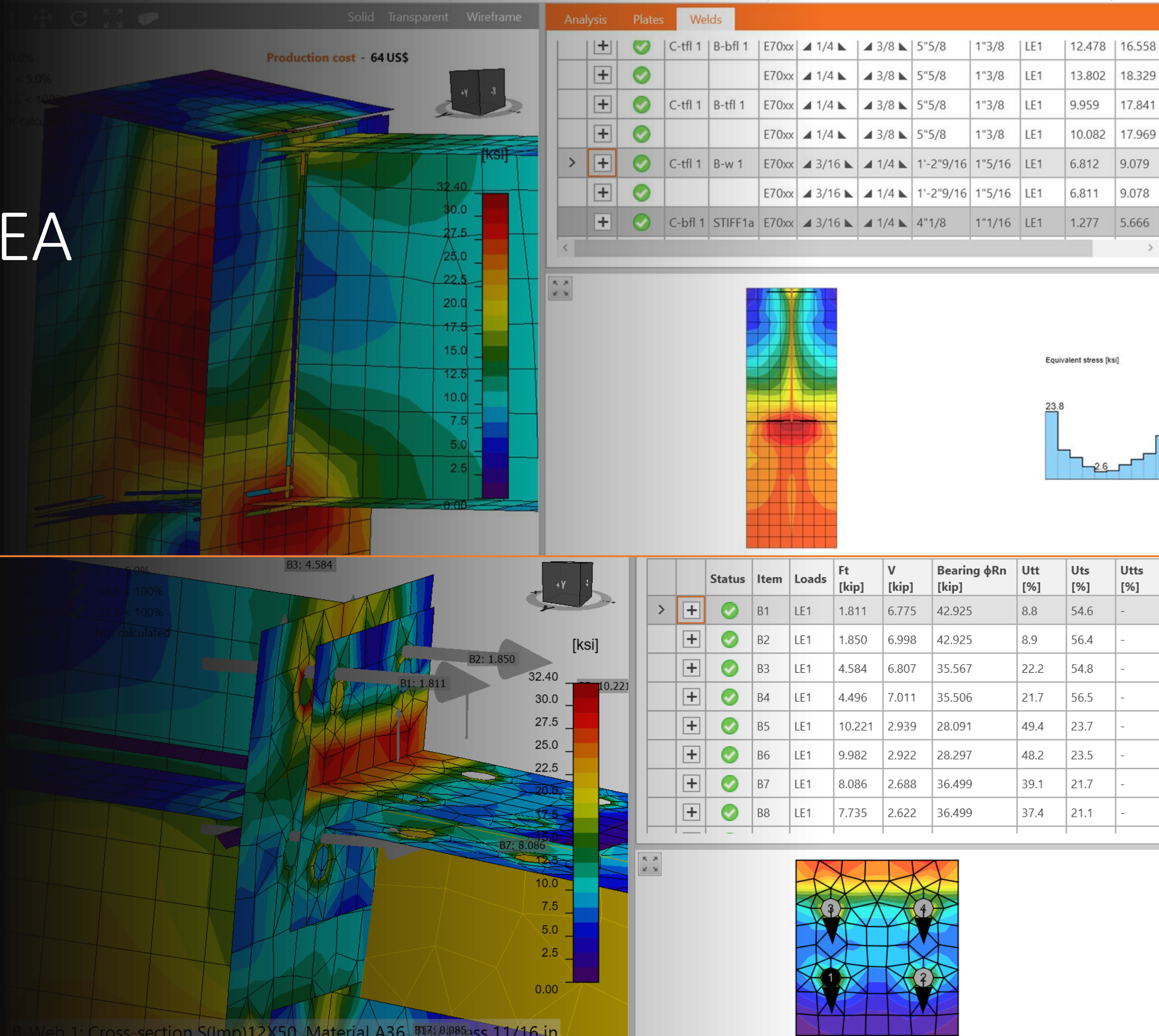
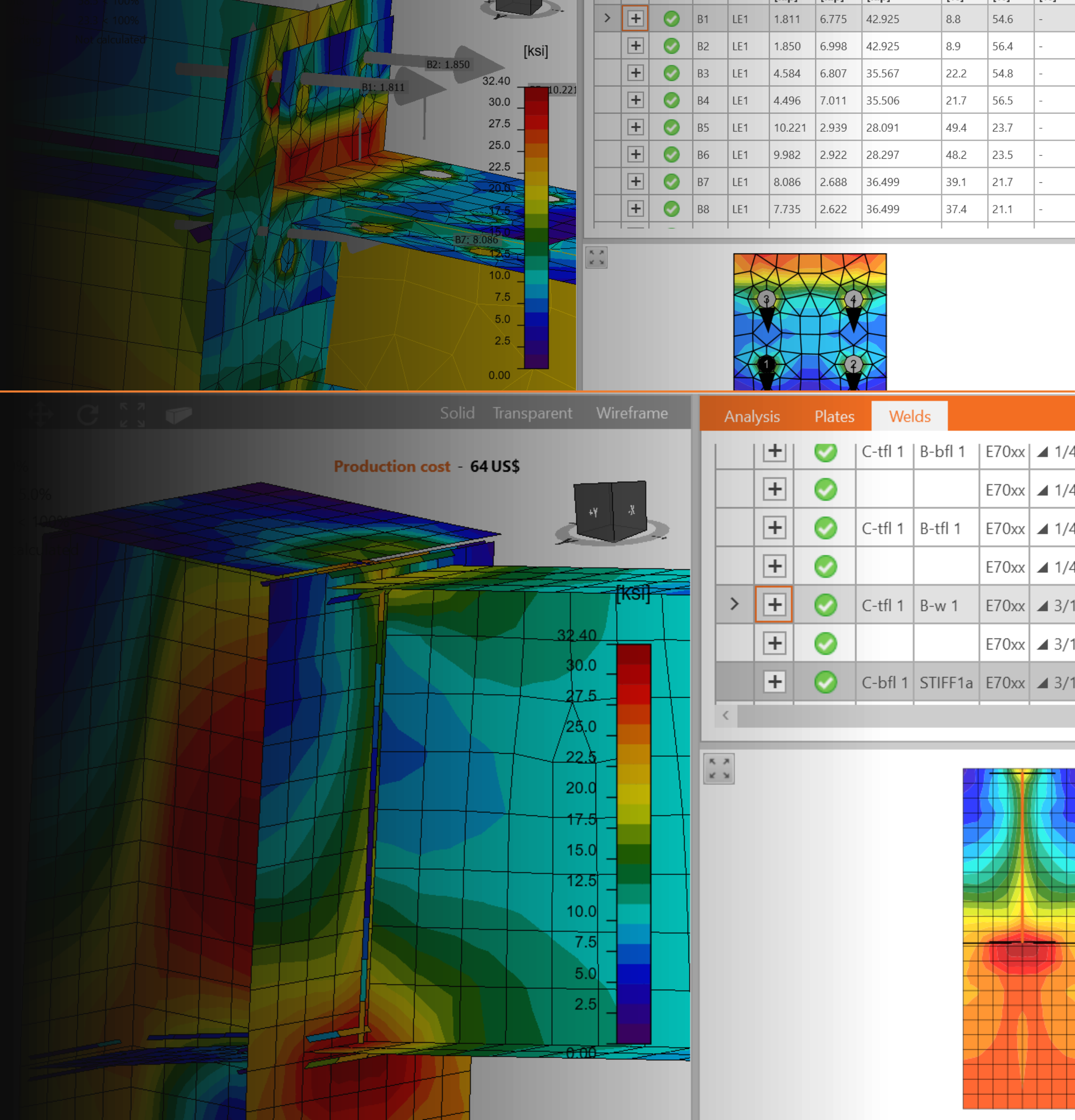
Weld&Bolts in IDEA StatiCa -AISC August 31st Noon-EDT



Calculate yesterday's estimates

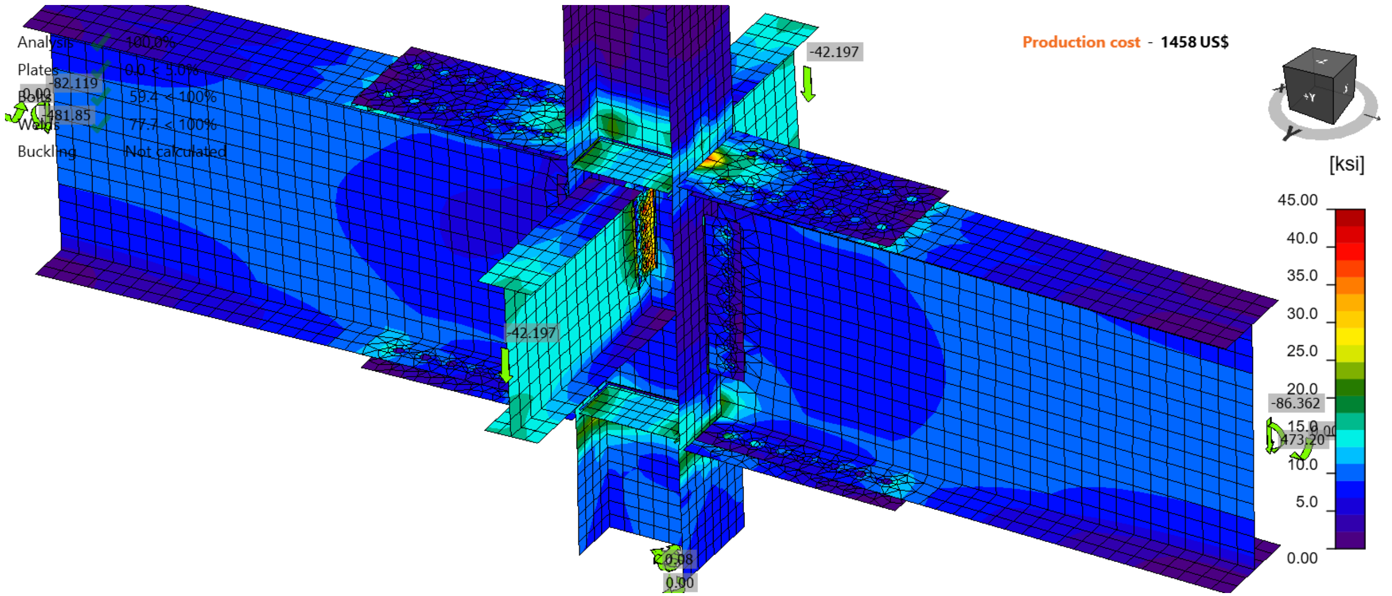
Agenda

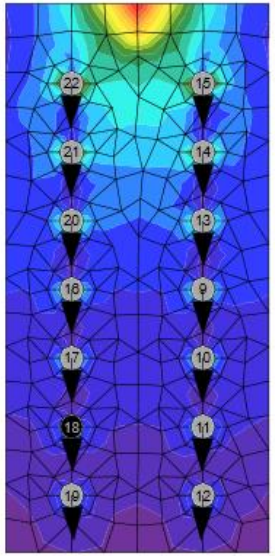
- CBFEM Introduction
- How are welds and bolts discretized in CBFEM?
- Options for modeling welds and bolts
- Design results
- Detailing checks



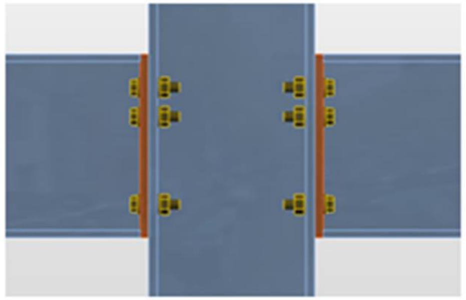
Calculate yesterday's estimates

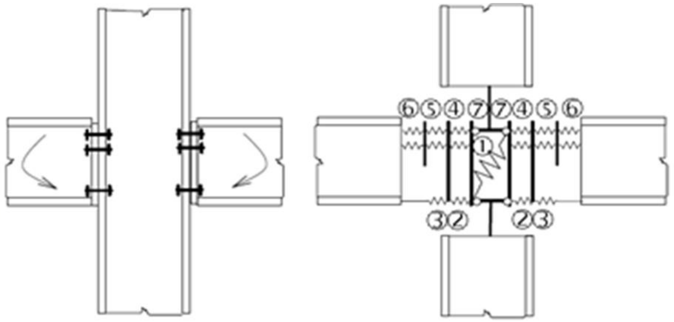
CBFEM:
Component Based + Finite Element Method



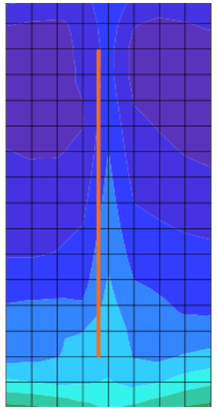


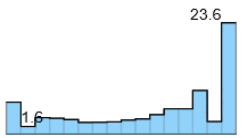
[Theoretical background]





1 – column web in shear, 2 – column web in compression, 3 – beam flange and web in compression, 4 - column flange in bending, 5 – bolts in tension, 6 – end plate in bending and 7 – column web in tension.





IDEA StatiCa®

FE Discretization

Beams, plates

- Shell elements (4-node quadrangle)
- Six degrees of freedom in each node
- Mesh density is independent- Automatic meshing

Bolts, welds

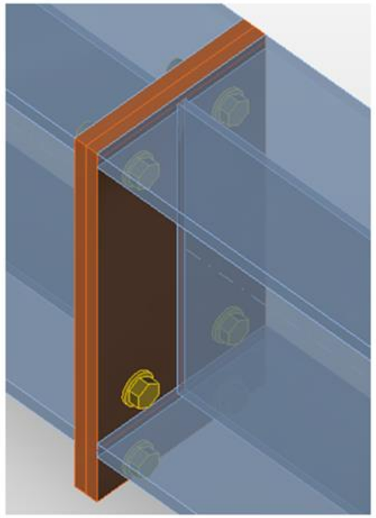
- Weld=elastoplastic shell element
- Bolts and anchors= Nonlinear springs

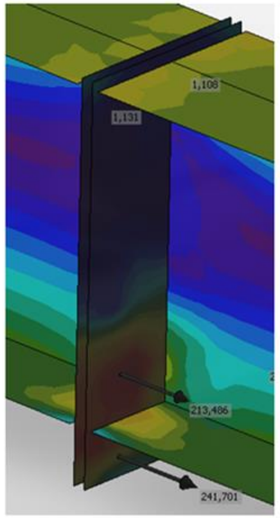
Node

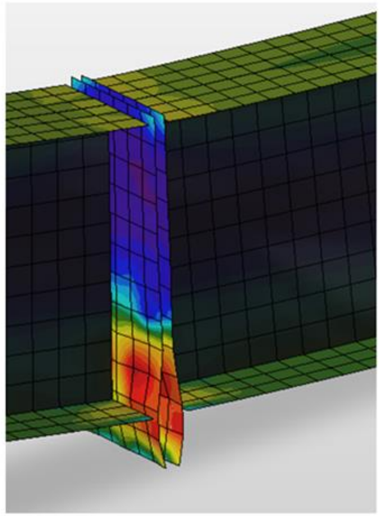
- Member intersection

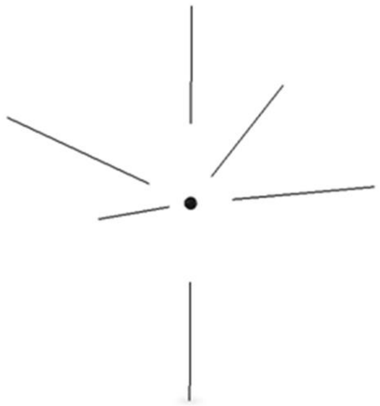
Contacts

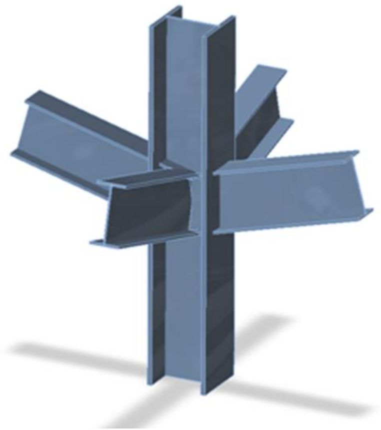
- Two surfaces
- Two edges
- Edge+surface

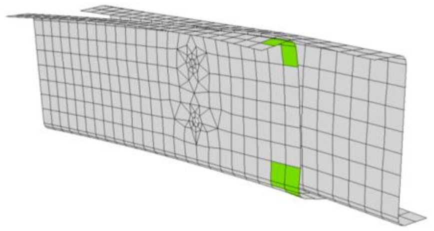


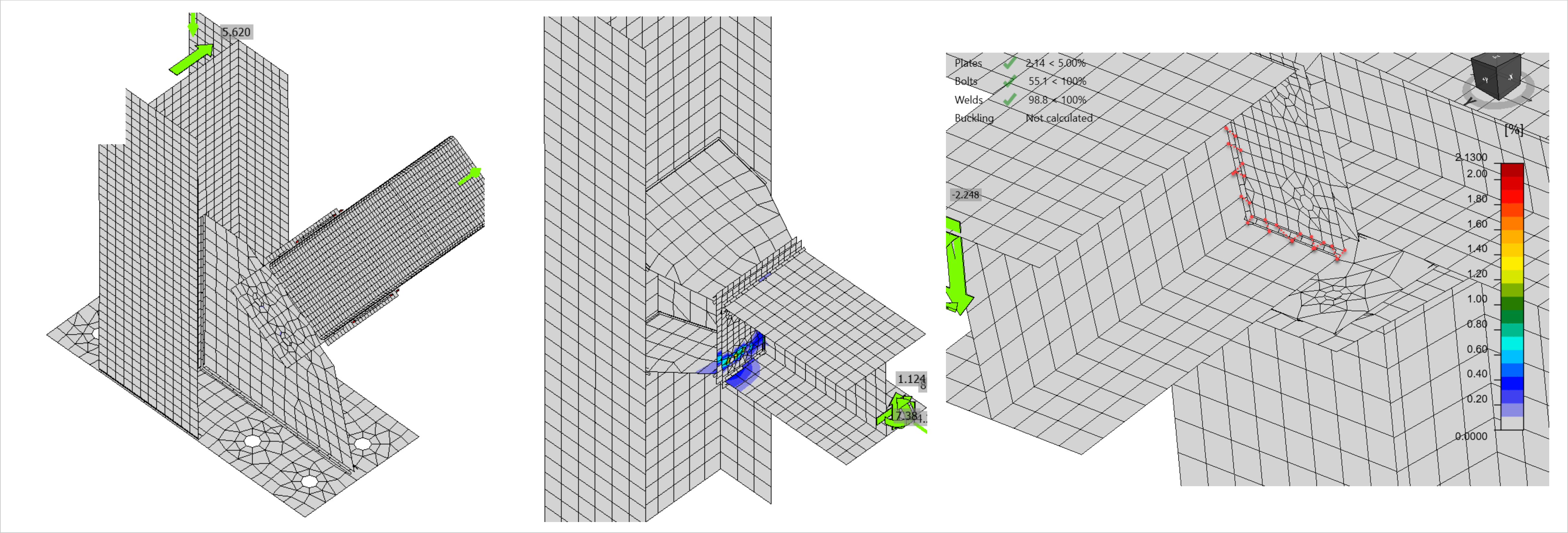








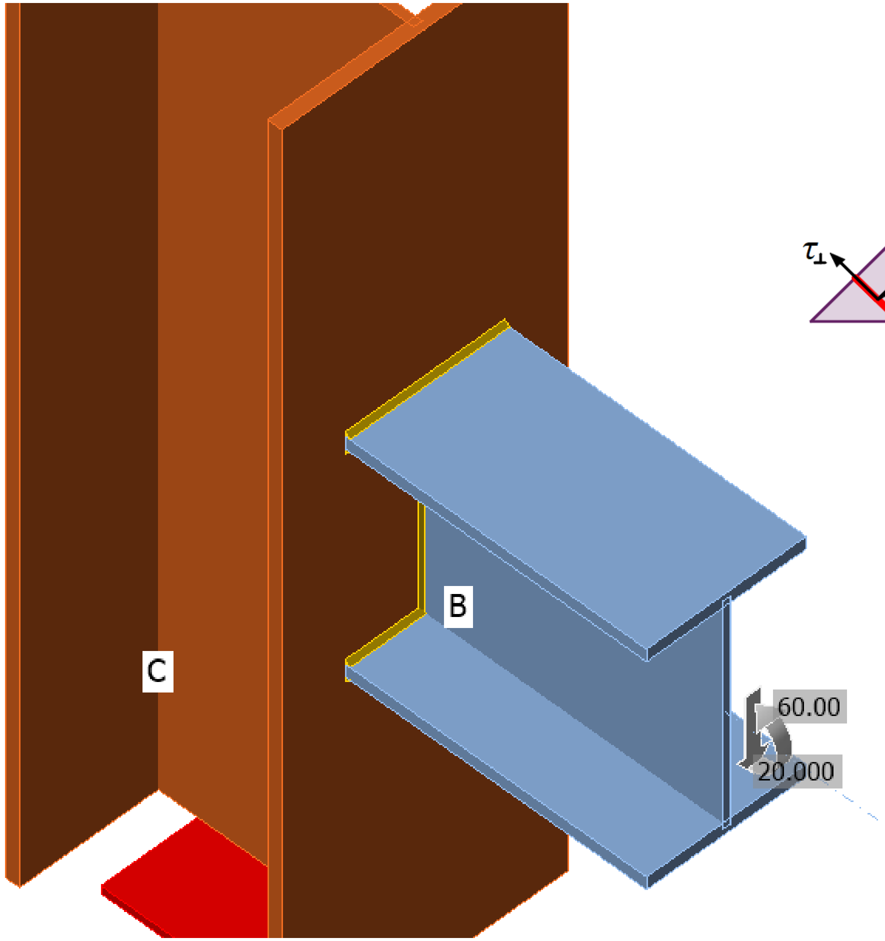


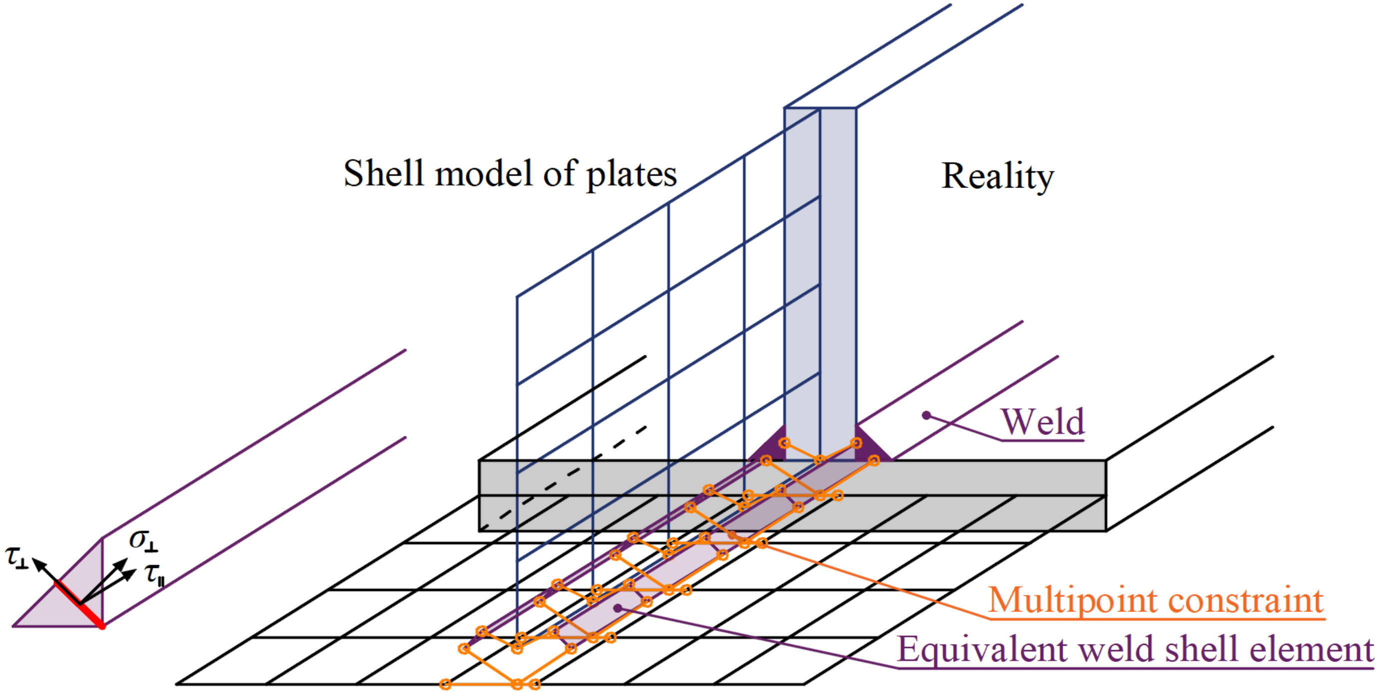


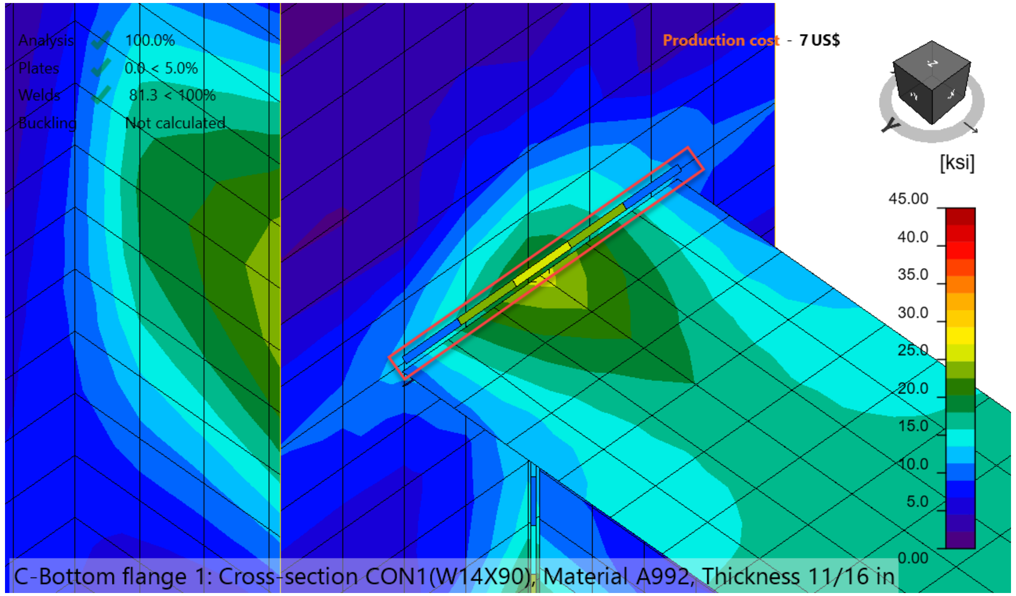
Multi-point constraint

- The load is transmitted through force-deformation constraints to the opposite plate.
- The connection is called multi-point constraint (MPC) and relates the finite element nodes of one plate edge to another.

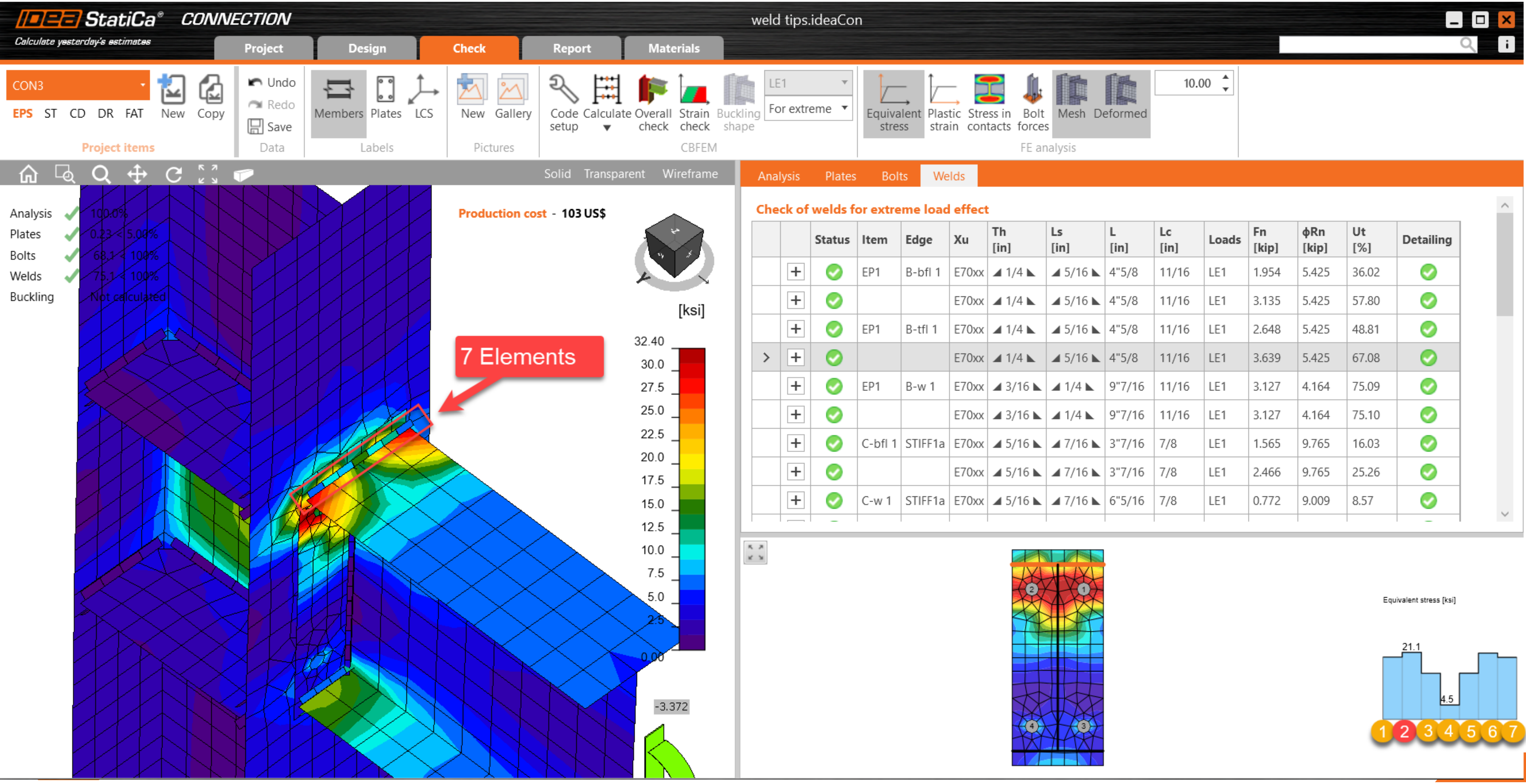
Weld model







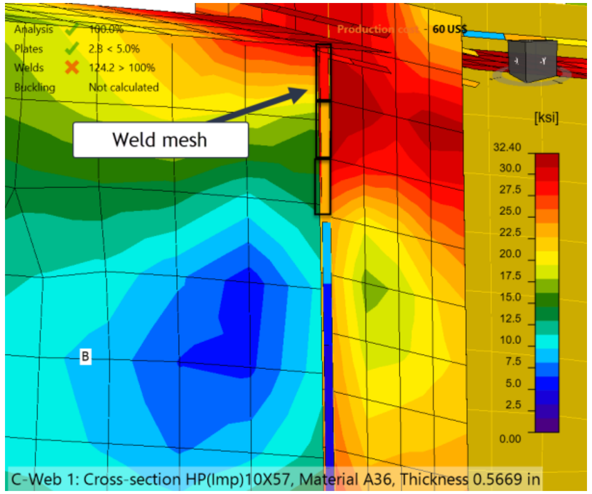
IDEA StatiCa®   [Welds IDEA StatiCa]

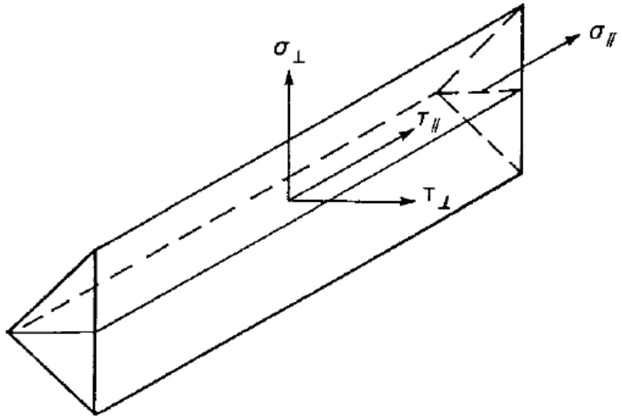

IDEA StatiCa® CONNECTION
Calculate yesterday's estimates
weld tips.ideaCon
Project
Design
Check
Report
Materials
CON3
EPS ST CD DR FAT
New
Copy
Project items
Undo
Redo
Save
Data
Members
Plates
LCS
Labels
New
Gallery
Pictures
Code setup
Calculate
Overall check
Strain check
Buckling shape
LE1
For extreme
CBFEM
Equivalent stress
Plastic strain
Stress in contacts
Bolt forces
Mesh
Deformed
10.00
FE analysis
Solid Transparent Wireframe
Analysis 100.0%
Plates 0.23 < 5.00%
Bolts 68.1 < 100%
Welds 75.1 < 100%
Buckling Not calculated
Production cost - 103 US$
[ksi]
32.40
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.00
-3.372
7 Elements
Analysis Plates Bolts Welds
Check of welds for extreme load effect
Status | Item | Edge | Xu | Th [in] | Ls [in] | L [in] | Lc [in] | Loads | Fn [kip] | φRn [kip] | Ut [%] | Detailing
EP1 | B-bfl 1 | E70xx | 1/4 | 5/16 | 4"5/8 | 11/16 | LE1 | 1.954 | 5.425 | 36.02
E70xx | 1/4 | 5/16 | 4"5/8 | 11/16 | LE1 | 3.135 | 5.425 | 57.80
EP1 | B-tfl 1 | E70xx | 1/4 | 5/16 | 4"5/8 | 11/16 | LE1 | 2.648 | 5.425 | 48.81
E70xx | 1/4 | 5/16 | 4"5/8 | 11/16 | LE1 | 3.639 | 5.425 | 67.08
EP1 | B-w 1 | E70xx | 3/16 | 1/4 | 9"7/16 | 11/16 | LE1 | 3.127 | 4.164 | 75.09
E70xx | 3/16 | 1/4 | 9"7/16 | 11/16 | LE1 | 3.127 | 4.164 | 75.10
C-bfl 1 | STIFF1a | E70xx | 5/16 | 7/16 | 3"7/16 | 7/8 | LE1 | 1.565 | 9.765 | 16.03
E70xx | 5/16 | 7/16 | 3"7/16 | 7/8 | LE1 | 2.466 | 9.765 | 25.26
C-w 1 | STIFF1a | E70xx | 5/16 | 7/16 | 6"5/16 | 7/8 | LE1 | 0.772 | 9.009 | 8.57
Equivalent stress [ksi]
21.1
4.5
1 2 3 4 5 6 7

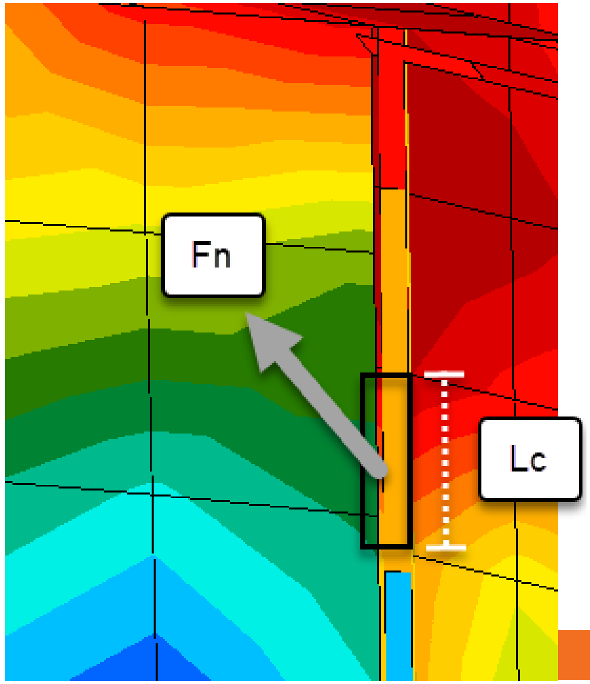
Weld force calculation

- From the most stressed mesh element in the weld:
- Fn=Force from Finite Element analysis
- Lc=Length of critical element
- Theta angle= Angle between Fn and longitudinal axis of the weld.

Paper about welds

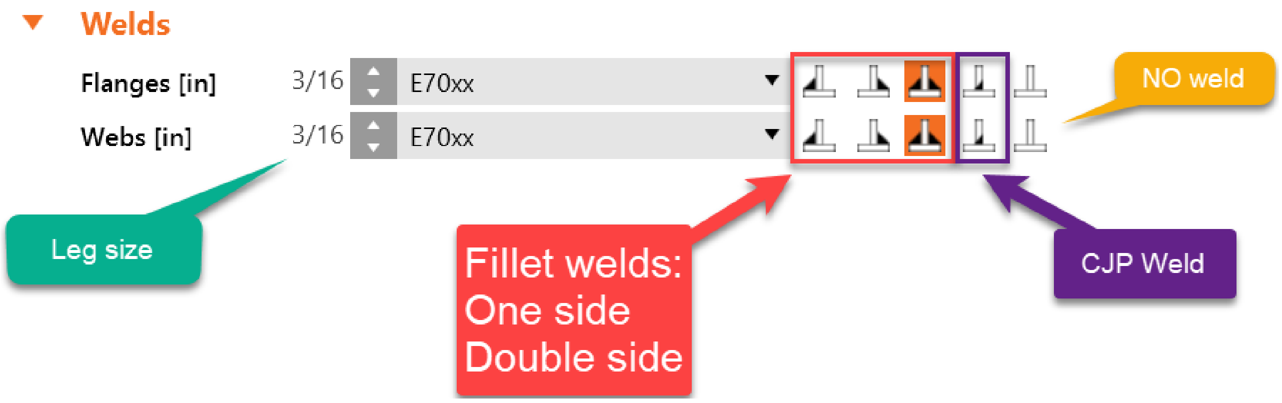


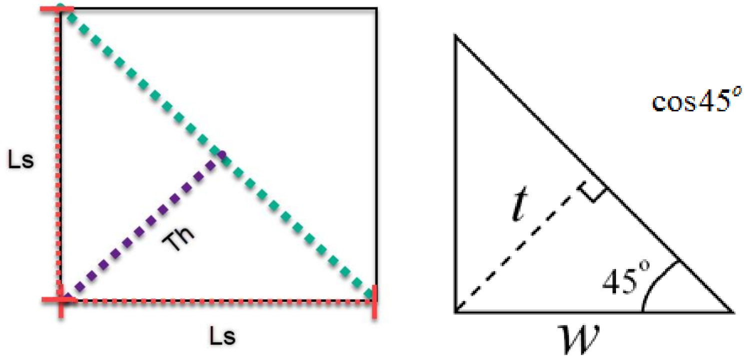




Weld modeling

- Leg size=0
- For single sided fillet weld, weld throat thickness is **equal to the thinner connected plate**.
- For double sided fillet weld, weld throat thickness **is equal to half of the thinner connected plate.**





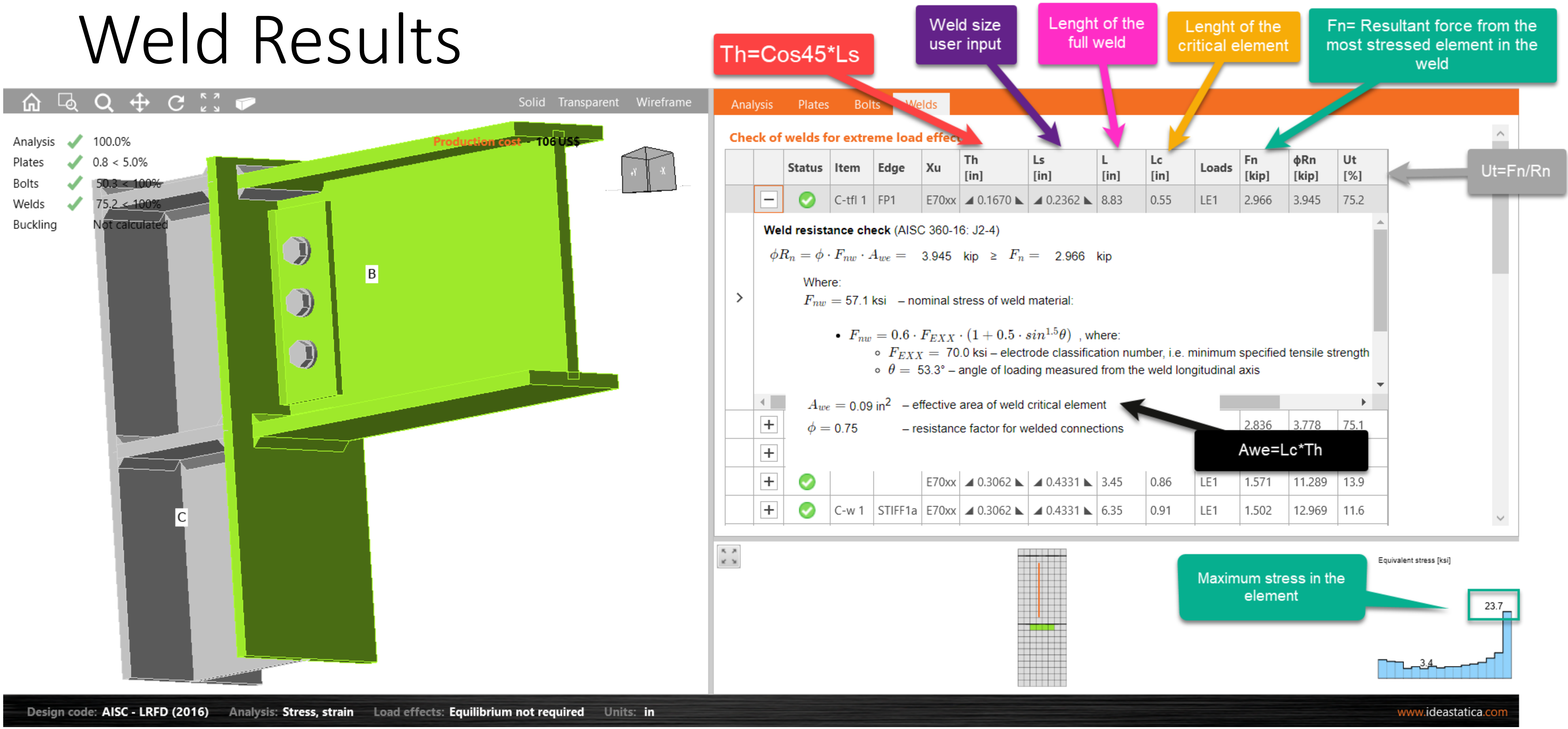
$$\cos 45^{o} = \frac{t}{w}$$

$$t = (\cos 45^{o})w$$

$$t = 0.707w$$

Ls=Leg size
Th=Throat thickness

Weld Results



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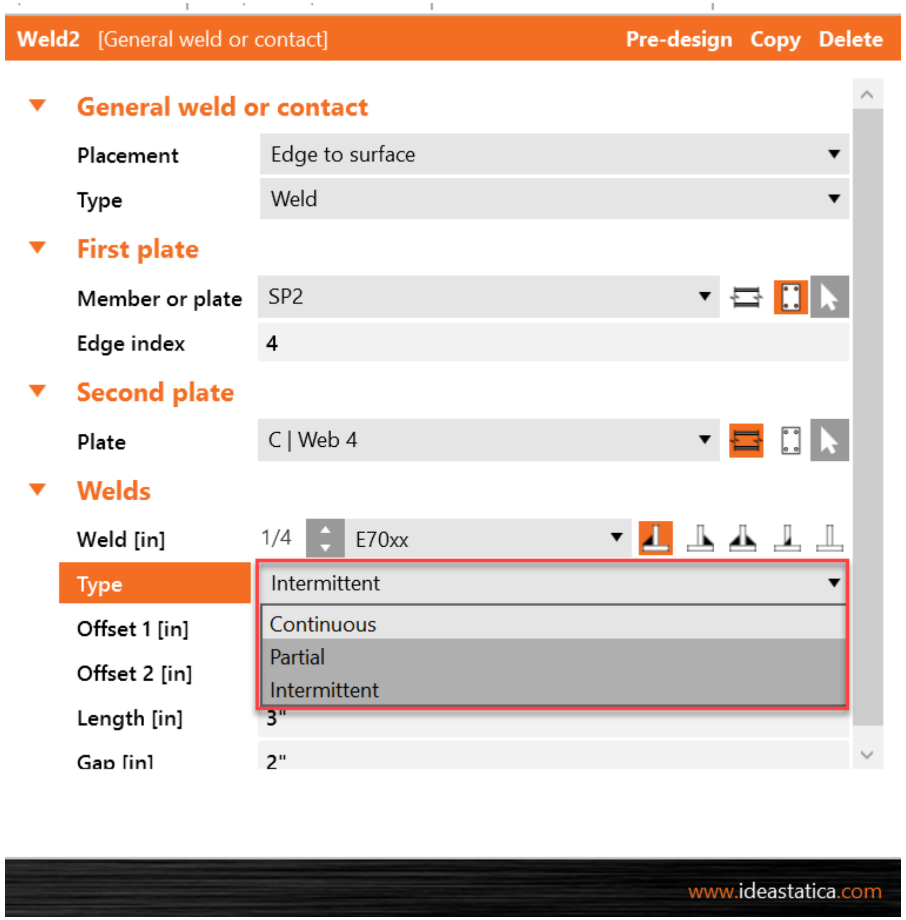
[Check of welds according AISC]

Type of weld



Weld2 [General weld or contact] Pre-design Copy Delete
General weld or contact
Placement
Edge to surface
Type
Weld
First plate
Member or plate
SP2
Edge index
4
Second plate
Plate
C | Web 4
Welds
Weld [in]
1/4
E70xx
Type
Intermittent
Continuous
Partial
Intermittent
Offset 1 [in]
Offset 2 [in]
Length [in]
3"
Gap [in]
2"
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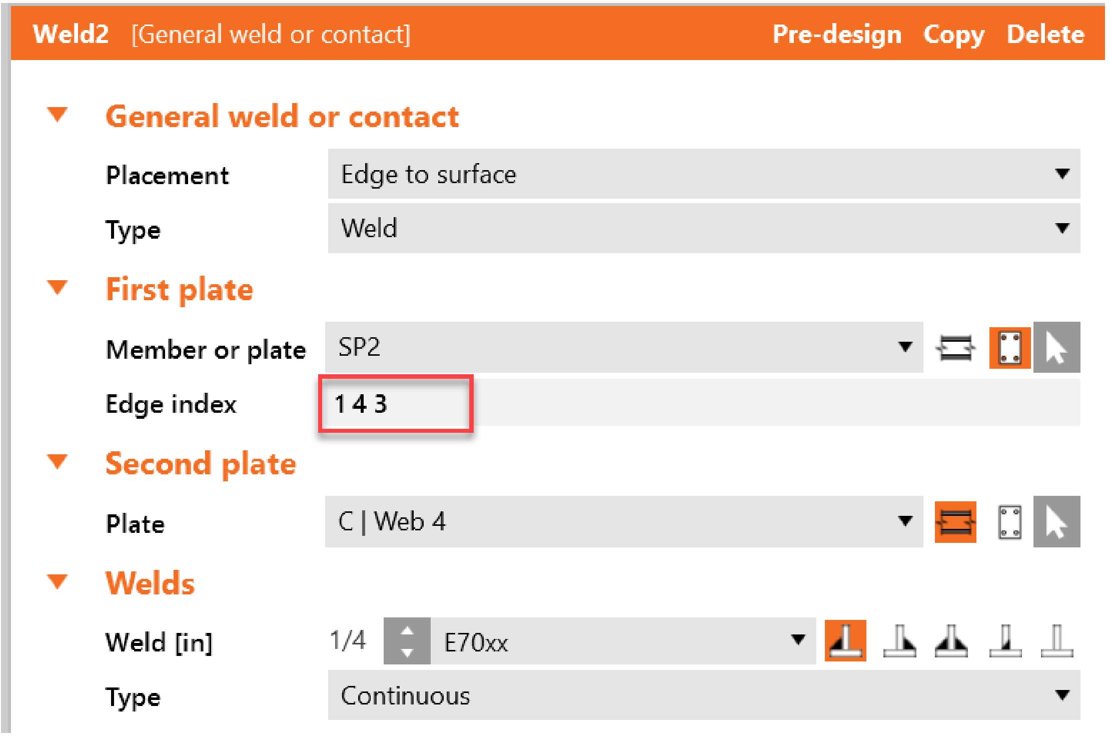
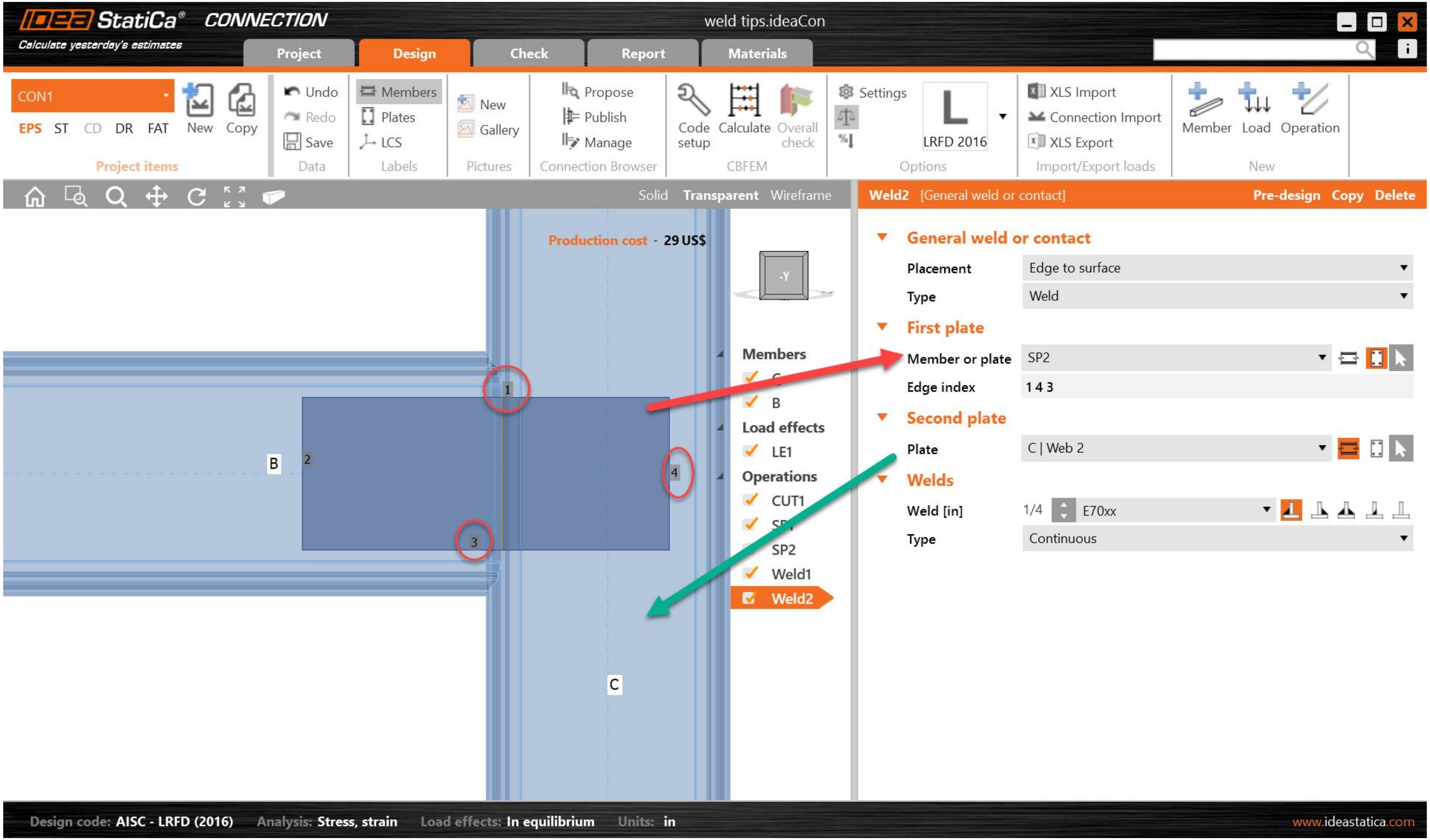


Weld2 [General weld or contact] Pre-design Copy Delete
General weld or contact
Placement
Edge to surface
Type
Weld
First plate
Member or plate
SP2
Edge index
1 4 3
Second plate
Plate
C | Web 4
Welds
Weld [in]
1/4
E70xx
Type
Continuous



StatiCa CONNECTION
Calculate yesterday's estimates
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Project
Design
Check
Report
Materials
CON1
EPS ST CD DR FAT
New
Copy
Project items
Undo
Redo
Save
Data
Members
Plates
LCS
Labels
New
Gallery
Pictures
Propose
Publish
Manage
Connection Browser
Code setup
Calculate
Overall check
CBFEM
Settings
LRFD 2016
Options
XLS Import
Connection Import
XLS Export
Import/Export loads
Member
Load
Operation
New
Solid Transparent Wireframe
Production cost - 29 US$
Members
B
Load effects
LE1
Operations
CUT1
SP2
Weld1
Weld2
B
C
1
2
3
4
Weld2 [General weld or contact]
Pre-design Copy Delete
General weld or contact
Placement
Edge to surface
Type
Weld
First plate
Member or plate
SP2
Edge index
1 4 3
Second plate
Plate
C | Web 2
Welds
Weld [in]
1/4
E70xx
Type
Continuous
Design code: AISC - LRFD (2016)
Analysis: Stress, strain
Load effects: In equilibrium
Units: in
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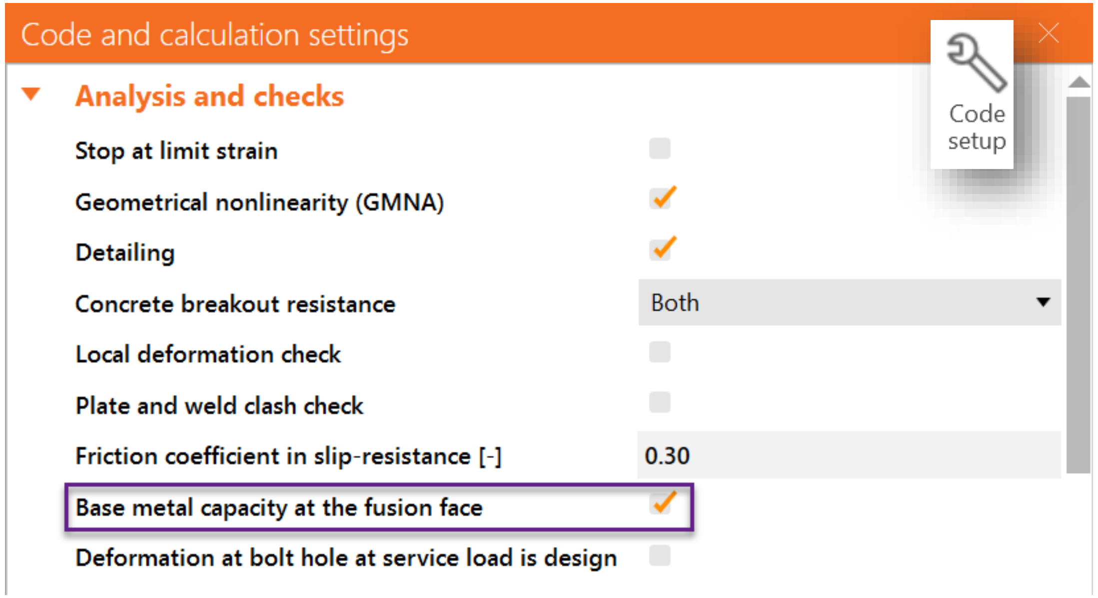
Base metal



Base metal capacity check (AISC 360-16: J2-2)

$\phi R_n = \phi \cdot F_{nBM} \cdot A_{BM} =$ 5.425 kip $\geq$ $F_n =$ 1.954 kip

Where:

$F_{nBM} =$ 34.8 ksi – nominal stress of the base metal:

- $F_{nBM} = 0.6 \cdot F_u$, where:
  - $F_u =$ 58.0 ksi – tensile strength of the connected material

$A_{BM} =$ 0.2078 in^2 – cross-sectional area of base metal:

- $A_{BM} = A_{we} \cdot \sqrt{2}$, where:
  - $A_{we} =$ 0.1469 in^2 – effective area of weld critical element

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

material, but not less than $^5/_8$ in. (16 mm).

4. Strength

(a) The design strength, ϕR_n and the allowable strength, R_n/Ω, of welded joints shall be the lower value of the base material strength determined according to the limit states of tensile rupture and shear rupture and the weld metal strength determined according to the limit state of rupture as follows:

For the base metal

$$R_n = F_{nBM} A_{BM} \quad \text{(J2-2)}$$

For the weld metal

$$R_n = F_{nw} A_{we} \quad \text{(J2-3)}$$

where

A_{BM} = cross-sectional area of the base metal, in.^{2} (mm^2)
A_{we} = effective area of the weld, in.^{2} (mm^2)
F_{nBM} = nominal stress of the base metal, ksi (MPa)
F_{nw} = nominal stress of the weld metal, ksi (MPa)

The values of ϕ, Ω, F_{nBM} and F_{nw}, and limitations thereon, are given in Table J2.5.

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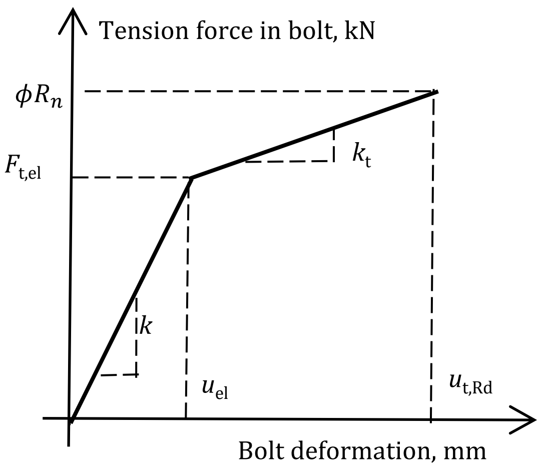
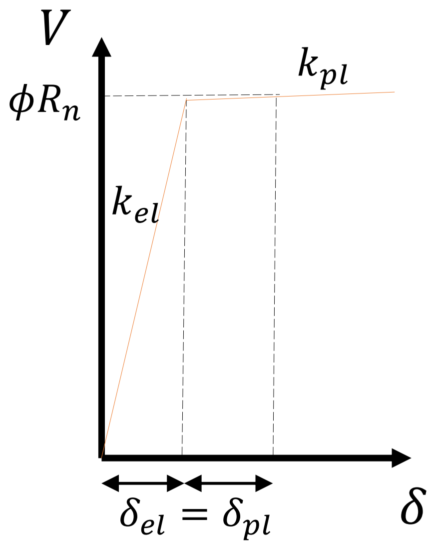
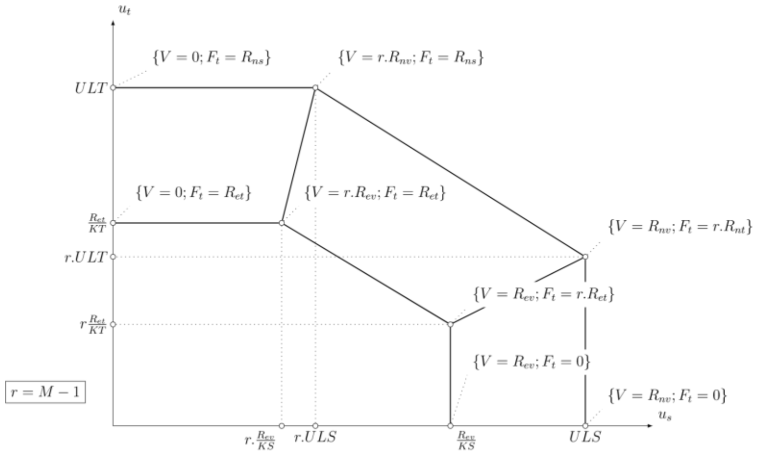
Bolts=Nonlinear springs



Load–deformation diagram of a bolt in tension

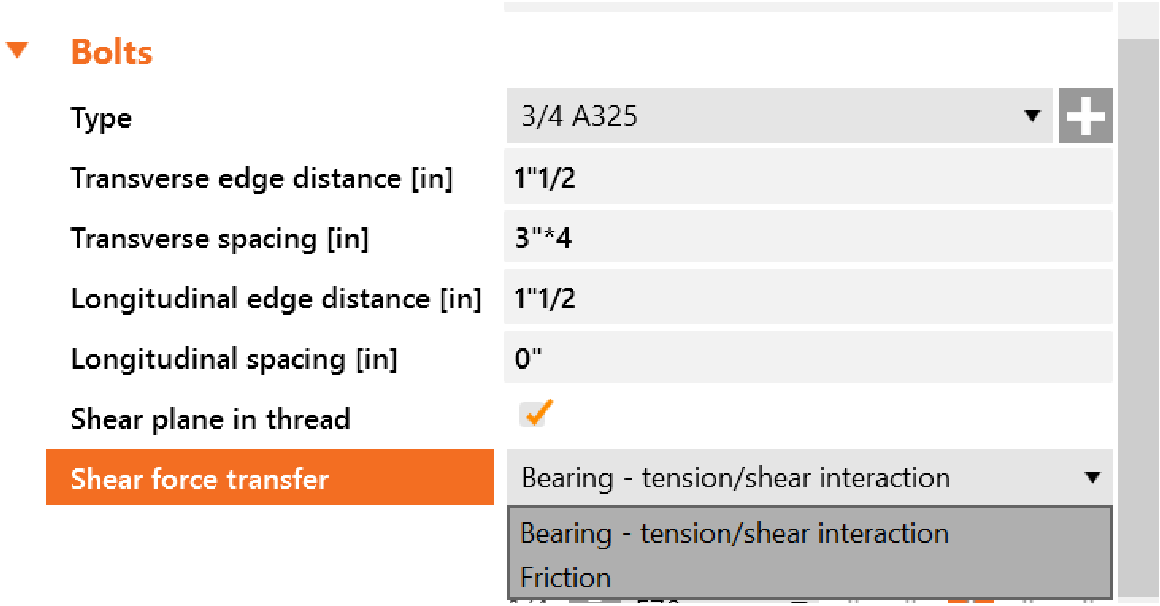


Load–deformation diagram of a bolt in shear



Bolt tension force as a function of deformation in shear and tension

Slip critical connections



[Checks of bolts according to AISC](#)

8. High-Strength Bolts in Slip-Critical Connections

Slip-critical connections shall be designed to prevent slip and for the limit states of bearing-type connections. When slip-critical bolts pass through fillers, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The single bolt available slip resistance for the limit state of slip shall be determined as follows:

$$R_n = \mu D_u h_f T_b n_s \qquad \text{(J3-4)}$$

(a) For standard size and short-slotted holes perpendicular to the direction of the load

$\phi = 1.00$ (LRFD) $\quad \Omega = 1.50$ (ASD)

(b) For oversized and short-slotted holes parallel to the direction of the load

$\phi = 0.85$ (LRFD) $\quad \Omega = 1.76$ (ASD)

(c) For long-slotted holes

$\phi = 0.70$ (LRFD) $\quad \Omega = 2.14$ (ASD)

where

D_u = 1.13, a multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension. The use of other values are permitted if approved by the engineer of record.

T_b = minimum fastener tension given in Table J3.1, kips, or Table J3.1M, kN

h_f = factor for fillers, determined as follows:

(1) For one filler between connected parts

$h_f = 1.0$

(2) For two or more fillers between connected parts

$h_f = 0.85$

n_s = number of slip planes required to permit the connection to slip

μ = mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:

(1) For Class A surfaces (unpainted clean mill scale steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

$\mu = 0.30$

(2) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

$\mu = 0.50$

Slip critical factor

8. High-Strength Bolts in Slip-Critical Connections

Slip-critical connections shall be designed to prevent slip and for the limit states of bearing-type connections. When slip-critical bolts pass through fillers, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The single bolt available slip resistance for the limit state of slip shall be determined as follows:

$$R_n = \mu D_u h_f T_b n_s \qquad \text{(J3-4)}$$

(a) For standard size and short-slotted holes perpendicular to the direction of the load

$\phi = 1.00$ (LRFD) $\quad \Omega = 1.50$ (ASD)

(b) For oversized and short-slotted holes parallel to the direction of the load

$\phi = 0.85$ (LRFD) $\quad \Omega = 1.76$ (ASD)

(c) For long-slotted holes

$\phi = 0.70$ (LRFD) $\quad \Omega = 2.14$ (ASD)

where

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$h_f = 1.0$

(2) For two or more fillers between connected parts

$h_f = 0.85$

n_s = number of slip planes required to permit the connection to slip

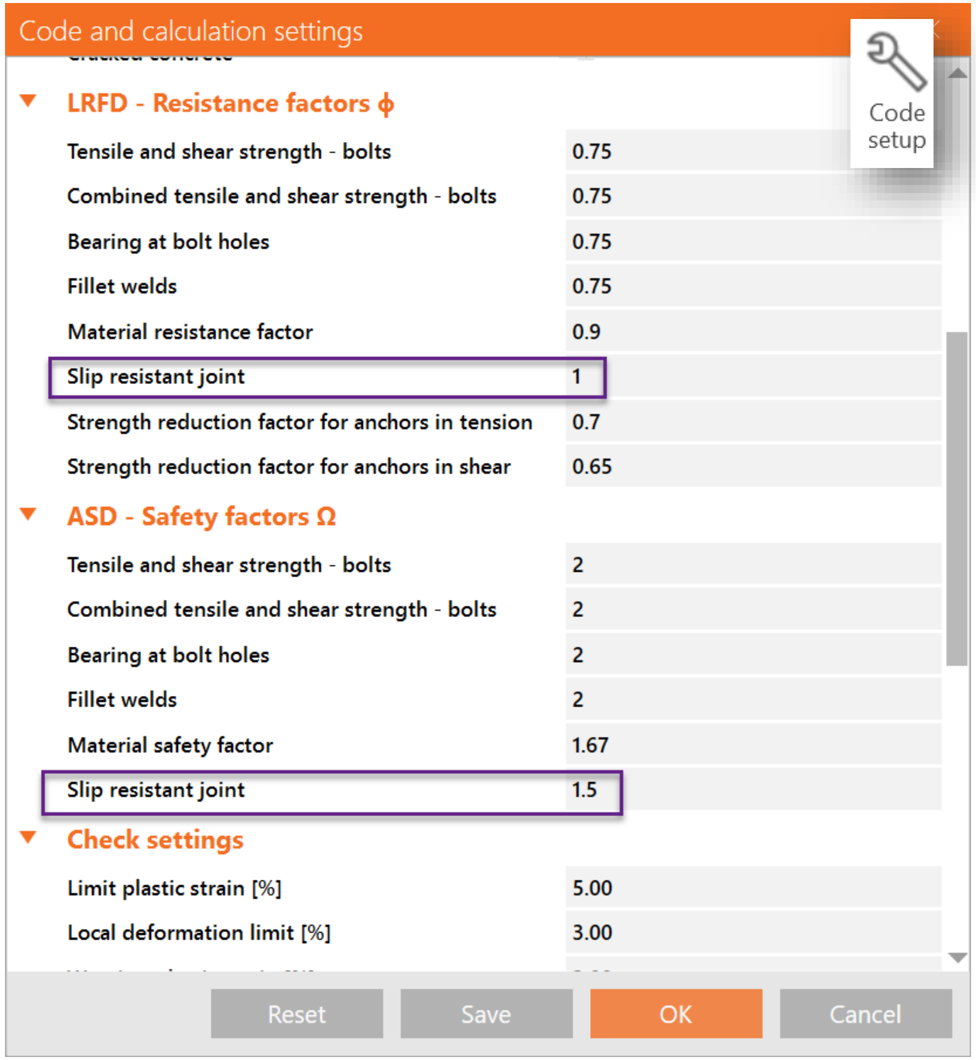
μ = mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:

(1) For Class A surfaces (unpainted clean mill scale steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

$\mu = 0.30$

(2) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

$\mu = 0.50$



Filler factor for slip critical connections

h_f = factor for fillers, determined as follows:

(1) For one filler between connected parts

$$h_f = 1.0$$

(2) For two or more fillers between connected parts

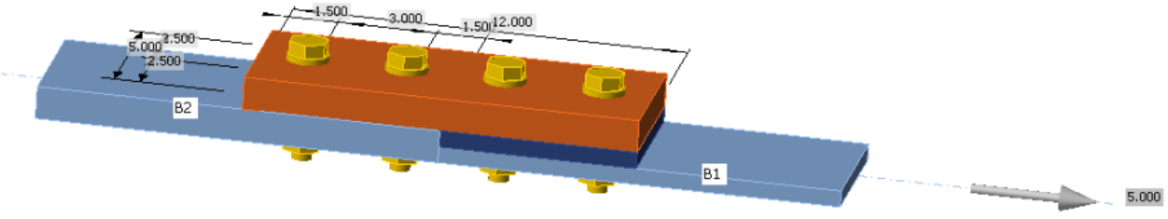
$$h_f = 0.85$$

- Fillers are detected and factor is changed.

Reduction of bolt shear resistance for connection with fillers

Bolt shear resistance for connections with fillers is now reduced according to AISC 360-16, J5.2. A filler is recognized by IDEA StatiCa as an inserted plate that is not connected to any other weld or bolt grid. It is not checked whether the filler is properly developed.

The factor for fillers of slip-critical connections, h_f, is now determined properly according to AISC 360-16, J3.8. For two or more filler plates, h_f is reduced to 0,85.



These three updates above are available since version 22.0.0.

Friction coefficient in slip-resistance

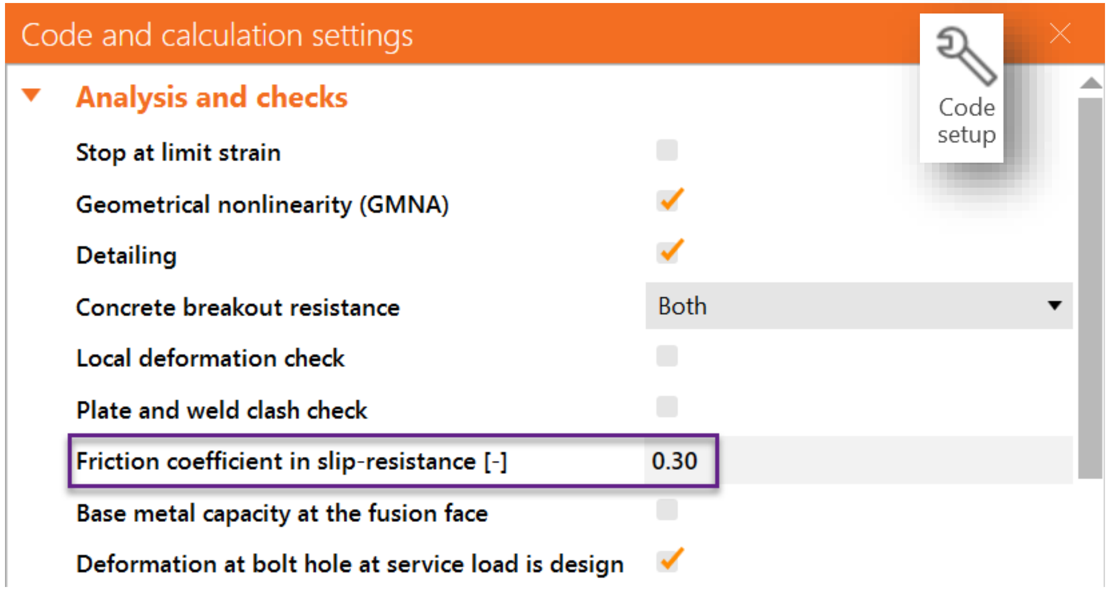
μ = mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:

(1) For Class A surfaces (unpainted clean mill scale steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

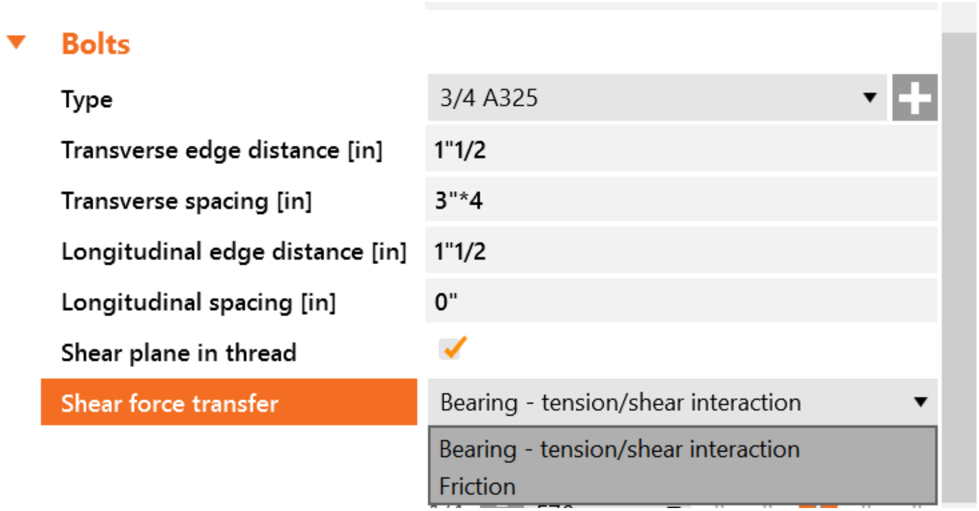
$$\mu = 0.30$$

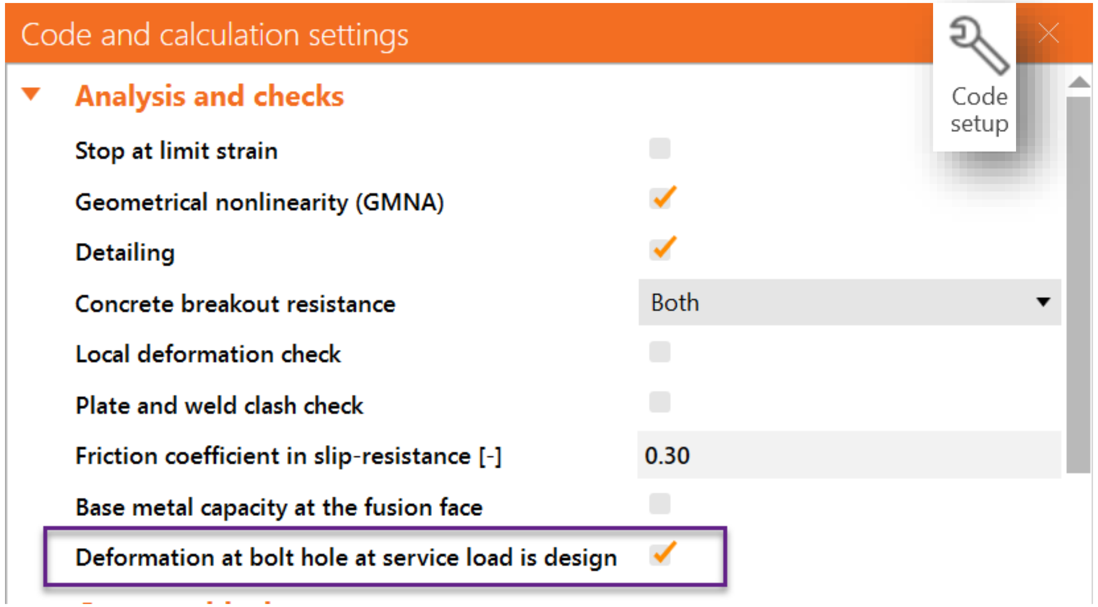
(2) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

$$\mu = 0.50$$



Bolts in bearing





(1) Bearing

(i) When deformation at the bolt hole at service load is a design consideration

$$R_n = 2.4dtF_u \quad \text{(J3-6a)}$$

(ii) When deformation at the bolt hole at service load is not a design consideration

$$R_n = 3.0dtF_u \quad \text{(J3-6b)}$$

(2) Tearout

(i) When deformation at the bolt hole at service load is a design consideration

$$R_n = 1.2l_c tF_u \quad \text{(J3-6c)}$$

(ii) When deformation at the bolt hole at service load is not a design consideration

$$R_n = 1.5l_c tF_u \quad \text{(J3-6d)}$$

Fillers in bearing bolts

2. Fillers in Bolted Bearing-Type Connections

When a bolt that carries load passes through fillers that are equal to or less than 1/4 in. (6 mm) thick, the shear strength shall be used without reduction. When a bolt that carries load passes through fillers that are greater than 1/4 in. (6 mm) thick, one of the following requirements shall apply:

(a) The shear strength of the bolts shall be multiplied by the factor

$$1 - 0.4(t - 0.25)$$

$$1 - 0.0154(t - 6) \quad \text{(S.I.)}$$

but not less than 0.85, where t is the total thickness of the fillers.

(b) The fillers shall be welded or extended beyond the joint and bolted to uniformly distribute the total force in the connected element over the combined cross section of the connected element and the fillers.

(c) The size of the joint shall be increased to accommodate a number of bolts that is equivalent to the total number required in (b).

- Filler is detected and reduction is applied:

Shear resistance check (AISC 360-16: J3-1)

$\phi R_n = \phi \cdot F_{nv} \cdot A_b \cdot r =$ 34.190 kip ≥ $V =$ 5.238 kip

Where:

$F_{nv} =$ 54.0 ksi – nominal shear stress from AISC 360-16 Table J3.2

$A_b =$ 0.9940 in^2 – gross bolt cross-sectional area

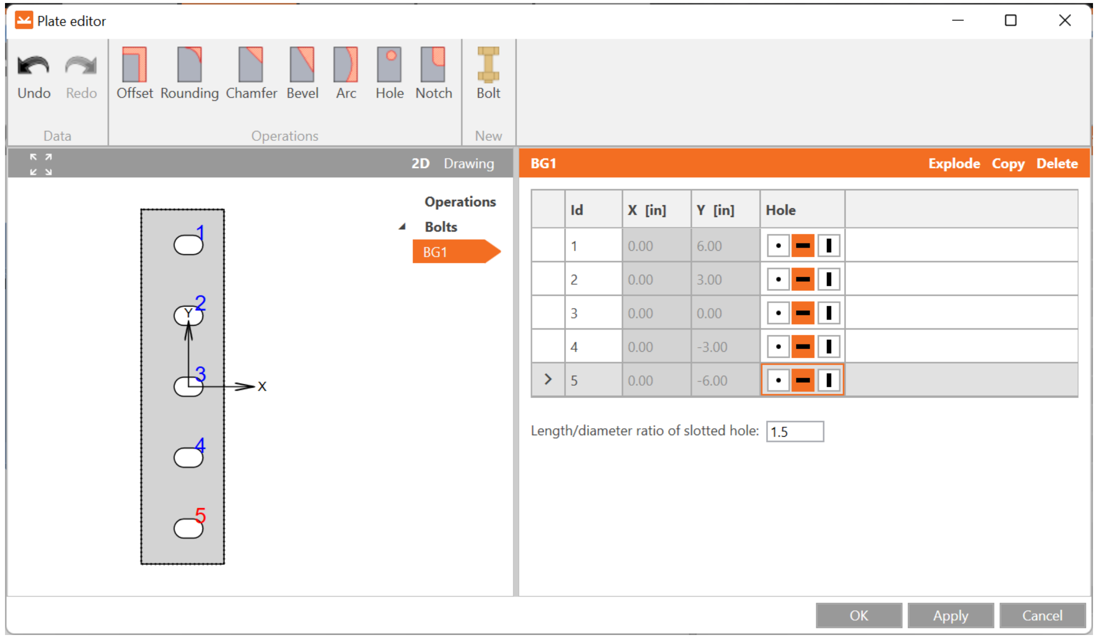
$\phi = 0.75$ – resistance factor

$r = 0.85$ – reduction factor for fillers (AISC 360-16: J5.2)

- $r = \max(0.85, 1 - 0.4 \cdot (t_f - 0.25))$
  - $t_f =$ 1" in – total thickness of fillers

Standard vs Slotted holes

- Bolts in *standard* holes can transfer shear force in all directions.
- Bolts in *slotted* holes have one direction excluded and can move in the selected direction freely.



Shear plane in thread

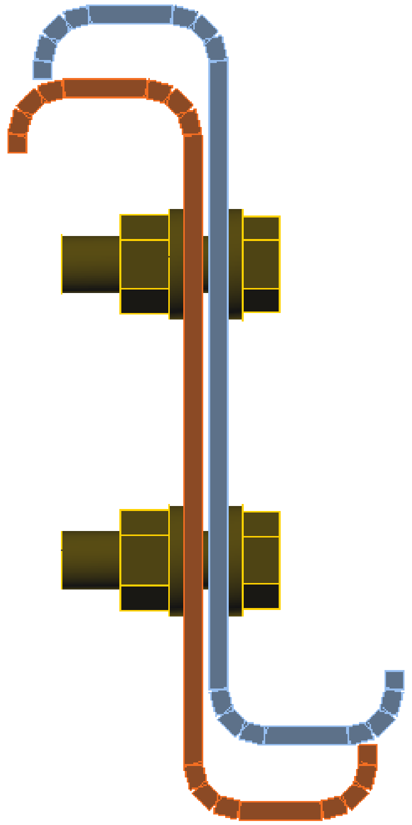
Shear plane in thread

TABLE J3.2
Nominal Strength of Fasteners and Threaded Parts, ksi (MPa)

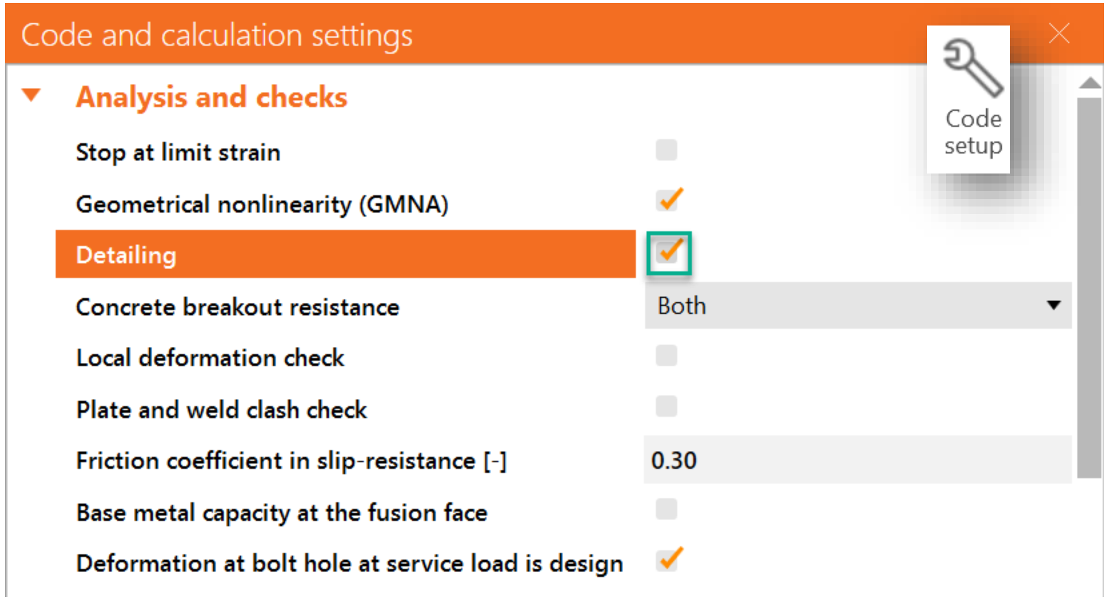
Description of Fasteners	Nominal Tensile Strength, F_{nt}, ksi (MPa)[a]	Nominal Shear Strength in Bearing-Type Connections, F_{nv}, ksi (MPa)[b]
A307 bolts	45 (310)[c]	27 (186)[c] [d]
Group A (e.g., A325) bolts, when threads are not excluded from shear planes	90 (620)	54 (372)
Group A (e.g., A325) bolts, when threads are excluded from shear planes	90 (620)	68 (469)
Group B (e.g., A490) bolts, when threads are not excluded from shear planes	113 (780)	68 (469)
Group B (e.g., A490) bolts, when threads are excluded from shear planes	113 (780)	84 (579)
Group C (e.g., F3043) bolt assemblies, when threads and transition area of shank are not excluded from the shear plane	150 (1040)	90 (620)
Group C (e.g., F3043) bolt assemblies, when threads and transition area of shank are excluded from the shear plane	150 (1040)	113 (779)
Threaded parts meeting the requirements of Section A3.4, when threads are not excluded from shear planes	$0.75F_u$	$0.450F_u$
Threaded parts meeting the requirements of Section A3.4, when threads are excluded from shear planes	$0.75F_u$	$0.563F_u$

Gap between connected plates

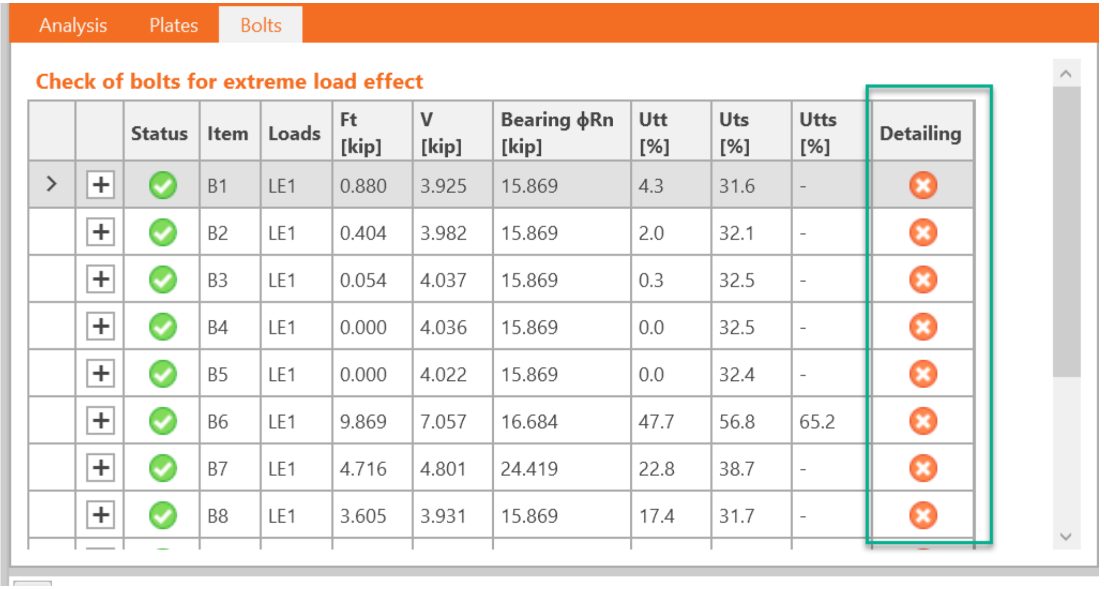
- The maximum distance allowed between two connected plates is 0.08 inches.



Detailing checks



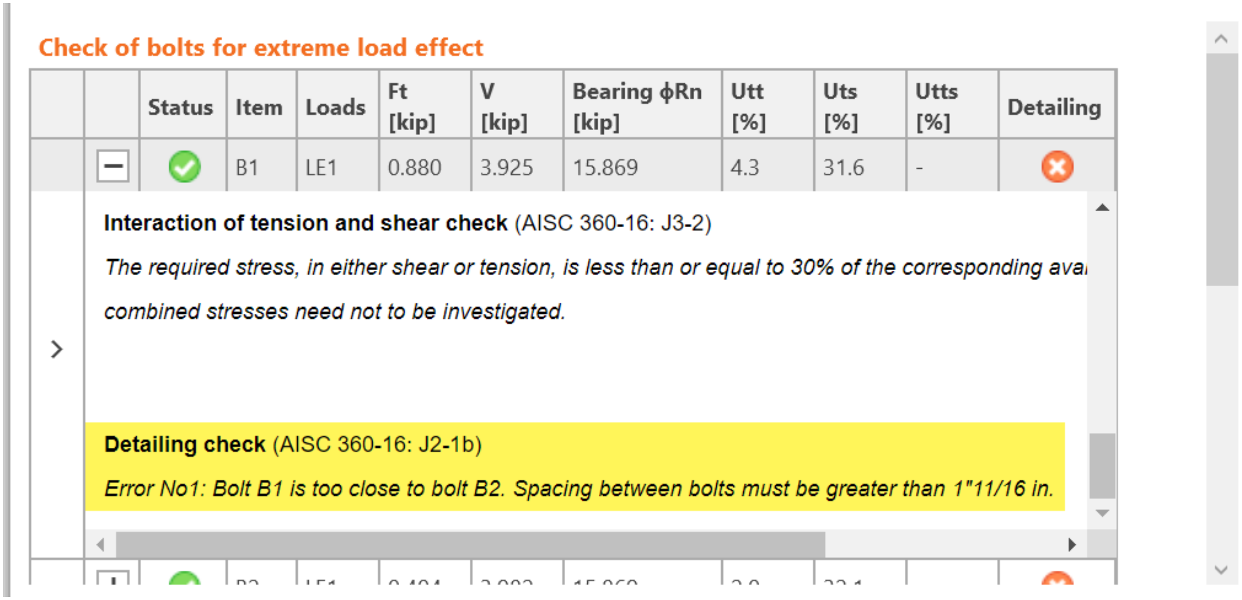
Analysis	✓	100.0%
Plates	✓	0.9 < 5.0%
Bolts	✗	Detailing
Buckling		Not calculated



Analysis | Plates | Bolts

Check of bolts for extreme load effect

Status	Item	Loads	Ft [kip]	V [kip]	Bearing ϕRn [kip]	Utt [%]	Uts [%]	Utts [%]	Detailing
✓	B1	LE1	0.880	3.925	15.869	4.3	31.6	-	✗
✓	B2	LE1	0.404	3.982	15.869	2.0	32.1	-	✗
✓	B3	LE1	0.054	4.037	15.869	0.3	32.5	-	✗
✓	B4	LE1	0.000	4.036	15.869	0.0	32.5	-	✗
✓	B5	LE1	0.000	4.022	15.869	0.0	32.4	-	✗
✓	B6	LE1	9.869	7.057	16.684	47.7	56.8	65.2	✗
✓	B7	LE1	4.716	4.801	24.419	22.8	38.7	-	✗
✓	B8	LE1	3.605	3.931	15.869	17.4	31.7	-	✗



Check of bolts for extreme load effect

Status	Item	Loads	Ft [kip]	V [kip]	Bearing ϕRn [kip]	Utt [%]	Uts [%]	Utts [%]	Detailing
✓	B1	LE1	0.880	3.925	15.869	4.3	31.6	-	✗

Interaction of tension and shear check (AISC 360-16: J3-2)

The required stress, in either shear or tension, is less than or equal to 30% of the corresponding avai

combined stresses need not to be investigated.

Detailing check (AISC 360-16: J2-1b)

Error No1: Bolt B1 is too close to bolt B2. Spacing between bolts must be greater than 1"11/16 in.

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Detailing checks (bolts)

3. Minimum Spacing

The distance between centers of standard, oversized or slotted holes shall not be less than $2^2/_3$ times the nominal diameter, d, of the fastener. However, the clear distance between bolt holes or slots shall not be less than d.

User Note: A distance between centers of standard, oversize or slotted holes of $3d$ is preferred.

TABLE J3.4
Minimum Edge Distance[a] from Center of Standard Hole[b] to Edge of Connected Part, in.

Bolt Diameter, in.	Minimum Edge Distance
1/2	3/4
5/8	7/8
3/4	1
7/8	1 1/8
1	1 1/4
1 1/8	1 1/2
1 1/4	1 5/8
Over 1 1/4	$1^1/_4d$

[a] If necessary, lesser edge distances are permitted provided the applicable provisions from Sections J3.10 and J4 are satisfied, but edge distances less than one bolt diameter are not permitted without approval from the engineer of record.
[b] For oversized or slotted holes, see Table J3.5.

Detailing checks welds

Analysis | Plates | Bolts | Welds

	Status	Item	Edge	Xu	Th [in]	Ls [in]	L [in]	Lc [in]	Loads	Fn [kip]	ϕRn [kip]	Ut [%]	Detailing
+	✓	C-bfl 1	FP1	E70xx	◢ 1/8 ◣	◢ 3/16 ◣	8"15/16	9/16	LE1	2.574	3.428	75.1	✓
+	✓			E70xx	◢ 1/8 ◣	◢ 3/16 ◣	8"15/16	9/16	LE1	1.203	3.247	37.0	✓
−	✓	GUSS1	D1-w 1	E70xx	◢ 1/8 ◣	◢ 3/16 ◣	10"11/16	3/8	LE1	0.370	1.609	23.0	✗

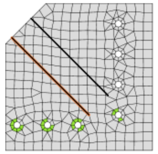
- $\theta = 27.3°$ – angle of loading measured from the weld longitudinal axis

$A_{we} = 0.0442$ in^2 – effective area of weld critical element

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

Detailing check (AISC 360-16: J2.2b, Table J2.4)

Error No1: Weld is too small. Weld's size must be greater than 3/16 in.



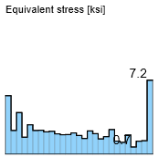


TABLE J2.4
Minimum Size of Fillet Welds

Material Thickness of Thinner Part Joined, in. (mm)	Minimum Size of Fillet Weld,[a] in. (mm)
To 1/4 (6) inclusive	1/8 (3)
Over 1/4 (6) to 1/2 (13)	3/16 (5)
Over 1/2 (13) to 3/4 (19)	1/4 (6)
Over 3/4 (19)	5/16 (8)

[a] Leg dimension of fillet welds. Single pass welds must be used.
Note: See Section J2.2b for maximum size of fillet welds.

Summary

Welds

- Elastoplastic Shell element
- Plastic redistribution
- Fillet, CJP
- Minimum weld thickness checks

Bolts

- Non-linear springs
- Slip critical connections
- Fillers are auto detected
- Slotted holes
- Detailing checks

Q&A