Verification example – Bolts in slip-critical connection

Type of connection: Bolts in slip-critical connection

Unit system: Metric

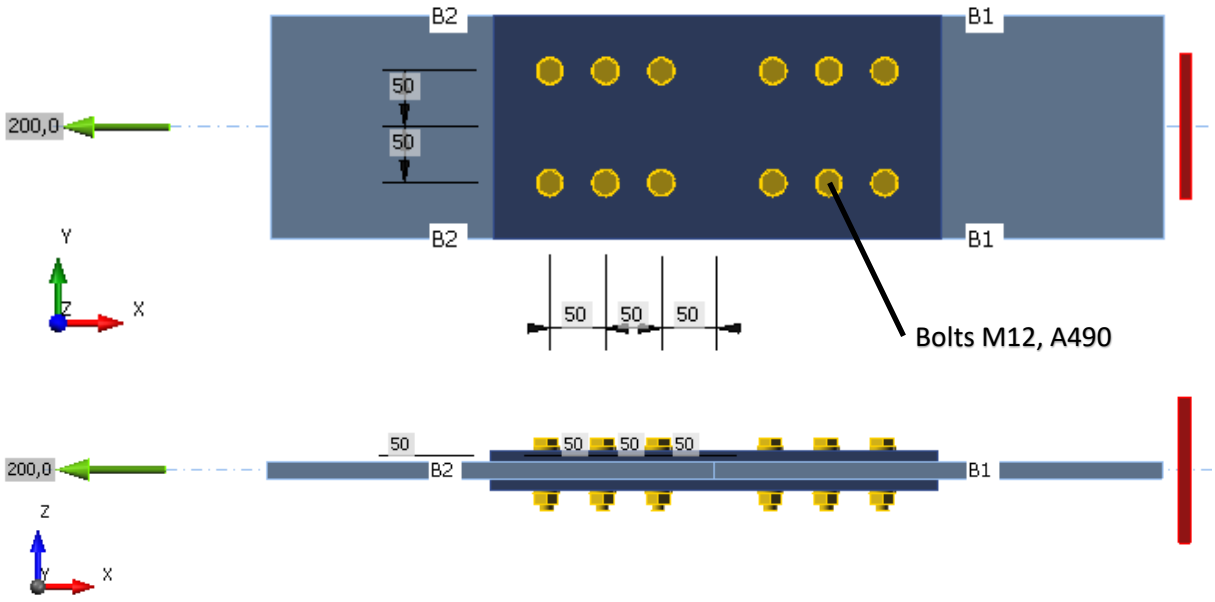
Designed acc. to: CSA S14-16

Investigated: Bolts, base material,

Plate Materials: Steel grade 350W,

Bolts: 1/2, grade A490

Geometry:



Applied forces:

N = 223 kN

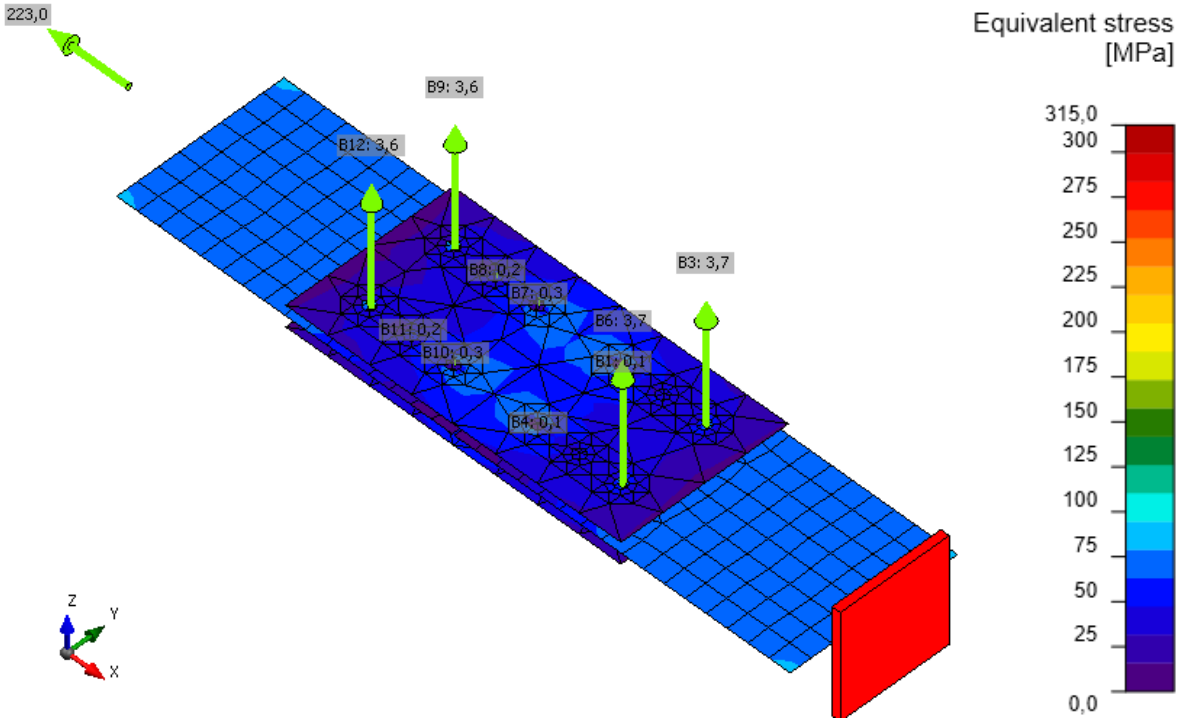
V = 0 kN

M = 0 kNm

Procedure:

The splice slip-critical connection is assessed. Bolts with diameter ½ in., steel grade A490 are used. In IDEA, both preloaded bolts (shear force transfer by friction) and regular bolts (shear force transfer by bearing), in case the slip occurs, should be checked as suggested by CSA S14-16 – Cl. 13.12.2. Note that slip resistance is often compared to specified loads and then the resistance of regular bolts to factored loads. It is assumed threads are not intercepted by shear plane.

IDEA StatiCa Connection



Check of preloaded bolts for extreme load effect

		Item	Grade	Loads	Tf [kN]	Vf [kN]	Tr [kN]	Vs [kN]	Utt [%]	Uts [%]	Utts [%]	Status
>	⊞	B1	1/2 A490	LE1	0,1	19,0/19,0	78,6	19,2	0,1	99,3	99,4	✓
	⊞	B2	1/2 A490	LE1	0,0	19,0/19,0	78,6	19,2	0,0	99,4	99,4	✓
	⊞	B3	1/2 A490	LE1	3,7	17,7/17,7	78,6	19,2	4,7	92,4	99,7	✓
	⊞	B4	1/2 A490	LE1	0,1	19,0/19,0	78,6	19,2	0,1	99,3	99,4	✓
	⊞	B5	1/2 A490	LE1	0,0	19,0/19,0	78,6	19,2	0,0	99,4	99,4	✓
	⊞	B6	1/2 A490	LE1	3,7	17,7/17,7	78,6	19,2	4,7	92,4	99,7	✓
	⊞	B7	1/2 A490	LE1	0,3	19,0/19,0	78,6	19,2	0,4	99,0	99,7	✓
	⊞	B8	1/2 A490	LE1	0,2	19,0/19,0	78,6	19,2	0,2	99,3	99,6	✓
	⊞	B9	1/2 A490	LE1	3,6	17,8/17,8	78,6	19,2	4,6	92,7	99,9	✓
	⊞	B10	1/2 A490	LE1	0,3	19,0/19,0	78,6	19,2	0,4	99,0	99,7	✓
	⊞	B11	1/2 A490	LE1	0,2	19,0/19,0	78,6	19,2	0,2	99,3	99,6	✓
	⊞	B12	1/2 A490	LE1	3,6	17,8/17,8	78,6	19,2	4,6	92,7	99,9	✓

6 bolts can transfer maximum normal force 223 kN by friction.

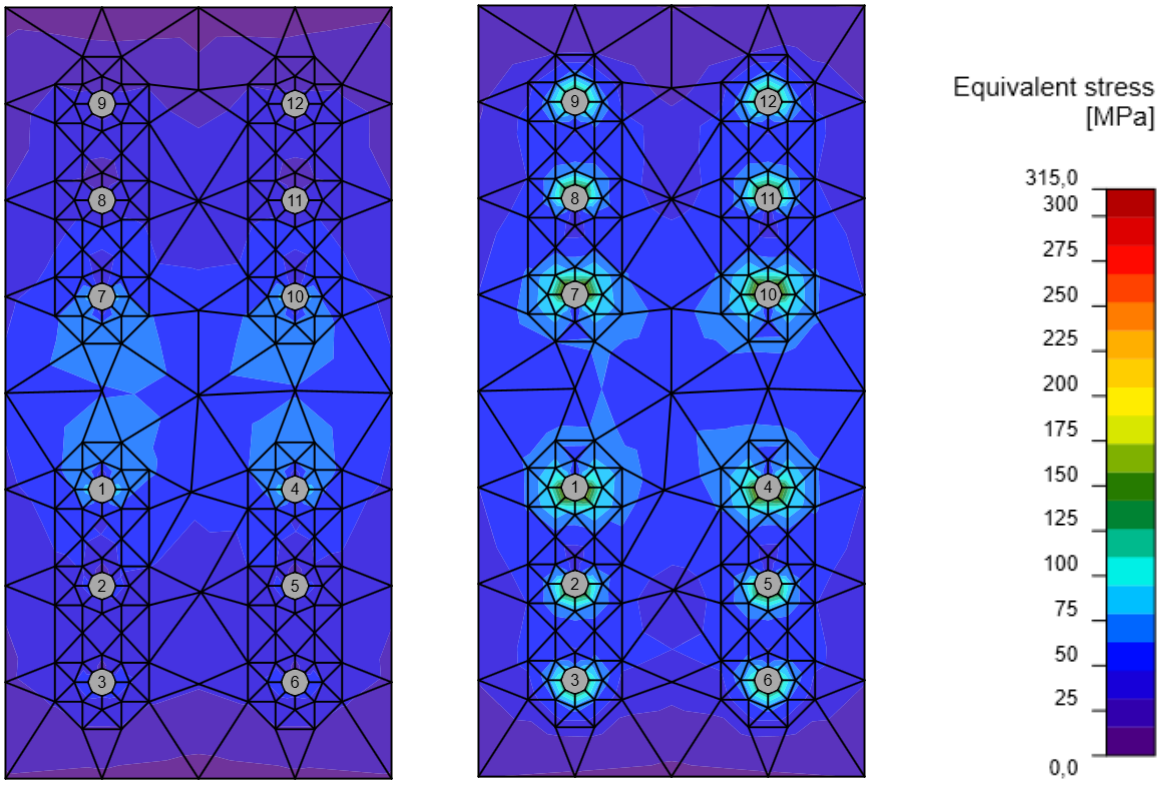
Check of bolts for extreme load effect

	Item	Loads	Tf [kN]	Vf [kN]	Utt [%]	Uts [%]	Utts [%]	Status
>	B1	LE1	1,4	18,6/18,6	1,8	42,3	17,9	✓
	B2	LE1	0,9	18,5/18,5	1,2	42,0	17,7	✓
	B3	LE1	4,4	18,6/18,6	5,5	42,4	18,3	✓
	B4	LE1	1,4	18,6/18,6	1,7	42,3	17,9	✓
	B5	LE1	0,9	18,5/18,5	1,2	42,0	17,7	✓
	B6	LE1	4,4	18,6/18,6	5,5	42,4	18,3	✓
	B7	LE1	1,4	18,6/18,6	1,8	42,3	17,9	✓
	B8	LE1	0,9	18,5/18,5	1,2	42,0	17,7	✓
	B9	LE1	4,3	18,6/18,6	5,5	42,4	18,3	✓
	B10	LE1	1,4	18,6/18,6	1,8	42,3	17,9	✓
	B11	LE1	0,9	18,5/18,5	1,2	42,0	17,7	✓
	B12	LE1	4,3	18,7/18,7	5,5	42,4	18,3	✓

Design data

	Item	Tr [kN]	Vr [kN]	Br [kN]
>	1/2 A490 - 1	78,6	44,0	205,7

Below is the comparison of shear force transfer – friction (on the left) and bearing (on the right).



The slip check is by far decisive.

Manual assessment

IDEA StatiCa Connection CISC Verification Example

Bolts in slip critical Connection

Material of steel: $F_y := 350\ \text{MPa}$
$F_u := 450\ \text{MPa}$

Material of bolts: $F_{ub} := 1040\ \text{MPa}$

Bolt diameter: $d := 12.7\ \text{mm}$

Cross-sectional area of a bolt based on its nominal diameter: $A_b := \pi \cdot \frac{d^2}{4}$

$A_b = 127\ \text{mm}^2$

Resistance factor for structural steel: $\phi := 0.9$

Resistance factor for bolts: $\phi_b := 0.8$

Resistance factor for tear-out: $\phi_u := 0.75$

Resistance factor for bearing of bolts on steel: $\phi_{br} := 0.8$

Geometrical parameters: $e := 50\ \text{mm}$
$t := 15\ \text{mm}$

Friction coefficient: $k_s := 0.3$

Coefficient: $c_s := 0.92$

Tensile strength of a bolt: $T_r := 0.75 \cdot \phi_b \cdot A_b \cdot F_{ub} = 79\ \text{kN}$

Number of shear planes: $m := 2$

Slip resistance of a bolt: $V_s := 0.53 \cdot c_s \cdot k_s \cdot m \cdot A_b \cdot F_{ub} = 38.5\ \text{kN}$

Shear strength of a bolt: $V_r := 0.6 \cdot \phi_b \cdot m \cdot A_b \cdot F_{ub} = 126.5\ \text{kN}$

Design tensile force: $T_f := 0\ \text{kN}$

Design shear force: $V_f := 34.4\ \text{kN}$

Combined tension and shear: $\left(\frac{T_f}{T_r}\right)^2 + \left(\frac{V_f}{V_r}\right)^2 = 7\%$

Combined tension and shear: $\frac{V_f}{V_s} + 1.9 \cdot \frac{T_f}{A_b \cdot F_{ub}} = 89\%$

Bearing strength in a regular bolt hole: $B_r := 3 \cdot \phi_{br} \cdot t \cdot d \cdot F_u = 205.7\ \text{kN}$

Gross area in shear: $A_{gv} := 2 \cdot t \cdot e = 1500\ \text{mm}^2$

Hole tear-out: $T_r := \phi_u \cdot 0.6 \cdot A_{gv} \cdot \frac{(F_y + F_u)}{2} = 270\ \text{kN}$

Tension and shear block: $U_t := 1$

Net area in tension: $A_n := t \cdot (200 - 2 \cdot 14.7)\ \text{mm} = 2559\ \text{mm}^2$

For 6 bolts: $T_r := \phi_u \cdot A_n \cdot F_u = 864\ \text{kN}$

Net area in tension: $A_n := t \cdot (100 - 14.7)\ \text{mm} = 1279.5\ \text{mm}^2$

Gross area in shear: $A_{gv} := t \cdot (150 \cdot 2)\ \text{mm} = 4500\ \text{mm}^2$

For 6 bolts: $T_r := \phi_u \cdot \left(U_t \cdot A_n \cdot F_u + 0.6 \cdot A_{gv} \cdot \frac{F_y + F_u}{2} \right) = 1242\ \text{kN}$

Gross area in shear: $A_{gv} := t \cdot (150 \cdot 4)\ \text{mm} = 9000\ \text{mm}^2$

For 6 bolts: $T_r := \phi_u \cdot 0.6 \cdot A_{gv} \cdot \frac{F_y + F_u}{2} = 1620\ \text{kN}$

Gross area in tension: $A_g := t \cdot 200\ \text{mm} = 3000\ \text{mm}^2$

Gross section yielding: $T_r := \phi \cdot A_g \cdot F_y = 945\ \text{kN}$

Number of bolts: $n := 6$

Shear resistance of a connection: $V_s := n \cdot V_s = 231\ \text{kN}$

Note that the factored loads to check the bolts in bearing should be used and specified loads to check the slip resistance. For simplification and easier comparison, the loads were kept the same in this verification study.

Comparison:

The results of both IDEA StatiCa Connection design and manual computation according to CSA 16-14 gives similar values: the slip resistance is 231 kN in manual assessment and 223 kN in IDEA. IDEA is slightly conservative (3% difference) due to the occurrence of small tensile forces caused by plate deformation. This deformation is neglected in manual computation. The slip resistance was decisive failure mode in both types of assessment.