Project data

Project name	
Project number	
Author	
Description	
Date	26/04/2017
Design code	AISC 360-10

Material

Steel	A36, A529, Gr. 50
Concrete	4000 psi

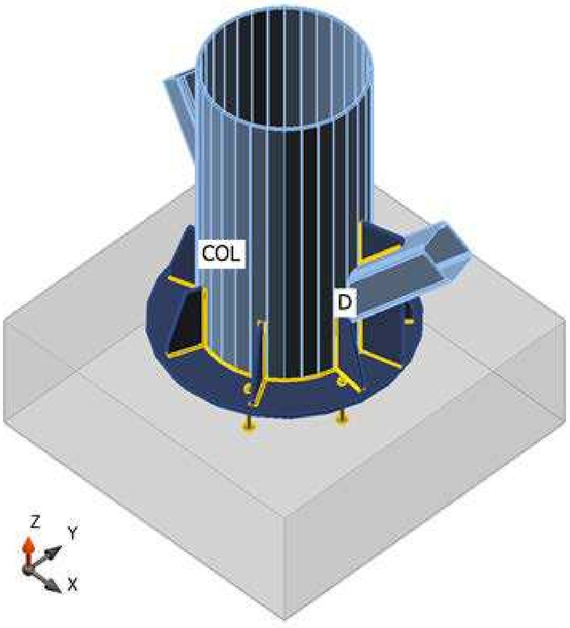
dome anchor

Connection

Item	
Name	dome anchor
Description	
Analysis	Stress, strain/ simplified loading
Design code	AISC - ASD

Beams and columns

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
COL	3 - CHS44,0.75	0.0	-90.0	0.0	0	0	0
D	4 - HSS(Imp)12X12X1/2	15.0	-45.0	0.0	0	0	0
D1	4 - HSS(Imp)12X12X1/2	165.0	-45.0	0.0	0	0	0



Cross-sections

Name	Material
3 - CHS44,0.75	A36
4 - HSS(Imp)12X12X1/2	A529, Gr. 50
4 - HSS(Imp)12X12X1/2	A529, Gr. 50

Material

Steel	A36, A529, Gr. 50
Concrete	4000 psi
Bolts	1 A325

Bolts/ Anchors

Name	Bolt assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
1 A325	1 A325	25	825.0	507

Load effects

Name	Member	Pos.	X [mm]	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	COL	End	0	-1338.914	266.893	106.757	-4.5	9.0	-111.9
	D	End	0	-1112.055	0.000	13.345	2.0	8.9	0.0
	D1	End	0	-1112.055	0.000	13.345	2.0	8.9	0.0

Foundation block

Item	Value	Unit
Offset	381; 381; 381; 381	mm
Depth	914	mm
Anchor	1 A325	
Anchoring length	305	mm
Shear force transfer	Shear iron	
Cross-section of shear iron	W(Imp)6X9	
Length of shear iron	457	mm

Results

Summary

Name	Value	Check status
Analysis	100.0%	OK
Plates	2.4 < 5%	OK
Anchors	5.3 < 100%	OK
Welds	89.1 < 100%	OK
Shear	18.7 < 100%	OK

Plates

Name	Material	Thickness [mm]	Loads	σ_{Ed} [MPa]	ε_{Pl} [%]	Check status
COL	A36	19	LE1	150.5	1.0	OK
D	A529, Gr. 50	13	LE1	207.7	0.8	OK
D1	A529, Gr. 50	13	LE1	210.8	2.4	OK
BP1	A36	20	LE1	148.7	0.1	OK
RIB1a	A36	19	LE1	113.3	0.0	OK
RIB1b	A36	19	LE1	137.3	0.0	OK
RIB1c	A36	19	LE1	125.3	0.0	OK
RIB1d	A36	19	LE1	76.4	0.0	OK
RIB1e	A36	19	LE1	108.6	0.0	OK
RIB1f	A36	19	LE1	117.3	0.0	OK
RIB1g	A36	19	LE1	84.9	0.0	OK
RIB2	A36	19	LE1	149.2	0.3	OK
RIB3	A36	19	LE1	149.3	0.3	OK

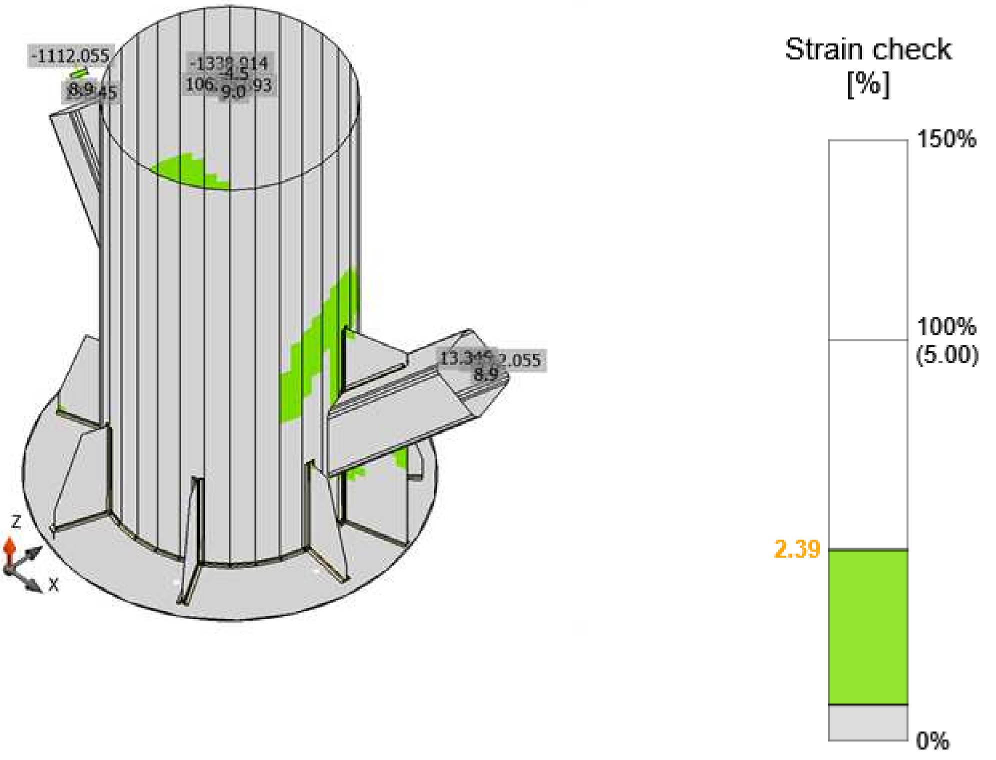
Design data

Material	fy [MPa]	ε_{lim} [1e-4]
A36	248.2	500.0

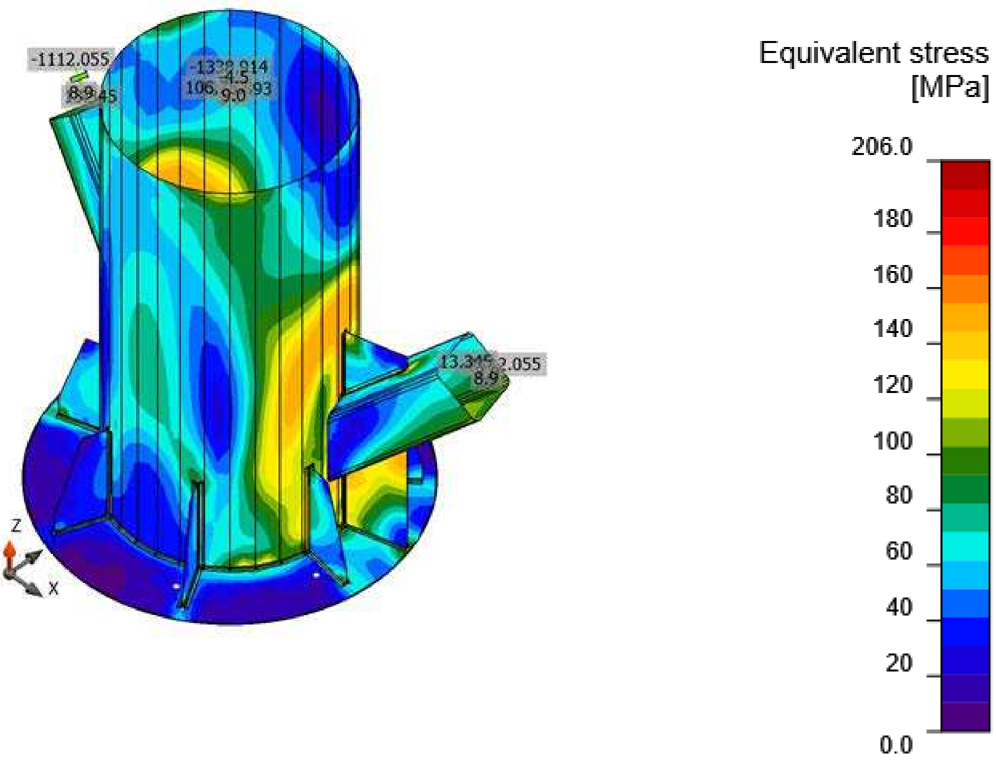
Material	fy [MPa]	ε_{lim} [1e-4]
A529, Gr. 50	344.0	500.0

Symbol explanation

Symbol	Symbol explanation
ε_{Pl}	Strain
σ_{Ed}	Eq. stress

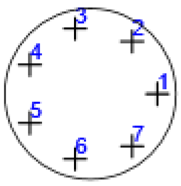


Strain check, LE1



Equivalent stress, LE1

Anchors

	Name	Grade	Loads	F_t [kN]	V [kN]	φN_{cbg} [kN]	Ut_t [%]	Ut_s [%]	φV_{cbg} [kN]	Detailing	Status
	B1	1 A325 - 1	LE1	0.000	0.000	0.000	0.0	0.0	0.000	OK	OK
	B2	(1 A325 - 2,)	LE1	8.326	0.000	232.592	5.3	0.0	0.000	OK	OK
	B3	(1 A325 - 1,)	LE1	0.000	0.000	0.000	0.0	0.0	0.000	OK	OK
	B4	(1 A325 - 1,)	LE1	0.000	0.000	0.000	0.0	0.0	0.000	OK	OK
	B5	(1 A325 - 1,)	LE1	0.000	0.000	0.000	0.0	0.0	0.000	OK	OK
	B6	(1 A325 - 1,)	LE1	0.000	0.000	0.000	0.0	0.0	0.000	OK	OK
	B7	(1 A325 - 1,)	LE1	0.000	0.000	0.000	0.0	0.0	0.000	OK	OK

Design data

Name	$Rn/\Omega_{Tension}$ [kN]	Rn/Ω_{Shear} [kN]	V_{rds} [kN]	S_{tf} [MN/m]	$Rn/\Omega_{Bearing}$ [kN]
1 A325 - 1	157.080	94.248	0.000	524	0.000
1 A325 - 2	157.080	0.000	0.000	524	243.840

Welds

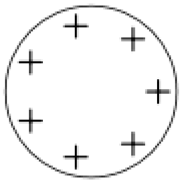
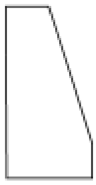
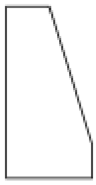
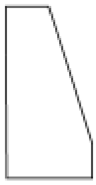
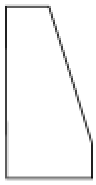
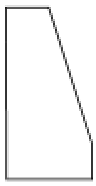
Item	Edge	Material	Thickness [mm]	Leg size S [mm]	Length [mm]	Loads	F_n [kN]	Rn/Ω_w [kN]	Ut [%]	Check status
BP1	COL-1	E70xx	◢9.5◣	◢13.5 ◣	3446	LE1	1994.722	12498.361	16.0	OK
BP1	RIB1a	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	211.812	980.516	21.6	OK
COL-arc 1	RIB1a	E70xx	◢10.2◣	◢14.4 ◣	508	LE1	210.368	1980.538	10.6	OK
BP1	RIB1b	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	10.559	398.827	2.6	OK
COL-arc 6	RIB1b	E70xx	◢10.2◣	◢14.7 ◣	508	LE1	43.261	580.267	7.5	OK
BP1	RIB1c	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	205.406	1078.076	19.1	OK
COL-arc 10	RIB1c	E70xx	◢10.2◣	◢14.5 ◣	508	LE1	205.406	2148.538	9.6	OK
BP1	RIB1d	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	126.960	1111.170	11.4	OK
COL-arc 15	RIB1d	E70xx	◢10.2◣	◢14.7 ◣	508	LE1	126.960	2119.753	6.0	OK
BP1	RIB1e	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	169.278	1103.783	15.3	OK
COL-arc 19	RIB1e	E70xx	◢10.2◣	◢14.7 ◣	508	LE1	169.278	2131.304	7.9	OK
BP1	RIB1f	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	88.710	935.273	9.5	OK
COL-arc 24	RIB1f	E70xx	◢10.2◣	◢14.7 ◣	508	LE1	86.116	1963.482	4.4	OK
BP1	RIB1g	E70xx	◢10.2◣	◢14.4 ◣	254	LE1	100.428	1096.913	9.2	OK
COL-arc 28	RIB1g	E70xx	◢10.2◣	◢14.7 ◣	508	LE1	100.428	2127.297	4.7	OK
BP1	RIB2	E70xx	◢10.2◣	◢14.4 ◣	305	LE1	46.940	161.035	29.1	OK
COL-arc 7	RIB2	E70xx	◢10.2◣	◢14.6 ◣	1143	LE1	654.252	3612.554	18.1	OK
BP1	RIB3	E70xx	◢7.6◣	◢10.8 ◣	305	LE1	48.516	121.378	40.0	OK
COL-arc 26	RIB3	E70xx	◢7.6◣	◢11.0 ◣	1143	LE1	205.766	652.300	31.5	OK
RIB2	D1-w 1	E70xx	◢12.7	◢18.0	432	LE1	136.527	153.264	89.1	OK
RIB2	D1-w 1	E70xx	◢12.7	◢18.0	432	LE1	125.635	373.866	33.6	OK
RIB2	D1-w 3	E70xx	◢12.7	◢18.0	432	LE1	123.486	309.826	39.9	OK
RIB2	D1-w 3	E70xx	◢12.7	◢18.0	432	LE1	142.734	427.423	33.4	OK
RIB3	D-w 1	E70xx	◢10.2	◢14.4	432	LE1	110.105	211.337	52.1	OK
RIB3	D-w 1	E70xx	◢10.2	◢14.4	432	LE1	149.800	171.724	87.2	OK
RIB3	D-w 3	E70xx	◢10.2	◢14.4	432	LE1	106.445	237.385	44.8	OK
RIB3	D-w 3	E70xx	◢10.2	◢14.4	432	LE1	132.454	241.071	54.9	OK

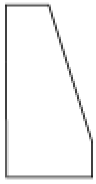
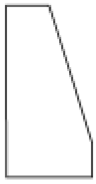
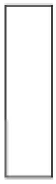
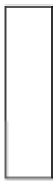
Symbol explanation

Symbol	Symbol explanation
F_n	Force in weld
Rn/Ω_w	Weld resistance AISC 360-10 J2.4
Ut	Utilization
Thickness	Throat thickness
Leg size S	Leg size of weld

Bill of material

Manufacturing operations

Name	Plates [mm]	Shape	Nr.	Welds [mm]	Length [mm]	Bolts	Nr.
BP1	P20.0x1752.6-0.0 (A36)		1	Double fillet: a = 9.5	3445.7	1 A325	7
CUT1				Bevel: a = 12.7	215.5		
CUT2				Bevel: a = 12.7	215.5		
RIB1	P19.1x256.6-508.0 (A36)		1	Double fillet: a = 10.2	5334.0		
	P19.1x254.1-508.0 (A36)		1				
	P19.1x256.6-508.0 (A36)		1				
	P19.1x255.4-508.0 (A36)		1				
	P19.1x256.1-508.0 (A36)		1				

Name	Plates [mm]	Shape	Nr.	Welds [mm]	Length [mm]	Bolts	Nr.
	P19.1x256.2-508.0 (A36)		1				
	P19.1x255.1-508.0 (A36)		1				
RIB2	P19.1x307.1-1143.0 (A36)		1	Double fillet: a = 10.2	1447.8		
RIB3	P19.1x307.1-1143.0 (A36)		1	Double fillet: a = 7.6	1447.8		
CUT3				Fillet: a = 12.7	1727.3		
CUT4				Fillet: a = 10.2	1727.3		

Welds

Type	Material	Thickness [mm]	Length [mm]
Double fillet	E70xx	9.5	3445.7
Bevel	E70xx	12.7	430.9
Double fillet	E70xx	10.2	6781.8
Double fillet	E70xx	7.6	1447.8
Fillet	E70xx	12.7	1727.3
Fillet	E70xx	10.2	1727.3

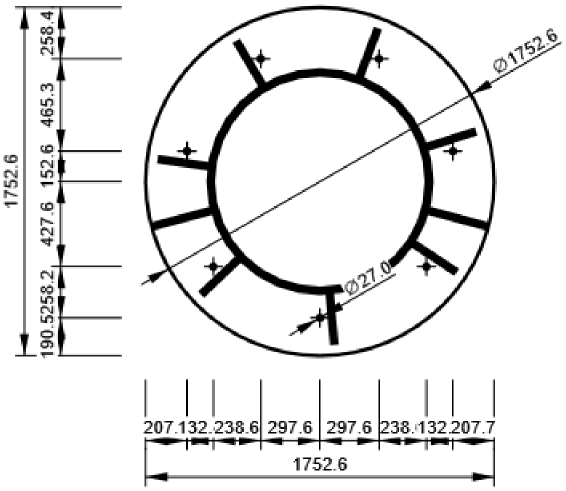
Bolts

Name	Count
1 A325	7

Drawing

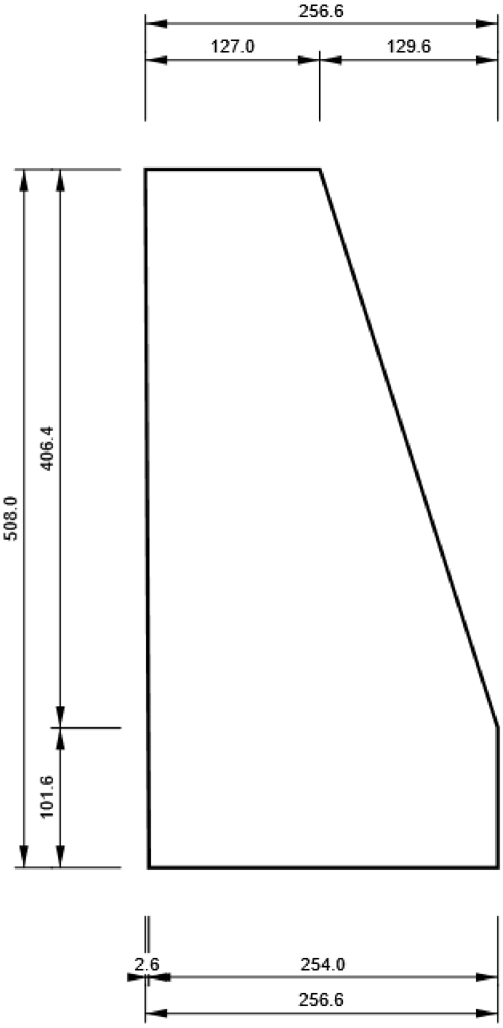
BP1

P20.0x1752.6-1752.6 (A36)



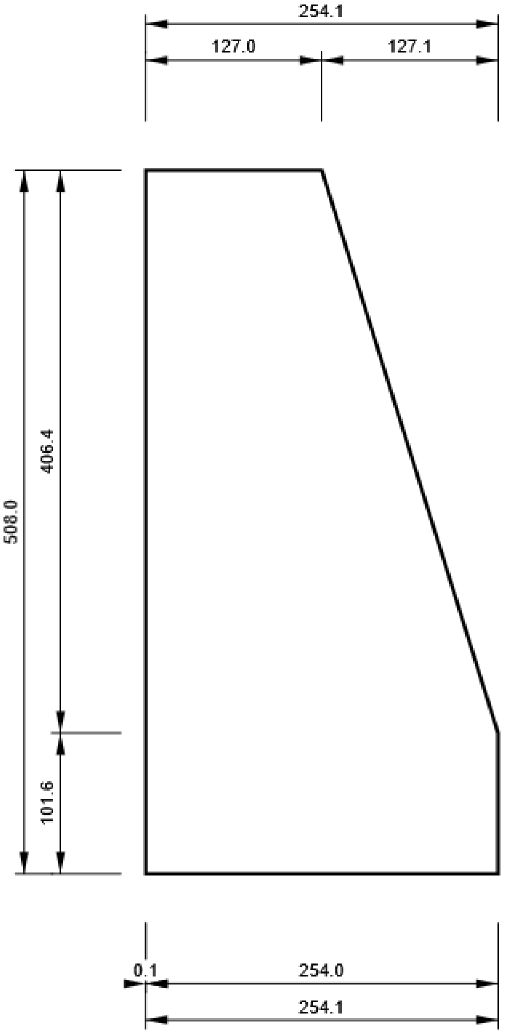
RIB1 - 1

P19.1x508.0-256.6 (A36)



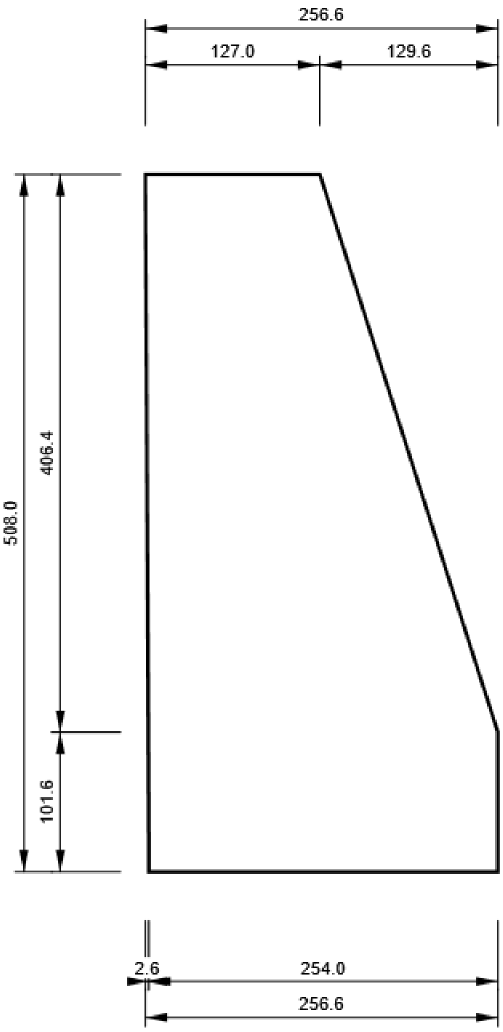
RIB1 - 2

P19.1x508.0-254.1 (A36)



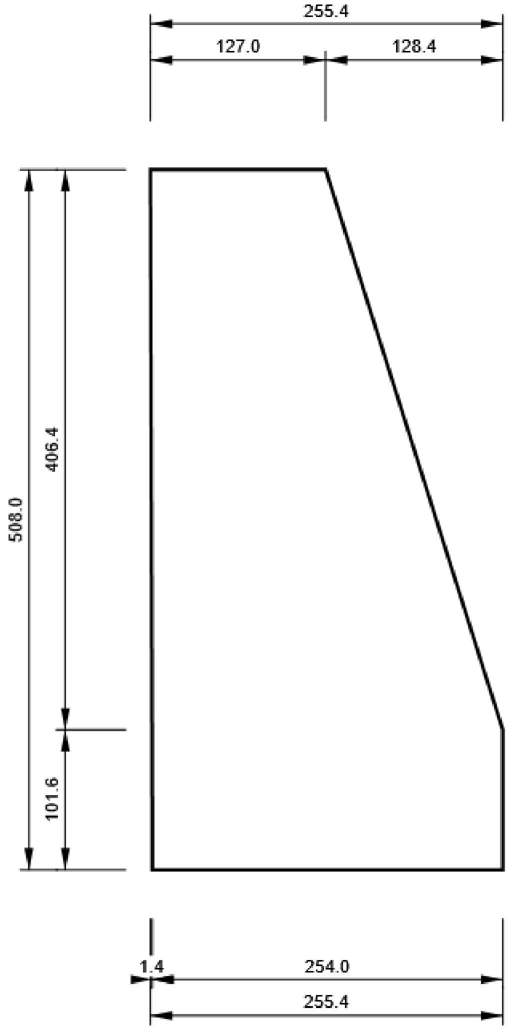
RIB1 - 3

P19.1x508.0-256.6 (A36)



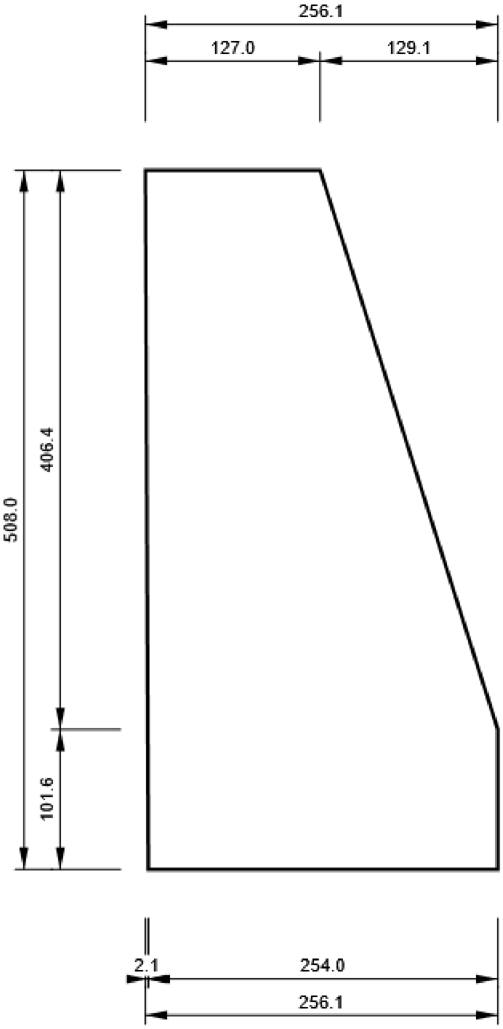
RIB1 - 4

P19.1x508.0-255.4 (A36)



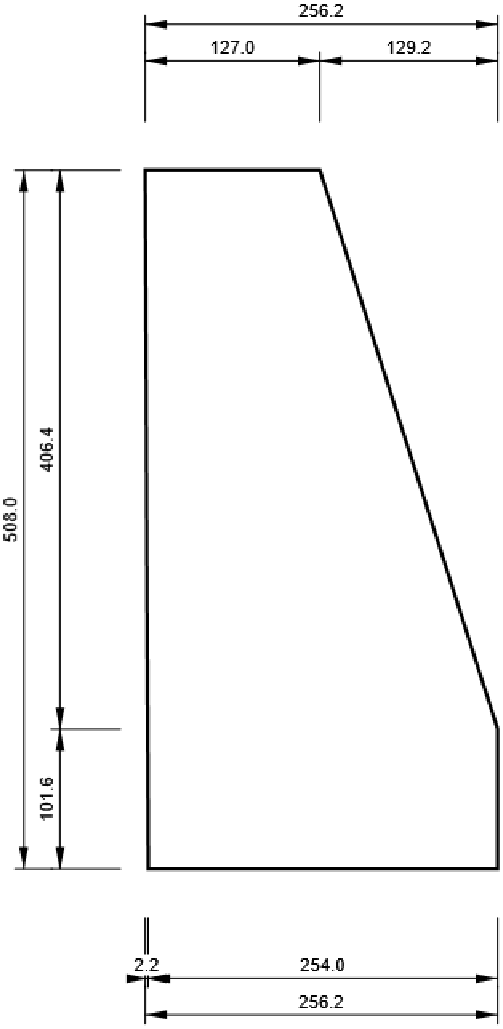
RIB1 - 5

P19.1x508.0-256.1 (A36)



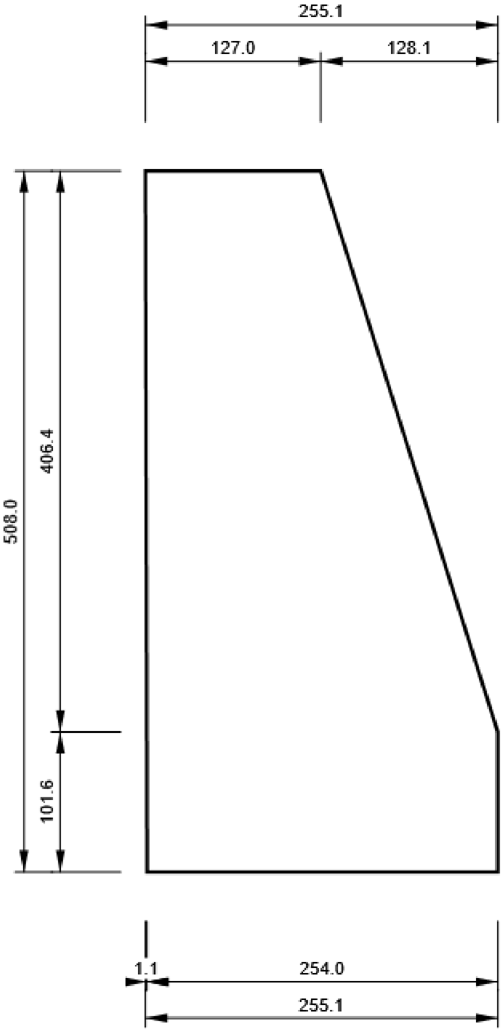
RIB1 - 6

P19.1x508.0-256.2 (A36)



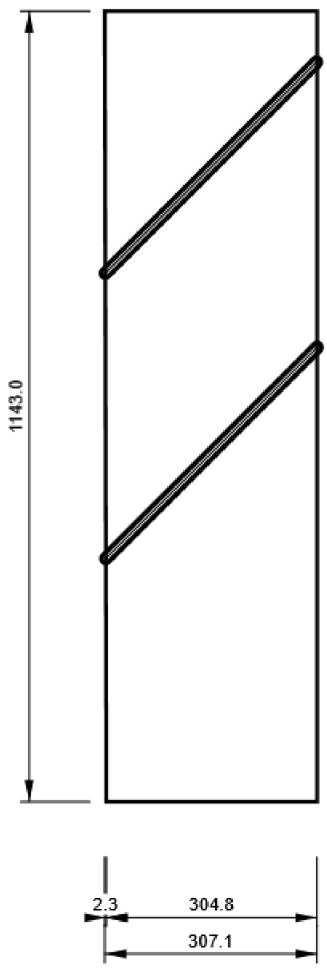
RIB1 - 7

P19.1x508.0-255.1 (A36)

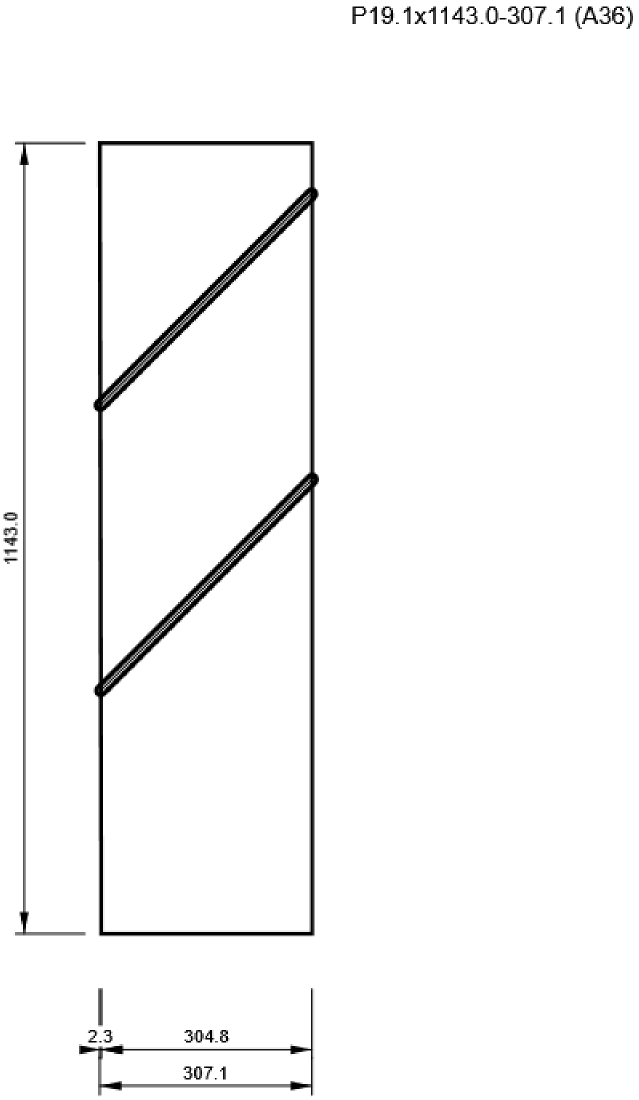


RIB2

P19.1x1143.0-307.1 (A36)



RIB3



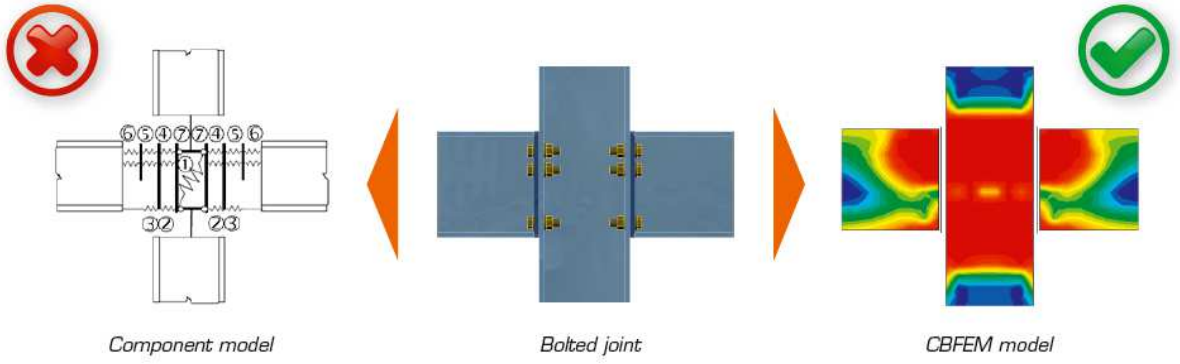
Code setting

Item	Value	Unit	Reference
Friction coefficient - concrete	0.25	-	
Friction coefficient in slip-resistance	0.30	-	
Limit plastic strain	0.05	-	
Weld stress evaluation	Average value		
Detailing	Yes		
Distance between bolts [d]	2.66	-	AISC 360-10 - J3
Distance between bolts and edge [d]	1.25	-	
Concrete cone breakout resistance	Yes		

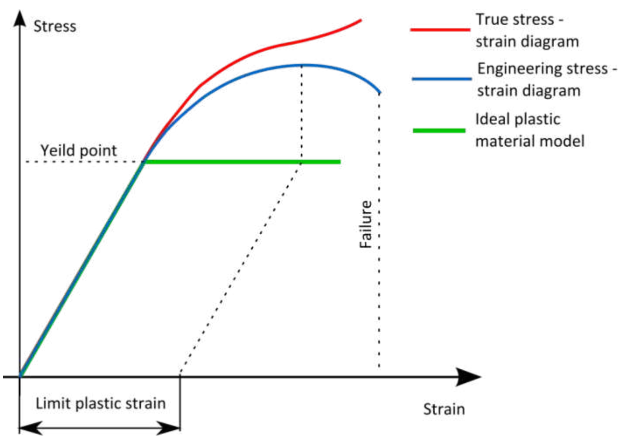
Theoretical Background

CBFEM versus Components method

The weak point of standard Component method is in analyzing of internal forces and stress in a joint. CBFEM replaces specific analysis of internal forces in joint with general FEA.

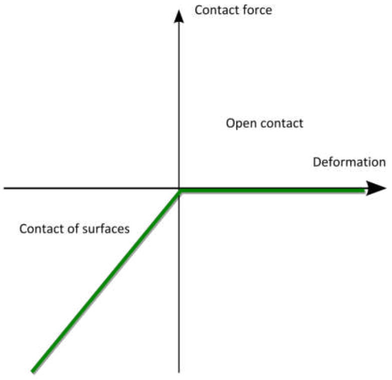


Check methods of specific components like bolts or welds are done according to standard Component method (Eurocode).
For the fasteners – bolts and welds – special FEM components had to be developed to model the welds and bolts behaviour in joint. All parts of 1D members and all additional plates are modelled as plate/walls. These elements are made of steel (metal in general) and the behaviour of this material is significantly nonlinear.
The real stress-strain diagram of steel is replaced by the ideal plastic material for design purposes in building practice. The advantage of ideal plastic material is, that only yield strength and modulus of elasticity must be known to describe the material curve. The granted ductility of construction steel is 15 %. The real usable value of limit plastic strain is 5% for ordinary design (1993-1-5 appendix C paragraph C.8 note 1).
The stress in steel cannot exceed the yield strength when using the ideal elastic-plastic stress-strain diagram.



Real tension curve and the ideal elastic-plastic diagram of material

CBFEM method tries to create to model the real state precisely. The analysis plate/walls are not interconnected, no intersections are generated between them, unlike it is used to when modelling structures and buildings. Mesh of finite elements is generated on each individual plate independently on mesh of other plates.
Welds are modelled as special massless force interpolation constrains, which ensure the connection between the edge of one plate and the surface or edge of the other plate.
This unique calculation model of bolt provides very good results – both for the point of view of precision and of the analysis speed. The method protected by patent.
The steel base plate is placed loosely on the concrete foundation. It is a contact element in the analysis model – the connection resists fully to compression, but does not resist to tension.



Stress-strain diagram of contact between the concrete block and the base plate

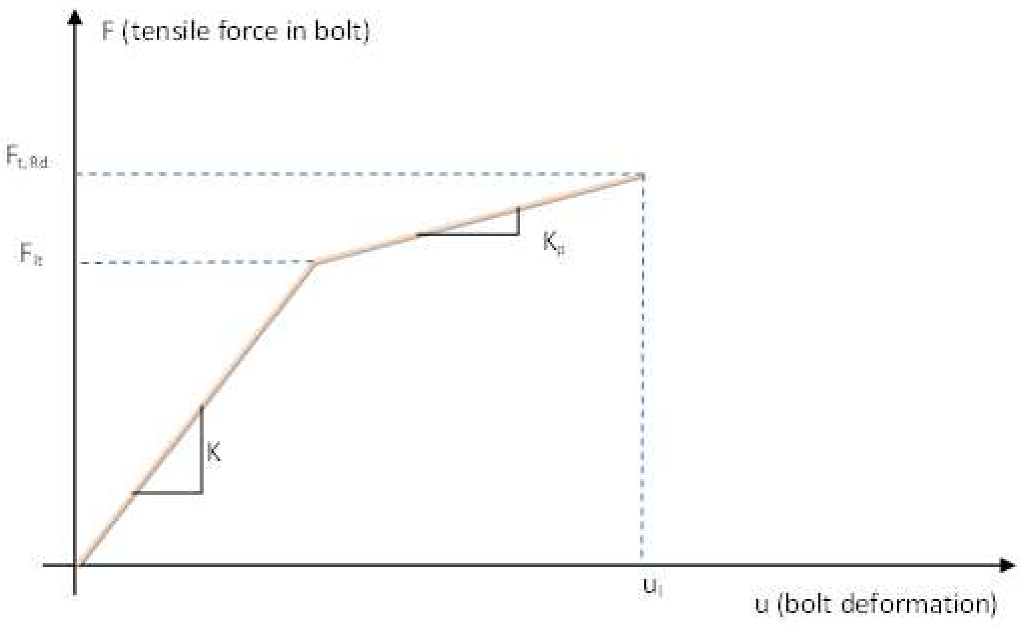
Two approaches of modelling welds are implemented.
The first option of weld model between plates is direct merge of meshes of welded plates. The load is transmitted through a force-deformation constrains to opposite plate. This model does not respect the stiffness of the weld and the stress distribution is conservative. Stress peaks, which appear at the end of plate edges, in corners and rounding, govern the resistance along the whole length of the weld. To eliminate the effect of stress peaks three methods for evaluation of the weld can be chosen:

- Maximal stress (conservative)
- Average stress on weld
- Linear interpolation along weld

The second approach uses an improved weld model. A special elastoplastic element is added between the plates. The element respects the weld throat thickness, position and orientation. Ideal plastic model is used and the plasticity state is controlled by stresses in the weld throat section. The stress peaks are redistributed along the longer part of the weld length.

Bolted connection consists of two or more clasped plates and one or more bolts. Plates are placed loosely on each other.
A contact element is inserted between plates in the analysis model, which acts only in compression. No forces are carried in tension.

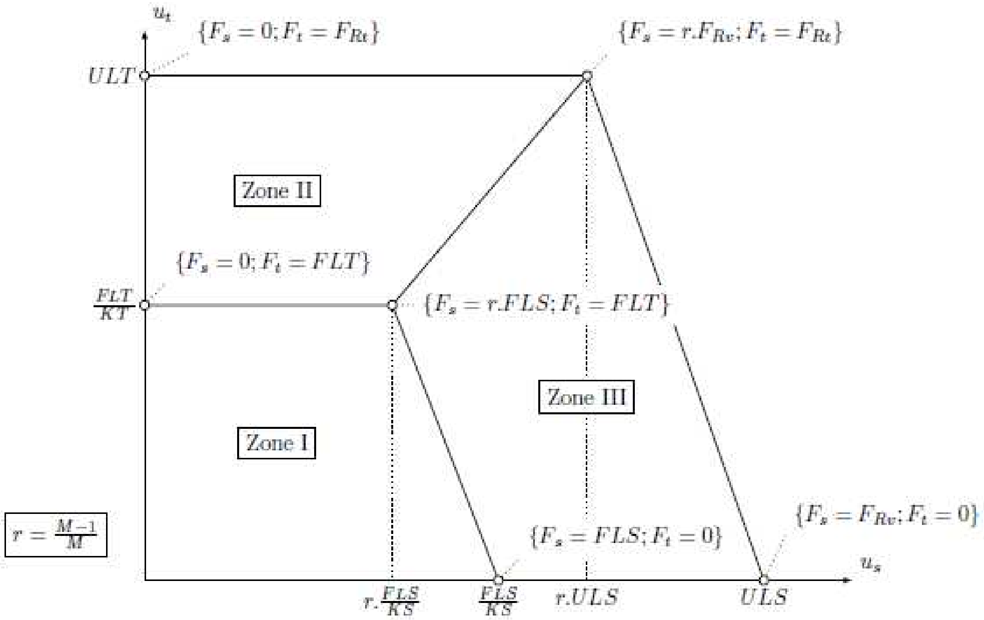
Shear force is taken by bearing. Special model for its transferring in the force direction only is implemented. IDEA StatiCa Connection can check bolts for interaction of shear and tension. The bolt behavior is implemented according following picture.



Bolt - tension

Symbols explanation:

- K – linear stiffness of bolt,
- K_p – stiffness of bolt at plastic branch,
- F_{lt} – limit force for linear behaviour of bolt,
- $F_{t,Rd}$ – limit bolt resistance,
- u_l – limit deformation of bolt.

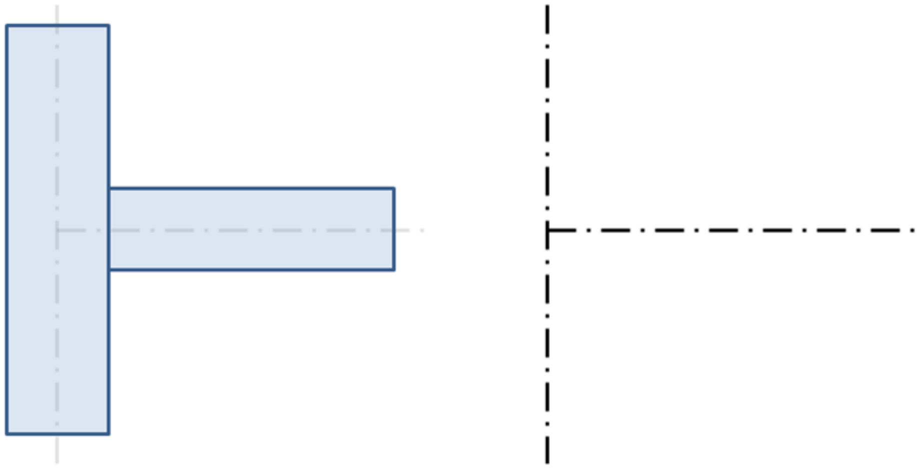


Bolt - interaction of shear and tension

The concrete block in CBFEM is modelled using Winkler-Pasternak subsoil model. The stiffness of subsoil is determined using modulus of elasticity of concrete and effective height of subsoil. The concrete block is not designed by CBFEM method. Only the minimal dimension of block under the base plate is determined to avoid the concrete cone breakout.

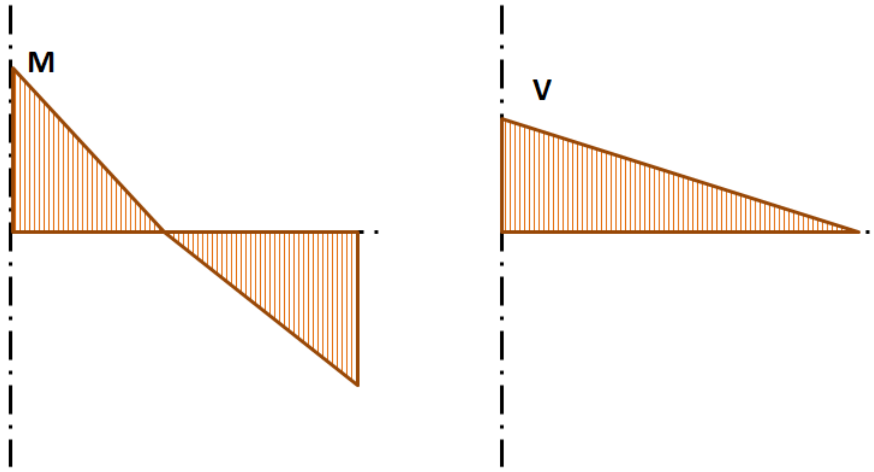
Loads

End forces of member of the frame analysis model are transferred to the ends of member segments. Eccentricities of members caused by the joint design are respected during transfer.
The analysis model created by CBFEM method corresponds to the real joint very precisely, whereas the analysis of internal forces is performed on very idealised 3D FEM 1D model, where individual beams are modelled using centrelines and the joints are modelled using immaterial nodes.



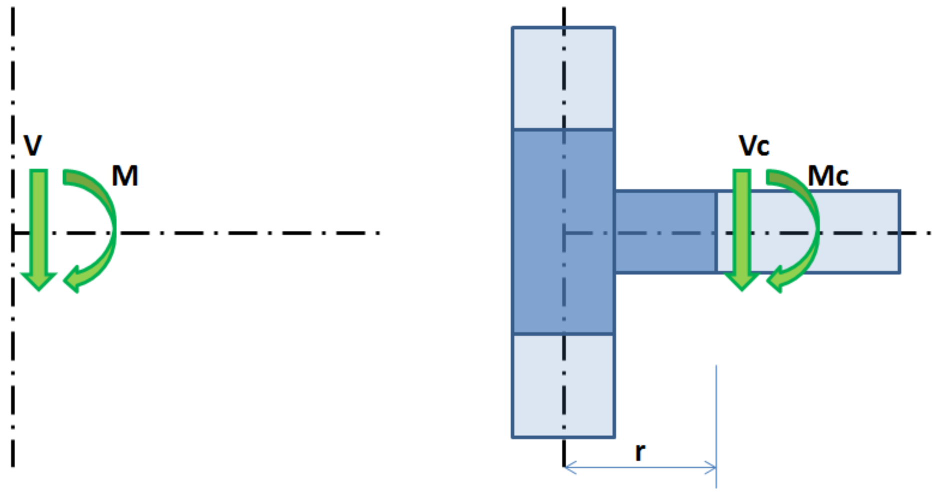
Real shape and theoretical 3D FEM model of joint of vertical column and horizontal beam

Internal forces are analysed using 1D members in 3D model. There is an example of courses of internal forces in the following picture.



Course of bending moment and shear force on horizontal beam. M and V are the end forces at joint.

The effects caused by member on the joint are important to design the joint (connection). The effects are illustrated in the following picture.



Effects of member on the joint in 1D members model and CBFEM model. CBFEM model is drawn in dark color.

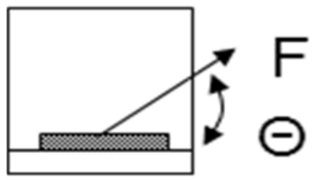
Moment M and force V act in theoretical joint. The point of theoretical joint does not exist ni CBFEM model, thus the load cannot be applied here. The model must be loaded by actions M and V, which have to be transferred to the end of segment in the distance r.
$M_c = M - V \cdot r$
$V_c = V$
In CBFEM model, the end section of segment is loaded by moment Mc and force Vc.

Welds

Fillet welds

The design strength, ΦRn and the allowable strength, Rn/Ω of welded joints are evaluated in connection weld check.
$\Phi = 0.75$ (LRFD)
$\Omega = 2.00$ (ASD)
Available strength of welded joints is evaluated according to AISC 360-10 table J2,5:
$R_n = F_{nw} A_{we}$
$F_{nw} = 0.60 F_{EXX} (1.0 + 0.50 \sin 1.5\,\Theta)$
where

- Fnw - nominal stress of weld material,
- Awe - effective area of the weld,
- FEXX - electrode classification number, i.e., minimum specified tensile strength,
- Θ - angle of loading measured from the weld longitudinal axis, degrees.



For end-loaded fillet welds with a length up to 100 times the weld size, it is permitted to take the effective length equal to the actual length. When the length of the end-loaded fillet weld exceeds 100 times the weld size, the effective length shall be determined by multiplying the actual length by the reduction factor, β, determined as follows:
$\beta = 1.2 - 0.002\,(l / w)$
where

- l - weld length,
- w - size of weld leg.

When the length of the weld exceeds 300 times the leg size, w, the effective length is taken as 180w.

CJP groove welds

AISC Specification Table J2.5 identifies four loading conditions that might be associated with JP groove welds, and shows that the strength of the joint is either controlled by the base metal or that the loads need not be considered in the design of the welds connecting the parts. Accordingly, when CJP groove welds are made with matching-strength filler metal, the strength of a connection is governed or controlled by the base metal, and no checks on the weld strength are required.

Bolts

Tensile and shear strength of bolts

The design tensile or shear strength, ΦRn, and the allowable tensile or shear strength, Rn/Ω of a snug-tightened bolt is determined according to the limit states of tension rupture and shear rupture as follows:
Rn = Fn Ab
Φ = 0.75 (LRFD)
Ω = 2.00 (ASD)
where

- Ab - nominal unthreaded body area of bolt or threaded part, in^2 (mm^2)
- Fn - nominal tensile stress, Fnt, or shear stress, Fnv, from Table J3.2, ksi (MPa)

The required tensile strength includes any tension resulting from prying action produced by deformation of the connected parts.

Combined Tension and shear in bearing type connection

The available tensile strength of a bolt subjected to combined tension and shear is determined according to the limit states of tension and shear rupture as follows:
Rn = F'nt Ab (AISC 360-10 J3-2)
Φ = 0.75 (LRFD)
Ω = 2.00 (ASD)
Fn't = 1,3Fnt - frv Fnt/ ΦFnv (AISC 360-10 J3-3a LRFD)
Fn′t = 1,3Fnt - frv Ω Fnt/Fnv (AISC 360-10 J3-3b ASD)
where

- Fn′t - nominal tensile stress modified to include the effects of shear stress
- Fnt - nominal tensile stress from AISC 360-10 Table J3.2
- Fnv - nominal shear stress from AISC 360-10 Table J3.2
- frv - required shear stress using LRFD or ASD load combinations. The available shear stress of the fastener shall be equal or exceed the required shear stress, frv.

Bearing strength in bolt holes

The available bearing strength, ΦRn and Rn/Ω at bolt holes is determined for the limit state of bearing as follows:
Φ = 0.75 (LRFD)
Ω = 2.00 (ASD)
The nominal bearing strength of the connected material, Rn, is determined as follows:
For a bolt in a connection with standard, oversized and short-slotted holes, independent of the direction of loading, or a long-slotted hole with the slot parallel to the direction of the bearing force

When deformation at the bolt hole at service load is a design consideration
Rn = 1.2 lc t Fu ≤ 2.4 d t Fu (AISC 360-10 J3-6a)

When deformation at the bolt hole at service load is not a design consideration
Rn = 1.5 lc t Fu ≤ 3.0 d t Fu (AISC 360-10 J3-6b)

where

- Fu - specified minimum tensile strength of the connected material,
- d - nominal bolt diameter,

- lc - clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material,
- t - thickness of connected material.

Preloaded bolts

The design slip resistance of a preloaded class A325 or A490 bolt without of effect of tensile force, $F_{t,Ed}$.
Preloading force to be used AISC 360-10 tab. J3.1.
$Tb = 0,7 f_{ub} A_s$
Design slip resistance per bolt AISC 360-10 par. 3.8
$Rn = 1.13 \mu Tb Ns$
Utilisation in shear [%]:
$U_{ts} = V / Rn$ where

- A_s - tensile stress area of the bolt,
- f_{ub} - ultimate tensile strength,
- μ - slip factor obtained,
- Ns - number of the friction surfaces. Check is calculated for each friction surface separately.
- V - shear force.

Anchors

Concrete Capacity Design (CCD). In the CCD method, the concrete cone is considered to be formed at an angle of approximately 34° (1 to 1.5 slope). For simplification, the cone is considered to be square rather than round in plan. The concrete breakout stress in the CCD method is considered to decrease with an increase in size of the breakout surface. Consequently, the increase in strength of the breakout in the CCD method is proportional to the embedment depth to the power of 1.5.
$\Phi N_{cbg} = \Phi \psi 3\ 24 \sqrt{fc}\ h_{ef}^{1,5}\ An/An0$ for $h_{ef} < 11$ in
$\Phi N_{cbg} = \Phi \psi 3\ 16 \sqrt{fc}\ h_{ef}^{1,66}\ An/An0$ for $h_{ef} >= 11$ in
where

- Φ = 0.70,
- ψ3 = 1.25 considering the concrete to be uncracked at service loads, otherwise =1.0,
- h_{ef} - depth of embedment,
- A_n - concrete breakout cone area for group,
- A_{n0} - concrete breakout cone area for single anchor.