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Pad Footing Strut-and-Tie Verification

This example verifies RKALC's implementation of the AS 3600:2018 Appendix A2 strut-and-tie provisions for a reinforced concrete pad footing. The verification covers automatic strut-and-tie model generation, force equilibrium, nodal stress checks, strut capacity, bursting reinforcement and reinforcement requirements. By documenting each stage of the calculation, the example demonstrates that the software produces a transparent and code-compliant design rather than simply reporting the final reinforcement quantities.



NON-Flexural Footing

Loading

Nsls = 4950 kN

N* = 6300 kN

Bearing Capacity = 3000 kPa

deff = 615 mm

Cover to centre = 85 mm

Applied soil pressure =
 $4950 / (1.1 \times 1.8) = 2500 \text{ kPa}$

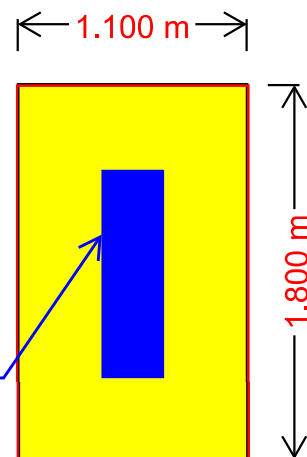
Ultimate pressure
 $2500 \times (6300 / 4950) = 3181 \text{ kPa}$

Span-depth ratio = $400 / 615 = 0.65 < 1$

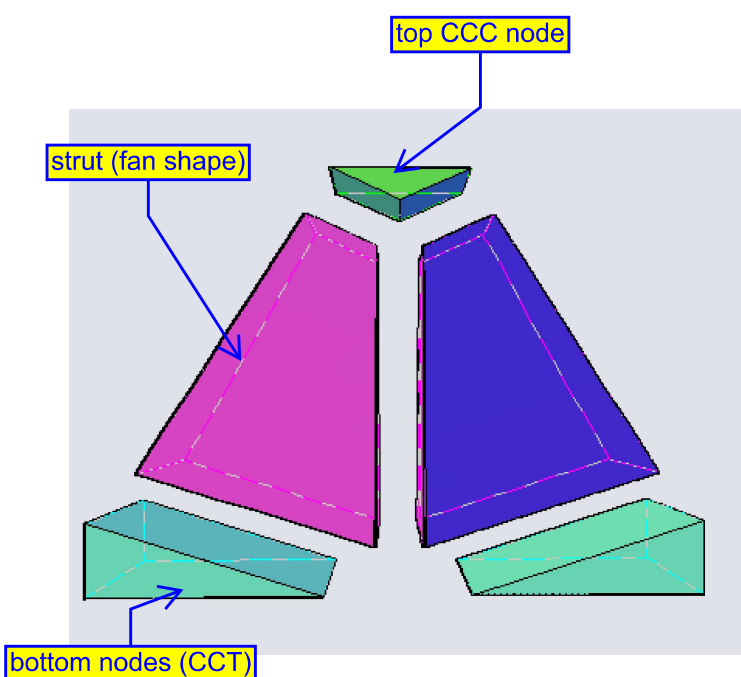
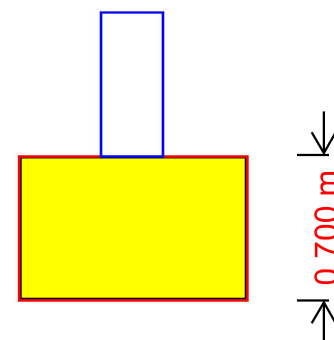
Therefore: Non-flexural member

[Sec. 12.1.1 of AS 3600]

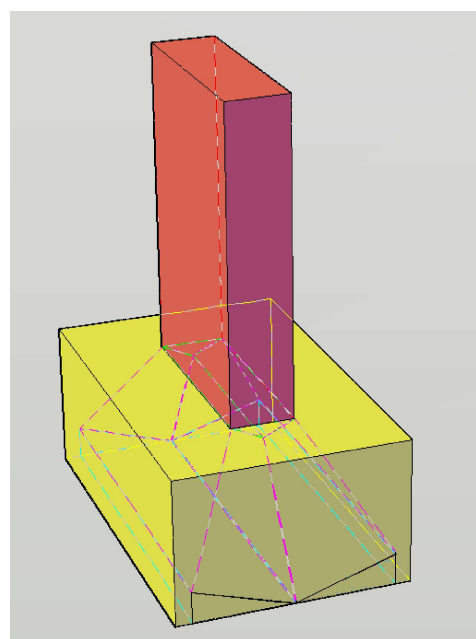
STRUT & TIE MODEL:



300x1000 column
 DL = 3750 kN
 LL = 1200 kN



Components of the STM model



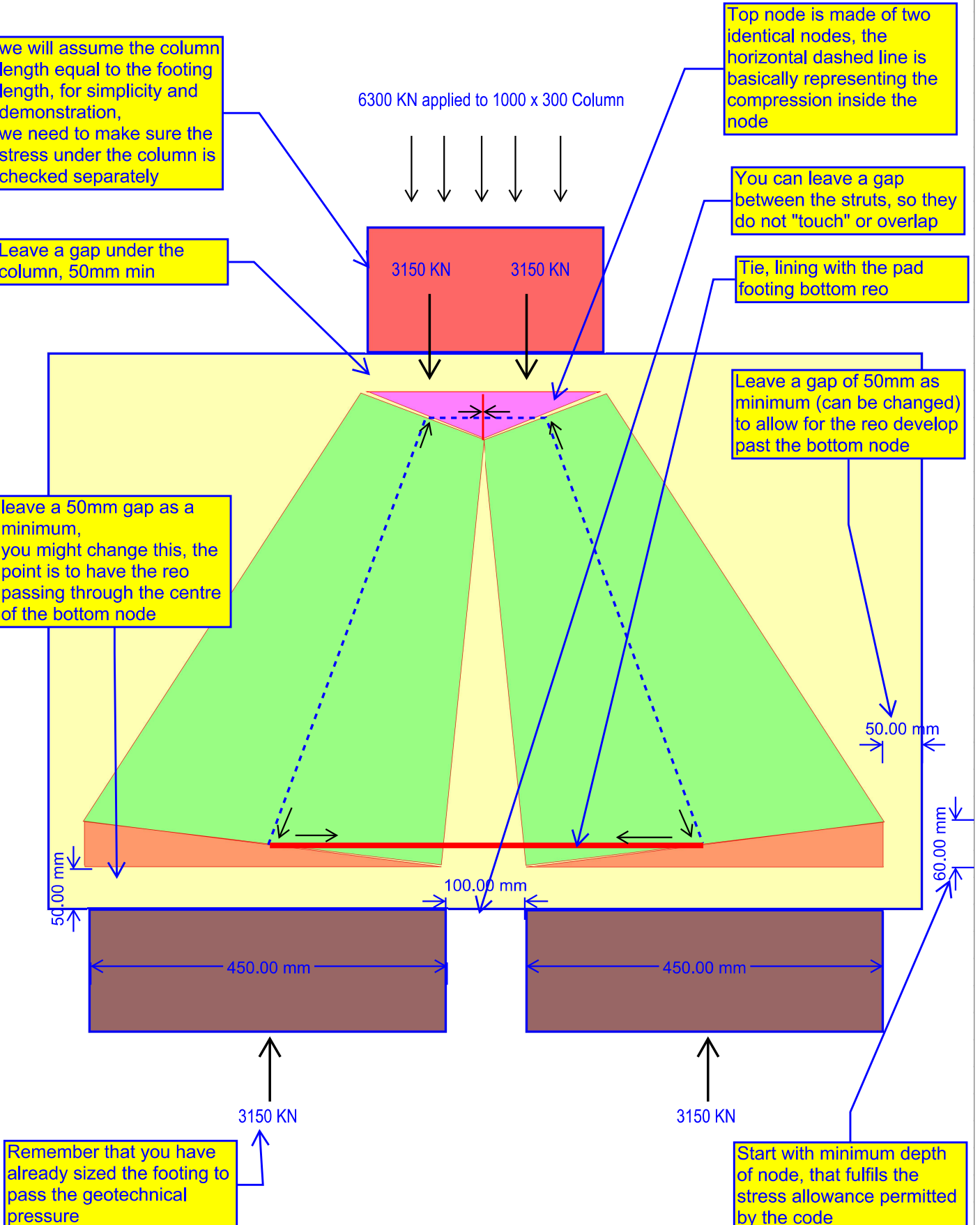
3D Shot showing the footing and proposed strut and tie mode



we will assume the column length equal to the footing length, for simplicity and demonstration, we need to make sure the stress under the column is checked separately

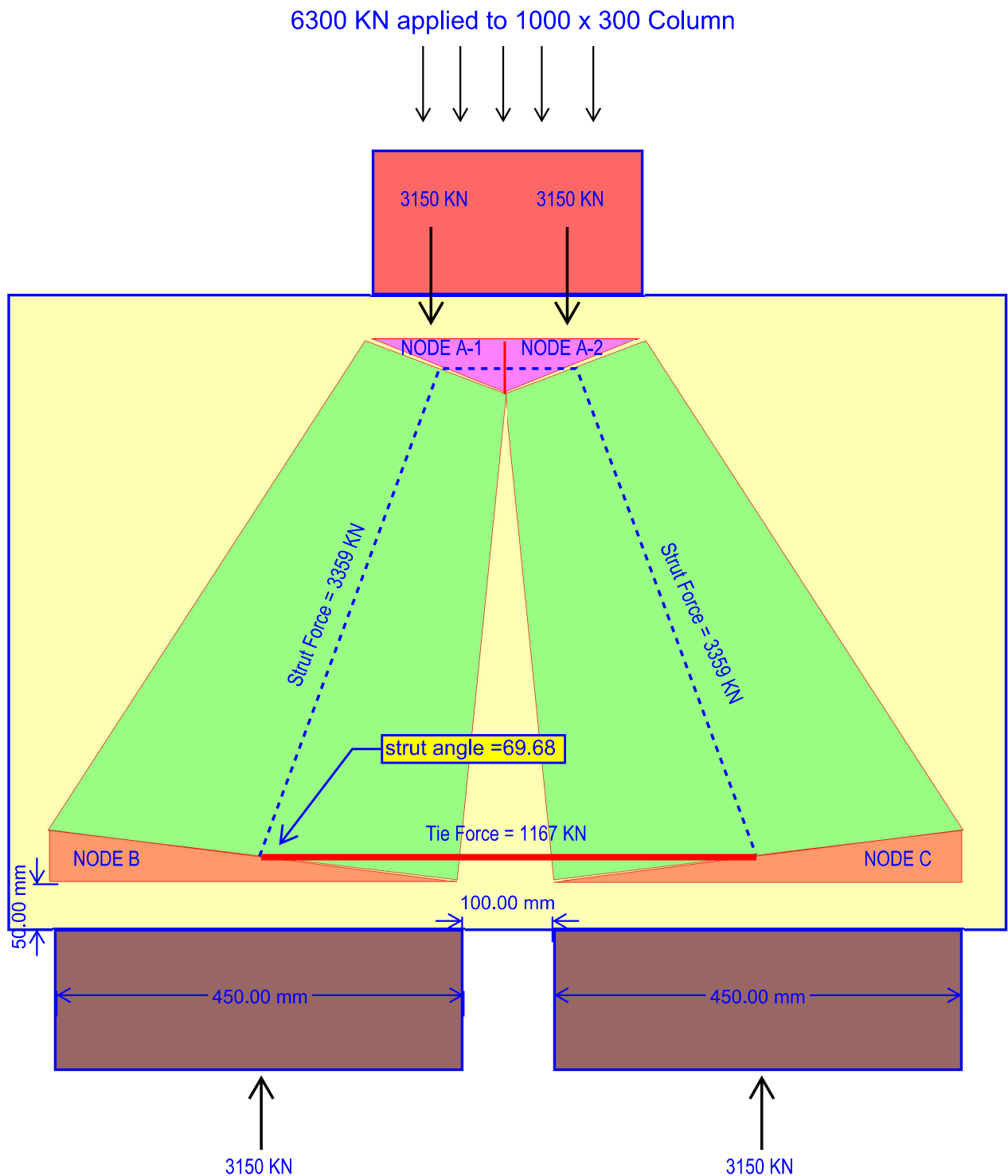
Leave a gap under the column, 50mm min

leave a 50mm gap as a minimum, you might change this, the point is to have the reo passing through the centre of the bottom node





Following figure shows the internal loads within the STM model, most important is to have everything in balance, start by calculating the reactions from the free body diagram of the whole footing (external forces), then calculate the strut / tie forces by balancing the nodes (projecting loads on X and Y axes etc).





Next step is to calculate the permitted stresses, refer to AS3600-2018 for this:

109

AS 3600:2018

0.65

7.4.2 Design strength of nodes

Where confinement is not provided to the nodal region, the design strength of the node shall be such that the principal compressive stress on any nodal face, determined from the normal and shear stresses on that face, is not greater than $\phi_{st} \beta_n 0.9 f'_c$ where—

- (a) for CCC nodes $\beta_n = 1.0$; or That is node A-1 and A-2
- (b) for CCT nodes $\beta_n = 0.8$; or Nodes B and C
- (c) for CTT nodes $\beta_n = 0.6$.

The value of the strength reduction factor (ϕ_{st}) shall be taken from Table 2.2.4.

Where confinement is provided to the nodal region, the design strength of the node may be determined by tests or calculation, considering the confinement, but shall not exceed a value corresponding to a maximum compressive principal stress on any face of $\phi_{st} 1.8 f'_c$.

With 40 MPa concrete, the following will be our allowance:

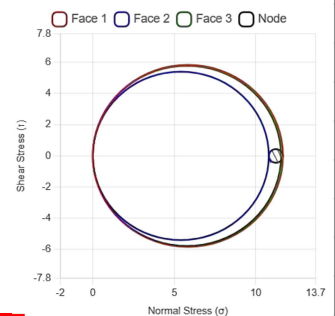
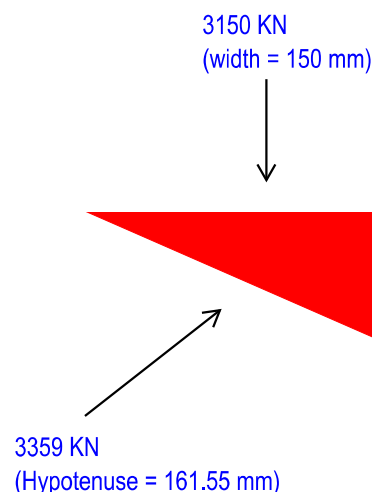
CCC node = $0.65 \times 1.00 \times 0.9 \times 40 = 23.40$ MPa

CCT node = $0.65 \times 0.80 \times 0.9 \times 40 = 18.72$ MPa

Next step is to calculate the stresses applied to each face of the nodes,

Starting with Node A-1 (top left node, which is a mirror image of the top right node in this very example)

Width (mm)	150	Top Stress	11.67
Height (mm)	60	Side Stress	10.8
Hypo (mm)	161.55	Incl. Stress	11.55
Strut/Node Angle	1.48	Shear Stress	0.3
Applied (MPa)	11.67	Allowed MPa	23.4



Note here that we've assumed the column length into the page = 1800 which is not accurate, (converted the matter to 2D rather than 3D) so if we are keen, all of the applied stresses should be increased by the ratio $1.8 / 1$, again within the capacity of the node

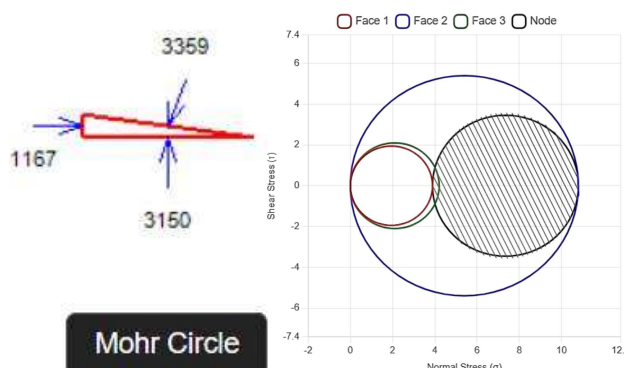
Note: Mohr circle should be constructed to calculate the internal stresses resulting from the angle of the strut is not exactly normal to the triangle but in most cases this is a trivia check, do not need to be performed for straightforward questions



Similarly, bottom node (node B and C are similar):

Left Node

Width (mm)	450	Base Stress	3.89
Height (mm)	60	Side Stress	10.8
Hypo (mm)	453.98	Incl. Stress	4.01
Strt./Nd. Ang	12.73	Shear Stress	0.91
Applied (MPa)	10.8	Allowed MPa	18.72



Now that all of the nodes are ok, we can reinforce the pad, the tie force is 1167 KN hence the total required reo is

AS = $1167 \times 1000 / 0.85 / 500 = 2745 \text{ mm}^2$ for the total length of the footing (1.8 m)
so per meter we will need $2745 / 1.8 = 1525 \text{ mm}^2$ (that is roughly N20 - 2000)

- NOTE

THIS MUST BE MORE THAN THE MINIMUM REO OF THE SECTION, SEE CLAUSE 21.3)

Next Step is to Check the Stress inside the strut

First things first, we can't go ahead with this step unless the nodes pass the stress check, if yes, then we need to calculate the stress as the "smallest cross section" per clause 7.2.3 which is nothing but the smaller node at the top (a plane perpendicular to the axis of the strut).

The allowable stress formulae is similar to the node, with difference at the Beta factor, in struts it relates to the angle of the inclination, the more vertical, the higher efficiency
In our question, the stress = $3359 \times 1000 / (1800 \times 162 / \cos(1.48)) = 12 \text{ MPa}$
Efficiency factor = 0.92 (for theta = 69.68)
allowed stress in strut = $0.65 \times 0.92 \times 0.9 \times 40 = 21.5 \text{ MPa}$ hence all good

7.2.3 Design strength of struts

The design strength of a concrete strut shall be taken as—

$$\phi_{st} \beta_s 0.9 f'_c A_c \quad \dots 7.2.3$$

where

A_c = smallest cross-sectional area of the concrete strut at any point along its length and measured normal to the line of action of the strut

β_s = an efficiency factor given in Clause 7.2.2

$$\beta_s = \frac{1}{1.0 + 0.66 \cot^2 \theta} \quad (\text{within the limits } 0.3 \leq \beta_s \leq 1.0)$$



Next step is to check against bursting

First thing is to understand the geometry of the strut,

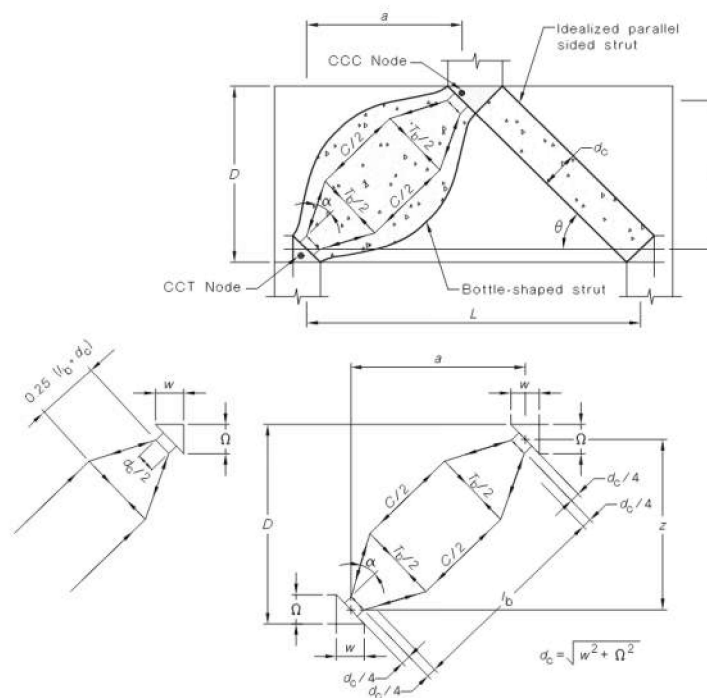
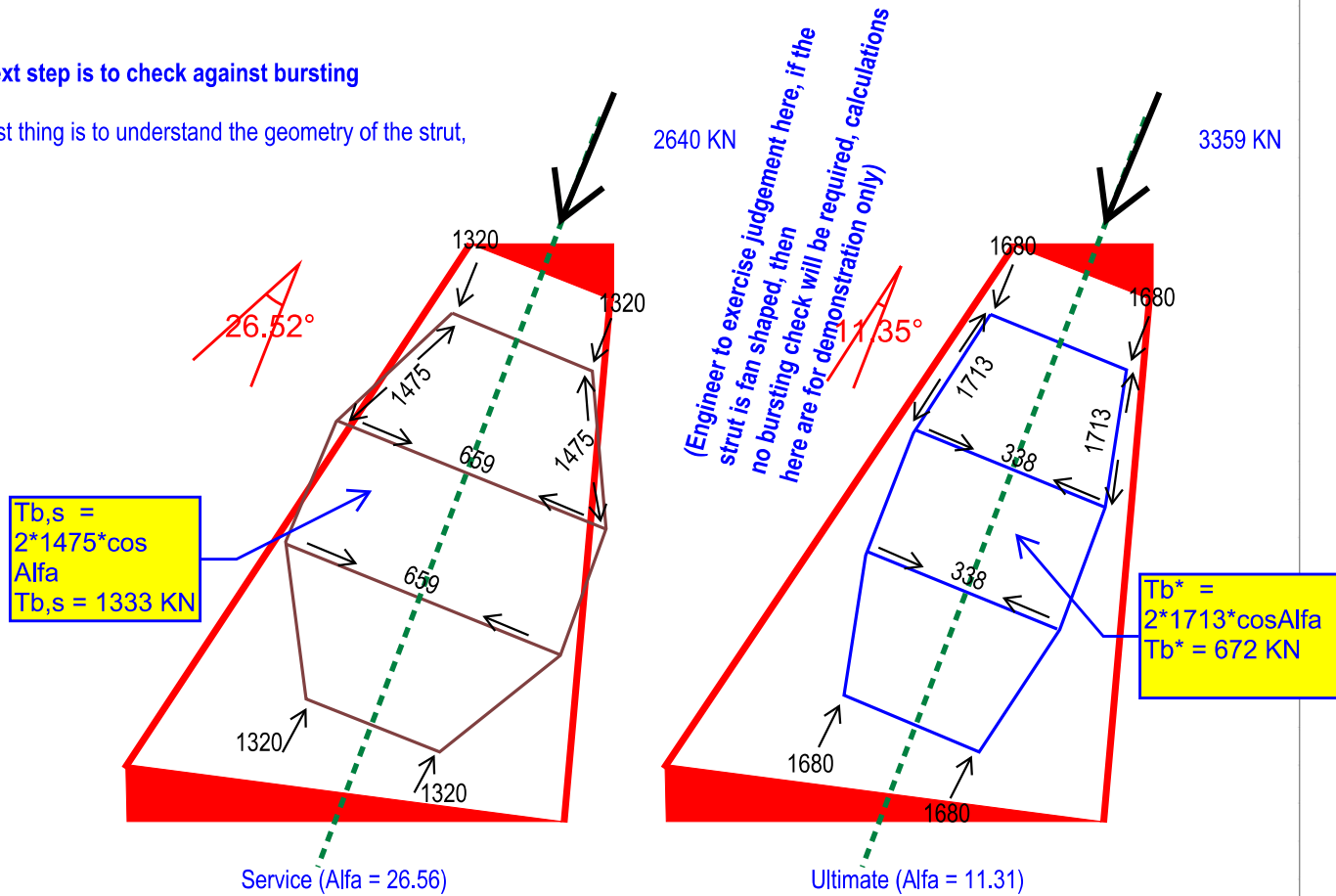


FIGURE 7.2.4(A) MODEL OF BURSTING FORCES IN BOTTLE-SHAPED STRUTS



Next is to calculate the capacity of the concrete at bursting

Average DC = $(162 + 453)/2 = 308$ mm

Strut length = $\text{SQRT}(540^2 + (540/\tan \theta)^2) = 576$

$L_b = 576 - 308 = 268$

Capacity of concrete at bursting = $0.7 \times f_{ct} \times L_b \times B = 0.7 \times 2.28 \text{ MPa} \times 268 \times 1800 = 769 \text{ KN}$

(note L_b to be calculated from the geometry, in this very example it is equal to 268 mm)

The code says:

If the calculated bursting force (T_b^*) is greater than $0.5T_{b,cr}$, with $\tan \alpha$ taken as $\frac{1}{2}$, then transverse reinforcement shall be provided in either—

- (i) two orthogonal directions at angles γ_1 and γ_2 to the axis of the strut [see Figure 7.2.4(B)]; or
- (ii) one direction at an angle γ_1 to the axis of the strut, where γ_1 shall be not less than 40° and shall satisfy the following:

(A) For serviceability

$$\sum A_{si} f_{si} \sin \gamma_i \geq \max(T_{b,s}^*, T_{b,cr}^*) \quad \dots 7.2.4(2)$$

(B) For strength

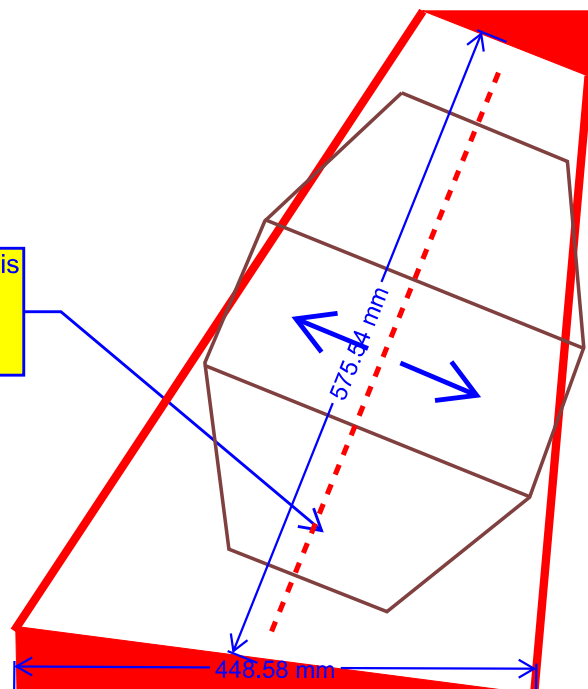
$$\phi_{st} \sum A_{si} f_{sy} \sin \gamma_i \geq T_b^* \quad \dots 7.2.4(3)$$

The transverse reinforcement shall be evenly distributed throughout the length of the bursting zone (l_b), which is given by—

$$l_b = \sqrt{z^2 + a^2} - d_c \quad \dots 7.2.4(4)$$

and a , d_c and z are the shear span, the depth of the idealized strut, and the projection of the inclined compressive strut normal to the shear span respectively [see Figure 7.2.4(A)].

this is the plane at which the bursting force is applied (cracks along this line)
The depth (into the page) is the other dimension of this plan





Which means we need to calculate the bursting force from ultimate load, but with an angle of 26.56, and compare this value with HALF of the concrete bursting capacity, if the load exceeds the HALF, then bursting reo will be required.

In this very example:

Capacity of concrete on bursting is 769 KN

Applied service bursting is 1318 KN (at angle of 26.56)

Applied Ultimate Bursting is 676 KN (at angle of 11.31)

—————> Hence we need to have bursting reo

—————> this is low

Hence
we need bursting
REO because
 $1691 > 0.5 \times 769$

and

Applied Ultimate bursting at angle of 26.56 is $676 \times 0.5 / 0.2 = 1691$ KN (multiplied by tangent of alfas to work out the number) ———>

Calculation of Bursting REO:

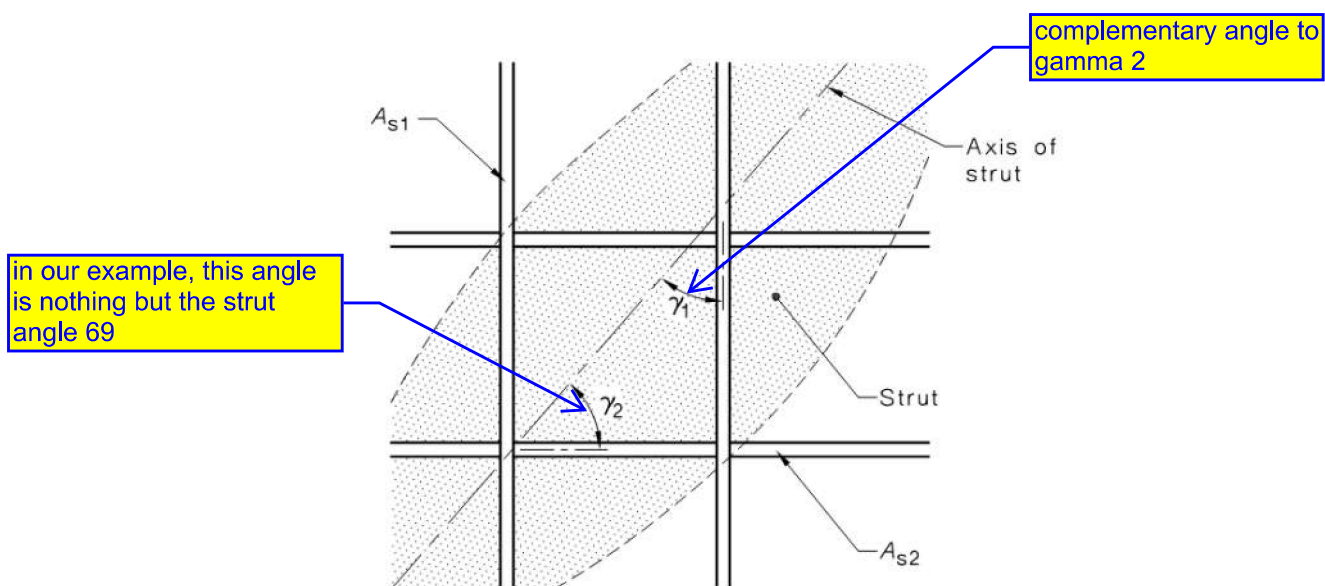


FIGURE 7.2.4(B) BURSTING REINFORCEMENT

For service

$$\text{Max}(T_{b,s} \text{ and } T_{b,c}) < 250 \text{ MPa} \times [A_{sh} \times \sin(69) + A_{sv} \times \cos(69)]$$

(note we used 250 MPa for service, read clause 12.7)

$$\text{Max}(1318 \times 769) = 1318 \text{ KN}$$

$$\text{try } A_{sh} = 4200 \text{ mm}^2$$

$$1317 \times 1000 = 250 \times (4200 \times 0.93 + A_{sv} \times 0.36)$$

$$\text{Hence } A_{sv} = 3800 \text{ mm}^2$$

(NOTE : see here the horizontal reo is most efficient)

(A) For serviceability

$$\sum A_{si} f_{si} \sin \gamma_i \geq \max(T_{b,s}^*, T_{b,cr}^*)$$

(B) For strength

$$\phi_{st} \sum A_{si} f_{sy} \sin \gamma_i \geq T_b^*$$

For Ultimate

$$\text{Capacity} = 0.85 \times 500 \times (4200 \times \sin(69) + 3800 \times \cos(69)) = 2245 \text{ KN} > 667 \text{ OK}$$

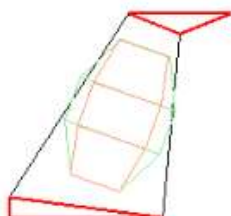


Left Strut

Min Width	162
Max Width	454
Average Dc (mm)	308
Length	576
Lb	268
Strut Angle	69.68
Efficiency Factor	0.92
Strut Force KN	3359
Applied σ (MPa)	11.55
Allowed σ (MPa)	21.46
f_{ct} (MPa)	2.28
Tb,cr Bursting (KN)	769
SLS* Burst. (KN)	1333
ULS* Burst. (KN)	672
Hor.REO Total Both Faces mm	4149
Vert. REO Total Both Faces mm	4149
ULS Burst. Capacity	2666
SLS Burst. Capacity	1333

Strut Situation

OK

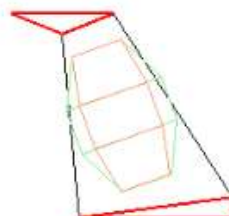


Right Strut

Min Width	162
Max Width	454
Average Dc (mm)	308
Length	576
Lb	268
Strut Angle	69.68
Efficiency Factor	0.92
Strut Force KN	3359
Applied σ (MPa)	11.55
Allowed σ (MPa)	21.46
f_{ct} (MPa)	2.28
Tb,cr Bursting (KN)	769
SLS* Burst. (KN)	1333
ULS* Burst. (KN)	672
Hor.REO Total Both Faces mm	4149
Vert. REO Total Both Faces mm	4149
ULS Burst. Capacity	2666
SLS Burst. Capacity	1333

Strut Situation

OK





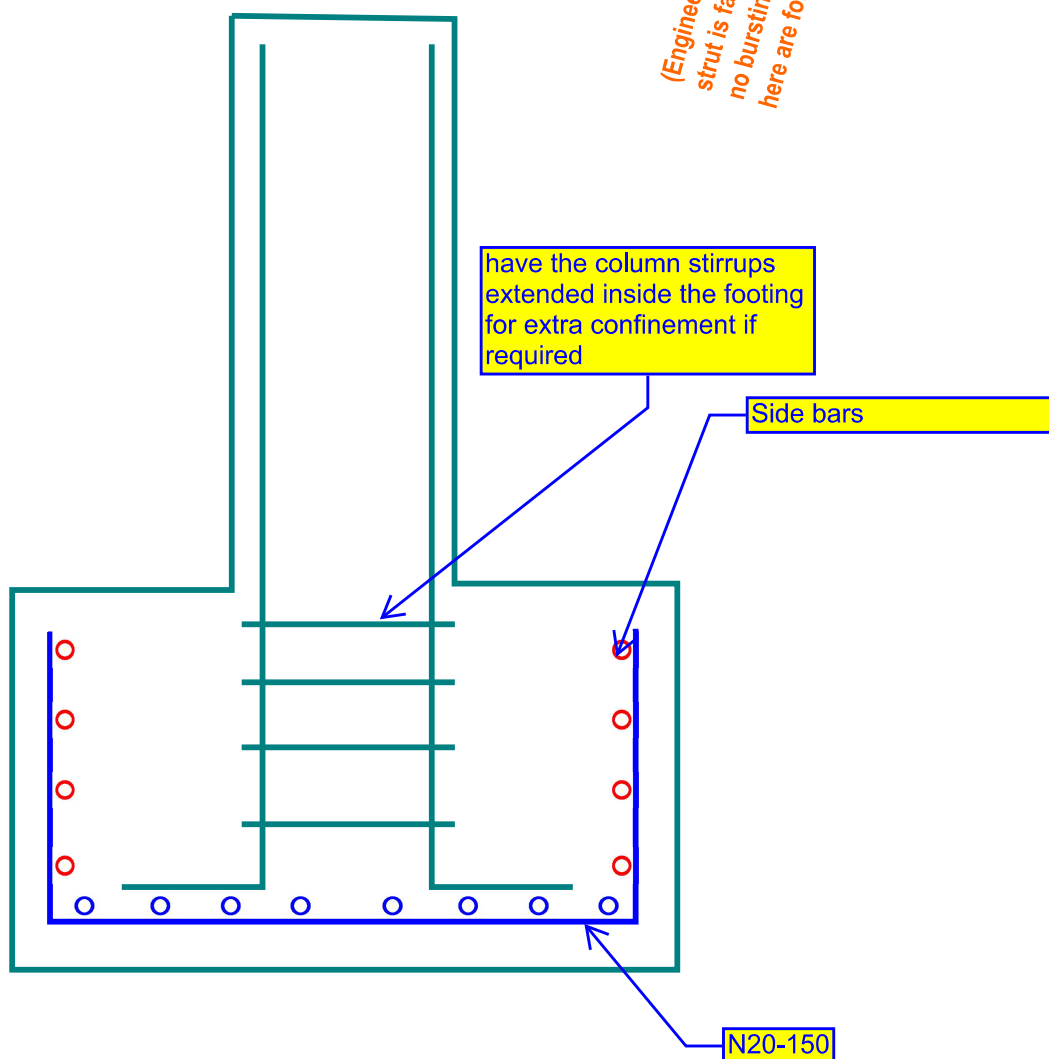
The above means we need to add heavy bursting reo for the footing, we will need $4100 / 2 = 2050 \text{ mm}^2$ each face, these are the side bars plus $3950 / 2 = 2000 \text{ mm}^2$ vertical bars (footing reo copped up - if we try N20-150 equals to 2093 mm^2 per meter)

However, this problem can be mitigated as follows:

- 1- Study the footing with reduced live load,
- 2- increase the MPa of footing
- 3 - Reduce the tension force in the footing by employing the rock confinement around
- 4- Study the model in different ways, for example having 3 nodes at the bottom
- 5- Extend the column ties inside the footing

in this very example, we will need some 5 N 24 side bars each face, which seems too much.

SUMMARY





Note on Anchorage

Developing the REO is required as a matter of fact, see below figures taken from ACI318-M 2011 showing where to start the anchorage length from, in our example we had N20 bars, so without a hook (cog) we need some $40 \times 20 = 800$ mm this is reduce to some 400 for the existence of hooks.

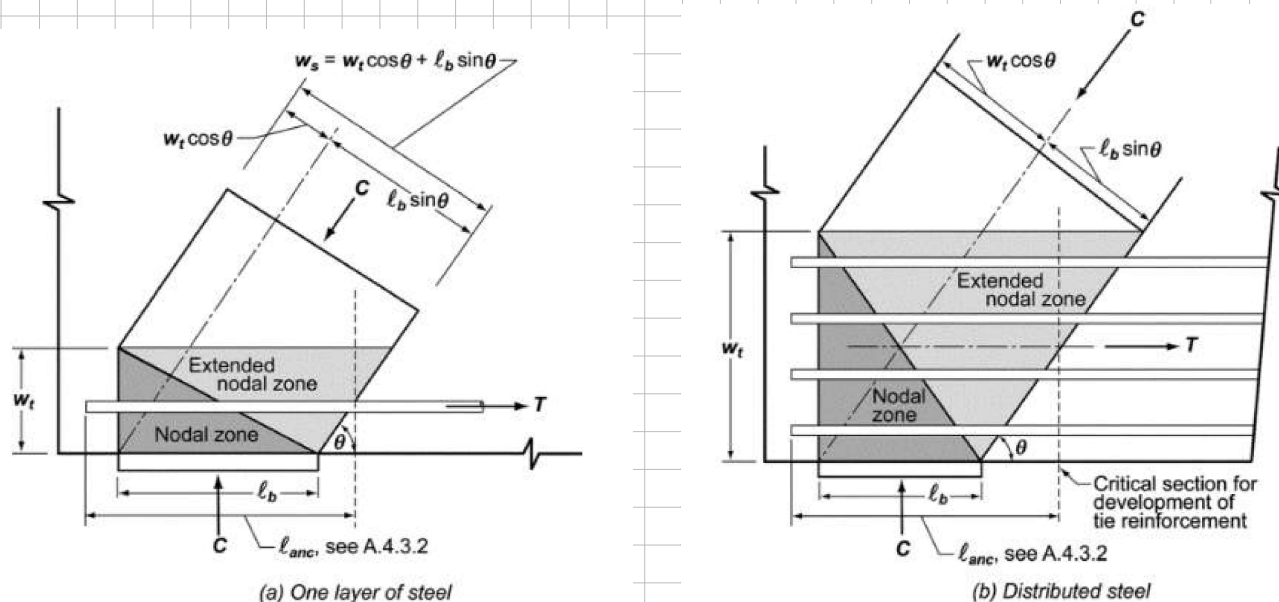


Fig. RA.1.5—Extended nodal zone showing the effect of the distribution of the force.

Note on Hydrostatic Nodes

See below from ACI

Nodal zone — Historically, hydrostatic nodal zones as shown in Fig. RA.1.4 were used. These were largely superseded by what are called extended nodal zones, shown in Fig. RA.1.5.

A **hydrostatic nodal zone** has loaded faces perpendicular to the axes of the struts and ties acting on the node and has equal stresses on the loaded faces. Figure RA.1.4(a) shows a C-C-C nodal zone. If the stresses on the face of the nodal zone are the same in all three struts, the ratios of the lengths of the sides of the nodal zone, $w_{n1} : w_{n2} : w_{n3}$ are in the same proportions as the three forces $C_1 : C_2 : C_3$. The faces of a hydrostatic nodal zone are perpendicular to the axes of the struts and ties acting on the nodal zone.

These nodal zones are called hydrostatic nodal zones because the in-plane stresses are the same in all directions. Strictly speaking, this terminology is incorrect because the in-plane stresses are not equal to the out-of-plane stresses.

RA.5 — Strength of nodal zones

RA.5.1 — If the stresses in all the struts meeting at a node are equal, a hydrostatic nodal zone can be used. The faces of such a nodal zone are perpendicular to the axes of the struts, and the widths of the faces of the nodal zone are proportional to the forces in the struts.

Assuming the principal stresses in the struts and ties act parallel to the axes of the struts and ties, the stresses on faces perpendicular to these axes are principal stresses, and A5.1(a) is used. If, as shown in Fig. RA.1.5(b), the face of a nodal zone is not perpendicular to the axis of the strut, there will be both shear stresses and normal stresses on the face of the nodal zone. Typically, these stresses are replaced by the normal (principal compression) stress acting on the cross-sectional area A_c of the strut, taken perpendicular to the axis of the strut as given in A.5.1(a).

Introduction

This document provides analysis of non-flexural element design in accordance with the Australian Standard AS3600-2018. It covers both the ultimate and service conditions, addressing the following aspects:

- Flexural Reinforcement
- Nodal Stresses and compliance with the Standard
- Strut Checks, including bursting

The design ensures structural integrity and compliance with the standard under the specified loading conditions. For detailed guidelines and requirements, refer to the relevant sections of AS3600-2018-A2.

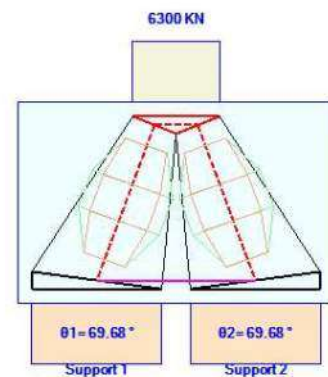
This calculation can be reproduced and checked independently. For more details, refer to the [RKALC website](#).

Material Properties

Parameter	Value	Unit
Concrete Strength f'_c	40	MPa
Rebar f_y	500	MPa
SLS Rebar stress f_{ys}	250	MPa

Geometry

Parameter	Value	Unit
Wall Height	700	mm
Wall Width	1100	mm
Wall Thickness	1800	mm
Width of Left Support	450	mm
Width of Right Support	450	mm
Width of Applied Load	300	mm



Applied Loads

Parameter	Value	Unit
Ultimate Load	6300	KN
Service Load	4950	KN
Width of Applied Load	300	mm
Centre of Applied Load (from left edge of the wall)	550	mm

Nodal Assumptions

Top Node

The node at the top is receiving the load, width of which equal to the node's width. Node is essentially divided into two triangulated nodes (left and right), these have widths constructed from the shares of load they take.

Parameter	Value	Unit
Top Node Width (total)	300	mm
Top Node Depth	60	mm
Node Thickness	1800	mm

Left Node

Parameter	Value	Unit
Left Node Width	450	mm
Left Node Depth	60	mm
Node Thickness	1800	mm

Right Node

Parameter	Value	Unit
Right Node Width	450	mm
Right Node Depth	60	mm
Node Thickness	1800	mm

Analysis and Required Reinforcement

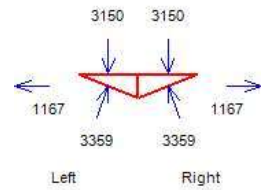
Parameter	Value	Unit
Span-Depth Ratio of the STM Model	1.57	
Left Node Reaction	3150	KN
Right Node Reaction	3150	KN
Resulting Tie Force	1167	KN
Required REO	2745	mm ²
Left Strut Force	3359	KN
Left Strut Angle	69.68	Degrees
Right Strut Force	3359	KN
Right Strut Angle	69.68	Degrees

Ensure the reinforcement is reasonable, not heavy. spread so the centre of bars is passing by the centre of the nodes at the bottom

Nodal Capacity Check

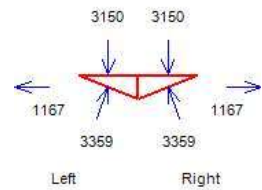
Top Node — Left part

Parameter	Value	Unit
Width (Based on Share of Load Taken)	150	mm
Base stress	1800	N/mm ²
Side stress	10.8	N/mm ²
Inclined stress	11.55	N/mm ²
Shear stress	0.3	N/mm ²
Allowed Stress (CCC Node)	23.4	N/mm ²
Status	Pass	



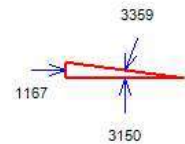
Top Node — Right part

Parameter	Value	Unit
Width (Based on Share of Load Taken)	150	mm
Base stress	1800	N/mm ²
Side stress	10.8	N/mm ²
Inclined stress	11.55	N/mm ²
Shear stress	0.3	N/mm ²
Allowed Stress (CCC Node)	23.4	N/mm ²
Status	Pass	



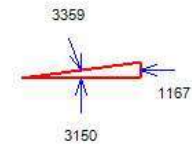
Bottom-Left node

Parameter	Value	Unit
Base stress	3.89	N/mm ²
Side stress	10.8	N/mm ²
Inclined stress	4.01	N/mm ²
Shear stress	0.91	N/mm ²
Allowed Stress (CCT Node)	18.72	N/mm ²
Status	Pass	



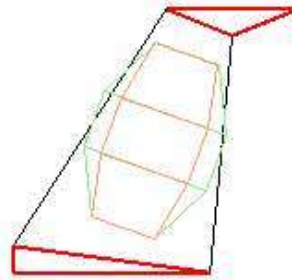
Bottom-Left node

Parameter	Value	Unit
Base stress	3.89	N/mm ²
Side stress	10.8	N/mm ²
Inclined stress	4.01	N/mm ²
Shear stress	0.91	N/mm ²
Allowed Stress (CCT Node)	18.72	N/mm ²
Status	Pass	



Left Strut

Strut Parameter	Value	Unit
Average Dc	308	mm
Lb	268	mm
Angle	69.68	Degrees
Efficiency Factor	0.92	
Applied MPa	11.55	
Allowed MPa	21.46	
fct	2.28	MPa
Tb,cr Bursting	769	MPa
SLS* Bursting	1320	KN
ULS* Burst	672	KN
Hor.REO Total Both Faces mm	4108	mm ²
Vert.REO Total Both Faces mm	4108	mm ²
ULS Burst. Capacity	2639	KN
SLS Burst. Capacity	1320	KN
Strut Status	OK	



Right Strut

Strut Parameter	Value	Unit
Average Dc	308	mm
Lb	268	mm
Angle	69.68	Degrees
Efficiency Factor	0.92	
Applied MPa	11.55	
Allowed MPa	21.46	
fct	2.28	MPa
Tb,cr Bursting	769	MPa
SLS* Bursting	1320	KN
ULS* Burst	672	KN
Hor.REO Total Both Faces mm	4108	mm ²
Vert.REO Total Both Faces mm	4108	mm ²
ULS Burst. Capacity	2639	KN
SLS Burst. Capacity	1320	KN
Strut Status	OK	

