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ProtaStructure Design Guide

Pad Footing Design per TS500

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Scope

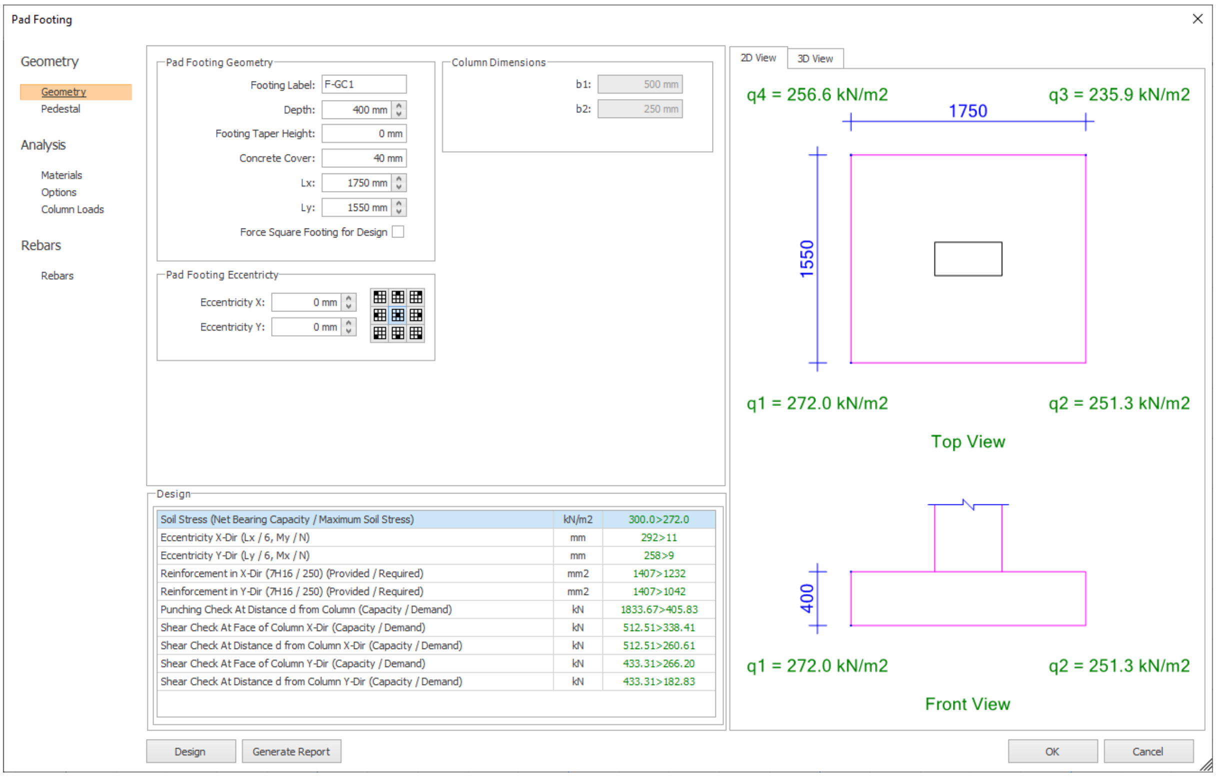
In this document, pad footing design in accordance with TS500 is explained. An arbitrary pad footing is selected and it is designed under a single load combination.

User Interface

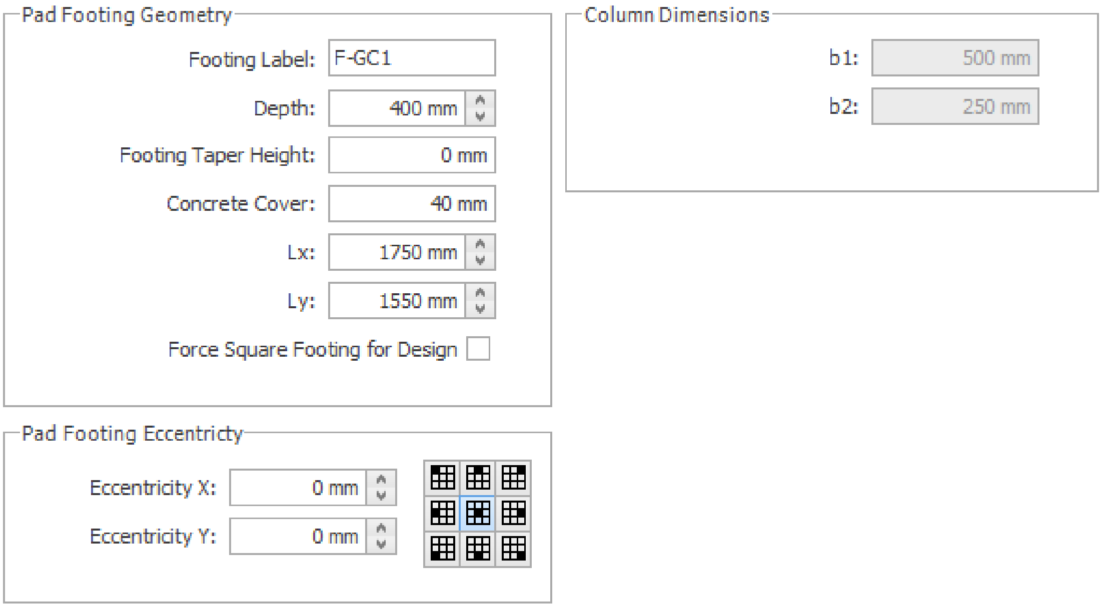
Before defining a Pad Footing:

- The building model must be completed and analysed, so that the column axial loads and moments are determined.
- The foundation storey 0 (ST: 0) must be set as the current storey.

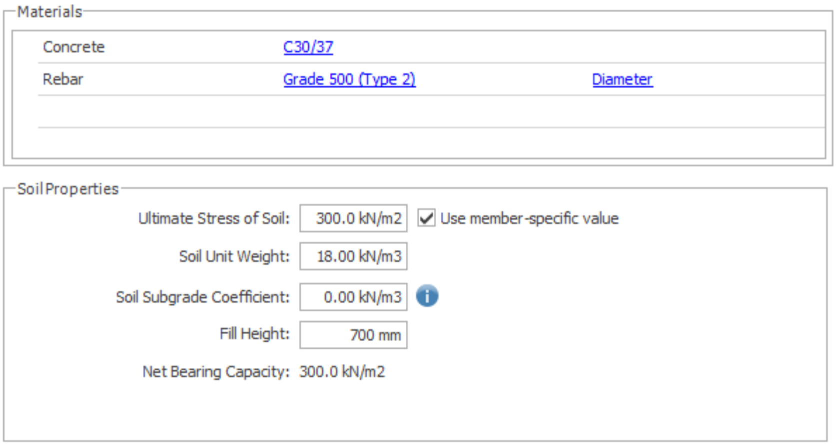
In ProtaStructure, geometry and design information is presented in a clear manner.



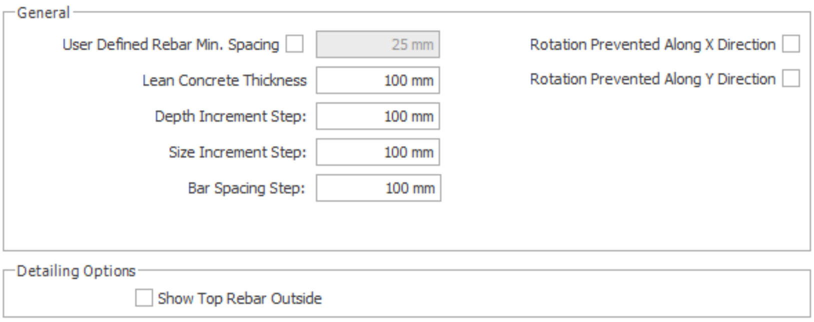
Pad footing geometry can be defined using the **Geometry** section. Column dimensions are obtained from the ProtaStructure model.



Material and soil properties are determined under the **Materials** section.



Design and detailing options are determined under the **Options** section.



Analysis results of the selected column are given under the **Column Loads** section.

Units: (kN, kN.m)

UnSelect All　　Loading: All Combinations

	Comb. No	Column	N	Vx	Vy	Mx	My	ΣN
☑	1	GC1	625.23	14.20	10.22	-12.8	-10.2	686.54
☑	2	GC1	627.50	14.35	10.29	-13.0	-10.2	688.80
☑	3	GC1	562.19	12.39	8.88	-11.1	-8.8	623.50
☑	4	GC1	624.96	14.11	10.21	-12.6	-10.1	686.26
☑	5	GC1	606.75	13.61	9.84	-12.1	-9.8	668.05
☑	6	GC1	625.50	14.30	10.22	-13.0	-10.2	686.81
☑	7	GC1	607.29	13.80	9.84	-12.5	-9.8	668.60
☑	8	GC1	624.31	13.91	10.22	-12.1	-10.2	685.62
☑	9	GC1	606.10	13.42	9.84	-11.7	-9.8	667.40
☑	10	GC1	626.15	14.49	10.22	-13.4	-10.1	687.45
☑	11	GC1	607.94	13.99	9.84	-13.0	-9.8	669.24

Import From CSV　　Add Selected To User Loads

Pad footing rebars are given under the **Rebars** section.

	Rebar Description	Quantity	Diameter	Spacing	Bob
☑	Rebar X	7.	16	250	☑
☑	Rebar Y	7.	16	250	☑
☑	Distribution Rebar (X-Dir)	0.	13	250	☐
☑	Distribution Rebar (Y-Dir)	0.	13	250	☐
☑	Top Rebar (X-Dir)	7.	13	250	☑
☑	Top Rebar (Y- Dir)	7.	13	250	☑

Further details on the process of defining pad footing at column bases are out of this document's scope and are given in detail at the Prota Help Center. You can reach the relevant page at:

https://support.protasoftware.com/portal/en/kb/articles/pad-footing

List of Symbols and Abbreviations

Input Parameters

h:	Pad footing height
h_{taper}:	Pad footing taper height
d_{cc}:	Concrete cover
L_x	Pad footing width in X direction
L_y:	Pad footing width in Y direction
B_x:	Column width in X direction
B_y:	Column width in Y direction
N:	Column axial force
V_x:	Shear force in X direction
V_y:	Shear force in Y direction
M_x:	Moment in X direction
M_y:	Moment in Y direction
e_x:	Pad footing eccentricity in X direction
e_y:	Pad footing eccentricity in Y direction
σ_{ult} :	Ultimate Soil Strength

Default Parameters

γ_c:	Unit weight of concrete
γ_s:	Unit weight of soil
f_{ctd}:	Tensile design strength of concrete

Calculated Parameters

d_{eff-x}:	Effective depth of pad footing in x-direction
d_{eff-y}:	Effective depth of pad footing in y-direction
$d_{eff-avg}$:	Average Effective depth of pad footing
I_x:	Moment of inertia (second moment of area) of the pad footing in x-direction
I_y:	Moment of inertia (second moment of area) of the pad footing in y-direction
ΣM_x	Total Moment in Y direction
ΣM_y:	Total Moment in Y direction
N_p:	Total Axial force acting on the footing
$L_{cf-fe-x}$:	The distance between column face and the footing edge in x-direction
$L_{cf-fe-y}$:	The distance between column face and the footing edge in y-direction
$L_{cfd-fe-x}$:	The distance between the point 'd_{eff}' distance away from column face and footing edge in x-direction
$L_{cfd-fe-y}$:	The distance between the point 'd_{eff}' distance away from column face and footing edge in y-direction
σ_{cf-x}:	Stress at column face in x-direction
σ_{cf-y}:	Stress at column face in y-direction
σ_{cfd-x}:	Stress at the point 'd' distance away from column face in x-direction
σ_{cfd-y}:	Stress at the point 'd' distance away from column face in y-direction

σ_{max}:	Max. corner stress
σ_{n-x} :	Stress at the x-direction neighbour corner of the max stress corner
σ_{n-y}:	Stress at the y-direction neighbour corner of the max stress corner
V_{cf-x}:	Design shear at column face in x-direction
V_{cf-y}:	Design shear at column face in y-direction
V_{cfd-x}:	Design shear at the point 'd' distance away from column face in x-direction
V_{cfd-y}:	Design shear at the point 'd' distance away from column face in y-direction
M_{cf-x}:	Design moment at column face in x-direction
M_{cf-y}:	Design moment at column face in y-direction
M_{cfd-x}:	Design moment at the point 'd' distance away from column face in x-direction
M_{cfd-y}:	Design moment at the point 'd' distance away from column face in x-direction
u_p:	Effective perimeter for punching
V_{pr}:	Punching strength
V_{pd}:	Punching demand
W_c:	Concrete weight of footing
W_s:	Soil weight above footing

Design Flow and Formulations

Initial Design

A pad footing is generated with initial dimensions and reinforcement based on the dimensions of the relevant column/columns. Initial dimensions are selected such that it satisfies the minimum dimension requirements in design codes.

Calculations and Checks

After determining the initial design for the pad footing, Prota Structures moves on to the first step of the design process, in which the footing dimensions and reinforcement details are modified iteratively until the design meets the specified criteria in the design code. Since some design parameters such as rebar diameter and footing dimensions affect the shear and bending demands, the design checks are repeated after the rebar configuration, and footing dimensions are set.

The design steps include:

- Calculation of the loading based on column input and footing dimensions
- Iteration for footing dimensions. (repeat until all criteria are met)
    - Check for soil pressure
    - Calculation of internal shear and moments
    - Check for eccentricity requirements
    - Increase footing dimensions if unsatisfactory
- Determine rebars for calculated internal moments
- Check for punching shear
- Re-check for soil pressure, punching, and eccentricity
    - Increase depth if not satisfactory

These steps are explained in detail in the following sections

Loads Acting on Pad Footing

Loads acting on the foundation:

- N: Column axial force
- N_p*: Total axial force acting on the foundation, calculated by the sum of the column axial force, soil weight on the footing, and self-weight.
- $V_{x,y}$: Column Shear force in X and Y directions
- $M_{x,y}$: Column base moments in X and Y directions.
- σ*: Stress at the soil-foundation boundary, resulting from the interaction between the moments and axial forces

* Calculated parameters

Total Axial Force, N_p

The total axial force acting on the foundation is:

- N: Axial force imposed by the column
- W_c: Concrete weight, including the cuboid part of the footing, the taper, and pedestal (for steel columns)

$$W_c = L_x * L_y \left(h + \frac{h_{taper}}{2}\right)\gamma_c + L_{x-pedestal} * L_{y-pedestal} * H_{pedestal} * \gamma_c$$

- W_s: Soil weight on top of the footing

$$W_s = L_x L_y \left(H_{fill} - \frac{h_{taper}}{2}\right)\gamma_s$$

Therefore the total axial force is

$$N_p = N + W_c + W_s$$

Soil Pressure Values

The soil pressure results from the interaction between the axial loads and moments. Each corner of the footing has different values of soil pressure.

The formula gives total soil pressure at a corner:

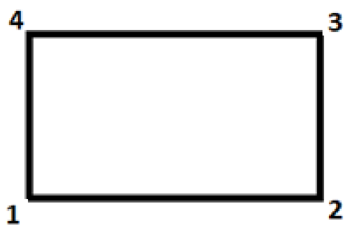
$$\sigma_{corner} = \frac{N_p}{A} \pm \frac{\sum M_x}{I_x} * \frac{L_x}{2} \pm \frac{\sum M_y}{I_y} * \frac{L_y}{2}$$

Where;

$\sum M_{x,y} = M_{x,y} - V_{x,y} * (h + h_{taper}) + e_{x,y} * N$ is the total moment in x or y directions

(if the user restricts rotation of the footing, only the $M_{x,y}$ values are taken into account)

$I_x = \frac{1}{12} L_y * L_x{}^3$, $I_y = \frac{1}{12} L_x * L_y{}^3$ are the moments of inertia in x or y directions.



Soil Pressure Check

After the stress in each corner is calculated, the corner with the maximum stress is determined. This maximum stress is checked against the allowable soil pressure limit. If the condition below is not satisfied, the planar footing dimensions are increased until the condition is met.

$$\sigma_{max} = Max(\sigma_1, \sigma_2, \sigma_3, \sigma_4)$$

$$\sigma_{max} < \sigma_{ult}$$

Eccentricity Check

The footing dimensions and loading must satisfy the following condition

$$ecc_x \leq e_{cx} \quad \text{and} \quad ecc_y \leq e_{cy}$$

Where;

$ecc_x = \left|\sum M_x/N_p\right|$ and $ecc_y = \left|\sum M_y/N_p\right|$ are the resultant eccentricities in x and y directions.

(Note that this is a value resulting purely from the loading calculations and is separate from the eccentricity caused by the geometry of the footing and the column)

$e_{cx} = L_x/6$ and $e_{cy} = L_y/6$ are the critical eccentricities in x and y directions

Calculation of Internal Shear Forces and Moments

The soil pressure under the footing is assumed to be trapezoidal in both directions. The slopes of the stress diagrams between the maximum stress corner and its neighboring corners in both directions are determined. The reinforced concrete design is based on this stress distribution and cantilever beam assumption. The self-weight of the footing in this section and the weight of the soil fill above are excluded from this calculation.

Distances between the column faces and footing edges in both directions:

$$L_{cf-fe} = \frac{(L_x - B_x)}{2} \; and \; \frac{(L_y - B_y)}{2}$$

Slopes of the stress distributions:

$$\frac{\Delta\sigma_x}{\Delta x} = \frac{\sigma_{max} - \sigma_{n-x}}{L_x}$$

$$\frac{\Delta\sigma_y}{\Delta y} = \frac{\sigma_{max} - \sigma_{n-y}}{L_y}$$

Stress at column face with normal parallel to the x-direction

$$\sigma_{cf-x} = \sigma_{n-x} + (L_x - L_{cf-fe-x}) * \frac{\Delta\sigma_x}{\Delta x}$$

Concrete weight of the cantilever section and the weight of the overlaying soil fill

$$W_{cs-x}^{c} = L_y * L_{cf-fe-x} * (H * \gamma_c + H_{fill} * \gamma_s)$$

Total shear at column face: (sum of rectangular and triangular stress distributions, i.e., area of the trapezoidal distribution minus the concrete and soil weight)

$$V_{cf-x} = L_y * \left(\sigma_{cf-x} * L_{cf-fe-x} + (\sigma_{max} - \sigma_{cf-x}) * \frac{L_{cf-fe-x}}{2} \right) - W_{cs-x}^{c}$$

Total Moment at column face: (sum of the moments of the rectangular and triangular stress distributions minus the moments of the concrete and soil weight)

$$M_{cf-x} = L_y * \left(\sigma_{cf-x} * \frac{1}{2} L_{cf-fe-x}{}^2 + (\sigma_{max} - \sigma_{cf-x}) * \frac{2}{6} L_{cf-fe-x}{}^2\right) - W^c_{cs-x} * L_{cf-fe-x}/2$$

Stress at column face with normal parallel to the y-direction

$$\sigma_{cf-y} = \sigma_{n-y} + (L_y - L_{cf-fe-y}) * \frac{\Delta\sigma_y}{\Delta y}$$

Concrete weight of the cantilever section and the weight of the overlaying soil fill

$$W^c_{cs-y} = L_x * L_{cf-fe-y} * (H * \gamma_c + H_{fill} * \gamma_s)$$

Total shear at column face: (sum of rectangular and triangular stress distributions, i.e., area of the trapezoidal distribution minus the concrete and soil weight)

$$V_{cf-y} = L_x * \left(\sigma_{cf-y} * L_{cf-fe-y} + (\sigma_{max} - \sigma_{cf-y}) * \frac{L_{cf-fe-y}}{2}\right) - W^c_{cs-y}$$

Total Moment at column face: (sum of the moments of the rectangular and triangular stress distributions minus the moments of the concrete and soil weight)

$$M_{cf-y} = L_x * \left(\sigma_{cf-y} * \frac{1}{2} L_{cf-fe-y}{}^2 + (\sigma_{max} - \sigma_{cf-y}) * \frac{2}{6} L_{cf-fe-y}{}^2\right) - W^c_{cs-y} * L_{cf-fe-y}/2$$

Bending Design

Based on calculated values, a bending design is performed for both directions. Hence required steel areas for both directions are calculated. The design is performed following the assumption that the footing behaves similarly to a cantilever beam in both directions. Thus the rebar requirements are calculated with this assumption. Reinforced concrete design flow for bending elements is out of the scope of this document.

Effective Depth

The effective depth is an essential parameter in shear and punching checks. It depends on the clear concrete cover distance, footing height, and the rebar diameter in both directions. Assuming the rebar in the x direction is below the rebar in the y direction:

$$d_{eff-x} = h + h_{taper} - d_{cc} - \Phi_x/2$$

$$d_{eff-y} = h + h_{taper} - d_{cc} - \Phi_x - \Phi_y/2$$

$$d_{eff-avg} = \frac{1}{2}(d_{eff-x} + d_{eff-y})$$

Effective Perimeter

The effective perimeter is the perimeter of the rectangle whose edges are d_{eff} distance from the column faces.

$$u_p = 2 * \left(B_x + B_y + d_{eff-avg}\right)$$

For both x and y directions, the design shear forces at the coordinates are determined similarly to the column face.

$$L_{ep-fe} = \frac{(L_x - B_x\ )}{2} - d_{eff-x} \ and \ \frac{\left(L_y - B_y\ \right)}{2} - d_{eff-y}$$

$$\sigma_{ep-x} = \ \sigma_{n-x} + (L_x - \ L_{ep-fe-x}) * \frac{\Delta\sigma_x}{\Delta x}$$

$$V_{ep-x} = \ \sigma_{ep-x} * L_{ep-fe-x} + \left(\sigma_{max} - \sigma_{ep-x}\right) * \frac{L_{ep-fe-x}}{2} - \ W_{sc}^{ep}$$

Where W_{sc}^{ep} is the weight of concrete plus soil fill over the cantilever section from the effective perimeter to the footing edge (Similar calculations apply for y-direction).

Shear Check

Shear capacities in both directions are calculated;

$$V_{crx} = 0.65\ f_{ctd} L_x d_{eff-x} \qquad\qquad V_{cry} = 0.65\ f_{ctd} L_y d_{eff-y}$$

These shear capacities should be greater than the design shear forces (both at column face and at the point ‘d’ away from column face) calculated in previous sections.

Punching Check

The bending factor, γ is calculated.

For rectangular columns:

$$\gamma = \frac{1}{1 + 1.5 \frac{0.4 * (ecc_x + ecc_y)}{\sqrt{B_x B_y}}}$$

For circular columns:

$$\gamma = \frac{1}{1 + \frac{2 * \sqrt{0.4 * (ecc_x^2 + ecc_y^2)}}{d_{eff-avg} * D_c}}$$

Where D_c is the column diameter.

Punching resistance at the effective perimeter is calculated:

$$V_{pr} = \gamma * f_{ctd} * u_p * d_{eff-avg}$$

Punching demand is calculated for each loading combination:

$$V_{pd} = N_p - \sigma_{avg} * A_{eff}$$

Where;

$\sigma_{avg} = N_p/(L_x * L_y)$ is the average soil pressure under the footing

$A_{eff} = \left(B_x + d_{eff-avg}\right) * \left(B_y + d_{eff-avg}\right)$ is the effective punching area

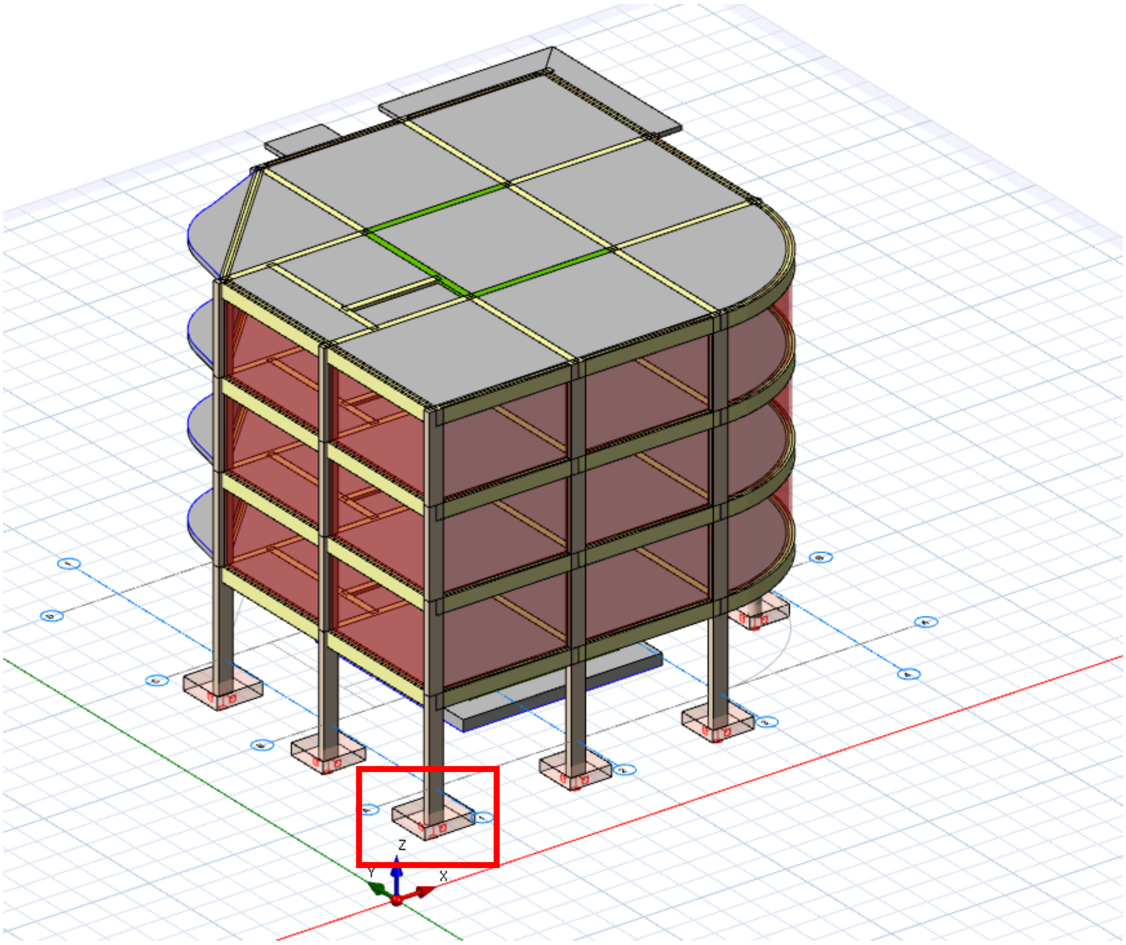
Then, the punching check is done for each combination:

$$V_{pd} < V_{pr}$$

The footing depth is modified if the condition is not met.

Verification

A single pad footing design for the corner column will be conducted to verify the software calculations. The step-by-step results will be compared to hand calculations based on the formulae described in the previous sections.



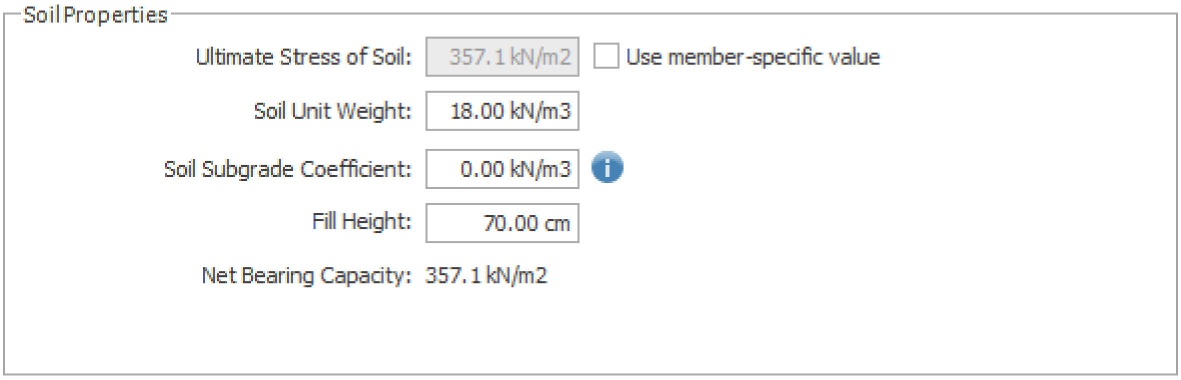
Input Parameters

Loading

For this verification, a single load combination defined by the envelope of regular loads will be used.

Design Axial Force	N_d =	598.58 kN
Design Shear X	V_x =	67.59 kN
Design Shear Y	V_y =	27.82 kN
Design Moment X	M_x =	-149.00 kNm
Design Moment Y	M_y =	-45.80 kNm
Concrete Cover	dcc =	50 mm

Soil and Material Properties



Concrete Unit Weight	γ_c =	25.00 kN/m³
Soil Unit Weight	γ_s =	18.00 kN/m³
Soil Ultimate Strength	σ_{ult} =	357.10 kPa

Footing Dimensions

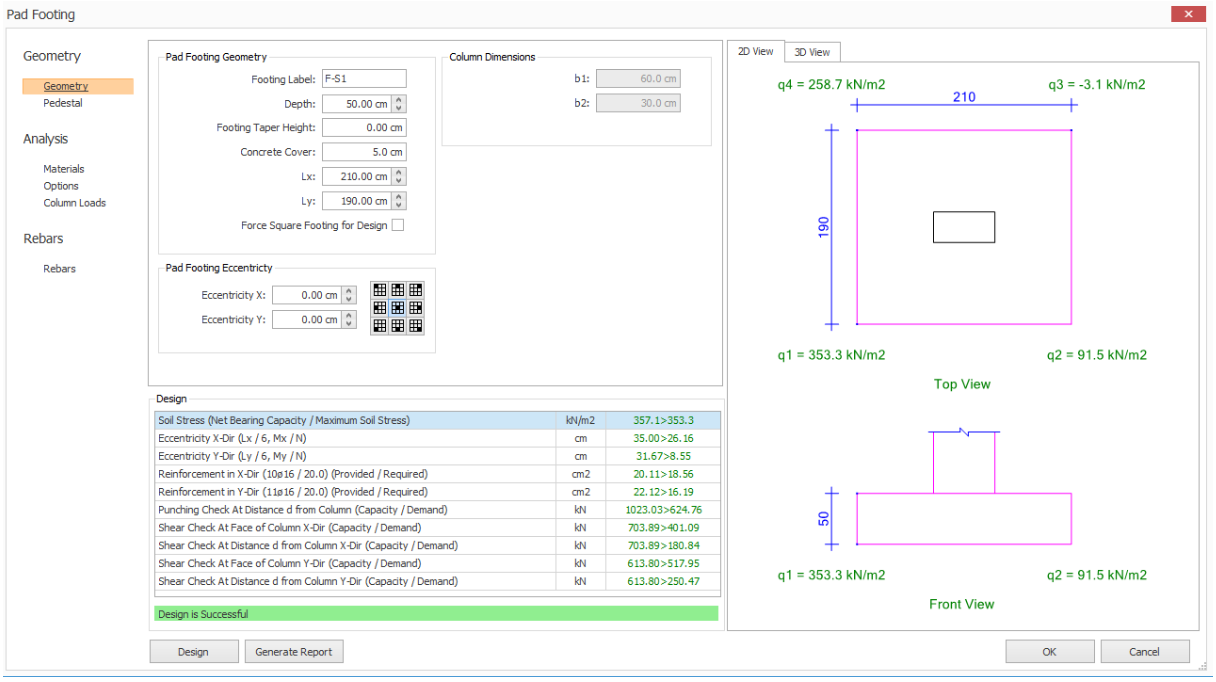
Initial depth is selected as the defined minimum footing depth, **400 mm**.

Initial footing dimensions are selected as 1m x 1m to satisfy the minimum 1m² requirement.

$$L_{x0} = 1\,m\,;\; L_{y0} = 1\,m\,;\; h_0 = 0.4\,m\,;\; h_{taper} = 0$$

After the design process, the footing dimensions are determined as follows:

$$L_x = 2.1\,m\,;\; L_y = 1.9\,m\,; h = 0.5\,m\,;\; h_{taper} = 0$$



Manual Calculations

To verify the model, the footing calculations will be conducted manually using the loading, material, and geometry parameters used in the model.

Total Axial Force

$$W_c = L_x * L_y\left(h + \frac{h_{taper}}{2}\right)\gamma_c + L_{x-pedestal} * L_{y-pedestal} * H_{pedestal} * \gamma_c$$

$$W_c = 1.8\,m * 1.9\,m * \left(0.5\,m + \frac{0\,m}{2}\right) * 25\frac{kN}{m^3} = 49.88\,kN$$

$$W_s = L_x L_y \left(H_{fill} - \frac{h_{taper}}{2}\right)\gamma_s$$

$$W_s = 1.8\,m * 1.9\,m * \left(0.7\,m - \frac{0\,m}{2}\right)18 = 50.27\,kN$$

$$N_p = N + W_c + W_s = 598.58\,kN + 42.75\,kN + 43.09\,kN = \mathbf{698.73\,kN}$$

Total Moments

$$I_x = \frac{1}{12}L_y * {L_x}^3 = \frac{1}{12}1.9\,m * (1.8\,m)^3 = 1.466\,m^4$$

$$I_y = \frac{1}{12}L_x * {L_y}^3 = \frac{1}{12}1.8\,m * (1.9\,m)^3 = 1.200\,m^4$$

$$\sum M_x = M_x + V_x * (h + h_{taper}) + e_x * N$$

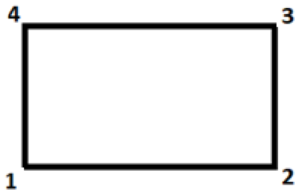
$$\sum M_x = \ -149\ kNm - 67.69\ kN * (0.5\ m + 0\ \ m) + 0\ m * 684.42\ kN = \ -182.80\ kNm$$

$$\sum M_y = \ M_y + V_y * \left(h + h_{taper}\right) + e_y * N$$

$$\sum M_y = \ -45.80\ kNm - 27.82\ kN * (0.5\ m + 0\ \ m) + 0\ m * 698.98\ kN = \ -59.71\ kNm$$

Corner Stresses

Manual Calculation:



$$\sigma_{corner} = \frac{N_p}{A} \pm \frac{\sum M_x}{I_x} * \frac{L_x}{2} \pm \frac{\sum M_y}{I_y} * \frac{L_y}{2}$$

$$\sigma_1 = \frac{N_p}{A} - \frac{\sum M_x}{I_x} * \frac{L_x}{2} - \frac{\sum M_y}{I_y} * \frac{L_y}{2} = \mathbf{353.27\ kPa}$$

$$\sigma_2 = \frac{N_p}{A} + \frac{\sum M_x}{I_x} * \frac{L_x}{2} - \frac{\sum M_y}{I_y} * \frac{L_y}{2} = \mathbf{91.48\ kPa}$$

$$\sigma_3 = \frac{N_p}{A} + \frac{\sum M_x}{I_x} * \frac{L_x}{2} + \frac{\sum M_y}{I_y} * \frac{L_y}{2} = \mathbf{-3.03\ kPa}$$

$$\sigma_4 = \frac{N_p}{A} - \frac{\sum M_x}{I_x} * \frac{L_x}{2} + \frac{\sum M_y}{I_y} * \frac{L_y}{2} = \mathbf{258.76\ kPa}$$

Soil Pressure Check

$$\boldsymbol{\sigma_{max} = 353.27\ kPa\ <\ \ 357.10\ kPa\ \ = \ \sigma_{ult}}$$

The soil pressure check is satisfied.

Eccentricity Check

$$ecc_x = \left|\sum M_x/N_p\right| = \left|\frac{-182.80\ kNm}{698.73\ kN}\right| = 0.2616\ m = 26.16\ cm$$

$$ecc_y = \left|\sum M_y/N_p\right| = \left|\frac{-59.71\ kNm}{596.73\ kN}\right| = 0.0854\ m = 8.54\ cm$$

$$\boldsymbol{ecc_x = 26.16\ cm < 35\ cm = \ L_x/6}$$

$$\boldsymbol{ecc_y = 8.54\ cm < 31.67\ cm = \ L_y/6}$$

The eccentricity check is satisfied.

Internal Forces and Moments

$$L_{cf-fe-x} = \frac{(L_x - B_x\,)}{2} = \frac{2.1\,m - 0.6\,m}{2} = 0.75\,m$$

$$L_{cf-fe-y} = \frac{\left(L_y - B_y\,\right)}{2} = \frac{1.9\,m - 0.3\,m}{2} = 0.8\,m$$

$$\frac{\Delta\sigma_x}{\Delta x} = \frac{\sigma_{max} - \sigma_{n-x}}{L_x} = \frac{353.27\,kPa - 91.48\,kPa}{2.1\,m} = 124.66\,kPa/m$$

$$\frac{\Delta\sigma_y}{\Delta x} = \frac{\sigma_{max} - \sigma_{n-y}}{L_y} = \frac{353.27\,kPa - 258.76\,kPa}{1.8\,m} = 49.74\,kPa/m$$

Stress, shear, and moment at column face with normal parallel to x-direction;

$$\sigma_{cf-x} = \sigma_{n-x} + (L_x - L_{cf-fe-x}) * \frac{\Delta\sigma_x}{\Delta x}$$

$$\sigma_{cf-x} = 91.48 + (2.1\,m - 0.75\,m) * 124.66\frac{kPa}{m} = \mathbf{259.78\,kPa}$$

$$W^c_{cs-x} = L_y * L_{cf-fe-x} * \left(H * \gamma_c + H_{fill} * \gamma_s\right)$$

$$W^c_{cs-x} = 1.9\,m * 0.75\,m * \left(0.5\,m * 25\frac{kN}{m^3} + 0.7\,m * 18\frac{kN}{m^3}\right) = 35.77\,kN$$

$$V_{cf-x} = L_y * \left(\sigma_{cf-x} * L_{cf-fe-x} + \left(\sigma_{max} - \sigma_{cf-x}\right) * \frac{L_{cf-fe-x}}{2}\right) - W^c_{cs-x}$$

$$V_{cf-x} = 1.9\,m * \left(259.78\,kPa * 0.75\,m + (353.27\,kPa - 259.78\,kPa) * \frac{0.75\,m}{2}\right) - 35.7\,kN$$
$$= \mathbf{401.03\,kN}$$

$$M_{cf-x} = L_y * \left(\sigma_{cf-x} * \frac{1}{2} L_{cf-fe-x}{}^2 + \left(\sigma_{max} - \sigma_{cf-x}\right) * \frac{2}{6} L_{cf-fe-x}{}^2\right) - W^c_{cs-x} * L_{cf-fe-x}/2$$

$$M_{cf-x} = 1.9\,m * \left(259.78\,kPa * \frac{1}{2}(0.75\,m)^2 + (353.27 - 259.78) * \frac{2}{6}(0.75\,m)^2\right)$$
$$- 35.77kN * \frac{0.75\,m}{2} = \mathbf{158.71\,kNm}$$

Stress, shear, and moment at column face with normal parallel to y-direction;

$$\sigma_{cf-y} = \sigma_{n-y} + (L_y - L_{cf-fe-y}) * \frac{\Delta\sigma_y}{\Delta y}$$

$$\sigma_{cf-y} = 258.76\,kPa + (1.9\,m - 0.8\,m) * 49.74\frac{kPa}{m} = \mathbf{313.48\,kPa}$$

$$W^c_{cs-y} = L_x * L_{cf-fe-y} * \left(H * \gamma_c + H_{fill} * \gamma_s\right)$$

$$W_{cs-y}^{c} = 2.1\,m * 0.8\,m * \left(0.5\,m * 25\frac{kN}{m^3} + 0.7\,m * 18\frac{kN}{m^3}\right) = 42.17\,kN$$

$$V_{cf-y} = L_x * \left(\sigma_{cf-y} * L_{cf-fe-y} + \left(\sigma_{max} - \sigma_{cf-y}\right) * \frac{L_{cf-fe-y}}{2}\right) - W_{cs-y}^{c}$$

$$V_{cf-y} = 2.1\,m * \left(313.48\,kPa * 0.8\,m + (353.27\,kPa - 313.48\,kPa) * \frac{0.8\,m}{2}\right) - 42.17\,kN = \mathbf{517.90\,kN}$$

$$M_{cf-y} = L_x * \left(\sigma_{cf-y} * \frac{1}{2}{L_{cf-fe-y}}^2 + \left(\sigma_{max} - \sigma_{cf-y}\right) * \frac{2}{6}{L_{cf-fe-y}}^2\right) - W_{cs-y}^{c} * L_{cf-fe-y}/2$$

$$M_{cf-y} = 2.1\,m * \left(313.48\,kPa * \frac{1}{2}(0.8\,m)^2 + (353.27\,kPa - 313.48\,kPa) * \frac{2}{6}(0.8\,m)^2\right) - 42.17\,kN * \frac{0.8\,m}{2} = \mathbf{211.62\,kNm}$$

Bending Design

With the above calculated internal moments, bending reinforcement design is conducted with the cantilever beam assumption.

The resulting bottom rebar distribution:

X- direction bottom rebar	19 ϕ 16 / 10
Y-direction bottom rebar	11 ϕ 16 / 20

Effective Depth

$$d_{eff-x} = h + h_{taper} - d_{cc} - \frac{\Phi_x}{2} = 0.5\,m + 0\,m - 0.05\,m - \frac{16\,mm}{2} = \mathbf{0.442\,m}$$

$$d_{eff-y} = h + h_{taper} - d_{cc} - \Phi_x - \frac{\Phi_y}{2} = 0.5\,m + 0\,m - 16\,mm - \frac{16\,mm}{2} = \mathbf{0.426\,m}$$

$$d_{eff-avg} = \frac{1}{2}\left(d_{eff-x} + d_{eff-y}\right) = \mathbf{0.434\,m}$$

Effective Perimeter

$$u_p = 2 * \left(B_x + B_y + d_{eff-avg}\right) = 2 * (0.6\,m + 0.3\,m + 0.434\,m) = \mathbf{2.67\,m}$$

Distance between footing edge and the effective perimeter

$$L_{ep-fe} = \frac{(L_x - B_x)}{2} - d_{eff-x} \text{ and } \frac{(L_y - B_y)}{2} - d_{eff-y}$$

$$L_{ep-fe-x} = \frac{(2.1\,m - 0.6\,m)}{2} - 0.442\,m = 0.308\,m$$

$$L_{ep-fe-y} = \frac{(1.9\,m - 0.80\,m\,)}{2} - 0.426\,m = 0.374\,m$$

Shear At Effective Perimeter

$$\sigma_{ep-x} = \sigma_{n-x} + (L_x - L_{ep-fe-x}) * \frac{\Delta\sigma_x}{\Delta x}$$

$$\sigma_{ep-x} = 91.48\,kPa + (2.1\,m - 0.308\,m) * 124.66\frac{kPa}{m} = 314.88\,kPa$$

$$W_{sc-x}^{ep} = L_y * L_{ep-fe-x} * \left(H * \gamma_c + h_{fill} * \gamma_s\right) = 14.69\,kN$$

$$V_{ep-x} = L_y * (\sigma_{ep-x} * L_{ep-fe-x} + \left(\sigma_{max} - \sigma_{ep-x}\right) * \frac{L_{ep-fe-x}}{2}) - W_{sc-x}^{ep}$$

$$V_{ep-x} = 1.9\,m * \left(314.88\,kPa * 0.308\,m + (353.27\,kPa - 314.88\,kPa) * \frac{0.308\,m}{2}\right) - 14.69\,kN = \mathbf{180.81\,kN}$$

$$\sigma_{ep-y} = \sigma_{n-y} + (L_y - L_{ep-fe-y}) * \frac{\Delta\sigma_y}{\Delta y}$$

$$\sigma_{ep-y} = 258.76\,kPa + (1.9\,m - 0.374\,m) * 49.74\frac{kPa}{m} = 334.67\,kPa$$

$$W_{sc-y}^{ep} = L_x * L_{ep-fe-y} * \left(H * \gamma_c + h_{fill} * \gamma_s\right) = 19.71\,kN$$

$$V_{ep-y} = L_x * (\sigma_{ep-y} * L_{ep-fe-y} + \left(\sigma_{max} - \sigma_{ep-y}\right) * \frac{L_{ep-fe-y}}{2}) - W_{sc-y}^{ep}$$

$$V_{ep-x} = 2.1\,m * \left(334.67\,kPa * 0.374\,m + (353.27\,kPa - 334.67\,kPa) * \frac{0.374\,m}{2}\right) - 19.71kN = \mathbf{250.44\,kN}$$

Shear Check

Critical shear values for concrete sections are calculated:

$$V_{crx} = 0.65\,f_{ctd}L_x d_{eff-x} = \mathbf{703.89\,kN}$$

$$V_{cry} = 0.65\,f_{ctd}L_y d_{eff-y} = \mathbf{613.80\,kN}$$

Shear values at the column face and the effective perimeter are smaller than critical shear values. Shear check is passed.

Punching Strength

Bending Factor:

$$\gamma = \frac{1}{1 + 1.5\frac{0.4 * (ecc_x + ecc_y)}{\sqrt{B_x B_y}}} = \frac{1}{1 + 1.5\frac{0.4 * (0.2616\ m + 0.0854\ m)}{\sqrt{(0.6\ m + 0.434\ m) * (0.3\ m + 0.434\ m)}}} = 0.8071$$

$$V_{pr} = \gamma * f_{ctd} * u_p * d_{eff-avg} = 0.8071 * 1166.67\ kPa * 3.536\ m * 0.434\ m = \mathbf{1445.00\ kN}$$

Punching Demand

$$V_{pd} = N_p - \sigma_{avg} * A_{eff}$$

$$A_{eff} = (B_x + d_{eff-avg}) * (B_y + d_{eff-avg}) = 0.76\ m^2$$

$$\sigma_{avg} = \frac{N_p}{A_{footing}} = 175.12\ kPa$$

$$V_{pd} = \mathbf{565.82\ kN}$$

Punching Check

$$V_{pd} = \mathbf{565.82\ kN} < \mathbf{1445.00\ kN} = V_{pr}$$

The section is safe against punching.

Comparison of Manual Calculations With Software Output

Value Name	Manual Calculation	PS Result
Soil Stress (Corner 1)	353.27 kPa	353.3 kPa
Soil Stress (Corner 2)	91.48 kPa	91.5 kPa
Soil Stress (Corner 3)	-3.03 kPa	-3.1 kPa
Soil Stress (Corner 4)	258.76 kPa	258.7 kPa
Eccentricity in X Direction	26.16 cm	26.16 cm
Eccentricity in Y Direction	8.55 cm	8.55 cm
Punching Capacity	1445.00 kN	1444.93 kN
Punching Demand	565.82 kN	565.82 kN
Shear Capacity in X Direction	703.89 kN	703.89 kN
Shear At Column Face X Direction	401.03 kN	401.09 kN
Shear At Effective Perimeter X Direction	180.81 kN	180.84 kN
Shear Capacity in Y Direction	613.80 kN	613.80 kN
Shear At Column Face Y Direction	517.90 kN	517.95 kN
Shear At Effective Perimeter Y Direction	250.44 kN	250.47 kN

Pad Footing Report (ProtaStructure Output)

F-S1 Design Summary

Footing Materials

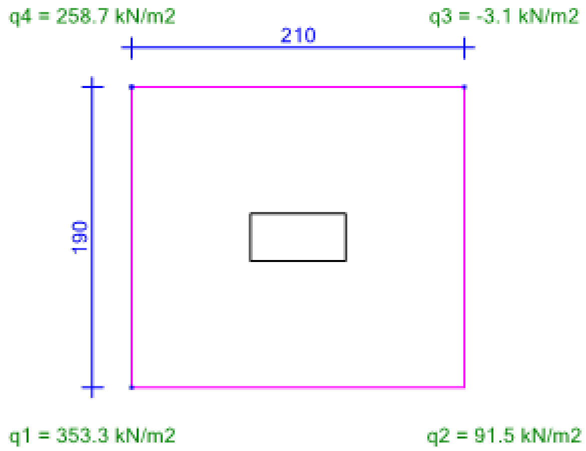
Concrete Material	C25
Rebar Material	S420

Geometric Properties

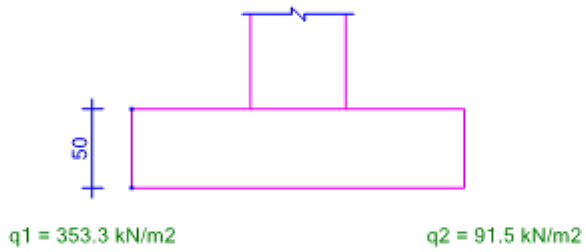
L_X	210.00 cm
L_Y	190.00 cm
Height	50.00 cm
Taper Height	0.00 cm

Corner Stresses

Lower-Left Corner	353.3 kN/m2
Lower-Right Corner	91.5 kN/m2
Upper-Right Corner	-3.1 kN/m2
Upper-Left Corner	258.7 kN/m2



Top View



Front View

Loading Info

Envelope

N	598.58 kN
V_X	67.59 kN
V_Y	27.82 kN
M_X	-149.0 kN.m
M_Y	-45.8 kN.m

Soil Stress Check

N	**:**	**Axial Load Of Combination**
$\sum N$	:	Total Axial Load
TW	:	Total Weight of Footing
h	:	Footing Depth
h_{taper}	:	Taper Height
Ecc_1	:	Column Eccentricity in X Direction
Ecc_2	:	Column Eccentricity in Y Direction
$\sum M_x$	:	Total Moment in X Direction
$\sum M_y$	:	Total Moment in Y Direction

Total footing, soil and pedestal weight is calculated.

Member		**Volume (m3)**	**Unit Weight (kN/m3)**	**Weight (kN)**
Pad Footing	:	1.995	25	49.875
Soil	:	2.793	18	50.274
Total	:			100.149

$\Sigma N = N + TW$

$\Sigma M_x = M_x + V_x (h - h_{taper}) + Ecc_1 N$

$\Sigma M_y = M_y + V_y (h - h_{taper}) + Ecc_2 N$

Corner stresses,

$\sigma_1 = \Sigma N / L_x L_y - 6 \Sigma M_x / (L_x L_y^2) - 6 \Sigma M_y / (L_x^2 L_y)$

$\sigma_2 = \Sigma N / L_x L_y + 6 \Sigma M_x / (L_x L_y^2) - 6 \Sigma M_y / (L_x^2 L_y)$

$\sigma_3 = \Sigma N / L_x L_y + 6 \Sigma M_x / (L_x L_y^2) + 6 \Sigma M_y / (L_x^2 L_y)$

$\sigma_4 = \Sigma N / L_x L_y - 6 \Sigma M_x / (L_x L_y^2) + 6 \Sigma M_y / (L_x^2 L_y)$

Comb	**ΣN (kN)**	**ΣMx (kN.m)**	**ΣMy (kN.m)**	**σ1 (kN/m2)**	**σ2 (kN/m2)**	**σ3 (kN/m2)**	**σ4 (kN/m2)**
Comb #Env - S1	698.73	0.00	0.00	353.32	91.50	-3.08	258.74

Demand	**Capacity**	**Status**
Maximum Soil Stress: 353.3 kN/m2	Allowable Maximum Soil Stress: 357.1 kN/m2	√

Eccentricity Check

Comb	Direction	Moment (kN.m)	Axial Load (kN)	Eccentricity (M/N)	Limit (L/6)	Status
Comb #Env - S1	X	0	698.73	261.64 mm	350 mm	✓
	Y	0	698.73	85.51 mm	316.67 mm	✓

Punching Check

V_{pd}	**:**	**Punching Demand**
V_{pc}	:	Punching Capacity
V_{pd-cf}	:	Punching Demand(On Column Face)
V_{pc-cf}	:	Punching Capacity(On Column Face)
V_{pd-ep}	:	Punching Demand(On Effective Perimeter)
V_{pc-ep}	:	Punching Capacity(On Effective Perimeter)
σ_{soil}	:	Soil Stress
A_{eff}	:	Effective Punching Area
β	:	Load Increment Factor For Shear Force
f_{ctd}	:	Concrete Design Tensile Strength
d_x	:	Effective Depth(X-Direction)
d_y	:	Effective Depth(Y-Direction)
γ	:	Factor which reflects the effect of bending
u_p	:	Effective Perimeter
B_{EPx}	:	Width of effective perimeter in X direction
B_{EPy}	:	Width of effective perimeter in X direction
d_{sect}	:	Distance from column face to effective perimeter edge
d	:	Effective Depth
r_{DiamX}	:	Longitudinal rebar diameter in X Direction
r_{DiamY}	:	Longitudinal rebar diameter in Y Direction

Punching force will be calculated according to TS500,

$V_{pd} = \sigma_{soil} * A_{eff}$

$\sigma_{soil} = \Sigma N / L_x L_y$

$A_{eff} = L_x L_y - B_x B_y$

Punching capacity will be calculated according to TS500 - 8.3.1,

$V_{pc} = \gamma f_{ctd} u_p d$

$u_p = 2(B_{EPx} + B_{EPy})$ = 3536 mm

$B_{EPx} = B_x + 2d_{sect}$ = 1034 mm

$B_{EPy} = B_y + 2d_{sect}$ = 734 mm

$d_{sect} = (d_x + d_y) / 2$ = 217 mm

$d_x = d - r_{DiamX} / 2$ = 442 mm

$d_y = d - r_{DiamX} - r_{DiamY} / 2$ = 426 mm

$\gamma = 1 / (1 + (1.5 (e_x + e_y) / (B_x B_y)^{\wedge}(1/2)))$ = 0.807

$V_{pc\text{-}cf}$ = 735.54 kN

$V_{pc\text{-}ep}$ = 1444.93 kN

Punching check is performed for each column on footing. The column having minimum capacity/demand ratio is considered for each combination.

Comb	ΣN (kN)	σ_{Soil}(kN/m2)	Vpd-cf (kN)	D/C-cf	Vpd-ep (kN)	D/C-ep
Comb #Env - S1	698.73	175.12	565.82	0.77	565.82	0.39

Comparison at	Demand / Capacity	Status
Effective Perimeter	565.82 kN / 1444.93 kN	√
Column Face	565.82 kN / 735.54 kN	√

Shear Check

$V_{dx\text{-}cf}$	:	**Shear Force On Column Face, X-Direction**
$V_{dy\text{-}cf}$	:	Shear Force On Column Face, Y-Direction
$V_{dx\text{-}d}$	:	Shear Force On Location d Away From Column Face, X-Direction
$V_{dy\text{-}d}$	:	Shear Force On Location d Away From Column Face, Y-Direction
d_{v1}	:	Distance from Column Face to Footing Edge
d_{v2}	:	Distance from Location d Away From Column Face to Footing Edge
σ_{cf}	:	Soil stress on column face
σ_c	:	Soil stress at nearest corner
σ_{max}	:	Max. corner stress

Shear capacity is calculated according to TS500,

(8.1) - $V_{crx} = 0.65 f_{ctd} L_x d_x$ = 703.89 kN

(8.1) - $V_{cry} = 0.65 f_{ctd} L_y d_y$ = 613.79 kN

$V_{dx\text{-}cf} = \sigma_{cf}\, d_{vx1}\, L_y + ((\sigma_{max} - \sigma_{cf})\, d_{vx1}\, L_y / 2)$

$V_{dy\text{-}cf} = \sigma_{cf}\, d_{vy1}\, L_x + ((\sigma_{max} - \sigma_{cf})\, d_{vy1}\, L_x / 2)$

$V_{dx\text{-}d} = \sigma_{cf}\, d_{vx2}\, L_y + ((\sigma_{max} - \sigma_{cf})\, d_{vx2}\, L_y / 2)$

$V_{dy\text{-}d} = \sigma_{cf}\, d_{vy2}\, L_x + ((\sigma_{max} - \sigma_{cf})\, d_{vy2}\, L_x / 2)$

On Column Face,

		X-Direction			Y-Direction	
Comb	**Demand (kN)**	**Capacity (kN)**	**Status (kN)**	**Demand (kN)**	**Capacity (kN)**	**Status (kN)**
Comb #Env - S1	401.09	703.89	✓	517.95	613.80	✓

On "d" Distance Away From Column Face,

		X-Direction			Y-Direction	
Comb	**Demand (kN)**	**Capacity (kN)**	**Status (kN)**	**Demand (kN)**	**Capacity (kN)**	**Status (kN)**
Comb #Env - S1	180.84	703.89	✓	250.47	613.80	✓

Comparison at	Demand / Capacity	Status
Column Face in X-Direction	401.09 kN / 703.89 kN	√
Column Face in Y-Direction	517.95 kN / 613.80 kN	√
Effective Perimeter in X-Direction	180.84 kN / 703.89 kN	√
Effective Perimeter in Y-Direction	250.47 kN / 613.80 kN	√

Bending Reinforcement Check

Comb	Md_x (kN.m)	Required As_x (cm2)	Md_y (kN.m)	Required As_y (cm2)
Comb #Env - S1	211.64	18.56	158.73	16.19

Comparison of	Design Moment	Selected Rebar	Required / Provided	Status
Reinforcement Area in X-Direction	211.6 kN.m	10ϕ16 / 20.0 cm	18.56 cm2/20.11 cm2	√
Reinforcement Area in Y-Direction	158.7 kN.m	11ϕ16 / 20.0 cm	16.19 cm2/22.12 cm2	√

Thank You…

Thank you for choosing the ProtaStructure Suite product family.

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