pad and the pier.
Foundation Weight = Concrete Volume * Concrete density:
Soil Weight = The weight of soil above the pad or mat based on the vertical projection.
Soil Weight = Soil Volume above pad * Soil density
φ.bc = Load factor for foundation weight for soil bearing; (1.0 for ASD)
φ.bs = Load factor for soil weight for soil bearing; (1.0 for ASD)

The maximum stress is calculated by one of the following methods:

Effective area (uniform distribution of stress)

The maximum soil pressure is calculated using the reduced effective footing area A'. [AASHTO]

Effective Area:
A' = B' * L'
Effective Foundation Dimensions:
B' = B – 2 * |ez|
L' = L – 2 * |ex|
Maximum Pressure = Load / A'

Variable distribution of stress for one-way eccentricity, and effective area for two-way eccentricity

Method of determining the forces depends on the position of the load.

- Trapezoidal distribution of pressure for eccentricities less than L / 6 (load in kern):
  (6 * |ex| / L + 6 * |ez| / B) < 1 [100% of pad is compressed]
- Triangular distribution of pressure for one way eccentricity to value L / 3:
  L / 3 > |ex| >= L / 6 and ez = 0
  B / 3 > |ez| >= L / 6 and ex = 0
- Rectangular distribution of pressure for one way eccentricity to value L / 2:
  L / 2 > |ex| >= L / 3 and ez = 0
  B / 2 > |ez| >= L / 3 and ex = 0
- Effective uniform distribution of pressure for two way eccentricity:
  (6 * |ex| / L + 6 * |ez| / B) >= 1 and |ex| > 0, |ez| > 0, |ex| < L / 2, |ez| < B / 2

Variable distribution of stress

Detailed calculation method for two way eccentricity that determines the tension at the four corners of the foundation taking into account the stress redistribution in the presence of a partial detachment of the foundation.

Load eccentricities, ex and ez

ex = (Mz + Hx * (hf + h)) / V
ez = (Mx - Hz * (hf + h)) / V

Where:

Mx, Mz = Bending moments
Hx, Hy = Horizontal loads
V = Total vertical load

hf + h = Distance from Foundation level to top of the pier

Sliding [Pad and Mat foundations]

The sliding calculations check the possible soil damage caused by the sliding of the foundation footing on the soil in direct contact with the footing.

The lateral pressure caused by displacement of a foundation is not taken into account. Therefore, the active pressure from the soil is zero.

The user can select **Include passive pressure in sliding resistance** on the **Calculation Parameters** tab in the **Parameters** window.

The sliding ratio is calculated separately in both the x and z directions as the sum of applied sliding forces divided by the sum of the resisting forces.

Ratio = Sliding Force / Sliding Resistance

Sliding Resistance

The sliding resistance is the resisting force calculated as the sum of the shear resistance and passive resistance.

LRFD
Sliding Resistance = φ.s * ResistS + φ.p * ResistP

Where:
ResistS = Shear resistance between footing and soil
ResistP = Passive resistance (soil passive pressure acting at the side of the foundation)
φ.s = Resistance factor for friction
φ.p = Resistance factor for passive resistance

ASD
Sliding Resistance = ResistS / FS.s + ResistP / FS.p

Where:
ResistS = Shear resistance between footing and soil
ResistP = Passive resistance (soil passive pressure acting at the side of the foundation)
FS.s = Safety factor for friction
FS.p = Safety factor for passive resistance

Shear Resistance

ResistS = The shear resistance is a shear between the soil and foundation calculated at the foundation level (for soil existing under the foundation base).

The shear resistance can be calculated by using a defined friction coefficient value or by using soil parameters. The method selection is done under **Sliding**, **Use friction coefficient to calculate shear resistance** on the **Calculation Parameters** tab of the **Parameters** window.

If this option is selected, the shear resistance is determined based on the vertical loads and the friction coefficient. Otherwise it will be based on the soil parameters.

Shear Resistance based on Vertical Loads and Friction Coefficient
ResistS = Friction coefficient * V

Where:
Friction coefficient = the coefficient of friction between the bottom of the footing and the soil.
V = vertical load from the weight of the foundation and the soil above

Shear Resistance based on Soil Parameters, Cohesive Soil
ResistS = cu * Ac   for cohesive soil, soil internal friction angle $\phi = 0$

Where:

cu = soil cohesion
Ac = foundation-soil contact area

Shear Resistance based on Soil Parameters, Cohesionless Soil
ResistS = tan(ϕ) * V   for cohesionless soil, soil cohesion = 0

Where:
ϕ = internal friction angle of the soil at formation level
V = vertical load from the weight of the foundation and the soil above

Shear Resistance based on Soil Parameters, Silt
Use resistance from cohesion when internal angle of friction < 20º, otherwise use resistance from friction
ResistS = tan(ϕ) * V   for ϕ >= 20deg [silt] or cu = 0 [cohesionless soil]
ResistS = cu * Ac   for ϕ < 20deg [silt] or ϕ = 0 [cohesive soil]

Where:
ϕ = internal friction angle of the soil at the formation level
V = vertical load from the weight of the foundation and the soil above
cu = soil cohesion
Ac = foundation-soil contact area

Shear Resistance based on Soil Parameters, Silt
Use the smaller of resistance from cohesion or friction
Minimum of:
ResistS = tan(ϕ) * V
ResistS = cu * Ac

Where:
ϕ = internal friction angle of the soil at the formation level
V = vertical load from the weight of the foundation and the soil above
cu = soil cohesion
Ac = foundation-soil contact area

Shear Resistance based on Soil Parameters, Silt
Use sum of resistances from cohesion and friction
ResistS = tan(ϕ) * V + cu * Ac

Where:
ϕ = internal friction angle of the soil at the formation level
V = vertical load from the weight of the foundation and the soil above
cu = soil cohesion
Ac = foundation-soil contact area

Passive Resistance
The passive resistance, ResistP, is the soil passive pressure acting at the side of the foundation.

Passive Resistance
ResistP = Foundation Side Area * Earth Passive Pressure

Where:
Earth Passive Pressure = Kp* 1/2 *D *(qvtop+qvbot) + CohesionPart
qvtop = vertical stress at top of pad
qbot = vertical stress at bottom of pad
CohesionPart = 2 * cu * ($Kp^{0.5}$) * D
cu = soil cohesion
Kp = coefficient of passive lateral earth pressure
D = height of pad

Vertical Stress
Vertical stress is calculated as the sum of the soil weight from all layers above.

qv = $\sum(h * \gamma_{ef})$

Where:

qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_{w}$$

Sliding [Anchor Block]

The block sliding calculations check the possible soil damage caused by the sliding of the anchor block on the soil in direct contact with the footing.

The lateral pressure caused by displacement of a foundation is not taken into account. Therefore, the active pressure from the soil is zero.

The user can select **Include passive pressure in sliding resistance** on the **Calculation Parameters** tab in the **Parameters** window.

The sliding ratio is calculated in one direction, along the resultant of vertical the force (perpendicular to the front of the anchor block) as the applied sliding force divided by the sum of the resisting forces.

Ratio = Sliding Force / Sliding Resistance

Sliding Resistance

The sliding resistance is the resisting force calculated as the sum of the shear resistance and passive resistance.

LRFD

Sliding Resistance = φ.s * ResistS + φ.p * ResistP

Where:

ResistS = shear resistance between footing and soil
ResistP = passive resistance (soil passive pressure acting on the front side of the block)
φ.s = resistance factor for friction
φ.p = resistance factor for passive resistance

ASD

Sliding Resistance = ResistS / FS.s + ResistP / FS.p

Where:

ResistS = shear resistance between footing and soil
ResistP = passive resistance (soil passive pressure acting on the front side of the block)
FS.s = safety factor for friction
FS.p = safety factor for passive resistance

Shear resistance

The shear resistance is a shear between the block and soil.

Shear Resistance

ResistS = ResistTop + ResistSide + ResistWedge

Where:

ResistTop = The horizontal resistance from friction on the top of the block surface. It is calculated once for the soil level at the top of the block.
ResistSide = The horizontal resistance from friction on the sides of the block surfaces. It is the sum of all soil layers above the bottom of the block and below the top of the block.
ResistWedge = The friction force from the front soil wedge. It is calculated for cohesionless soil only. This component is optional. **Include friction acting on the inclined plane of front wedge** can be found under **Anchor Block/Sliding** on the **Calculation Parameters** tab of the **Parameters** window.

Shear Resistance on Top of Block, Cohesive Soil

ResistTop = AdhesionFactor *cu * L * B   for cohesive soil, soil internal friction angle ϕ = 0

Where:

AdhesionFactor = soil adhesion factor
cu = soil cohesion
L = block length
B = block width

Shear Resistance on Top of Block, Cohesionless Soil

ResistTop = tan(2/3 ϕ) * V   for cohesionless soil, soil cohesion = 0

Where:

ϕ = internal friction angle of the soil
V = weight of the vertical projection of the soil above the anchor block

Shear Resistance on Top of Block, Silt

Use resistance from cohesion when internal angle of friction < 20^o, otherwise use resistance from friction

ResistTop = tan(2/3 ϕ) * V   for ϕ >= 20deg [silt] or cu = 0 [cohesionless soil]
ResistTop = AdhesionFactor *cu * L * B   for ϕ < 20deg [silt] or ϕ = 0 [cohesive soil]

Where:

AdhesionFactor = soil adhesion factor
cu = soil cohesion
L = block length
B = block width
ϕ = internal friction angle of the soil
V = weight of the vertical projection of the soil above the anchor block

Shear Resistance on Top of Block, Silt

Use the smaller of resistance from cohesion or friction

Minimum of:

ResistTop = AdhesionFactor *cu * L * B
ResistTop = tan(2/3 ϕ) * V

Where:

AdhesionFactor = soil adhesion factor
cu = soil cohesion
L = block length
B = block width
ϕ = internal friction angle of the soil
V = weight of the vertical projection of the soil above the anchor block

Shear Resistance on Top of Block, Silt

Use sum of resistances from cohesion and friction

ResistTop = AdhesionFactor *cu * L * B + tan(2/3 ϕ) * V

Where:

AdhesionFactor = soil adhesion factor
cu = soil cohesion
L = block length
B = block width
ϕ = internal friction angle of the soil
V = weight of the vertical projection of the soil above the anchor block

Limiting Shear Resistance on Top of Block

The shear resistance of the top of the block cannot exceed the passive resistance acting on the soil plug directly above the top of the block.

Passive Pressure From Soil Above = Kp * V

Where:

Kp = soil coefficient of passive lateral earth pressure
V = weight of the vertical projection of the soil above the anchor block

Shear Reistance on Sides of Block

The horizontal resistance from the friction on the sides of the block is a sum for all soil layers above the bottom of the block and below the top of the block.

ResistSide = 2 * L * ∑ (AdhesionFactor * cu * h)

Where:

L = block length
AdhesionFactor = soil adhesion factor

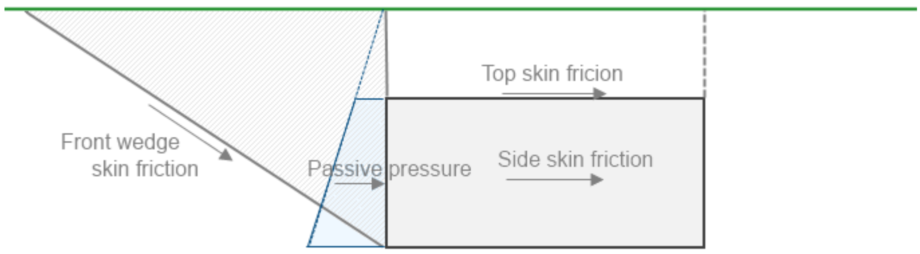
cu = soil cohesion
h = height of the soil layer

Shear Resistance from Front Soil Wedge
The friction force from the front soil wedge. It is calculated for cohesionless soil only. This component is optional.

ResistWedge = B * ∑ (h * cos(ϕ) * tan(ϕ) * qsoil)

Where:

B = block width
h = height of soil layer (for layers above the bottom of the block and below the top of the block)
ϕ = internal friction angle of the soil [user defined]
qsoil = pressure from soil at the midheight of the soil layer



Passive Resistance

The passive resistance is a resistance due to passive soil lateral bearing acting on the front side of the block. It is calculated as a sum of the passive pressure force for all soil layers above the bottom of block and below the top of block.

Passive Resistance
ResistP = B *D * Pp

Where:

B = block width
D = block height
Pp = Kp *(qvtop + qvbot) / 2 + 2 * cu * ($Kp^{0.5}$)
Pp = passive pressure acting on front side (linear value at unit height)
qvtop = vertical stress from soil weight at top level
qvbot = vertical stress from soil weight at bottom level
cu = soil cohesion
Kp = coefficient of passive lateral earth pressure

Vertical Stress
Vertical stress is calculated as the sum of the soil weight from all layers above.

qv = $\sum(h * \gamma_{ef})$

Where:

qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_w$$

Overturning [Pad and Mat foundations]

The overturning calculations determine the sum of overturning and stabilizing moments.

The overturning ratio is calculated separately in both the x and z directions as the sum of the overturning moments divided by the sum of the resisting moments. The worst case between the x and z directions is reported.

Ratio = Overturning moment / Resisting moment

Resisting moment

The Resisting moment is the sum of stabilizing moments about the rotation edge, including the moment due to the weight of the foundation and soil.

LRFD

Resisting moment = φ.o1 * Mresist.weight+ φ.o2 (Mresist.soil + Mresist.wedge) + φ.o3 * Mresist.cohesion + φ.o4 * Mresist.axial

Where:

φ.o1 = reduction factor for foundation weight
φ.o2 = reduction factor for soil weight
φ.o3 = reduction factor for soil cohesion
φ.o4 = reduction factor for vertical load

ASD

Resisting moment = (Mresist.weight + Mresist.soil + Mresist.wedge + Mresist.cohesion) / FS.o + Mresist.axial

Where:

FS.o = overturning Factor of safety

Resisting Moment from Foundation Weight

Mresist.weight = Foundation weight * 0.5 * Foundation width

Where:

Foundation weight = The weight of the foundation, including the pad and pier.

Resisting Moment from Soil Weight

Mresist.soil = Soil Vertical * 0.5 * Foundation width

Where:

Soil Vertical = The weight of the soil located directly above the foundation. The volume of the soil is reduced by volume of the pier(s).

Resisting Moment from Soil Wedges

Consider Weight of Soil Wedges and shear force from cohesion only at Non-Bearing Area (Not Selected) or Upward Vertical Load

The moment from the weight of the soil wedges above the foundation perimeter. Including the resisting moment from soil wedges is optional and can be found as **Include weight of soil wedges in overturning resistance** under **Overturning** on the **Calculations Parameters** tab in the **Parameters** window.

Mresist.wedge = Soil Wedge * Arm

Where:

Soil Wedge = The weight of soil wedges located around the full perimeter of the pad.
Soild Wedge = Wedges Volume around entire perimeter * Soil density
Arm = The distance from rotation point to the resultant of the soil wedges weight.
Arm = 0.5 * Foundation width

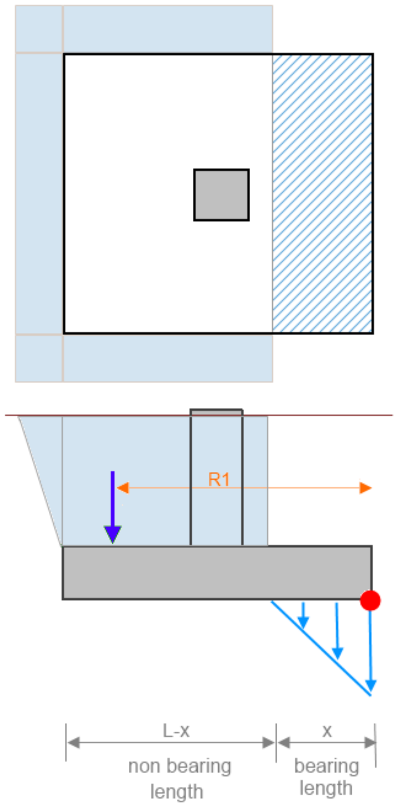
Resisting Moment from Soil Wedges

Consider Weight of Soil Wedges and shear force from cohesion only at Non-Bearing Area (Selected) and Downward Vertical Load
The moment from the weight of the soil wedges above the foundation perimeter. Including the resisting moment from soil wedges is optional and can be found as **Include weight of soil wedges in overturning resistance** under **Overturning** on the **Calculations Parameters** tab in the **Parameters** window.

Mresist.wedge = Soil Wedge * Arm

Where:

Soil Wedge = The weight of soil wedges around the non bearing part of the pad perimeter.
Soild Wedge = Wedges Volume around nonbearing pad perimeter * Soil density
Arm = R1, the distance from the rotation edge to resultant force from weight of soil wedges around the non bearing part of the pad perimeter.



<u>Resisting Moment from Cohesion</u>
Include shear force from cohesion in overturning resistance (Selected)
Consider Weight of Soil Wedges and shear force from cohesion only at Non-Bearing Area (Not Selected) or Upward Vertical Load
The moment from the shear force resulting from soil cohesion on the vertical plane at the pad perimeter. This component is optional and can be found as **Include shear force from cohesion in overturning resistance** under **Overturning** on the **Calculations Parameters** tab in the **Parameters** window. (The additional component, **Consider Weight of Soil Wedges and shear force from cohesion only at Non-Bearing Area**, is not selected or the vertical load is upward.)

Mresist.cohesion = Cohesion Resistance * Arm

Where:

Cohesion Resistance = Vertical shear force resulting from soil cohesion. It is calculated at vertical planes around the pad perimeter.
Cohesion Resistance = Foundation Perimeter * 0.5 * cu * Height
Foundation Perimeter = perimeter to calculate cohesion area

Foundation Perimeter = 4 * L
cu = soil cohesion
Height = distance from top of foundation level to the frost depth
Arm = distance from rotation point to the resultant of the cohesion shear force
Arm = 0.5 * Foundation width

Resisting Moment from Cohesion

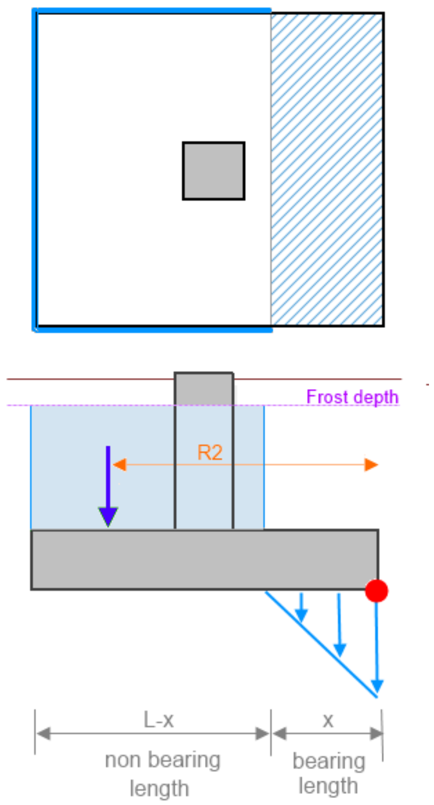
Include shear force from cohesion in overturning resistance (Selected) Consider Weight of Soil Wedges and shear force from cohesion only at Non-Bearing Area (Selected) and Downward Vertical Load

The moment from the shear force resulting from soil cohesion on the vertical plane at the pad perimeter. This component is optional and can be found as **Include shear force from cohesion** in overturning resistance under **Overturning** on the **Calculations Parameters** tab in the **Parameters** window. (The additional component, **Consider Weight of Soil Wedges and shear force from cohesion only at Non-Bearing Area**, is selected and the vertical load is downward.)

Mresist.cohesion = Cohesion Resistance * Arm

Where:

Cohesion Resistance = Vertical shear force resulting from soil cohesion. It is calculated at vertical planes around the pad perimeter.
Cohesion Resistance = Foundation Perimeter * 0.5 * cu * Height
Foundation Perimeter = perimeter to calculate cohesion area
Foundation Perimeter = L + 2 * (L – x)
x = Bearing length. It is calculated independently for the X and Z directions and is calculated separately for each load case
cu = soil cohesion
Height = distance from top of foundation level to the frost depth
Arm = distance from rotation point to the resultant of the cohesion shear force
Arm = R2, distance from the rotation edge to the resultant force from cohesion around the non-bearing part of the pad perimeter.



Resisting Moment from Vertical Load
Consider uplift vertical force as overturning (Selected or Not Selected) and Downward Vertical Load
Consider uplift vertical force as overturning (Not Selected) and Upward Vertical Load
The moment from the vertical load. This component is optional and can be found as **Consider uplift vertical force as overturning** under **Overturning** on the **Calculation Parameters** tab in the **Parameters** window.

Mresist.axial = Vertical force * 0.5 * Foundation width

Resisting Moment from Vertical Load
Consider uplift vertical force as overturning (Selected) and Upward Vertical Load
The moment from the vertical load. This component is optional and can be found as **Consider uplift vertical force as overturning** under **Overturning** on the **Calculation Parameters** tab in the **Parameters** window.

Mresist.axial = 0

Overturning moment

The Overturning moment is the sum of all applied moments, shears, and uplift forces that cause the footing to turn over.

LRFD
Mover = φ.o5 * Mover.loads - φ.o6 * Mover.passive

Where:
φ.o5 = load factor for overturning external loads
φ.o6 = reduction factor for passive pressure

ASD
Mover = Mover.loads / FS.o - Mover.passive / FS.o

Where:
FS.o = overturning Factor of safety

Overturning Moment from External Load
Consider uplift vertical force and overturning (Selected) and Upward Vertical Load
This option can be found under **Overturning** in the **Calculation Parameters** tab of the **Parameters** window.

Mover.loads = External Moment + Moment from Horizontal force + Moment from vertical load

Where:
Moment from vertical load = |Vertical force| * 0.5 * Foundation width

Overturning Moment from External Load
Consider uplift vertical force and overturning (Selected) and Downward Vertical Load
Consider uplift vertical force and overturning (Not Selected)
This option can be found under **Overturning** in the **Calculation Parameters** tab of the **Parameters** window.

Mover.loads = External Moment + Moment from Horizontal force + Moment from vertical load

Where:
Moment from vertical load = 0

Overturning Moment from Passive Pressure
Consider moment from passive pressure as reducing overturning moment (Selected) and Upward Vertical Load

This option can be found under **Overturning** in the **Calculation Parameters** tab of the **Parameters** window. The upward vertical load is calculated relative to the upper edge of the footing, Mpt. The rotation edge is at the bottom foundation level

Mover.passive = Mpt * Foundation width

Overturning Moment from Passive Pressure
Consider moment from passive pressure as reducing overturning moment (Selected) and Downward Vertical Load
This option can be found under **Overturning** in the **Calculation Parameters** tab of the **Parameters** window. The downward vertical load is calculated relative to the lower edge of the footing, Mp. The rotation edge is at the top foundation level

Mover.passive = Mp * Foundation width

Uplift [Pad and Mat foundation]

The uplift calculations check the possibility of complete detachment of the foundation due to the vertical force acting upwards.

The uplift ratio is calculated as an uplift force divided by an uplift resistance.

Ratio = Uplift Force / Uplift Resistance

Uplift Resistance

The uplift resistance is the resisting force to the upward vertical load. It is calculated as the sum of the resistance from the foundation, soil weight and the resistance from soil cohesion (optional).

LRFD

Uplift Resistance = φ.u1 *Foundation Weight + φ.u2 * Soil Weight + φ.u3* Uplift Cohesion Resistance

Where:

Foundation Weight = The sum of the pad and pier(s) weight.
Soil Weight = weight of soil
Uplift Cohesion Resistance = vertical resistance from soil cohesion
φ.u1 = load factor for foundation weight
φ.u2 = load factor for soil weight
φ.u3 = reduction factor for soil cohesion

ASD

Uplift Resistance = Foundation Weight / FS.c + Soil Weight / FS.s + Uplift Cohesion Resistance / FS.s

Where:

Foundation Weight = The sum of the pad and pier(s) weight.
Soil Weight = weight of soil
Uplift Cohesion Resistance = vertical resistance from soil cohesion
FS.s = safety factor for soil weight for uplift
FS.c = safety factor for foundation weight for uplift

Uplift Resistance from Soil Weight

It is the sum of weight of soil directly above the foundation pad and the weight of soil wedges around entire pad perimeter (optional). The option can be selected under **Uplift, Include weight of soil wedges around entire perimeter in the resistance**, on the **Calculation Parameters** tab in the **Parameters** window.

Soil Weight = Soil Vertical + Soil Wedge

Where:

Soil Vertical = weight of the soil directly above the pad
Soil Wedge = Weight of the soil wedges around the full perimeter of foundation. Calculated at the top of the foundation.

Uplift Resistance from Cohesion

Include shear force from skin friction and cohesion in the resistance (Selected)

Vertical resistance from soil cohesion calculated around entire pad perimeter for soil below the frost depth. The option can be selected under **Uplift** on the **Calculation Parameters tab** in the **Parameters** window.

Uplift Cohesion Resistance = Foundation Perimeter * 0.5 * cu * Height

Where:

Foundation Perimeter = perimeter to calculate the cohesion area
cu = soil cohesion
Height = distance from top of foundation level to the frost depth level

Uplift [Anchor Block]

The uplift calculations check the possibility of complete detachment of the foundation due to the vertical force acting upwards.

The uplift ratio is calculated as an uplift force divided by an uplift resistance.

Ratio = Uplift Force / Uplift Resistance

Uplift Resistance

The uplift resistance is the resisting force to the upward vertical load. It is calculated as the sum of the resistance from the foundation, soil weight and the resistance from soil cohesion (optional).

Uplift Resistance = φ.u1 *Foundation Weight + φ.u2 * Soil Weight + φ.u3* Uplift Cohesion Resistance

Where:

Foundation Weight = weight of the anchor block
Soil Weight = sum of the weight of soil directly above the block
Uplift Cohesion Resistance = vertical resistance from soil cohesion
φ.u1 = load factor for foundation weight
φ.u2 = load factor for soil weight
φ.u3 = reduction factor for soil friction

ASD
Uplift Resistance = Foundation Weight / FS.c + Soil Weight / FS.s + Uplift Cohesion Resistance / FS.r

Where:

Foundation Weight = weight of the anchor block
Soil Weight = = sum of the weight of soil directly above the block
Uplift Cohesion Resistance = vertical resistance from soil cohesion
FS.c = safety factor for foundation weight for uplift
FS.s = safety factor for soil weight for uplift
FS.r = safety factor for friction

Uplift Resistance from Skin Friction and Cohesion
Include shear force from skin friction and cohesion in the resistance (Selected)
Vertical resistance from soil cohesion below the frost depth and skin friction. It is the sum for all soil layers above the bottom of the block and below the frost depth. The option can be selected under **Anchor Block, Uplift** on the **Calculation Parameters** tab in the **Parameters** window.

Uplift Cohesion Resistance = CohesionPart + SkinFrictionPart

Uplift Resistance from Cohesion (CohesionPart)
It is the vertical resistance from the soil cohesion around the front and side surfaces of the anchor block and for soil above the full perimeter of the block below the frost depth.

For soil layers above the bottom of the anchor block and below the top of the block:
CohesionPart = PerimeterFront * ∑ (AdhesionFactor *cu * h)

For soil layers above the top of the block and below the frost depth:
CohesionPart = PerimeterTop * ∑ (0.5 * cu * h)

Where:

PerimeterFront = 2 * L + B
PerimeterTop = 2 * (L + B)
AdhesionFactor = soil adhesion factor
cu = soil cohesion
h = height of soil layer

Uplift Resistance from Cohesion (SkinFrictionPart)

It is the vertical resistance from skin friction at the front face of the anchor block.

For soil layers above the bottom of the anchor block and below the top of the block:
SkinFrictionPart = ∑ [B * 0.7 * tan(ϕ) * Kp * qsoil]

For soil layers above the top of the block and below the frost depth:
SkinFrictionPart = 0

Where :

B = anchor block width
ϕ = internal friction angle of the soil
Kp = coefficient of passive lateral earth pressure
qsoil = pressure from soil at midheight of soil layer

Vertical Stress
Vertical stress is calculated as the sum of the soil weight from all layers above.

qsoil = 0.5 * (qvtop + qvbot)
qv = $\sum(h * \gamma_{ef})$

Where:

qvtop = vertical stress from soil weight at top level
qvbot = vertical stress from soil weight at bottom level
qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_w$$

Single Pile Tension Capacity [Foundations with Piles]

The single pile tension verification checks the possibility of pull out of the single pile due to the action of the vertical force in a single pile acting upwards.

The ratio is calculated as an uplift force divided by tension resistance.

Ratio = Uplift Force in Pile / Tension Resistance

The uplift force in the pile is the maximum uplift force determined from all piles.

Tension Resistance

The tension resistance is the force resisting the upward vertical load, and is calculated as the cumulative skin friction resistance. It can be user defined or calculated. If **Calculate bearing and tension capacity of the pile** is not selected under **Piles Capacity** on the **Calculation Parameters** tab in the **Parameters** window, the user can define it as the **Pile tension capacity** directly below.

LRFD

Tension Resistance = φ.sid.t* Pile Shaft Resistance

Where:

φ.sid.t = resistance factor for uplift
Pile Shaft Resistance = vertical shaft resistance of the pile due to skin friction

ASD

Minimum of:

Tension Resistance = Pile Shaft Resistance / FS.gt
Tension Resistance = Pile Shaft Resistance / FS.st

Where:

FS.gt = global safety factor for Uplift
FS.st = safety factor for shaft resistance for Uplift
Pile Shaft Resistance = vertical shaft resistance of pile due to skin friction

Pile Shaft Resistance

Vertical shaft resistance of pile due to skin friction. It is the sum of the incremental external skin friction for soil layers from bottom of the pad to the bottom of the pile. The unit external skin friction can be calculated or user defined. If **Calculate unit skin friction (fs) and unit end bearing (qb)** is not selected under **Piles Capacity** on the **Calculation Parameters** tab in the **Parameters** window, the user can define the values in the **Soils** window.

Qs = Pe * dh * fs

Where:

Qs = The incremental external skin friction accumulated within a soil layer outside the pile.
Pe = external perimeter of the pile
dh = the thickness of the soil layer
fs = unit external skin friction in layer

External Skin Friction

The unit external skin friction, fs**,** is calculated according to two basic methods: the total stress or alpha method and the effective stress or beta method. The methods are selected automatically, according to soil internal angle of friction.

Total Stress Method:
fs = fs_alfa if $\phi <$ 20 [deg]
fs_alfa = $\alpha * $ cu

Effective Stress Method:
fs = fs_beta if $\phi >=$ 20 [deg]

fs_beta = Kt * tan(δ) * qsoil

Where:

α = adhesion factor
cu = soil cohesion
Kt = coefficient for lateral earth pressure
δ = friction angle between the soil and the pile
qsoil = vertical stress from soil at mid height of soil layer

Vertical Stress

Vertical stress is calculated as the sum of the soil weight from all layers above.

qsoil = 0.5 * (qvtop + qvbot)
qv = $\sum(h * \gamma_{ef})$

Where:

qvtop = vertical stress from soil weight at top level
qvbot = vertical stress from soil weight at bottom level
qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_{w}$$

Single Pile Compression Capacity [Foundations with Piles]

The single pile compression verification checks the soil resistance to compression of the single pile due to the vertical force in a single pile acting downwards.

The ratio is calculated as a compression force divided by compression resistance.

Ratio = Compression Force in Pile / Compression Resistance

The compression force in the pile is the maximum compression force determined from all piles.

Compression Resistance

The compression resistance is the force resisting the downward vertical load, and is calculated as the cumulative skin friction resistance and pile base resistance.

LRFD

Compression Resistance = φ.sid.c * Pile Shaft Resistance + φ.bas.c * Pile Base Resistance

Where:

φ.sid.c = resistance factor for compression
Pile Shaft Resistance = vertical shaft resistance of pile due to skin friction
φ.bas.c =resistance factor for base resistance for compression
Pile Base Resistance = pile end bearing resistance

ASD

Minimum of:

Compression Resistance = (Pile Shaft Resistance + Pile Base Resistance) / FS.gc
Compression Resistance = Pile Shaft Resistance / FS.sc + Pile Base Resistance / FS.bc

Where:

FS.gc = global safety factor for Compression
FS.sc = safety factor for shaft resistance for Compression
FS.bc = safety factor for base resistance for Compression
Pile Shaft Resistance = vertical shaft resistance of pile due to skin friction
Pile Base Resistance = pile end bearing resistance

Pile Shaft Resistance

Vertical shaft resistance of pile due to skin friction. It is the sum of the incremental external skin friction for soil layers from the bottom of the pad to the bottom of the pile. The unit external skin friction can be calculated or user defined. If **Calculate unit skin friction (fs) and unit end bearing (qb)** is not selected under **Piles Capacity** on the **Calculation Parameters** tab in the **Parameters** window, the user can define the values in the **Soils** window.

Qs = Pe * dh * fs

Where:

Qs = The incremental external skin friction accumulated within a soil layer outside the pile.
Pe = external perimeter of the pile
dh = the thickness of the soil layer
fs = unit external skin friction in layer

External Skin Friction

The unit external skin friction, fs**,** is calculated according to two basic methods: the total stress or alpha method and the effective stress or beta method. The methods are selected automatically, according to soil internal angle of friction.

Total Stress Method:
fs = fs_alfa if $\phi <$ 20 [deg]
fs_alfa = $\alpha * $ cu

Effective Stress Method:
fs = fs_beta if ϕ >= 20 [deg]
fs_beta = Kt * tan(δ) * qsoil

Where:
- α = adhesion factor
- cu = soil cohesion
- Kt = coefficient for lateral earth pressure
- δ = friction angle between the soil and the pile
- qsoil = vertical stress from soil at mid height of soil layer

Pile Base Resistance
Pile base resistance due to soil bearing. It is calculated for the soil level at the bottom of the pile.

Qb = qb * Ap

Where:
- Qb = is the end bearing capacity
- qb = unit end bearing stress
- Ap = the cross-sectional area of the pile base

Unit End Bearing Stress
The unit end bearing stress is calculated according to two basic methods: the total stress and the effective stress methods. The method is selected automatically, according to soil internal angle of friction. If **Calculate end bearing capacity factors (Nc and Nq)** is not selected under **Piles Capacity** in the **Calcualtion Parameters** tab of the **Parameters** window, the user can define the values in the **Soils** window.

Total Stress:
qb= qb_total if ϕ < 20 [deg]
qb_ total = Nc * cu

Effective Stress:
qb=qb_effective if ϕ >=20 [deg]
qb_ effective = Nq * σv

Where:
- Nc = bearing capacity factor Nc
- cu = soil cohesion
- Nq = bearing capacity factor Nq
- qv = the vertical effective stress at the pile base of the layer being considered

Vertical Stress
Vertical stress is calculated as the sum of the soil weight from all layers above.

qsoil = 0.5 * (qvtop + qvbot)
qv = $\sum(h * \gamma_{ef})$

Where:
- qvtop = vertical stress from soil weight at top level
- qvbot = vertical stress from soil weight at bottom level
- qv = vertical stress from soil weight at h level
- h = height of soil
- γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_w$$

Bearing Capacity Factors Nc and Nq

$Nq = e^{\pi * \tan(\phi)} * \tan^2(45 + \phi / 2)$

$Nc = 5.7$ if $\phi = 0$ [deg]
$Nc = (Nq - 1) * \cot(\phi)$ if $\phi > 0$ [deg]

Where:

ϕ = internal friction angle of the soil

Pile Group Tension Capacity [Foundations with Piles]

The pile group tension verification checks the possibility of pull out of the pile group due to the action of the resultant vertical force acting upwards.

The ratio is calculated as the uplift force divided by then tension resistance.

Ratio = Uplift Force / Tension Resistance

The uplift force is the maximum uplift force acting on the pad.

Tension Resistance

The tension resistance for the pile group is calculated per the selection made in the **Group of piles** section of the **Calculation Parameters** tab in the **Parameters** window.

a reduced sum of individual piles capacity
The tension pile group reduction factor is defined under **Group of piles, Reduction factor for a sum of pile capacity – tension** on the **Calculation Parameters** tab of the **Parameters** window.

Tension Resistance = nl * rtf * Single Pile Tension Resistance

Where:
nl = total number of piles
rft = pile group tension reduction factor
Single Pile Tension Resistance = tension resistance for one pile

one rigid pile capacity
The pile group is considered to be a block. The capacity is based on the single pile capacity but with the pile dimensions equal to the external dimensions of the group.

the lesser of a reduced sum of individual piles capacity and one rigid pile capacity
Capacity is taken as the smaller value from the values calculated by the two methods above.

Pile Group Compression Capacity [Foundations with Piles]

The pile group compression verification checks the soil resistance to the compression of the pile group due to the resultant vertical force acting downwards.

The ratio is calculated as the compression force divided by the compression resistance.

Ratio = Compression Force / Compression Resistance

The compression force is the maximum downward force acting on the pad.

Compression Resistance

The compression resistance for the pile group is calculated per the selection made in the **Group of piles** section of the **Calculation Parameters** tab in the **Parameters** window.

a reduced sum of individual piles capacity

The compression pile group reduction factor is defined under **Group of piles, Reduction factor for a sum of pile capacity – bearing** on the **Calculation Parameters** tab of the **Parameters** window.

Compression Resistance = nl * rtc * Single Pile Compression Resistance

Where:

nl = total number of piles
rfc = pile group compression reduction factor
Single Pile Compression Resistance = compression resistance for one pile

one rigid pile capacity

The pile group is considered to be a block. The capacity is based on the single pile capacity but with the pile dimensions equal to the external dimensions of the group.

the lesser of a reduced sum of individual piles capacity and one rigid pile capacity

Capacity is taken as the smaller value from the values calculated by the two methods above.

Pile Axial Structural Resistance [Foundations with Piles]

The single pile compression verification checks the soil resistance to compression of the single pile due to the action of the vertical force in a single pile acting downwards.

The ratio is calculated as a compression force divdided by compression resistance.

Ratio = Axial Force in Pile / Structural Resistance

The axial force in the pile is the maximum axial load acting on single pile.

Structural Resistance

The structural resistance is the steel pile structural resistance to axial forces.

Structural Resistance
Structural Resistance = φ.cp * PileFy * PileArea

where

φ.cp = resistance factor for steel piles in compression
PileFy = steel strength fy of steel piles
PileArea = pile cross section area

Caisson Compression Capacity [Caisson]

The caisson compression verification checks the soil resistance to compression due to the vertical force acting downwards.

The ratio is calculated as a compression force divided compression resistance.

Ratio = Compression Force in Pile / Compression Resistance

The compression force is the maximum compression force acting on the caisson.

Compression Resistance

The compression resistance is the force resisting the downward vertical load, and is calculated as the cumulative skin friction resistance and caisson base resistance.

LRFD

Compression Resistance = φ.sid.c * Caisson Shaft Resistance + φ.bas.c * Caisson Base Resistance

Where:

φ.sid.c = resistance factor for shaft resistance
Caisson Shaft Resistance = vertical shaft resistance of caisson due to skin friction
φ.bas.c – resistance factor for base resistance
Caisson Base Resistance = caisson end bearing resistance

ASD

Minimum of:
Compression Resistance = (Caisson Shaft Resistance + Caisson Base Resistance) / FS.gc
Compression Resistance = Caisson Shaft Resistance / FS.sc + Caisson Base Resistance / FS.bc

Where:

Caisson Shaft Resistance = vertical shaft resistance of caisson due to skin friction
Caisson Base Resistance = caisson end bearing resistance
FS.gc = global safety factor for Compression
FS.sc = safety factor for shaft resistance for Compression
FS.bc = safety factor for base resistance for Compression

Caisson Shaft Resistance

The vertical shaft resistance of the caisson due to skin friction. It is the sum of the incremental external skin friction for soil layers along the caisson length. The unit external skin friction can be calculated or user defined. If **Calculate unit skin friction (fs) and unit end bearing (qb)** is not selected under **Caisson parameters** on the **Calculation Parameters** tab in the **Parameters** window, the user can define the values in the **Soils** window.

Qs = Pe * dh * fs

where:

Qs = The incremental external skin friction accumulated within a soil layer outside the pile.
Pe = external perimeter of the caisson
dh = the thickness of soil layer
fs = unit external skin friction in layer

External Skin Friction

The unit external skin friction, fs**,** is calculated according to two basic methods: the total stress or alpha method and the effective stress or beta method. The methods are selected automatically, according to soil internal angle of friction.

Total Stress Method:
fs = fs_alfa if $\phi <$ 20 [deg]
fs_alfa = $\alpha *$ cu

Effective Stress Method:
fs = fs_beta if ϕ >= 20 [deg]
fs_beta = Kt * tan(δ) * qsoil

Where:
α = adhesion factor
cu = soil cohesion
Kt = coefficient for lateral earth pressure
δ = friction angle between the soil and the pile
qsoil = vertical stress from soil at mid height of soil layer

Vertical Stress
Vertical stress is calculated as the sum of the soil weight from all layers above.

qsoil = 0.5 * (qvtop + qvbot)
qv = $\sum(h * \gamma_{ef})$

Where:
qvtop = vertical stress from soil weight at top level
qvbot = vertical stress from soil weight at bottom level
qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_w$$

The value of Qs is calculated by taking into account each soil layer located between the Top Neglect Level and the Bottom Neglect Level.

Neglect Levels, Cohesive Soil
Belled Caisson
Compression Load
Top Neglect Level = Max(3ft, Frost Depth)
Bottom Neglect Level = hf – D – Hb
Uplift Load
Top Neglect Level = Frost Depth
Bottom Neglect Level = hf

Straight Caisson
Compression Load
Top Neglect Level = Max(3ft, Frost Depth)
Bottom Neglect Level = hf – Min(D, 5ft)
Uplift Load
Top Neglect Level = Max(3ft, Frost Depth)
Bottom Neglect Level = hf

Where:
D = diameter of the caisson
hf = caisson end level
Hb = height of the bell

Neglect Levels, Cohesionless Soil
Belled Caisson
Compression Load
Top Neglect Level = Max(0.5 * D, Frost Depth)
Bottom Neglect Level = hf – Hb
Uplift Load
Top Neglect Level, Qs = 0 for all layers

Bottom Neglect Level, Qs = 0 for all layers

Straight Caisson
Compression Load
Top Neglect Level = Max(0.5 * D, Frost Depth)
Bottom Neglect Level = hf
Uplift Load
Top Neglect Level = Max(0.5 * D, Frost Depth)
Bottom Neglect Level = hf

Where:
D = diameter of the caisson
hf = caisson end level
Hb = height of the bell

Caisson Base Resistance
Caisson base resistance due to soil bearing. It is calculated for the soil level at the bottom of the pile.

Qb = qb * Ap

Where:
Qb = is the end bearing capacity
qb = unit end bearing stress
Ap = the cross-sectional area of the pile base

Unit End Bearing Stress
The unit end bearing stress is calculated according to two basic methods: the total stress and the effective stress methods. The method is selected automatically, according to soil internal angle of friction. If **Calculate end bearing capacity factors (Nc and Nq)** is not selected under **Caisson parameters** in the **Calcualtion Parameters** tab of the **Parameters** window, the user can define the values in the **Soils** window.

Total Stress:
qb= qb_total　　　　　if $\phi <$ 20 [deg]
qb_ total = Nc * cu

Effective Stress:
qb=qb_effective　　　　　if ϕ >=20 [deg]
qb_ effective = Nq * σv

Where:
Nc = bearing capacity factor Nc
cu = soil cohesion
Nq = bearing capacity factor Nq
qv = the vertical effective stress at the pile base of the layer being considered

Vertical Stress
Vertical stress is calculated as the sum of the soil weight from all layers above.

qsoil = 0.5 * (qvtop + qvbot)
qv = $\sum(h * \gamma_{ef})$

Where:
qvtop = vertical stress from soil weight at top level
qvbot = vertical stress from soil weight at bottom level
qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_w$$

Bearing Capacity Factors Nc and Nq

$Nq = e^{\pi * \tan(\phi)} * \tan^2(45 + \phi / 2)$

$Nc = 5.7$	if $\phi = 0$ [deg]
$Nc = (Nq - 1) * \cot(\phi)$	if $\phi > 0$ [deg]

Where:

ϕ = internal friction angle of the soil

Caisson Uplift Capacity [Caisson]

The caisson uplift verification checks the possibility of pull out of the caisson due to the vertical force acting upwards.

The ratio is calculated as an uplift force divided by uplift resistance.

Ratio = Uplift Force / Uplift Resistance

The uplift force is the maximum external uplift force.

Uplift Resistance

The uplift resistance is the force resisting the upward vertical load, and is calculated as the cumulative skin friction resistance, caisson weight and soil weight (for belled caissons).

LRFD

Uplift Resistance = φ.sid.t * Caisson Shaft Resistance + φ.u1 * Caisson Weight + φ.u2 * Soil Weight

where:

φ.sid.t = resistance factor for uplift
Caisson Shaft Resistance = vertical shaft resistance of caisson due to skin friction
φ.u1 = uplift reduction factor for foundation weight
Caisson Weight = weight of caisson
φ.u2 = uplift reduction factor for soil weight
Soil Weight = weight of soil, for belled caissons only

ASD

Minimum of:

Uplift Resistance = (Caisson Shaft Resistance + Caisson Weight + Soil Weight) / FS.gt
Uplift Resistance = Caisson Shaft Resistance / FS.st + Caisson Weight / FS.uc + Soil Weight / FS.us

Where:

Caisson Shaft Resistance = vertical shaft resistance of caisson due to skin friction
Caisson Weight = weight of caisson
Soil Weight = weight of soil, for belled caissons only
FS.gt = global safety factor
FS.st = safety factor for shaft resistance in uplift
FS.uc = safety factor for concrete weight in uplift
FS.us = safety factor for soil weight in uplift

Caisson Shaft Resistance

The vertical shaft resistance of caisson due to skin friction. It is the sum of the incremental external skin friction for soil layers along the caisson length. The unit external skin friction can be calculated or user defined. If **Calculate unit skin friction (fs) and unit end bearing (qb)** is not selected under **Caisson parameters** on the **Calculation Parameters** tab in the **Parameters** window, the user can define the values in the **Soils** window.

Qs = Pe * dh * fs

where:

Qs = The incremental external skin friction accumulated within a soil layer outside the pile.
Pe = external perimeter of the caisson
dh = the thickness of soil layer
fs = unit external skin friction in layer

External Skin Friction

The unit external skin friction, fs**,** is calculated according to two basic methods: the total stress or alpha method and the effective stress or beta method. The methods are selected automatically, according to soil internal angle of friction.

Total Stress Method:
fs = fs_alfa if $\phi <$ 20 [deg]
fs_alfa = $\alpha * cu$

Effective Stress Method:
fs = fs_beta if $\phi >=$ 20 [deg]
fs_beta = Kt * tan(δ) * qsoil

Where:

α = adhesion factor
cu = soil cohesion
Kt = coefficient for lateral earth pressure
δ = friction angle between the soil and the pile
qsoil = vertical stress from soil at mid height of soil layer

Vertical Stress

Vertical stress is calculated as the sum of the soil weight from all layers above.

qsoil = 0.5 * (qvtop + qvbot)
qv = $\sum(h * \gamma_{ef})$

Where:

qvtop = vertical stress from soil weight at top level
qvbot = vertical stress from soil weight at bottom level
qv = vertical stress from soil weight at h level
h = height of soil
γ_{ef} = effective unit weight of soil

The effective unit weight of soil for the dry condition is equal to dry unit weight of the soil:

$$\gamma_{ef} = \gamma_{dry}$$

For soil with ground water, the effective unit weight of the soil is equal to the saturated unit weight of soil minus unit weight of water:

$$\gamma_{ef} = \gamma_{sat} - \gamma_w$$

The value of Qs is calculated by taking into account each soil layer located between the Top Neglect Level and the Bottom Neglect Level.

Neglect Levels, Cohesive Soil

Belled Caisson
- Compression Load
  - Top Neglect Level = Max(3ft, Frost Depth)
  - Bottom Neglect Level = hf – D – Hb
- Uplift Load
  - Top Neglect Level = Frost Depth
  - Bottom Neglect Level = hf

Straight Caisson
- Compression Load
  - Top Neglect Level = Max(3ft, Frost Depth)
  - Bottom Neglect Level = hf – Min(D, 5ft)
- Uplift Load
  - Top Neglect Level = Max(3ft, Frost Depth)
  - Bottom Neglect Level = hf

Where:

D = diameter of the caisson
hf = caisson end level
Hb = height of the bell

Neglect Levels, Cohesionless Soil

Belled Caisson

Compression Load

Top Neglect Level = Max(0.5 * D, Frost Depth)

Bottom Neglect Level = hf – Hb

Uplift Load

Top Neglect Level, Qs = 0 for all layers

Bottom Neglect Level, Qs = 0 for all layers

Straight Caisson

Compression Load

Top Neglect Level = Max(0.5 * D, Frost Depth)

Bottom Neglect Level = hf

Uplift Load

Top Neglect Level = Max(0.5 * D, Frost Depth)

Bottom Neglect Level = hf

Where:

D = diameter of the caisson

hf = caisson end level

Hb = height of the bell

Caisson Weight

The weight of the concrete. It is the caisson volume multiplied by the concrete self weight.

Soil Weight, Cohesive Soil

The weight of soil tube or cone above the caisson bell. For straight caissons, the soil weight is zero.

The soil volume is calculated for a tube with an internal diameter equal to the caisson diameter and constant outer diameter. For a single cohesive soil layer, the outer tube diameter is equal to the bell diameter. For multilayered soil, the outer tube diameter in cohesive soil layer is equal to the diameter of the soil tube or cone determined at the top of the lower soil layer.

Soil Weight, Cohesionless Soil

The weight of the soil tube or cone above the caisson bell. For straight caissons, the soil weight is zero.

The soil volume is calculated with a linearly increasing outer diameter creating a cone. The top diameter is equal to the base diameter + 2 * tan(ϕ) * layer height. For a single cohesionless soil layer, the base diameter is equal to the bell diameter. For multilayered soil, the outer base diameter in cohesionless soil layers equals to the diameter of the soil tube or cone determined at the top of the lower soil layer.

Caisson Lateral Capacity – Broms' method [Caisson]

The caisson lateral verification checks the possibility of overturning of the caisson due to the lateral force acting at the top of the caisson. The selection of Broms' method is made under **Caisson parameters, Lateral Capacity – Broms' method** on the **Calculation Parameters** tab of the **Parameters** window.

The ratio is calculated as a lateral force divided by a lateral resistance.

Ratio = Lateral Force / Lateral Resistance

Lateral Force

It is the maximum of the resultant force calculated in two directions: the direction of the resultant horizontal force and the direction of the resultant moment.

Resultant Horizontal Force

Lateral Force $= (Hx^2 + Hz^2)^{0.5}$

Where:

Hx, Hz = horizontal forces

Resultant Moment

Lateral Force = MM *(|Hx / Mx| + |Hz / Mz|)

Where:

MM = resultant bending moment
$MM = (Mx^2 + Mz^2)^{0.5}$
Hx, Hz = horizontal forces
Mx, Mz = bending moments

Lateral Resistance

The lateral resistance is force resisting the lateral load at the top of the caisson.

LRFD

Lateral Resistance = φ.sid.L* Caisson Lateral Resistance

Where:

φ.sid.L = side resistance factor
Caisson Lateral Resistance = resistance of caisson due to lateral forces

ASD

Lateral Resistance = Caisson Lateral Resistance / FS.L

Where:

Caisson Lateral Resistance = resistance of caisson due to lateral forces
FS.L = safety factor for lateral capacity

Caisson Lateral Resistance

Horizontal resistance of caisson due to lateral forces calculated according to Broms' method. Broms developed lateral capacity methods for both short and long piles in cohesive and cohesionless soil. The ultimate lateral load capacity of a caisson defines a loading condition in which a caisson can fail with the development of a plastic hinge (long caisson) or by unlimited deflection (short caisson).

Calculations are performed for a single soil layer. Multiple soil layers are not available.

There are two paths:

- calculations for cohesive soil if $\phi <$ 20 [deg]
- calculations for cohesionless soil if $\phi >=$ 20 [deg]

In both cases, the analysis is performed parallel for two variants:

- assuming that the caisson is long free headed
- assuming that the caisson is short free headed

The path selected is the one that gives worse results (higher ratio).

Bending Moment, Cohesive Soil
Maximum bending moment along the caisson.

Mmax = V * (e + 1.5 * D + 0.5 * f)
f = V / (9 * cu * D)

Where:

Mmax = max moment in caisson
V = resultant horizontal force
e = load eccentricity in direction of resultant horizontal force
f = distance from ground level to max moment in caisson
cu = soil cohesion
D = caisson diameter

Bending Moment, Cohesionless Soil
Mmax = V * (e + f * 2/3)
f = sqrt (V / (1.5 * gsoil * D * Kp))

Where:

Mmax = max moment in caisson
V = resultant horizontal force
e = load eccentricity in direction of resultant horizontal force
f = distance from ground level to max moment in caisson
cu = soil cohesion
gsoil = soil effective unit weight
D = caisson diameter
Kp = soil passive pressure coefficient

Caisson Lateral Capacity – p-y method [Caisson]

The p-y analysis is based on a numerical solution of differential equations describing the behavior of a beam with nonlinear support. The caisson is treated as a beam-column and the soil is replaced with nonlinear Winkler-type mechanisms. The selection of the p-y method is made under **Caisson parameters, Lateral Capacity – p-y method** on the **Calculation Parameters** tab of the **Parameters** window.

The nonlinear support springs are characterized by one p-y curve at each nodal point. The p-y curves give the relation between the integral value P of the mobilized resistance from the surrounding soil when the pile deflects a distance Y laterally.

The solution of caisson displacements and pile stresses at any point along the pile for any applied load at the caisson head results from the solution to the differential equation of the caisson.

This method allows you to define multiple layers of soil. For each soil layer an additional set of parameters dedicated to the p-y analysis must be specified. One of the key parameters is the p-y curve.

There are several methods available for the representation of the p-y curves that are essential in solving the differential equations for a laterally loaded pile.

List if available procedures for the p-y curve:

- **Soil Clay (Matlock) – with free water**
  - Describes the response of soft clay in the presence of free water by Matlock, for static loading and for cyclic loading.

<u>Soft Clay (Matlock) – with free water, static loading</u>

Curve definition:

for y >= 8 * y50

p = pu

for y < 8 * y50

$$p = pu * 0.5 * \sqrt[3]{\frac{y}{y50}}$$

Where:

p = soil resistance
pu = Ultimate soil resistance
pu = min(pu1, pu2)
pu1 = 9 * cu * b
pu2 = 3 * cu * b + gamma * b * z + 0.5 * cu * z
y = deflection
y50 = deflection at one-half the ultimate soil resistance
y50 = 2.5 * e50 * b
z = depth level
cu = undrained shear strength at depth z
b = diameter of the caisson
gamma = soil effective unit weight
e50 = the strain corresponding to one-half of the maximum principal stress difference

<u>Soft Clay (Matlock) – with free water, cyclic load</u>

Curve definition:

for y < 3 * y50

$$p = min\left(0.72 * pu,\ pu * 0.5 * \sqrt[3]{\frac{y}{y50}}\right)$$

for 3 * y50 <= y < 15 * y50

z >= xr; p = 0.72 * pu

z < xr; $p = 0.72 * pu * \frac{1}{12} * \left(\frac{y}{y50} * \left(\frac{x}{xr} - 1\right) + 3 * \left(5 - \frac{x}{xr}\right)\right)$

for y >= 15 * y50

z >= xr; p=0.72*pu

z < xr; $p = 0.72 * pu * \frac{x}{xr}$

Where:

pu = Ultimate soil resistance
pu = min(pu1, pu2)
pu1 = 9 * cu * b
pu2 = 3 * cu * b + gamma * b * z + 0.5 * cu * z
y50 = deflection at one-half the ultimate soil resistance
y50 = 2.5 * e50 * b
xr = transition depth
xr = max(2.5 * b, $\frac{6 * \mathrm{cu} * \mathrm{b}}{\mathrm{gamma} * \mathrm{b} + 0.5 * \mathrm{cu}}$)

- **Stiff Clay (Reese) – with free water**
  - Describes the response of stiff clay in the presence of free water by Reese, for static loading and for cyclic loading.

Stiff Clay (Reese) – with free water, static load

Curve definition:

for 0 < y <= to intersection with next curve

$$\mathrm{p} = \mathrm{k} * y$$

from intersection < y <= As * y50

$$\mathrm{p} = \mathrm{pu} * 0.5 * \sqrt[2]{\frac{y}{y50}}$$

for As * y50 < y <= 6 * As * y50

$$\mathrm{p} = \mathrm{pu} * 0.5 * \sqrt[2]{\frac{y}{y50}} - 0.055 * pu + \left(\frac{y - As * y50}{As * y50}\right)^{1.25}$$

for 6 * As * y50 < y <= 18 * As * y50

$$\mathrm{p} = \mathrm{pu} * 0.5 * \sqrt[2]{6 * As} - 0.411 * pu - \frac{0.0625}{y50} * pu * (y - 6 * As * y50)$$

for y > 18 * As * y50

$$\mathrm{p} = \mathrm{pu} * 0.5 * \sqrt[2]{6 * As} - 0.411 * pu - 0.75 * pu * As$$

Where:

pu = Ultimate soil resistance
pu = min(pu1, pu2)
pu1 = 11 * cu * b
pu2 = 2 * ca * b + gamma * b * z + 2.83 * ca * z
ca = the average undrained shear strength over the depth z
y50 = deflection at one-half the ultimate soil resistance
y50 = e50 * b
As = coefficient
for z < 4 * b
As = 0.01 * $(z / b)^3$ – 0.09 * $(z / b)^2$ + 0.3 * z / b + 0.2
for z >= 4 * b
As = 0.6
k = initial stiffness [pci], Value can be user defined or calculated based on the selection made under **P-Y Analysis Settings**, **Initial stiffness is calculated** on the **Calculation Parameters** tab of the **Parameters** window. If not selected, the value can be defind in the **Soils** window.
k = (30 * ca / 144 + 360) * 1728, [ca in psf]

Stiff Clay (Reese) – with free water, cyclic load

Curve definition:

for 0 < y <= to intersection with next curve

$$\mathrm{p} = \mathrm{k} * y$$

for from intersection < y <= 0.6 * yp

$$\mathrm{p} = \mathrm{pu} * Ac * \left[1 - \left(\left|\frac{y - 0.45 * yp}{0.45 * yp}\right|\right)^{2.5}\right]$$

for 0.6 * yp < y <= 1.8 * yp

$$\mathrm{p} = \mathrm{pu} * 0.936 * Ac - \frac{0.085}{y50} * pu * (y - 0.6 * yp)$$

for y > 1.8 * yp

$$\mathrm{p} = \mathrm{pu} * 0.936 * Ac - \frac{0.102}{y50} * pu * yp$$

Where:

pu = Ultimate soil resistance
pu = min(pu1, pu2)
pu1 = 11 * cu * b
pu2 = 2 * ca * b + gamma * b * z + 2.83 * ca * z
y50 = deflection at one-half the ultimate soil resistance
y50 = e50 * b
Ac = coefficient
for z < 3 * b
Ac= -0.017 * (z / b)^2 + 0.084 * z / b + 0.2
for z >= 3 * b
Ac = 0.3
yp = aux deflection
yp = 4.1 * Ac * y50
k = initial stiffness [pci], Value can be user defined or calculated based on the selection made under **P-Y Analysis Settings**, **Initial stiffness is calculated** on the **Calculation Parameters** tab of the **Parameters** window. If not selected, the value can be defind in the **Soils** window.
k = (13 * ca / 144 + 125) * 1728, [ca in psf]

- **Stiff Clay (Reese) – without free water**
  - Describes the response of stiff clay without free water by Reese, for static loading and for cyclic loading.

<u>Stiff Clay (Reese) – without free water, static load</u>

Curve definition:

for y >= 16 * y50
p = pu
for y < 16 * y50

$$p = pu * 0.5 * \sqrt[4]{\frac{y}{y50}}$$

Where:

pu = Ultimate soil resistance
pu = min(pu1, pu2)
pu1 = 9 * cu * b
pu2 = 3 * cu * b + gamma * b * z + 0.5 * cu * z
y50 = deflection at one-half the ultimate soil resistance
y50 = 2.5 * e50 * b

<u>Stiff Clay (Reese) – without free water, cyclic load</u>

Steps:

1. Calculate pu, p and y as for Stiff Clay (Reese) – without free water, static load.
2. Calculate cyclic load parameter:

$$cc = 9.6 * \left(\frac{p}{pu}\right)^4$$

3. Calculate deflection for cyclic load:
   yc = y + y50 * C * log|NL|
4. Recalculate curve with new data:
   y = yc, p = p

- **Sand (Reese)**
  - Describes the response of sand by Reese, for static loading and for cyclic loading.

<u>Sand (Reese)</u>

Curve definition:

for y < yk
p = k * z * y
for yk <= y < ym
p = C * y $^{1/n}$

for ym <= y < yu

p = (y - ym) * m + pm

for y >= yu

p = pu

Where:

Aux. data:

alfa = $\phi/2$

beta = 45^o + alfa

ko = 0.4

ka = tan^2(45^o - alfa)

tf = tan(ϕ)

ta = tan(alfa)

tb = tan(beta)

tc = tan(beta- ϕ)

sb = sin(beta)

ca = cos(alfa)

ϕ = internal friction angle

ps = ultimate soil resistance per unit length

ps = min(ps1, ps2)

ps1 = gamma * z * [ka * b * (tb^8 – 1) + b * ko * tf * tb^4)]

ps2 = gamma * z * [ko * $\frac{tf * sb}{tc * ca}$ + $\frac{tb}{tc}$ * (b + z * tb * ta) + ko * z * tb * (tf * sb – ta) – ka * b]

coefficients A & B

for static load:

for z < 5 * b

A = 0.09 * (z / b)^2 - 0.86 * z / b + 2.9

B = 0.07 * (z / b)^2 - 0.69 * z / b + 2.2

for z >= 5 * b

A = 0.88

B = 0.55

for cyclic load:

for z < 5 * b

A = -0.005 * (z / b)^4 + 0.077 * (z / b)^3 – 0.393 * (z / b)^2 + 0.71 * z / b + 0.7

B = -0.0034 * (z / b)^4 + 0.059 * (z / b)^3 – 0.34 * (z / b)^2 + 0.65 * z / b + 0.5

for z >= 5 * b

A = 0.88

B = 0.5

yu, ym, pu, pm

yu = 3 * b / 80

ym = b / 60

pu = ps * A

pm = ps * B

m = (pu - pm) / (yu - ym)

n = pm / (m * ym)

C = pm / (ym$^{1 / n}$)

yk = (C / (k * z))$^{(n / (n-1))}$

k = initial stiffness [pci], Value can be user defined or calculated based on the selection made under **P-Y Analysis Settings**, **Initial stiffness is calculated** on the **Calculation Parameters** tab of the **Parameters** window. If not selected, the value can be defind in the **Soils** window.

if sand is above the water table

$$\begin{cases} for\ \emptyset < 30^o \\ for\ 30^o \le \emptyset < 36^o \\ for\ \emptyset \ge 36^o \end{cases} \quad k=\begin{cases} 35\ 000 \\ 100\ 000 \\ 216\ 000 \end{cases} \text{[k in pcf]}$$

if sand is below the water table

$$\begin{cases} for\ \emptyset < 30^o \\ for\ 30^o \le \emptyset < 36^o \\ for\ \emptyset \ge 36^o \end{cases} \text{k=} \begin{cases} 43\,000 \\ 155\,000 \\ 390\,000 \end{cases} \text{[k in pcf]}$$

- **Sand (API)**
  - Describes the response of sand by API RP 2A recommendation, for static loading and for cycling loading.

Sand (API)
Curve definition:

$$p = A * pu * \tanh\left(\frac{k * z}{A * pu} * y\right)$$

Where:

Aux. data:

alfa = ϕ / 2
beta = 45º + alfa
ko = 0.4
ka = $\tan^2$(45º - alfa)
kp = $\tan^2$(45º + alfa)
tf = tan(ϕ)
ta = tan(alfa)
tb = tan(beta)
sb = sin(beta)
ca = cos(alfa)

pu = ultimate lateral resistance [lb/ft]
pu = min(pu1, pu2)
pu1 = gamma * z * [C1 * z + C2 * b]
pu2 = gamma * z * b * C3

Coefficients C1, C2, C3
C1 = tb * (kp * ta) + ko * (tf * sb * (1 + 1 / ca)) – ta))
C2 = kp - ka
C3 = kp * kp * (kp + ko * tf) - ka

Coefficient A
for static load:
A = max(0.9, (3 – 0.8 * z / b))

for cyclic load:
A = 0.9

k = initial stiffness [pci], Value can be user defined or calculated based on the selection made under **P-Y Analysis Settings**, **Initial stiffness is calculated** on the **Calculation Parameters** tab of the **Parameters** window. If not selected, the value can be defind in the **Soils** window.

if sand is above the water table

$$\text{k=} \begin{cases} 15\ \ for\ \emptyset < 29^o \\ 0.22 * \emptyset^2 + 8.3 * \emptyset - 410\ \ for\ 29^o \le \emptyset < 40^o \\ 280\ \ for\ \emptyset \ge 40^o \end{cases}$$

if sand is below the water table

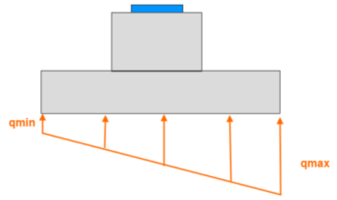
$$\text{k=} \begin{cases} 15\ \ for\ \emptyset < 29^o \\ 0.239 * \emptyset^2 - 3.48 * \emptyset - 85\ \ for\ 29^o \le \emptyset < 40^o \\ 280\ \ for\ \emptyset \ge 40^o \end{cases}$$

Design

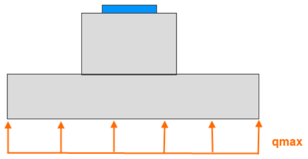
For shear verification and steel reinforcement calculations, the net load without soil and foundation weight is used. Bending moments and shear forces for the pad are calculated for each load combination based on the net soil pressure.

The stress distribution used for the calculation of shear and bending moments for design is set under **Stress Distribution for Design**, **Calculate internal loads according to** on the **Design** tab of the **Parameters** window. There are two available methods:

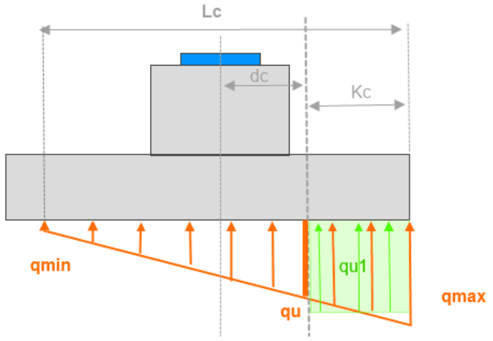
<u>**Linear variable stress distribution**</u>
The stress distribution is defined as linear from the minimum to the maximum net stress value.



<u>**Uniform maximum stress distribution**</u>
The stress distribution is uniform and is equal to the maximum net stress value.



The shear forces and bending moments used in the pad design are calculated at critical points based on the stress distribution outside the critical section. The shear force used for one way shear verification is calculated from the average stress, qu1. For the bending moment the trapezoidal distribution of stress is used from qu to qmax. For the punching shear the average stress at the critical area is used.



Where:

Lc = effective length
dc = location of critical section
Kc = distance where the average stress is calculated
qu = stress at the critical section
qu1 - average stress to check shear at the critical section

Pad Shear

tnxFoundation checks punching (two-way) shear as well as one-way (wide beam) shear in each direction per ACI 318-11, 15.5.

The shear ratio is calculated separately for punching shear and one-way shear as a shear force at the critical section divided by the shear strength.

Shear Ratio
Ratio = Vu / (φ * Vn)

Where:
Vu = the factored shear force at the section considered
φ = Strength reduction factor for shear
Vn = nominal shear strength
Vn = Vc + Vs
Vc = nominal shear strength provided by concrete
Vs = nominal shear strength provided by shear reinforcement (Vs = 0 for a pad)

Verification of shear is performed for:

- one-way shear (wide beam) – in x direction
- one-way shear (wide beam) – in z direction
- punching shear (two-way shear)

Values Vu and φ * Vn are calculated independently for each one.

One-Way (Wide Beam Shear) Shear

Verification is provided for all critical sections in both x and z directions.

One-way shear is calculated at critical sections – at distance d from the face of the column. The d value is an effective depth, calculated as the distance from the top of the footing to the centerline of the reinforcing steel.

Design Shear
φVn = φ * Vc

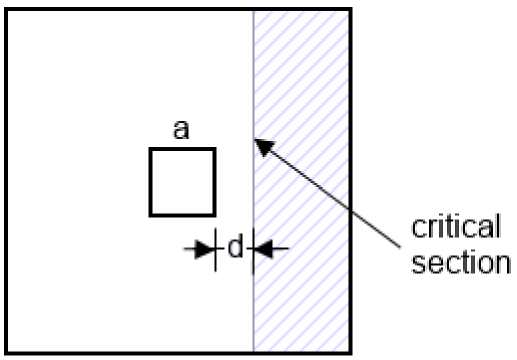
Where:
φ = reduction factor for shear
Vc = shear strength provide by concrete [ACI 318-11, 11.12.3.1]

Nominal Shear
Vc = 2 * $f'c^{0.5}$ * L * d

Where:
d = effective depth
L = foundation width
f'c = strength of concrete

Shear Force at the Critical Section
Vu = qu * L * (L / 2- dc)

Where:
qu = stress for shear calculation at critical section for x direction
dc = location of critical section, d from the pier edge
L = foundation width



Punching (Two-Way) Shear

Verification is provided at the critical section, which is located around the column at a distance d / 2.

Design Shear

$\varphi Vn = \varphi * Vc$

Where:

φ = reduction factor for shear
Vc = shear strength provide by concrete

Nominal Shear

Vc = min(Vc1, Vc2, Vc3)

Where :

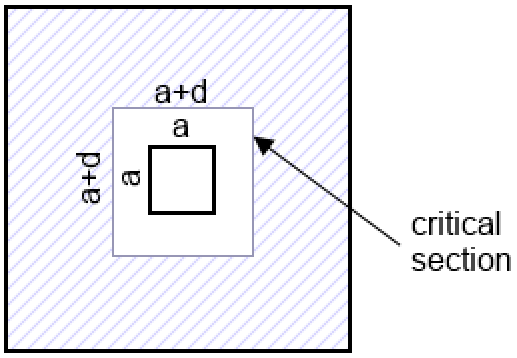
$Vc1 = (2 + 4 / \beta) * f'c^{0.5} * bo * d$
$Vc2 = (2 + \alpha s * d / bo) * f'c^{0.5} * bo * d$
$Vc3 = 4 * f'c^{0.5} * bo * d$
$\beta = 1$
$\alpha s = 40$
bo = length of critical shear perimeter
bo = 4 * (a + d)
d = Effective depth of reinforcement, the distance from top of pad to the mid-level of reinforcement in x or y direction.

Shear Force at the Critical Section

Vu = Vz * critical area

Where:

critical area = $(a + d)^2$
a = column width
Vz = average stress at critical area



Pad Flexural Reinforcement

The flexural design includes the determination of the maximum moment and required steel for the x and z directions.

The bending moment is calculated at the critical section based on the net stress distribution. The critical section for bending moment is defined in ACI 318-11, 15.4.2. In the case when a steel plate is not defined, the critical section is set at the face of the pier. In the case when a steel plate is defined, the critical section is set halfway between the face of the column and the edge of the steel base.

Steel Calculation Steps (done for each direction, x and z)

1. Calculate the effective depth of reinforcement, d. This value is not less than minimum value of effective depth per ACI 318-11, 15.7.

2. Calculate the bending moment, Mu, at the critical section based on the net stress distribution.

3. Calculate the temporary reinforcement area, As.tmp.

   As.tmp = Mu / (φ.t * fy * 0.95 * d)

   Where:

   fy = Steel strength for bottom steel
   φ.t = reduction factor for tension

4. Calculate the minimum reinforcement area, As.min.

   As.min= ρmin * b * D

   Where:

   b = width of foundation
   ρmin = min ratio of reinforcement area
   D = pad depth

5. Verifiy the temporary reinforcement area, As.tmp.

   If As.tmp <= As.min
   then As.tmp = As.min
   else As.tmp = As.tmp

6. Calculate the number and spacing of the reinforcement bars and the final reinforcement area.

7. Calculate the compressed area, a.

   a = As.b * fy / (0.85 * f'c * b)

   Where:

   f'c = concrete strength

8. Calculate φMu.

   φMu = φ.t * As.b * fy * (d - 0.5 * a)

9. Final verification.

   φMu >= Mu

10. Distribution of bars.

The same number of uniformly spaced bars is set for each direction per ACI 318-11, 15.4.3.

Development Length of Bars in Pad / Mat

Verification of development length or anchorage length of the foundation reinforcement is performed for both the x and z directions. Calculation of the required development length, ld, is performed per ACI 318-11, 12.2.2. The available length, la, is the distance from the critical point for bending moment to the foundation edge minus the concrete cover.

Pier Shear

The program determines the pier shear capacity as the sum of the capacities from the concrete per ACI 318-11, 11.2.1.2 and from the ties per ACI 318-11, 11.4.7.2. The program verifies the stirrup spacing and the resulting demand versus capacity ratio is given per ACI 318-11, 11.1.1.

The maximum spacing of ties (smax) is calculated as per ACI 318-11, 11.4.5:

Tie Spacing

smax = min(0.25 * dt, 1 ft) for Vsmin >= Vslim
smax = min(0.5 * dt, 2 ft) for Vsmin < Vslim

Where:

Vsmin = Min value for the shear steel capacity
Vsmin = Av * fy * d / s
Vslim = Limit value for the shear steel capacity
Vslim = 4 * $(144*f'c)^{0.5}$ * a * d
d = Effective depth for pier
d = a – Pier Cover – 0.5 * Tie Diameter
s = tie spacing
fy = tie steel strength
a = pier width

Pier Force Transfer

The program analyzes the ability to transfer forces from the pier to pad. These calculations include the following checks:

- Compressive force transfer verification is the sum of the forces transferred by the concrete and vertical bars per ACI 318-11, 10.14.1.
- Tension force transfer verification of the vertical bars in the pier per ACI 318-11, 10.14.1.
- Concrete bearing verification of the pad per ACI 318-11, 10.14.1.
- Minimum steel across the pier section verification per ACI 318-11, 15.8.2.1.

Axial and Flexural Pier Capacity

For pier flexure design tnxFoundation uses calculations for biaxial flexure with axial compression or tension load per ACI 318-11, 10.3.6, R10.3.6 and R10.3.7.

For both the x and z directions, the uniaxial capacity at the design eccentricity is calculated. The ultimate axial load capacity value, phiPn, and the ultimate moment capacity, phiMn, are evaluated at the design eccentricity based on the vertical load, Vu, and the bending moment, Mu. These values are interpolated using straight-line interpolation from the flexure and axial load interaction diagram points for a rectangular section. The load interaction diagram is created by using the universal column formulas according to the CRSI Design Handbook.

For a vertical load greater than 0.1 * f'c * Pier Section, the biaxial capacity is determined by the following approximation using the Bresler Reciprocal Load equation:

1 / phiPn = 1 / phiPnx + 1 / phiPny – 1 / phiPo.

The biaxial stress ratio is then calculated using the equation:

Ratio = Vu / phiPn

For a vertical load less than 0.1 * f'c * Pier Section, the biaxial stress ratio is determined by the following approximation using the Bresler Load Contour interaction equation:

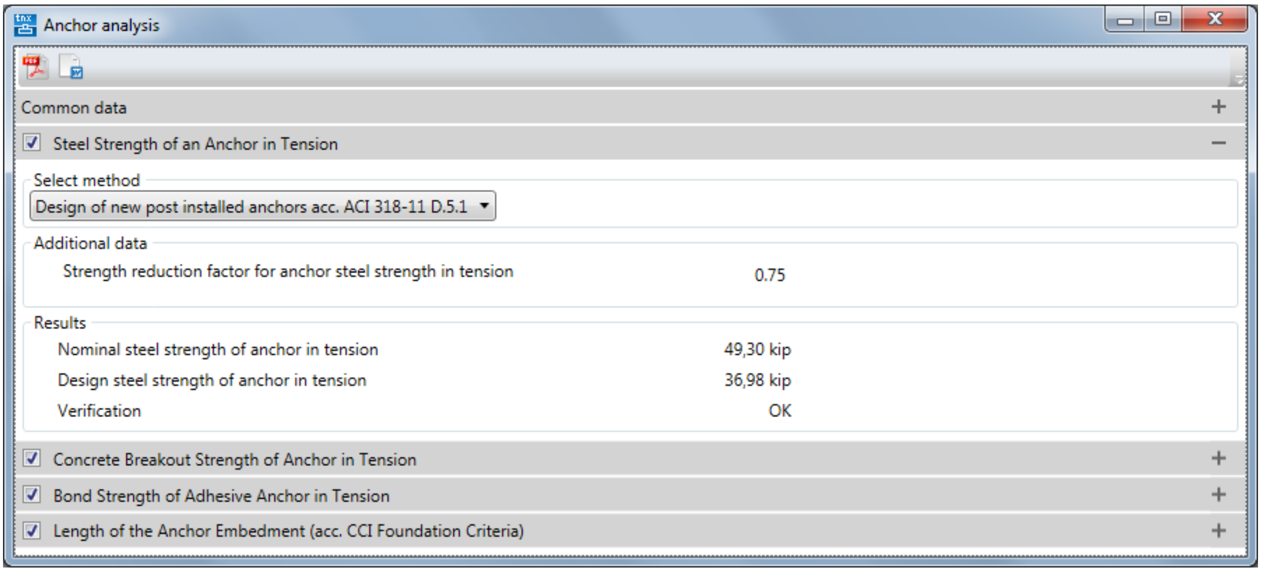
$$\text{Ratio} = (\text{Mux} / \text{phiMnx})^{1.15} + (\text{Muy} / \text{phiMny})^{1.15}$$

Other assumptions used in the calculation of pier reinforcement:

- The pier is assumed as a non-slender column.
- The reinforcement is assumed to be symmetric.
- The steel yield strength, fy, for vertical bars is equal to 60 ksi.
- For vertical reinforcement design the program meets the provisions of the ACI code, which states that in piers a minimum reinforcement ratio is equal to 0.005 of the pier cross section.

Calculation of post-installed anchors

The calculations for post-installed anchors are found in the menu bar under **Extras**.



There are four verifications of post-installed anchors:

- **Steel Strength of an Anchor in Tension**:
  - **Design of new post-installed anchors according to ACI 318-11 D.5.1**
  - **Design of new post-installed anchors according to CCI Foundation Criteria**
  - **Analysis of existing post-installed anchors according to CCI Foundation Criteria**
- **Concrete Brekout Strength of Anchor in Tension per ACI 318-11 D.5.2**
- **Bond Strength of Adhesive Anchor in Tension per ACI 318-11 D.5.5**
- **Length of the Anchor Embedment per CCI Foundation Criteria**

All verifications are independent and can be turned on or off using the checkboxes.

Common data

This section contains editable data common to all types of analysis:

- **Load**
- **Material**
- **Anchor**
- **Anchor Geometry**

Steel Strength of an Anchor in Tension

It verifies the design steel strength of an anchor in tension based on the selection made under **Select method**.

- **Design of new post-installed anchors according to ACI 318-11 D.5.1**
  - It verifies the design steel strength of an anchor in tension per ACI 318-11, D.5.1. It is used for the verification of the anchor diameter.

Results

Nominal steel strength of anchor in tension

Nsa = Ase * futa

Design steel strength of anchor in tension

phiNsa = phi_sa * Nsa

Where:

phi_sa = strength reduction factor for anchor steel strength in tension

Ase = Effective cross-sectional area, tensile net area An
futa = Specified tensile strength of anchor, Fu

- **Design of new post-installed anchors according to CCI Foundation Criteria**
    - It verifies the design steel strength of an anchor in tension per CCI Foundation Criteria. It is used for the verification of the anchor diameter for the design of new post-installed anchors.

Results
Nominal steel strength of anchor in tension
Nsa = Ase * futa
Proof load limit
phiProofLoad= phi_sa * Ase * fya
Design steel strength of anchor in tension
phiNsa=phi_sa * Nsa

Where:
phi_sa = strength reduction factor for anchor steel strength in tension
Ase = Effective cross-sectional area, tensile net area An
futa = Specified tensile strength of anchor, Fu
fya = Specified yield strength of anchor, Fy

- **Analysis of existing post-installed anchors according to CCI Foundation Criteria**
    - It verifies the design steel strength of an anchor in tension per CCI Foundation Criteria. It is used for the verification of the anchor diameter for the analysis of existing post-installed anchors.

Results
Design steel strength of anchor in tension for TIA G:
If Proof load is provided:
phiNsaG = min(phi_G * Nsa, ProofLoad * futa / fya)
If Proof load is not provided:
phiNsaG = phi_G * Nsa
Allowable capacity of anchor in tension for TIA F, material A615:
If Proof load is provided:
phiNsaF = min(phi_F * NsaG * asif, ProofLoad)
If Proof load is not provided:
phiNsaF = phi_F * NsaG * asif
Allowable capacity of anchor in tension for TIA F, material other than A615:
If Proof load is provided:
phiNsaFJ = min(phi_FJ * NsaP * asif, ProofLoad)
If Proof load is not provided:
phiNsaFJ = phi_FJ * NsaP * asif

Where:
phi_G = Strength reduction factor for anchor steel strength in tension for TIA G
phi_F = Strength reduction factor for anchor steel strength in tension for TIA F for rod material A615.
phi_FJ = Strength reduction factor for anchor steel strength in tension for TIA F, rod material other than A615
Nsa = Nominal steel strength of anchor in tension for TIA G
Nsa = Ase * futa
NsaP = Nominal capacity of anchor in tension for TIA F, material A615
NsaP = Ase * fya
NsaG = Nominal capacity of anchor in tension for TIA F, material other than A615
NsaG= Ag * futa
Ase = Effective cross-sectional area, tensile net area An
Ag = Equivalent rod gross area
futa = Specified tensile strength of anchor, Fu
fya = Specified yield strength of anchor, Fy
asif = Safety factor, ASIF, for tension for TIA-F

Concrete Breakout Strength of Anchor in Tension
It verifies the concrete breakout strength of an anchor in tension per ACI 318-11, D.5.2.

Results:

- Design concrete breakout strength of an anchor group in tension
- Design concrete breakout strength of a single anchor in tension
- Nominal concrete breakout strength of a group of anchors in tension per ACI 318-11, D.5.1.1.b
- Nominal concrete breakout strength of a single anchor in tension per ACI 318-11, D.5.1.1.a
- Basis concrete strength of a single anchor in tension in cracked concrete per ACI 318-11, D.5.2.2

Bond Strength of Adhesive Anchor in Tension
It verifies the bond strength of adhesive anchor in tension per ACI 318-11, D.5.5.

Results:

- Design bond strength of adhesive anchor in tension
- Nominal bond strength of adhesive anchor in tension per ACI 318-11, D.5.5.1.a
- Basis bond strength of a single adhesive anchor in tension in cracked concrete per ACI 318-11, D.5.2.2

Length of the Anchor Embedment
It verifies the length of the anchor embedment per CCI Foundation Criteria.

Results

Height of concrete breakout cone

L_cone = max(0.01 * perc * Edev, ld + cover + G / 1.5)

Reinforcing anchor rod embedment

L1 = max(Edev, L_cone + (100 - perc) * Edev)

Where:

perc = % of the depth of the epoxy cylinder to define the bottom of the concrete breakout level, 100% is at the bottom
Edev = epoxy or grout development length used in bond strength calculation
ld = vertical bars development length, set by user or calculated per ACI 318-11, 12.2
cover = concrete cover
G = max distance from anchor rod to a single rebar

Calculation of horizontal passive pressure

The horizontal passive pressure for the layered soil is calculated as a linear value at a unit width.

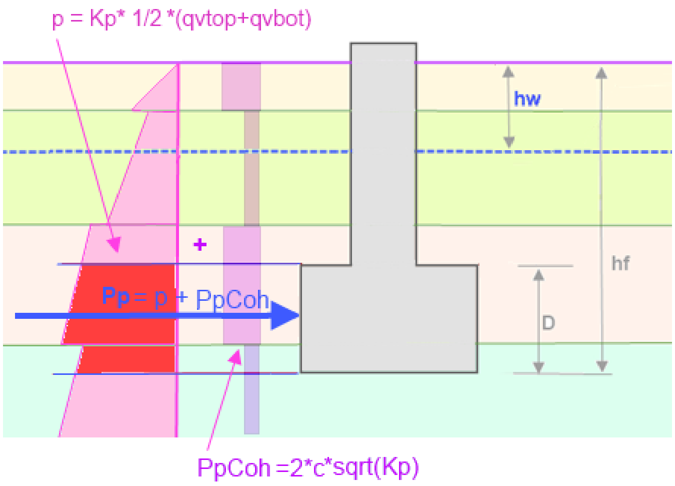
Each layer has a uniform specific gravity. When the layer is divided by water, it is split into separate layers for calculations.

Passive Pressure on Pad

Passive pressure = Kp * 1/2 * D * (qvtop + qvbot) + PpCohesion

Where:

Kp = coefficient of passive lateral earth pressure and is defined for each soil layer
D = foundation or pad height
qvtop = vertical stress from soil weight at top pad level
qvbot = vertical stress from soil weight at bottom pad level
PpCohesion = part of passive pressure from cohesion, can be selected under Include Cohesion for Passive Pressure Calculation on the Parameters window
PpCohesion = 2 * c * $Kp^{0.5}$ * D
c = soil cohesion [ksf]



Vertical Stress

qv = $\sum(h * \gamma_{ef})$

Where:

qv = vertical stress from soil weight at level h
h = height of soil layer
γ_{ef} = effective unit weight of soil

Effective unit weight of soil for dry condition is equal to dry unit weight of soil.

For soil with ground water, effective unit weight of soil is equal to saturated unit weight of soil minus unit weight of water.

Passive Pressure Moment at Bottom Edge of Pad

Mp = Kp * [qvtop + 1/3 * (qvbot - qvtop)] * 1/2 * D^2 + PpCohesion * 1/2 * D

Passive Pressure Moment at Top Edge of Pad

Mpt = Kp * [qvtop + 2/3 * (qvbot - qvtop)] * 1/2 * D^2 + PpCohesion * 1/2 * D

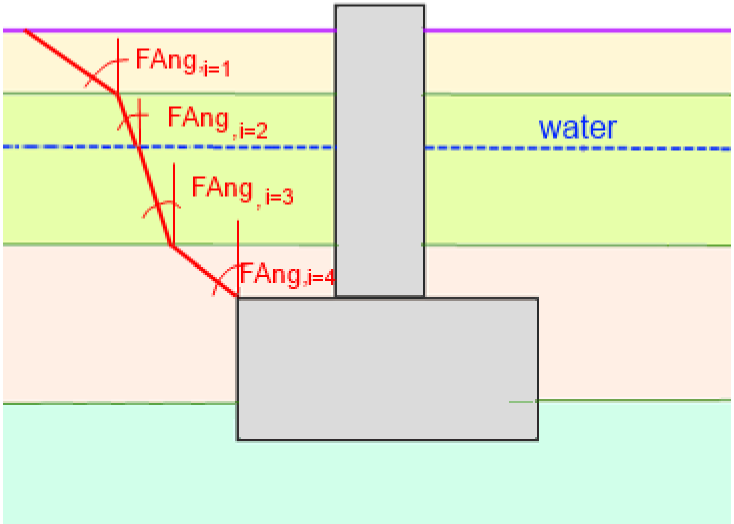
Soil weight

The soil weight is calculated for each soil layer. A soil layer is defined as a layer with uniform specific gravity. When the layer is divided by water, it is treated as two separate layers.

The soil weight is the sum of the soil directly above the foundation pad or mat, and in special cases it is also calculated taking into account the weight of the soil wedges around the perimeter of the foundation using a failure angle.

Types of soil weights used in the calculations:

- **Soil Vertical** – A soil weight directly above the foundation, the vertical projection.
- **Soil Wedge** – The weight of soil wedges calculated from the top surface of foundation level and located above full perimeter of foundation.
- **Soil Wedge at Non-Bearing Area** – The weight of the soil wedges calculated from the top surface of the foundation level. The soil wedges are located above the external perimeter (windward and side) of the non-bearing area of the foundation. They are calculated for each load combination.
- **FAng** – The failure angle to the vertical axis used to calculate the soil pyramid. It is calculated for each layer and is equal to angle of internal friction of soil.



- **Soil Weight** – The soil weight is the soil volume multiplied by the soil density.