Project data

Project name	
Project number	
Author	
Description	
Date	4/17/2025
Code	AISC/ACI

Material

Steel	S235JR-Rolled, A572 Gr.50, A992, S235JR-Plate, S275JR-Rolled, S275JR-Plate

Project item BUEPP

Design

Name	BUEPP
Description	4 Bolt without stiffener
Analysis	Capacity design
Design code	AISC - LRFD (2022)

Members

Geometry

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
PG4001230025	4 - PGC430*300 25 12(Iw430x300)	0.0	90.0	0.0	0	0	0
PG3601220015	5 - PG3601220015(Iw360x200)	0.0	0.0	0.0	0	0	0

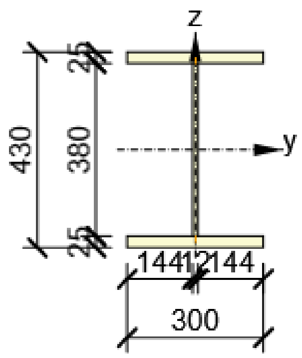
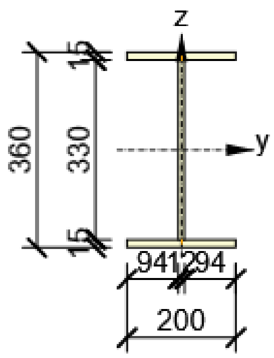
Supports and forces

Name	Support	Forces in	X [mm]
PG4001230025 / begin	N-Vy-Vz-Mx-My-Mz	Node	0
PG4001230025 / end	Mx-My-Mz	Node	0
PG3601220015 / end	Vy-Mx-Mz	Position	405

Cross-sections

Name	Material
4 - PGC430*300 25 12(Iw430x300)	S235JR-Plate
5 - PG3601220015(Iw360x200)	S235JR-Plate

Cross-sections

Name	Material	Drawing
4 - PGC430*300 25 12(Iw430x300)	S235JR-Plate	
5 - PG3601220015(Iw360x200)	S235JR-Plate	

Bolts

Name	Diameter [mm]	f_y [MPa]	f_u [MPa]	Gross area [mm^2]
36 A325M	36	660.0	830.0	1018

Load effects

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE-MC1	PG3601220015 / End	0.0	0.0	-168.9	0.0	422.4	0.0

Check

Summary

Name	Value	Check status
Analysis	100.0%	OK
Plates	1.2 < 5.0%	OK
Preloaded bolts	99.7 < 100%	OK
Welds	89.3 < 100%	OK
Buckling	Not calculated	

Plates

Name	Material	t_p [mm]	Loads	σ_{Ed} [MPa]	ε_{Pl} [%]	$\sigma_{c,Ed}$ [MPa]	Status
PG4001230025-tfl 1	S235JR-Plate	25.0	LE-MC1	202.5	0.0	0.0	OK
PG4001230025-bfl 1	S235JR-Plate	25.0	LE-MC1	203.7	0.6	71.3	OK
PG4001230025-w 1	S235JR-Plate	12.0	LE-MC1	205.0	1.2	0.0	OK
PG3601220015-tfl 1	S235JR-Plate *	15.0	LE-MC1	344.1	16.4	0.0	OK
PG3601220015-bfl 1	S235JR-Plate *	15.0	LE-MC1	343.0	16.2	0.0	OK
PG3601220015-w 1	S235JR-Plate *	12.0	LE-MC1	320.6	11.9	0.0	OK
End-Plate-30 mm	S275JR-Plate	30.0	LE-MC1	249.5	1.0	80.9	OK
STIFF1a	S275JR-Plate	15.0	LE-MC1	247.6	0.0	0.0	OK
STIFF1b	S275JR-Plate	15.0	LE-MC1	247.6	0.0	0.0	OK
STIFF1c	S275JR-Plate	15.0	LE-MC1	240.0	0.0	0.0	OK
STIFF1d	S275JR-Plate	15.0	LE-MC1	242.0	0.0	0.0	OK
doubler-1	S275JR-Plate	10.0	LE-MC1	247.6	0.1	0.0	OK
doubler-2	S275JR-Plate	10.0	LE-MC1	247.6	0.1	0.0	OK

Design data

Material	Φ [-]	R_y [-]	F_y [MPa]	$F_{y,FEM}$ [MPa]	C_{pr} [-]	ε_{lim} [%]
S235JR-Plate	0.90	-	225.0	202.5	-	5.0
S235JR-Plate *	-	1.15	225.0	258.8	1.10	5.0
S275JR-Plate	0.90	-	275.0	247.5	-	5.0

Symbol explanation

t_p	Plate thickness
σ_{Ed}	Equivalent stress
ε_{Pl}	Plastic strain
$\sigma_{c,Ed}$	Contact stress
Φ	Safety factor
R_y	Material overstrength factor
F_y	Yield strength
$F_{y,FEM}$	Yield strength used in finite element analysis
C_{pr}	Strain hardening
ε_{lim}	Limit of plastic strain
*	Dissipative item

Detailed result for PG3601220015-tfl 1

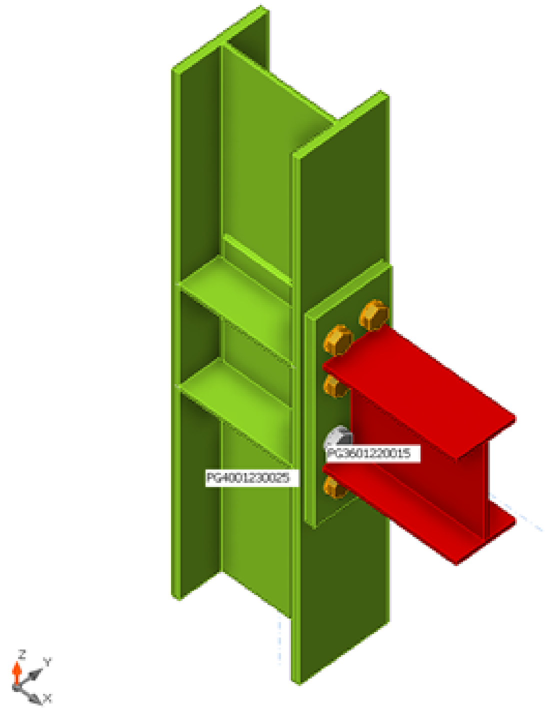
Design values used in the analysis

$R_y F_y =$ 258.8 MPa

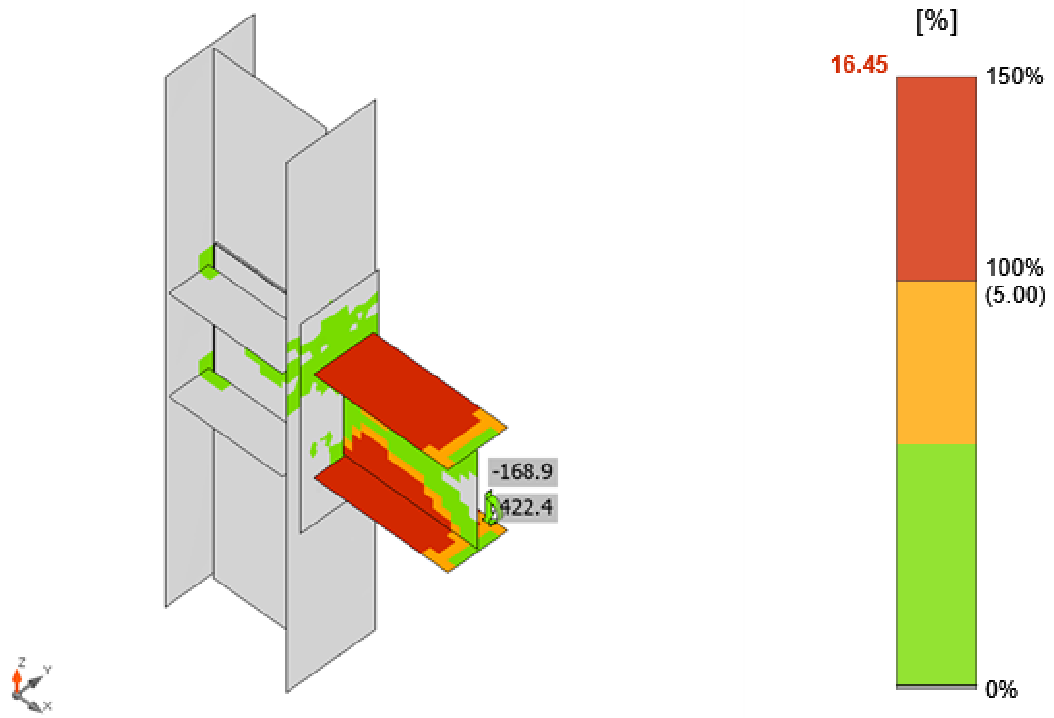
Where:

$F_y = 225.0$ MPa – characteristic yield strength

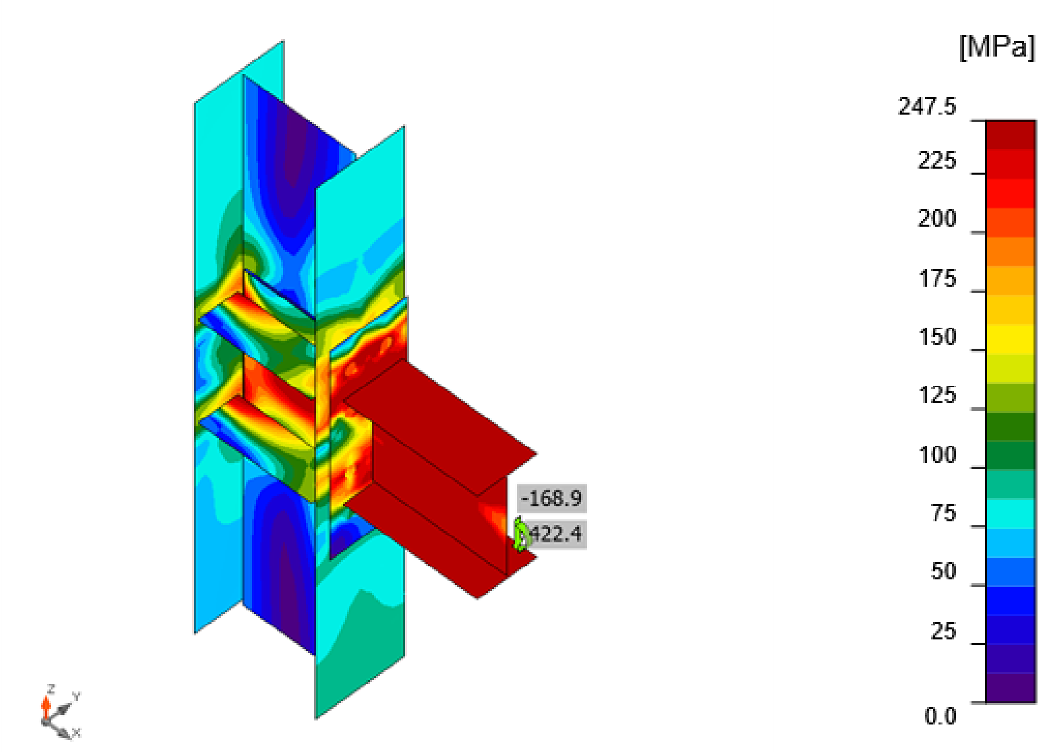
$R_y = 1.15$ – ratio of expected to minimum yield strength AISC 341-16 – Table A3.1



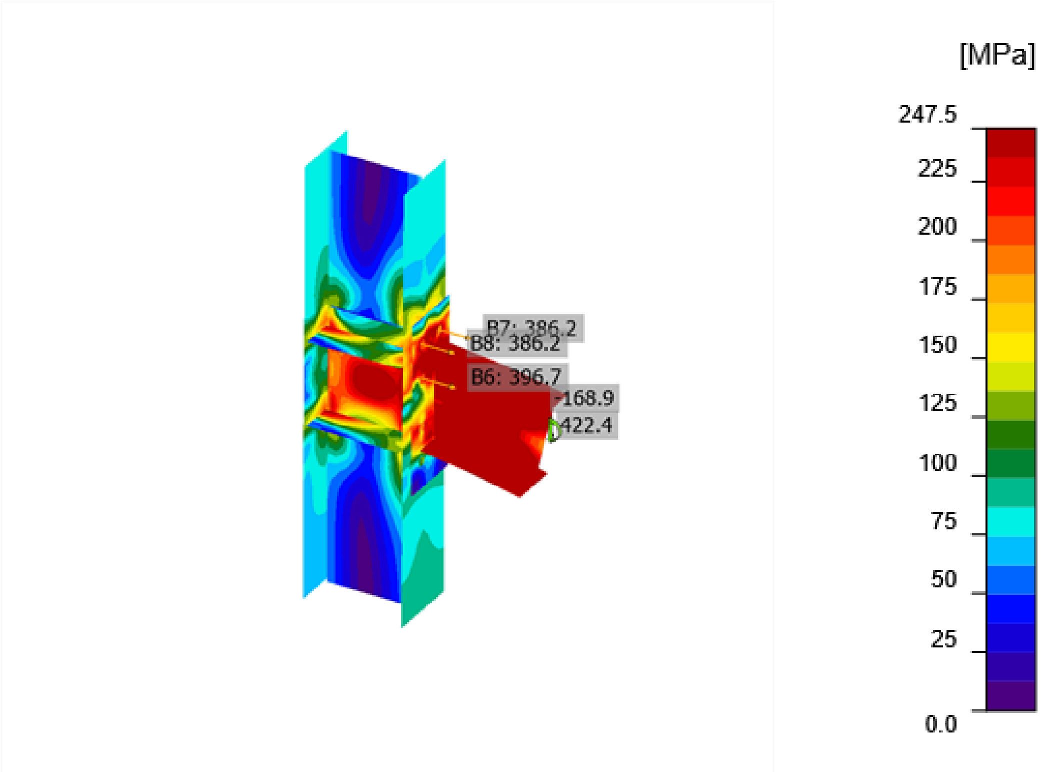
Overall check, LE-MC1



Strain check, LE-MC1

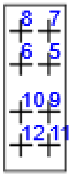


Equivalent stress, LE-MC1



Equivalent stress, LE-MC1

Preloaded bolts



Shape	Item	Grade	Loads	F_t [kN]	V [kN]	$\phi R_{n,slip}$ [kN]	Ut_t [%]	Ut_s [%]	Detailing	Status
	B5	36 A325M	LE-MC1	396.7	41.2	41.9	83.8	98.2	OK	OK
	B6	36 A325M	LE-MC1	396.7	41.2	41.9	83.8	98.3	OK	OK
	B7	36 A325M	LE-MC1	386.2	44.9	45.0	81.6	99.7	OK	OK
	B8	36 A325M	LE-MC1	386.2	44.9	45.1	81.6	99.7	OK	OK
	B9	36 A325M	LE-MC1	0.0	79.5	160.9	0.0	49.4	OK	OK
	B10	36 A325M	LE-MC1	0.0	80.0	160.9	0.0	49.7	OK	OK
	B11	36 A325M	LE-MC1	0.0	158.9	160.9	0.0	98.7	OK	OK
	B12	36 A325M	LE-MC1	0.0	158.9	160.9	0.0	98.7	OK	OK

Design data

Grade	$\phi R_{n,tension}$ [kN]	μ [-]
36 A325M	473.4	0.30

Symbol explanation

F_t	Tension force
V	Resultant of shear forces Vy and Vz in shear planes transferred by friction
$\phi R_{n,slip}$	Bolt slip resistance - AISC 360-22 – J3.9
Ut_t	Utilization in tension
Ut_s	Utilization in shear
$\phi R_{n,tension}$	Bolt tension resistance - AISC 360-22 – J3.7
μ	Friction coefficient in slip-resistance

Detailed result for B7

Tension resistance check (AISC 360-22 – J3-1)

$$\phi R_n = \phi \cdot F_{nt} \cdot A_b = \quad 473.4 \text{ kN} \geq F_t = \quad 386.2 \text{ kN}$$

Where:

F_{nt} = 620.0 MPa – nominal tensile stress AISC 360-22 – Table J3.2

A_b = 1018 mm^2 – gross bolt cross-sectional area

ϕ = 0.75 – resistance factor

Slip resistance check (AISC 360-22 – J3.9)

$\phi R_n = \phi \cdot k_{sc} \cdot \mu \cdot D_u \cdot h_f \cdot T_b \cdot n_s =$ 45.0 kN ≥ $V =$ 44.9 kN

Where:

$\mu =$ 0.30 – slip factor

$D_u =$ 1.13 – multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension

$h_f =$ 1.00 – factor for fillers

$T_b =$ 474.7 kN – preloading force

$n_s =$ 1 – number of the friction surfaces

$k_{sc} =$ 0.28 – factor for combined tension and shear:

- $k_{sc} = 1 - \frac{F_t}{D_u \cdot T_b \cdot n_b}$, where:
  - $F_t =$ 386.2 kN – required tension force using LFRD load combinations
  - $n_b =$ 1 – number of bolts carrying the applied tension

$\phi =$ 1.00 – resistance factor for slip resistant joint

Welds

Item	Edge	Xu	t_w [mm]	w [mm]	L [mm]	L_c [mm]	Loads	F_n [kN]	ϕR_n [kN]	Ut [%]	Ut_c [%]	Detailing	Status
End-Plate-30 mm	PG3601220015-tfl 1	E70xx	-	-	200	-	-	-	-	-	-	OK	OK
End-Plate-30 mm	PG3601220015-bfl 1	E70xx	-	-	200	-	-	-	-	-	-	OK	OK
End-Plate-30 mm	PG3601220015-w 1	E70xx	-	-	330	-	-	-	-	-	-	OK	OK
PG4001230025-bfl 1	STIFF1a	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-tfl 1	STIFF1a	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-bfl 1	STIFF1b	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-tfl 1	STIFF1b	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-bfl 1	STIFF1c	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-tfl 1	STIFF1c	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-bfl 1	STIFF1d	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-tfl 1	STIFF1d	E70xx	-	-	134	-	-	-	-	-	-	OK	OK
PG4001230025-w 1	doubler-1	E70xx	◢ 5.0	◢ 7.1	349	25	LE-MC1	27.6	35.9	76.7	47.6	OK	OK
PG4001230025-w 1	doubler-1	E70xx	◢ 5.0	◢ 7.1	498	25	LE-MC1	34.5	38.7	89.2	89.2	OK	OK
PG4001230025-w 1	doubler-1	E70xx	◢ 5.0	◢ 7.1	349	25	LE-MC1	27.2	35.0	77.7	58.0	OK	OK
PG4001230025-w 1	doubler-1	E70xx	◢ 5.0	◢ 7.1	498	25	LE-MC1	26.9	34.7	77.5	63.8	OK	OK
PG4001230025-w 1	doubler-2	E70xx	◢ 5.0	◢ 7.1	349	25	LE-MC1	27.6	35.9	76.7	47.6	OK	OK
PG4001230025-w 1	doubler-2	E70xx	◢ 5.0	◢ 7.1	498	25	LE-MC1	34.5	38.7	89.3	89.3	OK	OK
PG4001230025-w 1	doubler-2	E70xx	◢ 5.0	◢ 7.1	349	25	LE-MC1	27.3	35.1	77.7	57.8	OK	OK
PG4001230025-w 1	doubler-2	E70xx	◢ 5.0	◢ 7.1	498	25	LE-MC1	26.9	34.7	77.5	63.8	OK	OK

Design data

Material	F_{exx} [MPa]
E70xx	0.0
E70xx	482.6

Symbol explanation

t_w	Throat thickness of weld
w	Leg size of weld
L	Length of weld
L_c	Length of weld critical element
F_n	Force in weld critical element
ϕR_n	Weld resistance - AISC 360-22 – J2-4
Ut	Utilization
Ut_c	Weld capacity estimation
◢	Fillet weld
F_{exx}	Ultimate strength as rated by electrode classification number

Detailed result for PG4001230025-w 1 / doubler-2

Weld resistance check (AISC 360-22 – J2-4)

$\phi R_n = \phi \cdot F_{nw} \cdot A_{we} =$ 38.7 kN ≥ $F_n =$ 34.5 kN

Where:

$F_{nw} =$ 414.3 MPa – nominal stress of weld material:

- $F_{nw} = 0.6 \cdot F_{EXX} \cdot (1 + 0.5 \cdot sin^{1.5}\theta)$, where:
  - $F_{EXX} =$ 482.6 MPa – electrode classification number, i.e. minimum specified tensile strength
  - $\theta =$ 64.9° – angle of loading measured from the weld longitudinal axis

$A_{we} =$ 125 mm^2 – effective area of weld critical element

$\phi =$ 0.75 – resistance factor for welded connections

Prequalified connection

System:	Intermediate moment frames (IMF)
Connection type:	Bolted unstiffened extended end plate (BUEEP - 4E)

Limit checks

Item	Value	Requirement	Reference	Status
PG4001230025 – depth	430	≤ 1095 mm	[1] 6.3.2(3)	OK
PG4001230025 – flange slenderness	6.00	≤ 11.12	[1] 6.3.2(6)	OK
PG4001230025 – web slenderness	31.67	≤ 43.65	[1] 6.3.2(6)	OK
PG3601220015 – depth	360	≥ 349 mm ≤ 1397 mm	[1] 6.3.1(2)	OK
PG3601220015 – flange thickness	15.0	≥ 9.5 mm ≤ 19.1 mm	[1] Tab. 6.1	OK
PG3601220015 – width	200	≥ 152 mm ≤ 235 mm	[1] Tab. 6.1	OK
PG3601220015 – flange slenderness	6.67	≤ 11.12	[1] 6.3.1(6)	OK
PG3601220015 – web slenderness	27.50	≤ 110.10	[1] 6.3.1(6)	OK
End-Plate-30 mm – width	260	≥ 200 mm	[1] 6.7.3	OK
End-Plate-30 mm – width	260	≥ 178 mm ≤ 273 mm	[1] Tab. 6.1	OK
End-Plate-30 mm – thickness	30.0	≥ 12.7 mm ≤ 57.2 mm	[1] Tab. 6.1	OK
PG3601220015 – end plate	Fulfilled	Connected to column flange	[1] 6.3.2(2)	OK
End-Plate-30 mm – bolt grid grade	A325M	A325, A325M, A490, A490M, F1852, F2280	[1] 4.1	OK
End-Plate-30 mm – bolts detailing	Fulfilled	Geometry	[1] Tab. 6.1	OK
End-Plate-30 mm – bolts detailing	Fulfilled	Geometry	[1] 6.7.1/2	OK
End-Plate-30 mm : PG3601220015-tfl 1 – weld type	CJP	CJP	[1] 6.7.6(2)	OK
End-Plate-30 mm : PG3601220015-tfl 1 – weld material	E70xx	E70xx/E80xx/E90xx	[1] 6.7.6(2)	OK
End-Plate-30 mm : PG3601220015-bfl 1 – weld type	CJP	CJP	[1] 6.7.6(2)	OK
End-Plate-30 mm : PG3601220015-bfl 1 – weld material	E70xx	E70xx/E80xx/E90xx	[1] 6.7.6(2)	OK
End-Plate-30 mm : PG3601220015-w 1 – weld type	CJP	CJP	[1] 6.7.6(3)	OK
PG3601220015 – protected zone	Fulfilled	Free from other equipment	[1] 6.3.1(8)	OK

Reference

[1] ANSI/AISC 358-16, ANSI/AISC 358s1-18

Cost estimation

Steel

Steel grade	Total weight [kg]	Unit cost [US$/kg]	Cost [US$]
S275JR-Plate	94.32	2.50	235.80

Bolts

Bolt assembly	Total weight [kg]	Unit cost [US$/kg]	Cost [US$]
36 A325M	19.81	6.00	118.86

Welds

Weld type	Throat thickness [mm]	Leg size [mm]	Effective throat [mm]	Total weight [kg]	Unit cost [US$/kg]	Cost [US$]
Fillet weld	5.0	7.1	-	0.67	45.00	30.03
Butt weld	-	-	15.0	1.56	60.00	93.60
Butt weld	-	-	12.0	0.22	60.00	13.43

Hole drilling

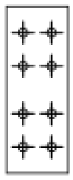
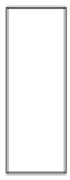
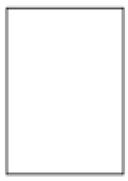
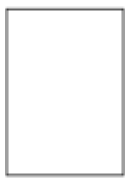
Bolt assembly cost [US$]	Percentage of bolt assembly cost [%]	Cost [US$]
118.86	30.0	35.66

Cost summary

Cost estimation summary	Cost [US$]
Total estimated cost	527.37

Bill of material

Manufacturing operations

Name	Plates [mm]	Shape	Nr.	Welds [mm]	Length [mm]	Bolts	Nr.
End-Plate-30 mm	P30.0x260-700 (S275JR-Plate)		1	Butt: 15.0 Butt: 12.0	400 330	36 A325M	8
STIFF1	P15.0x134-380 (S275JR-Plate)		4	Butt: 15.0	1072		
doubler-1	P10.0x350-500 (S275JR-Plate)		1				
doubler-2	P10.0x350-500 (S275JR-Plate)		1				

Symbol explanation

Butt weld	plate thickness

Welds

Type	Material	Throat thickness [mm]	Leg size [mm]	Effective throat [mm]	Length [mm]
Butt	E70xx	-	-	15.0	1472
Butt	E70xx	-	-	12.0	330
Fillet	E70xx	5.0	7.1	-	3400

Bolts

Name	Grip length [mm]	Count
36 A325M	55	8

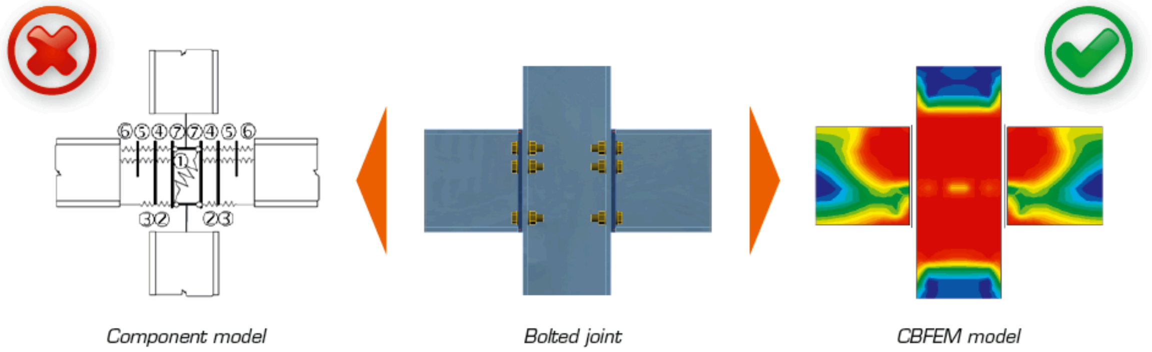
Code settings

Item	Value	Unit	Reference
Friction coefficient - concrete	0.40	-	ACI 349-01 – B.6.1.4
Friction coefficient in slip-resistance	0.30	-	AISC 360-22 – J3.9
Limit plastic strain	0.05	-	
Detailing	Yes		
Distance between bolts [d]	2.66	-	AISC 360-22 – J3.4
Concrete breakout resistance check	Both		
Base metal capacity check at weld fusion face	No		AISC 360-22 – J2-2
Deformation at bolt hole at service load is design consideration	Yes		AISC 360-22 – J3.11
Cracked concrete	Yes		ACI 318-14 – 17
Local deformation check	Yes		
Local deformation limit	0.03	-	CIDECT DG 1, 3 – 1.1
Geometrical nonlinearity (GMNA)	Yes		Analysis with large deformations for hollow section joints

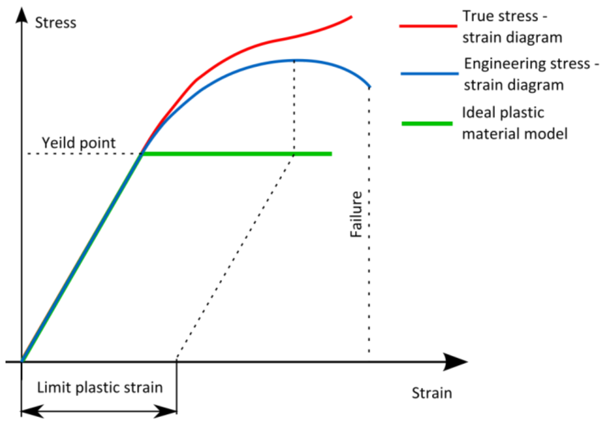
Theoretical Background

CBFEM versus AISC 360

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

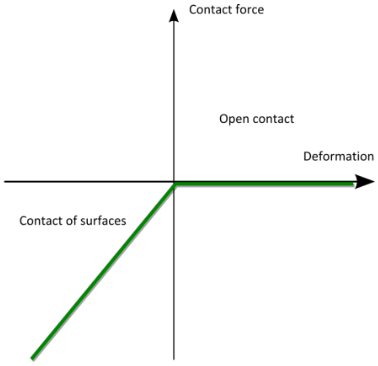


Check methods of specific components like bolts or welds are done according to standard AISC 360.
For the fasteners – bolts and welds – special FEM components had to be developed to model the welds and bolts behaviour in the connection. All parts of 1D members and all additional plates are modeled as 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 yield strength is multiplied by resistance factor (LRFD) or divided by safety factor (ASD) – AISC 360, Appendix 1. The granted ductility of construction steel is 15 %. The real usable value of limit plastic strain is 5% for ordinary design (EN 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 aims to model the real state precisely. Meshes of plates / walls are not merged, no intersections are generated between them, unlike it is used to when modeling structures and buildings. Mesh of finite elements is generated on each individual plate independently on mesh of other plates.
Between the meshes, special massless force interpolation constraints are added. They ensure the connection between the edge of one plate and the surface or edge of the other plate.
This unique calculation model provides very good results – both for the point of view of precision and of the analysis speed. The method is 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 compression fully, but does not resist tension.



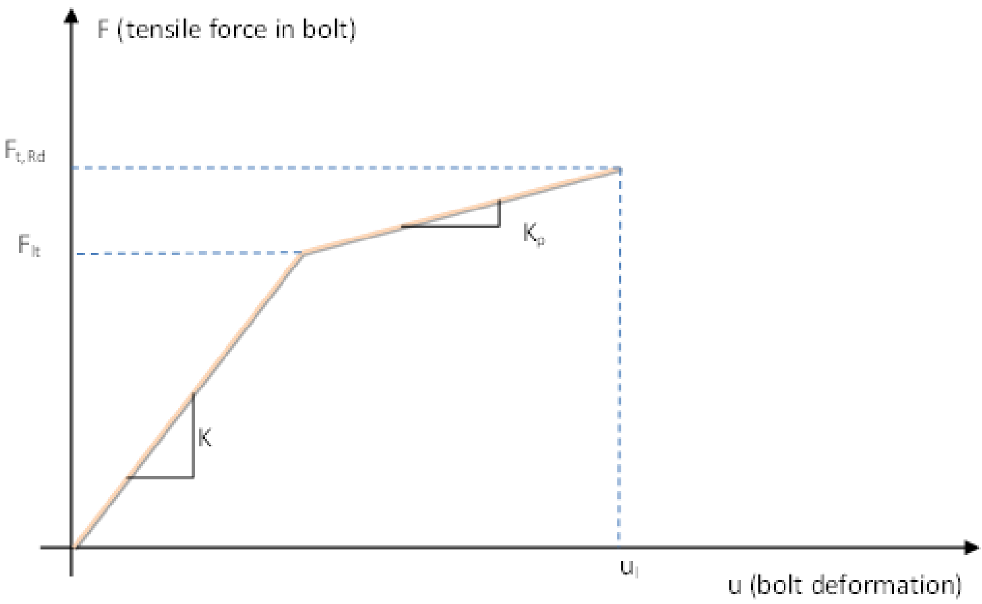
Stress-strain diagram of contact between the concrete block and the base plate

The concrete block in CBFEM is modeled 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.

Welds are modeled using a special elastoplastic element, which is added to the interpolation links between the plates. The element respects the weld throat thickness, position and orientation. The plasticity state is controlled by stresses in the weld throat section. The plastic redistribution of stress in welds allows for stress peaks to be redistributed along the longer part of the weld.

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.

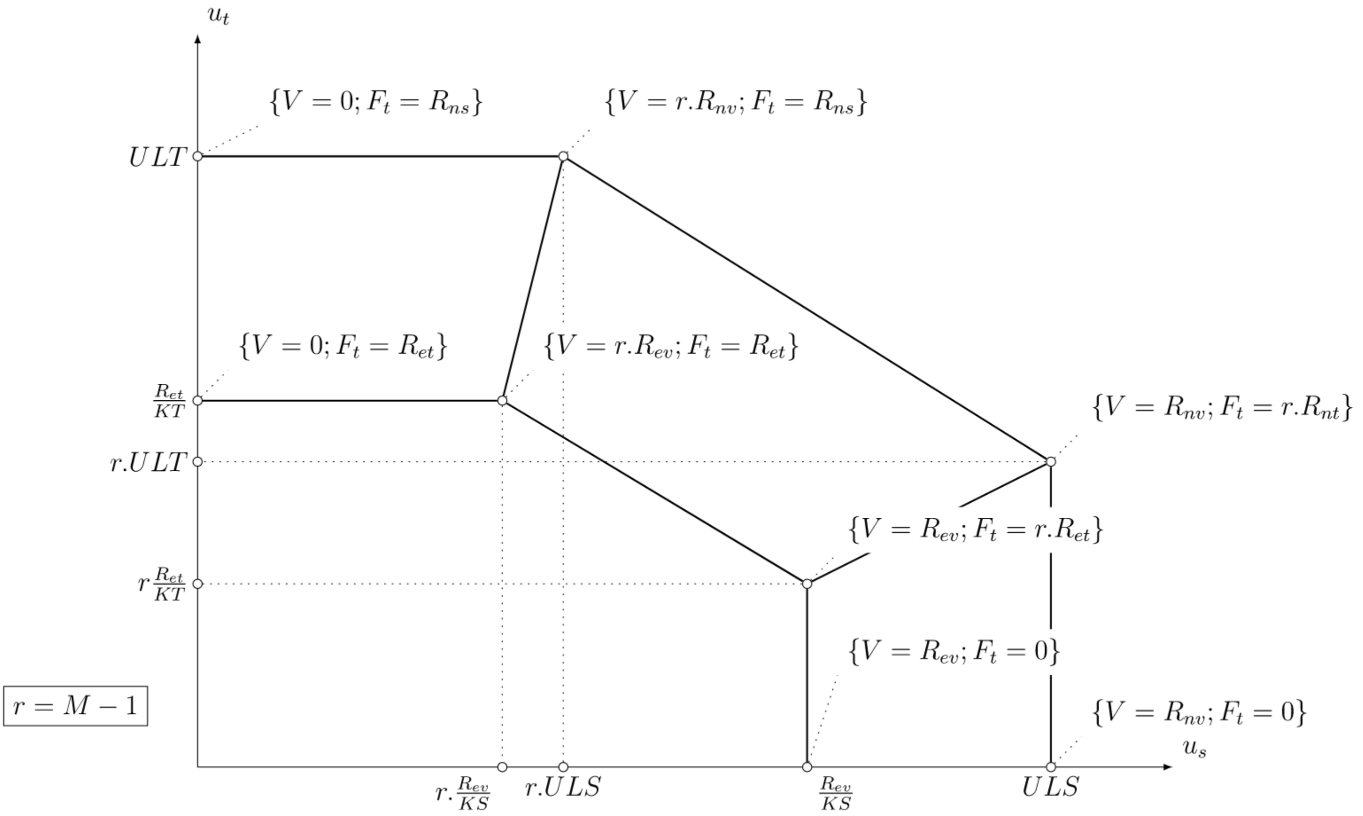
Shear force is taken by bearing. Special model for its transferring in the force direction only is implemented. IDEA StatiCa Connection can check bolts for interaction of shear and tension. The bolt behavior is implemented according to the following picture.



Bolt – tension

Symbols explanation:

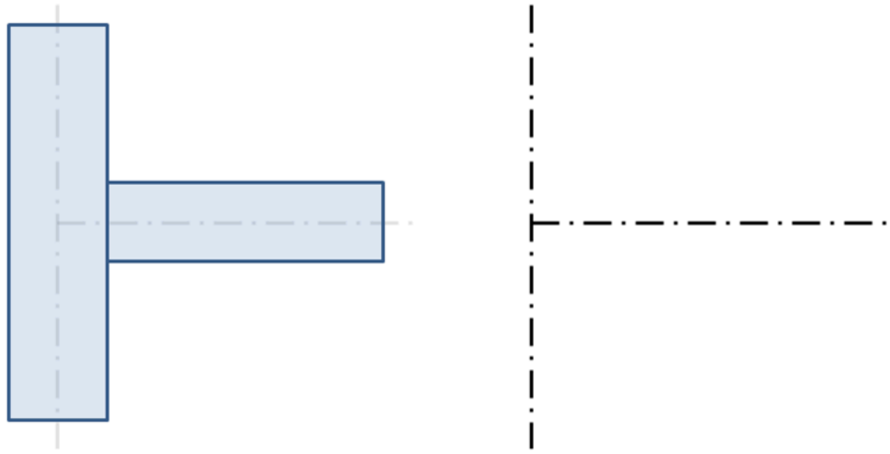
- K – linear stiffness of bolt,
- K_p – stiffness of bolt at plastic branch,
- F_{lt} – limit force for linear behaviour of bolt,
- $F_{t,Rd}$ – limit bolt resistance,
- u_l – limit deformation of bolt.



Bolt – interaction of shear and tension

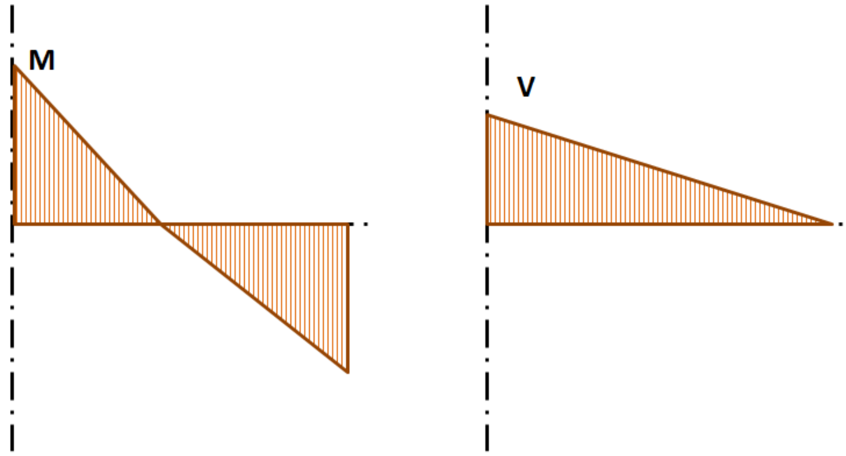
Loads

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 load 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 bar model, where individual beams are modeled using centrelines and the joints are modeled using immaterial nodes.



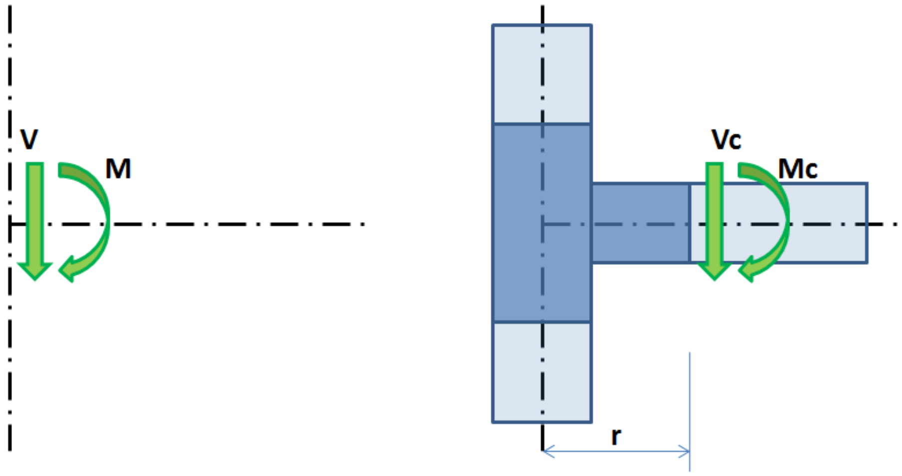
Joint of a vertical column and a horizontal beam

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



Internal forces in horizontal beam. M and V are the end forces at joint.

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



Effects of the member on the joint. CBFEM model is drawn in dark blue color.

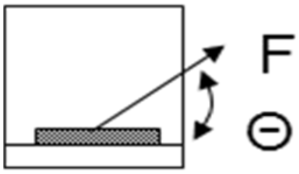
Moment *M* and shear force *V* act in a theoretical joint. The point of theoretical joint does not exist in CBFEM model, thus the load cannot be applied here. The model must be loaded by actions *M* and *V*, which have to be transferred to the end of segment in the distance *r*.
$M_c = M - V \cdot r$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

Welds

Fillet welds

The design strength, ϕR_n and the allowable strength, R_n/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 – J2.4:
$R_n = F_{nw} A_{we}$
$F_{nw} = 0.60\ F_{EXX}\ (1.0 + 0.50 \sin^{1.5}\Theta)$
where

- F_{nw} – nominal stress of weld material,
- A_{we} – effective area of the weld,
- F_{EXX} – electrode classification number, i.e., minimum specified tensile strength,
- Θ – angle of loading measured from the weld longitudinal axis.



For long welds and welding to unstiffened flanges or webs of rectangular hollow sections, the weld material model is fine-tuned so that no reduction factor is necessary. The weld resistance is governed by most stressed weld element.

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, ϕR_n, and the allowable tensile or shear strength, R_n / Ω of a snug-tightened bolt is determined according to the limit states of tension rupture and shear rupture as follows:
$R_n = F_n A_b$
$\phi = 0.75$ (LRFD)
$\Omega = 2.00$ (ASD)
where

- A_b – nominal unthreaded body area of bolt or threaded part,
- F_n – nominal tensile stress, F_{nt}, or shear stress, F_{nv}, from Table J3.2.

The tensile force, against which the required tensile strength is checked, 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:
$R_n = F'_{nt} A_b$ (AISC 360 J3-2)
$\phi = 0.75$ (LRFD)
$\Omega = 2.00$ (ASD)
$F'_{nt} = 1.3\, F_{nt} - f_{rv} F_{nt} / \phi F_{nv}$ (AISC 360 J3-3a LRFD)
$F'_{nt} = 1.3\, F_{nt} - f_{rv} \Omega\, F_{nt} / F_{nv}$ (AISC 360 J3-3b ASD)
where

- F'_{nt} – nominal tensile stress modified to include the effects of shear stress,
- F_{nt} – nominal tensile stress from AISC 360 – Tab. J3.2,
- F_{nv} – nominal shear stress from AISC 360 – Tab. J3.2,
- f_{rv} – 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, f_{rv}.

Bearing strength in bolt holes

The available bearing strength, ϕR_n and R_n/Ω at bolt holes is determined for the limit state of bearing as follows:
For a bolt in a connection with standard holes:
$R_n = 1.2\, l_c t F_u \le 2.4\, d\, t\, F_u$ (AISC 360 J3-6a, c)
For a bolt in a connection with slotted holes:
$R_n = 1.0\, l_c t\, F_u \le 2.0\, d\, t\, F_u$ (AISC 360 J3-6e, f)
$\phi = 0.75$ (LRFD)
$\Omega = 2.00$ (ASD)

where

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

- l_c – 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 with of effect of tensile force, $F_{t,Ed}$ according to AISC 360 – J3.9.
Preloading force to be used AISC 360 – Tab. J3.1.
$T_b = 0.7\ f_{ub}A_s$
Design slip resistance per bolt AISC 360 – J3.8
$R_n = 1.13\ \mu\ T_bN_s$
Utilisation in shear [%]:
$U_{ts} = V\ /\ R_n$
where

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

Anchors

The anchor bolt element is elastic-plastic with significant strain hardening. The maximum steel tensile resistance is expected at the strain which equals to 0.25 × guaranteed elongation. The failure mode due to concrete cracking may occur before the anchor steel tensile resistance is reached and is considered as a completely brittle failure.
Similarly, the steel components in shear (anchor bolt, base plate in bearing) are able to yield but failure modes connected with concrete cracking may occur suddenly as a brittle failure.
All standards use Concrete Capacity Design method developed by prof. R. Eligehausen at University of Stuttgart. The theory is based on vast experimental and numerical testing mostly on unreinforced concrete blocks and relatively short, often post-installed, anchors.
Anchorage is designed according to ACI 318-14 – Chapter 17. The design is available only for LRFD. Some failure modes (e.g. steel resistance) are evaluated for single anchors, others (e.g. concrete breakout) are checked for group of anchors.