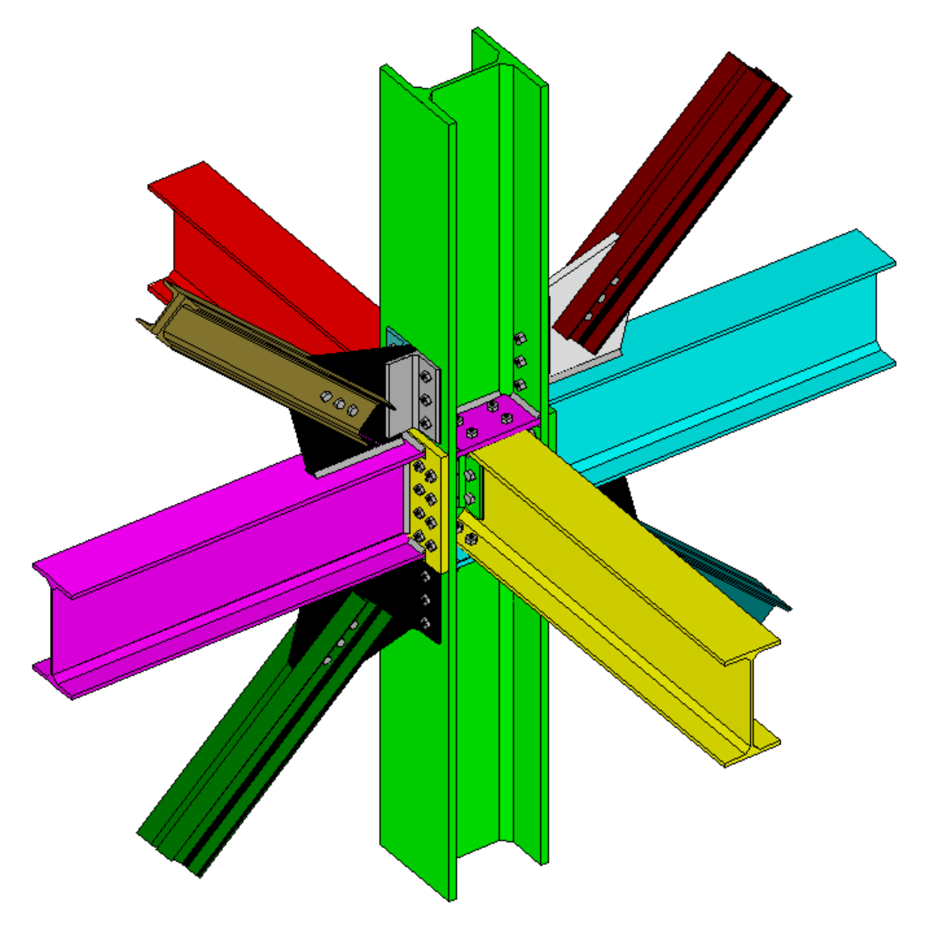
C.S.E.

Connection Study Environment

WORKED EXAMPLES, VALIDATION



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CSE version 6.92
Rev. 06 Date January, 21, 2016

CASTALIA

CONTENTS

A. INTRODUCTION

A.1 SCOPE OF THE DOCUMENT AND VALIDATION CRITERIA

This document contains the cross-check between CSE's results and separate computations (by hand, using MS Excel or other structural analysis software). The purpose is to get information about CSE's reliability in steel joints computation.

The document, albeit quite voluminous, in at an intermediate stage. More validation work is in the pipeline.

CSE also uses external solvers CSE, CURAN and WBUCKLING as a tool to get linear static analyses results, nonlinear static analyses results, and buckling analyses results. These programs have been tested independently and their validation schedules can be found at the two websites www.castaliaweb.com (Italian) and www.steeelchecks.com (English). FEM computation of components (end-plates, gusset-plates, and so on) and of set of components (ideally the whole node) is a very important checking tool in CSE.

Several models have been set, in order to test all the different checks done by CSE. Cross-check computations are reported in detail and all the computational stages are given as well, so that is possible to redo every check. Where needed, proper reference to the theory is done, to clear some aspects. CSE's final and intermediate results are reported in a clear and detailed way, as well the results of cross-check software.

Quite "typical" problems are studied, so that hand computation can be done easily, using theoretical formulae and models. In CSE, a simple or typical joint is just a general joint: what we call "bolted cover plate splice joint", for CSE is just an aggregate of members, plates and bolts freely placed in the space and connected together. Its computation is done according to components properties and position; for this reason, even if we use "typical" models as benchmarks, we are cross-checking generic joints for CSE.

The results reported in this document are useful to appreciate CSE's accuracy, so that we believe that, due to these checks and the many more unreferenced checks we have done, the program can be used also in complex problems, difficult to be computed by hand. CSE, indeed, has been used in such contexts. Obviously, a critical analysis of the results is needed, but this holds true for any other computation software. Moreover, the problems related to steel connection checks are particularly complex, so a special attention is expected when dealing with them.

Since the validation document has been developed together with CSE's development, the structure of the document reflects the growth of the program. Parts B and C of this document refer to different stages of CSE's development. When a new tool is added to CSE, oldest models are re-run to test if new results are equal to the previous ones.

The scope of this document is not to define realistic or properly designed joints: the purpose is to validate CSE's computations. For this reason, sometimes the examples are set to get a particular computation condition, maybe not usual or common, in order to check program reliability and consistency. For the same reason, for example, sometimes bolts could have a larger diameter or their number could be greater than that suggested by proper design criteria, in order to check different and unpredictable conditions.

A.2 STRUCTURE OF THE VALIDATION DOCUMENT

As previously said, the document is divided into two different parts, which follow CSE's development process. Before doing any other check, the first step is to compute the forces carried by each bolt and each weld of the joint. After that, it will be possible to check the *joiners* (bolts and welds) according to those forces, and then, according to the action and reaction principle, it will be possible to check all the other components (members and cleats) connected to the joiners.

A.2.1 Forces distribution in joiners and basic checks (part B)

Part B checks forces distribution in joiners (bolts and welds). CSE's results are compared with hand computations or other programs' results. In addition, joiners resistance check is tested in this part, as well as bolt bearing on components drilled by bolts.

Joiners resistance check is a basic check, always done by CSE. Other components checks (including bolt bearing) can be enabled or disabled by the user according to the problem at hand; since in the earlier versions of the program it was not possible to disable bolt bearing checks, this check was included in part B.

When part B was prepared, CSE had not all the latest features and checks yet; for this reason, only some features are validated here in part B. These features are:

- distribution of the forces in each bolt and in each weld
- bolts resistance check
- welds resistance check
- bolt bearing check for components drilled by bolts

Some earliest models use an imported FEM model to get load combinations, since it was the only way to get geometry and internal forces in the beginning. Now models can be created directly in CSE and the internal forces can be defined also importing tables, typing values or using factored elastic or plastic limits of the members.

A.2.2 Components checks and flexibility index (part C)

Part C includes the validation of all the other checks which can be enabled or disabled by the user (these checks have been added to CSE after basic checks). In addition, the behaviour of the same joint is tested changing bolt layouts *flexibility index* (this parameter will be explained later; it is a value to modify bolt layouts stiffness).

The starting stage for all the checks, that is the computation of forces distribution, has already been tested in part B. Here it will not be deepened; we will focusing on the following features:

- anchor bolts pull-out checks
- automatic FEM models creation and analysis for components
- shear check of slip-resistant bolt layouts
- members net sections checks
- simplified resistance checks for cleats (with equivalent beam models)
- bearing surface check
- user's checks
- bolt layout stiffness according to flexibility index modification

A.3 PROGRAMS USED FOR CROSS-CHECK

The following programs have been used to validate CSE's results.

Saldature (Weldings)

Author: Prof. Ing. G. Ballio (steel structures professor at Politecnico of Milan, formerly Dean of the same University). It is an application of the E.Str.A.D.A. package (Education to structural assisted design and analysis) produced by Castalia s.r.l. and Politecnico of Milano, distributed by Castalia s.r.l. This application is used in alternative to hand computations in CSE's validation for stress in welds computation. The application has been developed independently from Castalia and using completely different software tools.

Lisa© Ver. 3.5

Author: Prof. Ing. M. A. Pisani, professor of Structural Engineering at Politecnico of Milan, distributed by Castalia s.r.l. until 2009. This program is used to cross-check CSE's results on bearing surface. The application has been developed independently from Castalia and using completely different software tools.

Both programs are in Italian.

A.4 NOTES

1) The document could be extended in the future, following the development of the program. Some dialog boxes shown here could be different in later versions of CSE; they could have additional options, buttons, etc. Checks are periodically redone to assess that results are the same under the same hypotheses.

2) Output listing abstracts in some cases have a small font size to keep the original format for the columns.

3) This document is periodically updated, but it could happen that current results are different from those shown here. For example, before CSE's version 4.15, automatic FEM models were created using *thin* plate elements. From that version on, models use *thick* plate elements: obviously results change, and the validation document was updated few weeks later than new version's release.

B. FORCES DISTRIBUTION IN JOINERS AND BASIC CHECKS

B.1 PRELIMINARY CHECKS: JOINERS, COMPUTATION PROPERTIES

B.1.1 Introduction

This chapter validates how CSE computes joiners properties (bolt and weld layouts). All the properties are printed in the output listing and can be used by the users for additional checks. Models used here are the same used later to validate other computation aspects.

B.1.2 Bolt layouts

We will consider a cover plate splice joint to see how CSE computes bolt layout properties. The same model (*Validation_SP_1_1.CSE*) will be used later to validate forces distribution in single bolts, for bolts resistance check and for bolt bearing check.

The following figure shows a 3D view of the model. There are six different bolt layouts: for both members, there are a bolt layout on the web and two on the flanges.

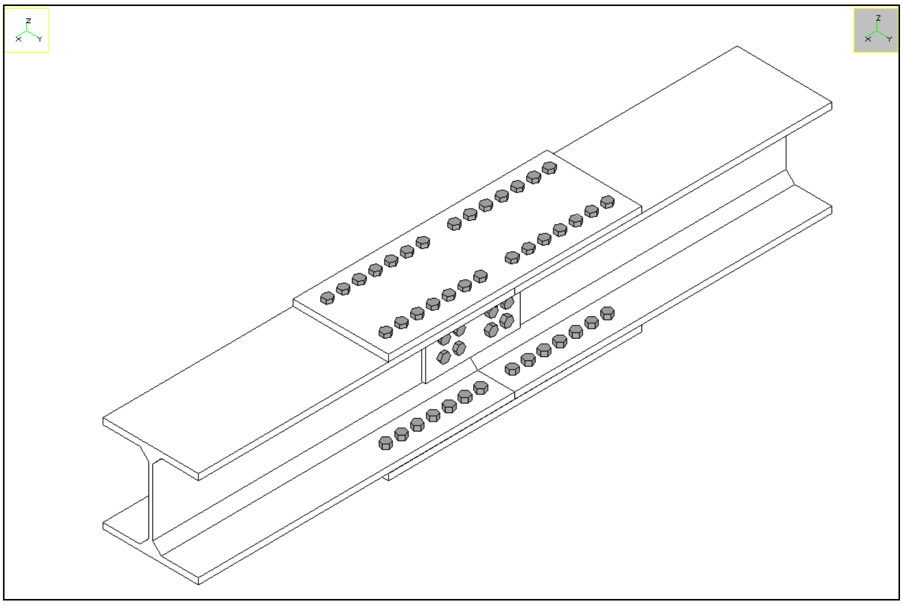


Figure B-1 3D view of the splice joint

Let's see how CSE computes the polar inertia moment of a bolt layout: consider, for example, bolt layout B3, the one highlighted in blue in the next figure.

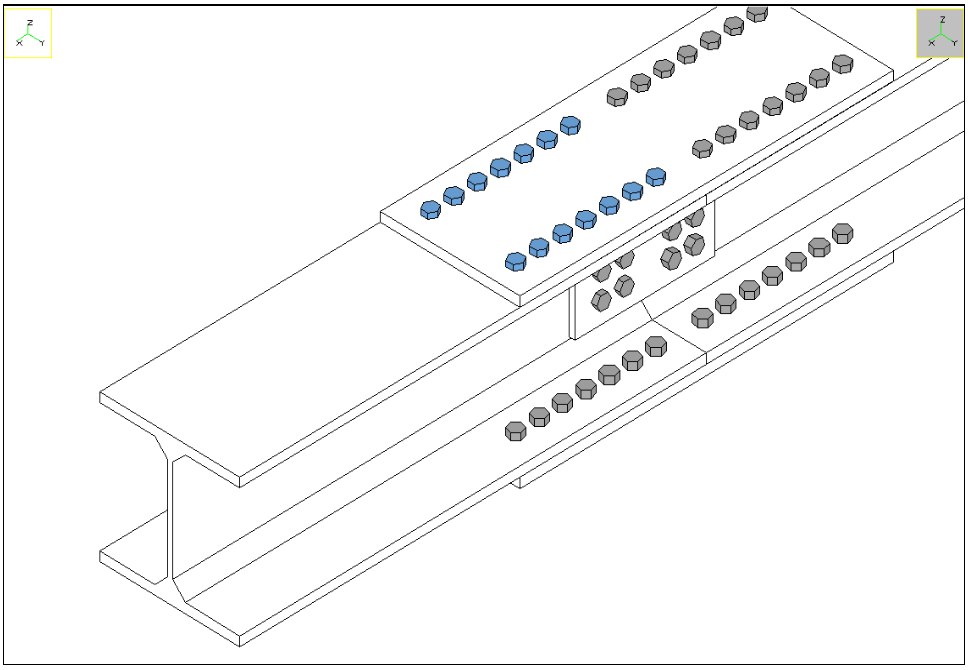


Figure B-2 Bolt layout B3 (in blue)

Polar inertia moment (J_p) computed by CSE is reported in following output listing abstract. All the bolts of a layout have the same diameter; J_p is a polar inertia moment per bolt area [length^2].

```
------
Units
------
Length    Force         Temperature   Time
 mm         N                °C          s

[…]

------------------------------------
Boltlayouts computational properties
------------------------------------

Id      xc            yc            AcT          Jx           Jy           Jxy          Ju           Jv          Pangle          Jp

B3   0.000e+000    0.000e+000    3.563e+003   1.400e+005   1.172e+005   0.000e+000   1.400e+005   1.172e+005   0.000e+000   2.572e+005
```

The value computed by CSE is J_p = 2.572*10^{5}mm^2; now we are going to hand compute it in order to to validate CSE' value. Next figure shows bolts distances (distances between rows and columns, distance from each bolt to layout centre).

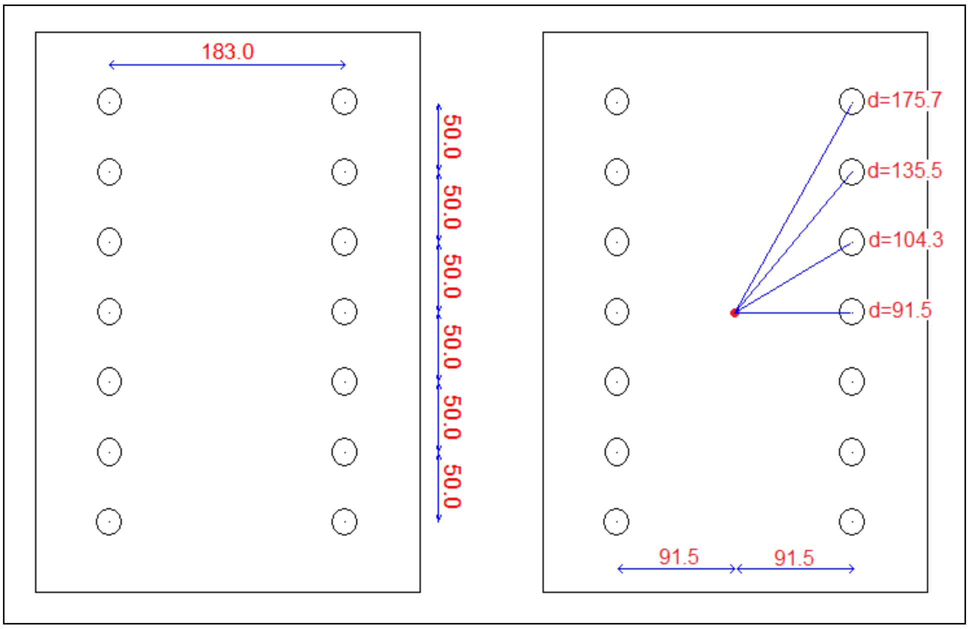


Figure B-3 Distances between bolts and from centre

We have:

- 2 bolts at 91.5mm from the centre
- 4 bolts at $\sqrt{91.5^2+50^2}=104.3mm$ from the centre
- 4 bolts at $\sqrt{91.5^2+100^2}=135.5mm$ from the centre
- 4 bolts at $\sqrt{91.5^2+150^2}=175.7mm$ from the centre

Polar inertia moment per bolt area is

$$J_p=\Sigma\left(d_i^2\right)=2\cdot 91.5^2+4\cdot 104.3^2+4\cdot 135.5^2+4\cdot 175.7^2=2.572\cdot 10^5\,mm^2$$

that is the same value computed by CSE.

Now we are going to compute **bolts moduli**. We have a total modulus and its two components along bolt layout principal axes:

$$W_{T,i}=\frac{J_p}{d_i}$$

$$W_{Tu,i}=\frac{J_p}{v_i}$$

$$W_{Tv,i} = \frac{J_p}{u_i}$$

Consider, for example, the bolt highlighted in next figure, and compute its moduli.

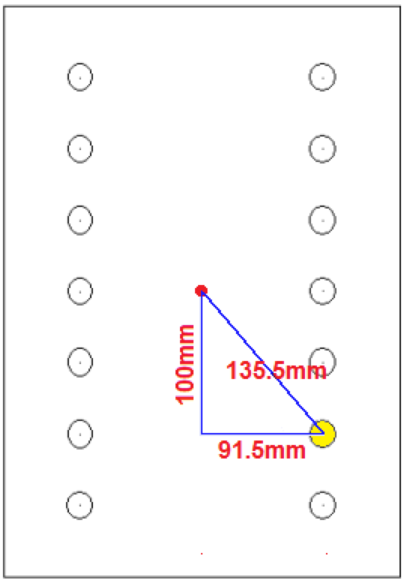


Figure B-4

$$W_{T,i} = \frac{J_p}{d_i} = \frac{2.572 \cdot 10^5 mm^2}{135.5mm} = 1.898 \cdot 10^3 mm$$

$$W_{Tu,i} = \frac{J_p}{v_i} = \frac{2.572 \cdot 10^5 mm^2}{-100mm} = -2.572 \cdot 10^3 mm$$

$$W_{Tv,i} = \frac{J_p}{u_i} = \frac{2.572 \cdot 10^5 mm^2}{-91.5mm} = -2.811 \cdot 10^3 mm$$

The same values are given by CSE:

```
-----------------------------------------------
Boltlayouts single bolts position and moduli
-----------------------------------------------

   Id  Bolt      x           y          AcT        WTui        WTvi        WTi         Wui         Wvi

   B1  11   -9.150e+001  1.000e+002  3.563e+003  -2.572e+003  -2.811e+003  1.898e+003  1.400e+003  1.281e+003
```

NOTE WELL: in the output listing, distances are given in *x*-*y* layout reference axes; in a general case, they do not coincide with *u*-*v* principal axes.

Considering layout **principal axes u-v**, let's compute layout **inertia moments per area**. Model used is *Validation_BC_3.CS*E, used also later to validate forces in joiners, joiners and bolt bearing. Next figure shows the joint; considered bolt layout is in red; distances between bolts and layout centre are given.

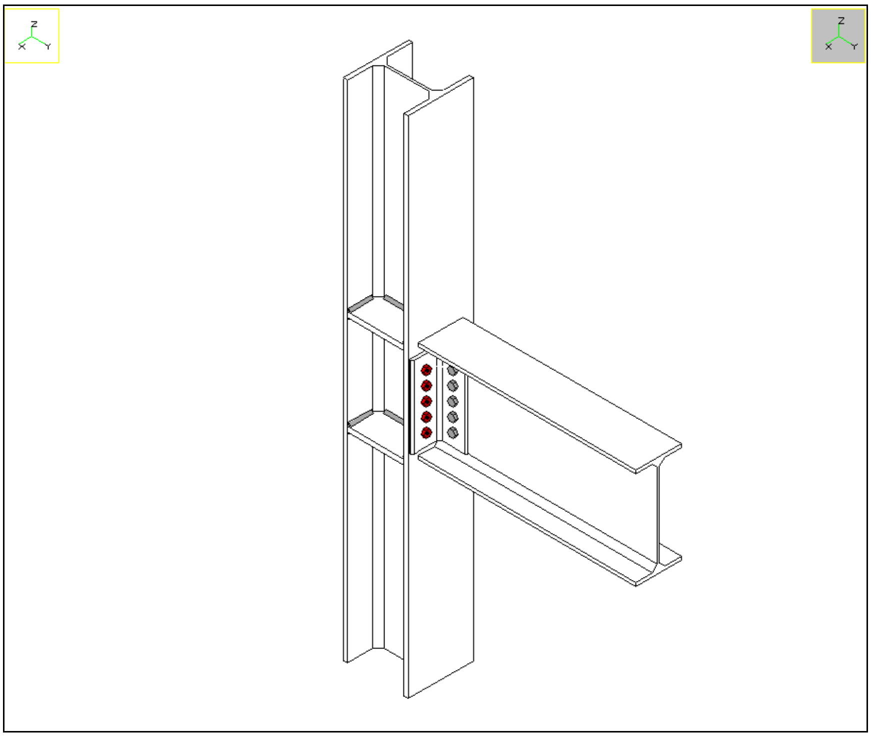


Figure B-5 3D view of the joint

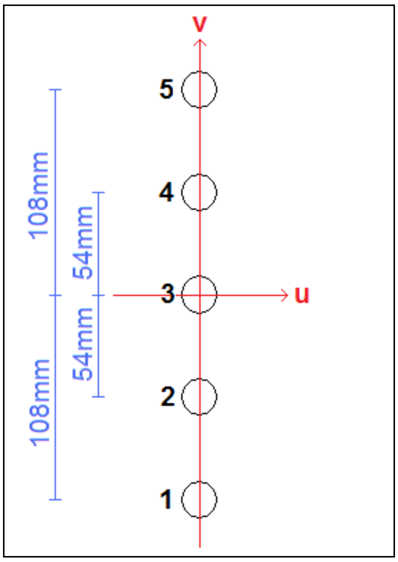


Figure B-6 Distances from the centre

J_u is the inertia moment per area about axis *u*: it is the sum of the square of the distances from bolts to layout centre, along axis *v*.

J_v is the inertia moment per area about axis *v*: it is the sum of the square of the distances from bolts to layout centre, along axis *u*.

We have:

$$J_u = \Sigma\left(dv_i^2\right) = 1\cdot(0mm)^2 + 2\cdot(54mm)^2 + 2\cdot(108mm)^2 = 29160mm^2$$
$$J_v = \Sigma\left(du_i^2\right) = 5\cdot(0mm)^2 = 0mm^2$$

The same values are computed by CSE:

```
------------------------------------
Boltlayouts computational properties
------------------------------------

Id      xc            yc            AcT           Jx            Jy            Jxy           Ju            Jv            Pangle         Jp

 B1  0.000e+000    0.000e+000    1.272e+003    2.916e+004    0.000e+000    0.000e+000    2.916e+004    0.000e+000   -0.000e+000    2.916e+004
```

NOTE WELL: when CSE computes the distribution of axial force in the bolts, it adds also the inertia moment of each single bolt, per area. This aspect is validated in B.5.3.

Let's compute **bolts moduli**:

$$W_{u,i} = \frac{J_u}{v_i}$$
$$W_{v,i} = \frac{J_v}{u_i}$$

Now we compute $W_{u,i}$ values for the bolts, which are numbered according to Figure B-6:

$$W_{u,1} = \frac{J_u}{v_1} = \frac{29160mm^2}{-108mm} = -270mm$$
$$W_{u,2} = \frac{J_u}{v_2} = \frac{29160mm^2}{-54mm} = -540mm$$
$$W_{u,3} = \frac{J_u}{v_3} = \frac{29160mm^2}{0mm} = \infty$$
$$W_{u,4} = \frac{J_u}{v_4} = \frac{29160mm^2}{54mm} = 540mm$$

$$W_{u,5} = \frac{J_u}{v_5} = \frac{29160mm^2}{108mm} = 270mm$$

CSE the same values (see following listing abstract, column W_{ui}). Note that when distance is null (for example for bolt 3, with v=0) $W_{u,i}$ would be infinite; in this case, for computational reasons, CSE uses the value $W_{u,i}=10^{12}$mm.

```
---------------------------------------------
Boltlayouts single bolts position and moduli
---------------------------------------------

   Id  Bolt       x            y            AcT         WTui         WTvi          WTi          Wui          Wvi

   B1   1   0.000e+000  -1.080e+002   1.272e+003   2.700e+002   1.000e+012   2.700e+002  -2.700e+002   1.000e+012
   B1   2   0.000e+000  -5.400e+001   1.272e+003   5.400e+002   1.000e+012   5.400e+002  -5.400e+002   1.000e+012
   B1   3   0.000e+000   0.000e+000   1.272e+003   1.000e+012   1.000e+012   1.000e+012   1.000e+012   1.000e+012
   B1   4   0.000e+000   5.400e+001   1.272e+003  -5.400e+002   1.000e+012   5.400e+002   5.400e+002   1.000e+012
   B1   5   0.000e+000   1.080e+002   1.272e+003  -2.700e+002   1.000e+012   2.700e+002   2.700e+002   1.000e+012
```

Since the distance in u direction is equal to 0 for all the bolts, W_{vi} column contains all $W_{u,i}=10^{12}$mm; it would be impossible to determine that value, otherwise:

$$W_{v,i} = \frac{J_v}{u_i} = \frac{0mm^2}{0mm} = NaN$$

Moduli are used in single bolts axial forces computation, starting from bending in the whole layout.

Now we are going to validate the computation of bolts design resistance for shear and tension. Consider model *Validation_CB_1.CSE*, used later in this document. Bolts are M24, class 8.8. According to formulae given in EN1993-1-8 Table 3.4 (see appendix), resistance to shear and for tension are:

$$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$$

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$$

with

α_v=0.6

f_{ub}=800N/mm^2

A=353mm^2

A_s=452mm^2

k_2=0.9

γ_{M2}=1.25

NOTE WELL: in the computation of $F_{v,Rd}$, gross area is used if threaded are does not involve check section, as in this case (see next figure). For tension, instead, net area A_s is always used. For class 8.8 bolts, α_v is always equal to 0.6.

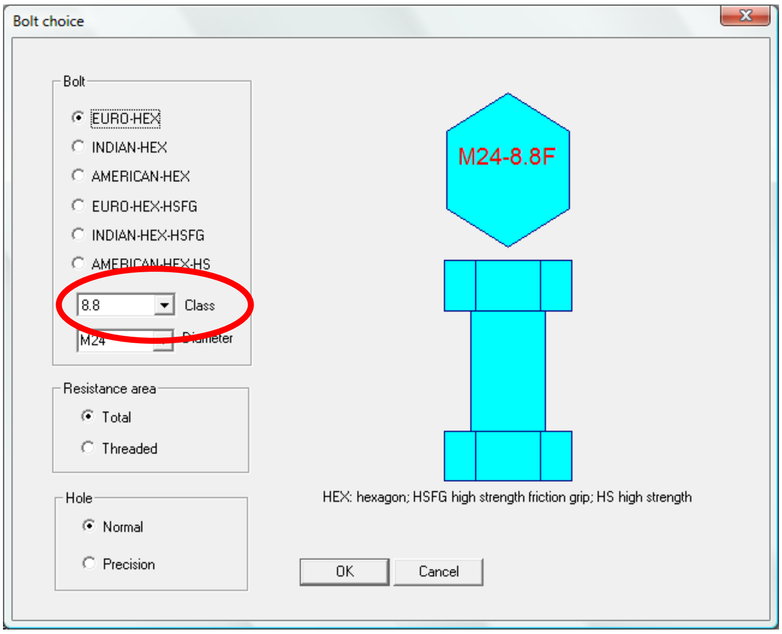


Figure B-7

According to the previous values, we have:

$$F_{v,Rd} = \frac{0.6 \cdot 800 N/mm^2 \cdot 452.4 mm^2}{1.25} = 1.737 \cdot 10^5 N$$

$$F_{t,Rd} = \frac{0.9 \cdot 800 N/mm^2 \cdot 353 mm^2}{1.25} = 2.033 \cdot 10^5 N$$

CSE computes the same values (V_{lim} is design resistance for shear, N_{lim} is design resistance for tension):

```
----------------------------
Boltlayouts bolt properties
----------------------------
```

Id	Class	Dia	Dia H	Sec	Full	Precision	Area	Ares	Vlim	Nlim	Nini
B1	8.8	24.0	26.0	1	yes	not	4.524e+002	3.530e+002	1.737e+005	2.033e+005	0.000e+000

B.1.3 Weld layouts

Here we are going to validate area and inertia moments computation for a fillet welds layout. Consider model *Validation_CC_1.CSE*: welds are applied to a HEB320 cross-section, with the following layout.

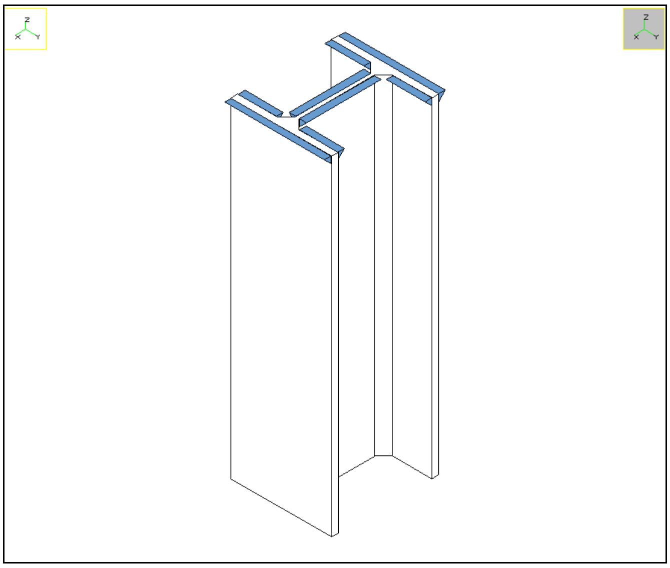


Figure B-8 Fillet welds in blue

Fillet welds have a thickness equal to 20mm; they have a rectangular triangle section, and their throat section is equal to $a = 20mm/\sqrt{2} = 14.1421mm$. Cross-section dimensions are given in next figure.

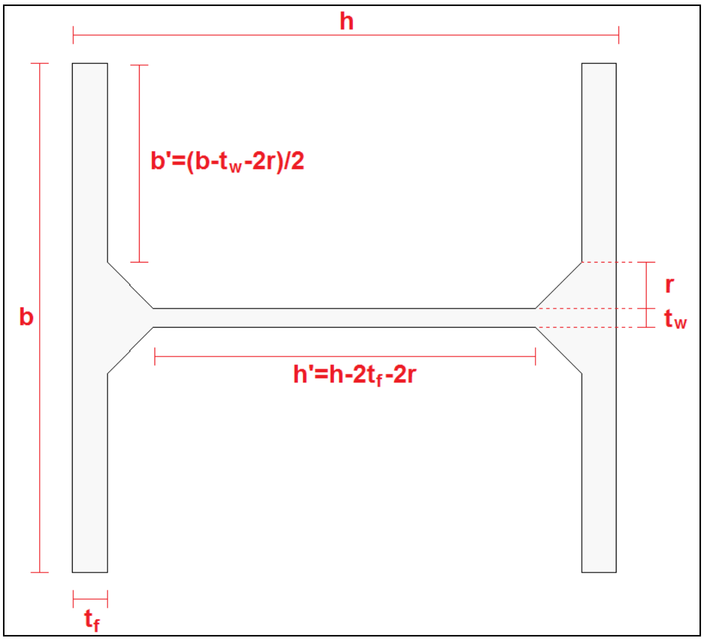


Figure B-9

The distances shown in previous figure are given in the following table.

HEB 320	
h	320mm
b	300mm
t_w	11.5mm
t_f	20.5mm
r	27mm
$h'=h-2t_f-2r$	225mm
$b'=(b-t_w-2r)/2$	117.25mm

Fillet welds end 1mm before cross-sections sides extremes. Their lengths are reported in next table. Fillet welds are named A, B and C according to Figure B-10.

Filled welds	Length (L_i)	
A	$L_A=b$-2mm	298mm
B	$L_B=b'$-2mm	115.25mm
C	$L_C=h'$-2mm	223mm

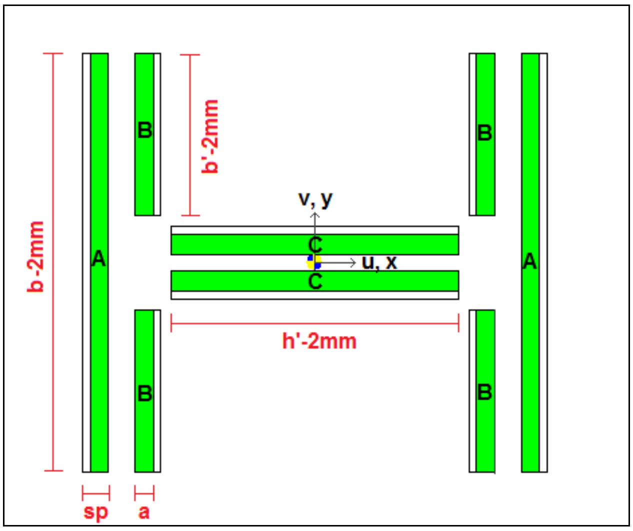


Figure B-10

In order to validate CSE's results, we use *Saldature* (Weldings) application by Prof. Ing. Giulio Ballio (see reference in A.3, page 11 of this document).

Figure B-12 shows *Saldature*'s interface, with data for welds definition (throat section, direction, length and position of each weld) and the results computed by the application for:

- Layout total area A (A_T in CSE), equal to the sum of single welds area; the area of a weld is equal to its throat section and its length)
- Inertia moment I_{Gxx} about principal axis x (J_u about axis u in CSE)
- Inertia moment I_{Gyy} about principal axis v (J_v about axis v in CSE)

Welds insertion points in *Saldature* are shown in Figure B-11; starting from thos points, welds direction is along $+x$ or $+y$, according to the side to which they are parallel. Next figure shows the coordinates of starting points (only negative values are reported for x direction, the layout is symmetric).

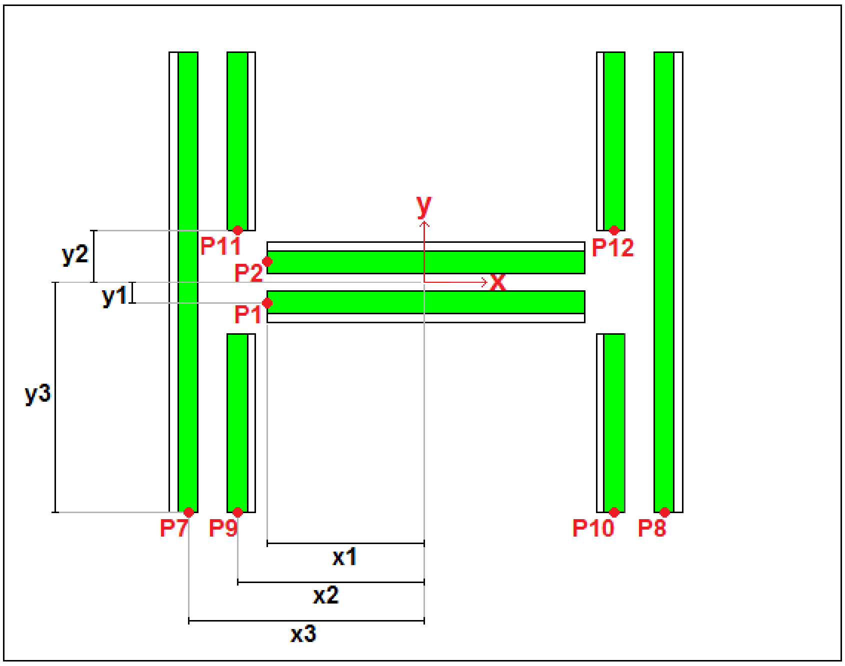
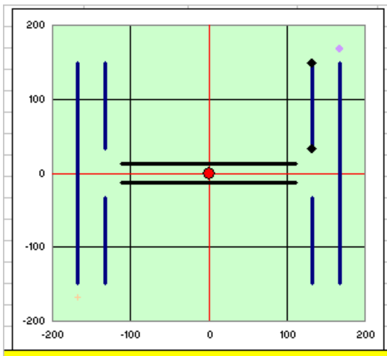
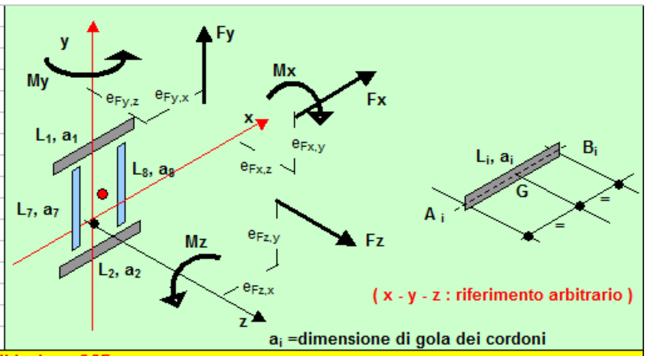


Figure B-11

Distances reported in Figure B-11		
x1	$-L_C/2$	-11.5mm
x2	$-h/2+t_f+a/2$	-132.43mm
x3	$-h/2-a/2$	-167.07mm
y1	$-t_w/2-a/2$	-12.821mm
y2	$t_w+r+1\text{mm}$	33.75mm
y3	$-L_A/2$	-149mm





Validazione CSE												
tutti i cordoni hanno eguale dimensione della gola pari a: mm					14,1421356	il dato sostituisce tale valore			riferite ad assi principali			
posizione cordoni	cordone w	a_i	L_i	$x_{A,i}$	$y_{A,i}$	$x_{G,i}$	$y_{G,i}$	A_i	$\xi_{A,i}$	$\xi_{B,i}$	$\eta_{A,i}$	$\eta_{B,i}$
		mm	mm	mm	mm	mm	mm	cm^2	mm	mm	mm	mm
cordoni paralleli ad asse x	1		223	-111,5	-12,821	0,0	-12,8	31,5	-111,5	111,5	-12,8	-12,8
	2		223	-111,5	12,821	0,0	12,8	31,5	-111,5	111,5	12,8	12,8
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		298	-167,07	-149	-167,1	0	42,1	-167	-167	-149	149
	8		298	167,07	-149	167,1	0,0	42,1	167	167	-149	149
	9		115,25	-132,43	-149	-132,4	-91,4	16,3	-132	-132	-149	-34
	10		115,25	132,43	-149	132,4	-91,4	16,3	132	132	-149	-34
	11		115,25	-132,43	33,75	-132,4	91,4	16,3	-132	-132	34	149
(blu)	12		115,25	132,43	33,75	132,4	91	16,3	132	132	34	149
caratteristiche della sezione		A	x_G	y_G	I_{Gxx}	I_{Gyy}	I_{Gxy}	α		$I_{G\xi\xi}$	$I_{G\eta\eta}$	
		cm^2	mm	mm	cm^4	cm^4	cm^4	radianti	gradi	cm^4	cm^4	
		212,6	0	0	12.506	37.574	0	0,0000	0	12.506	37.574	

Figure B-12 Layout area and inertia moments computed by *Saldature*

Results computed by *Saldature* are, given in mm^4 and rounded to the fourth significant digit:

$$A = 2.126 \cdot 10^4 mm^2$$
$$I_{Gxx} = 1.251 \cdot 10^8 mm^4$$
$$I_{Gyy} = 3.757 \cdot 10^8 mm^4$$

The same values are computed by CSE:

```
-------------------------------------
Weldlayouts computational properties
-------------------------------------

   Id       xc            yc            beta          AT            Ju           Jv            Jp

   W1   1.233e+001    4.559e+001   -7.070e-016   2.126e+004    1.251e+008   3.757e+008    5.008e+008
```

Polar inertia moment J_p is equal to the sum of J_u and J_v:

$$J_p = 1.251*10^8mm^4 + 3.757*10^8mm^4 = 5.008*10^8mm^4$$

NOTES

- x_c and y_c values printed in CSE's output listing are the coordinates of layout centre referred to insertion face clicked in the scene.
- From version 4.1 on, CSE includes also penetration welds.

B.2 HORIZONTAL SPLICE JOINTS

B.2.1 Bolted cover plate

B.2.1.1 Introduction

We have a bolted cover plate splice joint with HEB300 cross-section (model *Validation_SP_1_1.CSE*, Figure B-13). In Figure B-14 are reported the properties of the shape used.

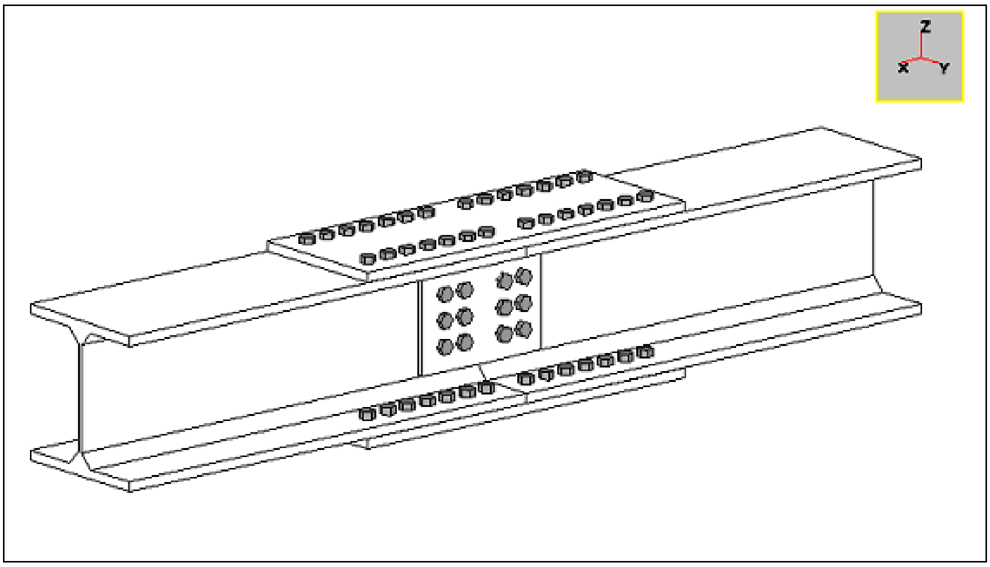


Figure B-13 3D view of the model

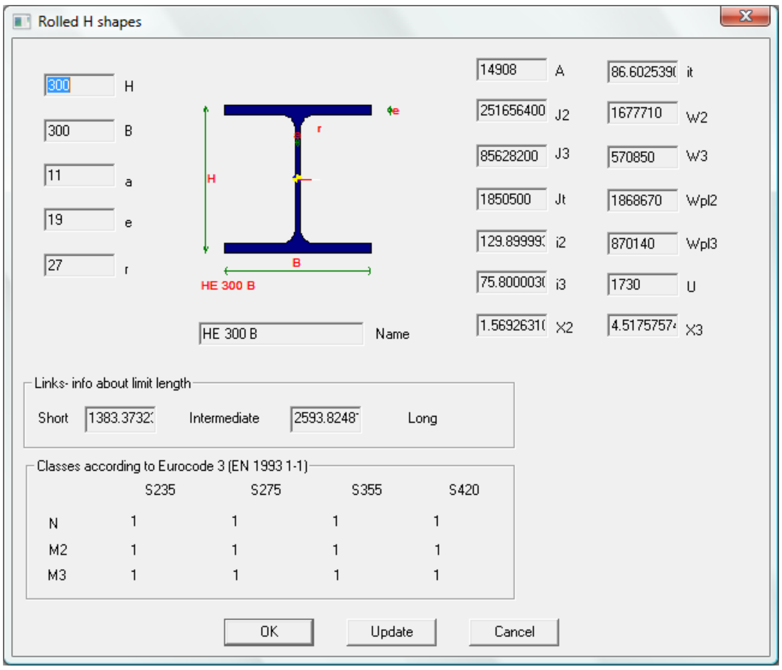


Figure B-14 Cross-section properties (units: mm, mm^2, etc.)

Members and plates material is S235; bolts are M18 class 10.9 (f_{yb}=900n/mm^2, f_{ub}=1000N/mm^2). Next figures show different views of the model and of bolt layouts schemes).

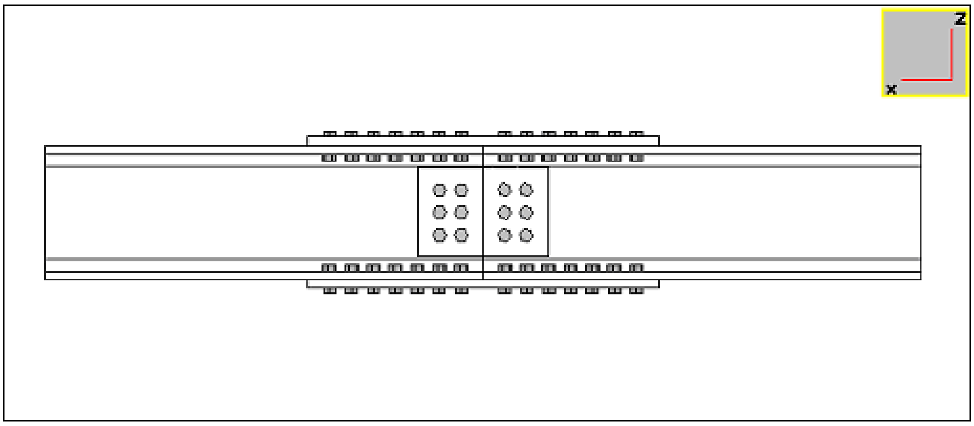


Figure B-15 Side view

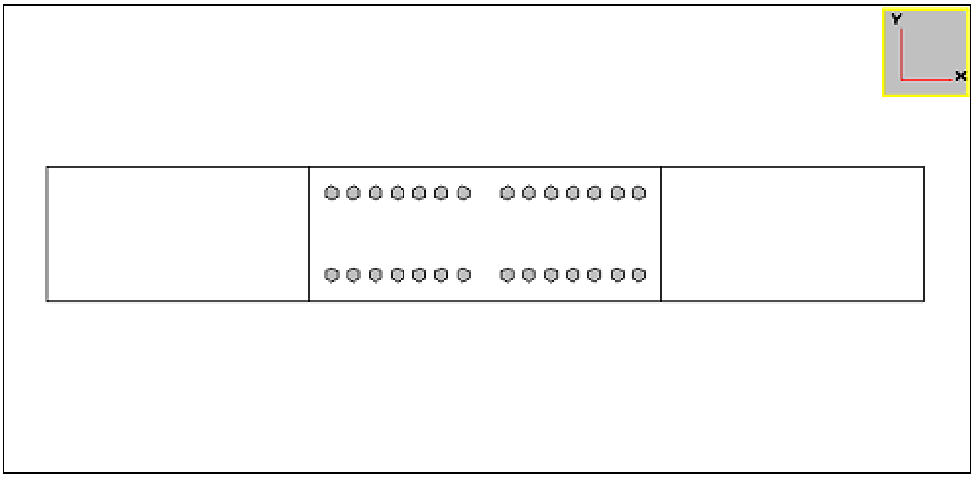


Figure B-16 Top view

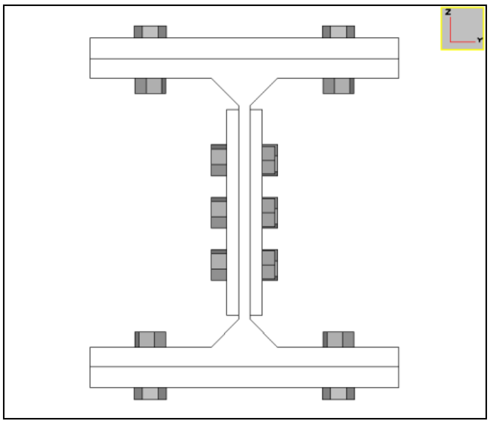


Figure B-17 Front view

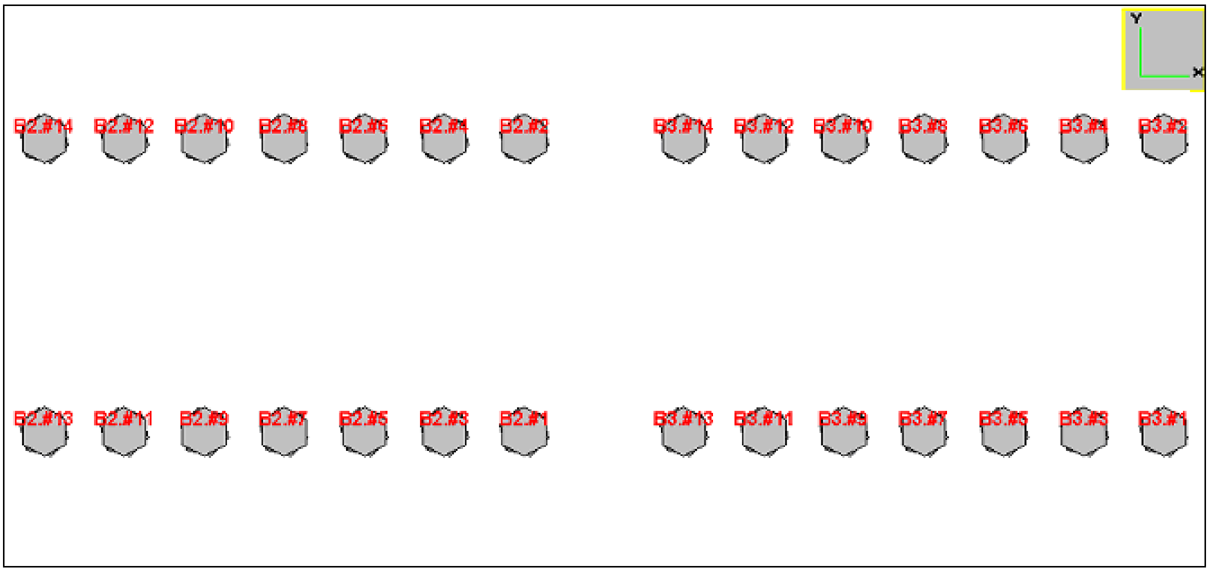


Figure B-18 Upper flange bolts numbering (distances: 183mm, 50mm)

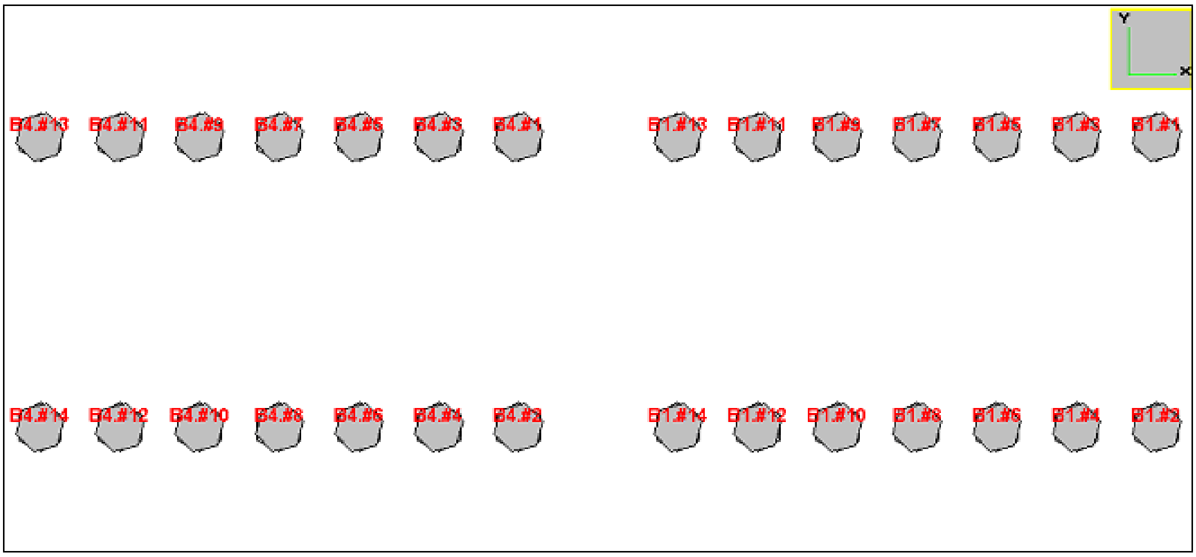


Figure B-19 Lower flange bolts numbering (distances: 183mm, 50mm)

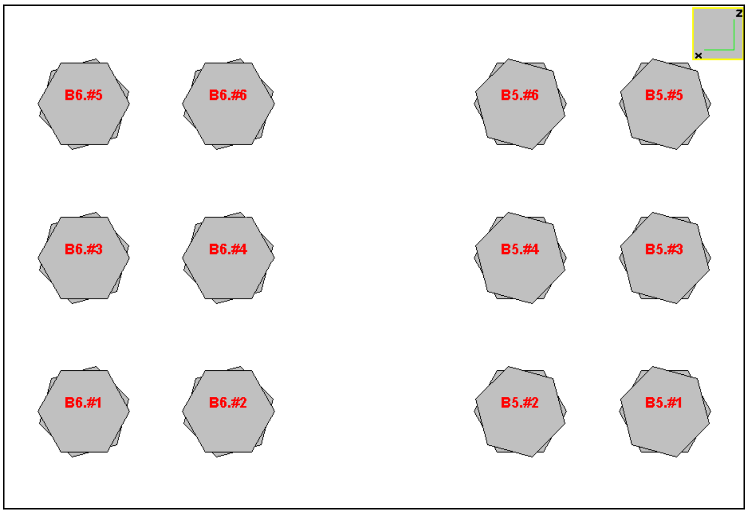


Figure B-20 Web bolts numbering (distances: 49mm, 51mm)

Bolt layouts have the **“shear only”** option on: it means that a single layout **is not able to carry out of plate actions** (bending and axial force), **but in-plane actions only (shear and torque, which produces shear in single bolts)**. If “shear only” layouts are used for joints in bending, they must be properly positioned so that bending (or axial forces) can be carried as shear forces in some layouts.

B.2.1.2 Bending about strong axis

B.2.1.2.1 Checks

In imported Sargon© model, constraints and loads are applied to get only a bending moment in the node of the joint. The moment is equal to 1.2 times the plastic modulus of the cross-section (overstrength factor). Moment is equal to $1.2*W_{pl}*f_y = 5.27*10^8$Nmm. For the validation purpose, any other moment value could be used.

Note well: in early versions of the program, FEM model importing was the only way to get geometry and internal forces. Now the same condition could be created defining the node directly in CSE and defining the loads using amplified plastic limit of the member, a defined value or an imported combination.

The following abstract report show the forces are distributed by CSE in each bolt layout. Bending moment is carried as shear force by flanges bolt layouts (B1, B2, B3 and B4) and a torque by web bolt layouts (B5 and B6). The most part of the load is carried by flages bolt layouts.

Forces acting over bolt layouts at different extremes, global system

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Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B3	1	1	1	-1.4745e-006	-1.5487e+006	1.9401e-006	-1.4170e+007	1.2367e-005	2.9493e-004
B3	1	1	2	1.4745e-006	1.5487e+006	-1.9401e-006	-1.6028e+007	1.6386e-005	-2.9493e-004
B1	1	1	1	-1.4745e-006	1.5487e+006	-1.9401e-006	1.4170e+007	1.2367e-005	2.9493e-004
B1	1	1	2	1.4745e-006	-1.5487e+006	1.9401e-006	1.6028e+007	1.6386e-005	-2.9493e-004
B2	1	1	1	1.4745e-006	1.5487e+006	1.7709e-006	1.4170e+007	-1.2367e-005	2.9493e-004
B2	1	1	2	-1.4745e-006	-1.5487e+006	-1.7709e-006	1.6028e+007	-1.6386e-005	-2.9493e-004
B4	1	1	1	1.4745e-006	-1.5487e+006	-1.7709e-006	-1.4170e+007	-1.2367e-005	2.9493e-004
B4	1	1	2	-1.4745e-006	1.5487e+006	1.7709e-006	-1.6028e+007	-1.6386e-005	-2.9493e-004
B5	1	1	1	-8.6227e-006	-5.7521e-004	-3.3269e-020	-3.7420e-003	4.9580e-005	2.9932e+007
B5	1	1	2	1.7245e-005	1.1113e-003	6.9568e-020	-1.4709e-004	8.4676e-017	-5.9864e+007
B5	1	1	3	-8.6227e-006	-5.3608e-004	-3.6300e-020	3.4390e-003	-4.9580e-005	2.9932e+007
B6	1	1	1	-8.6227e-006	6.6062e-004	-4.3419e-020	3.4390e-003	4.9580e-005	2.9932e+007
B6	1	1	2	1.7245e-005	-1.3865e-003	8.5367e-020	-4.4717e-004	1.1917e-016	-5.9864e+007
B6	1	1	3	-8.6227e-006	7.2584e-004	-4.1949e-020	-3.7420e-003	-4.9580e-005	2.9932e+007

Id	bolt layout identification number
Inst	joint instance
Combi	load combination
Ext	bolt layout extreme
Fx,y,z	forces acting on bolt layout (axes *x* and *y* lie on layout plane)
Mx,y,z	moments acting on bolt layout

Shear computed on flanges by CSE is $1.5487*10^6$N; considering both flanges, total carried moment is:

$$2 \cdot 1.547 \cdot 10^6 N \cdot \frac{h}{2} = 2 \cdot 1.547 \cdot 10^6 N \cdot \frac{300}{2} = 4.646 \cdot 10^8 Nmm$$

which is the 88% of total applied moment ($5.27*10^8$Nmm).

We can evaluate via hand computation the distribution of the forces in elastic range.

$$M_{tot} = 2bt_f \frac{h}{2} f_y + t_w \frac{h_1^2}{6} f_y =$$
$$= 2 \cdot 300mm \cdot 19mm \times \frac{300mm}{2} \cdot 235N/mm^2 + 11mm \cdot \frac{208mm^2}{6} \cdot 235N/mm^2 = 4.205 \cdot 10^8 \, Nmm$$

Flanges carry the following moment

$$M_f = 2bt_f \frac{h}{2} f_y == 2 \cdot 300mm \cdot 19mm \cdot \frac{300mm}{2} \cdot 235N/mm^2 = 4.019 \cdot 10^8 \, Nmm$$

which is the 95.6% del of total applied moment.

CSE assigns to flanges bolt layout a small moment, but this aspect must be considered: forces distribution depends on flanges and web *geometry* but also on bolt layouts *translational stiffness* (if there is not a bearing surface, it is proportional to bolt numbers, bolt radius raised to the 4^{th} power, and inversely proportional to cubed net length; net length depends on number and thickness of bolted plates). Consider, for example, to remove bolts on the web: obviously, the 100% of the load would be carried by the flanges.

At the end of this paragraph, we will see how forces distribution changes when bolt number on flanges changes, or when bolts diameter changes on flanges or web. It must be underlined that each distribution which guarantees equilibrium is acceptable, according to limit analysis theorem, if all the checks are done with coherence to assumed distribution.

The distribution computed by CSE (flexibility index was not change) is near to the one we could find "by hand". If the ratio web bolt layout / flanges bolt layout is greater than the ratio web area / flanges area, web bolt layout will carry a greater load than that computed considering areas only. The actual distribution is not so easy to be computed by hand.

In part C we will see how the *flexibility index* drives forces distribution. Flexibility index is a parameter used to change translational stiffness of a bolt layout.

Let's validate CSE results. Each bolt on the flanges should carry 1/14 of the total load on the layout (since there are 14 bolts). We have $1.5487*10^6$N / 14 = $1.106*10^5$N.

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B3	1	1	1.386e-007	1.386e-007	6.667e-008	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	2	1	1.386e-007	1.386e-007	6.667e-008	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	3	1	1.386e-007	1.386e-007	9.341e-009	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	4	1	1.386e-007	1.386e-007	9.341e-009	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	5	1	1.386e-007	1.386e-007	-4.799e-008	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	6	1	1.386e-007	1.386e-007	-4.799e-008	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	7	1	1.386e-007	1.386e-007	-1.053e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	8	1	1.386e-007	1.386e-007	-1.053e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	9	1	1.386e-007	1.386e-007	-1.627e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	10	1	1.386e-007	1.386e-007	-1.627e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	11	1	1.386e-007	1.386e-007	-2.200e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	12	1	1.386e-007	1.386e-007	-2.200e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	13	1	1.386e-007	1.386e-007	-2.773e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B3	14	1	1.386e-007	1.386e-007	-2.773e-007	-1.106e+005	1.106e+005	9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	1	1	-1.386e-007	-1.386e-007	6.667e-008	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	2	1	-1.386e-007	-1.386e-007	6.667e-008	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	3	1	-1.386e-007	-1.386e-007	9.340e-009	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	4	1	-1.386e-007	-1.386e-007	9.340e-009	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	5	1	-1.386e-007	-1.386e-007	-4.799e-008	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	6	1	-1.386e-007	-1.386e-007	-4.799e-008	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	7	1	-1.386e-007	-1.386e-007	-1.053e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	8	1	-1.386e-007	-1.386e-007	-1.053e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	9	1	-1.386e-007	-1.386e-007	-1.627e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	10	1	-1.386e-007	-1.386e-007	-1.627e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	11	1	-1.386e-007	-1.386e-007	-2.200e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	12	1	-1.386e-007	-1.386e-007	-2.200e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	13	1	-1.386e-007	-1.386e-007	-2.773e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B1	14	1	-1.386e-007	-1.386e-007	-2.773e-007	1.106e+005	1.106e+005	-9.401e+004	-1.699e-007	9.401e+004	0.906	resis
1	1	B2	1	1	1.265e-007	1.265e-007	2.773e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	2	1	1.265e-007	1.265e-007	2.773e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	3	1	1.265e-007	1.265e-007	2.200e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	4	1	1.265e-007	1.265e-007	2.200e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	5	1	1.265e-007	1.265e-007	1.627e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	6	1	1.265e-007	1.265e-007	1.627e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	7	1	1.265e-007	1.265e-007	1.053e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	8	1	1.265e-007	1.265e-007	1.053e-007	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	9	1	1.265e-007	1.265e-007	4.799e-008	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	10	1	1.265e-007	1.265e-007	4.799e-008	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	11	1	1.265e-007	1.265e-007	-9.340e-009	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	12	1	1.265e-007	1.265e-007	-9.340e-009	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	13	1	1.265e-007	1.265e-007	-6.667e-008	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B2	14	1	1.265e-007	1.265e-007	-6.667e-008	1.106e+005	1.106e+005	-9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	1	1	-1.265e-007	-1.265e-007	2.773e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	2	1	-1.265e-007	-1.265e-007	2.773e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	3	1	-1.265e-007	-1.265e-007	2.200e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	4	1	-1.265e-007	-1.265e-007	2.200e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	5	1	-1.265e-007	-1.265e-007	1.627e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	6	1	-1.265e-007	-1.265e-007	1.627e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	7	1	-1.265e-007	-1.265e-007	1.053e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	8	1	-1.265e-007	-1.265e-007	1.053e-007	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	9	1	-1.265e-007	-1.265e-007	4.799e-008	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	10	1	-1.265e-007	-1.265e-007	4.799e-008	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	11	1	-1.265e-007	-1.265e-007	-9.340e-009	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	12	1	-1.265e-007	-1.265e-007	-9.340e-009	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	13	1	-1.265e-007	-1.265e-007	-6.667e-008	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B4	14	1	-1.265e-007	-1.265e-007	-6.667e-008	-1.106e+005	1.106e+005	9.401e+004	1.699e-007	9.401e+004	0.906	resis
1	1	B5	1	1	-5.545e-021	-5.545e-021	1.090e+005	-5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis
1	1	B5	1	2	6.050e-021	6.050e-021	-1.090e+005	5.236e+004	1.209e+005	-3.710e-005	-3.593e-007	3.710e-005	0.990	
1	1	B5	2	1	-5.545e-021	-5.545e-021	1.090e+005	5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis
1	1	B5	2	2	6.050e-021	6.050e-021	-1.090e+005	-5.236e+004	1.209e+005	-3.710e-005	-3.593e-007	3.710e-005	0.990	
1	1	B5	3	1	-5.545e-021	-5.545e-021	-1.437e-006	-5.236e+004	5.236e+004	-4.845e-005	-3.593e-007	4.845e-005	0.429	resis
1	1	B5	3	2	6.050e-021	6.050e-021	1.437e-006	5.236e+004	5.236e+004	-3.710e-005	-3.593e-007	3.710e-005	0.429	
1	1	B5	4	1	-5.545e-021	-5.545e-021	-1.437e-006	5.236e+004	5.236e+004	-4.845e-005	-3.593e-007	4.845e-005	0.429	
1	1	B5	4	2	6.050e-021	6.050e-021	1.437e-006	-5.236e+004	5.236e+004	-3.710e-005	-3.593e-007	3.710e-005	0.429	resis
1	1	B5	5	1	-5.545e-021	-5.545e-021	-1.090e+005	-5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis
1	1	B5	5	2	6.050e-021	6.050e-021	1.090e+005	5.236e+004	1.209e+005	-3.710e-005	-3.593e-007	3.710e-005	0.990	
1	1	B5	6	1	-5.545e-021	-5.545e-021	-1.090e+005	5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis
1	1	B5	6	2	6.050e-021	6.050e-021	1.090e+005	-5.236e+004	1.209e+005	-3.710e-005	-3.593e-007	3.710e-005	0.990	
1	1	B6	1	1	-7.236e-021	-7.236e-021	1.090e+005	-5.236e+004	1.209e+005	-8.744e-005	-3.593e-007	8.744e-005	0.990	resis
1	1	B6	1	2	6.991e-021	6.991e-021	-1.090e+005	5.236e+004	1.209e+005	-1.022e-004	-3.593e-007	1.022e-004	0.990	
1	1	B6	2	1	-7.236e-021	-7.236e-021	1.090e+005	5.236e+004	1.209e+005	-8.744e-005	-3.593e-007	8.744e-005	0.990	resis
1	1	B6	2	2	6.991e-021	6.991e-021	-1.090e+005	-5.236e+004	1.209e+005	-1.022e-004	-3.593e-007	1.022e-004	0.990	
1	1	B6	3	1	-7.236e-021	-7.236e-021	-1.437e-006	-5.236e+004	5.236e+004	-8.744e-005	-3.593e-007	8.744e-005	0.429	resis
1	1	B6	3	2	6.991e-021	6.991e-021	1.437e-006	5.236e+004	5.236e+004	-1.022e-004	-3.593e-007	1.022e-004	0.429	
1	1	B6	4	1	-7.236e-021	-7.236e-021	-1.437e-006	5.236e+004	5.236e+004	-8.744e-005	-3.593e-007	8.744e-005	0.429	
1	1	B6	4	2	6.991e-021	6.991e-021	1.437e-006	-5.236e+004	5.236e+004	-1.022e-004	-3.593e-007	1.022e-004	0.429	resis
1	1	B6	5	1	-7.236e-021	-7.236e-021	-1.090e+005	-5.236e+004	1.209e+005	-8.744e-005	-3.593e-007	8.744e-005	0.990	resis
1	1	B6	5	2	6.991e-021	6.991e-021	1.090e+005	5.236e+004	1.209e+005	-1.022e-004	-3.593e-007	1.022e-004	0.990	
1	1	B6	6	1	-7.236e-021	-7.236e-021	-1.090e+005	5.236e+004	1.209e+005	-8.744e-005	-3.593e-007	8.744e-005	0.990	resis
1	1	B6	6	2	6.991e-021	6.991e-021	1.090e+005	-5.236e+004	1.209e+005	-1.022e-004	-3.593e-007	1.022e-004	0.990	

- *Bolt*: number of bolt (from 1 to n for each layout)
- *Sec*: check section (number of drilled plates less 1)
- *NB*, *TuB*, *TvB*, *MuB*, *MvB*: axial force, shear and moments in each check section
- *NTB*: total axial force (including preload)
- *TB*: sum of *Tu* and *Tv*

- *MB*: sum of *Mu* and *Mv*
- *expl*: utilization factor according to the Standard (EN1993-1-8 in this case)

NOTE WELL: CSE computes also the parasitic bending in bolt shafts: this can be considered or neglected in the checks.

Utilization factor, neglecting axial force in the bolt (it is quite null) is the ratio between shear force in the bolt ($F_{V,Ed}$) and design resistance ($F_{V,Rd}$):

$$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$$

γ_{M2} is equal to 1.25; resisting area for shear is the total one; α_v=0.6 (see following abstract from EN 1993-1-8: 2005).

All the bolts are equal, so they have the same design resistance:

$$F_{v,Rd} = \frac{0.6 \cdot 1000 \cdot 254.5}{1.25} = 1.221 \cdot 10^5\, N$$

CSE computes the following data, that are the same:

```
----------------------------
Boltlayouts bolt properties
----------------------------

   Id  Class    Dia   Dia H    Sec  Full  Precision     Area          Ares          Vlim          Nlim          Nini

   B3   10.9   18.0   20.0      1   yes      not     2.545e+002   1.920e+002   1.221e+005   1.382e+005   0.000e+000
   B1   10.9   18.0   20.0      1   yes      not     2.545e+002   1.920e+002   1.221e+005   1.382e+005   0.000e+000
   B2   10.9   18.0   20.0      1   yes      not     2.545e+002   1.920e+002   1.221e+005   1.382e+005   0.000e+000
   B4   10.9   18.0   20.0      1   yes      not     2.545e+002   1.920e+002   1.221e+005   1.382e+005   0.000e+000
   B5   10.9   18.0   20.0      2   yes      not     2.545e+002   1.920e+002   1.221e+005   1.382e+005   0.000e+000
   B6   10.9   18.0   20.0      2   yes      not     2.545e+002   1.920e+002   1.221e+005   1.382e+005   0.000e+000
```

Table 3.4: Design resistance for individual fasteners subjected to shear and/or tension

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{v,Rd} = \frac{\alpha_v \; f_{ub} \; A}{\gamma_{M2}}$ - where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt A_s): - for classes 4.6, 5.6 and 8.8: $\alpha_v = 0{,}6$ - for classes 4.8, 5.8, 6.8 and 10.9: $\alpha_v = 0{,}5$ - where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt): $\alpha_v = 0{,}6$	$F_{v,Rd} = \frac{0{,}6 \; f_{ur} \; A_0}{\gamma_{M2}}$

Figure B-21 Abstract from EN 1993-1-8: 2005: bolts design resistance

Bolts of layouts B1, B2, B3 and B4 are subject to the same force, equal to 1.106E+05N; utilization facto is equal to:

$$\frac{F_{V,Ed}}{F_{V,Rd}} = \frac{1.106 \cdot 10^5 \, N}{1.221 \cdot 10^5 \, N} = 0.906$$

```
--------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
--------------------------------------------------------------

Inst  Combi  Name Bolt -?-      NB           NTB          TuB          TvB          TB           MuB          MvB          MB          Expl  cause

   1     1    B1   4   1  -1.386e-007  -1.386e-007   9.340e-009   1.106e+005  1.106e+005  -9.401e+004 -1.699e-007   9.401e+004   0.906 resis
```

Consider now the forces acting on web bolt layouts. The torque computed by CSE (equal to -5.9864x10^7Nmm) is distributed in two check sections, loaded with the half of that moment. Internal force on each bolt depends on the distance from each bolt to the centre, considering an elastic distribution.

$$T_b = \frac{M_t / 2}{J_p} \cdot d$$

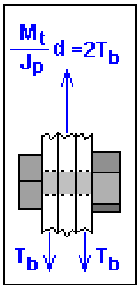


Figure B-22

J_p is bolt layout polar inertia moment; with the distances printed in next figure, we have:

$$J_p = 4 * 56.6^2 + 2 * 24.5^2 = 1.401*10^4 mm^2$$

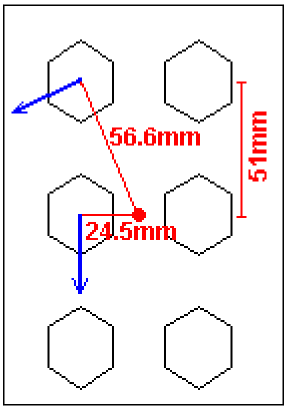


Figure B-23

Shear is equal to:

$$T_b = \frac{5.986 \cdot 10^7\ Nmm/2}{1.401 \cdot 10^4\ mm^2} \cdot 24.5mm = 5.234 \cdot 10^4\ N \text{ for central bolts}$$

$$T_b = \frac{5.986 \cdot 10^7\ Nmm/2}{1.401 \cdot 10^4\ mm^2} \cdot 56.6mm = 1.209 \cdot 10^5\ N \text{ for external bolts}$$

These forces are the same computed by CSE:

```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B5	1	1	-5.545e-021	-5.545e-021	1.090e+005	-5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis
1	1	B5	1	2	6.050e-021	6.050e-021	-1.090e+005	5.236e+004	1.209e+005	-3.710e-005	-3.593e-007	3.710e-005	0.990	
1	1	B5	2	1	-5.545e-021	-5.545e-021	1.090e+005	5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis
1	1	B5	2	2	6.050e-021	6.050e-021	-1.090e+005	-5.236e+004	1.209e+005	-3.710e-005	-3.593e-007	3.710e-005	0.990	
1	1	B5	3	1	-5.545e-021	-5.545e-021	-1.437e-006	-5.236e+004	5.236e+004	-4.845e-005	-3.593e-007	4.845e-005	0.429	resis
1	1	B5	3	2	6.050e-021	6.050e-021	1.437e-006	5.236e+004	5.236e+004	-3.710e-005	-3.593e-007	3.710e-005	0.429	
1	1	B5	4	1	-5.545e-021	-5.545e-021	-1.437e-006	5.236e+004	5.236e+004	-4.845e-005	-3.593e-007	4.845e-005	0.429	
1	1	B5	4	2	6.050e-021	6.050e-021	1.437e-006	-5.236e+004	5.236e+004	-3.710e-005	-3.593e-007	3.710e-005	0.429	resis
1	1	B5	5	1	-5.545e-021	-5.545e-021	-1.090e+005	-5.236e+004	1.209e+005	-4.845e-005	-3.593e-007	4.845e-005	0.990	resis

```
1     1    B5   5   2   6.050e-021   6.050e-021   1.090e+005   5.236e+004  1.209e+005  -3.710e-005 -3.593e-007   3.710e-005   0.990
1     1    B5   6   1  -5.545e-021  -5.545e-021  -1.090e+005   5.236e+004  1.209e+005  -4.845e-005 -3.593e-007   4.845e-005   0.990 resis
1     1    B5   6   2   6.050e-021   6.050e-021   1.090e+005  -5.236e+004  1.209e+005  -3.710e-005 -3.593e-007   3.710e-005   0.990

1     1    B6   1   1  -7.236e-021  -7.236e-021   1.090e+005  -5.236e+004  1.209e+005  -8.744e-005 -3.593e-007   8.744e-005   0.990 resis
1     1    B6   1   2   6.991e-021   6.991e-021  -1.090e+005   5.236e+004  1.209e+005  -1.022e-004 -3.593e-007   1.022e-004   0.990
1     1    B6   2   1  -7.236e-021  -7.236e-021   1.090e+005   5.236e+004  1.209e+005  -8.744e-005 -3.593e-007   8.744e-005   0.990 resis
1     1    B6   2   2   6.991e-021   6.991e-021  -1.090e+005  -5.236e+004  1.209e+005  -1.022e-004 -3.593e-007   1.022e-004   0.990
1     1    B6   3   1  -7.236e-021  -7.236e-021  -1.437e-006  -5.236e+004  5.236e+004  -8.744e-005 -3.593e-007   8.744e-005   0.429 resis
1     1    B6   3   2   6.991e-021   6.991e-021   1.437e-006   5.236e+004  5.236e+004  -1.022e-004 -3.593e-007   1.022e-004   0.429
1     1    B6   4   1  -7.236e-021  -7.236e-021  -1.437e-006   5.236e+004  5.236e+004  -8.744e-005 -3.593e-007   8.744e-005   0.429
1     1    B6   4   2   6.991e-021   6.991e-021   1.437e-006  -5.236e+004  5.236e+004  -1.022e-004 -3.593e-007   1.022e-004   0.429 resis
1     1    B6   5   1  -7.236e-021  -7.236e-021  -1.090e+005  -5.236e+004  1.209e+005  -8.744e-005 -3.593e-007   8.744e-005   0.990 resis
1     1    B6   5   2   6.991e-021   6.991e-021   1.090e+005   5.236e+004  1.209e+005  -1.022e-004 -3.593e-007   1.022e-004   0.990
1     1    B6   6   1  -7.236e-021  -7.236e-021  -1.090e+005   5.236e+004  1.209e+005  -8.744e-005 -3.593e-007   8.744e-005   0.990 resis
1     1    B6   6   2   6.991e-021   6.991e-021   1.090e+005  -5.236e+004  1.209e+005  -1.022e-004 -3.593e-007   1.022e-004   0.990
```

Consider, for example, bolt number 3 of layout B5. Its utilization factor is $5.234*10^4$N/$1.221*10^5$N=0.429, as computed by CSE.

Now consider bolt bearing. The check according to EN1993-1-8 is given by the following formula.

Bearing resistance [1), 2), 3)]	$F_{b,Rd} = \dfrac{k_1\, a_b\, f_u\, d\, t}{\gamma_{M2}}$ where α_b is the smallest of α_d ; $\dfrac{f_{ub}}{f_u}$ or 1,0; in the direction of load transfer: - for end bolts: $\alpha_d = \dfrac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \dfrac{p_1}{3d_0} - \dfrac{1}{4}$ perpendicular to the direction of load transfer: - for edge bolts: k_1 is the smallest of $2{,}8\dfrac{e_2}{d_0} - 1{,}7$ or 2,5 - for inner bolts: k_1 is the smallest of $1{,}4\dfrac{p_2}{d_0} - 1{,}7$ or 2,5

Figure B-24 Abstract from EN 1993-1-8: 2005: design resistance for bolt bearing

Distances e_1, e_2, p_1 and p_2 are defined in the following schemes.

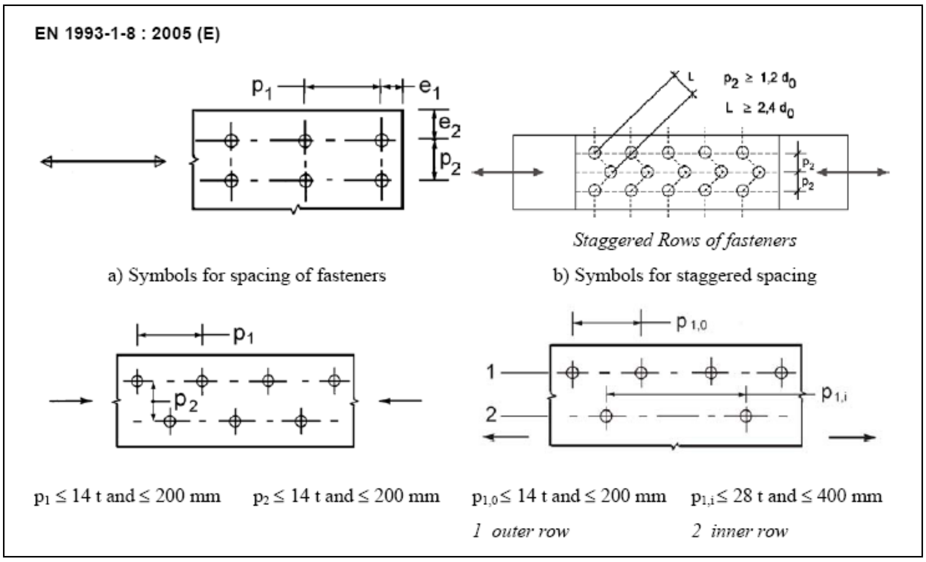


Figure B-25 Abstract from EN 1993-1-8: 2005: distances e_1, e_2, p_1, p_2

NOTE WELL: bolts are classified inner or end/edge according to their position depending on load direction (parallel to one of the sides). If a force is not parallel to any side, it must be divided in its parallel and normal components.

The Standard states to apply the check in the two directions separately. This does not seem on the safe side, so CSE gives an utilization factor equal to the square root of the sum of the square of the two partial utilizations.

In addition, the Standard does not consider situations with different plate shapes, with non-parallel edges (for example circular plates, see next figure), of members cut with an inclined plate, etc. To be always on the safe side, CSE uses minimum distance from the edge of each drilled object.

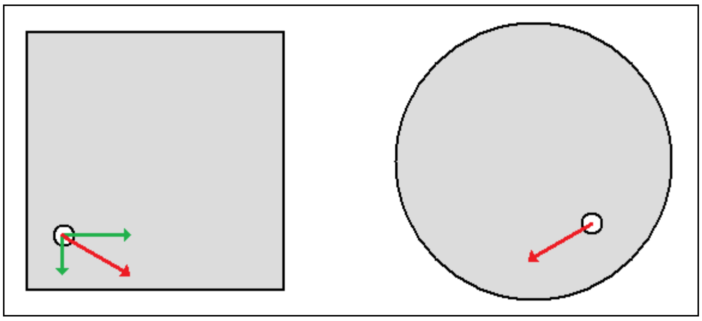


Figure B-26

Bolt bearing check requires a long computation for each bolt. Let's consider just one bolt and validate it accurately. For example, we can choose one of most loaded bolts (for web layout they are upper and lower bolts) and considering the effect on member's web.

The force applied by the bolts to the web is the reaction to the torque in bolt layout central section. In this symmetrical case, forces on web are twice the forces in bolts check sections; they are:

$$F_x = \frac{M_t}{J_p} \times d = \frac{5.986 \times 10^7 \, Nmm}{1.401 \times 10^4 \, mm^2} \times 51mm = 2.179 \times 10^5 \, N$$

$$F_y = \frac{M_t}{J_p} \times d = \frac{5.986 \times 10^7 \, Nmm}{1.401 \times 10^4 \, mm^2} \times 24.5mm = 1.047 \times 10^5 \, N$$

According to the formulae in Figure B-25, next table contains the data for bolt bearing resistance in the two directions; distances are given in next figure.

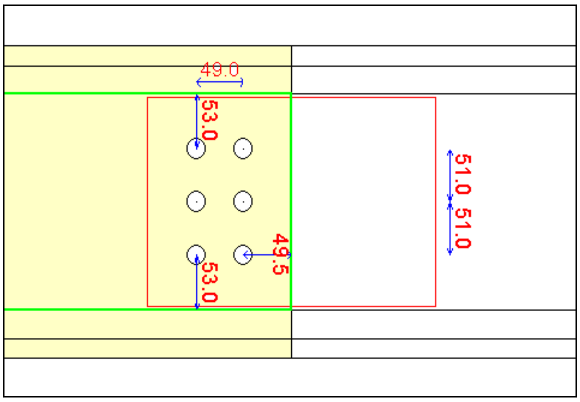


Figure B-27 Web bolt layout: distances between bolts and from edges

Fx	2,179E+05	Fy	1,047E+05
$F_{b,Rd,x}$	6,043E+04	$F_{b,Rd,y}$	5,919E+04
k_1	1,87	k_1	1,73
$2,8e_2/d_0$-1,7	5,23	$2,8e_2/d_0$-1,7	5,23
$1,4p_2/d_0$-1,7	1,87	$1,4p_2/d_0$-1,7	1,73
	2,5		2,5
a_b	0,566666667	a_b	0,600
a_d	0,825	a_d	0,825
f_{ub}/f_u	2,78	f_{ub}/f_u	2,78
$p_1/3d_0$-0,25	0,57	$p_1/3d_0$-0,25	0,60
	1		1
fu	360	fu	360
d	18	d	18
d_0	20	d_0	20
t	11	t	11
e_1=min(e_1,e_2)	49,5	e_1=min(e_1,e_2)	49,5
e_2=min(e_1,e_2)	49,5	e_2=min(e_1,e_2)	49,5
p_1	49	p_1	51

p_2	51	p_2	49
expl x	3,606	expl y	1,769
	EXPL=	4,017	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

Let's compute $F_{b,Rd,x}$ and $F_{b,Rd,y}$ step by step, and then the utilization factor.

$$F_{b,Rd,x} = \frac{k_1 \alpha_b f_u dt}{\gamma_{M2}}$$

$$\alpha_b = \min(\alpha_d;\ \frac{f_{ub}}{f_u};\ 1.0)$$

$$\frac{f_{ub}}{f_u} = \frac{1000N/mm^2}{360N/mm^2} = 2.78$$

$$\alpha_d = \min\{\frac{e_1}{3d_0}; \frac{p_1}{3d_0} - 0,25) = \min(\frac{49.5mm}{3 \cdot 20mm}, \frac{49mm}{3 \cdot 20mm} - 0,25\} = 0.57 \quad \textit{for end bolts}$$

$$\alpha_b = \alpha_d = 0.57$$

$$k_1 = \min(2.8\frac{e_2}{d_0} - 1.7;\ 1.4\frac{p_2}{d_0} - 1.7; 2.5) \quad \textit{for}\ \text{edge bolts}$$

$$2.8\frac{e_2}{d_0} - 1.7 = 2.8\frac{49.5mm}{20mm} - 1.7 = 5.23 > 2.5$$

$$1.4\frac{p_2}{d_0} - 1.7 = 1,87$$

$$k_1 = 1.87$$

$$F_{b,Rd,x} = \frac{k_1 \alpha_b f_u dt}{\gamma_{M2}} = \frac{1.87 \cdot 0.57 \cdot 360N/mm^2 \cdot 18mm \cdot 11mm}{1.25} = 0.6043 \cdot 10^5 N$$

$$\text{expl}_x = \frac{F_x}{F_{b,Rd,x}} = \frac{2.179 \cdot 10^5 N}{0.60 \cdot 10^5 N} = 3.606$$

$$F_{b,Rd,y} = \frac{k_1 \alpha_b f_u dt}{\gamma_{M2}}$$

$$\alpha_b = \min(\alpha_d;\ \frac{f_{ub}}{f_u};\ 1.0)$$

$$\frac{f_{ub}}{f_u} = \frac{1000N/mm^2}{360N/mm^2} = 2.78$$

$$\alpha_d = \min\{\frac{e_1}{3d_0}; \frac{p_1}{3d_0} - 0,25) = \min(\frac{49.5mm}{3 \cdot 20mm}, \frac{51mm}{3 \cdot 20mm} - 0,25\} = 0.60 \quad \textit{for end bolts}$$

$$\alpha_d = \frac{e_1}{3d_0} = \frac{49.5mm}{3 \cdot 20mm} = 0.60 \quad \textit{for end bolts}$$

$$\alpha_b = \alpha_d = 0.60$$

$$k_1 = \min(2.8\frac{e_2}{d_0} - 1.7;\ 1.4\frac{p_2}{d_0} - 1.7; 2.5)\ \ \text{for edge bolts}$$

$$2.8\frac{e_2}{d_0} - 1.7 = 2.8\frac{49.5mm}{20mm} - 1.7 = 5.23 > 2.5$$

$$1.4\frac{p_2}{d_0} - 1.7 = 1{,}73$$

$$k_1 = 1.73$$

$$F_{b,Rd,y} = \frac{k_1 \alpha_b f_u dt}{\gamma_{M2}} = \frac{1.73 \cdot 0.600 \cdot 360 N/mm^2 \cdot 18mm \cdot 11mm}{1.25} = 0.5919 \cdot 10^5 N$$

$$\text{exp1}_y = \frac{F_y}{F_{b,Rd,y}} = \frac{1.047 \cdot 10^5 N}{0.59 \cdot 10^5 N} = 1.769$$

Total utilization is:

$$\text{exp1} = \sqrt{\text{exp1}_x^2 + \text{exp1}_y^2} = 4.017$$

Maximum value computed by CSE is the same, because we have chosen the most loaded bolt. A complete check by hand would require the previous computations for each bolt of the web and for each bolt of the flanges, considering applied forces, distances between bolts and distances from edges every time different.

```
-------------------------------------------------------------------
Members whose maximum utilization ratio is due to bearing stresses
-------------------------------------------------------------------

 Inst Combi  Name    Boltlay   Bolt   Extr.        Sigma       Sigma M     Expl
                                                 (  N/ mm²)    (  N/ mm²)

    1     1    m1      B5         1       2         1221.4        304.0    4.018 !!!
    1     1    m2      B6         2       2         1221.4        304.0    4.018 !!!
```

NOTE WELL: Sigma M (max) value printed in the listing is computed dividing utilization factor by sigma: the value is referred to current force direction. If force direction changes, limit value changes as well.

Here we have a very high utilization, but **the scope is to validate CSE** results, not to design a proper joint.

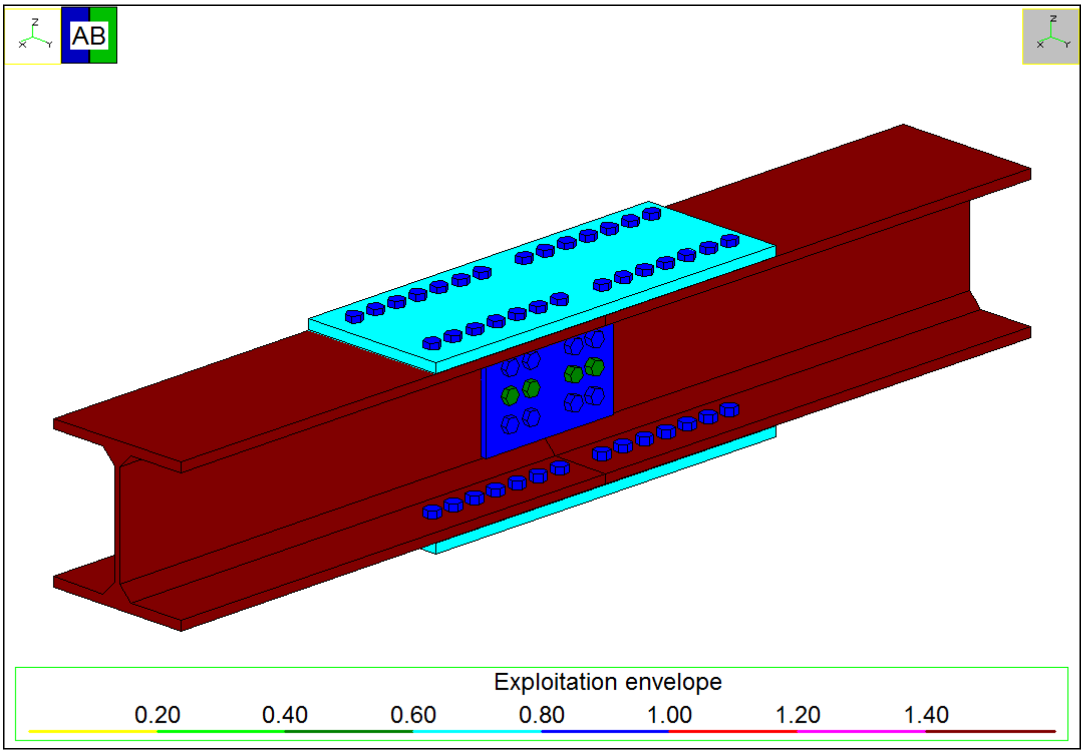


Figure B-28 Utilization of the components according to EN 1993-1-8: 2005

B.2.1.2.2 How bolt layout stiffness rules forces distribution

The translational stiffness of a bolt layout is proportional to:

- Bolts number (n_b)
- Bolts radius raised to the 4th power (r_b^4)

It is inversely proportional to:

- Cubed bolts net length (l)

The *flexibility index* will be introduced in part C: this index can be used to modify the translational stiffness of a layout. Here the stiffness is modified by changing bolts diameter or number.

Some modifications have been done to the original model, in order to see how CSE computes, in different conditions, he distribution of forces flanges bolt layouts (V_f). Total applied moment (M_{tot}) is compared to the part carried by flanges bolt layout (M_f):

$$M_f / M_{tot}$$

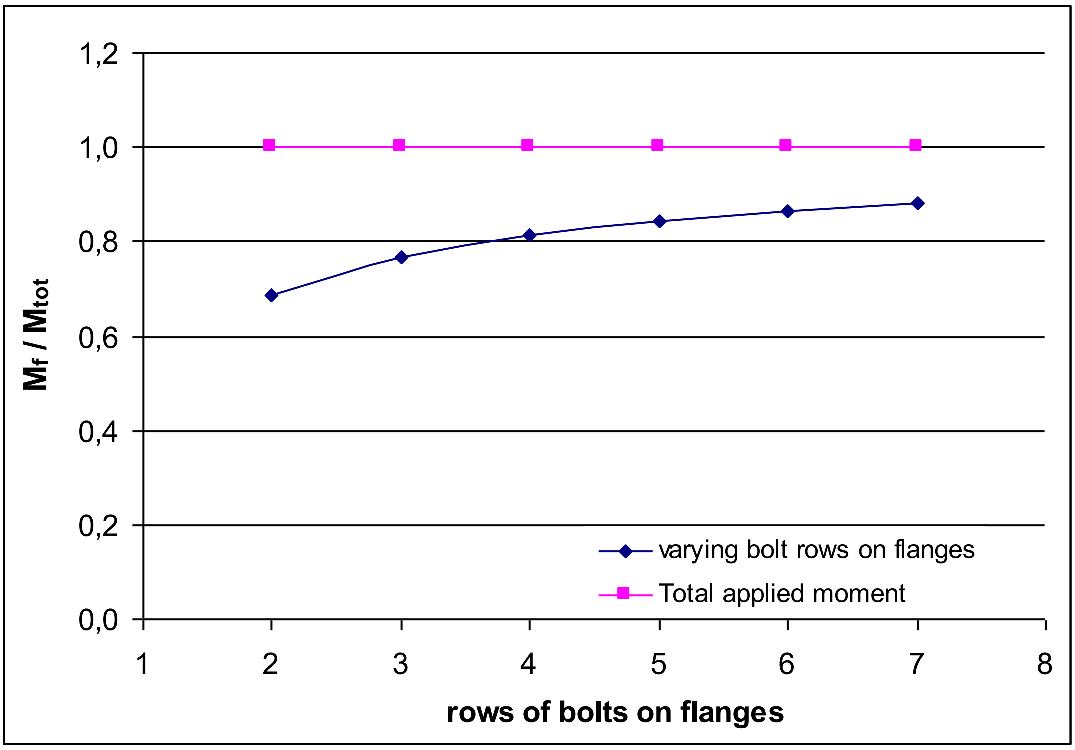
M_f is equal to:

$$M_f = 2 * V_f * h/2 = 2 * V_f * 150 = V_f * 300$$

where V_f is the shear carried by flanges bolt layout, as computed by CSE, *h*/2 is the lever arm of the shear (half of the height of HEB300 shape) and 2 is the number of layouts on the flanges (upper and lower).

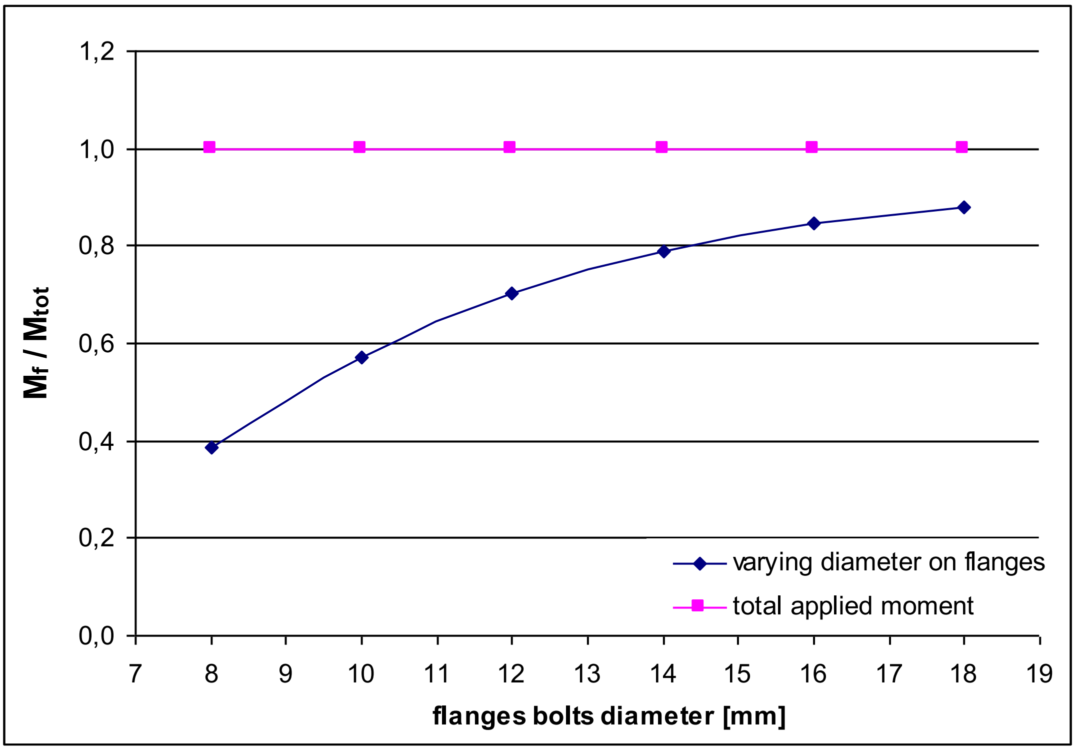
1) Modification of bolts number on flanges; web bolt layouts not modified (models: Validation_SP_1_1_001.CSE → Validation_SP_1_1_006.CSE)

Web bolt layouts are unchanged. On the flanges, starting from original configuration (7 rows / 2 columns) we remove a row (6 rows), and so on until last condition (2 rows). These are the results according to shears computed by CSE in flanges bolt layouts (with two rows only, the 69% of applied load is carried by the flanges).



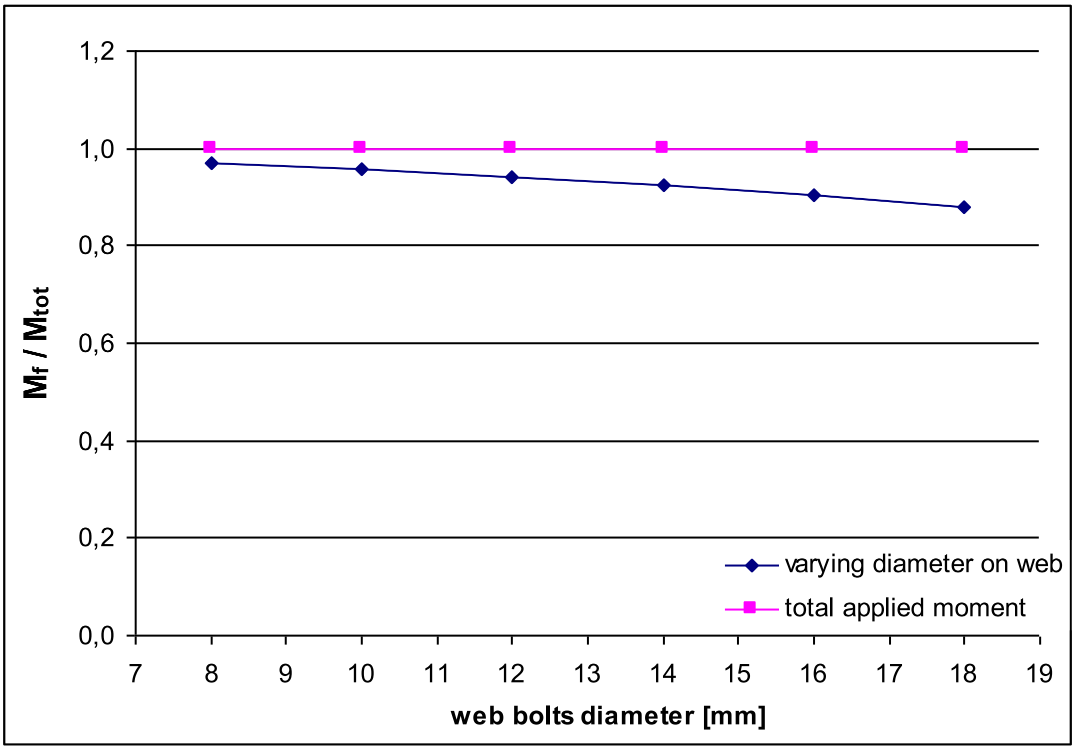
2) Modification of bolts diameter on flanges; web bolt layouts not modified

Starting from original model, we reduce flange bolts diameter: M18, M16, M14, M12, M10, M8. When bolts diameter decreases, the load carried by the flanges decreases too. With M8 bolts, flanges carry only the 39% of the applied load.



3) *Modification of bolts diameter on web; flanges bolt layouts not modified*

In this case, we reduce web bolts diameter: the load carried by the flanges increases. Using M8 bolts on the web, quite the total load (97%) is carried by the flanges, since web bolt layout stiffness is reduced.



These results show that forces distribution computed by CSE does not depend on cross-section geometry only, but it depends also on bolt layouts stiffness ratio.

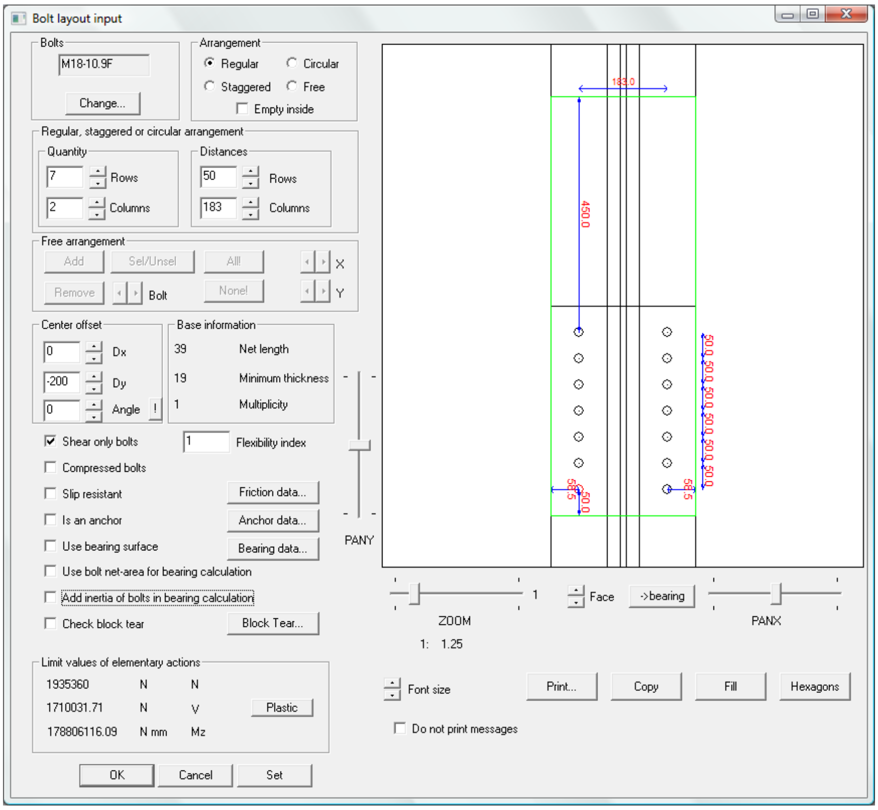


Figure B-29 Dialog box: bolt layout modification

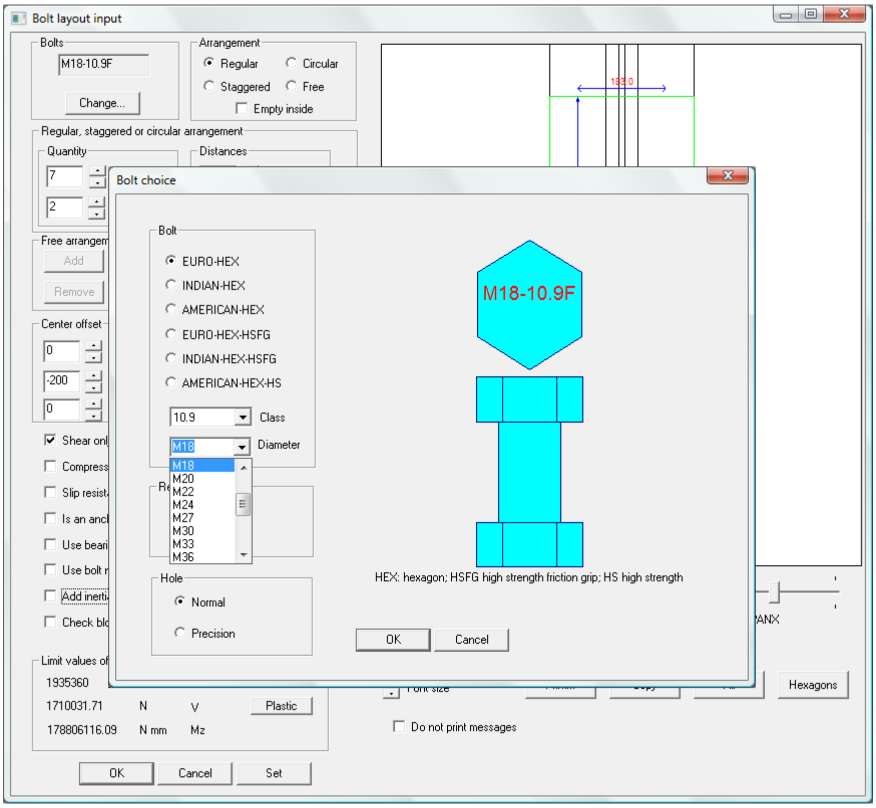


Figure B-30 Dialog box: bolts diameter modification

B.2.1.3 Shear parallel to the web

Constraints and loads were modified in a copy of the model used previously, in order to have only a shear parallel to web in joint node (new model name *Validation_SP_1_2.CSE*). Shear value is the plastic limit of the member with overstrength factor 1.2:

$$V = \gamma_{RD} \cdot V_{pl,RD} = 1.2 \cdot \frac{A_v f_y}{\sqrt{3}} = 772221N$$

with f_y = 235N/mm^2 and

$$A_v = A - 2bt_f + (t_w + 2r) \cdot t_f = 4743mm^2$$

3D real joint has the same geometry and properties of the one shown in B.2.1. In CSE computation, the almost the whole load is carried by web bolt layout.

Forces acting over bolt layouts at different extremes, global system

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B3	1	1	1	1.8062e-006	-3.4619e-004	1.4133e+001	2.8267e+003	-1.5149e-005	-3.6124e-004
B3	1	1	2	-1.8062e-006	3.4619e-004	-1.4133e+001	-2.8267e+003	-2.0072e-005	3.6124e-004
B1	1	1	1	1.8062e-006	3.4629e-004	-1.4133e+001	-2.8267e+003	-1.5149e-005	-3.6124e-004
B1	1	1	2	-1.8062e-006	-3.4629e-004	1.4133e+001	2.8267e+003	-2.0072e-005	3.6124e-004
B2	1	1	1	-1.8062e-006	3.4619e-004	-1.4134e+001	2.8267e+003	1.5149e-005	-3.6124e-004
B2	1	1	2	1.8062e-006	-3.4619e-004	1.4134e+001	-2.8267e+003	2.0072e-005	3.6124e-004
B4	1	1	1	-1.8062e-006	-3.4629e-004	1.4134e+001	-2.8267e+003	1.5149e-005	-3.6124e-004
B4	1	1	2	1.8062e-006	3.4629e-004	-1.4134e+001	2.8267e+003	2.0072e-005	3.6124e-004
B5	1	1	1	4.7923e-008	-3.8610e+005	-2.4005e-011	-2.2201e+006	-2.7556e-007	-2.8571e+007
B5	1	1	2	-9.5845e-008	7.7219e+005	4.8009e-011	-2.1144e-005	2.1165e-017	5.7142e+007
B5	1	1	3	4.7923e-008	-3.8610e+005	-2.4005e-011	2.2201e+006	2.7556e-007	-2.8571e+007
B6	1	1	1	4.7923e-008	3.8610e+005	-2.3641e-011	2.2201e+006	-2.7556e-007	2.8571e+007
B6	1	1	2	-9.5845e-008	-7.7219e+005	4.7282e-011	5.4767e-004	-2.1861e-017	-5.7142e+007
B6	1	1	3	4.7923e-008	3.8610e+005	-2.3641e-011	-2.2201e+006	2.7556e-007	2.8571e+007

Shear carried by web bolt layouts (B5 and B6, section number 2, the central one) is 772190N; total load is 772221N. A very small part is carried by flanges bolt layout (via a bending moment in bolts shafts, as we will see later). Note well: all bolts layouts in this model are “shear only”.

The shear applied to member extreme produces an equal shear applied to bolt layout centre. In addition, there is a moment of transport equal to:

$$M' = T * b = 772190N * 74mm = 5.714*10^7 Nmm.$$

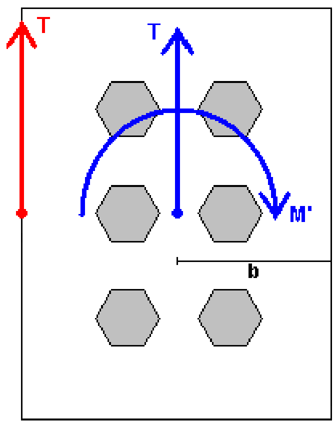


Figure B-31

Shear force acting on each bolt is the sum of two components:

1. total shear divided by bolts number (*V*/6)
2. shear due to torque (*M’*) on the layout

For the second components, force in the bolts depends on their distance from the centre. First contribution is shown on the left in next figure; in the middle there is the second contribution, on the right the sum of them.

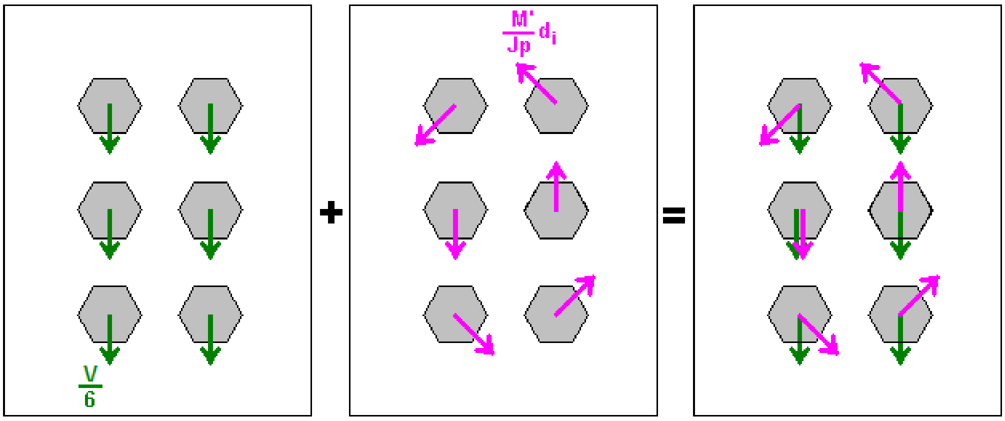


Figure B-32

Resulting shear force is higher on bolts were the components have the same direction. Now we are going to compute those values, and then we'll compare them with CSE values. The following formula defines the resultant force on each bolt:

$$R_i = \frac{\sqrt{(V_{V,i} + V_{M,i,y})^2 + V_{M,i,x}^2}}{2}$$

where

R_i is the resultant force on each bolt.

$V_{V,i}$ is the force due to total shear divided by bolts number: $V_{V,i}$=$V/6$=1.287e+05N

$V_{M,i}$ is the component due to moment of transport M' (it is divided into x-direction and y-direction forces).

Polar inertia moment of the layout is equal to

$$J_p = 4 * 56.6^2 + 2 * 24.5^2 = 1.401*10^4 \text{mm}^2$$

According to distances shown in Figure B-27, we have:

$$V_{M,i,x} = \frac{M'}{J_p} d_{i,y} = \frac{5.714 \cdot 10^7\, N}{1.401 \cdot 10^4\, mm^2} \cdot 51mm = 2.080 \cdot 10^5\, N$$

$$V_{M,i,y} = \frac{M'}{J_p} d_{i,x} = \frac{5.714 \cdot 10^7\, Nmm}{1.401 \cdot 10^4\, mm^2} \cdot 24.5mm = 9.993 \cdot 10^4\, N$$

For central bolts (d=24.5mm) $V_{Mi,x}$ is null and $V_{Mi,y}$ is 9.993e+04N. Last value must be added to $V/6$ on one bolt and subtracted from the other. Since we have two different check sections, resultant forces must be divided by 2. It results:

$$(V/6 + V_{Mi,y}) / 2 = (1.287*10^5\text{N} + 9.9927*10^4\text{N}) / 2 = 1.143*10^5\text{N}$$

$$(V/6 - V_{Mi,y}) / 2 = (1.287*10^5\text{N} – 9.9927*10^4\text{N}) / 2 = 1.439*10^4\text{N}$$

For the other bolts (dx=24.5mm, dy=51mm) $V_{Mi,x}$ is equal to 2.080e+05N; $V_{Mi,y}$ has the same values computed for central bolts. This must be added or subtracted to V/6, depending on bolt position. Considering two check sections, we have:

$$\frac{1}{2}\sqrt{\left(V/6+V_{Mi,y}\right)^2+V_{M,ix}^2}=\frac{1}{2}\sqrt{\left(1.287\cdot10^5\,N+9.993\cdot10^4\,N\right)^2+2.080\cdot10^5\,N}=1.545\cdot10^5\,N$$

or $$\frac{1}{2}\sqrt{\left(V/6-V_{Mi,y}\right)^2+V_{M,ix}^2}=\frac{1}{2}\sqrt{\left(1.287\cdot10^5\,N-9.993\cdot10^4\,N\right)^2+2.080\cdot10^5\,N}=1.050\cdot10^5\,N$$

CSE computes the same values:

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-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------

Inst  Combi  Name Bolt -?-       NB           NTB           TuB           TvB          TB           MuB         MvB          MB        Expl  cause

    1     1    B5   1   1  -4.001e-012  -4.001e-012  -1.040e+005  -1.437e+004  1.050e+005   1.609e+004  1.997e-009   1.609e+004   0.860 resis
    1     1    B5   1   2   4.001e-012   4.001e-012   1.040e+005   1.437e+004  1.050e+005   1.609e+004  1.997e-009   1.609e+004   0.860
    1     1    B5   2   1  -4.001e-012  -4.001e-012  -1.040e+005  -1.143e+005  1.546e+005   1.609e+004  1.997e-009   1.609e+004   1.266 resis ***
    1     1    B5   2   2   4.001e-012   4.001e-012   1.040e+005   1.143e+005  1.546e+005   1.609e+004  1.997e-009   1.609e+004   1.266       ***
    1     1    B5   3   1  -4.001e-012  -4.001e-012   7.987e-009  -1.437e+004  1.437e+004   1.609e+004  1.997e-009   1.609e+004   0.118
    1     1    B5   3   2   4.001e-012   4.001e-012  -7.987e-009   1.437e+004  1.437e+004   1.609e+004  1.997e-009   1.609e+004   0.118 resis
    1     1    B5   4   1  -4.001e-012  -4.001e-012   7.987e-009  -1.143e+005  1.143e+005   1.609e+004  1.997e-009   1.609e+004   0.936
    1     1    B5   4   2   4.001e-012   4.001e-012  -7.987e-009   1.143e+005  1.143e+005   1.609e+004  1.997e-009   1.609e+004   0.936 resis
    1     1    B5   5   1  -4.001e-012  -4.001e-012   1.040e+005  -1.437e+004  1.050e+005   1.609e+004  1.997e-009   1.609e+004   0.860 resis
    1     1    B5   5   2   4.001e-012   4.001e-012  -1.040e+005   1.437e+004  1.050e+005   1.609e+004  1.997e-009   1.609e+004   0.860
    1     1    B5   6   1  -4.001e-012  -4.001e-012   1.040e+005  -1.143e+005  1.546e+005   1.609e+004  1.997e-009   1.609e+004   1.266 resis ***
    1     1    B5   6   2   4.001e-012   4.001e-012  -1.040e+005   1.143e+005  1.546e+005   1.609e+004  1.997e-009   1.609e+004   1.266       ***

    1     1    B6   1   1  -3.940e-012  -3.940e-012   1.040e+005   1.437e+004  1.050e+005  -1.609e+004  1.997e-009   1.609e+004   0.860
    1     1    B6   1   2   3.940e-012   3.940e-012  -1.040e+005  -1.437e+004  1.050e+005  -1.609e+004  1.997e-009   1.609e+004   0.860 resis
    1     1    B6   2   1  -3.940e-012  -3.940e-012   1.040e+005   1.143e+005  1.546e+005  -1.609e+004  1.997e-009   1.609e+004   1.266 resis ***
    1     1    B6   2   2   3.940e-012   3.940e-012  -1.040e+005  -1.143e+005  1.546e+005  -1.609e+004  1.997e-009   1.609e+004   1.266       ***
    1     1    B6   3   1  -3.940e-012  -3.940e-012   7.987e-009   1.437e+004  1.437e+004  -1.609e+004  1.997e-009   1.609e+004   0.118 resis
    1     1    B6   3   2   3.940e-012   3.940e-012  -7.987e-009  -1.437e+004  1.437e+004  -1.609e+004  1.997e-009   1.609e+004   0.118
    1     1    B6   4   1  -3.940e-012  -3.940e-012   7.987e-009   1.143e+005  1.143e+005  -1.609e+004  1.997e-009   1.609e+004   0.936 resis
    1     1    B6   4   2   3.940e-012   3.940e-012  -7.987e-009  -1.143e+005  1.143e+005  -1.609e+004  1.997e-009   1.609e+004   0.936
    1     1    B6   5   1  -3.940e-012  -3.940e-012  -1.040e+005   1.437e+004  1.050e+005  -1.609e+004  1.997e-009   1.609e+004   0.860
    1     1    B6   5   2   3.940e-012   3.940e-012   1.040e+005  -1.437e+004  1.050e+005  -1.609e+004  1.997e-009   1.609e+004   0.860 resis
    1     1    B6   6   1  -3.940e-012  -3.940e-012  -1.040e+005   1.143e+005  1.546e+005  -1.609e+004  1.997e-009   1.609e+004   1.266 resis ***
    1     1    B6   6   2   3.940e-012   3.940e-012   1.040e+005  -1.143e+005  1.546e+005  -1.609e+004  1.997e-009   1.609e+004   1.266       ***
```

NOTE WELL: CSE computes also bending in bolts shaft, but here we have excluded the from the checks (this choice is up to the user).

Utilization of bolts belonging to layouts B1, B2, B3 and B4 are null, since they carry no loads.

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-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------

Inst  Combi  Name Bolt -?-       NB           NTB           TuB           TvB          TB           MuB         MvB          MB        Expl  cause

    1     1    B3   1   1   1.010e+000   1.010e+000  -8.165e-008  -2.460e-005  2.460e-005   2.019e+002  2.081e-007   2.019e+002   0.000 resis
    1     1    B3   2   1   1.010e+000   1.010e+000  -8.165e-008  -2.486e-005  2.486e-005   2.019e+002  2.081e-007   2.019e+002   0.000 resis
```

1	1	B3	3	1	1.010e+000	1.010e+000	-1.143e-008	-2.460e-005	2.460e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	4	1	1.010e+000	1.010e+000	-1.143e-008	-2.486e-005	2.486e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	5	1	1.010e+000	1.010e+000	5.879e-008	-2.460e-005	2.460e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	6	1	1.010e+000	1.010e+000	5.879e-008	-2.486e-005	2.486e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	7	1	1.010e+000	1.010e+000	1.290e-007	-2.460e-005	2.460e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	8	1	1.010e+000	1.010e+000	1.290e-007	-2.486e-005	2.486e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	9	1	1.010e+000	1.010e+000	1.992e-007	-2.460e-005	2.460e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	10	1	1.010e+000	1.010e+000	1.992e-007	-2.486e-005	2.486e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	11	1	1.010e+000	1.010e+000	2.695e-007	-2.460e-005	2.460e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	12	1	1.010e+000	1.010e+000	2.695e-007	-2.486e-005	2.486e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	13	1	1.010e+000	1.010e+000	3.397e-007	-2.460e-005	2.460e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B3	14	1	1.010e+000	1.010e+000	3.397e-007	-2.486e-005	2.486e-005	2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	1	1	-1.010e+000	-1.010e+000	-8.165e-008	2.486e-005	2.486e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	2	1	-1.010e+000	-1.010e+000	-8.165e-008	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	3	1	-1.010e+000	-1.010e+000	-1.143e-008	2.486e-005	2.486e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	4	1	-1.010e+000	-1.010e+000	-1.143e-008	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	5	1	-1.010e+000	-1.010e+000	5.879e-008	2.486e-005	2.486e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	6	1	-1.010e+000	-1.010e+000	5.879e-008	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	7	1	-1.010e+000	-1.010e+000	1.290e-007	2.486e-005	2.486e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	8	1	-1.010e+000	-1.010e+000	1.290e-007	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	9	1	-1.010e+000	-1.010e+000	1.992e-007	2.486e-005	2.486e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	10	1	-1.010e+000	-1.010e+000	1.992e-007	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	11	1	-1.010e+000	-1.010e+000	2.695e-007	2.486e-005	2.486e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	12	1	-1.010e+000	-1.010e+000	2.695e-007	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	13	1	-1.010e+000	-1.010e+000	3.397e-007	2.486e-005	2.487e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B1	14	1	-1.010e+000	-1.010e+000	3.397e-007	2.461e-005	2.461e-005	-2.019e+002	2.081e-007	2.019e+002	0.000	resis
1	1	B2	1	1	-1.010e+000	-1.010e+000	-3.397e-007	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	2	1	-1.010e+000	-1.010e+000	-3.397e-007	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	3	1	-1.010e+000	-1.010e+000	-2.695e-007	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	4	1	-1.010e+000	-1.010e+000	-2.695e-007	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	5	1	-1.010e+000	-1.010e+000	-1.992e-007	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	6	1	-1.010e+000	-1.010e+000	-1.992e-007	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	7	1	-1.010e+000	-1.010e+000	-1.290e-007	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	8	1	-1.010e+000	-1.010e+000	-1.290e-007	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	9	1	-1.010e+000	-1.010e+000	-5.879e-008	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	10	1	-1.010e+000	-1.010e+000	-5.879e-008	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	11	1	-1.010e+000	-1.010e+000	1.143e-008	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	12	1	-1.010e+000	-1.010e+000	1.143e-008	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	13	1	-1.010e+000	-1.010e+000	8.165e-008	2.486e-005	2.486e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B2	14	1	-1.010e+000	-1.010e+000	8.165e-008	2.460e-005	2.460e-005	2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	1	1	1.010e+000	1.010e+000	-3.397e-007	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	2	1	1.010e+000	1.010e+000	-3.397e-007	-2.486e-005	2.487e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	3	1	1.010e+000	1.010e+000	-2.695e-007	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	4	1	1.010e+000	1.010e+000	-2.695e-007	-2.486e-005	2.486e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	5	1	1.010e+000	1.010e+000	-1.992e-007	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	6	1	1.010e+000	1.010e+000	-1.992e-007	-2.486e-005	2.486e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	7	1	1.010e+000	1.010e+000	-1.290e-007	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	8	1	1.010e+000	1.010e+000	-1.290e-007	-2.486e-005	2.486e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	9	1	1.010e+000	1.010e+000	-5.879e-008	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	10	1	1.010e+000	1.010e+000	-5.879e-008	-2.486e-005	2.486e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	11	1	1.010e+000	1.010e+000	1.143e-008	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	12	1	1.010e+000	1.010e+000	1.143e-008	-2.486e-005	2.486e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	13	1	1.010e+000	1.010e+000	8.165e-008	-2.461e-005	2.461e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis
1	1	B4	14	1	1.010e+000	1.010e+000	8.165e-008	-2.486e-005	2.486e-005	-2.019e+002	-2.081e-007	2.019e+002	0.000	resis

Let's choose a bolt of layout B6, for example bolt 6, and compute its utilization.

$$R_6 / F_{V,Rd} = 1.546 \cdot 10^5 \text{N} / 1.221 \cdot 10^5 \text{N} = 1.266$$

CSE computes the same value ($F_{V,Rd}$ was computed in B.2.1.2)

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause	
1	1	B6	6	1	-3.940e-012	-3.940e-012	-1.040e+005	1.143e+005	1.546e+005	-1.609e+004	1.997e-009	1.609e+004	1.266	resis	***
1	1	B6	6	2	3.940e-012	3.940e-012	1.040e+005	-1.143e+005	1.546e+005	-1.609e+004	1.997e-009	1.609e+004	1.266		***

Now we are going to validate bolt bearing on the members (one of them, since they are I the same condition). Flanges bolts are not loaded; let's consider web bolts (choosing most loaded bolt). Force acting on member is twice the internal force in bolts check sections. Considering bolt 6 of layout B6, we have the following forces on member:

$$F_x = V_{Mi,x} = 2.080 \cdot 10^5 \text{N}$$

$$F_y = V/6 + V_{Mi,y} = 1.287 \cdot 10^5 \text{N} + 9.993 \cdot 10^4 \text{N} = 2.286 \cdot 10^5 \text{N}$$

According to EN1993-1-8:2005, we have (see formulae in the appendix, Figure D-4):

Bolt bearing		(B5 bolt 6)	
Fx	2,080E+05	Fy	2,286E+05
$F_{b,Rd,x}$	6,043E+04	$F_{b,Rd,y}$	5,919E+04
k_1	1,87	k_1	1,73
$2{,}8e_2/d_0-1{,}7$	5,23	$2{,}8e_2/d_0-1{,}7$	5,23
$1{,}4p_2/d_0-1{,}7$	1,87	$1{,}4p_2/d_0-1{,}7$	1,73
	2,5		2,5
a_b	0,566666667	a_b	0,600
a_d	0,825	a_d	0,825
f_{ub}/f_u	2,78	f_{ub}/f_u	2,78
$p_1/3d_0-0{,}25$	0,57	$p_1/3d_0-0{,}25$	0,60
	1		1
fu	360	fu	360
d	18	d	18
d_0	20	d_0	20
t	11	t	11
$e_1=\min(e_1,e_2)$	49,5	e_1	49,5
$e_2=\min(e_1,e_2)$	49,5	e_2	49,5
p_1	49	p_1	51
p_2	51	p_2	49
expl x	3,442	expl y	3,863
	EXPL=	**5,174**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\text{expl} = \sqrt{\text{expl}_x^2 + \text{expl}_y^2} = 5.174$$

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

We have chose the most loaded bolt to compute the utilization (exploitation), but, as we can see in the following abstract, CSE computes a higher utilization, caused by another bolt:

```
-------------------------------------------------------------------
Members whose maximum utilization ratio is due to bearing stresses
-------------------------------------------------------------------

 Inst Combi  Name   Boltlay   Bolt   Extr.        Sigma       Sigma M    Expl
                                                ( N/ mm²)    ( N/ mm²)

    1     1    m1      B5        6       2       1561.4        301.7   5.175 !!!
    1     1    m2      B6        2       2       1561.4        301.7   5.175 !!!
```

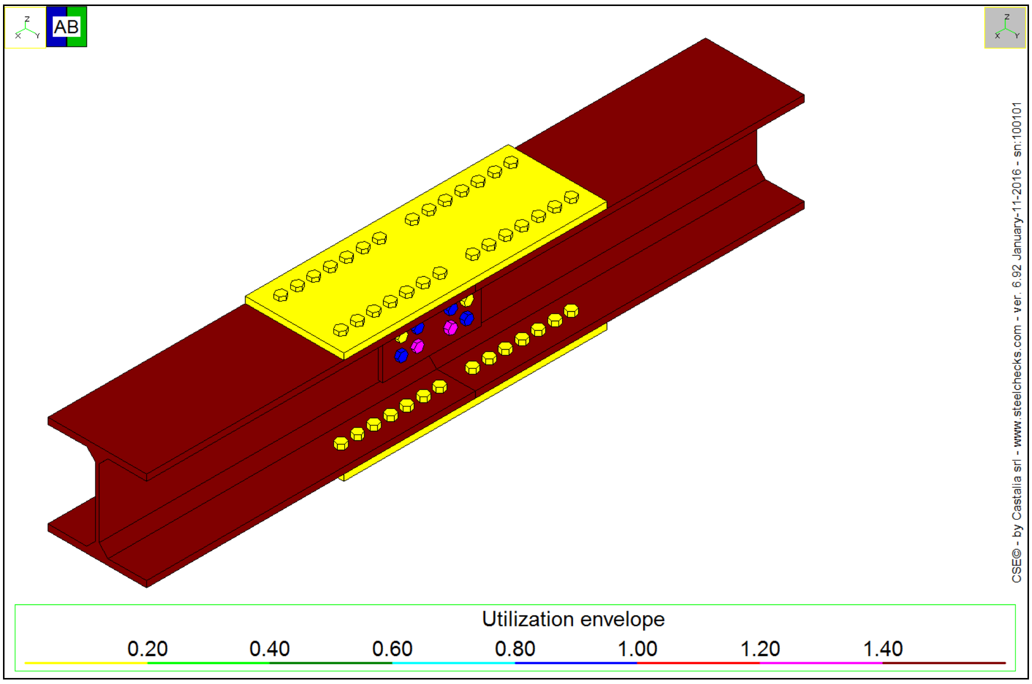


Figure B-33 Components utilization envelope

B.2.1.4 Axial force

Now let's check previous joint behaviour under axial force (model name: *Validation_SP_1_3.CSE*). Consider plastic limit of the member, with an overstrength factor equal to 1.2. The force applied to imported Fem model is:

$$N_{pl}=A_{sez}*f_y*\gamma_{RD}=14908*235*1.2=4204056N$$

In the current model we have 34 bolts (M18, class 10.9). We can compute the minimum number of bolts needed to carry the applied force:

$$n_{min}*A_b*f_{yb}=N_{pl} \rightarrow n_{min}=N_{pl}/A_b/f_{yb}=31.83 \rightarrow \text{32 bolts needed}$$

This is the minimum number of bolts needed to carry the loads, but it is not guaranteed that 32 bolts are able to do that: it depends also on the distribution of the appliad load on flanges and web bolt layouts.

Flanges area is A_f=2*b*t_f=11400mm: the part of total plastic axial force carried by flanges only is 3214800N, considering also the overstrength factor. 24.31 (→ 25) bolts would be enough, and we have 28 bolts on flanges. Just with this simplified computation, it seems that web bolts would not be able to carry the load. Web area is $A_w=A-A_f$. It could be able to carry a part of total axial force equal to 989256N (including overstrength). Needed bolts are 7.48 → 8, but we have 6 bolts only.

As previously said, it this not guaranteed that total axial force will be distributed on web and flanges bolt layouts proportionally to web and flanges area. Assuming that distribution, we would need to add bolts on the web. Let’s see what happens with current geometry. Note well: in part C we will see how to drive forces distribution in different layouts (flexibility index). The most important aspect is that, even changing layouts stiffness, and subsequently forces distribution) CSE always guarantees the equilibrium of the forces. For current model, CSE computes the following distribution.

```
-------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
-------------------------------------------------------------------
```

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B3	1	1	1	-1.6007e-010	1.0819e+006	2.7009e-010	1.0548e+007	1.5606e-009	-6.0132e-006
B3	1	1	2	1.6007e-010	-1.0819e+006	-2.7009e-010	1.0548e+007	1.5606e-009	6.0132e-006
B1	1	1	1	1.4908e-010	1.0819e+006	2.6322e-010	1.0548e+007	-1.4536e-009	6.0132e-006
B1	1	1	2	-1.4908e-010	-1.0819e+006	-2.6322e-010	1.0548e+007	-1.4536e-009	-6.0132e-006
B2	1	1	1	1.4908e-010	-1.0819e+006	-2.6516e-010	-1.0548e+007	-1.4536e-009	6.0420e-006
B2	1	1	2	-1.4908e-010	1.0819e+006	2.6516e-010	-1.0548e+007	-1.4536e-009	-6.0420e-006
B4	1	1	1	-1.4908e-010	-1.0819e+006	-2.5828e-010	-1.0548e+007	1.4536e-009	-6.0420e-006
B4	1	1	2	1.4908e-010	1.0819e+006	2.5828e-010	-1.0548e+007	1.4536e-009	6.0420e-006
B5	1	1	1	1.0202e+006	-9.3910e-008	-4.3837e-010	-5.3998e-007	-5.8659e+006	-4.1364e-005
B5	1	1	2	-2.0403e+006	1.8782e-007	2.3006e-010	1.6357e-016	-1.2120e-005	8.2728e-005
B5	1	1	3	1.0202e+006	-9.3910e-008	2.0831e-010	5.3998e-007	5.8659e+006	-4.1363e-005
B6	1	1	1	1.0202e+006	9.3910e-008	2.0814e-010	5.3998e-007	-5.8659e+006	-2.7465e-005
B6	1	1	2	-2.0403e+006	-1.8782e-007	2.3036e-010	6.4694e-016	-1.2047e-005	5.4930e-005
B6	1	1	3	1.0202e+006	9.3910e-008	-4.3850e-010	-5.3998e-007	5.8659e+006	-2.7465e-005

The load carried by flanges bolt layouts is $2*1.0819*10^6$N=$2.1638*10^6$N (two flanges); the load carried by the web bolt layout is $2.0403*10^6$N (force sign depends on layout reference system). Web carries a higher load than the one computed considering areas ratios, because bolt layouts stiffness depends from bolts net length. On the web we have two cover plates, on the flanges there is a cover plate only, so web layout is more stiff. It is clear that previously computed minimum bolts number for bolts is not enough.

Divide total flanges layout force by bolts number to find the force on each bolt:

$$2.1638*10^6\text{N} / 28 = 7.728*10^4\text{N}$$

Now divide half[1] of web layout force by bolts number to find the force on each bolt:

$$2.0403*10^6\text{N} / 6 /2 = 1.700*10^5\text{N}$$

Dividing the force on each bolt by design resistance $F_{V,Rd}$ (previously computed in B.2.1.2), we get the following utilization factors:

$$\text{flanges: } 7.728*10^4\text{N} / 1.221*10^5\text{N} = 0.633 < 1$$

$$\text{web: } 1.700*10^5\text{N} / 1.221*10^5\text{N} = 1.392 > 1$$

[1] Since we have two check sections, each one carries half of the load, as previously said.

CSE computes the same values.

```
------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B3	1	1	1.929e-011	1.929e-011	-3.518e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	2	1	1.929e-011	1.929e-011	-3.518e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	3	1	1.929e-011	1.929e-011	-2.349e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	4	1	1.929e-011	1.929e-011	-2.349e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	5	1	1.929e-011	1.929e-011	-1.180e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	6	1	1.929e-011	1.929e-011	-1.180e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	7	1	1.929e-011	1.929e-011	-1.143e-011	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	8	1	1.929e-011	1.929e-011	-1.143e-011	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	9	1	1.929e-011	1.929e-011	1.157e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	10	1	1.929e-011	1.929e-011	1.157e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	11	1	1.929e-011	1.929e-011	2.326e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	12	1	1.929e-011	1.929e-011	2.326e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	13	1	1.929e-011	1.929e-011	3.495e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B3	14	1	1.929e-011	1.929e-011	3.495e-009	7.728e+004	7.728e+004	-1.932e+004	-2.858e-012	1.932e+004	0.633	resis
1	1	B1	1	1	1.880e-011	1.880e-011	3.517e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	2	1	1.880e-011	1.880e-011	3.517e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	3	1	1.880e-011	1.880e-011	2.348e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	4	1	1.880e-011	1.880e-011	2.348e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	5	1	1.880e-011	1.880e-011	1.180e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	6	1	1.880e-011	1.880e-011	1.180e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	7	1	1.880e-011	1.880e-011	1.065e-011	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	8	1	1.880e-011	1.880e-011	1.065e-011	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	9	1	1.880e-011	1.880e-011	-1.158e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	10	1	1.880e-011	1.880e-011	-1.158e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	11	1	1.880e-011	1.880e-011	-2.327e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	12	1	1.880e-011	1.880e-011	-2.327e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	13	1	1.880e-011	1.880e-011	-3.496e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B1	14	1	1.880e-011	1.880e-011	-3.496e-009	7.728e+004	7.728e+004	-1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	1	1	-1.894e-011	-1.894e-011	3.534e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	2	1	-1.894e-011	-1.894e-011	3.534e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	3	1	-1.894e-011	-1.894e-011	2.360e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	4	1	-1.894e-011	-1.894e-011	2.360e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	5	1	-1.894e-011	-1.894e-011	1.185e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	6	1	-1.894e-011	-1.894e-011	1.185e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	7	1	-1.894e-011	-1.894e-011	1.065e-011	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	8	1	-1.894e-011	-1.894e-011	1.065e-011	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	9	1	-1.894e-011	-1.894e-011	-1.164e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	10	1	-1.894e-011	-1.894e-011	-1.164e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	11	1	-1.894e-011	-1.894e-011	-2.338e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	12	1	-1.894e-011	-1.894e-011	-2.338e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	13	1	-1.894e-011	-1.894e-011	-3.513e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B2	14	1	-1.894e-011	-1.894e-011	-3.513e-009	-7.728e+004	7.728e+004	1.932e+004	2.662e-012	1.932e+004	0.633	resis
1	1	B4	1	1	-1.845e-011	-1.845e-011	-3.534e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	2	1	-1.845e-011	-1.845e-011	-3.534e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	3	1	-1.845e-011	-1.845e-011	-2.360e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	4	1	-1.845e-011	-1.845e-011	-2.360e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	5	1	-1.845e-011	-1.845e-011	-1.185e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	6	1	-1.845e-011	-1.845e-011	-1.185e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	7	1	-1.845e-011	-1.845e-011	-1.065e-011	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	8	1	-1.845e-011	-1.845e-011	-1.065e-011	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	9	1	-1.845e-011	-1.845e-011	1.164e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	10	1	-1.845e-011	-1.845e-011	1.164e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	11	1	-1.845e-011	-1.845e-011	2.338e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	12	1	-1.845e-011	-1.845e-011	2.338e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	13	1	-1.845e-011	-1.845e-011	3.513e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B4	14	1	-1.845e-011	-1.845e-011	3.513e-009	-7.728e+004	7.728e+004	1.932e+004	-2.662e-012	1.932e+004	0.633	resis
1	1	B5	1	1	-7.306e-011	-7.306e-011	1.700e+005	5.671e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B5	1	2	-3.472e-011	-3.472e-011	-1.700e+005	-5.671e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B5	2	1	-7.306e-011	-7.306e-011	1.700e+005	-8.801e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B5	2	2	-3.472e-011	-3.472e-011	-1.700e+005	8.801e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B5	3	1	-7.306e-011	-7.306e-011	1.700e+005	5.671e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B5	3	2	-3.472e-011	-3.472e-011	-1.700e+005	-5.671e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B5	4	1	-7.306e-011	-7.306e-011	1.700e+005	-8.801e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B5	4	2	-3.472e-011	-3.472e-011	-1.700e+005	8.801e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B5	5	1	-7.306e-011	-7.306e-011	1.700e+005	5.671e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B5	5	2	-3.472e-011	-3.472e-011	-1.700e+005	-5.671e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B5	6	1	-7.306e-011	-7.306e-011	1.700e+005	-8.801e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B5	6	2	-3.472e-011	-3.472e-011	-1.700e+005	8.801e-008	1.700e+005	3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B6	1	1	3.469e-011	3.469e-011	1.700e+005	6.370e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B6	1	2	7.308e-011	7.308e-011	-1.700e+005	-6.370e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B6	2	1	3.469e-011	3.469e-011	1.700e+005	-3.239e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B6	2	2	7.308e-011	7.308e-011	-1.700e+005	3.239e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B6	3	1	3.469e-011	3.469e-011	1.700e+005	6.370e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B6	3	2	7.308e-011	7.308e-011	-1.700e+005	-6.370e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B6	4	1	3.469e-011	3.469e-011	1.700e+005	-3.239e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B6	4	2	7.308e-011	7.308e-011	-1.700e+005	3.239e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B6	5	1	3.469e-011	3.469e-011	1.700e+005	6.370e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B6	5	2	7.308e-011	7.308e-011	-1.700e+005	-6.370e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	!!!
1	1	B6	6	1	3.469e-011	3.469e-011	1.700e+005	-3.239e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	resis !!!
1	1	B6	6	2	7.308e-011	7.308e-011	-1.700e+005	3.239e-008	1.700e+005	-3.913e-009	4.251e+004	4.251e+004	1.392	!!!

According to EN1993-1-8:2005 (see appendix or previous paragraphs) now we compute bolt beating for member web. All bolts are to be considered end/edge in the direction parallel to load transfer (α_d computation) since we have two columns only; in normal direction (k_1 computation) central bolts are inner, other bolts are end edge. We are going to compute bolt bearing on web for both central and external bolts. Force applied to the web is twice the internal force in bolts. (2*1.700e+05N=3.400e+05N).

Fx	3,400E+05
$F_{b,Rd,x}$	6,043E+04
k_1	1,87
$2,8e_2/d_0$-1,7	5,23
$1,4p_2/d_0$-1,7	1,87
	2,5
a_b	0,566666667
a_d	0,825
f_{ub}/f_u	2,78
$p_1/3d_0$-0,25	0,57
	1
fu	360
d	18
d_0	20
t	11
e_1=min(e_1,e_2)	49,5
e_2=min(e_1,e_2)	49,5
p_1	49
p_2	51
expl x	5,627

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

For inner bolts we have:

Fx	3,400E+05
$F_{b,Rd,x}$	6,043E+04
k_1	1,87
$1,4p_2/d_0$-1,7	1,87
	2,5
a_b	0,56666667
a_d	0,825
f_{ub}/f_u	2,78
$p_1/3d_0$-0,25	0,57
	1
fu	360
d	18
d_0	20
t	11
e_1=min(e_1,e_2)	49,5
e_2=min(e_1,e_2)	49,5
p_1	49

p_2	51
expl x	5,627

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

The results are equal as for edge bolts we have to keep into account also the inner distance to the next bolt, and this is the governing parameter.

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

Maximum utilization (3.865) is due to inner bolts. The same values is computed by CSE.

```
-----------------------------------------------------------------
Members whose maximum utilization ratio is due to bearing stresses
-----------------------------------------------------------------

 Inst Combi  Name   Boltlay   Bolt   Extr.        Sigma      Sigma M    Expl
                                                ( N/ mm²)    ( N/ mm²)

    1     1    m1      B5        1       2        1717.4       305.2   5.628 !!!
    1     1    m2      B6        1       2        1717.4       305.2   5.628 !!!
```

It is clear that web bolts number should be increased, with this computation settings, to reduce web utilization for bolt bearing. In a real case, bolt bearing would cause a re-distribution of forces in flanges layout. For this reason, flexibility index has been added to CSE. It is used to modify bolt layout translational stiffness (see part C). With the flexibility index is possible to assign a greater load to the flanges and reach a checked condition of the joint, simulating forces re-distribution after bolt bearing.

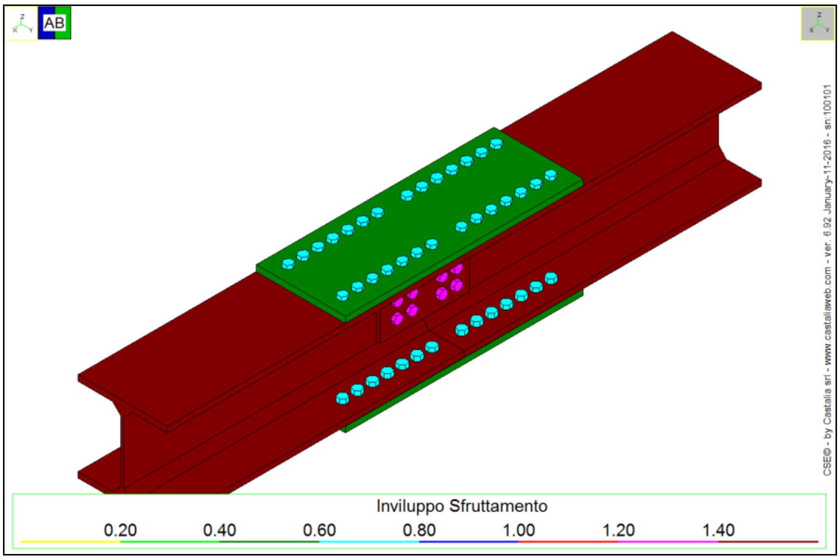


Figure B-34 Components utilization envelope

B.2.1.5 Bending about weak axis

Model used is *Validation_SP_1_4.CSE*. Plastic moment of the cross-section about weak axis, including a 1.2 overstrength factor, is.

$$M_{pl,z} = W_{pl,z} \times f_y \times \gamma_{RD} = 2.454e+08\text{N}$$

Constraints and loads in original imported FEM model were properly set to get that value in joint node. This is forces distribution computed by CSE.

Forces acting over bolt layouts at different extremes, global system
----

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B3	1	1	1	5.9052e-005	-1.1188e-008	-4.7302e-022	-1.0908e-007	-5.3546e-004	1.2232e+008
B3	1	1	2	-5.9052e-005	1.1188e-008	4.7302e-022	-1.0908e-007	-6.1604e-004	-1.2232e+008
B1	1	1	1	-6.6056e-005	-1.1188e-008	4.6750e-022	-1.0908e-007	5.9421e-004	-1.2232e+008
B1	1	1	2	6.6056e-005	1.1188e-008	-4.6750e-022	-1.0908e-007	6.9389e-004	1.2232e+008
B2	1	1	1	-4.9807e-005	1.1188e-008	4.7297e-022	1.0908e-007	5.3546e-004	-1.2232e+008
B2	1	1	2	4.9807e-005	-1.1188e-008	-4.7297e-022	1.0908e-007	4.3578e-004	1.2232e+008
B4	1	1	1	5.6812e-005	1.1188e-008	-4.6755e-022	1.0908e-007	-5.9421e-004	1.2232e+008
B4	1	1	2	-5.6812e-005	-1.1188e-008	4.6755e-022	1.0908e-007	-5.1362e-004	-1.2232e+008
B5	1	1	1	-2.1088e+004	1.0335e-007	-1.2758e-005	-2.8744e-006	-1.3350e+005	7.6482e-006
B5	1	1	2	6.4560e-008	-3.1504e-017	2.5509e-005	8.1259e-006	7.5203e+005	4.6753e-011
B5	1	1	3	2.1088e+004	-1.0335e-007	-1.2751e-005	-2.8744e-006	-1.3350e+005	-7.6482e-006
B6	1	1	1	2.1088e+004	1.0335e-007	1.2785e-005	-2.8744e-006	1.3350e+005	7.6482e-006
B6	1	1	2	-2.2370e-008	6.8821e-022	-2.5611e-005	8.1259e-006	-7.5203e+005	4.6049e-011
B6	1	1	3	-2.1088e+004	-1.0335e-007	1.2826e-005	-2.8744e-006	1.3350e+005	-7.6482e-006

CSE assings 1.2232e+08Nmm to each flange bolt layout and 7.5203×10^5Nmm to web bolt layout. Total moment is equal to applied moment:

$$2 \times 1.2232 \times 10^8\text{Nmm} + 7.5203 \times 10^5\text{Nmm} = 2.454 \times 10^8\text{Nmm}$$

Bending in web bolt layouts[2] (B5 and B6) produces shears with opposite sign in bolt layout external extremes.

We are going to compute the force in each bolt of flanges layout. According to what was previously done for web bolt layout (see Figure B-32), the force in a bolt depends on total torque, polar inertia moment (J_p) of the layout ad bolt distance from layout centre.

Polar inertia moment was previously computer in paragraph B.1.2; it is J_p=257211mm^2: Force acting on each bolt is equal to:

$$T_b, i = \frac{M_t / 2}{J_p} \times d_i$$

[2] Note well: we are using “shear only” bolts, so there is no axial force in shafts

According to Figure B-3, the 14 bolts have four different distances from layout centre. Distances are given in the following table. Shear in bolts ($V_{b,i}$) depend on bolts distance d_i; utilization factor is also printed ($V_{b,i}$ / $F_{V,Rd}$, see B.2.1.2).

d_i [mm]	$V_{b,i}$ [N]	*expl*
91.5	4.352E+04	0.356
104.3	4.959E+04	0.406
135.5	6.446E+04	0.528
175.7	8.356E+04	0.684

On the web, all bolts carry the same load equal to layout shear divided by bolts number:

$$2.1086*10^4 / 6 = 3.514*10^3 N$$

with an utilization equal to 0.029. CSE computes the same values.

```
--------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
--------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B3	1	1	-3.379e-023	-3.379e-023	7.133e+004	-4.351e+004	8.356e+004	1.998e-010	3.932e-006	3.932e-006	0.684	resis
1	1	B3	2	1	-3.379e-023	-3.379e-023	7.133e+004	4.351e+004	8.356e+004	1.998e-010	3.932e-006	3.932e-006	0.684	resis
1	1	B3	3	1	-3.379e-023	-3.379e-023	4.755e+004	-4.351e+004	6.446e+004	1.998e-010	3.932e-006	3.932e-006	0.528	resis
1	1	B3	4	1	-3.379e-023	-3.379e-023	4.755e+004	4.351e+004	6.446e+004	1.998e-010	3.932e-006	3.932e-006	0.528	resis
1	1	B3	5	1	-3.379e-023	-3.379e-023	2.378e+004	-4.351e+004	4.959e+004	1.998e-010	3.932e-006	3.932e-006	0.406	resis
1	1	B3	6	1	-3.379e-023	-3.379e-023	2.378e+004	4.351e+004	4.959e+004	1.998e-010	3.932e-006	3.932e-006	0.406	resis
1	1	B3	7	1	-3.379e-023	-3.379e-023	4.218e-006	-4.351e+004	4.351e+004	1.998e-010	3.932e-006	3.932e-006	0.356	resis
1	1	B3	8	1	-3.379e-023	-3.379e-023	4.218e-006	4.351e+004	4.351e+004	1.998e-010	3.932e-006	3.932e-006	0.356	resis
1	1	B3	9	1	-3.379e-023	-3.379e-023	-2.378e+004	-4.351e+004	4.959e+004	1.998e-010	3.932e-006	3.932e-006	0.406	resis
1	1	B3	10	1	-3.379e-023	-3.379e-023	-2.378e+004	4.351e+004	4.959e+004	1.998e-010	3.932e-006	3.932e-006	0.406	resis
1	1	B3	11	1	-3.379e-023	-3.379e-023	-4.755e+004	-4.351e+004	6.446e+004	1.998e-010	3.932e-006	3.932e-006	0.528	resis
1	1	B3	12	1	-3.379e-023	-3.379e-023	-4.755e+004	4.351e+004	6.446e+004	1.998e-010	3.932e-006	3.932e-006	0.528	resis
1	1	B3	13	1	-3.379e-023	-3.379e-023	-7.133e+004	-4.351e+004	8.356e+004	1.998e-010	3.932e-006	3.932e-006	0.684	resis
1	1	B3	14	1	-3.379e-023	-3.379e-023	-7.133e+004	4.351e+004	8.356e+004	1.998e-010	3.932e-006	3.932e-006	0.684	resis
1	1	B1	1	1	3.339e-023	3.339e-023	-7.133e+004	4.351e+004	8.356e+004	1.998e-010	-4.739e-006	4.739e-006	0.684	resis
1	1	B1	2	1	3.339e-023	3.339e-023	-7.133e+004	-4.351e+004	8.356e+004	1.998e-010	-4.739e-006	4.739e-006	0.684	resis
1	1	B1	3	1	3.339e-023	3.339e-023	-4.755e+004	4.351e+004	6.446e+004	1.998e-010	-4.739e-006	4.739e-006	0.528	resis
1	1	B1	4	1	3.339e-023	3.339e-023	-4.755e+004	-4.351e+004	6.446e+004	1.998e-010	-4.739e-006	4.739e-006	0.528	resis
1	1	B1	5	1	3.339e-023	3.339e-023	-2.378e+004	4.351e+004	4.959e+004	1.998e-010	-4.739e-006	4.739e-006	0.406	resis
1	1	B1	6	1	3.339e-023	3.339e-023	-2.378e+004	-4.351e+004	4.959e+004	1.998e-010	-4.739e-006	4.739e-006	0.406	resis
1	1	B1	7	1	3.339e-023	3.339e-023	-4.718e-006	4.351e+004	4.351e+004	1.998e-010	-4.739e-006	4.739e-006	0.356	resis
1	1	B1	8	1	3.339e-023	3.339e-023	-4.718e-006	-4.351e+004	4.351e+004	1.998e-010	-4.739e-006	4.739e-006	0.356	resis
1	1	B1	9	1	3.339e-023	3.339e-023	2.378e+004	4.351e+004	4.959e+004	1.998e-010	-4.739e-006	4.739e-006	0.406	resis
1	1	B1	10	1	3.339e-023	3.339e-023	2.378e+004	-4.351e+004	4.959e+004	1.998e-010	-4.739e-006	4.739e-006	0.406	resis
1	1	B1	11	1	3.339e-023	3.339e-023	4.755e+004	4.351e+004	6.446e+004	1.998e-010	-4.739e-006	4.739e-006	0.528	resis
1	1	B1	12	1	3.339e-023	3.339e-023	4.755e+004	-4.351e+004	6.446e+004	1.998e-010	-4.739e-006	4.739e-006	0.528	resis
1	1	B1	13	1	3.339e-023	3.339e-023	7.133e+004	4.351e+004	8.356e+004	1.998e-010	-4.739e-006	4.739e-006	0.684	resis
1	1	B1	14	1	3.339e-023	3.339e-023	7.133e+004	-4.351e+004	8.356e+004	1.998e-010	-4.739e-006	4.739e-006	0.684	resis
1	1	B2	1	1	3.378e-023	3.378e-023	-7.133e+004	4.351e+004	8.356e+004	-1.998e-010	2.671e-006	2.671e-006	0.684	resis
1	1	B2	2	1	3.378e-023	3.378e-023	-7.133e+004	-4.351e+004	8.356e+004	-1.998e-010	2.671e-006	2.671e-006	0.684	resis
1	1	B2	3	1	3.378e-023	3.378e-023	-4.755e+004	4.351e+004	6.446e+004	-1.998e-010	2.671e-006	2.671e-006	0.528	resis
1	1	B2	4	1	3.378e-023	3.378e-023	-4.755e+004	-4.351e+004	6.446e+004	-1.998e-010	2.671e-006	2.671e-006	0.528	resis
1	1	B2	5	1	3.378e-023	3.378e-023	-2.378e+004	4.351e+004	4.959e+004	-1.998e-010	2.671e-006	2.671e-006	0.406	resis
1	1	B2	6	1	3.378e-023	3.378e-023	-2.378e+004	-4.351e+004	4.959e+004	-1.998e-010	2.671e-006	2.671e-006	0.406	resis
1	1	B2	7	1	3.378e-023	3.378e-023	-3.558e-006	4.351e+004	4.351e+004	-1.998e-010	2.671e-006	2.671e-006	0.356	resis
1	1	B2	8	1	3.378e-023	3.378e-023	-3.558e-006	-4.351e+004	4.351e+004	-1.998e-010	2.671e-006	2.671e-006	0.356	resis
1	1	B2	9	1	3.378e-023	3.378e-023	2.378e+004	4.351e+004	4.959e+004	-1.998e-010	2.671e-006	2.671e-006	0.406	resis
1	1	B2	10	1	3.378e-023	3.378e-023	2.378e+004	-4.351e+004	4.959e+004	-1.998e-010	2.671e-006	2.671e-006	0.406	resis
1	1	B2	11	1	3.378e-023	3.378e-023	4.755e+004	4.351e+004	6.446e+004	-1.998e-010	2.671e-006	2.671e-006	0.528	resis
1	1	B2	12	1	3.378e-023	3.378e-023	4.755e+004	-4.351e+004	6.446e+004	-1.998e-010	2.671e-006	2.671e-006	0.528	resis
1	1	B2	13	1	3.378e-023	3.378e-023	7.133e+004	4.351e+004	8.356e+004	-1.998e-010	2.671e-006	2.671e-006	0.684	resis
1	1	B2	14	1	3.378e-023	3.378e-023	7.133e+004	-4.351e+004	8.356e+004	-1.998e-010	2.671e-006	2.671e-006	0.684	resis
1	1	B4	1	1	-3.340e-023	-3.340e-023	7.133e+004	-4.351e+004	8.356e+004	-1.998e-010	-1.864e-006	1.864e-006	0.684	resis
1	1	B4	2	1	-3.340e-023	-3.340e-023	7.133e+004	4.351e+004	8.356e+004	-1.998e-010	-1.864e-006	1.864e-006	0.684	resis
1	1	B4	3	1	-3.340e-023	-3.340e-023	4.755e+004	-4.351e+004	6.446e+004	-1.998e-010	-1.864e-006	1.864e-006	0.528	resis
1	1	B4	4	1	-3.340e-023	-3.340e-023	4.755e+004	4.351e+004	6.446e+004	-1.998e-010	-1.864e-006	1.864e-006	0.528	resis
1	1	B4	5	1	-3.340e-023	-3.340e-023	2.378e+004	-4.351e+004	4.959e+004	-1.998e-010	-1.864e-006	1.864e-006	0.406	resis
1	1	B4	6	1	-3.340e-023	-3.340e-023	2.378e+004	4.351e+004	4.959e+004	-1.998e-010	-1.864e-006	1.864e-006	0.406	resis
1	1	B4	7	1	-3.340e-023	-3.340e-023	4.058e-006	-4.351e+004	4.351e+004	-1.998e-010	-1.864e-006	1.864e-006	0.356	resis
1	1	B4	8	1	-3.340e-023	-3.340e-023	4.058e-006	4.351e+004	4.351e+004	-1.998e-010	-1.864e-006	1.864e-006	0.356	resis
1	1	B4	9	1	-3.340e-023	-3.340e-023	-2.378e+004	-4.351e+004	4.959e+004	-1.998e-010	-1.864e-006	1.864e-006	0.406	resis
1	1	B4	10	1	-3.340e-023	-3.340e-023	-2.378e+004	4.351e+004	4.959e+004	-1.998e-010	-1.864e-006	1.864e-006	0.406	resis
1	1	B4	11	1	-3.340e-023	-3.340e-023	-4.755e+004	-4.351e+004	6.446e+004	-1.998e-010	-1.864e-006	1.864e-006	0.528	resis
1	1	B4	12	1	-3.340e-023	-3.340e-023	-4.755e+004	4.351e+004	6.446e+004	-1.998e-010	-1.864e-006	1.864e-006	0.528	resis
1	1	B4	13	1	-3.340e-023	-3.340e-023	-7.133e+004	-4.351e+004	8.356e+004	-1.998e-010	-1.864e-006	1.864e-006	0.684	resis
1	1	B4	14	1	-3.340e-023	-3.340e-023	-7.133e+004	4.351e+004	8.356e+004	-1.998e-010	-1.864e-006	1.864e-006	0.684	resis
1	1	B5	1	1	-2.126e-006	-2.126e-006	-3.515e+003	3.847e-009	3.515e+003	-5.824e-007	-4.334e+004	4.334e+004	0.029	resis
1	1	B5	1	2	2.125e-006	2.125e-006	-3.515e+003	3.847e-009	3.515e+003	5.824e-007	4.334e+004	4.334e+004	0.029	
1	1	B5	2	1	-2.126e-006	-2.126e-006	-3.515e+003	3.060e-008	3.515e+003	-5.824e-007	-4.334e+004	4.334e+004	0.029	resis
1	1	B5	2	2	2.125e-006	2.125e-006	-3.515e+003	3.060e-008	3.515e+003	5.824e-007	4.334e+004	4.334e+004	0.029	

1	1	B5	3	1	-2.126e-006	-2.126e-006	-3.515e+003	3.847e-009	3.515e+003	-5.824e-007	-4.334e+004	4.334e+004	0.029	resis
1	1	B5	3	2	2.125e-006	2.125e-006	-3.515e+003	3.847e-009	3.515e+003	5.824e-007	4.334e+004	4.334e+004	0.029	
1	1	B5	4	1	-2.126e-006	-2.126e-006	-3.515e+003	3.060e-008	3.515e+003	-5.824e-007	-4.334e+004	4.334e+004	0.029	resis
1	1	B5	4	2	2.125e-006	2.125e-006	-3.515e+003	3.060e-008	3.515e+003	5.824e-007	4.334e+004	4.334e+004	0.029	
1	1	B5	5	1	-2.126e-006	-2.126e-006	-3.515e+003	3.847e-009	3.515e+003	-5.824e-007	-4.334e+004	4.334e+004	0.029	resis
1	1	B5	5	2	2.125e-006	2.125e-006	-3.515e+003	3.847e-009	3.515e+003	5.824e-007	4.334e+004	4.334e+004	0.029	
1	1	B5	6	1	-2.126e-006	-2.126e-006	-3.515e+003	3.060e-008	3.515e+003	-5.824e-007	-4.334e+004	4.334e+004	0.029	resis
1	1	B5	6	2	2.125e-006	2.125e-006	-3.515e+003	3.060e-008	3.515e+003	5.824e-007	4.334e+004	4.334e+004	0.029	
1	1	B6	1	1	2.131e-006	2.131e-006	3.515e+003	3.847e-009	3.515e+003	-5.824e-007	4.334e+004	4.334e+004	0.029	resis
1	1	B6	1	2	-2.138e-006	-2.138e-006	3.515e+003	3.847e-009	3.515e+003	5.824e-007	-4.334e+004	4.334e+004	0.029	
1	1	B6	2	1	2.131e-006	2.131e-006	3.515e+003	3.060e-008	3.515e+003	-5.824e-007	4.334e+004	4.334e+004	0.029	resis
1	1	B6	2	2	-2.138e-006	-2.138e-006	3.515e+003	3.060e-008	3.515e+003	5.824e-007	-4.334e+004	4.334e+004	0.029	
1	1	B6	3	1	2.131e-006	2.131e-006	3.515e+003	3.847e-009	3.515e+003	-5.824e-007	4.334e+004	4.334e+004	0.029	resis
1	1	B6	3	2	-2.138e-006	-2.138e-006	3.515e+003	3.847e-009	3.515e+003	5.824e-007	-4.334e+004	4.334e+004	0.029	
1	1	B6	4	1	2.131e-006	2.131e-006	3.515e+003	3.060e-008	3.515e+003	-5.824e-007	4.334e+004	4.334e+004	0.029	resis
1	1	B6	4	2	-2.138e-006	-2.138e-006	3.515e+003	3.060e-008	3.515e+003	5.824e-007	-4.334e+004	4.334e+004	0.029	
1	1	B6	5	1	2.131e-006	2.131e-006	3.515e+003	3.847e-009	3.515e+003	-5.824e-007	4.334e+004	4.334e+004	0.029	resis
1	1	B6	5	2	-2.138e-006	-2.138e-006	3.515e+003	3.847e-009	3.515e+003	5.824e-007	-4.334e+004	4.334e+004	0.029	
1	1	B6	6	1	2.131e-006	2.131e-006	3.515e+003	3.060e-008	3.515e+003	-5.824e-007	4.334e+004	4.334e+004	0.029	resis
1	1	B6	6	2	-2.138e-006	-2.138e-006	3.515e+003	3.060e-008	3.515e+003	5.824e-007	-4.334e+004	4.334e+004	0.029	

Now we compute bolt bearing on a flange cover plate. Consider an end/edge bolt and the most loaded one among inner bolts. Distances are shown in following figure.

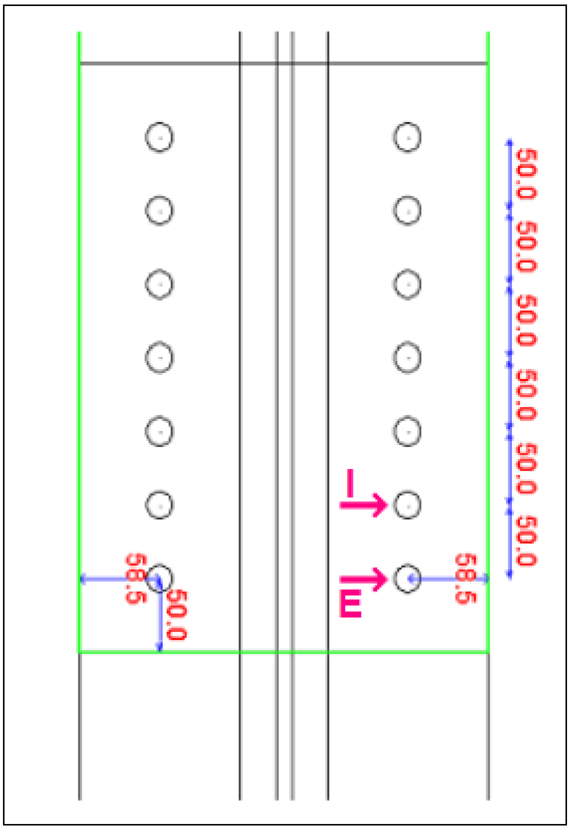


Figure B-35

In this case, forces acting on the plate are equal to those in bolts check sections.

```
-------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
-------------------------------------------------------------------

Id       Inst  Combi  Ext        Fx            Fy            Fz            Mx            My            Mz

   B3      1      1      1  5.9052e-005 -1.1188e-008 -4.7302e-022 -1.0908e-007 -5.3546e-004  1.2232e+008
```

```
-----------------------------------------
Overall internal actions over Bolt Layouts
-----------------------------------------

Id      Inst  Combi  Sec        NT           TuT          TvT          MtT          MuT          MvT

   B3     1     1      1 -4.7302e-022  5.9052e-005 -1.1188e-008  1.2232e+008  2.7969e-009  5.5054e-005
```

Following table contains all the data needed to compute plate bolt bearing according to the formulae given in previous paragraphs (see also the appendix). Considered bolt is an external on (“E” in Figure B-35).

External bolt “E”

Fx	4,351E+04	**Fy**	7,133E+04
$F_{b,Rd,x}$	1,512E+05	**$F_{b,Rd,y}$**	1,555E+05
k_1	2,5	**k_1**	1,8
$2{,}8e_2/d_0-1{,}7$	5,3	**$2{,}8e_2/d_0-1{,}7$**	5,3
$1{,}4p_2/d_0-1{,}7$	11,11	**$1{,}4p_2/d_0-1{,}7$**	1,8
	2,5		2,5
a_b	0,583	**a_b**	0,833
a_d	0,833	**a_d**	0,833
f_{ub}/f_u	2,78	**f_{ub}/f_u**	2,78
$p_1/3d_0-0{,}25$	0,58	**$p_1/3d_0-0{,}25$**	2,80
	1		1
fu	360	**fu**	360
d	18	**d**	18
d_0	20	**d_0**	20
t	20	**t**	20
$e_1=\min(e_1,e_2)$	50	**$e_1=\min(e_1,e_2)$**	50
$e_2=\min(e_1,e_2)$	50	**$e_2=\min(e_1,e_2)$**	50
p_1	50	**p_1**	183
p_2	183	**p_2**	50
$expl_x$	0,288	**$expl_y$**	0,459
	EXPL=	**0,541**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\exp 1 = \sqrt{\exp 1_x^2 + \exp 1_y^2} = 0.541$$

Now we are going to compute bolt bearing due to a inner bolt (most loaded inner bolt, see “I” in Figure B-35).

Inner bolt "I"

Fx	4,351E+04	**Fy**	4,755E+04
$F_{b,Rd,x}$	2,592E+05	**$F_{b,Rd,y}$**	1,512E+05
k_1	2,5	**k_1**	2,5
$1,4p_2/d_0$-1,7	11,11		
$2,8e_2/d_0$-1,7	5,3	**$1,4p_2/d_0$-1,7**	11,11
	2,5		2,5
a_b	1,000	**a_b**	0,583
a_d (ext)		**a_d (ext)**	0,833
f_{ub}/f_u	2,78	**f_{ub}/f_u**	2,78
$p_1/3d_0$-0,25	2,80	**$p_1/3d_0$-0,25**	0,58
	1		1
fu	360	**fu**	360
d	18	**d**	18
d_0	20	**d_0**	20
t	20	**t**	20
$e_1=\min(e_1,e_2)$	50	**$e_1=\min(e_1,e_2)$**	50
$e_2=\min(e_1,e_2)$	50	**$e_2=\min(e_1,e_2)$**	50
p_1	183	**p_1**	50
p_2	50	**p_2**	183
$expl_x$	0,168	**$expl_y$**	0,314
	EXPL=	**0,356**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\text{expl} = \sqrt{\text{expl}_x^2 + \text{expl}_y^2} = 0.356$$

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

Here is the value computed by CSE:

```
-----------------------------------------------------------------
Cleats whose maximum utilization ratio is due to bearing stresses
-----------------------------------------------------------------

 Inst  Combi  Name   Boltlay   Bolt   Extr.         Sigma      Sigma M    Expl
                                                  (  N/ mm²)   (  N/ mm²)

    1      1     P1      B3      13        1         232.1       428.6    0.541
    1      1     P2      B1      14        1         232.1       428.6    0.541
```

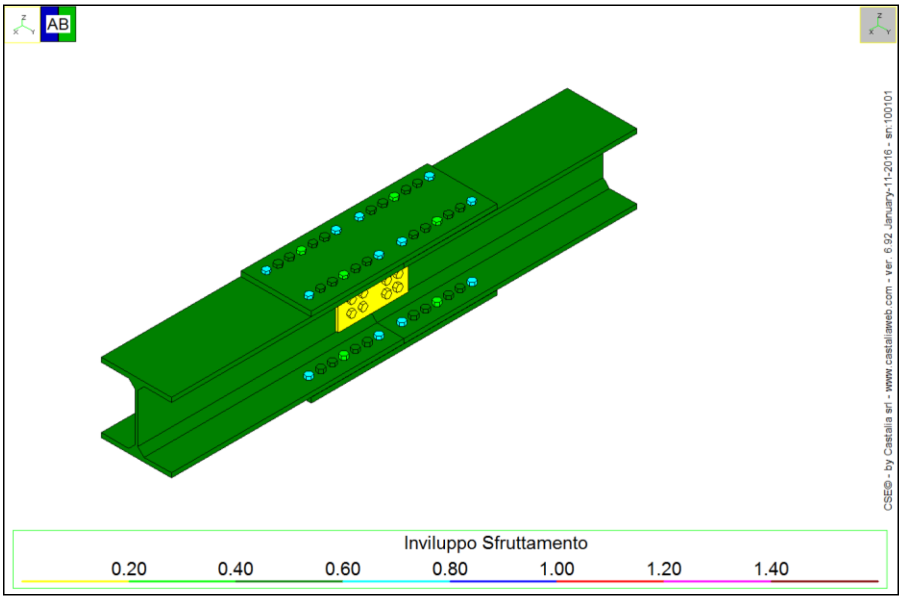


Figure B-36 Components utilization envelope

B.2.1.6 Shear parallel to flanges

Now consider the shear parallel to the flanges (model: *Validation_SP_1_5.CSE*).

With an overstrength factor equal to 1.2, we compute limit shear parallel to flanges and set imported FEM model to obtain that load in joint node:

$$V_{pl,RD} \cdot \gamma_{RD} = \frac{f_y \cdot 2 \cdot bt_f \cdot \gamma_{RD}}{\sqrt{3}} = 1.856 \cdot 10^6 N$$

Note well: EN1993-1-1 includes a part of flanges area in the shear area for shear parallel to web. That part should be excluded from shear area for shear parallel to flanges. Here a simplified computation was done for the load to be applied, considering total flanges area ($2bt_f$).

CSE assigns almost the total load to flanges bolt layouts. A very small part is carried by web bolt layouts (as bending moment). We will consider flanges bolt, that carry a shear equal to V=9.2799*10^5N.

```
--------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
--------------------------------------------------------------------

Id       Inst  Combi  Ext        Fx            Fy            Fz            Mx            My            Mz

   B3      1      1      1 -9.2799e+005 -2.8846e-012 -2.0938e-021 -2.8126e-011  9.0479e+006  1.8560e+008
   B3      1      1      2  9.2799e+005  2.8846e-012  2.0938e-021 -2.8123e-011  9.0479e+006 -1.8560e+008
```

```
B1      1      1      1  9.2799e+005  6.5351e-012  2.0938e-021  6.3716e-011 -9.0479e+006 -1.8560e+008
B1      1      1      2 -9.2799e+005 -6.5351e-012 -2.0938e-021  6.3719e-011 -9.0479e+006  1.8560e+008
B2      1      1      1  9.2799e+005 -6.5351e-012  2.0938e-021 -6.3716e-011 -9.0479e+006  1.8560e+008
B2      1      1      2 -9.2799e+005  6.5351e-012 -2.0938e-021 -6.3718e-011 -9.0479e+006 -1.8560e+008
B4      1      1      1 -9.2799e+005 -6.5351e-012 -2.0938e-021 -6.3716e-011  9.0479e+006 -1.8560e+008
B4      1      1      2  9.2799e+005  6.5351e-012  2.0938e-021 -6.3719e-011  9.0479e+006  1.8560e+008
B5      1      1      1  8.5935e-002  4.6021e-007 -4.4584e+001 -1.2799e-005  3.2998e+003  3.4056e-005
B5      1      1      2 -4.1848e-010 -1.4027e-016  8.9168e+001  3.6183e-005 -6.6015e+003 -4.2191e-013
B5      1      1      3 -8.5935e-002 -4.6021e-007 -4.4584e+001 -1.2799e-005  3.2998e+003 -3.4056e-005
B6      1      1      1 -8.5935e-002  4.6021e-007 -4.4584e+001 -1.2799e-005  3.2987e+003  3.4056e-005
B6      1      1      2  1.4502e-010 -5.7175e-021  8.9169e+001  3.6183e-005 -6.5954e+003  4.1298e-013
B6      1      1      3  8.5935e-002 -4.6021e-007 -4.4584e+001 -1.2799e-005  3.2987e+003 -3.4056e-005
```

As previously seen for shear parallel to web, we have two components acting on bolts: the applied shear divided by bolts number and the shear produced by the moment of transport (torque in the layout).

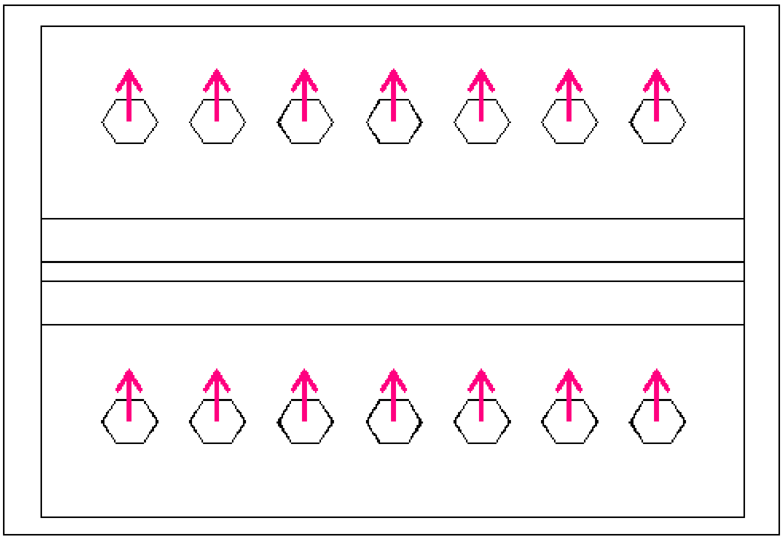


Figure B-37 Total shear / bolts number (V/14)

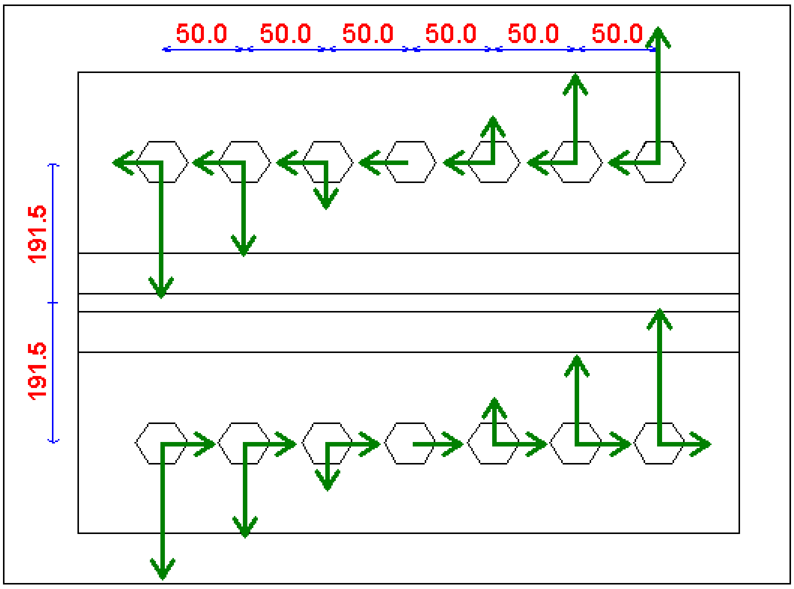


Figure B-38 Shears due to torque

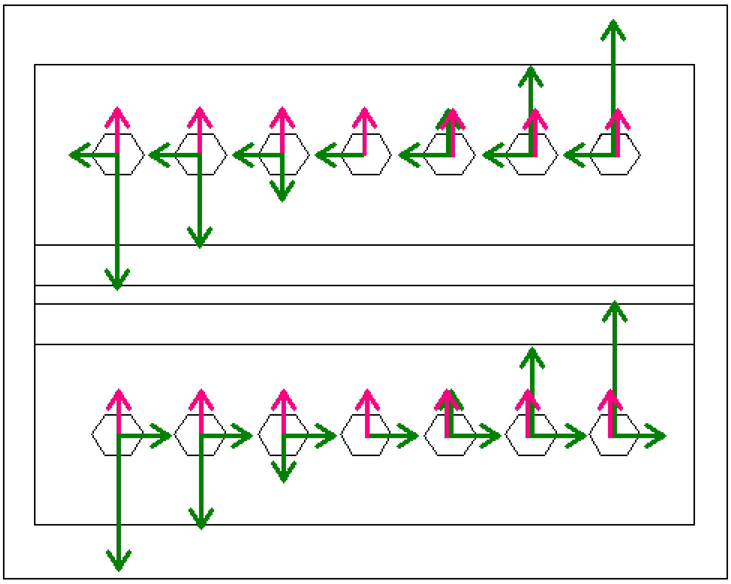


Figure B-39 Resultant forces

Couples of bolts are subjected to the same force, given by the following formula:

$$R_i = \sqrt{(\frac{V}{14} + V_{M',x,i})^2 + V_{M',y,i}^2}$$

where $V_{M',x,i}$ and $V_{M',y,i}$ are the components parallel and normal to the applied shear:

$$V_{M',x,i} = M'/J_p * d_{y,i}$$

$$V_{M',y,i}=M'/J_p*d_{x,i}$$

J_p = 257211mm^2 is the polar inertia moment, previously computed in B.1.2.

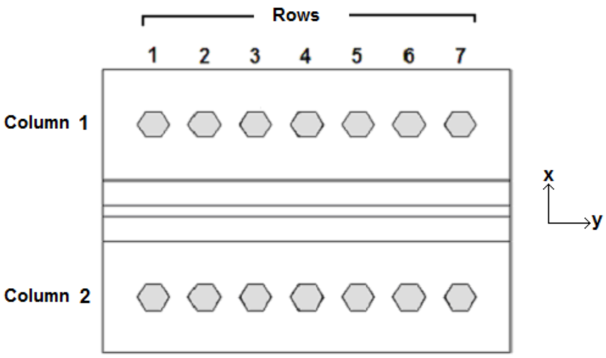


Figure B-40

According to distances shown in previous paragraphs and according to bolts division in bolts and columns (Figure B-40) we have the same forces acting on bolts (Newton). Note that $V_{M',x,i}$ can be oriented like $V/14$ or opposite to it. Flanges bolt layout are all in the same condition, of course.

	1	2	3	4	5	6	7
Col 1	7.823E+04	6.629E+04	7.261E+04	9.356E+04	1.218E+05	1.534E+05	1.866E+05
Col 2	7.823E+04	6.629E+04	7.261E+04	9.356E+04	1.218E+05	1.534E+05	1.866E+05

Dividing previous table forces by previously computed $F_{v,Rd}$=1.221*10^{5}N we get the following utilization factors.

	1	2	3	4	5	6	7
Col 1	0.640	0.543	0.594	0.766	0.997	1.256	1.528
Col 2	0.640	0.543	0.594	0.766	0.997	1.256	1.528

Let's compute step by step the utilization factor of one of the bolts (for example, column 1 – row 1). Before doing that, we can see that CSE results are equal to previous computations.

```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------

Inst  Combi  Name Bolt -?-       NB          NTB          TuB         TvB         TB          MuB         MvB          MB        Expl  cause

   1     1    B3   1   1  -1.496e-022  -1.496e-022   4.195e+004  -6.602e+004  7.822e+004   5.140e-014 -1.657e+004   1.657e+004   0.640 resis
   1     1    B3   2   1  -1.496e-022  -1.496e-022   4.195e+004   6.602e+004  7.822e+004   5.140e-014 -1.657e+004   1.657e+004   0.640 resis
   1     1    B3   3   1  -1.496e-022  -1.496e-022   5.873e+003  -6.602e+004  6.628e+004   5.140e-014 -1.657e+004   1.657e+004   0.543 resis
```

1	1	B3	4	1	-1.496e-022	-1.496e-022	5.873e+003	6.602e+004	6.628e+004	5.140e-014	-1.657e+004	1.657e+004	0.543	resis	
1	1	B3	5	1	-1.496e-022	-1.496e-022	-3.021e+004	-6.602e+004	7.261e+004	5.140e-014	-1.657e+004	1.657e+004	0.594	resis	
1	1	B3	6	1	-1.496e-022	-1.496e-022	-3.021e+004	6.602e+004	7.261e+004	5.140e-014	-1.657e+004	1.657e+004	0.594	resis	
1	1	B3	7	1	-1.496e-022	-1.496e-022	-6.628e+004	-6.602e+004	9.356e+004	5.140e-014	-1.657e+004	1.657e+004	0.766	resis	
1	1	B3	8	1	-1.496e-022	-1.496e-022	-6.628e+004	6.602e+004	9.356e+004	5.140e-014	-1.657e+004	1.657e+004	0.766	resis	
1	1	B3	9	1	-1.496e-022	-1.496e-022	-1.024e+005	-6.602e+004	1.218e+005	5.140e-014	-1.657e+004	1.657e+004	0.997	resis	
1	1	B3	10	1	-1.496e-022	-1.496e-022	-1.024e+005	6.602e+004	1.218e+005	5.140e-014	-1.657e+004	1.657e+004	0.997	resis	
1	1	B3	11	1	-1.496e-022	-1.496e-022	-1.384e+005	-6.602e+004	1.534e+005	5.140e-014	-1.657e+004	1.657e+004	1.256	resis	***
1	1	B3	12	1	-1.496e-022	-1.496e-022	-1.384e+005	6.602e+004	1.534e+005	5.140e-014	-1.657e+004	1.657e+004	1.256	resis	***
1	1	B3	13	1	-1.496e-022	-1.496e-022	-1.745e+005	-6.602e+004	1.866e+005	5.140e-014	-1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B3	14	1	-1.496e-022	-1.496e-022	-1.745e+005	6.602e+004	1.866e+005	5.140e-014	-1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B1	1	1	1.496e-022	1.496e-022	-4.195e+004	6.602e+004	7.822e+004	-1.168e-013	1.657e+004	1.657e+004	0.640	resis	
1	1	B1	2	1	1.496e-022	1.496e-022	-4.195e+004	-6.602e+004	7.822e+004	-1.168e-013	1.657e+004	1.657e+004	0.640	resis	
1	1	B1	3	1	1.496e-022	1.496e-022	-5.873e+003	6.602e+004	6.628e+004	-1.168e-013	1.657e+004	1.657e+004	0.543	resis	
1	1	B1	4	1	1.496e-022	1.496e-022	-5.873e+003	-6.602e+004	6.628e+004	-1.168e-013	1.657e+004	1.657e+004	0.543	resis	
1	1	B1	5	1	1.496e-022	1.496e-022	3.021e+004	6.602e+004	7.261e+004	-1.168e-013	1.657e+004	1.657e+004	0.594	resis	
1	1	B1	6	1	1.496e-022	1.496e-022	3.021e+004	-6.602e+004	7.261e+004	-1.168e-013	1.657e+004	1.657e+004	0.594	resis	
1	1	B1	7	1	1.496e-022	1.496e-022	6.628e+004	6.602e+004	9.356e+004	-1.168e-013	1.657e+004	1.657e+004	0.766	resis	
1	1	B1	8	1	1.496e-022	1.496e-022	6.628e+004	-6.602e+004	9.356e+004	-1.168e-013	1.657e+004	1.657e+004	0.766	resis	
1	1	B1	9	1	1.496e-022	1.496e-022	1.024e+005	6.602e+004	1.218e+005	-1.168e-013	1.657e+004	1.657e+004	0.997	resis	
1	1	B1	10	1	1.496e-022	1.496e-022	1.024e+005	-6.602e+004	1.218e+005	-1.168e-013	1.657e+004	1.657e+004	0.997	resis	
1	1	B1	11	1	1.496e-022	1.496e-022	1.384e+005	6.602e+004	1.534e+005	-1.168e-013	1.657e+004	1.657e+004	1.256	resis	***
1	1	B1	12	1	1.496e-022	1.496e-022	1.384e+005	-6.602e+004	1.534e+005	-1.168e-013	1.657e+004	1.657e+004	1.256	resis	***
1	1	B1	13	1	1.496e-022	1.496e-022	1.745e+005	6.602e+004	1.866e+005	-1.168e-013	1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B1	14	1	1.496e-022	1.496e-022	1.745e+005	-6.602e+004	1.866e+005	-1.168e-013	1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B2	1	1	1.496e-022	1.496e-022	1.745e+005	-6.602e+004	1.866e+005	1.168e-013	1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B2	2	1	1.496e-022	1.496e-022	1.745e+005	6.602e+004	1.866e+005	1.168e-013	1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B2	3	1	1.496e-022	1.496e-022	1.384e+005	-6.602e+004	1.534e+005	1.168e-013	1.657e+004	1.657e+004	1.256	resis	***
1	1	B2	4	1	1.496e-022	1.496e-022	1.384e+005	6.602e+004	1.534e+005	1.168e-013	1.657e+004	1.657e+004	1.256	resis	***
1	1	B2	5	1	1.496e-022	1.496e-022	1.024e+005	-6.602e+004	1.218e+005	1.168e-013	1.657e+004	1.657e+004	0.997	resis	
1	1	B2	6	1	1.496e-022	1.496e-022	1.024e+005	6.602e+004	1.218e+005	1.168e-013	1.657e+004	1.657e+004	0.997	resis	
1	1	B2	7	1	1.496e-022	1.496e-022	6.628e+004	-6.602e+004	9.356e+004	1.168e-013	1.657e+004	1.657e+004	0.766	resis	
1	1	B2	8	1	1.496e-022	1.496e-022	6.628e+004	6.602e+004	9.356e+004	1.168e-013	1.657e+004	1.657e+004	0.766	resis	
1	1	B2	9	1	1.496e-022	1.496e-022	3.021e+004	-6.602e+004	7.261e+004	1.168e-013	1.657e+004	1.657e+004	0.594	resis	
1	1	B2	10	1	1.496e-022	1.496e-022	3.021e+004	6.602e+004	7.261e+004	1.168e-013	1.657e+004	1.657e+004	0.594	resis	
1	1	B2	11	1	1.496e-022	1.496e-022	-5.873e+003	-6.602e+004	6.629e+004	1.168e-013	1.657e+004	1.657e+004	0.543	resis	
1	1	B2	12	1	1.496e-022	1.496e-022	-5.873e+003	6.602e+004	6.629e+004	1.168e-013	1.657e+004	1.657e+004	0.543	resis	
1	1	B2	13	1	1.496e-022	1.496e-022	-4.195e+004	-6.602e+004	7.823e+004	1.168e-013	1.657e+004	1.657e+004	0.640	resis	
1	1	B2	14	1	1.496e-022	1.496e-022	-4.195e+004	6.602e+004	7.823e+004	1.168e-013	1.657e+004	1.657e+004	0.640	resis	
1	1	B4	1	1	-1.496e-022	-1.496e-022	-1.745e+005	6.602e+004	1.866e+005	1.168e-013	-1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B4	2	1	-1.496e-022	-1.496e-022	-1.745e+005	-6.602e+004	1.866e+005	1.168e-013	-1.657e+004	1.657e+004	1.528	resis	!!!
1	1	B4	3	1	-1.496e-022	-1.496e-022	-1.384e+005	6.602e+004	1.534e+005	1.168e-013	-1.657e+004	1.657e+004	1.256	resis	***
1	1	B4	4	1	-1.496e-022	-1.496e-022	-1.384e+005	-6.602e+004	1.534e+005	1.168e-013	-1.657e+004	1.657e+004	1.256	resis	***
1	1	B4	5	1	-1.496e-022	-1.496e-022	-1.024e+005	6.602e+004	1.218e+005	1.168e-013	-1.657e+004	1.657e+004	0.997	resis	
1	1	B4	6	1	-1.496e-022	-1.496e-022	-1.024e+005	-6.602e+004	1.218e+005	1.168e-013	-1.657e+004	1.657e+004	0.997	resis	
1	1	B4	7	1	-1.496e-022	-1.496e-022	-6.628e+004	6.602e+004	9.356e+004	1.168e-013	-1.657e+004	1.657e+004	0.766	resis	
1	1	B4	8	1	-1.496e-022	-1.496e-022	-6.628e+004	-6.602e+004	9.356e+004	1.168e-013	-1.657e+004	1.657e+004	0.766	resis	
1	1	B4	9	1	-1.496e-022	-1.496e-022	-3.021e+004	6.602e+004	7.261e+004	1.168e-013	-1.657e+004	1.657e+004	0.594	resis	
1	1	B4	10	1	-1.496e-022	-1.496e-022	-3.021e+004	-6.602e+004	7.261e+004	1.168e-013	-1.657e+004	1.657e+004	0.594	resis	
1	1	B4	11	1	-1.496e-022	-1.496e-022	5.873e+003	6.602e+004	6.629e+004	1.168e-013	-1.657e+004	1.657e+004	0.543	resis	
1	1	B4	12	1	-1.496e-022	-1.496e-022	5.873e+003	-6.602e+004	6.629e+004	1.168e-013	-1.657e+004	1.657e+004	0.543	resis	
1	1	B4	13	1	-1.496e-022	-1.496e-022	4.195e+004	6.602e+004	7.823e+004	1.168e-013	-1.657e+004	1.657e+004	0.640	resis	
1	1	B4	14	1	-1.496e-022	-1.496e-022	4.195e+004	-6.602e+004	7.823e+004	1.168e-013	-1.657e+004	1.657e+004	0.640	resis	
1	1	B5	1	1	-7.431e+000	-7.431e+000	1.432e-002	1.713e-008	1.432e-002	-2.593e-006	5.500e+002	5.500e+002	0.000		
1	1	B5	1	2	7.431e+000	7.431e+000	1.432e-002	1.713e-008	1.432e-002	2.593e-006	-5.500e+002	5.500e+002	0.000	resis	
1	1	B5	2	1	-7.431e+000	-7.431e+000	1.432e-002	1.363e-007	1.432e-002	-2.593e-006	5.500e+002	5.500e+002	0.000		
1	1	B5	2	2	7.431e+000	7.431e+000	1.432e-002	1.363e-007	1.432e-002	2.593e-006	-5.500e+002	5.500e+002	0.000	resis	
1	1	B5	3	1	-7.431e+000	-7.431e+000	1.432e-002	1.713e-008	1.432e-002	-2.593e-006	5.500e+002	5.500e+002	0.000		
1	1	B5	3	2	7.431e+000	7.431e+000	1.432e-002	1.713e-008	1.432e-002	2.593e-006	-5.500e+002	5.500e+002	0.000	resis	
1	1	B5	4	1	-7.431e+000	-7.431e+000	1.432e-002	1.363e-007	1.432e-002	-2.593e-006	5.500e+002	5.500e+002	0.000		
1	1	B5	4	2	7.431e+000	7.431e+000	1.432e-002	1.363e-007	1.432e-002	2.593e-006	-5.500e+002	5.500e+002	0.000	resis	
1	1	B5	5	1	-7.431e+000	-7.431e+000	1.432e-002	1.713e-008	1.432e-002	-2.593e-006	5.500e+002	5.500e+002	0.000		
1	1	B5	5	2	7.431e+000	7.431e+000	1.432e-002	1.713e-008	1.432e-002	2.593e-006	-5.500e+002	5.500e+002	0.000	resis	
1	1	B5	6	1	-7.431e+000	-7.431e+000	1.432e-002	1.363e-007	1.432e-002	-2.593e-006	5.500e+002	5.500e+002	0.000		
1	1	B5	6	2	7.431e+000	7.431e+000	1.432e-002	1.363e-007	1.432e-002	2.593e-006	-5.500e+002	5.500e+002	0.000	resis	
1	1	B6	1	1	-7.431e+000	-7.431e+000	-1.432e-002	1.713e-008	1.432e-002	-2.593e-006	5.497e+002	5.497e+002	0.000		
1	1	B6	1	2	7.431e+000	7.431e+000	-1.432e-002	1.713e-008	1.432e-002	2.593e-006	-5.497e+002	5.497e+002	0.000	resis	
1	1	B6	2	1	-7.431e+000	-7.431e+000	-1.432e-002	1.363e-007	1.432e-002	-2.593e-006	5.497e+002	5.497e+002	0.000		
1	1	B6	2	2	7.431e+000	7.431e+000	-1.432e-002	1.363e-007	1.432e-002	2.593e-006	-5.497e+002	5.497e+002	0.000	resis	
1	1	B6	3	1	-7.431e+000	-7.431e+000	-1.432e-002	1.713e-008	1.432e-002	-2.593e-006	5.497e+002	5.497e+002	0.000		
1	1	B6	3	2	7.431e+000	7.431e+000	-1.432e-002	1.713e-008	1.432e-002	2.593e-006	-5.497e+002	5.497e+002	0.000	resis	
1	1	B6	4	1	-7.431e+000	-7.431e+000	-1.432e-002	1.363e-007	1.432e-002	-2.593e-006	5.497e+002	5.497e+002	0.000		
1	1	B6	4	2	7.431e+000	7.431e+000	-1.432e-002	1.363e-007	1.432e-002	2.593e-006	-5.497e+002	5.497e+002	0.000	resis	
1	1	B6	5	1	-7.431e+000	-7.431e+000	-1.432e-002	1.713e-008	1.432e-002	-2.593e-006	5.497e+002	5.497e+002	0.000		
1	1	B6	5	2	7.431e+000	7.431e+000	-1.432e-002	1.713e-008	1.432e-002	2.593e-006	-5.497e+002	5.497e+002	0.000	resis	
1	1	B6	6	1	-7.431e+000	-7.431e+000	-1.432e-002	1.363e-007	1.432e-002	-2.593e-006	5.497e+002	5.497e+002	0.000		
1	1	B6	6	2	7.431e+000	7.431e+000	-1.432e-002	1.363e-007	1.432e-002	2.593e-006	-5.497e+002	5.497e+002	0.000	resis	

Now we compute the utilization for bolt in column 1 – row 1 (Figure B-40). The formula is the following, already used in previous paragraphs.

$$R_i = \sqrt{\left(\frac{V}{14} + V_{M',x,i}\right)^2 + V_{M',y,i}^2}$$

with

$$V/14 = 9.280 \cdot 10^5 \text{N} / 14 = 6.629 \cdot 10^4 \text{N}$$

$V_{M',x,i} = M'/\ J_p * d_{y,i}$ = 1.856*10^{8}Nmm / 257211 * 150mm = 1.082*10^{5}N
$V_{M',y,i} = M'/\ J_p * d_{x,i}$ = 1.856*10^{8}Nmm / 257211 * 91.5mm = 6.603*10^{4}N

where M' is the moment of transport due to the shear. According to the distance shown in the following figure, we have:

$M' = T * d$ = 9.280*10^{5}N * 200mm = 1.856*10^{8}Nmm.

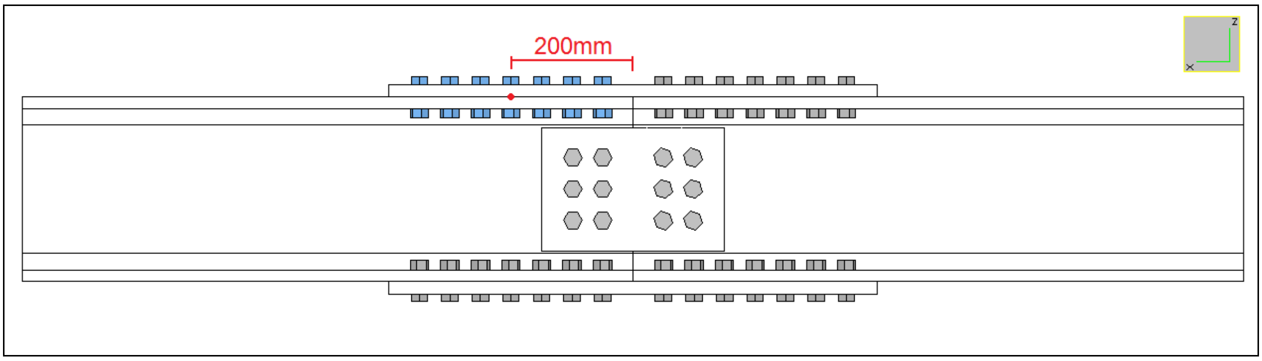


Figure B-41 Distance between bolt layout centre and shear application point

On considered bolt, parallel shear components have opposite (see Figure B-39); we have:

$$R_i = \sqrt{\left(\frac{V}{14} + V_{M',x,i}\right)^2 + V_{M',y,i}^2} = \sqrt{\left[6.629 \cdot 10^4 N + \left(-1.082 \cdot 10^5 N\right)\right]^2 + \left(6.603 \cdot 10^4 N\right)^2} = 7.823 \cdot 10^4 N$$

It is the force given for column 1 – row 1 in previous table.

Now we are going to compute bolt bearing on a flange cover plate. As previously done in last paragraph, we will consider the most loaded among end/edge bolts (col 1 row 7, referring to Figure B-40) and the most loaded among inner bolts (row 1, column 6).

Bolt: col 1 – row 7

Fx	1,745E+05	**Fy**	6,602E+04
$F_{b,Rd,x}$	1,555E+05	**$F_{b,Rd,y}$**	1,512E+05
k_1	1,8	**k_1**	2,5
$2,8e_2/d_0$-1,7	5,3	**$2,8e_2/d_0$-1,7**	5,3
$1,4p_2/d_0$-1,7	1,8	**$1,4p_2/d_0$-1,7**	11,11

	2,5		2,5
a_b	0,833	**a_b**	0,583
a_d	0,833	**a_d**	0,833
f_{ub}/f_u	2,78	**f_{ub}/f_u**	2,78
$p_1/3d_0$-0,25	2,80	**$p_1/3d_0$-0,25**	0,58
	1		1
fu	360	**fu**	360
d	18	**d**	18
d_0	20	**d_0**	20
t	20	**t**	20
e_1=min(e_1,e_2)	50	**e_1=min(e_1,e_2)**	50
e_2=min(e_1,e_2)	50	**e_2=min(e_1,e_2)**	50
p_1	183	**p_1**	50
p_2	50	**p_2**	183
$expl_x$	1,122	**$expl_y$**	0,437
	EXPL=	**1,204**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\exp 1 = \sqrt{\exp 1_x^2 + \exp 1_y^2} = 1.204$$

Bolt: col 1 – row 6

Fx	1,384E+05	**Fy**	6,602E+04
$F_{b,Rd,x}$	2,160E+05	**$F_{b,Rd,y}$**	1,512E+05
k_1	2,5	**k_1**	2,5
1,4p_2/d_0-1,7	11,11	**2,8e2/d0-1,7**	5,3
		1,4p_2/d_0-1,7	11,11
	2,5		2,5
a_b	0,833	**a_b**	0,583
a_d (end)	0,833	**a_d (inner)**	2,800
f_{ub}/f_u	2,78	**f_{ub}/f_u**	2,78
$p_1/3d_0$-0,25	2,80	**$p_1/3d_0$-0,25**	0,58
	1		1
fu	360	**fu**	360
d	18	**d**	18
d_0	20	**d_0**	20
t	20	**t**	20
e_1=min(e_1,e_2)	50	**e_1=min(e_1,e_2)**	50
e_2=min(e_1,e_2)	50	**e_2=min(e_1,e_2)**	50
p_1	183	**p_1**	50
p_2	50	**p_2**	183
$expl_x$	0,641	**$expl_y$**	0,437

	EXPL=	0,776	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\text{expl} = \sqrt{\text{expl}_x^2 + \text{expl}_y^2} = 0.992$$

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

Inner bolt gives maximum utilization for plate bolt bearing check. CSE computes the same value.

```
-------------------------------------------------------------------
Cleats whose maximum utilization ratio is due to bearing stresses
-------------------------------------------------------------------

 Inst Combi   Name    Boltlay    Bolt    Extr.          Sigma       Sigma M     Expl
                                                     (   N/ mm²)    (   N/ mm²)

    1     1     P1      B2          1        1          518.3         430.4    1.204 ***
    1     1     P2      B4          1        1          518.3         430.4    1.204 ***
    1     1     P3      B6          6        1            0.0         305.2    0.000
    1     1     P4      B6          6        3            0.0         305.2    0.000
```

For example, considering plate P2, maximum utilization is due to bolt #1 of bolt layout B4, corresponding to column 1-row 7 (see next figure).

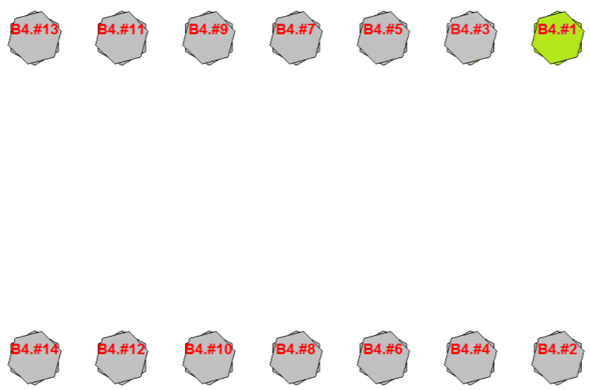


Figure B-42 Bolt layout B4 – Bolt #3 highlighted

Web plates utilization is null, since web bolt layouts do not carry loads (see P3 and P4 in previous output listing abstract).

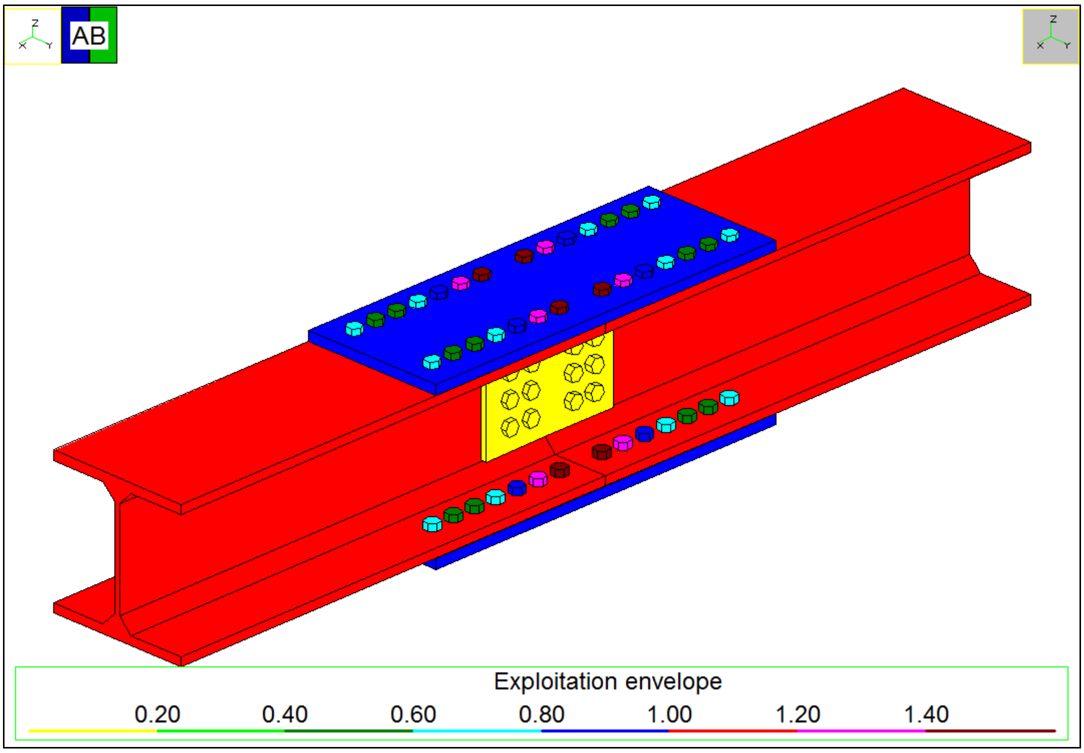


Figure B-43 Exploitation envelope according to EN 1993-1-8: 2005

B.2.1.7 Torque

Model name: *Validation_SP_1_6.CSE*. Constraints and loads on imported FEM model are set to get, in joint node, only a torque equal to member elastic limit. Its value is computed through the following formula.

$$M_t = \frac{J_t f_y}{t_{\max}\sqrt{3}} = 1.321 \cdot 10^7 \, Nmm$$

It is not easy to compute forces distribution by hand. If the whole loads would be carried by flanges bolt layouts, we would have the following shear force on each flange bolt layout:

$$V = M_t / h = 4.405 * 10^4 \text{N}$$

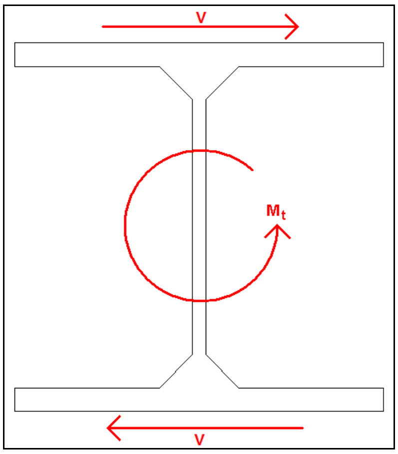


Figure B-44

We expect that also web bolt layouts carry a small part of the load. Let's see how CSE computes forces distribution.

```
--------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
--------------------------------------------------------------------

Id      Inst  Combi  Ext      Fx            Fy            Fz            Mx            My            Mz

   B3      1      1     1  4.3239e+004  8.5056e-008  5.9098e-012  7.7949e-007 -3.6190e+005 -8.9393e+006
   B3      1      1     2 -4.3239e+004 -8.5056e-008 -5.9098e-012  8.7911e-007 -4.8126e+005  8.9393e+006
   B1      1      1     1  4.3239e+004 -8.5038e-008 -5.8796e-012 -7.7928e-007 -3.6190e+005 -8.5508e+006
   B1      1      1     2 -4.3239e+004  8.5038e-008  5.8796e-012 -8.7897e-007 -4.8126e+005  8.5508e+006
   B2      1      1     1 -4.3239e+004 -8.5056e-008 -5.9098e-012 -7.7706e-007  3.6190e+005 -8.7454e+006
   B2      1      1     2  4.3239e+004  8.5056e-008  5.9098e-012 -8.8152e-007  4.8126e+005  8.7454e+006
   B4      1      1     1 -4.3239e+004  8.5038e-008  5.8796e-012  7.7693e-007  3.6190e+005 -8.7448e+006
   B4      1      1     2  4.3239e+004 -8.5038e-008 -5.8796e-012  8.8132e-007  4.8126e+005  8.7448e+006
   B5      1      1     1  1.6721e+001 -1.2923e+003  2.6607e-002  3.5941e+004  1.0389e+002 -9.5632e+004
   B5      1      1     2 -5.1017e-011  3.9390e-007 -5.3214e-002 -1.0161e+005 -5.9237e+002  3.2232e-005
   B5      1      1     3 -1.6721e+001  1.2923e+003  2.6607e-002  3.5941e+004  1.0389e+002  9.5632e+004
   B6      1      1     1 -1.6721e+001 -1.2923e+003  2.6607e-002  3.5941e+004 -1.0782e+002 -9.5632e+004
   B6      1      1     2  1.7600e-011  1.3188e-011 -5.3215e-002 -1.0161e+005  6.0024e+002 -2.5657e-005
   B6      1      1     3  1.6721e+001  1.2923e+003  2.6607e-002  3.5941e+004 -1.0782e+002  9.5632e+004
```

CSE assigns $V_f = 4.324 \cdot 10^4$N to each flange bolt layout: it is the 98.2% of shear they would carry neglecting web bolt layout contribution. Note well: we are using "shear only" bolts, as previously explained.

To compute shear force in each bolt, we use the same scheme used in paragraph B.2.1.6), using current values of *V* and *M'* computed by CSE; forces are in Newton, bolts numbering is the same of Figure B-40.

	1	2	3	4	5	6	7
Col1	3.825E+03	3.204E+03	3.455E+03	4.433E+03	5.780E+03	7.294E+03	8.890E+03
Col 2	3.825E+03	3.204E+03	3.455E+03	4.433E+03	5.780E+03	7.294E+03	8.890E+03

Dividing previous forces by bolt design resistance to shear ($F_{v,Rd}$=1.221*10^{5}N, see previous paragraphs) we get the following utilization factors.

	1	2	3	4	5	6	7
Col 1	0.031	0.026	0.028	0.036	0.047	0.060	0.073
Col 2	0.031	0.026	0.028	0.036	0.047	0.060	0.073

Let's compute in detail one of the bolts, for example the one in row 1, column 1.

$$R_i = \sqrt{\left(\frac{V_f}{14} + V_{M',x,i}\right)^2 + V_{M',y,i}^2}$$

with

$$V_f/14 = 4.324\text{x}10^4\text{N} / 14 = 3.089*10^3\text{N}$$

$$V_{M',x,i} = M'/ J_p * d_{y,i} = 8.9393 * 10^6\text{Nmm} / 257211 * 150\text{mm} = 5.213*10^3\text{N}$$

$$V_{M',y,i} = M'/ J_p * d_{x,i} = 8.9393 * 10^6\text{Nmm} / 257211 * 91.5\text{mm} = 3.180*10^3\text{N}$$

Where M' is the moment of transport due to the shear. With a simplified V*d computation it would be:

$$M' = V * d = 4.324 * 10^4\text{N} * 200\text{mm} = 8.650*10^6\text{Nmm}$$

CSE considers also the bending in bolts shafts, at each bolting level, computing a more accurate moment of transport. Computed moment value is **8.9393*10^{6}Nmm** (see previous output listing abstract). Let's continue with accurate computation done by CSE.

On considered bolt, forces components have opposite sign (see Figure B-39); we have:

$$R_i = \sqrt{\left(\frac{V_f}{14} + V_{M',x,i}\right)^2 + V_{M',y,i}^2} = \sqrt{\left[3.089 \cdot 10^3 N + \left(-5.213 \cdot 10^3 N\right)\right]^2 + \left(3.180 \cdot 10^3 N\right)^2} = 3.825 \cdot 10^3 N$$

According to previous table, CSE computes the same forces and exploitation values.

```
-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------

Inst  Combi  Name Bolt -?-       NB           NTB           TuB          TvB          TB           MuB          MvB           MB         Expl  cause

    1      1    B3   1   1  4.221e-013  4.221e-013  -2.125e+003   3.180e+003  3.825e+003  -5.077e-009  5.035e+003   5.035e+003  0.031 resis
    1      1    B3   2   1  4.221e-013  4.221e-013  -2.125e+003  -3.180e+003  3.825e+003  -5.077e-009  5.035e+003   5.035e+003  0.031 resis
    1      1    B3   3   1  4.221e-013  4.221e-013  -3.870e+002   3.180e+003  3.204e+003  -5.077e-009  5.035e+003   5.035e+003  0.026 resis
    1      1    B3   4   1  4.221e-013  4.221e-013  -3.870e+002  -3.180e+003  3.204e+003  -5.077e-009  5.035e+003   5.035e+003  0.026 resis
    1      1    B3   5   1  4.221e-013  4.221e-013   1.351e+003   3.180e+003  3.455e+003  -5.077e-009  5.035e+003   5.035e+003  0.028 resis
```

1	1	B3	6	1	4.221e-013	4.221e-013	1.351e+003	-3.180e+003	3.455e+003	-5.077e-009	5.035e+003	5.035e+003	0.028 resis
1	1	B3	7	1	4.221e-013	4.221e-013	3.088e+003	3.180e+003	4.433e+003	-5.077e-009	5.035e+003	5.035e+003	0.036 resis
1	1	B3	8	1	4.221e-013	4.221e-013	3.088e+003	-3.180e+003	4.433e+003	-5.077e-009	5.035e+003	5.035e+003	0.036 resis
1	1	B3	9	1	4.221e-013	4.221e-013	4.826e+003	3.180e+003	5.780e+003	-5.077e-009	5.035e+003	5.035e+003	0.047 resis
1	1	B3	10	1	4.221e-013	4.221e-013	4.826e+003	-3.180e+003	5.780e+003	-5.077e-009	5.035e+003	5.035e+003	0.047 resis
1	1	B3	11	1	4.221e-013	4.221e-013	6.564e+003	3.180e+003	7.294e+003	-5.077e-009	5.035e+003	5.035e+003	0.060 resis
1	1	B3	12	1	4.221e-013	4.221e-013	6.564e+003	-3.180e+003	7.294e+003	-5.077e-009	5.035e+003	5.035e+003	0.060 resis
1	1	B3	13	1	4.221e-013	4.221e-013	8.302e+003	3.180e+003	8.890e+003	-5.077e-009	5.035e+003	5.035e+003	0.073 resis
1	1	B3	14	1	4.221e-013	4.221e-013	8.302e+003	-3.180e+003	8.890e+003	-5.077e-009	5.035e+003	5.035e+003	0.073 resis
1	1	B1	1	1	-4.200e-013	-4.200e-013	-1.898e+003	3.042e+003	3.585e+003	5.079e-009	5.035e+003	5.035e+003	0.029 resis
1	1	B1	2	1	-4.200e-013	-4.200e-013	-1.898e+003	-3.042e+003	3.585e+003	5.079e-009	5.035e+003	5.035e+003	0.029 resis
1	1	B1	3	1	-4.200e-013	-4.200e-013	-2.359e+002	3.042e+003	3.051e+003	5.079e-009	5.035e+003	5.035e+003	0.025 resis
1	1	B1	4	1	-4.200e-013	-4.200e-013	-2.359e+002	-3.042e+003	3.051e+003	5.079e-009	5.035e+003	5.035e+003	0.025 resis
1	1	B1	5	1	-4.200e-013	-4.200e-013	1.426e+003	3.042e+003	3.360e+003	5.079e-009	5.035e+003	5.035e+003	0.028 resis
1	1	B1	6	1	-4.200e-013	-4.200e-013	1.426e+003	-3.042e+003	3.360e+003	5.079e-009	5.035e+003	5.035e+003	0.028 resis
1	1	B1	7	1	-4.200e-013	-4.200e-013	3.088e+003	3.042e+003	4.335e+003	5.079e-009	5.035e+003	5.035e+003	0.035 resis
1	1	B1	8	1	-4.200e-013	-4.200e-013	3.088e+003	-3.042e+003	4.335e+003	5.079e-009	5.035e+003	5.035e+003	0.035 resis
1	1	B1	9	1	-4.200e-013	-4.200e-013	4.751e+003	3.042e+003	5.641e+003	5.079e-009	5.035e+003	5.035e+003	0.046 resis
1	1	B1	10	1	-4.200e-013	-4.200e-013	4.751e+003	-3.042e+003	5.641e+003	5.079e-009	5.035e+003	5.035e+003	0.046 resis
1	1	B1	11	1	-4.200e-013	-4.200e-013	6.413e+003	3.042e+003	7.098e+003	5.079e-009	5.035e+003	5.035e+003	0.058 resis
1	1	B1	12	1	-4.200e-013	-4.200e-013	6.413e+003	-3.042e+003	7.098e+003	5.079e-009	5.035e+003	5.035e+003	0.058 resis
1	1	B1	13	1	-4.200e-013	-4.200e-013	8.075e+003	3.042e+003	8.629e+003	5.079e-009	5.035e+003	5.035e+003	0.071 resis
1	1	B1	14	1	-4.200e-013	-4.200e-013	8.075e+003	-3.042e+003	8.629e+003	5.079e-009	5.035e+003	5.035e+003	0.071 resis
1	1	B2	1	1	-4.221e-013	-4.221e-013	-8.189e+003	3.111e+003	8.760e+003	5.250e-009	-5.035e+003	5.035e+003	0.072 resis
1	1	B2	2	1	-4.221e-013	-4.221e-013	-8.189e+003	-3.111e+003	8.760e+003	5.250e-009	-5.035e+003	5.035e+003	0.072 resis
1	1	B2	3	1	-4.221e-013	-4.221e-013	-6.489e+003	3.111e+003	7.196e+003	5.250e-009	-5.035e+003	5.035e+003	0.059 resis
1	1	B2	4	1	-4.221e-013	-4.221e-013	-6.489e+003	-3.111e+003	7.196e+003	5.250e-009	-5.035e+003	5.035e+003	0.059 resis
1	1	B2	5	1	-4.221e-013	-4.221e-013	-4.789e+003	3.111e+003	5.710e+003	5.250e-009	-5.035e+003	5.035e+003	0.047 resis
1	1	B2	6	1	-4.221e-013	-4.221e-013	-4.789e+003	-3.111e+003	5.710e+003	5.250e-009	-5.035e+003	5.035e+003	0.047 resis
1	1	B2	7	1	-4.221e-013	-4.221e-013	-3.088e+003	3.111e+003	4.384e+003	5.250e-009	-5.035e+003	5.035e+003	0.036 resis
1	1	B2	8	1	-4.221e-013	-4.221e-013	-3.088e+003	-3.111e+003	4.384e+003	5.250e-009	-5.035e+003	5.035e+003	0.036 resis
1	1	B2	9	1	-4.221e-013	-4.221e-013	-1.388e+003	3.111e+003	3.407e+003	5.250e-009	-5.035e+003	5.035e+003	0.028 resis
1	1	B2	10	1	-4.221e-013	-4.221e-013	-1.388e+003	-3.111e+003	3.407e+003	5.250e-009	-5.035e+003	5.035e+003	0.028 resis
1	1	B2	11	1	-4.221e-013	-4.221e-013	3.116e+002	3.111e+003	3.127e+003	5.250e-009	-5.035e+003	5.035e+003	0.026 resis
1	1	B2	12	1	-4.221e-013	-4.221e-013	3.116e+002	-3.111e+003	3.127e+003	5.250e-009	-5.035e+003	5.035e+003	0.026 resis
1	1	B2	13	1	-4.221e-013	-4.221e-013	2.012e+003	3.111e+003	3.705e+003	5.250e-009	-5.035e+003	5.035e+003	0.030 resis
1	1	B2	14	1	-4.221e-013	-4.221e-013	2.012e+003	-3.111e+003	3.705e+003	5.250e-009	-5.035e+003	5.035e+003	0.030 resis
1	1	B4	1	1	4.200e-013	4.200e-013	-8.188e+003	3.111e+003	8.759e+003	-5.247e-009	-5.035e+003	5.035e+003	0.072 resis
1	1	B4	2	1	4.200e-013	4.200e-013	-8.188e+003	-3.111e+003	8.759e+003	-5.247e-009	-5.035e+003	5.035e+003	0.072 resis
1	1	B4	3	1	4.200e-013	4.200e-013	-6.488e+003	3.111e+003	7.196e+003	-5.247e-009	-5.035e+003	5.035e+003	0.059 resis
1	1	B4	4	1	4.200e-013	4.200e-013	-6.488e+003	-3.111e+003	7.196e+003	-5.247e-009	-5.035e+003	5.035e+003	0.059 resis
1	1	B4	5	1	4.200e-013	4.200e-013	-4.788e+003	3.111e+003	5.710e+003	-5.247e-009	-5.035e+003	5.035e+003	0.047 resis
1	1	B4	6	1	4.200e-013	4.200e-013	-4.788e+003	-3.111e+003	5.710e+003	-5.247e-009	-5.035e+003	5.035e+003	0.047 resis
1	1	B4	7	1	4.200e-013	4.200e-013	-3.088e+003	3.111e+003	4.384e+003	-5.247e-009	-5.035e+003	5.035e+003	0.036 resis
1	1	B4	8	1	4.200e-013	4.200e-013	-3.088e+003	-3.111e+003	4.384e+003	-5.247e-009	-5.035e+003	5.035e+003	0.036 resis
1	1	B4	9	1	4.200e-013	4.200e-013	-1.389e+003	3.111e+003	3.407e+003	-5.247e-009	-5.035e+003	5.035e+003	0.028 resis
1	1	B4	10	1	4.200e-013	4.200e-013	-1.389e+003	-3.111e+003	3.407e+003	-5.247e-009	-5.035e+003	5.035e+003	0.028 resis
1	1	B4	11	1	4.200e-013	4.200e-013	3.113e+002	3.111e+003	3.126e+003	-5.247e-009	-5.035e+003	5.035e+003	0.026 resis
1	1	B4	12	1	4.200e-013	4.200e-013	3.113e+002	-3.111e+003	3.126e+003	-5.247e-009	-5.035e+003	5.035e+003	0.026 resis
1	1	B4	13	1	4.200e-013	4.200e-013	2.011e+003	3.111e+003	3.704e+003	-5.247e-009	-5.035e+003	5.035e+003	0.030 resis
1	1	B4	14	1	4.200e-013	4.200e-013	2.011e+003	-3.111e+003	3.704e+003	-5.247e-009	-5.035e+003	5.035e+003	0.030 resis
1	1	B5	1	1	4.435e-003	4.435e-003	-3.454e+002	-4.810e+001	3.488e+002	7.282e+003	3.404e+001	7.283e+003	0.003 resis
1	1	B5	1	2	-4.435e-003	-4.435e-003	-3.454e+002	-4.810e+001	3.488e+002	-7.282e+003	-3.404e+001	7.283e+003	0.003
1	1	B5	2	1	4.435e-003	4.435e-003	-3.454e+002	-3.827e+002	5.155e+002	7.282e+003	3.404e+001	7.283e+003	0.004 resis
1	1	B5	2	2	-4.435e-003	-4.435e-003	-3.454e+002	-3.827e+002	5.155e+002	-7.282e+003	-3.404e+001	7.283e+003	0.004
1	1	B5	3	1	4.435e-003	4.435e-003	2.787e+000	-4.810e+001	4.818e+001	7.282e+003	3.404e+001	7.283e+003	0.000 resis
1	1	B5	3	2	-4.435e-003	-4.435e-003	2.787e+000	-4.810e+001	4.818e+001	-7.282e+003	-3.404e+001	7.283e+003	0.000
1	1	B5	4	1	4.435e-003	4.435e-003	2.787e+000	-3.827e+002	3.827e+002	7.282e+003	3.404e+001	7.283e+003	0.003 resis
1	1	B5	4	2	-4.435e-003	-4.435e-003	2.787e+000	-3.827e+002	3.827e+002	-7.282e+003	-3.404e+001	7.283e+003	0.003
1	1	B5	5	1	4.435e-003	4.435e-003	3.510e+002	-4.810e+001	3.543e+002	7.282e+003	3.404e+001	7.283e+003	0.003 resis
1	1	B5	5	2	-4.435e-003	-4.435e-003	3.510e+002	-4.810e+001	3.543e+002	-7.282e+003	-3.404e+001	7.283e+003	0.003
1	1	B5	6	1	4.435e-003	4.435e-003	3.510e+002	-3.827e+002	5.193e+002	7.282e+003	3.404e+001	7.283e+003	0.004 resis
1	1	B5	6	2	-4.435e-003	-4.435e-003	3.510e+002	-3.827e+002	5.193e+002	-7.282e+003	-3.404e+001	7.283e+003	0.004
1	1	B6	1	1	4.435e-003	4.435e-003	-3.510e+002	-4.810e+001	3.543e+002	7.282e+003	-3.469e+001	7.283e+003	0.003
1	1	B6	1	2	-4.435e-003	-4.435e-003	-3.510e+002	-4.810e+001	3.543e+002	-7.282e+003	3.469e+001	7.283e+003	0.003 resis
1	1	B6	2	1	4.435e-003	4.435e-003	-3.510e+002	-3.827e+002	5.193e+002	7.282e+003	-3.469e+001	7.283e+003	0.004
1	1	B6	2	2	-4.435e-003	-4.435e-003	-3.510e+002	-3.827e+002	5.193e+002	-7.282e+003	3.469e+001	7.283e+003	0.004 resis
1	1	B6	3	1	4.435e-003	4.435e-003	-2.787e+000	-4.810e+001	4.818e+001	7.282e+003	-3.469e+001	7.283e+003	0.000 resis
1	1	B6	3	2	-4.435e-003	-4.435e-003	-2.787e+000	-4.810e+001	4.818e+001	-7.282e+003	3.469e+001	7.283e+003	0.000
1	1	B6	4	1	4.435e-003	4.435e-003	-2.787e+000	-3.827e+002	3.827e+002	7.282e+003	-3.469e+001	7.283e+003	0.003
1	1	B6	4	2	-4.435e-003	-4.435e-003	-2.787e+000	-3.827e+002	3.827e+002	-7.282e+003	3.469e+001	7.283e+003	0.003 resis
1	1	B6	5	1	4.435e-003	4.435e-003	3.454e+002	-4.810e+001	3.488e+002	7.282e+003	-3.469e+001	7.283e+003	0.003
1	1	B6	5	2	-4.435e-003	-4.435e-003	3.454e+002	-4.810e+001	3.488e+002	-7.282e+003	3.469e+001	7.283e+003	0.003 resis
1	1	B6	6	1	4.435e-003	4.435e-003	3.454e+002	-3.827e+002	5.155e+002	7.282e+003	-3.469e+001	7.283e+003	0.004
1	1	B6	6	2	-4.435e-003	-4.435e-003	3.454e+002	-3.827e+002	5.155e+002	-7.282e+003	3.469e+001	7.283e+003	0.004 resis

Now we compute bolt bearing for a cover plate. As previously done, consider most loaded end/edge bolt and most loaded inner bolt (see Figure B-40).

Bolt: col 1 – row 7 (B1#14)

Fx	8,629E+03	**Fy**	3,042E+03
$\mathbf{F_{b,Rd,x}}$	1,555E+05	$\mathbf{F_{b,Rd,y}}$	1,512E+05
$\mathbf{k_1}$	1,8	$\mathbf{k_1}$	2,5
$\mathbf{2,8e_2/d_0-1,7}$	5,3	$\mathbf{2,8e_2/d_0-1,7}$	5,3
$\mathbf{1,4p_2/d_0-1,7}$	1,8	$\mathbf{1,4p_2/d_0-1,7}$	11,11

	2,5		2,5
a_b	0,833	**a_b**	0,583
a_d	0,833	**a_d**	0,833
f_{ub}/f_u	2,78	**f_{ub}/f_u**	2,78
$p_1/3d_0$-0,25	2,80	**$p_1/3d_0$-0,25**	0,58
	1		1
fu	360	**fu**	360
d	18	**d**	18
d_0	20	**d_0**	20
t	20	**t**	20
e_1=min(e_1,e_2)	50	**e_1=min(e_1,e_2)**	50
e_2=min(e_1,e_2)	50	**e_2=min(e_1,e_2)**	50
p_1	183	**p_1**	50
p_2	50	**p_2**	183
$expl_x$	0,055	**$expl_y$**	0,020
	EXPL=	**0,059**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\exp 1 = \sqrt{\exp 1_x^2 + \exp 1_y^2} = 0.059$$

Bolt: col 1 – row 6

Fx	6,489E+03	**Fy**	3,111E+03
$F_{b,Rd,x}$	2,160E+05	**$F_{b,Rd,y}$**	1,512E+05
k_1	2,5	**k_1**	2,5
1,4p_2/d_0-1,7	11,11	**2,8e_2/d_0-1,7**	5,3
		1,4p_2/d_0-1,7	11,11
	2,5		2,5
a_b	0,833	**a_b**	0,583
a_d (end)	0,833	**a_d (inner)**	2,800
f_{ub}/f_u	2,78	**f_{ub}/f_u**	2,78
$p_1/3d_0$-0,25	2,80	**$p_1/3d_0$-0,25**	0,58
	1		1
fu	360	**fu**	360
d	18	**d**	18
d_0	20	**d_0**	20
t	20	**t**	20
e_1=min(e_1,e_2)	50	**e_1=min(e_1,e_2)**	50
e_2=min(e_1,e_2)	50	**e_2=min(e_1,e_2)**	50
p_1	183	**p_1**	50
p_2	50	**p_2**	183
$expl_x$	0,030	**$expl_y$**	0,021
	EXPL=	**0,036**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\exp 1 = \sqrt{\exp 1_x^2 + \exp 1_y^2} = 0.036$$

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

As for the previous cases, most critical bolt is the most loaded inner bolt, which is not the most loaded in general (maximum shear is computed for a end/edge bolt).

Members whose maximum utilization ratio is due to bearing stresses

Inst	Combi	Name	Boltlay	Bolt	Extr.	Sigma (N/ mm²)	Sigma M (N/ mm²)	Expl
1	1	m1	B2	2	2	25.6	430.4	0.060
1	1	m2	B1	14	2	25.2	430.5	0.059

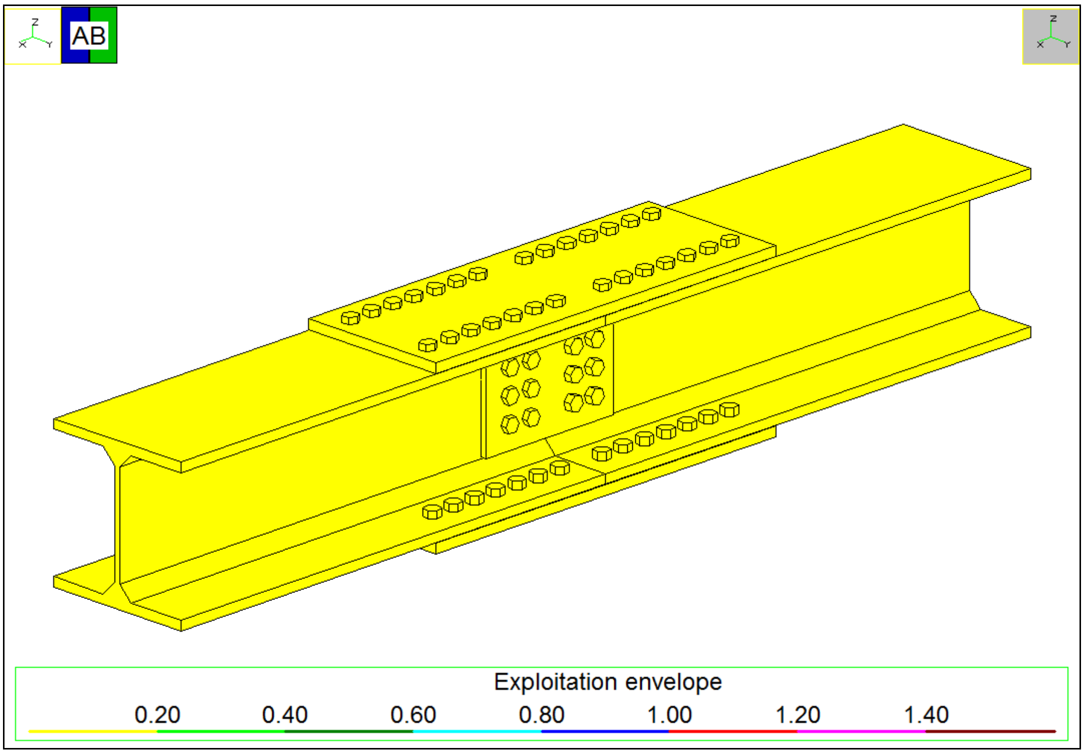


Figure B-45 Components utilization envelope

B.2.1.8 Axial force plus bending moments

Model name: *Validation_SP_1_7.CSE*; constraints and loads are set in the imported FEM model in order to have the following internal actions in joint node: axial force, bending moment about strong axis and bending moment about weak axis. Actions are equal to 1/3 of the corresponding actions computed in previous paragraphs. We have:

$$N_{pl,RD} / 3 = 1.401*10^6 N$$
$$M_{y,pl,RD} / 3 = 1.757*10^8 Nmm$$
$$M_{z,pl,RD} / 3 = 8.179*10^7 Nmm$$

Since load condition is

$$(N_{pl,RD} + M_{y,pl,RD} + M_{z,pl,RD}) / 3$$

for the superposition principle, shear force must be equal to

$$(V_{Npl,RD} + V_{My,pl,RD} + V_{Mz,pl,RD}) / 3$$

where $V_{Npl,RD}$ is the shear previously computed for joint under axial force, etc. (see B.2.1.2, B.2.1.4, B.2.1.5).

The following forces distribution is computed by CSE:

Forces acting over bolt layouts at different extremes, global system

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B3	1	1	1	1.9192e-005	-1.5544e+005	6.4660e-007	-1.2060e+006	-1.7436e-004	4.0771e+007
B3	1	1	2	-1.9192e-005	1.5544e+005	-6.4660e-007	-1.8251e+006	-1.9988e-004	-4.0771e+007
B1	1	1	1	-2.2510e-005	8.7672e+005	-6.4643e-007	8.2384e+006	2.0219e-004	-4.0771e+007
B1	1	1	2	2.2510e-005	-8.7672e+005	6.4643e-007	8.8576e+006	2.3675e-004	4.0771e+007
B2	1	1	1	-1.6111e-005	1.5544e+005	5.9006e-007	1.2060e+006	1.7436e-004	-4.0771e+007
B2	1	1	2	1.6111e-005	-1.5544e+005	-5.9006e-007	1.8251e+006	1.3980e-004	4.0771e+007
B4	1	1	1	1.9428e-005	-8.7672e+005	-5.9023e-007	-8.2384e+006	-2.0219e-004	4.0771e+007
B4	1	1	2	-1.9428e-005	8.7672e+005	5.9023e-007	-8.8576e+006	-1.7666e-004	-4.0771e+007
B5	1	1	1	3.3303e+005	-1.9168e-004	-4.2529e-006	-1.2481e-003	-1.9999e+006	9.9747e+006
B5	1	1	2	-6.8013e+005	3.7039e-004	8.5030e-006	-4.6307e-005	2.5067e+005	-1.9949e+007
B5	1	1	3	3.4709e+005	-1.7871e-004	-4.2501e-006	1.1453e-003	1.9109e+006	9.9747e+006
B6	1	1	1	3.4709e+005	2.2021e-004	4.2617e-006	1.1453e-003	-1.9109e+006	9.9747e+006
B6	1	1	2	-6.8013e+005	-4.6209e-004	-8.5368e-006	-1.4631e-004	-2.5067e+005	-1.9949e+007
B6	1	1	3	3.3303e+005	2.4188e-004	4.2751e-006	-1.2481e-003	1.9999e+006	9.9747e+006

Consider extreme 1 of bolt layout 3., expected shear force (F_y) should be equal to 1/3 of the sum of previously computed basic conditions. The same stands for M_z.

Abstracts already reported in previous paragraphs are listed below (only the rows referring to B3).

Bending about strong axis (B.2.1.2)

```
----------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
----------------------------------------------------------------------

Id       Inst   Combi  Ext       Fx            Fy            Fz            Mx            My            Mz

   B3      1      1      1 -1.4745e-006 -1.5487e+006  1.9401e-006 -1.4170e+007  1.2367e-005  2.9493e-004
```

Axial force (B.2.1.4)

```
----------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
----------------------------------------------------------------------

Id       Inst   Combi  Ext       Fx            Fy            Fz            Mx            My            Mz

   B3      1      1      1 -1.6007e-010  1.0819e+006  2.7009e-010  1.0548e+007  1.5606e-009 -6.0132e-006
```

Bending about weak axis (B.2.1.5)

```
----------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
----------------------------------------------------------------------

Id       Inst   Combi  Ext       Fx            Fy            Fz            Mx            My            Mz

   B3      1      1      1   5.9052e-005 -1.1188e-008 -4.7302e-022 -1.0908e-007 -5.3546e-004  1.2232e+008
```

The sum of the three components gives the following results (M_z is null for axial force and bending about strong axis, F_y is null for bending about weak axis).

$$F_y = \frac{-1.5487 \cdot 10^6\,N}{3} + \frac{1.0819 \cdot 10^6\,N}{3} = -1.555 \cdot 10^6\,N$$

$$M_z = \frac{1.2232 \cdot 10^8\,Nmm}{3} = 4.077 \cdot 10^7\,Nmm$$

Superposition principle is valid also for shear force in each bolt's check section. Consider check section 1 of bolt 1 of layout B3.

Bending about strong axis:

```
-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------

Inst   Combi  Name Bolt -?-       NB          NTB          TuB          TvB          TB          MuB          MvB          MB       Expl  cause

   1      1     B3   1   1   1.386e-007   1.386e-007   6.667e-008  -1.106e+005  1.106e+005   9.401e+004 -1.699e-007   9.401e+004   0.906 resis
```

Axial force:

```
-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------

Inst   Combi  Name Bolt -?-       NB          NTB          TuB          TvB          TB          MuB          MvB          MB       Expl  cause

   1      1     B3   1   1   1.929e-011   1.929e-011  -3.518e-009   7.728e+004  7.728e+004  -1.932e+004 -2.858e-012   1.932e+004   0.633 resis
```

Bending about weak axis:

```
-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B3	1	1	-3.379e-023	-3.379e-023	7.133e+004	-4.351e+004	8.356e+004	1.998e-010	3.932e-006	3.932e-006	0.684	resis

Summing the values and dividing by 3, we get:

$$V_{uB} = 7.133*10^4 N / 3 = 2.378*10^4 N$$

$$V_{vB} = (-1.106*10^5 N + 7.728*10^4 N – 4.351*10^4 N) / 3 = -2.561*10^4 N$$

The same values are computed by CSE in the model with combined internal forces.

```
-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B3	1	1	4.619e-008	4.619e-008	2.378e+004	-2.561e+004	3.494e+004	2.489e+004	1.254e-006	2.489e+004	0.286	resis
1	1	B3	2	1	4.619e-008	4.619e-008	2.378e+004	3.401e+003	2.402e+004	2.489e+004	1.254e-006	2.489e+004	0.197	resis
1	1	B3	3	1	4.619e-008	4.619e-008	1.585e+004	-2.561e+004	3.012e+004	2.489e+004	1.254e-006	2.489e+004	0.247	resis
1	1	B3	4	1	4.619e-008	4.619e-008	1.585e+004	3.401e+003	1.621e+004	2.489e+004	1.254e-006	2.489e+004	0.133	resis
1	1	B3	5	1	4.619e-008	4.619e-008	7.926e+003	-2.561e+004	2.681e+004	2.489e+004	1.254e-006	2.489e+004	0.219	resis
1	1	B3	6	1	4.619e-008	4.619e-008	7.926e+003	3.401e+003	8.624e+003	2.489e+004	1.254e-006	2.489e+004	0.071	resis
1	1	B3	7	1	4.619e-008	4.619e-008	1.371e-006	-2.561e+004	2.561e+004	2.489e+004	1.254e-006	2.489e+004	0.210	resis
1	1	B3	8	1	4.619e-008	4.619e-008	1.371e-006	3.401e+003	3.401e+003	2.489e+004	1.254e-006	2.489e+004	0.028	resis
1	1	B3	9	1	4.619e-008	4.619e-008	-7.926e+003	-2.561e+004	2.681e+004	2.489e+004	1.254e-006	2.489e+004	0.219	resis
1	1	B3	10	1	4.619e-008	4.619e-008	-7.926e+003	3.401e+003	8.624e+003	2.489e+004	1.254e-006	2.489e+004	0.071	resis
1	1	B3	11	1	4.619e-008	4.619e-008	-1.585e+004	-2.561e+004	3.012e+004	2.489e+004	1.254e-006	2.489e+004	0.247	resis
1	1	B3	12	1	4.619e-008	4.619e-008	-1.585e+004	3.401e+003	1.621e+004	2.489e+004	1.254e-006	2.489e+004	0.133	resis
1	1	B3	13	1	4.619e-008	4.619e-008	-2.378e+004	-2.561e+004	3.494e+004	2.489e+004	1.254e-006	2.489e+004	0.286	resis
1	1	B3	14	1	4.619e-008	4.619e-008	-2.378e+004	3.401e+003	2.402e+004	2.489e+004	1.254e-006	2.489e+004	0.197	resis
1	1	B1	1	1	-4.617e-008	-4.617e-008	-2.378e+004	7.713e+004	8.071e+004	-3.777e+004	-1.636e-006	3.777e+004	0.661	resis
1	1	B1	2	1	-4.617e-008	-4.617e-008	-2.378e+004	4.812e+004	5.367e+004	-3.777e+004	-1.636e-006	3.777e+004	0.439	resis
1	1	B1	3	1	-4.617e-008	-4.617e-008	-1.585e+004	7.713e+004	7.874e+004	-3.777e+004	-1.636e-006	3.777e+004	0.645	resis
1	1	B1	4	1	-4.617e-008	-4.617e-008	-1.585e+004	4.812e+004	5.066e+004	-3.777e+004	-1.636e-006	3.777e+004	0.415	resis
1	1	B1	5	1	-4.617e-008	-4.617e-008	-7.926e+003	7.713e+004	7.753e+004	-3.777e+004	-1.636e-006	3.777e+004	0.635	resis
1	1	B1	6	1	-4.617e-008	-4.617e-008	-7.926e+003	4.812e+004	4.877e+004	-3.777e+004	-1.636e-006	3.777e+004	0.399	resis
1	1	B1	7	1	-4.617e-008	-4.617e-008	-1.608e-006	7.713e+004	7.713e+004	-3.777e+004	-1.636e-006	3.777e+004	0.631	resis
1	1	B1	8	1	-4.617e-008	-4.617e-008	-1.608e-006	4.812e+004	4.812e+004	-3.777e+004	-1.636e-006	3.777e+004	0.394	resis
1	1	B1	9	1	-4.617e-008	-4.617e-008	7.926e+003	7.713e+004	7.753e+004	-3.777e+004	-1.636e-006	3.777e+004	0.635	resis
1	1	B1	10	1	-4.617e-008	-4.617e-008	7.926e+003	4.812e+004	4.877e+004	-3.777e+004	-1.636e-006	3.777e+004	0.399	resis
1	1	B1	11	1	-4.617e-008	-4.617e-008	1.585e+004	7.713e+004	7.874e+004	-3.777e+004	-1.636e-006	3.777e+004	0.645	resis
1	1	B1	12	1	-4.617e-008	-4.617e-008	1.585e+004	4.812e+004	5.066e+004	-3.777e+004	-1.636e-006	3.777e+004	0.415	resis
1	1	B1	13	1	-4.617e-008	-4.617e-008	2.378e+004	7.713e+004	8.071e+004	-3.777e+004	-1.636e-006	3.777e+004	0.661	resis
1	1	B1	14	1	-4.617e-008	-4.617e-008	2.378e+004	4.812e+004	5.367e+004	-3.777e+004	-1.636e-006	3.777e+004	0.439	resis
1	1	B2	1	1	4.215e-008	4.215e-008	-2.378e+004	2.561e+004	3.494e+004	-2.489e+004	9.468e-007	2.489e+004	0.286	resis
1	1	B2	2	1	4.215e-008	4.215e-008	-2.378e+004	-3.401e+003	2.402e+004	-2.489e+004	9.468e-007	2.489e+004	0.197	resis
1	1	B2	3	1	4.215e-008	4.215e-008	-1.585e+004	2.561e+004	3.012e+004	-2.489e+004	9.468e-007	2.489e+004	0.247	resis
1	1	B2	4	1	4.215e-008	4.215e-008	-1.585e+004	-3.401e+003	1.621e+004	-2.489e+004	9.468e-007	2.489e+004	0.133	resis
1	1	B2	5	1	4.215e-008	4.215e-008	-7.926e+003	2.561e+004	2.681e+004	-2.489e+004	9.468e-007	2.489e+004	0.219	resis
1	1	B2	6	1	4.215e-008	4.215e-008	-7.926e+003	-3.401e+003	8.624e+003	-2.489e+004	9.468e-007	2.489e+004	0.071	resis
1	1	B2	7	1	4.215e-008	4.215e-008	-1.151e-006	2.561e+004	2.561e+004	-2.489e+004	9.468e-007	2.489e+004	0.210	resis
1	1	B2	8	1	4.215e-008	4.215e-008	-1.151e-006	-3.401e+003	3.401e+003	-2.489e+004	9.468e-007	2.489e+004	0.028	resis
1	1	B2	9	1	4.215e-008	4.215e-008	7.926e+003	2.561e+004	2.681e+004	-2.489e+004	9.468e-007	2.489e+004	0.219	resis
1	1	B2	10	1	4.215e-008	4.215e-008	7.926e+003	-3.401e+003	8.624e+003	-2.489e+004	9.468e-007	2.489e+004	0.071	resis
1	1	B2	11	1	4.215e-008	4.215e-008	1.585e+004	2.561e+004	3.012e+004	-2.489e+004	9.468e-007	2.489e+004	0.247	resis
1	1	B2	12	1	4.215e-008	4.215e-008	1.585e+004	-3.401e+003	1.621e+004	-2.489e+004	9.468e-007	2.489e+004	0.133	resis
1	1	B2	13	1	4.215e-008	4.215e-008	2.378e+004	2.561e+004	3.494e+004	-2.489e+004	9.468e-007	2.489e+004	0.286	resis
1	1	B2	14	1	4.215e-008	4.215e-008	2.378e+004	-3.401e+003	2.402e+004	-2.489e+004	9.468e-007	2.489e+004	0.197	resis
1	1	B4	1	1	-4.216e-008	-4.216e-008	2.378e+004	-7.713e+004	8.071e+004	3.777e+004	-5.646e-007	3.777e+004	0.661	resis
1	1	B4	2	1	-4.216e-008	-4.216e-008	2.378e+004	-4.812e+004	5.367e+004	3.777e+004	-5.646e-007	3.777e+004	0.439	resis
1	1	B4	3	1	-4.216e-008	-4.216e-008	1.585e+004	-7.713e+004	7.874e+004	3.777e+004	-5.646e-007	3.777e+004	0.645	resis
1	1	B4	4	1	-4.216e-008	-4.216e-008	1.585e+004	-4.812e+004	5.066e+004	3.777e+004	-5.646e-007	3.777e+004	0.415	resis
1	1	B4	5	1	-4.216e-008	-4.216e-008	7.926e+003	-7.713e+004	7.753e+004	3.777e+004	-5.646e-007	3.777e+004	0.635	resis
1	1	B4	6	1	-4.216e-008	-4.216e-008	7.926e+003	-4.812e+004	4.877e+004	3.777e+004	-5.646e-007	3.777e+004	0.399	resis
1	1	B4	7	1	-4.216e-008	-4.216e-008	1.388e-006	-7.713e+004	7.713e+004	3.777e+004	-5.646e-007	3.777e+004	0.631	resis
1	1	B4	8	1	-4.216e-008	-4.216e-008	1.388e-006	-4.812e+004	4.812e+004	3.777e+004	-5.646e-007	3.777e+004	0.394	resis
1	1	B4	9	1	-4.216e-008	-4.216e-008	-7.926e+003	-7.713e+004	7.753e+004	3.777e+004	-5.646e-007	3.777e+004	0.635	resis
1	1	B4	10	1	-4.216e-008	-4.216e-008	-7.926e+003	-4.812e+004	4.877e+004	3.777e+004	-5.646e-007	3.777e+004	0.399	resis
1	1	B4	11	1	-4.216e-008	-4.216e-008	-1.585e+004	-7.713e+004	7.874e+004	3.777e+004	-5.646e-007	3.777e+004	0.645	resis
1	1	B4	12	1	-4.216e-008	-4.216e-008	-1.585e+004	-4.812e+004	5.066e+004	3.777e+004	-5.646e-007	3.777e+004	0.415	resis
1	1	B4	13	1	-4.216e-008	-4.216e-008	-2.378e+004	-7.713e+004	8.071e+004	3.777e+004	-5.646e-007	3.777e+004	0.661	resis
1	1	B4	14	1	-4.216e-008	-4.216e-008	-2.378e+004	-4.812e+004	5.367e+004	3.777e+004	-5.646e-007	3.777e+004	0.439	resis
1	1	B5	1	1	-7.088e-007	-7.088e-007	9.183e+004	-1.745e+004	9.347e+004	-1.634e-005	-2.765e+002	2.765e+002	0.765	
1	1	B5	1	2	7.084e-007	7.084e-007	-9.417e+004	1.745e+004	9.577e+004	-1.217e-005	2.862e+004	2.862e+004	0.784	resis
1	1	B5	2	1	-7.088e-007	-7.088e-007	9.183e+004	1.745e+004	9.347e+004	-1.634e-005	-2.765e+002	2.765e+002	0.765	

1	1	B5	2	2	7.084e-007	7.084e-007	-9.417e+004	-1.745e+004	9.577e+004	-1.217e-005	2.862e+004	2.862e+004	0.784 resis
1	1	B5	3	1	-7.088e-007	-7.088e-007	5.551e+004	-1.745e+004	5.818e+004	-1.634e-005	-2.765e+002	2.765e+002	0.476
1	1	B5	3	2	7.084e-007	7.084e-007	-5.785e+004	1.745e+004	6.042e+004	-1.217e-005	2.862e+004	2.862e+004	0.495 resis
1	1	B5	4	1	-7.088e-007	-7.088e-007	5.551e+004	1.745e+004	5.818e+004	-1.634e-005	-2.765e+002	2.765e+002	0.476
1	1	B5	4	2	7.084e-007	7.084e-007	-5.785e+004	-1.745e+004	6.042e+004	-1.217e-005	2.862e+004	2.862e+004	0.495 resis
1	1	B5	5	1	-7.088e-007	-7.088e-007	1.918e+004	-1.745e+004	2.593e+004	-1.634e-005	-2.765e+002	2.765e+002	0.212
1	1	B5	5	2	7.084e-007	7.084e-007	-2.153e+004	1.745e+004	2.771e+004	-1.217e-005	2.862e+004	2.862e+004	0.227 resis
1	1	B5	6	1	-7.088e-007	-7.088e-007	1.918e+004	1.745e+004	2.593e+004	-1.634e-005	-2.765e+002	2.765e+002	0.212
1	1	B5	6	2	7.084e-007	7.084e-007	-2.153e+004	-1.745e+004	2.771e+004	-1.217e-005	2.862e+004	2.862e+004	0.227 resis
1	1	B6	1	1	7.103e-007	7.103e-007	9.417e+004	-1.745e+004	9.577e+004	-2.933e-005	2.862e+004	2.862e+004	0.784 resis
1	1	B6	1	2	-7.125e-007	-7.125e-007	-9.183e+004	1.745e+004	9.347e+004	-3.386e-005	-2.765e+002	2.765e+002	0.765
1	1	B6	2	1	7.103e-007	7.103e-007	9.417e+004	1.745e+004	9.577e+004	-2.933e-005	2.862e+004	2.862e+004	0.784 resis
1	1	B6	2	2	-7.125e-007	-7.125e-007	-9.183e+004	-1.745e+004	9.347e+004	-3.386e-005	-2.765e+002	2.765e+002	0.765
1	1	B6	3	1	7.103e-007	7.103e-007	5.785e+004	-1.745e+004	6.042e+004	-2.933e-005	2.862e+004	2.862e+004	0.495 resis
1	1	B6	3	2	-7.125e-007	-7.125e-007	-5.551e+004	1.745e+004	5.818e+004	-3.386e-005	-2.765e+002	2.765e+002	0.476
1	1	B6	4	1	7.103e-007	7.103e-007	5.785e+004	1.745e+004	6.042e+004	-2.933e-005	2.862e+004	2.862e+004	0.495 resis
1	1	B6	4	2	-7.125e-007	-7.125e-007	-5.551e+004	-1.745e+004	5.818e+004	-3.386e-005	-2.765e+002	2.765e+002	0.476
1	1	B6	5	1	7.103e-007	7.103e-007	2.153e+004	-1.745e+004	2.771e+004	-2.933e-005	2.862e+004	2.862e+004	0.227 resis
1	1	B6	5	2	-7.125e-007	-7.125e-007	-1.918e+004	1.745e+004	2.593e+004	-3.386e-005	-2.765e+002	2.765e+002	0.212
1	1	B6	6	1	7.103e-007	7.103e-007	2.153e+004	1.745e+004	2.771e+004	-2.933e-005	2.862e+004	2.862e+004	0.227 resis
1	1	B6	6	2	-7.125e-007	-7.125e-007	-1.918e+004	-1.745e+004	2.593e+004	-3.386e-005	-2.765e+002	2.765e+002	0.212

Here we checked in detail one bolt layout and then one single bolt. The same could be done for every layout and every bolt: for each one of them, the force in this load case is equal to 1/3 of the sum of forces computed in basic load cases, being this load case equal to 1/3 of the sum of those basic conditions (superposition principle). Forces due to basic load cases have the same sign on some bolts (sum) and opposite sign on other bolts (subtraction): symmetry in bolts utilization is lost (see next figure).

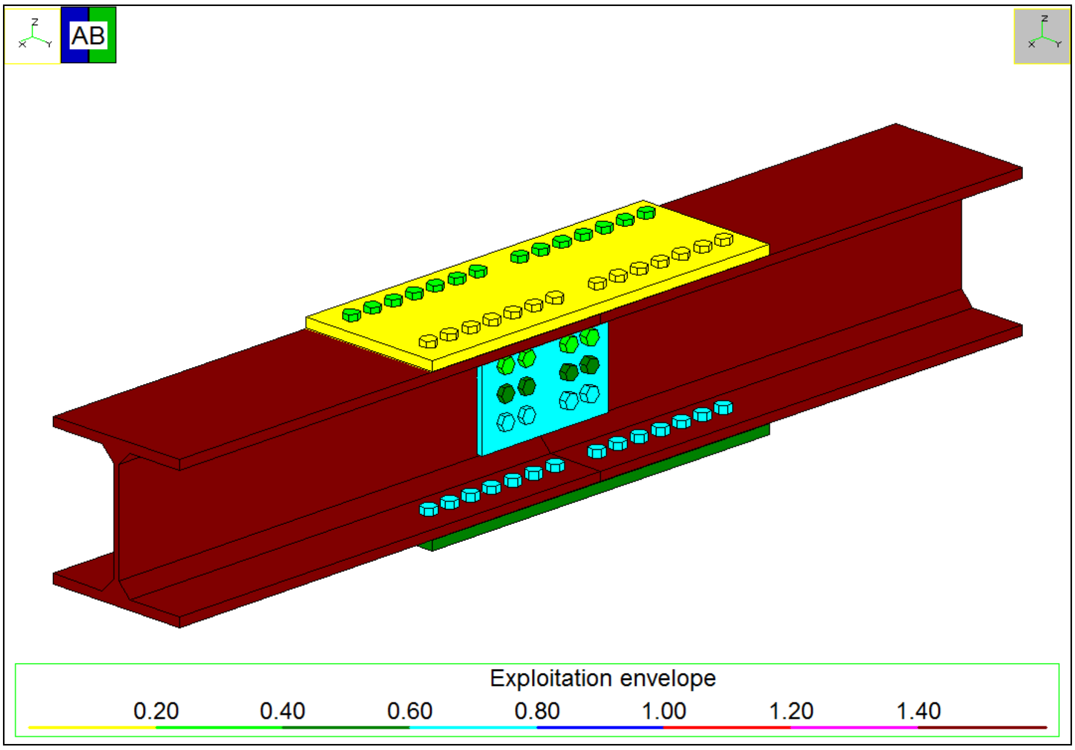


Figure B-46 Components utilization envelope

B.3 VERTICAL SPLICE JOINT

B.3.1 End plates splice joint

B.3.1.1 Introduction

Consider an end plates splice joint between two members with HEB320 cross-section and S235 material. Following figures show CSE model. Fillet welds have a thickness equal to 20mm (throat section is 14.1mm). Welds end 1mm before member sides extremes. Four M33 - class 8.8 bolts are used.

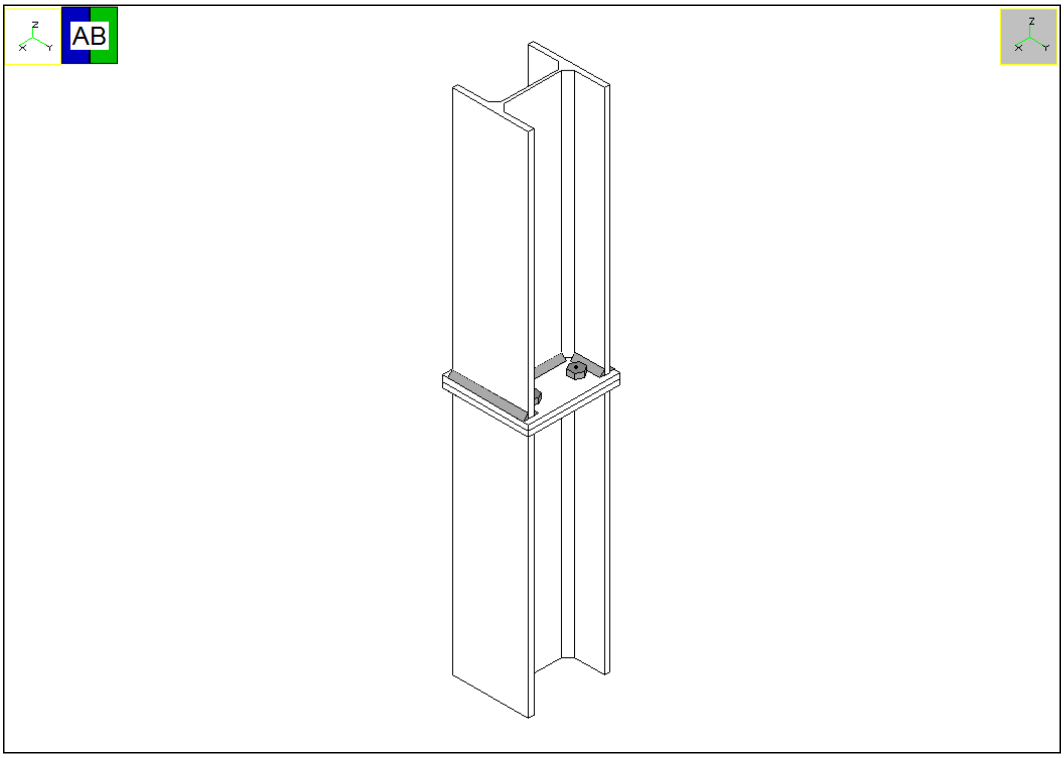


Figure B-47 3D view of the model

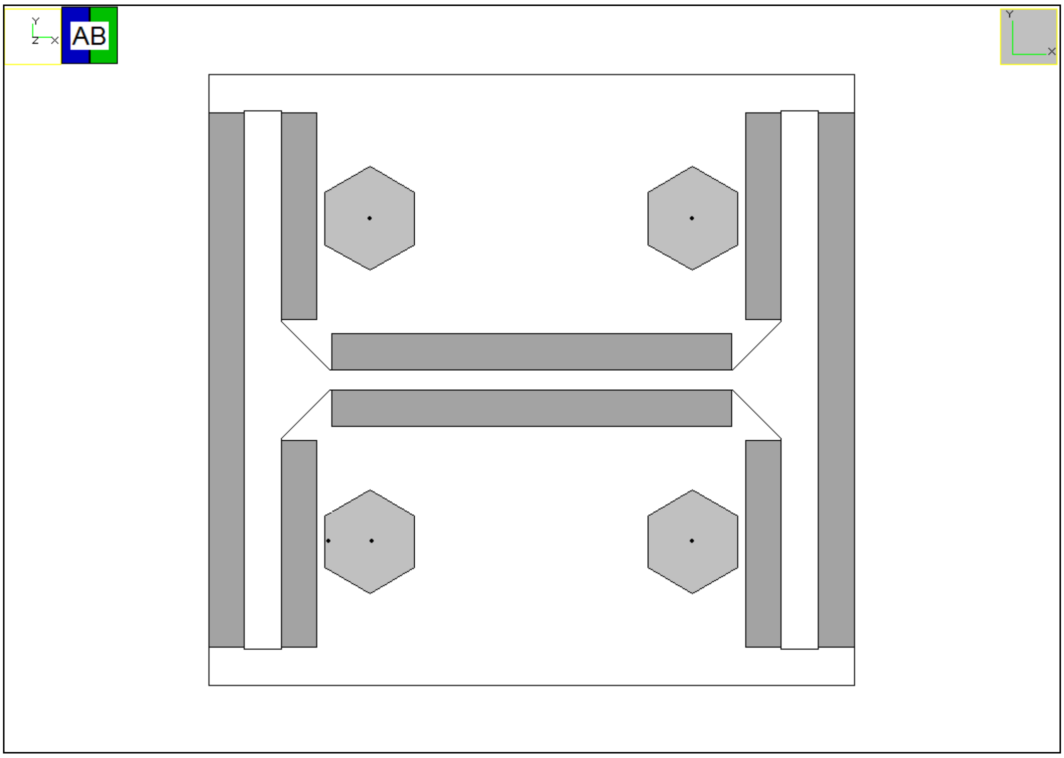


Figure B-48 Top view

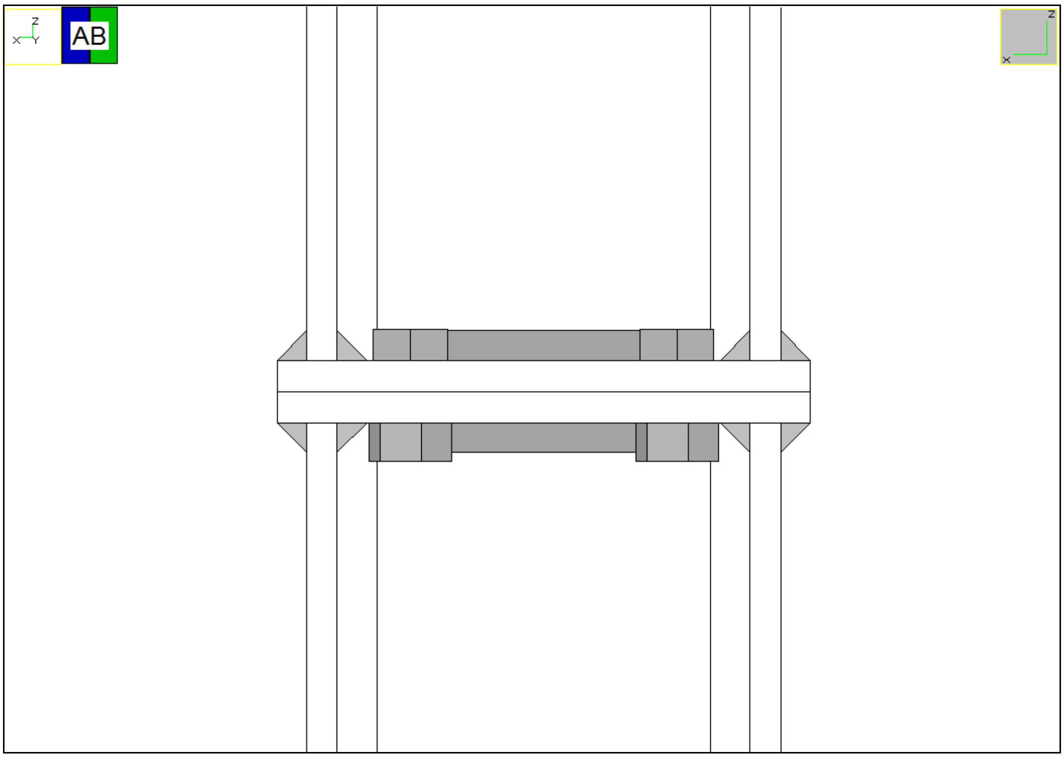


Figure B-49 Side view

Cross-section dimensions are the following.

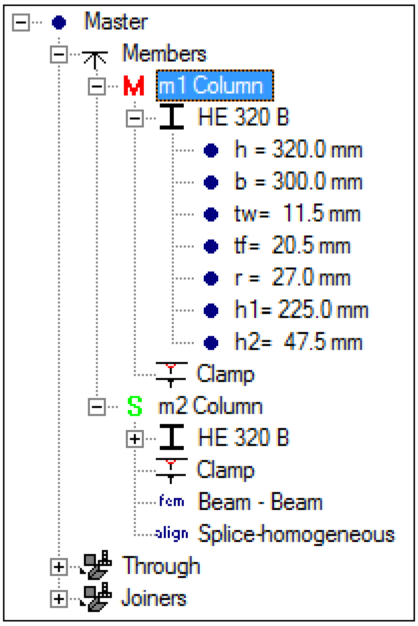


Figure B-50

Next figures show welds and bolts numbering.

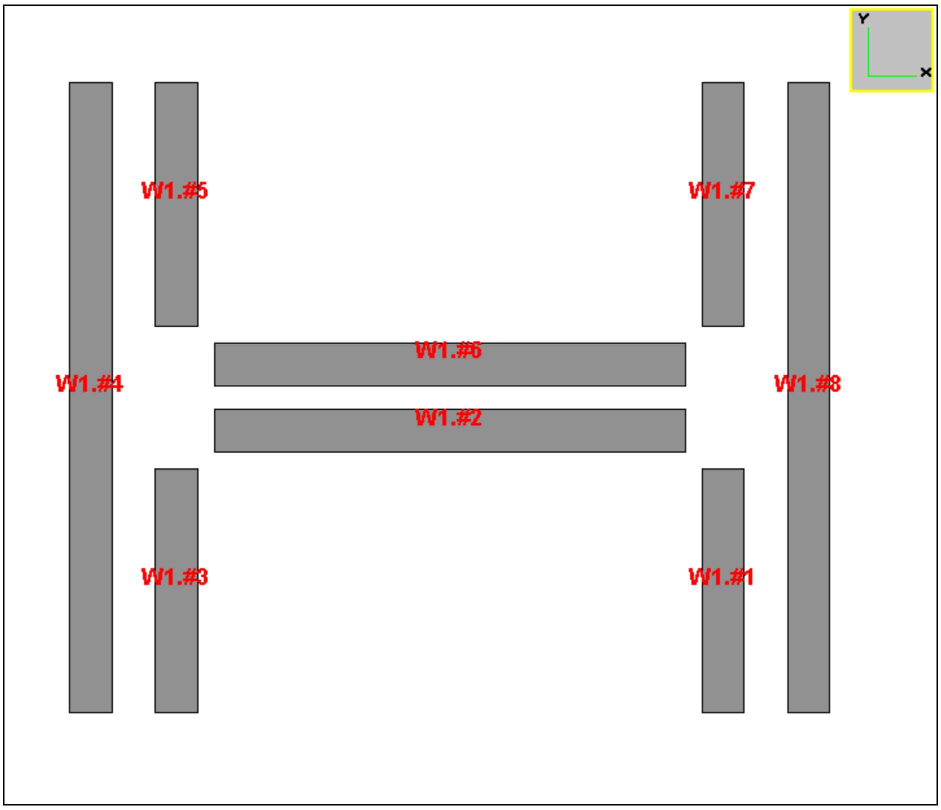


Figure B-51 Upper weld layout (W1): fillet welds numbering

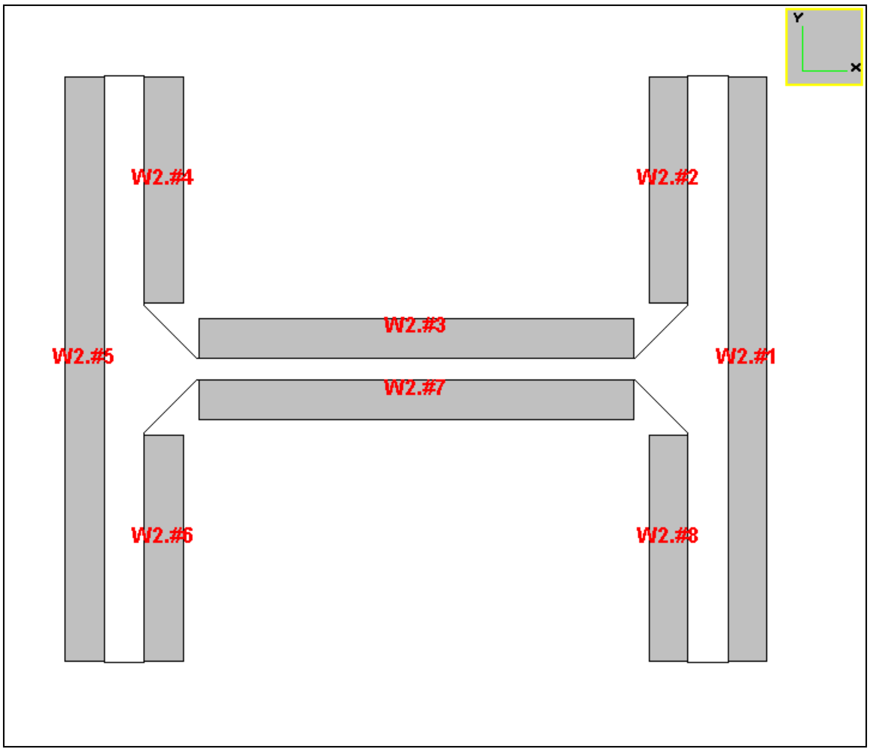


Figure B-52 Lower weld layout (W2): fillet welds numbering

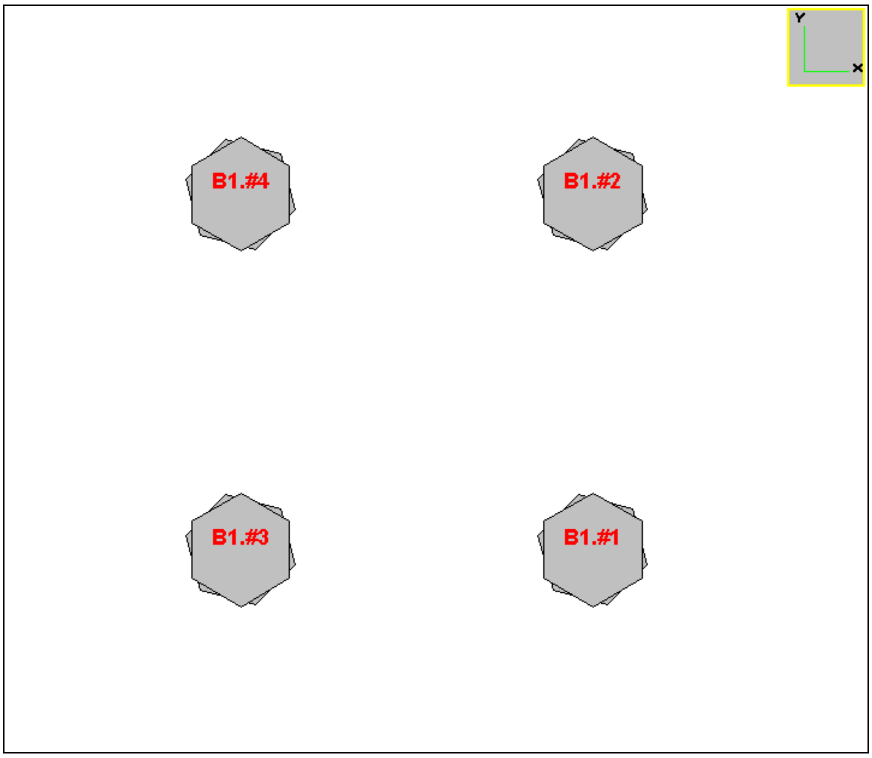


Figure B-53 Bolts numbering

The following are the distances between the bolts and from the bolts to the edges.

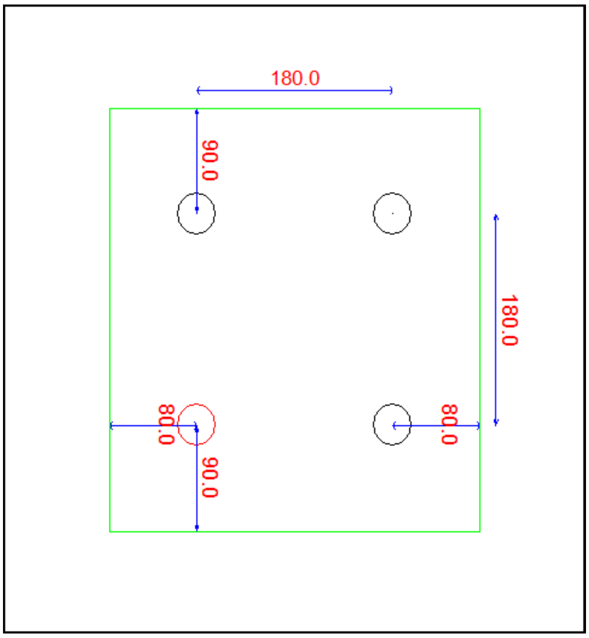


Figure B-54 Distances between bolts and from edges

No bearing surface is used now: **compression is carried by bolts shaft** (for bearing surface check, see part C). Chosen check settings do not consider compression check for bolts: only resistance to tension is checked now.

B.3.1.2 Compression

Amplified plastic axial force of the cross-section is applied to model *Validation_VSP_1_1.CSE* (compression force).

$$N_{pl,Rd} = A*f_y*\gamma_{RD} = 16134 * 235 * 1.2 = 4.550*10^6 \text{N}$$

Since bolts resistance is not checked in compression (according to check settings) we expect a null utilization factor in this case of compression only. These are CSE' results.

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	-1.137e+006	-1.137e+006	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000	
1	1	B1	2	1	-1.137e+006	-1.137e+006	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000	
1	1	B1	3	1	-1.137e+006	-1.137e+006	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000	
1	1	B1	4	1	-1.137e+006	-1.137e+006	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000	

Bolts compression check can be included. A bearing surface can be defined to carry compression loads (see part C).

For fillet welds check, CSE uses the method in EN 1993-1-8:2005 paragraph 4.5.3.3. This method considers forces per length unit on welds. Utilization on a weld is computed as the ratio between design force per length unit ($F_{w,Ed}$) and design resistance per length unit ($F_{w, Rd}$).

In this case, all the welds have equal section and they are subjected to the same force per length unit ($F_{w,Ed}$). This is equal to total applied force ($N_{pl,Rd}$) divided by the sum of welds length (L_{tot}).

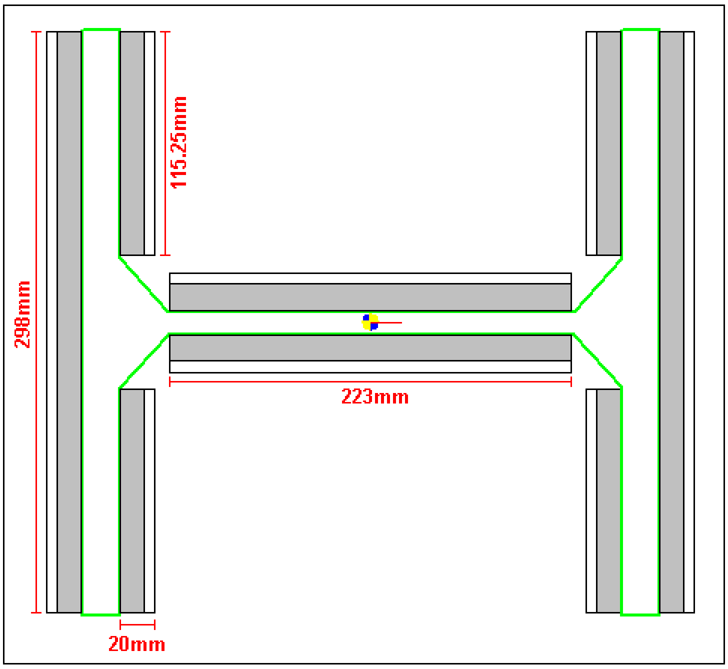


Figure B-55 Welds dimensions

We have

$$L_{tot} = 2 * 298\text{mm} + 4 * 115.25\text{mm} + 2 * 223\text{mm} = 1503\text{mm}$$

$$F_{w,Ed} = N_{pl,Rd} =/ L_{tot} = 4.550*10^6\text{N} / 1503\text{mm} = 3027\text{N/mm}$$

Design resistance is:

$$F_{w,Rd} = f_{vw,d} \cdot a$$

where

$$f_{vw,d} = \frac{f_u / \sqrt{3}}{\beta_w \gamma_{M2}}$$

with the following values:

a = 14.1mm (throat section)

β_w = 0.8 for S235 (EN1993-1-8, *Table 4.1*)

f_u = 360MPa

γ_{M2} = 1.25

we have:

$$f_{vw,d} = \frac{360MPa / \sqrt{3}}{0.8 \cdot 1.25} = 207.85MPa$$

$$F_{w,Rd} = 207.85MPa \cdot 14.1mm = 2931N/mm$$

$$\frac{F_{w,Ed}}{F_{w,Rd}} = \frac{3027N/mm}{2931N/mm} = 1.03$$

CSE computes the same value.

```
-----------------------------------------
Internal stresses in welds, exploitations
-----------------------------------------

Inst  Combi  Name Weld     nPer        tPar         tPer        force      Cause  Ext   Expl

    1      1    W1   1  -2.141e+002  0.000e+000  -0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   2  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   3  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   4  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   5  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   6  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   7  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W1   8  -2.141e+002 -0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *

    1      1    W2   1  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   2  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   3  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   4  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   5  -2.141e+002 -0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   6  -2.141e+002  0.000e+000  -0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   7  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
    1      1    W2   8  -2.141e+002  0.000e+000   0.000e+000   3.027e+003     3     1   1.030 *
```

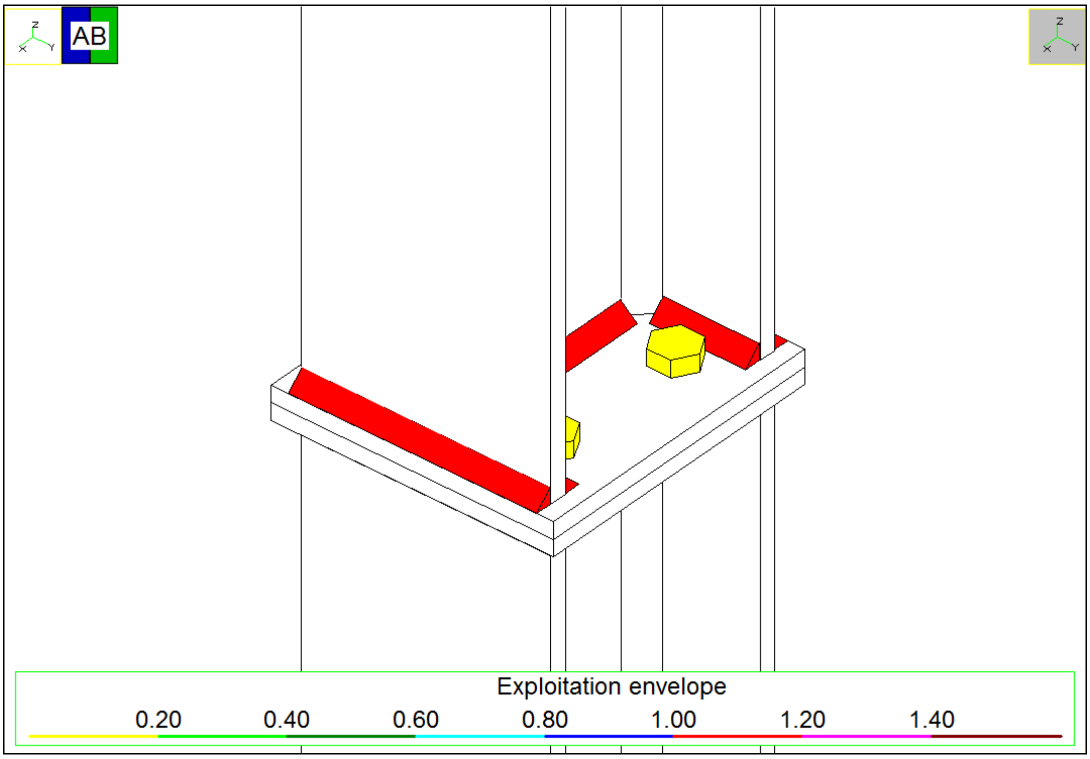


Figure B-56 Components utilization envelope

NOTE WELL: checks on members and plates are not included in this computation. Only bearing check is included, but shear forces are null here. For example, the following automatic checks could be done on the plates (see part C of the document):

- bearing surface check;
- automatic FEM model creation and analysis (linear on non linear), including forces due to bolts, welds and bearing surfaces, in each combination;
- additional user's checks (user can define new check conditions and CSE will check them in all the combinations).

B.3.1.3 Tension

This case is the opposite of the previous one: instead of the compression, a tension with the same value is applied (4.550*10^6N - model: *Validation_VSP_1_2.CSE*). Forces on fillet welds are the same, with opposite sign. Expected utilizations are the same of compression, as computed by CSE.

```
Internal stresses in welds, exploitations
-------------------------------------------

Inst  Combi  Name Weld     nPer         tPar          tPer         force      Cause  Ext    Expl

   1     1     W1   1   2.141e+002  0.000e+000  -0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   2   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   3   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   4   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   5   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   6   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   7   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W1   8   2.141e+002 -0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *

   1     1     W2   1   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   2   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   3   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   4   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   5   2.141e+002 -0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   6   2.141e+002  0.000e+000  -0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   7   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
   1     1     W2   8   2.141e+002  0.000e+000   0.000e+000   3.027e+003     2     1    1.030 *
```

Now consider the bolts. Total load is equally distributed[3] on each bolt; tension in a single bolt is:

$$F_{t,Ed} = T/4 = 1.137*10^6 \text{N}$$

Design resistance for bolts in tension according to EN1993-1-8 is (see appendix):

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$$

where k_2=0.9, A_s=694mm^2, f_{ub}=800 and γ_{M2}=1.25.

$F_{t,Rd}$ is equal to 3.997*10^{5}N; bolts utilization factor is:

$$\frac{F_{t,Ed}}{F_{t,Rd}} = 2.845$$

CSE computes the following value.

```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------

Inst  Combi  Name Bolt -?-      NB          NTB          TuB          TvB         TB           MuB         MvB          MB         Expl  cause

   1     1     B1   1   1   1.138e+006  1.138e+006  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  2.846 resis !!!
   1     1     B1   2   1   1.138e+006  1.138e+006  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  2.846 resis !!!
   1     1     B1   3   1   1.138e+006  1.138e+006  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  2.846 resis !!!
   1     1     B1   4   1   1.138e+006  1.138e+006  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  0.000e+000  2.846 resis !!!
```

[3] It is equally distributed on bolts since load application point, weld layout and bolt layout are centred; if there was an offset due to non-symmetrical geometry, forces distribution would have been different

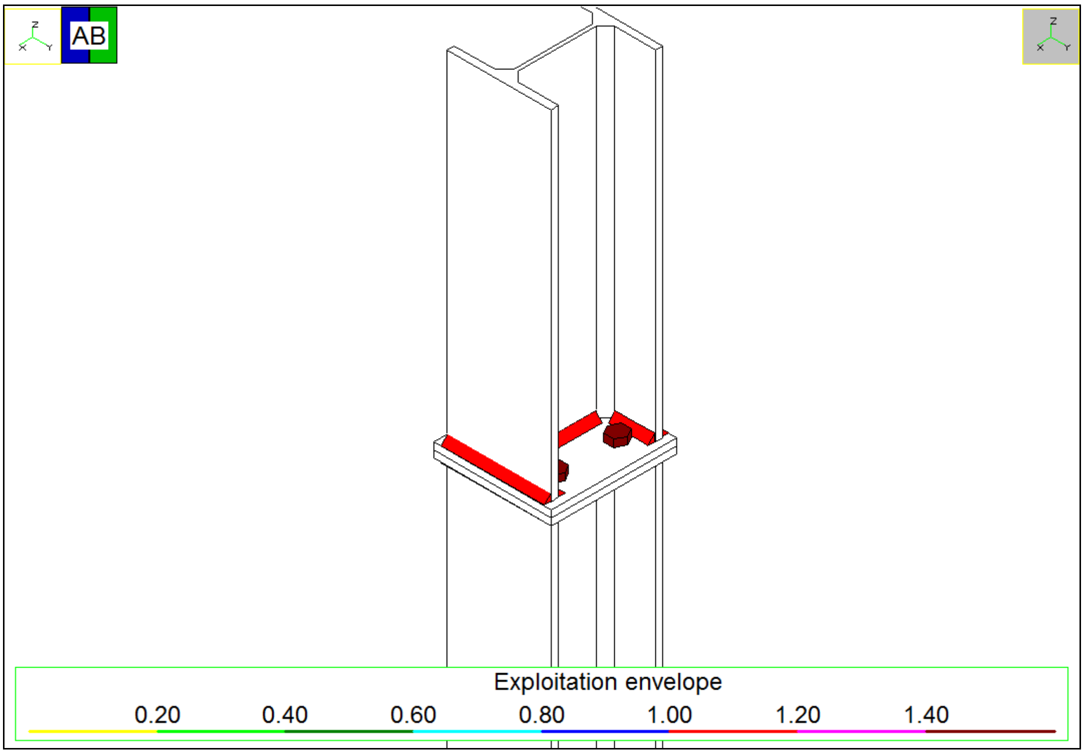


Figure B-57 Components utilization envelope

NOTE WELL: as for compression case, checks for the plates are not included (see part C).

B.3.1.4 Bending

B.3.1.4.1 Checks

A load parallel to members web is applied to imported FEM model in order to have the following bending moment[4] in joint node (model: *Validation_VSP_1_3.CSE*):

$$M = 1.225 \cdot 10^{8} \text{Nmm}.$$

Bending can be carried in different ways by a bolt layout:

1. compression and tension in bolts (compression can be excluded from resistance check)
2. compression on bearing surface + tension in bolts beyond elastic neutral axis
3. compression on bearing surface and in bolts + tension in bolts beyond neutral axis

[4] Simply supported beam; column height = 7m, joint node at 3.4m; distributed load = 20N/mm

For bearing surface check, see part C of this document. Here condition 1 is assumed, with bolts resistance check for compression not included. For this reason, we extpect two compressed bolts with null utilization and two bolts in tension. Force on each bolt:

$$\frac{1}{2}\frac{M}{d} = 3.403 \cdot 10^5\, N$$

where d=180mm is the distance between bolts. Dividing that force by design resistance computed in previous paragraph, we get an utilization factor equal to 0.851.

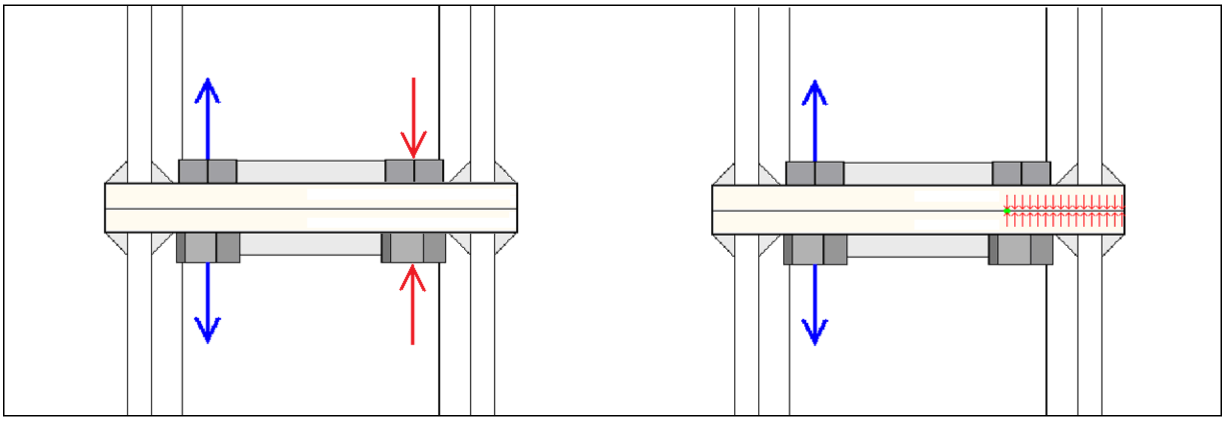


Figure B-58 Without bearing surface (left); with bearing surface (right)

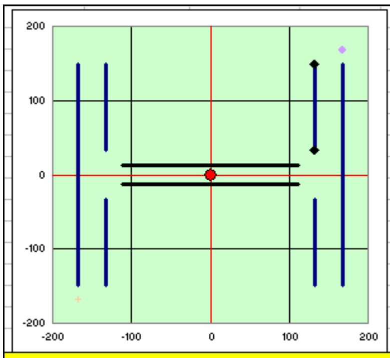
CSE computes a slightly lower value (-0.85%). It must be considered that the program computes also parasitic bending in bolt shafts; this bending is usually omitted in hand computations. Note well: shafts bending is always computed by CSE; it is possible to exclude it from the checks (like in this case). The difference between bolt force computed by CSE and bolt force hand computed with simplified scheme (no bending in shafts) is proportional to utilization factor computed by CSE and by hand.

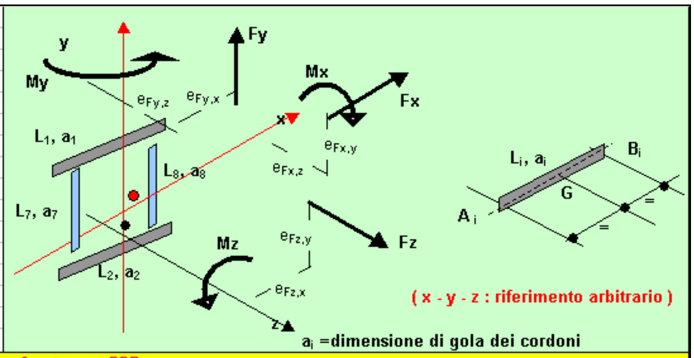
```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------

Inst  Combi  Name Bolt -?-       NB          NTB          TuB          TvB          TB           MuB          MvB          MB        Expl  cause

   1      1    B1    1   1   3.374e+005   3.374e+005   0.000e+000  -3.579e-003  3.579e-003  -2.552e+005  0.000e+000   2.552e+005   0.844 resis
   1      1    B1    2   1   3.374e+005   3.374e+005   0.000e+000  -3.579e-003  3.579e-003  -2.552e+005  0.000e+000   2.552e+005   0.844 resis
   1      1    B1    3   1  -3.374e+005  -3.374e+005   0.000e+000  -3.579e-003  3.579e-003  -2.552e+005  0.000e+000   2.552e+005   0.000 resis
   1      1    B1    4   1  -3.374e+005  -3.374e+005   0.000e+000  -3.579e-003  3.579e-003  -2.552e+005  0.000e+000   2.552e+005   0.000 resis
```

To validate CSE results for fillet welds, we are going to use the application *Saldature* (Weldings) by Giulio Ballio (see A.3).





Confronto con CSE												
tutti i cordoni hanno eguale dimensione della gola pari a: mm					***14,14***	*il dato sostituisce tale valore*			riferite ad assi principali			
posizione cordoni	cordone w	a_i	L_i	$x_{A,i}$	$y_{A,i}$	$x_{G,i}$	$y_{G,i}$	A_i	$\xi_{A,i}$	$\xi_{B,i}$	$\eta_{A,i}$	$\eta_{B,i}$
		mm	mm	mm	mm	mm	mm	cm^2	mm	mm	mm	mm
cordoni paralleli ad asse x	1		223,0	-111,5	12,8	0,0	12,8	31,5	-111,5	111,5	12,8	12,8
	2		223,0	-111,5	-12,8	0,0	-12,8	31,5	-111,5	111,5	-12,8	-12,8
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		298,0	-167,1	-149,0	-167,1	0	42,1	-167	-167	-149	149
	8		298,0	167,1	-149,0	167,1	0,0	42,1	167	167	-149	149
	9		115,3	-132,4	-149,0	-132,4	-91,4	16,3	-132	-132	-149	-34
	10		115,3	-132,4	33,8	-132,4	91,4	16,3	-132	-132	34	149
	11		115,3	132,4	-149,0	132,4	-91,4	16,3	132	132	-149	-34
(blu)	12		115,3	132,4	33,8	132,4	91	16,3	132	132	34	149
caratteristiche della sezione		A	x_G	y_G	I_{Gxx}	I_{Gyy}	I_{Gxy}	α		$I_{G\xi\xi}$	$I_{G\eta\eta}$	
		cm^2	mm	mm	cm^4	cm^4	cm^4	radianti	gradi	cm^4	cm^4	
		212,5	**0**	**0**	**12.504**	**37.568**	**0**	**0,0000**	**0**	**12.504**	**37.568**	

Figure B-59 ***Saldature*** **application: input data**

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
carico	asse x				asse y				asse z			
	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1						122.500,0						
2												
3												

Figure B-60 ***Saldature*** **application: applied loads**

condizione di carico 1	unità di misura degli sforzi:			N/mm2						
cordoni	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	36,36	0,0	36,36	0,0	0,0	0,0	0,0	0,0	0,0
1B	0,0	-36,36	0,0	-36,36	0,0	0,0	0,0	0,0	0,0	0,0
2A	0,0	36,36	0,0	36,36	0,0	0,0	0,0	0,0	0,0	0,0
2B	0,0	-36,36	0,0	-36,36	0,0	0,0	0,0	0,0	0,0	0,0
						F_x			F_y	
7A	0,0	54,48	0,0	54,48	0,0	0,0	0,0	0,0	0,0	0,0
7B	0,0	54,48	0,0	54,48	0,0	0,0	0,0	0,0	0,0	0,0
8A	0,0	-54,48	0,0	-54,48	0,0	0,0	0,0	0,0	0,0	0,0
8B	0,0	-54,48	0,0	-54,48	0,0	0,0	0,0	0,0	0,0	0,0
9A	0,0	43,18	0,0	43,18	0,0	0,0	0,0	0,0	0,0	0,0
9B	0,0	43,18	0,0	43,18	0,0	0,0	0,0	0,0	0,0	0,0
10A	0,0	43,18	0,0	43,18	0,0	0,0	0,0	0,0	0,0	0,0
10B	0,0	43,18	0,0	43,18	0,0	0,0	0,0	0,0	0,0	0,0
11A	0,0	-43,18	0,0	-43,18	0,0	0,0	0,0	0,0	0,0	0,0
11B	0,0	-43,18	0,0	-43,18	0,0	0,0	0,0	0,0	0,0	0,0
12A	0,0	-43,18	0,0	-43,18	0,0	0,0	0,0	0,0	0,0	0,0
12B	0,0	-43,18	0,0	-43,18	0,0	0,0	0,0	0,0	0,0	0,0

Figure B-61 *Saldature* application: stresses in fillet welds

CSE stress results are the same computed using *Saldature*. Welds numbering is different in CSE and *Saldature*. For CSE, weld numbering in W1 layout is shown in Figure B-51. See Figure B-59 to get welds numbering in *Saldature*.

```
------------------------------------------
Internal stresses in welds, exploitations
------------------------------------------

Inst  Combi  Name Weld     nPer         tPar         tPer         force      Cause  Ext   Expl

    1      1    W1    1   4.317e+001  5.785e-023   9.448e-007   6.106e+002     2     1   0.208
    1      1    W1    2  -3.635e+001  9.448e-007  -1.166e-023   5.141e+002     2     1   0.175
    1      1    W1    3  -4.317e+001  5.785e-023  -9.448e-007   6.106e+002     2     1   0.208
    1      1    W1    4  -5.447e+001  5.785e-023   9.448e-007   7.703e+002     2     1   0.262
    1      1    W1    5  -4.317e+001  5.785e-023  -9.448e-007   6.106e+002     2     1   0.208
    1      1    W1    6   3.635e+001 -9.448e-007  -1.157e-022   5.141e+002     2     1   0.175
    1      1    W1    7   4.317e+001  5.785e-023   9.448e-007   6.106e+002     2     1   0.208
    1      1    W1    8   5.447e+001  5.785e-023  -9.448e-007   7.703e+002     2     1   0.262

    1      1    W2    1   5.447e+001 -5.205e-024  -8.500e-008   7.703e+002     2     1   0.262
    1      1    W2    2   4.317e+001 -5.205e-024   8.500e-008   6.106e+002     2     1   0.208
    1      1    W2    3  -3.635e+001  8.500e-008   1.041e-023   5.141e+002     2     1   0.175
    1      1    W2    4  -4.317e+001 -5.205e-024  -8.500e-008   6.106e+002     2     1   0.208
    1      1    W2    5  -5.447e+001 -5.205e-024   8.500e-008   7.703e+002     2     1   0.262
    1      1    W2    6  -4.317e+001 -5.205e-024  -8.500e-008   6.106e+002     2     1   0.208
    1      1    W2    7  -3.635e+001 -8.500e-008   0.000e+000   5.141e+002     2     2   0.175
    1      1    W2    8   4.317e+001 -5.205e-024   8.500e-008   6.106e+002     2     1   0.208
```

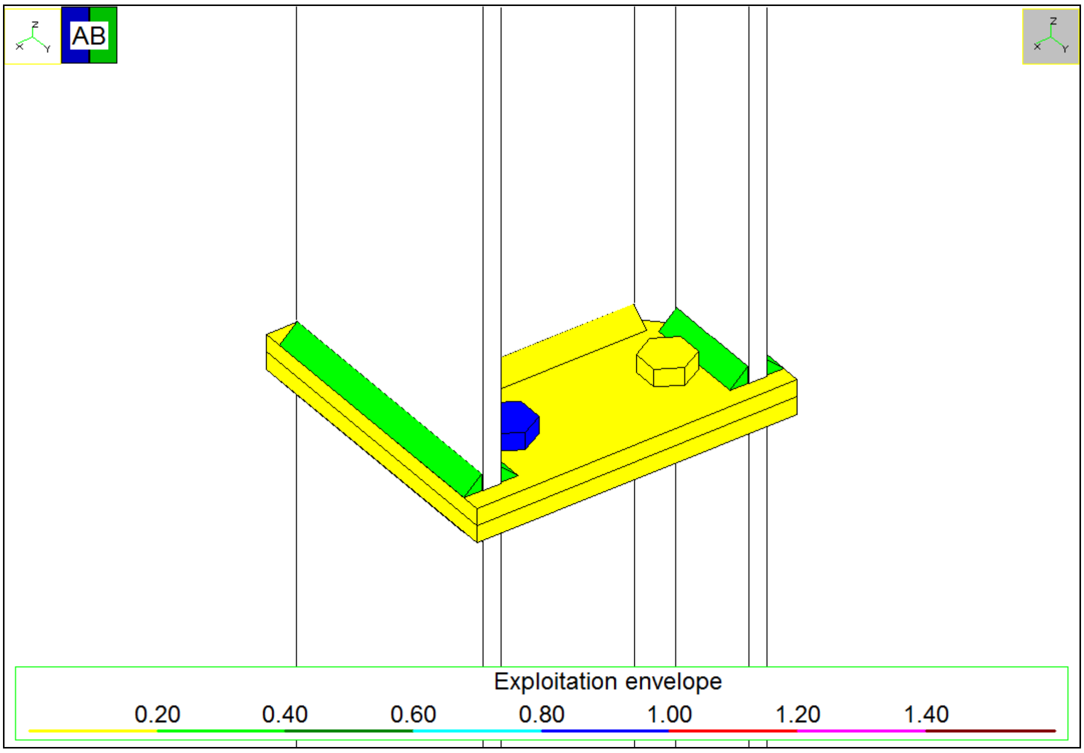


Figure B-62 Components utilization envelope

B.3.1.4.2 Bending with non-symmetric bending

In order to check CSE generality, we modify W1 weld layout deleting some fillet welds. Layout W2 is not modified. Mode name: *Validation_VSP_1_4.CSE*.

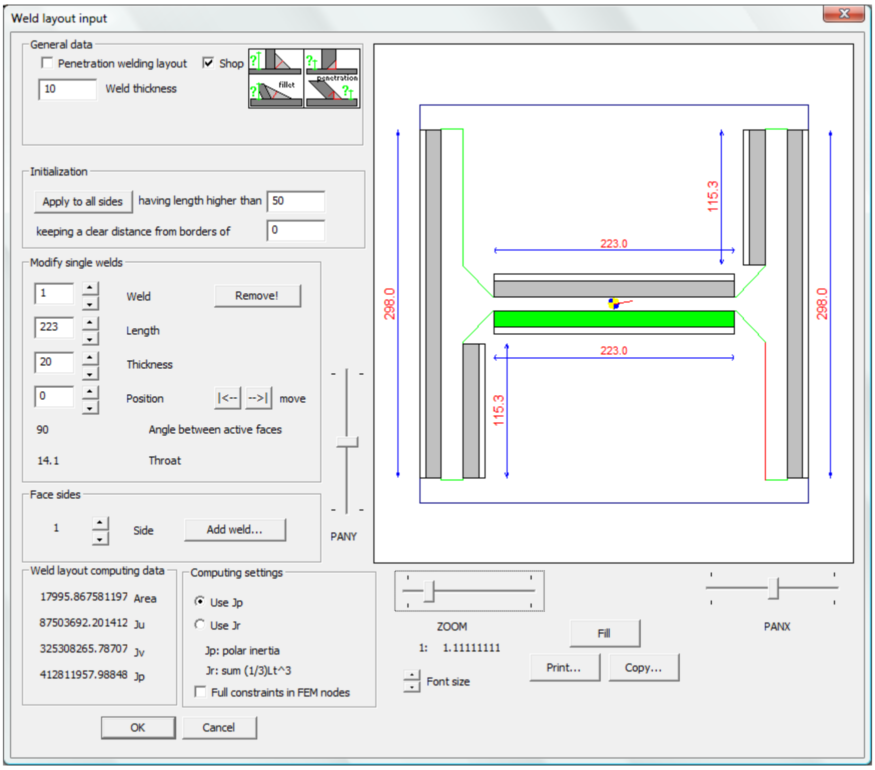


Figure B-63 Modified weld layout

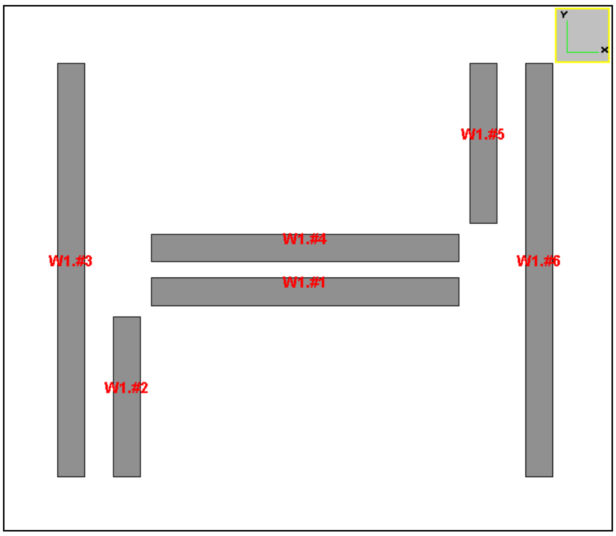
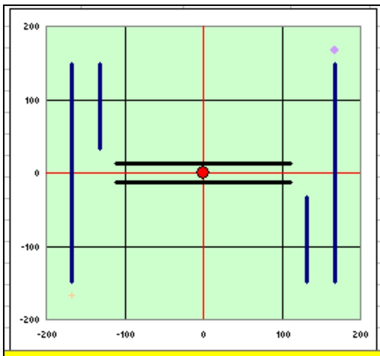
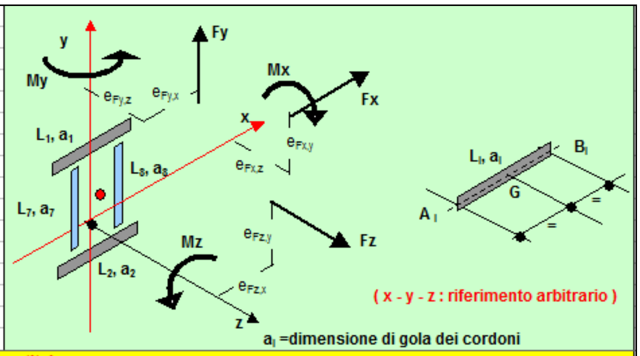


Figure B-64 Welds numbering (layout W1)

Two welds were removed from the flanges (Figure B-63, Figure B-64). We will use *Saldature* to cross-check CSE results, like in previous paragraph. Input data are the following.





titolo												
tutti i cordoni hanno eguale dimensione della gola pari a: mm					***14,14***	*il dato sostituisce tale valore*			riferite ad assi principali			
posizione cordoni	cordone w	a_i	L_i	$x_{A,i}$	$y_{A,i}$	$x_{G,i}$	$y_{G,i}$	A_i	$\xi_{A,i}$	$\xi_{B,i}$	$\eta_{A,i}$	$\eta_{B,i}$
		mm	mm	mm	mm	mm	mm	cm²	mm	mm	mm	mm
cordoni paralleli ad asse x	1		223,0	-111,5	12,8	0,0	12,8	31,5	-112,1	107,8	-6,2	31,4
	2		223,0	-111,5	-12,8	0,0	-12,8	31,5	-107,8	112,1	-31,4	6,1
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		298,0	-167,1	-149,0	-167,1	0	42,1	-140	-190	-175	119
	8		298,0	167,1	-149,0	167,1	0,0	42,1	190	140	-119	175
	9		115,3	-132,4	33,8	-132,4	91,5	16,3	-136	-156	11	125
	10		115,3	132,4	-149,0	132,4	-91,4	16,3	156	136	-125	-11
	11											
(blu)	12											
caratteristiche della sezione		A	x_G	y_G	I_{Gxx}	I_{Gyy}	I_{Gxy}	α		$I_{G\xi\xi}$	$I_{G\eta\eta}$	
		cm²	mm	mm	cm⁴	cm⁴	cm⁴	radianti	gradi	cm⁴	cm⁴	
		179,9	**0**	**0**	**9.425**	**31.861**	**-3.946**	**-0,1691**	**-10**	**8.751**	**32.535**	

Figure B-65 *Saldature* application: input data

Saldature gives the following results.

condizione di carico 1	unità di misura degli sforzi:				N/mm2					
cordoni	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	1,45	41,59	0,00	43,04	0,0	0,0	0,0	0,0	0,0	0,0
1B	-7,39	-39,99	0,00	**-47,39**	0,0	0,0	0,0	0,0	0,0	0,0
2A	7,40	39,99	0,00	**47,39**	0,0	0,0	0,0	0,0	0,0	0,0
2B	-1,45	-41,59	0,00	-43,04	0,0	0,0	0,0	0,0	0,0	0,0
						F_x			F_y	
7A	41,23	51,83	0,00	**93,06**	0,0	0,0	0,0	0,0	0,0	0,0
7B	-27,98	70,44	0,00	42,47	0,0	0,0	0,0	0,0	0,0	0,0
8A	27,98	-70,44	0,00	-42,46	0,0	0,0	0,0	0,0	0,0	0,0
8B	-41,23	-51,83	0,00	**-93,05**	0,0	0,0	0,0	0,0	0,0	0,0
9A	-2,60	50,55	0,00	**47,95**	0,0	0,0	0,0	0,0	0,0	0,0
9B	-29,37	57,75	0,00	28,38	0,0	0,0	0,0	0,0	0,0	0,0
10A	29,36	-57,75	0,00	-28,39	0,0	0,0	0,0	0,0	0,0	0,0
10B	2,58	-50,55	0,00	**-47,97**	0,0	0,0	0,0	0,0	0,0	0,0

Figure B-66 *Saldature* application: stresses in welds

Differences between normal stresses computed by CSE and *Saldature* are very small: maximum is 0.06% between 47.98 (CSE) and 47.95 (*Saldature*). Note well: welds numbering is different in the two programs.

```
-----------------------------------------
Internal stresses in welds, exploitations
-----------------------------------------

Inst  Combi  Name Weld     nPer         tPar         tPer         force      Cause  Ext   Expl

   1      1    W1   1   4.739e+001  8.688e-007 -2.489e-007  6.703e+002     2     2   0.228
   1      1    W1   2  -4.798e+001 -2.489e-007 -8.688e-007  6.785e+002     2     2   0.231
   1      1    W1   3  -9.305e+001  2.489e-007  8.688e-007  1.316e+003     2     1   0.448
   1      1    W1   4  -4.739e+001 -8.688e-007  2.489e-007  6.703e+002     2     2   0.228
   1      1    W1   5   4.798e+001  2.489e-007  8.688e-007  6.785e+002     2     2   0.231
   1      1    W1   6   9.305e+001 -2.489e-007 -8.688e-007  1.316e+003     2     1   0.448

   1      1    W2   1   5.447e+001 -4.245e-009 -4.264e-007  7.703e+002     2     1   0.262
   1      1    W2   2   4.317e+001  4.245e-009  4.264e-007  6.106e+002     2     2   0.208
   1      1    W2   3   3.635e+001  4.264e-007 -4.245e-009  5.141e+002     2     2   0.175
   1      1    W2   4  -4.317e+001 -4.245e-009 -4.264e-007  6.106e+002     2     2   0.208
   1      1    W2   5  -5.447e+001  4.245e-009  4.264e-007  7.703e+002     2     1   0.262
   1      1    W2   6  -4.317e+001 -4.245e-009 -4.264e-007  6.106e+002     2     2   0.208
   1      1    W2   7  -3.635e+001 -4.264e-007  4.245e-009  5.141e+002     2     2   0.175
   1      1    W2   8   4.317e+001  4.245e-009  4.264e-007  6.106e+002     2     2   0.208
```

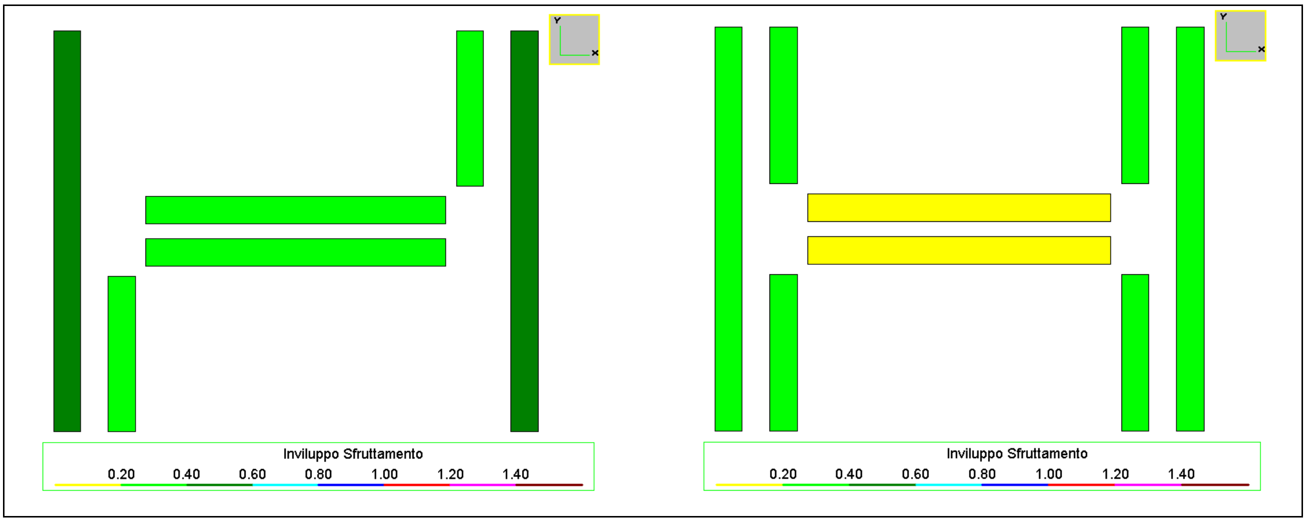


Figure B-67 Weld layouts exploitation envelope (W1: left; W2: right)

B.3.1.5 Torque

Model: *Validation_VSP_1_5.CSE*. In the joint node, the only internal force in members is a torque.

$$M_t=1.341*10^7 \text{Nmm}.$$

According to Figure B-68, we can compute shear force in bolts: they are all subjected to a shear equal to $V_b=M_t/J_p*d$. Polar inertia moment J_p is:

$$J_p = \Sigma\left(d_i^2\right) = 4 \cdot \left(\frac{180mm}{2} \cdot \sqrt{2}\right)^2 = 64800mm^2$$

distance is

$$d = 180\sqrt{2}/2 = 127.3mm$$

We have:

$$V_b = \frac{1.341 \cdot 10^7\ Nmm}{6.48 \cdot 10^4\ mm^2} \cdot 127.3mm = 2.633 \cdot 10^4\ N$$

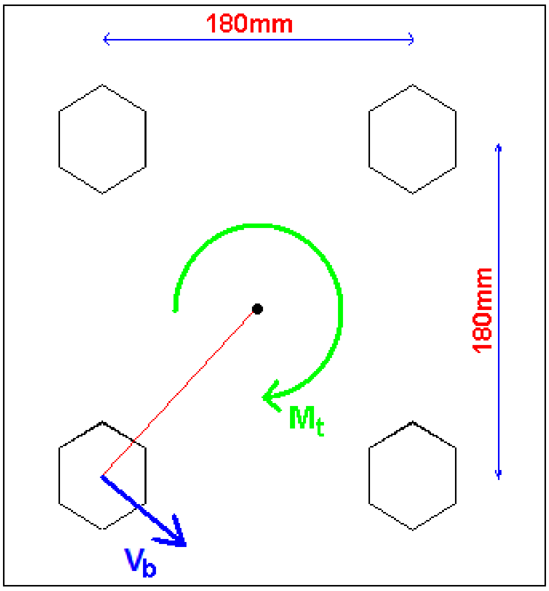


Figure B-68

Bolts design resistance is $F_{V,Rd}=a_v*f_{ub}*A/\gamma_{M2}=3.284*10^5$N, with $a_v=0.6$, $f_{ub}=800$N/mm^2, $A=855.3$mm^2 and $\gamma_{M2}=1.25$. Utilization is $V_b/F_{V,Rd}$ =0.08. CSE computes the same results.

```
--------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
--------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	0.000e+000	0.000e+000	1.862e+004	-1.862e+004	2.633e+004	0.000e+000	0.000e+000	0.000e+000	0.080	resis
1	1	B1	2	1	0.000e+000	0.000e+000	1.862e+004	1.862e+004	2.633e+004	0.000e+000	0.000e+000	0.000e+000	0.080	resis
1	1	B1	3	1	0.000e+000	0.000e+000	-1.862e+004	-1.862e+004	2.633e+004	0.000e+000	0.000e+000	0.000e+000	0.080	resis
1	1	B1	4	1	0.000e+000	0.000e+000	-1.862e+004	1.862e+004	2.633e+004	0.000e+000	0.000e+000	0.000e+000	0.080	resis

To cross-check fillet welds stresses results, we are going to use Saldature application again. Input data are the same shown in Figure B-59. Applied load and computed results are shown in following figures.

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
carico	asse x				asse y				asse z			
	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1										13.406,4		
2												
3												

Figure B-69 *Saldature* application: applied loads

condizione di carico 1	unità di misura degli sforzi:			N/mm2					
cordoni	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	0,0	0,0	0,0	-2,985	0,0	-2,985	-0,343	0,0	-0,343
1B	0,0	0,0	0,0	0,0	2,985	0,0	2,985	-0,343	0,0	-0,343
2A	0,0	0,0	0,0	0,0	-2,985	0,0	-2,985	0,343	0,0	0,343
2B	0,0	0,0	0,0	0,0	2,985	0,0	2,985	0,343	0,0	0,343
						F_x			F_y	
7A	0,0	0,0	0,0	0,0	3,989	0,0	3,989	-4,473	0,0	-4,473
7B	0,0	0,0	0,0	0,0	-3,989	0,0	-3,989	-4,473	0,0	-4,473
8A	0,0	0,0	0,0	0,0	3,989	0,0	3,989	4,473	0,0	4,473
8B	0,0	0,0	0,0	0,0	-3,989	0,0	-3,989	4,473	0,0	4,473
9A	0,0	0,0	0,0	0,0	3,989	0,0	3,989	-3,546	0,0	-3,546
9B	0,0	0,0	0,0	0,0	0,904	0,0	0,904	-3,546	0,0	-3,546
10A	0,0	0,0	0,0	0,0	-0,904	0,0	-0,904	-3,546	0,0	-3,546
10B	0,0	0,0	0,0	0,0	-3,989	0,0	-3,989	-3,546	0,0	-3,546
11A	0,0	0,0	0,0	0,0	3,989	0,0	3,989	3,546	0,0	3,546
11B	0,0	0,0	0,0	0,0	0,904	0,0	0,904	3,546	0,0	3,546
12A	0,0	0,0	0,0	0,0	-0,904	0,0	-0,904	3,546	0,0	3,546
12B	0,0	0,0	0,0	0,0	-3,989	0,0	-3,989	3,546	0,0	3,546

Figure B-70 *Saldature* application: stresses in fillet welds

CSE results are quite the same. Note well: correspondance between CSE and *Saldature* results is t_{Par} - $t_{//}$ (parallel) and t_{Per} - t_L (normal). For welds numbering (different for the two programs) see paragraph B.3.1.4.1.

```
-------------------------------------------
Internal stresses in welds, exploitations
-------------------------------------------

Inst  Combi  Name Weld    nPer          tPar          tPer          force      Cause  Ext    Expl

   1      1    W1   1   0.000e+000 -3.545e+000   3.989e+000   7.547e+001     3      2   0.026
   1      1    W1   2   0.000e+000  3.432e-001   2.985e+000   4.249e+001     3      2   0.014
   1      1    W1   3   0.000e+000 -3.545e+000  -3.989e+000   7.547e+001     3      1   0.026
   1      1    W1   4  -0.000e+000  4.472e+000  -3.989e+000   8.475e+001     3      1   0.029
   1      1    W1   5  -0.000e+000 -3.545e+000   3.989e+000   7.547e+001     3      2   0.026
   1      1    W1   6   0.000e+000  3.432e-001  -2.985e+000   4.249e+001     3      1   0.014
   1      1    W1   7   0.000e+000 -3.545e+000  -3.989e+000   7.547e+001     3      1   0.026
   1      1    W1   8   0.000e+000  4.472e+000   3.989e+000   8.475e+001     3      2   0.029
```

1	1	W2	1	-0.000e+000	4.472e+000	-3.989e+000	8.475e+001	3	1	0.029
1	1	W2	2	-0.000e+000	-3.545e+000	3.989e+000	7.547e+001	3	2	0.026
1	1	W2	3	0.000e+000	3.432e-001	-2.985e+000	4.249e+001	3	1	0.014
1	1	W2	4	0.000e+000	-3.545e+000	-3.989e+000	7.547e+001	3	1	0.026
1	1	W2	5	0.000e+000	4.472e+000	-3.989e+000	8.475e+001	3	1	0.029
1	1	W2	6	0.000e+000	-3.545e+000	3.989e+000	7.547e+001	3	2	0.026
1	1	W2	7	0.000e+000	3.432e-001	2.985e+000	4.249e+001	3	2	0.014
1	1	W2	8	0.000e+000	-3.545e+000	-3.989e+000	7.547e+001	3	1	0.026

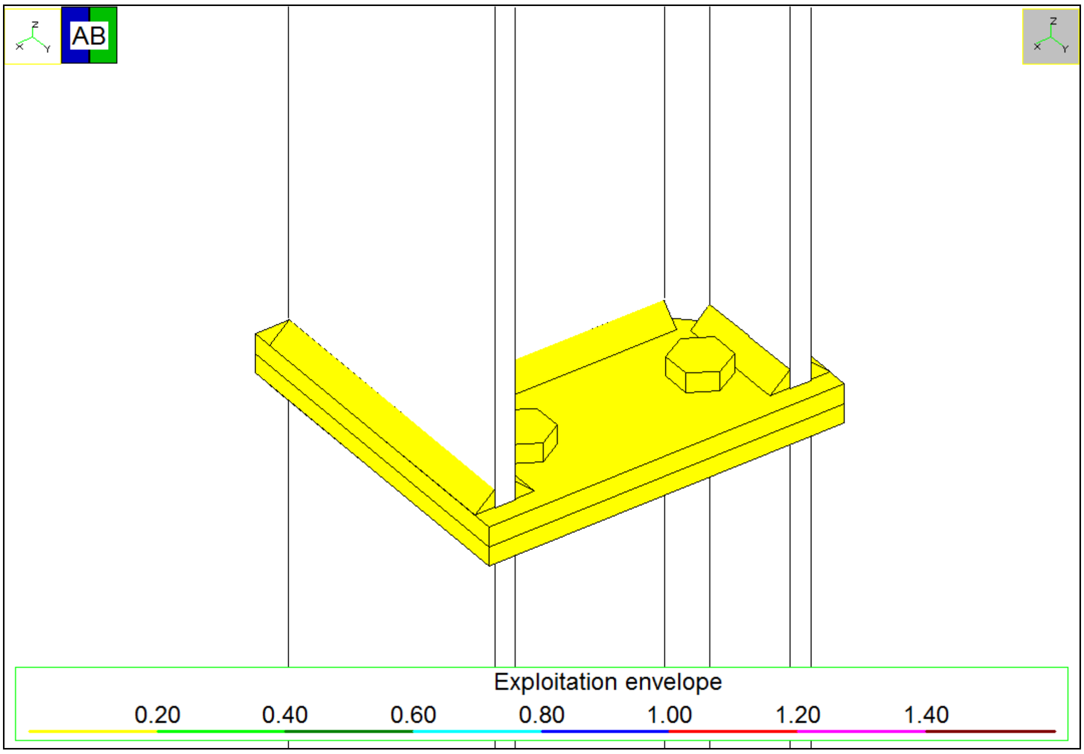


Figure B-71 Components utilization envelope

B.4 BEAM TO BEAM JOINTS

B.4.1 Single sided simply supported beam to beam (DAC)

The joint we are going to study is able to transfer only shear from supported beam to supporting beam. The joint is built using double angle cleat; bolts used can carry shear forces only. (model: *Validation_BB_1.CSE*).

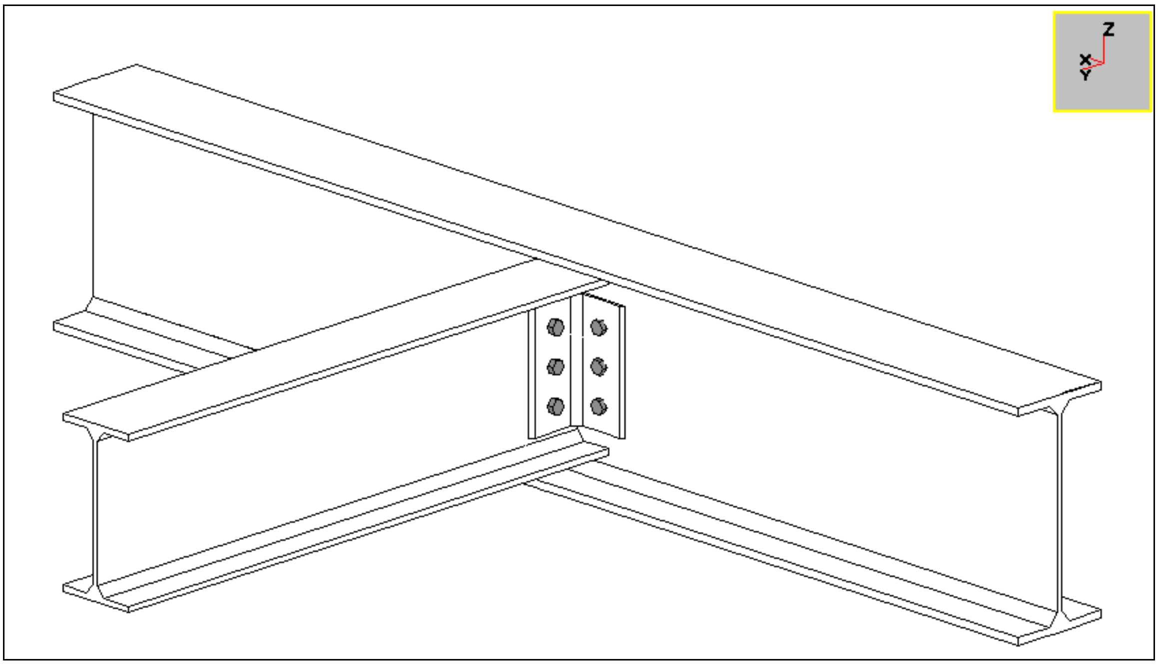


Figure B-72 3D view of the joint

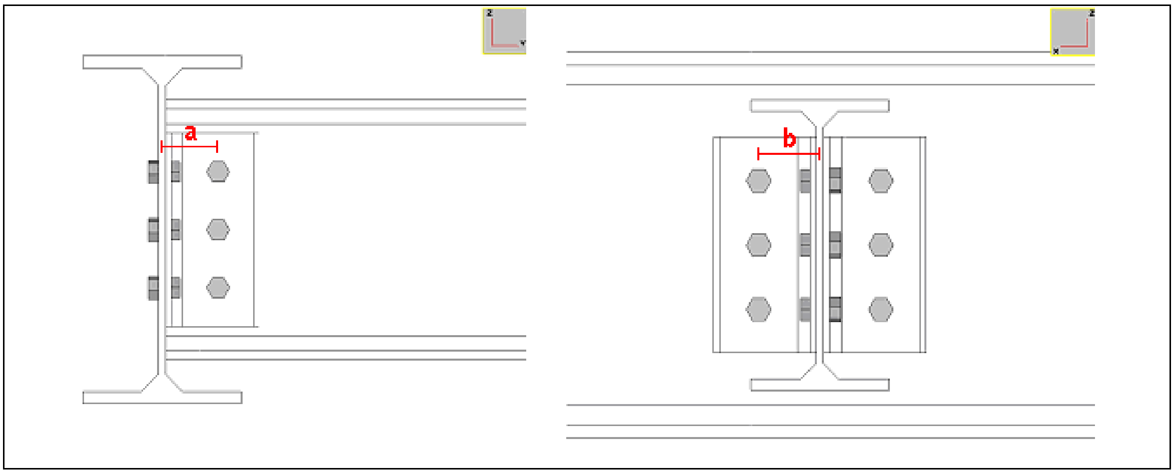


Figure B-73 Bolt layouts offsets

Model data: - material: S235.

- supporting beam: IPE360
- supported beam: IPE 270
- angles: L100x100x6mm, length 200mm
- bolts: M14, class 10.9F (1 column and 3 rows, distance 60mm)
- maximum shear force: 68347N

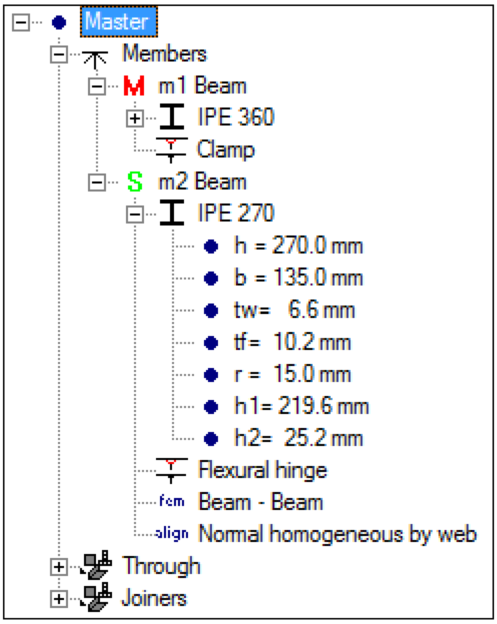


Figure B-74 Cross-section properties

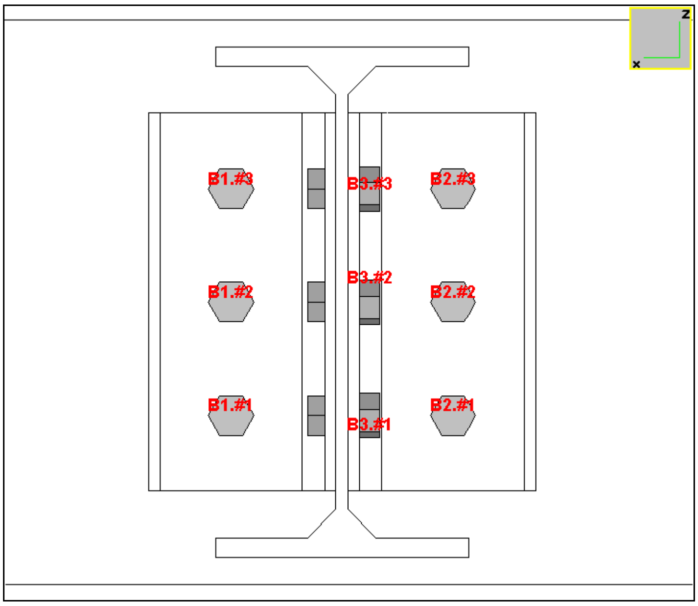


Figure B-75 Bolts numbering

Maximum shear force has been computed in imported FEM model, in the envelope of check combinations. Now compute force distribution in the bolts. We will call “1” the bolt layout on supported beam and “2” the bolt layouts on supporting beam.

Distance between bolt layout “1” and supporting beam axis is a=60mm (Figure B-73). Being an offset equal to 60mm, ther is also a moment of transport in bolt layout. It produces additional shear in external bolts (not in central one, which is in layout centre); this shear (H_1) is normal to V_1. (Figure B-76). We have:

$$V_{B1} = V = 68347\text{N}$$

$$M'_1 = V^*a = 4100820\text{Nmm}$$

where h' = 120mm (see Figure B-76).

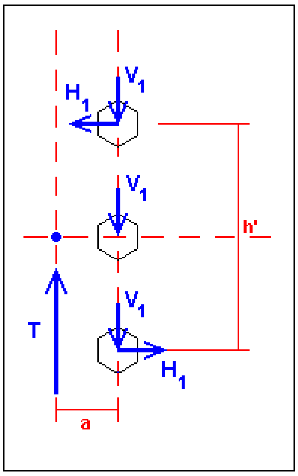


Figure B-76

Shear V_{B1} is equally distributed on each bolt. V1 and H1 are the following:

$$V_1 = V_{B1}/3 = 68347/3 = 22782.3\text{N}$$

$$H1 = M'_1/h' = 4100820\text{Nmm} / 120\text{mm} = 34173.5\text{N}$$

External bolts are subjected to the following total shear force:

$$R_1 = \sqrt{V_1^2 + H_1^2} = 41071.4\text{N}$$

Since bolts have two check sections (see Figure B-77), internal force in each section is $R_1/2$ = 20535.7N.

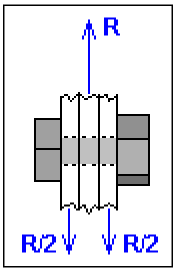


Figure B-77

Parasitic bending in bolts shaft was not considered.

Now compute shear forces in bolts on supporting beam. Total force is equally distributed to the two bolt layouts:

$$V_{B2} = V/2 = 34173.5\text{N}$$

each bolt carries one third of this force

$$V_2 = V_{B2}/3 = 11391.2\text{N}$$

Also in this case we have to consider the moment of transport. Offset is b=59.3mm (see Figure B-73). Moment is:

$$M'_2 = V_{B2} * b = 2026488.6\text{Nmm}$$

Normal shear on external bolts is, with $h''=h'$=120mm:

$$H_2 = M'_2/h'' = 16887.4\text{N}$$

Total force on external bolts is equal to (neglecting parasitic bending on shafts):

$$R_2 = \sqrt{V_2^2 + H_2^2} = 20370.2\text{N}$$

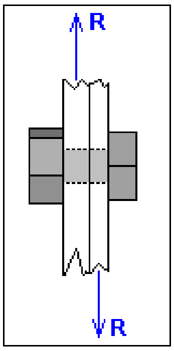


Figure B-78

Let’s see how CSE computes forces distribution:

Forces acting over bolt layouts at different extremes, global system
----

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B1	1	3	1	0.0000e+000	-3.4173e+004	0.0000e+000	-2.3921e+005	0.0000e+000	-1.8910e+006
B1	1	3	2	0.0000e+000	3.4173e+004	0.0000e+000	-6.8802e-004	0.0000e+000	1.8910e+006
B2	1	3	1	0.0000e+000	-3.4173e+004	0.0000e+000	-2.3921e+005	0.0000e+000	1.8910e+006
B2	1	3	2	0.0000e+000	3.4173e+004	0.0000e+000	-6.8607e-004	0.0000e+000	-1.8910e+006
B3	1	3	1	0.0000e+000	3.4173e+004	0.0000e+000	7.9761e+004	0.0000e+000	-2.0504e+006
B3	1	3	2	0.0000e+000	-6.8347e+004	0.0000e+000	0.0000e+000	0.0000e+000	4.1008e+006
B3	1	3	3	0.0000e+000	3.4173e+004	0.0000e+000	-7.9761e+004	0.0000e+000	-2.0504e+006

Forces and moment computed for supported beam bolt layout are the same. There is a difference in moment on supporting beam bolt layout (–6.69%): this is due to bending in bolts shaft, neglected in simplified hand computations but computed by CSE. The reason is the following: bolt layout on supported beam has the primary offset (a) only, so hand computation gives the same results; force is transferred in correspondence of supported beam axis. On supporting beam bolt layout, in addition to primary offset (b), we should consider that forces coming from supported beam weld layout are transferred to cleats in correspondence of angle sides: there is **an additional offset to be considered** (it reduces primary offset).

The following abstract gives the forces computed by CSE on supporting beam bolts (layouts B1 and B2, one check section) and on supported beam bolts (layout B3, two check sections). Differences from hand computation on B1 and B2 are due to the difference on moment computation explained above.

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	0.000e+000	0.000e+000	-1.569e+004	-1.134e+004	1.937e+004	-4.538e+004	0.000e+000	4.538e+004	0.262	resis
1	1	B1	2	1	0.000e+000	0.000e+000	0.000e+000	-1.134e+004	1.134e+004	-4.538e+004	0.000e+000	4.538e+004	0.154	resis
1	1	B1	3	1	0.000e+000	0.000e+000	1.569e+004	-1.134e+004	1.937e+004	-4.538e+004	0.000e+000	4.538e+004	0.262	resis
1	1	B2	1	1	0.000e+000	0.000e+000	1.569e+004	-1.134e+004	1.937e+004	-4.538e+004	0.000e+000	4.538e+004	0.262	resis
1	1	B2	2	1	0.000e+000	0.000e+000	0.000e+000	-1.134e+004	1.134e+004	-4.538e+004	0.000e+000	4.538e+004	0.154	resis
1	1	B2	3	1	0.000e+000	0.000e+000	-1.569e+004	-1.134e+004	1.937e+004	-4.538e+004	0.000e+000	4.538e+004	0.262	resis
1	1	B3	1	1	0.000e+000	0.000e+000	-1.702e+004	1.134e+004	2.045e+004	-7.555e+003	0.000e+000	7.555e+003	0.277	
1	1	B3	1	2	0.000e+000	0.000e+000	1.702e+004	-1.134e+004	2.045e+004	-7.555e+003	0.000e+000	7.555e+003	0.277	resis
1	1	B3	2	1	0.000e+000	0.000e+000	0.000e+000	1.134e+004	1.134e+004	-7.555e+003	0.000e+000	7.555e+003	0.154	resis
1	1	B3	2	2	0.000e+000	0.000e+000	0.000e+000	-1.134e+004	1.134e+004	-7.555e+003	0.000e+000	7.555e+003	0.154	
1	1	B3	3	1	0.000e+000	0.000e+000	1.702e+004	1.134e+004	2.045e+004	-7.555e+003	0.000e+000	7.555e+003	0.277	
1	1	B3	3	2	0.000e+000	0.000e+000	-1.702e+004	-1.134e+004	2.045e+004	-7.555e+003	0.000e+000	7.555e+003	0.277	resis
1	2	B1	1	1	0.000e+000	0.000e+000	-1.132e+004	-8.183e+003	1.397e+004	-3.273e+004	0.000e+000	3.273e+004	0.189	resis
1	2	B1	2	1	0.000e+000	0.000e+000	0.000e+000	-8.183e+003	8.183e+003	-3.273e+004	0.000e+000	3.273e+004	0.111	resis
1	2	B1	3	1	0.000e+000	0.000e+000	1.132e+004	-8.183e+003	1.397e+004	-3.273e+004	0.000e+000	3.273e+004	0.189	resis
1	2	B2	1	1	0.000e+000	0.000e+000	1.132e+004	-8.183e+003	1.397e+004	-3.273e+004	0.000e+000	3.273e+004	0.189	resis

```
 1     2    B2   2   1   0.000e+000   0.000e+000   0.000e+000  -8.183e+003  8.183e+003  -3.273e+004  0.000e+000   3.273e+004   0.111 resis
 1     2    B2   3   1   0.000e+000   0.000e+000  -1.132e+004  -8.183e+003  1.397e+004  -3.273e+004  0.000e+000   3.273e+004   0.189 resis

 1     2    B3   1   1   0.000e+000   0.000e+000  -1.227e+004   8.183e+003  1.475e+004  -5.450e+003  0.000e+000   5.450e+003   0.200
 1     2    B3   1   2   0.000e+000   0.000e+000   1.227e+004  -8.183e+003  1.475e+004  -5.450e+003  0.000e+000   5.450e+003   0.200 resis
 1     2    B3   2   1   0.000e+000   0.000e+000   0.000e+000   8.183e+003  8.183e+003  -5.450e+003  0.000e+000   5.450e+003   0.111 resis
 1     2    B3   2   2   0.000e+000   0.000e+000   0.000e+000  -8.183e+003  8.183e+003  -5.450e+003  0.000e+000   5.450e+003   0.111
 1     2    B3   3   1   0.000e+000   0.000e+000   1.227e+004   8.183e+003  1.475e+004  -5.450e+003  0.000e+000   5.450e+003   0.200
 1     2    B3   3   2   0.000e+000   0.000e+000  -1.227e+004  -8.183e+003  1.475e+004  -5.450e+003  0.000e+000   5.450e+003   0.200 resis

 1     3    B1   1   1   0.000e+000   0.000e+000  -1.576e+004  -1.139e+004  1.944e+004  -4.556e+004  0.000e+000   4.556e+004   0.263 resis
 1     3    B1   2   1   0.000e+000   0.000e+000   0.000e+000  -1.139e+004  1.139e+004  -4.556e+004  0.000e+000   4.556e+004   0.154 resis
 1     3    B1   3   1   0.000e+000   0.000e+000   1.576e+004  -1.139e+004  1.944e+004  -4.556e+004  0.000e+000   4.556e+004   0.263 resis

 1     3    B2   1   1   0.000e+000   0.000e+000   1.576e+004  -1.139e+004  1.944e+004  -4.556e+004  0.000e+000   4.556e+004   0.263 resis
 1     3    B2   2   1   0.000e+000   0.000e+000   0.000e+000  -1.139e+004  1.139e+004  -4.556e+004  0.000e+000   4.556e+004   0.154 resis
 1     3    B2   3   1   0.000e+000   0.000e+000  -1.576e+004  -1.139e+004  1.944e+004  -4.556e+004  0.000e+000   4.556e+004   0.263 resis

 1     3    B3   1   1   0.000e+000   0.000e+000  -1.709e+004   1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278
 1     3    B3   1   2   0.000e+000   0.000e+000   1.709e+004  -1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278 resis
 1     3    B3   2   1   0.000e+000   0.000e+000   0.000e+000   1.139e+004  1.139e+004  -7.586e+003  0.000e+000   7.586e+003   0.154 resis
 1     3    B3   2   2   0.000e+000   0.000e+000   0.000e+000  -1.139e+004  1.139e+004  -7.586e+003  0.000e+000   7.586e+003   0.154
 1     3    B3   3   1   0.000e+000   0.000e+000   1.709e+004   1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278
 1     3    B3   3   2   0.000e+000   0.000e+000  -1.709e+004  -1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278 resis
```

Design shear resistance for M14 (class 10.9) bolts according to EN1993-1-8 is:

$F_{V,Rd}=a_v f_{ub} A/\gamma_{M2}$	7.387E+04N
a_v	0.6 *
f_{ub}	1000N/mm^2
A	153.9mm^2
γ_{M2}	1.25

* threaded part is not involved in check sections, according to check settings

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Boltlayouts bolt properties
----------------------------

   Id  Class   Dia   Dia H    Sec  Full  Precision    Area         Ares         Vlim         Nlim         Nini

   B1   10.9   14.0   15.0     1   yes      not    1.539e+002   1.150e+002   7.389e+004   8.280e+004   0.000e+000
   B2   10.9   14.0   15.0     1   yes      not    1.539e+002   1.150e+002   7.389e+004   8.280e+004   0.000e+000
   B3   10.9   14.0   15.0     2   yes      not    1.539e+002   1.150e+002   7.389e+004   8.280e+004   0.000e+000
```

If we consider section 2 of bolt 3 of bolt layout B3 (supported beam bolt layout, external bolt, see Figure B-75) we have the following utilization factor:

$$2.054 \cdot 10^4 \text{N} / 7.387 \cdot 10^4 \text{N} = 0.278$$

This is the same value computed by CSE (see abstract).

Now we are going to compute bolt bearing utilization factor for supported beam, according to EN1993-1-8 formulae (see appendix). Force on beam web is twice the force in bolts check sections. Consider one of the external bolts (the most loaded ones).

Fx	3,418E+04	**Fy**	2,278E+04
$F_{b,Rd,x}$	6,653E+04	**$F_{b,Rd,y}$**	6,653E+04
k_1	2,5	**k_1**	2,5
$2,8e_2/d_0$-1,7	7,596	**$2,8e_2/d_0$-1,7**	7,596
	2,5		2,5

a_b	1	a_b	1,000
a_d	1,106666667	a_d	1,107
f_{ub}/f_u	2,78	f_{ub}/f_u	2,78
		$p_1/3d_0$-0,25	1,08
	1		1
fu	360	fu	360
d	14	d	14
d_0	15	d_0	15
t	6,6	t	6,6
e_1=min(e_1,e_2)	49,8	e_1=min(e_1,e_2)	49,8
e_2=min(e_1,e_2)	49,8	e_2=min(e_1,e_2)	49,8
p_1	0	p_1	60
p_2	60	p_2	0
expl x	0,514	expl y	0,342
	EXPL=	0,617	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\text{expl} = \sqrt{\text{expl}_x^2 + \text{expl}_y^2} = 0{,}617$$

Now compute bolt bearing for the central bolt (only force parallel to applied load, see Figure B-76):

Fy	2.278E+04N
$F_{b,Rd,y}$	6.653E+04N
k_1	2.5
2.8e_2/d_0-1.7	7.596
α_b	1
α_d	1.083
f_{ub}/f_u	2.78
f_u	360N/mm^2
d	14mm
d_0	15mm
t	6.6mm
e_1	49.8mm
e_2	49.8mm
p_1	60mm
p_2	/
$expl_y$	0.342

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

Maximum utilization factor is 0.617, the same computed by CSE.

```
-----------------------------------------------------------------
Members whose maximum utilization ratio is due to bearing stresses
-----------------------------------------------------------------
```

Inst	Combi	Name	Boltlay	Bolt	Extr.	Sigma (N/ mm²)	Sigma M (N/ mm²)	Expl
1	3	m1	B2	1	2	173.6	720.0	0.241
1	3	m2	B3	1	2	444.5	720.0	0.617

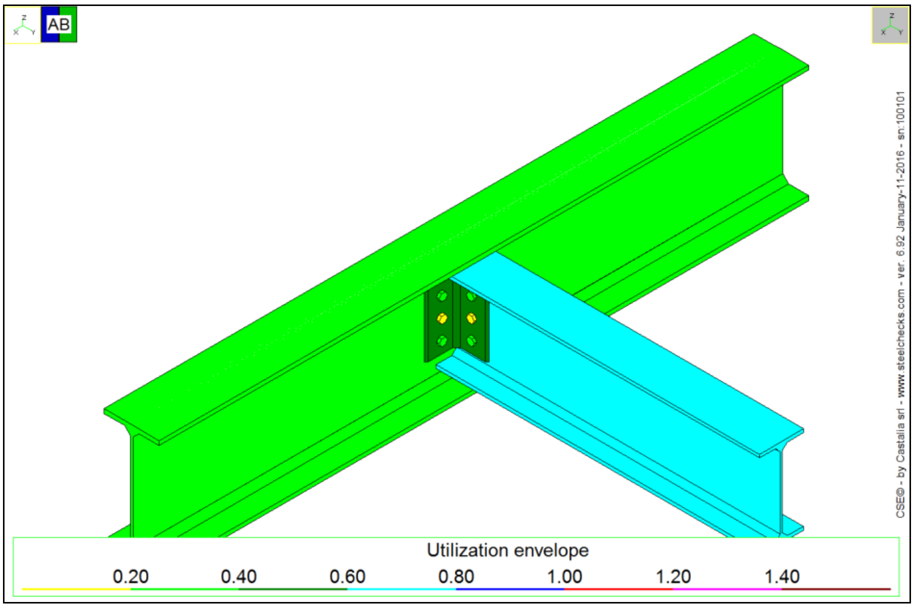


Figure B-79 Components utilization envelope

B.4.2 Double sided simply supported beam to beam (DAC)

We add another finite element to the imported FEM model, to consider a double sided beam to beam joint; loads are the same, 3D joint is again with double angle cleats. The difference, now, is that bolt layouts on supported beam have 2 check sections. (model: *Validation_BB_2.CSE*).

Supported beams are exactly in the same condition of single supported beam in previous case. Supporting beam now carries a load that is twice than before. Since bolt layouts now have two check sections, internal forces should be equal to the previous case.

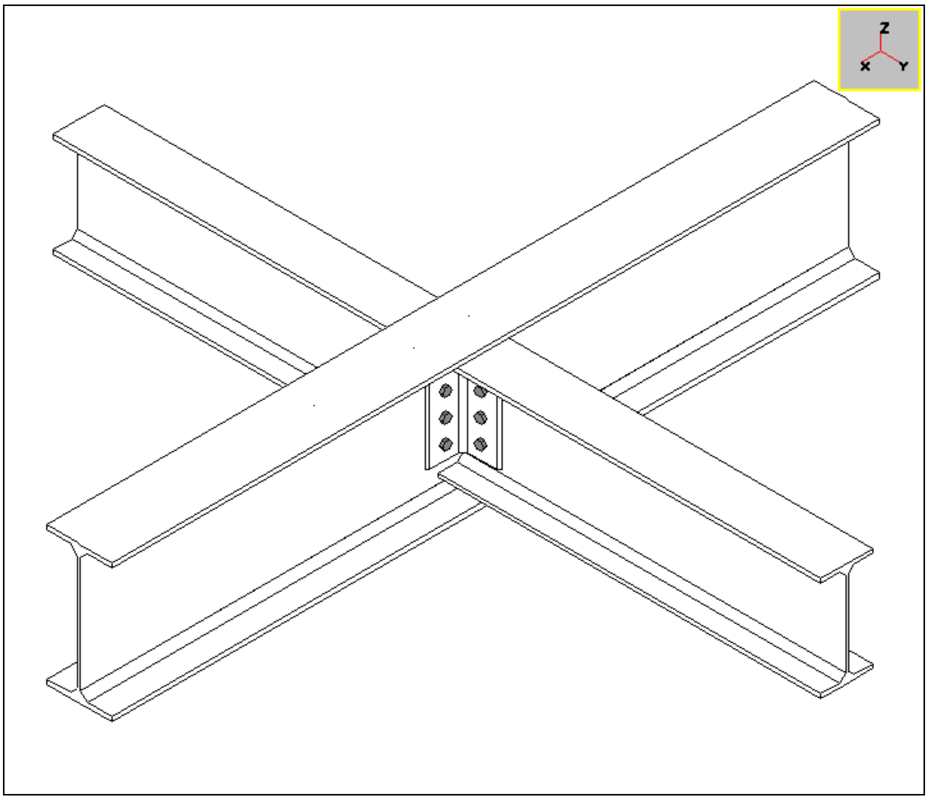


Figure B-80 3D view of the joint

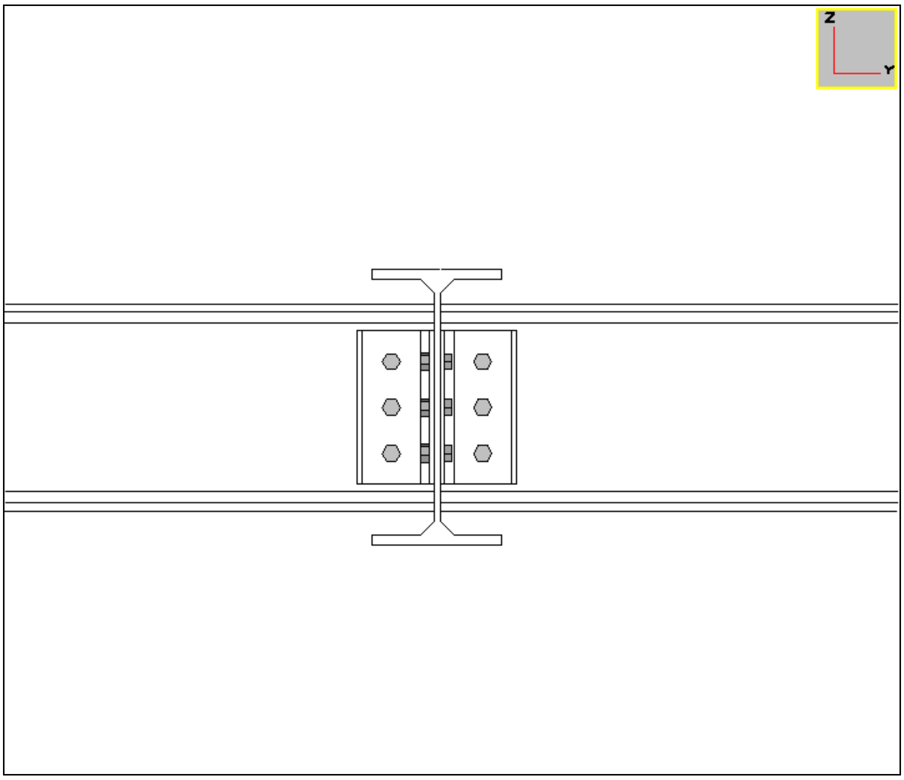


Figure B-81 Front view

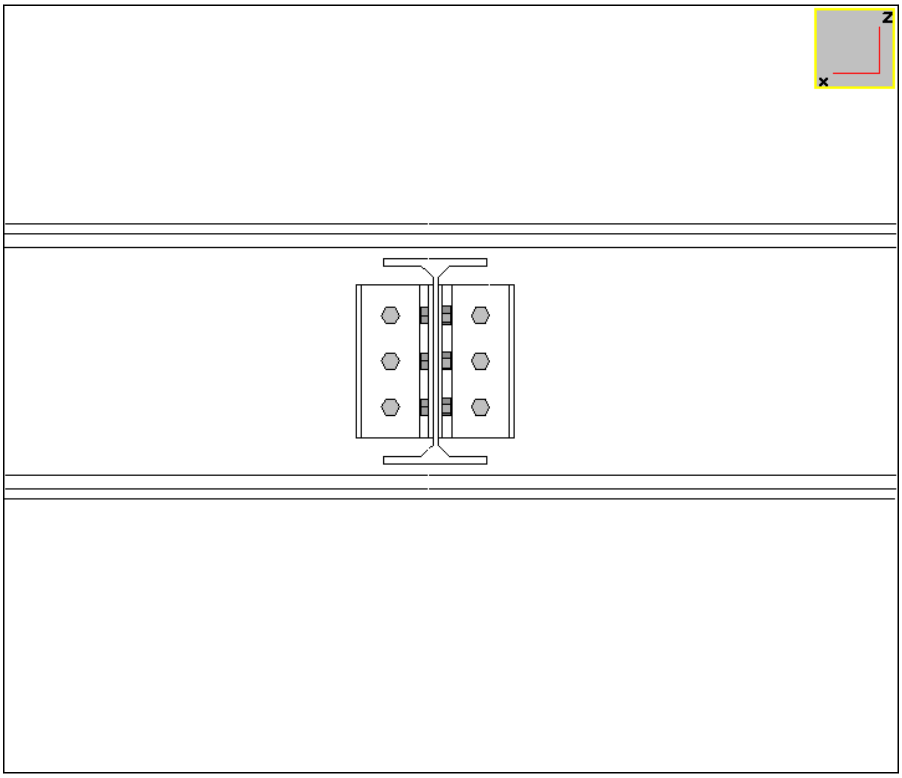


Figure B-82 Side view

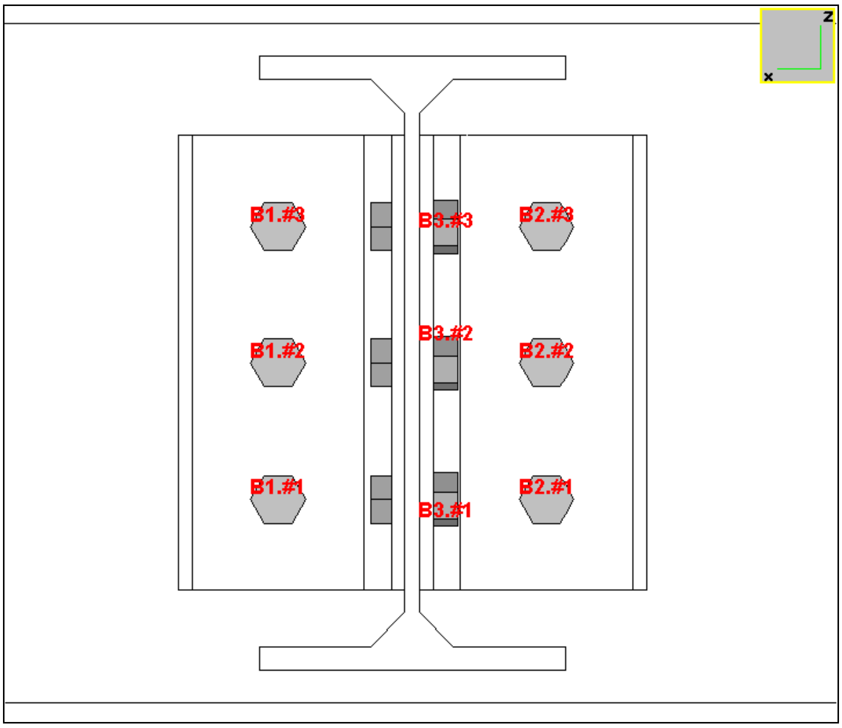


Figure B-83 Bolts numbering

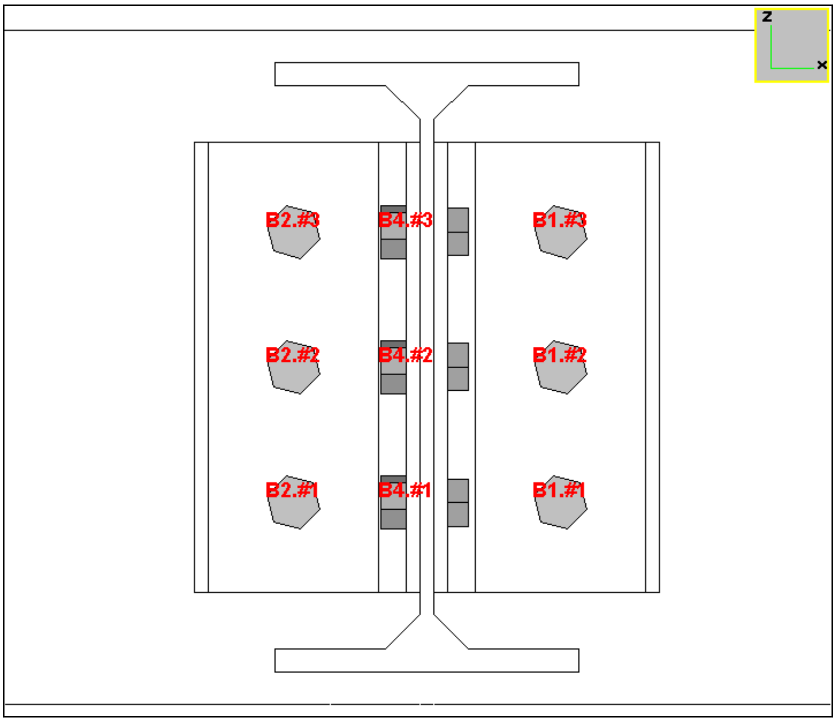


Figure B-84 Bolts numbering

The following abstract gives CSE results for combination 3, the most critical one: forces acting on layouts and then forces in single bolts. B1 and B2 are supporting beam bolt layouts; B3 and B4 are supported beam bolt layouts.

Forces acting over bolt layouts at different extremes, global system

----

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B1	1	3	1	0.0000e+000	-3.4173e+004	0.0000e+000	-2.3921e+005	0.0000e+000	-1.8910e+006
B1	1	3	2	0.0000e+000	6.8347e+004	0.0000e+000	-6.0607e-004	0.0000e+000	3.7819e+006
B1	1	3	3	0.0000e+000	-3.4173e+004	0.0000e+000	2.3921e+005	0.0000e+000	-1.8910e+006
B2	1	3	1	0.0000e+000	-3.4173e+004	0.0000e+000	-2.3921e+005	0.0000e+000	1.8910e+006
B2	1	3	2	0.0000e+000	6.8347e+004	0.0000e+000	-6.0369e-004	0.0000e+000	-3.7819e+006
B2	1	3	3	0.0000e+000	-3.4173e+004	0.0000e+000	2.3921e+005	0.0000e+000	1.8910e+006
B3	1	3	1	0.0000e+000	3.4173e+004	0.0000e+000	7.9761e+004	0.0000e+000	-2.0504e+006
B3	1	3	2	0.0000e+000	-6.8347e+004	0.0000e+000	2.0373e-010	0.0000e+000	4.1008e+006
B3	1	3	3	0.0000e+000	3.4173e+004	0.0000e+000	-7.9761e+004	0.0000e+000	-2.0504e+006
B4	1	3	1	0.0000e+000	3.4173e+004	0.0000e+000	7.9761e+004	0.0000e+000	2.0504e+006
B4	1	3	2	0.0000e+000	-6.8347e+004	0.0000e+000	-1.6589e-009	0.0000e+000	-4.1008e+006
B4	1	3	3	0.0000e+000	3.4173e+004	0.0000e+000	-7.9761e+004	0.0000e+000	2.0504e+006

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	3	B1	1	1	0.000e+000	0.000e+000	-1.576e+004	-1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	resis
1	3	B1	1	2	0.000e+000	0.000e+000	1.576e+004	1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	
1	3	B1	2	1	0.000e+000	0.000e+000	0.000e+000	-1.139e+004	1.139e+004	-4.556e+004	0.000e+000	4.556e+004	0.154	resis
1	3	B1	2	2	0.000e+000	0.000e+000	0.000e+000	1.139e+004	1.139e+004	-4.556e+004	0.000e+000	4.556e+004	0.154	
1	3	B1	3	1	0.000e+000	0.000e+000	1.576e+004	-1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	resis
1	3	B1	3	2	0.000e+000	0.000e+000	-1.576e+004	1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	
1	3	B2	1	1	0.000e+000	0.000e+000	1.576e+004	-1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	resis
1	3	B2	1	2	0.000e+000	0.000e+000	-1.576e+004	1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	
1	3	B2	2	1	0.000e+000	0.000e+000	0.000e+000	-1.139e+004	1.139e+004	-4.556e+004	0.000e+000	4.556e+004	0.154	resis
1	3	B2	2	2	0.000e+000	0.000e+000	0.000e+000	1.139e+004	1.139e+004	-4.556e+004	0.000e+000	4.556e+004	0.154	
1	3	B2	3	1	0.000e+000	0.000e+000	-1.576e+004	-1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	resis
1	3	B2	3	2	0.000e+000	0.000e+000	1.576e+004	1.139e+004	1.944e+004	-4.556e+004	0.000e+000	4.556e+004	0.263	

```
1     3    B3   1   1   0.000e+000   0.000e+000  -1.709e+004   1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278 resis
1     3    B3   1   2   0.000e+000   0.000e+000   1.709e+004  -1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278
1     3    B3   2   1   0.000e+000   0.000e+000   0.000e+000   1.139e+004  1.139e+004  -7.586e+003  0.000e+000   7.586e+003   0.154 resis
1     3    B3   2   2   0.000e+000   0.000e+000   0.000e+000  -1.139e+004  1.139e+004  -7.586e+003  0.000e+000   7.586e+003   0.154
1     3    B3   3   1   0.000e+000   0.000e+000   1.709e+004   1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278 resis
1     3    B3   3   2   0.000e+000   0.000e+000  -1.709e+004  -1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278

1     3    B4   1   1   0.000e+000   0.000e+000   1.709e+004   1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278 resis
1     3    B4   1   2   0.000e+000   0.000e+000  -1.709e+004  -1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278
1     3    B4   2   1   0.000e+000   0.000e+000   0.000e+000   1.139e+004  1.139e+004  -7.586e+003  0.000e+000   7.586e+003   0.154
1     3    B4   2   2   0.000e+000   0.000e+000   0.000e+000  -1.139e+004  1.139e+004  -7.586e+003  0.000e+000   7.586e+003   0.154 resis
1     3    B4   3   1   0.000e+000   0.000e+000  -1.709e+004   1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278 resis
1     3    B4   3   2   0.000e+000   0.000e+000   1.709e+004  -1.139e+004  2.054e+004  -7.586e+003  0.000e+000   7.586e+003   0.278
```

Comparing these results we can see, as expected, that internal forces (and utilizations factors) in bolts on supported beams are the same of previous cases. Bolts on supporting beams carry twice the load of previous case, but it is divided in two check sections, as expected.

Bolt bearing utilization of supported beams is the same of previous case; supporting beam utilization factor is twice the previous value, as expected (0.482 versus 0.241), because carried force is twice the previous one.

```
-------------------------------------------------------------
Members whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

    Inst  Combi  Name   Boltlay   Bolt   Extr.     Sigma        Sigma M     Expl

    1      3     m1       B1       1       2     3.472e+002   7.200e+002   0.482
    1      3     m2       B3       1       2     4.445e+002   7.200e+002   0.617
    1      3     m3       B4       1       2     4.445e+002   7.200e+002   0.617
```

We can also check that cleats utilization is the same in both cases (first abstract: double sided beam to beam; second abstract: single sided beam to beam).

```
-------------------------------------------------------------
Through whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

  Inst  Combi  Name   Boltlay   Bolt   Extr.     Sigma      Sigma M      Expl

    1      3     L1       B3       1       1     2.445e+002   6.080e+002   0.402
    1      3     L2       B4       1       1     2.445e+002   6.080e+002   0.402
    1      3     L3       B3       1       3     2.445e+002   6.080e+002   0.402
    1      3     L4       B4       1       3     2.445e+002   6.080e+002   0.402
```

```
-------------------------------------------------------------
Through whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

  Inst  Combi  Name   Boltlay   Bolt   Extr.     Sigma      Sigma M      Expl

    1      3     L1       B3       1       1     2.445e+002   6.080e+002   0.402
    1      3     L2       B3       1       3     2.445e+002   6.080e+002   0.402
```

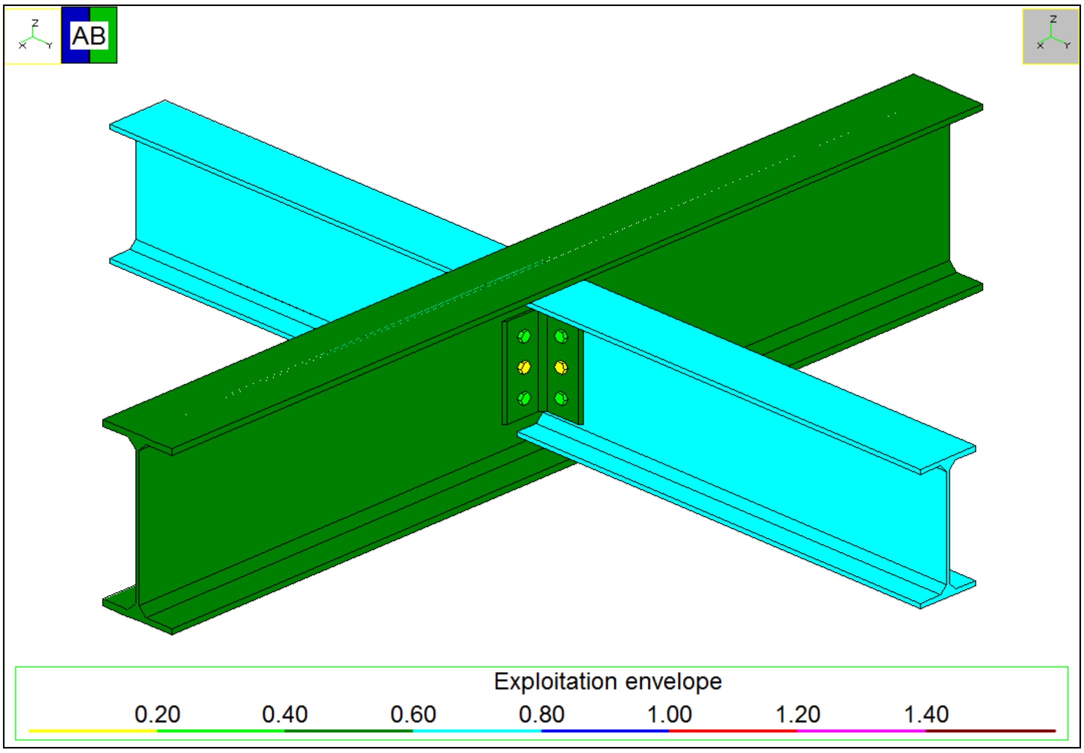


Figure B-85 Components utilization envelope

B.4.3 Single sided simply supported beam to beam (flexible end plate)

We make some modifications to the model used in B.4.1. Imported FEM model is the same (geometry, loads, etc.). Now, instead of double angle cleats, we use a flexible end plate connection (model: *Validation_BB_3.CSE*).

Model data:
- material: S235
- supporting beam: IPE360
- supported beam IPE 270
- plate: 200x206.6mm, thickness 6mm
- bolts: M14 class 10.9F (3 rows, 2 columns)
- maximum shear force: 68347N

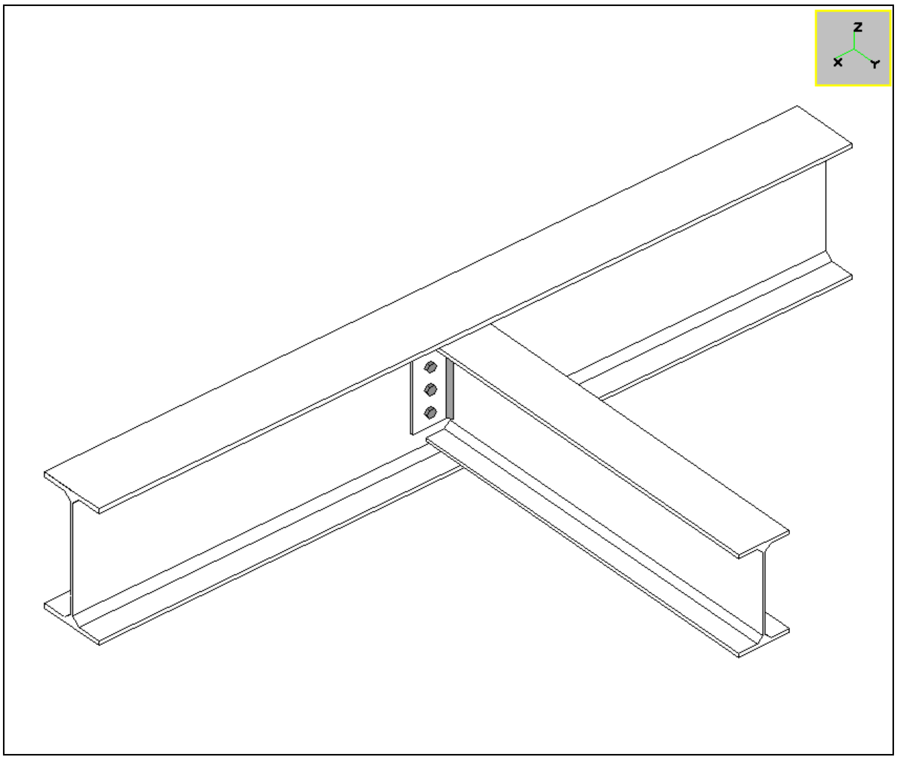


Figure B-86 3D view of the joint

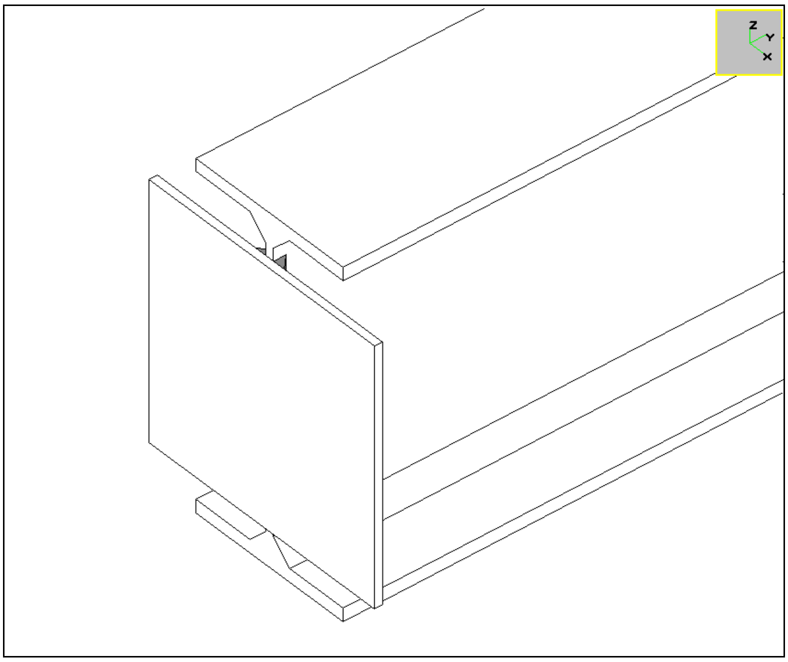


Figure B-87 Detail of the plate

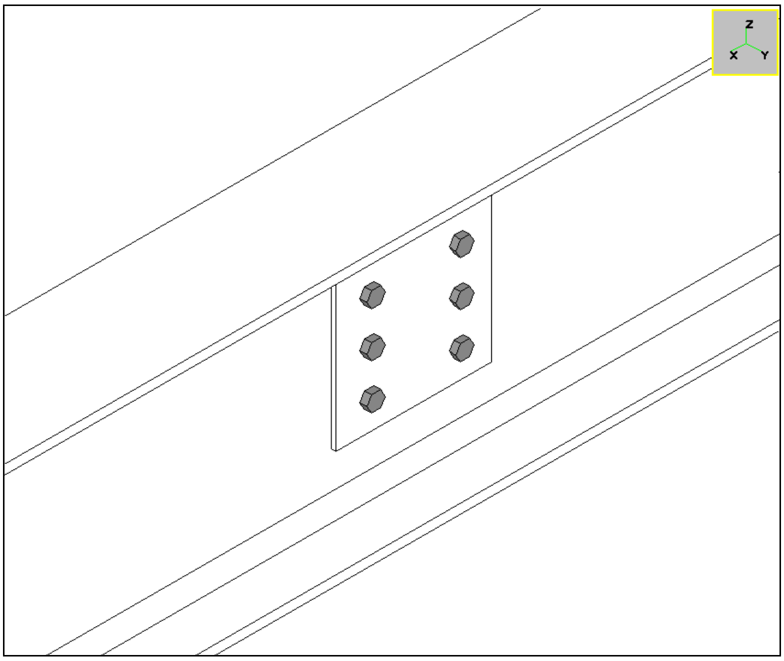


Figure B-88 Detail of bolt layout

Consider the bolt layout: in B.4.1. bolts on supporting beam belonged to 2 different bolt layouts; here we have a single bolt layout. It is centered (no offset) so there is no moment of transport acting on it.

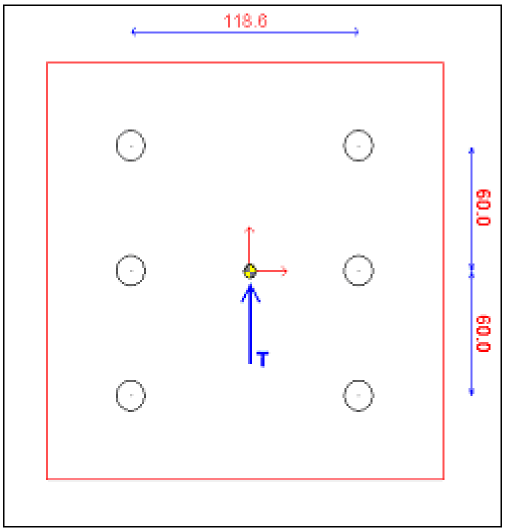


Figure B-89

The physical difference is that, in the first case, bolts must avoid angles slip/rotation, while in this case is the plate to prevent that with its stiffness. Since we have 6 bolts, each one of them carries 1/6 of total applied load:

$$68347 / 6 = 11391.17N$$

If we divide that force by bolts design resistance to shear (previously computed in B.4.1) we get the following utilization factor:

11391.17 / 73872 = **0.154**

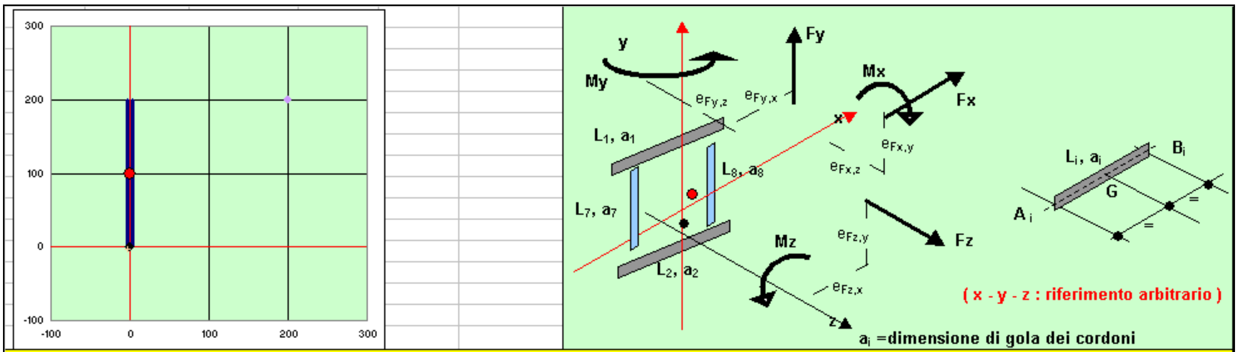
It is the same utilization of central bolts in DAC case, where there was no additional shear due to moment of transport (see B.4.1). CSE computes the same value:

```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------

Inst  Combi  Name Bolt -?-        NB           NTB           TuB           TvB         TB          MuB         MvB          MB        Expl  cause

   1      3    B2    1   1 -2.557e-014  -2.557e-014   9.859e-011   1.139e+004  1.139e+004   4.556e+004  5.240e-010   4.556e+004   0.154 resis
   1      3    B2    2   1 -2.557e-014  -2.557e-014   9.859e-011   1.139e+004  1.139e+004   4.556e+004  5.240e-010   4.556e+004   0.154 resis
   1      3    B2    3   1 -2.557e-014  -2.557e-014   9.864e-011   1.139e+004  1.139e+004   4.556e+004  5.240e-010   4.556e+004   0.154 resis
   1      3    B2    4   1 -2.557e-014  -2.557e-014   9.864e-011   1.139e+004  1.139e+004   4.556e+004  5.240e-010   4.556e+004   0.154 resis
   1      3    B2    5   1 -2.557e-014  -2.557e-014   9.869e-011   1.139e+004  1.139e+004   4.556e+004  5.240e-010   4.556e+004   0.154 resis
   1      3    B2    6   1 -2.557e-014  -2.557e-014   9.869e-011   1.139e+004  1.139e+004   4.556e+004  5.240e-010   4.556e+004   0.154 resis
```

To validate stress results for fillet weld, we use *Saldature* application again (see A.3). Following images show input data and stress results.



Confronto con CSE

tutti i cordoni hanno eguale dimensione della gola pari a: mm					**7,1**	il dato sostituisce tale valore			riferite ad assi principali			
posizione cordoni	cordone w	a_i (mm)	L_i (mm)	$x_{A,i}$ (mm)	$y_{A,i}$ (mm)	$x_{G,i}$ (mm)	$y_{G,i}$ (mm)	A_i (cm^2)	$\xi_{A,i}$ (mm)	$\xi_{B,i}$ (mm)	$\eta_{A,i}$ (mm)	$\eta_{B,i}$ (mm)
cordoni paralleli ad asse x	1											
	2											
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		199,6	-3,3		-3,3	100	14,2	-3	-3	-100	100
	8		199,6	3,3		3,3	99,8	14,2	3	3	-100	100
	9											
	10											
	11											
(blu)	12											

caratteristiche della sezione	A	x_G	y_G	I_{Gxx}	I_{Gyy}	I_{Gxy}	α		$I_{G\xi\xi}$	$I_{G\eta\eta}$
	cm^2	mm	mm	cm^4	cm^4	cm^4	radianti	gradi	cm^4	cm^4
	28,3	**0**	**100**	**941**	**3**	**0**	**0,0000**	**0**	**941**	**3**

Figure B-90 *Saldature* application: input data

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1		683,5			68.347,0							
2												
3												

Figure B-91 ***Saldature*** **application: applied loads**

Where F_y is the applied shear and M_x is the moment of tran sport due to the eccentricity between welds and supporting beam axis.

$$M_x = F_y * d = 68347\text{N} * 10\text{mm} = 683470\text{Nmm}$$

where d=10 is the sum of half supporting beam web (8/2=4mm) and plate thickness (6mm).

Stresses computed by *Saldature* are the following.

condizione di carico 1	unità di misura degli sforzi:			N/mm2						
cordoni	n_L dovuto a:				t_L dovuto a:			t_W dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
7A	-7,278	0,0	0,0	-7,278	0,0	0,0	0,0	0,0	24,21	24,21
7B	7,278	0,0	0,0	7,278	0,0	0,0	0,0	0,0	24,21	24,21
8A	-7,278	0,0	0,0	-7,278	0,0	0,0	0,0	0,0	24,21	24,21
8B	7,278	0,0	0,0	7,278	0,0	0,0	0,0	0,0	24,21	24,21

Figure B-92 ***Saldature*** **application: stresses in welds**

CSE computes the same values:

```
------------------------------------------
Internal stresses in welds, exploitations
------------------------------------------

Inst  Combi  Name Weld     nPer         tPar         tPer         force      Cause  Ext   Expl

   1      3    W1   1   7.278e+000  -2.421e+001  -9.128e-015   1.788e+002     2     1   0.122
   1      3    W1   2  -7.278e+000   2.421e+001   6.176e-015   1.788e+002     2     1   0.122
```

NOTE WELL: values for both extremes of each weld are given in *Saldature*, while CSE gives only maximum value.

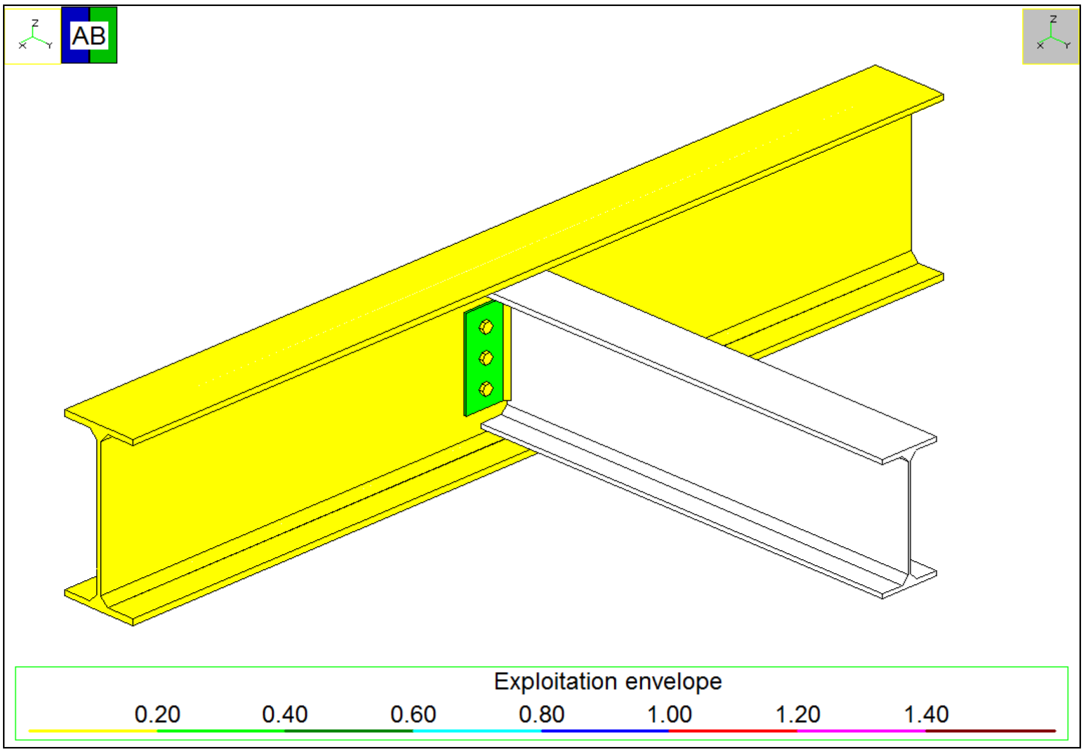


Figure B-93 Components utilization envelope

B.5 BEAM TO COLUMN JOINT

B.5.1 Double angle cleats (connection on column web)

Consider a beam to column joint with double angle cleats (hinge). Beam cross-section is IPE400, column cross-section is HEB 260 (both in S235). In imported FEM model we have two identical joints sharing the same horizontal beam: CSE recognizes them as different instances of the same joints and checks them at the same time (model: *Validation_BC_1.CSE*). A vertical load is applied in the middle point of horizontal beam.

Angle cleats have the following sizes: 160x80x10mm (S235). Bolts are M8 class 8.8, with the following geometry: a layout with 2 columns per 10 rows on the beam, two layouts with 1 column per 10 rows on the column.

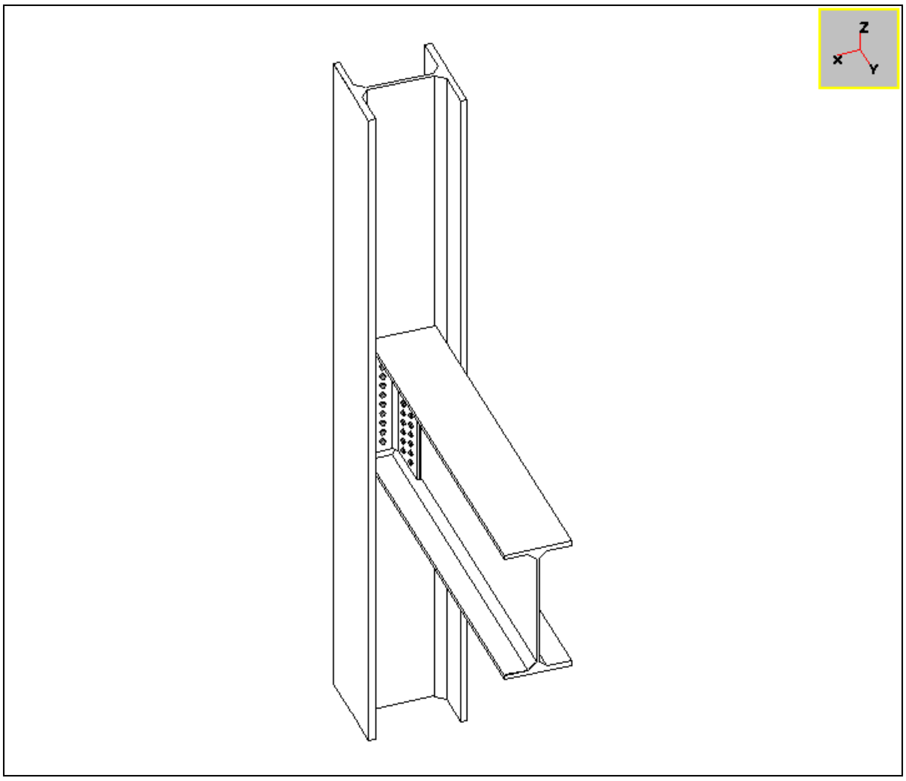


Figure B-94 3D view of the joint

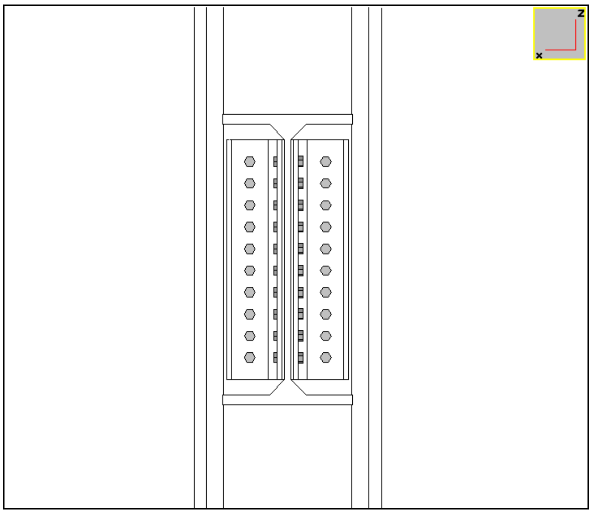


Figure B-95 Front view

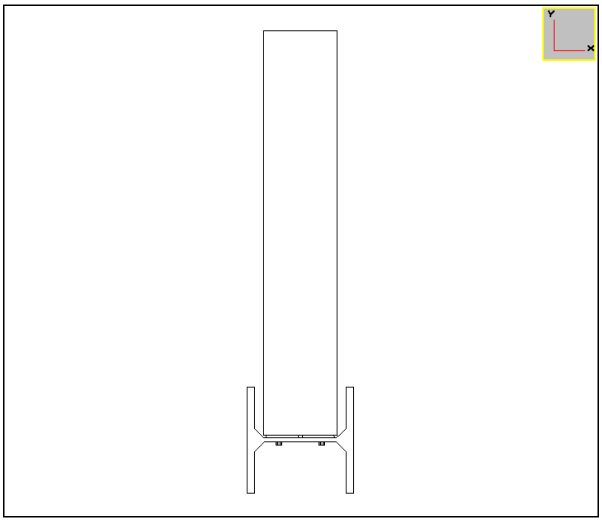


Figure B-96 Top view

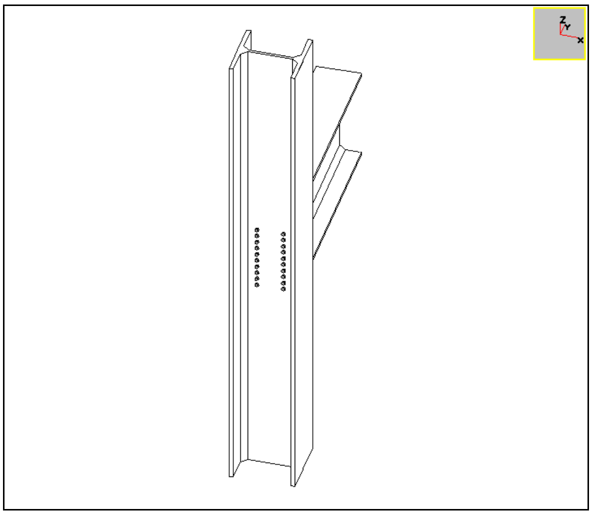


Figure B-97 Back view

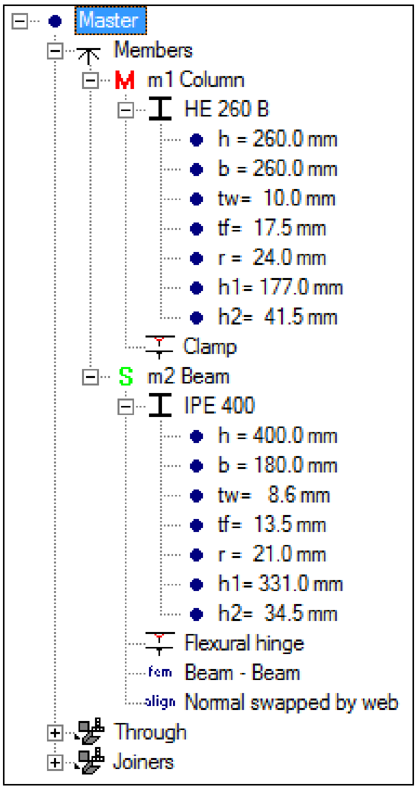


Figure B-98 Cross-section properties

Figure B-99 Bolts numbering (beam)

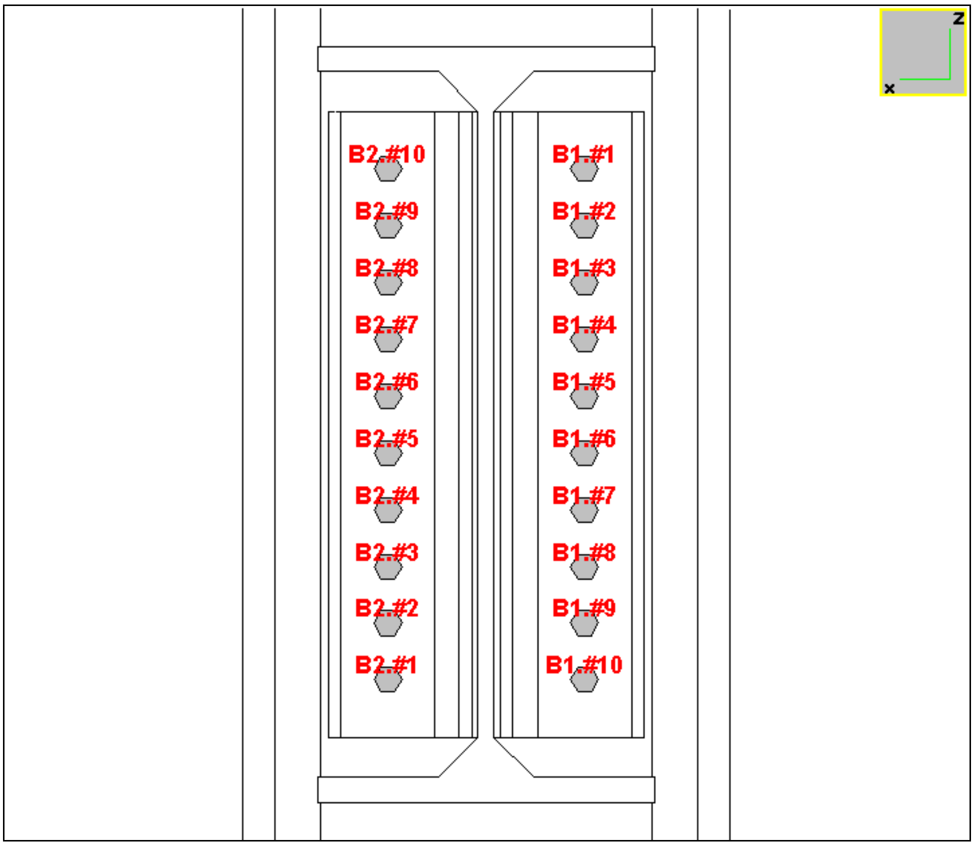


Figure B-100 Bolts numbering (column)

Force applied in imported model is *P*=500kN, in the middle of the beam. Half of the load is carried by one joint and half by the other one (*V*=250kN).

Now we are going to compute forces in bolt layouts with the same simplified hand computations used in previous paragraphs. On column web, V shear is distributed in two different bolt layouts: each one carries half of the load and a moment of transport due to the offset.

$V_c=V/2$	1.2500E+05N
A	52.55mm
$M_c'=V_c/2*a$	6.5688E+06Nmm

For beam web we have:

V_b	2.5000E+05N
b	97.25m
$M_b'=V_b*b$	2.4313E+07Nmm

CSE computes in a more accurate way the distribution of the forces, considering also bolts length (see paragraph B.4.1). Bolt layouts on column web have also an additional offset in beam axis direction: the program computes a different moment of transport, because in simplified hand computation $M'=V*a$ this further offset is not considered. As shown in following abstract, value computed by CSE is è $5.9695*10^6$Nmm; we will use this value from now on. All the other values are equal to those hand computed. B1 and B2 are bolt layouts on column web (1 check section), B3 is bolt layout on beam web (2 check sections).

```
---------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
---------------------------------------------------------------------

Id      Inst  Combi  Ext       Fx           Fy           Fz           Mx           My           Mz

   B2      1      1      1  4.8750e-006 -1.2500e+005 -1.1313e-008 -1.2500e+006 -4.8156e-005 -5.9695e+006
   B2      1      1      2 -4.8750e-006  1.2500e+005  1.1313e-008 -4.6148e-002 -5.9430e-007  5.9695e+006
   B1      1      1      1 -4.8750e-006  1.2500e+005  1.1313e-008  1.2500e+006  4.8156e-005  5.9695e+006
   B1      1      1      2  4.8750e-006 -1.2500e+005 -1.1313e-008  4.6277e-002  5.9430e-007 -5.9695e+006
   B3      1      1      1  1.1313e-008  1.2500e+005  4.8750e-006  5.6327e+005  4.7399e-004 -1.2156e+007
   B3      1      1      2 -7.9621e-020 -2.5000e+005 -9.7500e-006  7.7998e-009 -9.4819e-004  2.4312e+007
   B3      1      1      3 -1.1313e-008  1.2500e+005  4.8750e-006 -5.6327e+005  4.7399e-004 -1.2156e+007
```

Internal forces in check sections of B1 and B2 bolts are (bolts distance is equal to 30mm, forces are in Newton):

$d_{y,i}$	$F_x=M_c'/J_p*dy_i$	$F_y=V_c/10$	$R=\sqrt{F_x^2+F_y^2}$	expl
135	1.085E+04	1.250E+04	1.655E+04	0.857
105	8.442E+03	1.250E+04	1.508E+04	0.781
75	6.030E+03	1.250E+04	1.388E+04	0.719
45	3.618E+03	1.250E+04	1.301E+04	0.674
15	1.206E+03	1.250E+04	1.256E+04	0.650
15	1.206E+03	1.250E+04	1.256E+04	0.650
45	3.618E+03	1.250E+04	1.301E+04	0.674
75	6.030E+03	1.250E+04	1.388E+04	0.719
105	8.442E+03	1.250E+04	1.508E+04	0.781
135	1.085E+04	1.250E+04	1.655E+04	0.857

F_y is the total shear on the layout divided by bolts number (10). F_x is the force on each bolt due to moment of transport: it is equal to the moment multiplied by considered bolt distance from layout centre (d_y) and divided by layout polar inertia moment J_p.

$$J_p = \Sigma(dy_i) = 2 * (15^2 + 45^2 + 75^2 + 105^2 + 135^2) = 74250\text{mm}^2$$

R is the resultant force on each bolt (sum of F_x e F_y components). In previous table, bolts utilization factor is also given (expl). It is equal to R divided by bolts design resistance for $F_{V,Rd}=a_V*f_{ub}*A_{tot}/\gamma_{M2}=1.932*10^4$N, with a_v=0.6 and γ_{M2}=1.25.

Now we are going to compute in detail the firs bolt of previous table.

$$F_x = M_c'/J_p*dy_i = 5969500\text{Nmm} / 74250\text{mm}^2\ \ 135\text{mm} * 1.085*10^4\text{N}$$

$$F_y = V_c/10 = 125000\text{N} / 10 = 12500\text{N}$$

F_x and F_y composition on considered bolt is:

$$R=\sqrt{F_x^2+F_y^2}=\sqrt{\left(1.085\cdot 10^4 N\right)^2+\left(1.250\cdot 10^4 N\right)^2}=1.655\cdot 10^4 N$$

On beam web bolt layout we have the same distance between bolts in a column. Distance between the columns is 54mm. Bolts have 2 check sections, so internal forces are half of the forces acting on bolt layout extremes.

As we have seen in B.2.1.3, y component of the force is the sum of applied shear divided by bolts number and the component in *y* direction of the reaction to torque (moment of transport); the only force in *x* direction is the component of the reaction to the torque. For both rows the *x* component is:

dy	$Vx_{M'}=M'dy/J_p$
135	1.0062E+04
105	7.8259E+03
75	5.5899E+03

45	3.3540E+03
15	1.1180E+03
15	1.1180E+03
45	3.3540E+03
75	5.5899E+03
105	7.8259E+03
135	1.0062E+04

In *y* direction, the force due to applied shear distribution on bolts ($6.250 \cdot 10^3$N) and the force due to reaction to torque ($2.0124 \cdot 10^3$N) have the same sign on the bolts of one column (resultant is $8.262 \cdot 10^3$N). F_x and F_y composition is, in Newton:

T_{tot}	
1.302E+04	1.092E+04
1.138E+04	8.900E+03
9.976E+03	7.015E+03
8.917E+03	5.404E+03
8.338E+03	4.383E+03
8.338E+03	4.383E+03
8.917E+03	5.404E+03
9.976E+03	7.015E+03
1.138E+04	8.900E+03
1.302E+04	1.092E+04

Utilization factors are:

expl B3	
0.674	0.565
0.589	0.461
0.516	0.363
0.462	0.280
0.432	0.227
0.432	0.227
0.462	0.280
0.516	0.363
0.589	0.461
0.674	0.565

As we see in following abstract, CSE computes the same values, unless negligible roundings.

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B2	1	1	-1.131e-009	-1.131e-009	-1.085e+004	-1.250e+004	1.655e+004	-6.250e+004	-2.378e-006	6.250e+004	0.858	resis
1	1	B2	2	1	-1.131e-009	-1.131e-009	-8.442e+003	-1.250e+004	1.508e+004	-6.250e+004	-2.378e-006	6.250e+004	0.781	resis
1	1	B2	3	1	-1.131e-009	-1.131e-009	-6.030e+003	-1.250e+004	1.388e+004	-6.250e+004	-2.378e-006	6.250e+004	0.719	resis
1	1	B2	4	1	-1.131e-009	-1.131e-009	-3.618e+003	-1.250e+004	1.301e+004	-6.250e+004	-2.378e-006	6.250e+004	0.674	resis
1	1	B2	5	1	-1.131e-009	-1.131e-009	-1.206e+003	-1.250e+004	1.256e+004	-6.250e+004	-2.378e-006	6.250e+004	0.651	resis
1	1	B2	6	1	-1.131e-009	-1.131e-009	1.206e+003	-1.250e+004	1.256e+004	-6.250e+004	-2.378e-006	6.250e+004	0.651	resis
1	1	B2	7	1	-1.131e-009	-1.131e-009	3.618e+003	-1.250e+004	1.301e+004	-6.250e+004	-2.378e-006	6.250e+004	0.674	resis
1	1	B2	8	1	-1.131e-009	-1.131e-009	6.030e+003	-1.250e+004	1.388e+004	-6.250e+004	-2.378e-006	6.250e+004	0.719	resis
1	1	B2	9	1	-1.131e-009	-1.131e-009	8.442e+003	-1.250e+004	1.508e+004	-6.250e+004	-2.378e-006	6.250e+004	0.781	resis
1	1	B2	10	1	-1.131e-009	-1.131e-009	1.085e+004	-1.250e+004	1.655e+004	-6.250e+004	-2.378e-006	6.250e+004	0.858	resis
1	1	B1	1	1	1.131e-009	1.131e-009	1.085e+004	1.250e+004	1.655e+004	6.250e+004	2.378e-006	6.250e+004	0.858	resis
1	1	B1	2	1	1.131e-009	1.131e-009	8.442e+003	1.250e+004	1.508e+004	6.250e+004	2.378e-006	6.250e+004	0.781	resis
1	1	B1	3	1	1.131e-009	1.131e-009	6.030e+003	1.250e+004	1.388e+004	6.250e+004	2.378e-006	6.250e+004	0.719	resis
1	1	B1	4	1	1.131e-009	1.131e-009	3.618e+003	1.250e+004	1.301e+004	6.250e+004	2.378e-006	6.250e+004	0.674	resis
1	1	B1	5	1	1.131e-009	1.131e-009	1.206e+003	1.250e+004	1.256e+004	6.250e+004	2.378e-006	6.250e+004	0.651	resis
1	1	B1	6	1	1.131e-009	1.131e-009	-1.206e+003	1.250e+004	1.256e+004	6.250e+004	2.378e-006	6.250e+004	0.651	resis
1	1	B1	7	1	1.131e-009	1.131e-009	-3.618e+003	1.250e+004	1.301e+004	6.250e+004	2.378e-006	6.250e+004	0.674	resis
1	1	B1	8	1	1.131e-009	1.131e-009	-6.030e+003	1.250e+004	1.388e+004	6.250e+004	2.378e-006	6.250e+004	0.719	resis
1	1	B1	9	1	1.131e-009	1.131e-009	-8.442e+003	1.250e+004	1.508e+004	6.250e+004	2.378e-006	6.250e+004	0.781	resis
1	1	B1	10	1	1.131e-009	1.131e-009	-1.085e+004	1.250e+004	1.655e+004	6.250e+004	2.378e-006	6.250e+004	0.858	resis
1	1	B3	1	1	2.437e-007	2.437e-007	-1.006e+004	8.263e+003	1.302e+004	-3.087e+003	2.370e-005	3.087e+003	0.675	
1	1	B3	1	2	-2.437e-007	-2.437e-007	1.006e+004	-8.263e+003	1.302e+004	-3.087e+003	-2.370e-005	3.087e+003	0.675	resis
1	1	B3	2	1	2.437e-007	2.437e-007	-1.006e+004	4.237e+003	1.092e+004	-3.087e+003	2.370e-005	3.087e+003	0.566	
1	1	B3	2	2	-2.437e-007	-2.437e-007	1.006e+004	-4.237e+003	1.092e+004	-3.087e+003	-2.370e-005	3.087e+003	0.566	resis
1	1	B3	3	1	2.437e-007	2.437e-007	-7.827e+003	8.263e+003	1.138e+004	-3.087e+003	2.370e-005	3.087e+003	0.590	
1	1	B3	3	2	-2.437e-007	-2.437e-007	7.827e+003	-8.263e+003	1.138e+004	-3.087e+003	-2.370e-005	3.087e+003	0.590	resis
1	1	B3	4	1	2.437e-007	2.437e-007	-7.827e+003	4.237e+003	8.900e+003	-3.087e+003	2.370e-005	3.087e+003	0.461	
1	1	B3	4	2	-2.437e-007	-2.437e-007	7.827e+003	-4.237e+003	8.900e+003	-3.087e+003	-2.370e-005	3.087e+003	0.461	resis
1	1	B3	5	1	2.437e-007	2.437e-007	-5.591e+003	8.263e+003	9.976e+003	-3.087e+003	2.370e-005	3.087e+003	0.517	
1	1	B3	5	2	-2.437e-007	-2.437e-007	5.591e+003	-8.263e+003	9.976e+003	-3.087e+003	-2.370e-005	3.087e+003	0.517	resis
1	1	B3	6	1	2.437e-007	2.437e-007	-5.591e+003	4.237e+003	7.015e+003	-3.087e+003	2.370e-005	3.087e+003	0.363	
1	1	B3	6	2	-2.437e-007	-2.437e-007	5.591e+003	-4.237e+003	7.015e+003	-3.087e+003	-2.370e-005	3.087e+003	0.363	resis
1	1	B3	7	1	2.437e-007	2.437e-007	-3.354e+003	8.263e+003	8.918e+003	-3.087e+003	2.370e-005	3.087e+003	0.462	resis
1	1	B3	7	2	-2.437e-007	-2.437e-007	3.354e+003	-8.263e+003	8.918e+003	-3.087e+003	-2.370e-005	3.087e+003	0.462	
1	1	B3	8	1	2.437e-007	2.437e-007	-3.354e+003	4.237e+003	5.404e+003	-3.087e+003	2.370e-005	3.087e+003	0.280	resis
1	1	B3	8	2	-2.437e-007	-2.437e-007	3.354e+003	-4.237e+003	5.404e+003	-3.087e+003	-2.370e-005	3.087e+003	0.280	
1	1	B3	9	1	2.437e-007	2.437e-007	-1.118e+003	8.263e+003	8.338e+003	-3.087e+003	2.370e-005	3.087e+003	0.432	resis
1	1	B3	9	2	-2.437e-007	-2.437e-007	1.118e+003	-8.263e+003	8.338e+003	-3.087e+003	-2.370e-005	3.087e+003	0.432	
1	1	B3	10	1	2.437e-007	2.437e-007	-1.118e+003	4.237e+003	4.382e+003	-3.087e+003	2.370e-005	3.087e+003	0.227	resis
1	1	B3	10	2	-2.437e-007	-2.437e-007	1.118e+003	-4.237e+003	4.382e+003	-3.087e+003	-2.370e-005	3.087e+003	0.227	
1	1	B3	11	1	2.437e-007	2.437e-007	1.118e+003	8.263e+003	8.338e+003	-3.087e+003	2.370e-005	3.087e+003	0.432	resis
1	1	B3	11	2	-2.437e-007	-2.437e-007	-1.118e+003	-8.263e+003	8.338e+003	-3.087e+003	-2.370e-005	3.087e+003	0.432	
1	1	B3	12	1	2.437e-007	2.437e-007	1.118e+003	4.237e+003	4.382e+003	-3.087e+003	2.370e-005	3.087e+003	0.227	resis
1	1	B3	12	2	-2.437e-007	-2.437e-007	-1.118e+003	-4.237e+003	4.382e+003	-3.087e+003	-2.370e-005	3.087e+003	0.227	
1	1	B3	13	1	2.437e-007	2.437e-007	3.354e+003	8.263e+003	8.918e+003	-3.087e+003	2.370e-005	3.087e+003	0.462	resis
1	1	B3	13	2	-2.437e-007	-2.437e-007	-3.354e+003	-8.263e+003	8.918e+003	-3.087e+003	-2.370e-005	3.087e+003	0.462	
1	1	B3	14	1	2.437e-007	2.437e-007	3.354e+003	4.237e+003	5.404e+003	-3.087e+003	2.370e-005	3.087e+003	0.280	resis
1	1	B3	14	2	-2.437e-007	-2.437e-007	-3.354e+003	-4.237e+003	5.404e+003	-3.087e+003	-2.370e-005	3.087e+003	0.280	
1	1	B3	15	1	2.437e-007	2.437e-007	5.591e+003	8.263e+003	9.976e+003	-3.087e+003	2.370e-005	3.087e+003	0.517	
1	1	B3	15	2	-2.437e-007	-2.437e-007	-5.591e+003	-8.263e+003	9.976e+003	-3.087e+003	-2.370e-005	3.087e+003	0.517	resis
1	1	B3	16	1	2.437e-007	2.437e-007	5.591e+003	4.237e+003	7.015e+003	-3.087e+003	2.370e-005	3.087e+003	0.363	
1	1	B3	16	2	-2.437e-007	-2.437e-007	-5.591e+003	-4.237e+003	7.015e+003	-3.087e+003	-2.370e-005	3.087e+003	0.363	resis
1	1	B3	17	1	2.437e-007	2.437e-007	7.827e+003	8.263e+003	1.138e+004	-3.087e+003	2.370e-005	3.087e+003	0.590	
1	1	B3	17	2	-2.437e-007	-2.437e-007	-7.827e+003	-8.263e+003	1.138e+004	-3.087e+003	-2.370e-005	3.087e+003	0.590	resis
1	1	B3	18	1	2.437e-007	2.437e-007	7.827e+003	4.237e+003	8.900e+003	-3.087e+003	2.370e-005	3.087e+003	0.461	
1	1	B3	18	2	-2.437e-007	-2.437e-007	-7.827e+003	-4.237e+003	8.900e+003	-3.087e+003	-2.370e-005	3.087e+003	0.461	resis
1	1	B3	19	1	2.437e-007	2.437e-007	1.006e+004	8.263e+003	1.302e+004	-3.087e+003	2.370e-005	3.087e+003	0.675	
1	1	B3	19	2	-2.437e-007	-2.437e-007	-1.006e+004	-8.263e+003	1.302e+004	-3.087e+003	-2.370e-005	3.087e+003	0.675	resis
1	1	B3	20	1	2.437e-007	2.437e-007	1.006e+004	4.237e+003	1.092e+004	-3.087e+003	2.370e-005	3.087e+003	0.566	
1	1	B3	20	2	-2.437e-007	-2.437e-007	-1.006e+004	-4.237e+003	1.092e+004	-3.087e+003	-2.370e-005	3.087e+003	0.566	resis

Now we compute the utilization factor for column web bolt bearing: an external bolt and the most loaded among internal bolts.

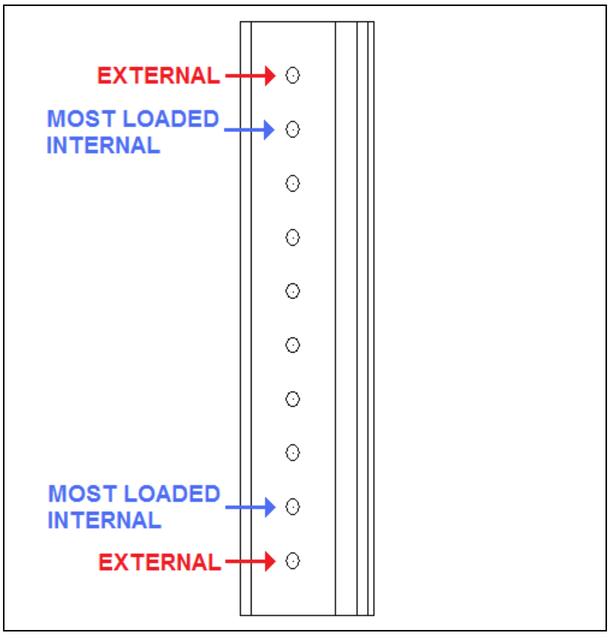


Figure B-101

Bolt layout geometry is given in next image. Formulae used are the same of previous paragraphs, according to EN-1993-1-8:2005 (see appendix).

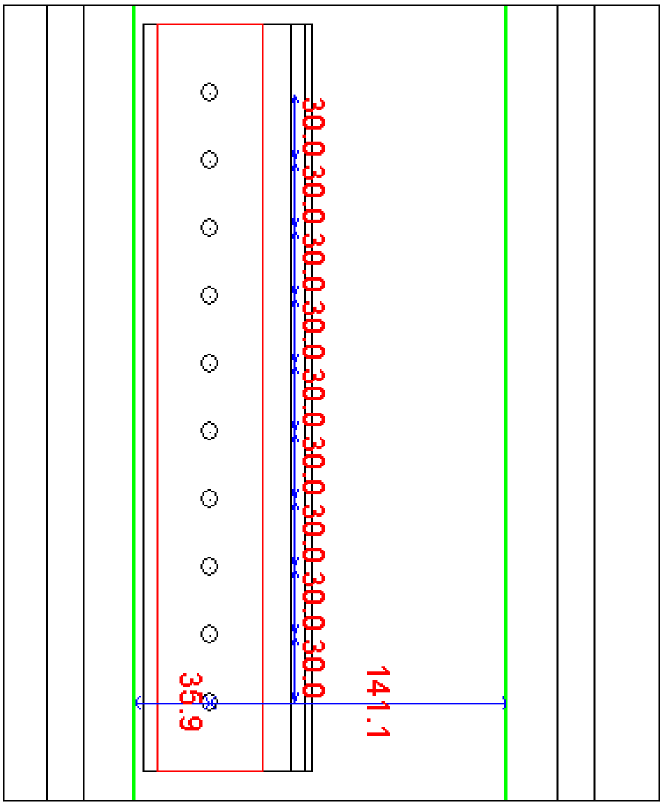


Figure B-102 Distances between bolts and from edges

External bolts (Figure B-101)

Fx	1,085E+04	**Fy**	1,250E+04
$F_{b,Rd,x}$	5,760E+04	**$F_{b,Rd,y}$**	4,960E+04
k_1	2,5	**k_1**	2,5
$2,8e_2/d_0$-1,7	9,469	**$2,8e_2/d_0$-1,7**	9,469
$1,4p_2/d_0$-1,7	2,967		
	2,5		2,5
a_b	1,000	**a_b**	0,861
a_d	1,330	**a_d**	1,330
f_{ub}/f_u	2,22	**f_{ub}/f_u**	2,22
		$p_1/3d_0$-0,25	0,86
	1		1
fu	360	**fu**	360
d	10	**d**	10
d_0	9	**d_0**	9
t	8	**t**	8
e_1=min(e_1,e_2)	35,9	**e_1=min(e_1,e_2)**	35,9
e_2=min(e_1,e_2)	35,9	**e_2=min(e_1,e_2)**	35,9
p_1	0	**p_1**	30
p_2	30	**p_2**	0
$expl_x$	0,188	**$expl_y$**	0,252
	EXPL=	**0,315**	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\exp 1 = \sqrt{\exp 1_x^2 + \exp 1_y^2} = 0.315$$

Most loaded internal bolts (Figure B-101)

Fx	8,442E+03	**Fy**	1,250E+04
$F_{b,Rd,x}$	5,760E+04	**$F_{b,Rd,y}$**	4,960E+04
k_1	2,5	**k_1**	2,5
$1,4p_2/d_0$-1,7	2,967	**$2,8e_2/d_0$-1,7**	9,469
	2,5		2,5
a_b	1,000	**a_b**	0,861
a_d	1,330	**a_d**	0,861
f_{ub}/f_u	2,22	**f_{ub}/f_u**	2,22
		$p_1/3d_0$-0,25	0,86
	1		1
fu	360	**fu**	360
d	10	**d**	10
d_0	9	**d_0**	9

t	8	t	8
e_1=min(e_1,e_2)	35,9	e_1=min(e_1,e_2)	35,9
e_2=min(e_1,e_2)	35,9	e_2=min(e_1,e_2)	35,9
p_1	0	p_1	30
p_2	30	p_2	0
$expl_x$	0,147	$expl_y$	0,252
	EXPL=	0,292	

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\mathrm{expl} = \sqrt{\mathrm{expl}_x^2 + \mathrm{expl}_y^2} = 0.292$$

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

Maximum value for column bolt bearing utilization is 0.292; CSE computes the same value (the column is m1).

```
-------------------------------------------------------------------
Members whose maximum utilization ratio is due to bearing stresses
-------------------------------------------------------------------

 Inst Combi  Name   Boltlay   Bolt   Extr.          Sigma      Sigma M    Expl
                                                 (  N/ mm²)    (  N/ mm²)

    1     1    m1      B2       10      2          206.9        657.6   0.315
    1     1    m2      B3        1      2          378.5        674.2   0.561
    2     1    m1      B2       10      2          206.9        657.6   0.315
    2     1    m2      B3        1      2          378.5        674.2   0.561
```

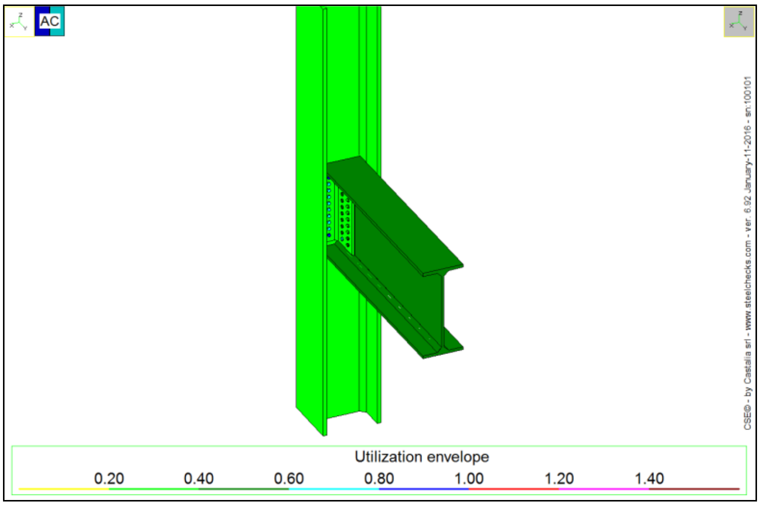


Figure B-103 Components utilization envelope

B.5.2 End plate (connection on column web)

Some modifications have been done to the model of previous paragraph. Instead of the double angle cleat, a flexible end plate is used. Plate has the same thickness of column web. A single bolt layout is used (2 columns, 10 rows, M8 class 8.8). Applied loads are the same of previous paragraph.(model: *Validation_BC_2.CSE*).

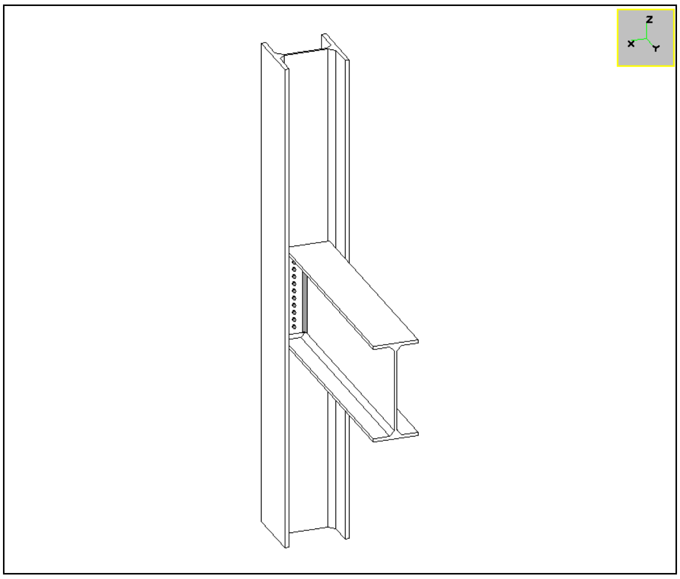


Figure B-104 3D view of the model

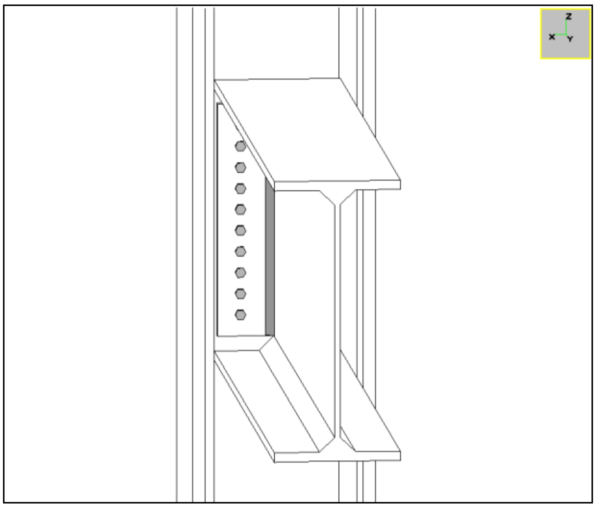


Figure B-105 Detail: bolt layout and weld layout

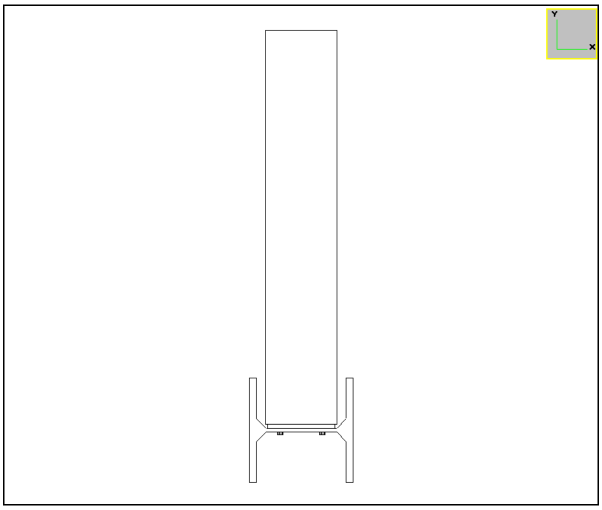


Figure B-106 Top view

Shear acting on joint (2.500*10^5N) is equally distributed on the 20 bolts of the layout. Each one of them carries 1.250*10^4N. Dividing that force by bolts design resistance to shear ($F_{V,Rd}$=1.932*10^4N, previously computed according to EN1993-1-8) we get an utilization factor equal to **0.647**.

As we have seen in B.4.3, when we replace two different bolt layouts on two angles with a single bolt layout on a single plate, there is no moment of transport in the layout, because it is centred to load application point e the torque is carried by the plate.

```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	2	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	3	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	4	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	5	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	6	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	7	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	8	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	9	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	10	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	11	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	12	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	13	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	14	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	15	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	16	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	17	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	18	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	19	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis
1	1	B1	20	1	7.695e-013	7.695e-013	-4.875e-007	1.250e+004	1.250e+004	6.250e+004	2.438e-006	6.250e+004	0.648	resis

See previous paragraph for bolt bearing check of the member; here we are going to consider weld layout computation.

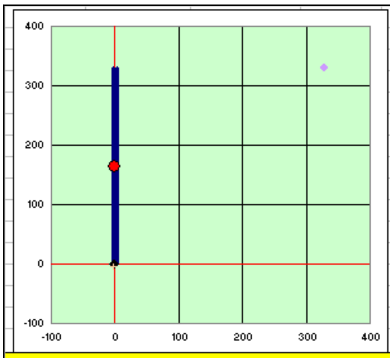
In weld layout computation it is not enough to consider only the applied shear, but also a moment due to the offset, often neglected in manual computation. This moment is always computed by CSE.

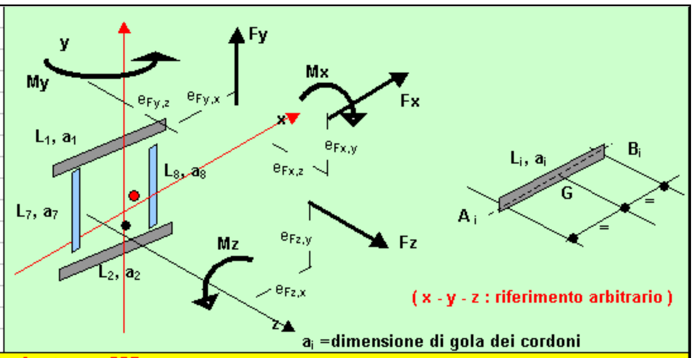
```
-----------------------------------------
Overall internal actions over Weld Layouts
-----------------------------------------

Id      Inst   Combi      NT             TuT            TvT            MtT            MuT            MvT

   W1      1       1   8.0214e-014   9.7500e-006 -2.5000e+005 -5.0866e-014 -3.7500e+006 -1.4625e-004
   W1      2       1   8.0214e-014   9.7500e-006 -2.5000e+005 -5.0866e-014 -3.7500e+006 -1.4625e-004
```

To cross-check CSE results, we use *Saldature* application againt (see A.3).





Confronto con CSE

tutti i cordoni hanno eguale dimensione della gola pari a: mm					**8,485**	*il dato sostituisce tale valore*			riferite ad assi principali			
posizione cordoni	cordone w	a_i	L_i	$x_{A,i}$	$y_{A,i}$	$x_{G,i}$	$y_{G,i}$	A_i	$\xi_{A,i}$	$\xi_{B,i}$	$\eta_{A,i}$	$\eta_{B,i}$
		mm	mm	mm	mm	mm	mm	cm^2	mm	mm	mm	mm
cordoni paralleli ad asse x	1											
	2											
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		329,0	-3,4		-3,4	165	27,9	-3	-3	-165	165
	8		329,0	3,4		3,4	164,5	27,9	3	3	-165	165
	9											
	10											
	11											
(blu)	12											
caratteristiche della sezione		A	x_G	y_G	I_{Gxx}	I_{Gyy}	I_{Gxy}	α		$I_{G\xi\xi}$	$I_{G\eta\eta}$	
		cm^2	mm	mm	cm^4	cm^4	cm^4	radianti	gradi	cm^4	cm^4	
		55,8	**0**	**165**	**5.036**	**6**	**0**	**0,0000**	**0**	**5.036**	**6**	

Figure B-107 *Saldature* application: input data

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
carico	**asse x**				**asse y**				**asse z**			
	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1		3.750,0			250.000,0							
2												
3												

Figure B-108 *Saldature* application: applied loads

condizione di carico 1	unità di misura degli sforzi:				N/mm2					
cordoni	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
						F_x			F_y	
7A	-12,25	0,0	0,0	-12,25	0,0	0,0	0,0	0,0	44,78	44,78
7B	12,25	0,0	0,0	12,25	0,0	0,0	0,0	0,0	44,78	44,78
8A	-12,25	0,0	0,0	-12,25	0,0	0,0	0,0	0,0	44,78	44,78
8B	12,25	0,0	0,0	12,25	0,0	0,0	0,0	0,0	44,78	44,78

Figure B-109 *Saldature* application: welds stresses results

Values for parallel τ and normal n are the same computed by CSE.

```
-----------------------------------------
Internal stresses in welds, exploitations
-----------------------------------------

Inst  Combi  Name Weld      nPer         tPar         tPer         force       Cause  Ext    Expl

    1      1     W1   1   1.225e+001  -4.478e+001  -1.746e-009   3.939e+002     3      1   0.223
    1      1     W1   2  -1.225e+001   4.478e+001   1.746e-009   3.939e+002     3      1   0.223

    2      1     W1   1   1.225e+001  -4.478e+001  -1.746e-009   3.939e+002     3      1   0.223
    2      1     W1   2  -1.225e+001   4.478e+001   1.746e-009   3.939e+002     3      1   0.223
```

Beam is not checked by CSE in this case (according to check settings). Note well: welds check also include beam check because in welds check the weakest material of connected objects is included.

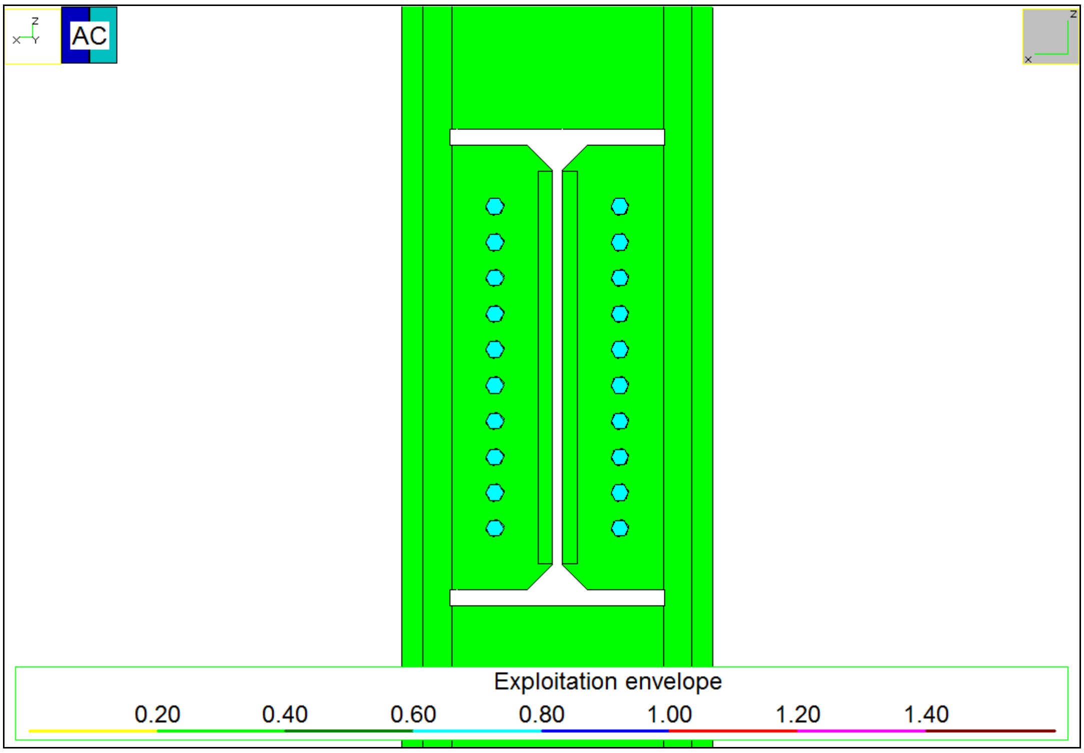


Figure B-110 Components utilization envelope

B.5.3 Double angle cleats (connection on column flange)

Starting from the same FEM model of the previous paragraphs, a 90° rotation pf the column about its axis was applied, before re-analysing the model and re-importing it in CSE (model: *Validation_BC_3.CSE*).

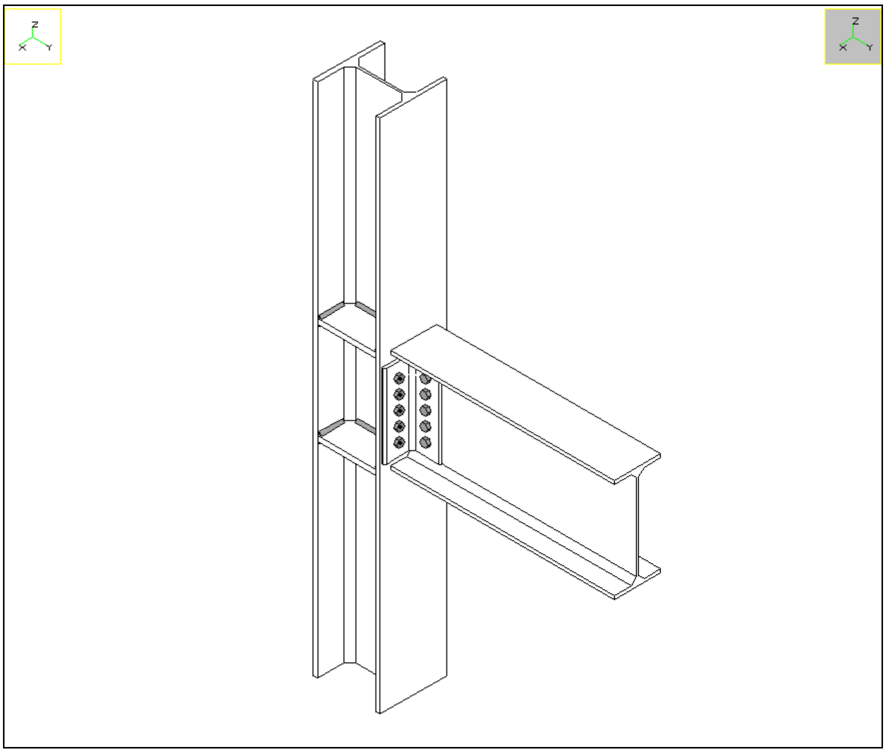


Figure B-111 3D view of the model

When the connection was on column web, it was possible to discard load application point offset (it was half of web thickness). Now the offset is half of column cross-section height and must be considered in bolt layouts computation. Bolts on column flange cannot be "shear only", because the offset produces a moment of transport. The layout must be able to carry bending via tension and compression in bolts (or via tension in bolts and compression in bearing surface, see part C of this document).

Model data: Column: HEB260

Beam: IPE 400

Angles: 120x120x12mm

Stiffeners: thickness 20mm

Material: S235

Bolts: M16 class 8.8, 1 column and 5 rows

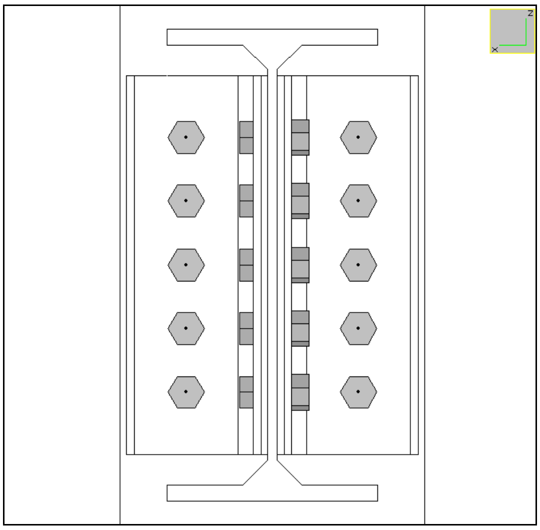


Figure B-112 Front view

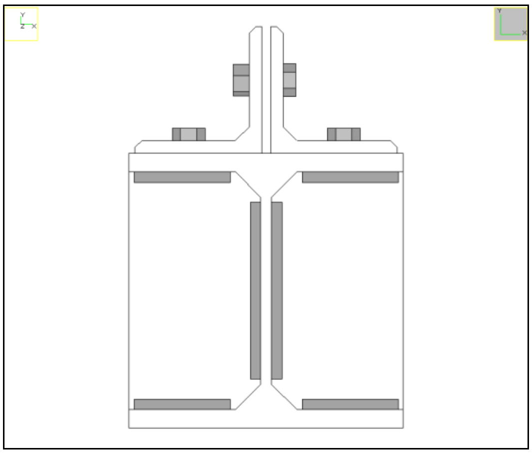


Figure B-113 Top view (beam not displayed)

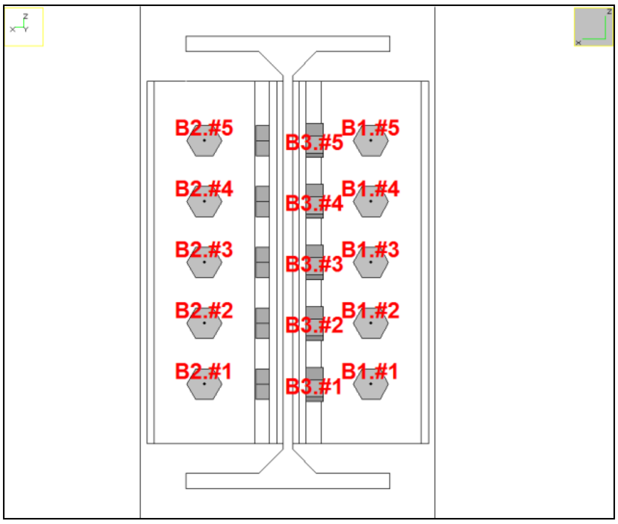


Figure B-114 Bolts numbering

Applied shear on beam middle point is 125000N (a different value was applied to previous models). Half of the load is carried by a joint and half by the other (62500N on each joint). Shear is transferred on column axis. The offset between column axis and column flange external face must be considered.

We have two equal bolt layouts on column flange: they are in symmetrical conditions. As said, the offset along beam axis produces a bending moment on column flange bolt layouts (shear multiplied by half of column cross-section height). In addition, the offset in normal direction (b in next figure) produces a torque in bolt layouts, carried as additional shear by the bolts. External bolts are the most exploited ones.

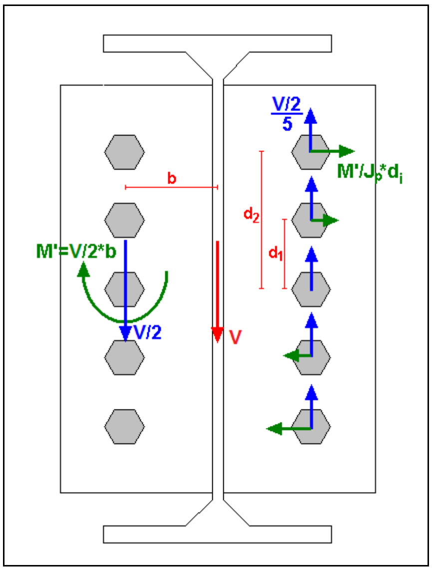


Figure B-115

Consider a single bolt layout. Shear is equal to $V/2=3.125*10^4$N. Distance between layout centre and load application point is 73.55mm, so a moment of transport computed in a simplified way would be equal to $73.55 \times 3.125 \times 10^4=2.298*10^6$Nmm. As shown in following abstract, CSE computes a smaller value: $2.110*10^6$Nmm (92% of simplified hand computation).

```
------------------------------------------
Overall internal actions over Bolt Layouts
------------------------------------------
```

Id	Inst	Combi	Sec	NT	TuT	TvT	MtT	MuT	MvT
B1	1	1	1	-2.2543e-006	-1.2187e-006	3.1250e+004	-2.1102e+006	4.0625e+006	-7.3675e-006
B2	1	1	1	2.2543e-006	-1.2188e-006	3.1250e+004	2.1102e+006	4.0625e+006	-7.3675e-006

The reason of the difference between simplified hand computation and CSE accurate computation is that in simplified computations we do not consider bolts length, parasitic bending in bolt shafts and the different planes along bolts length where forces are transferred. Consider also that shear is not transferred to the angles in correspondence of beam vertical middle plane, but there is a distance that reduces the total offset. For these reasons, CSE computation is more accurate than our simplified hand computation. From now on, we will consider moment value computed by the program.

As we previously said, there is another offset to be considered. It produces bending in bolt layouts:

$$M'' = V/2 * b' = 3.125*10^6\text{N} * 130\text{mm} = 4.0625*10^6\text{Nmm}$$

where b' is half of the height of HEB260 cross-section (column M_{uT} in CSE output listing).

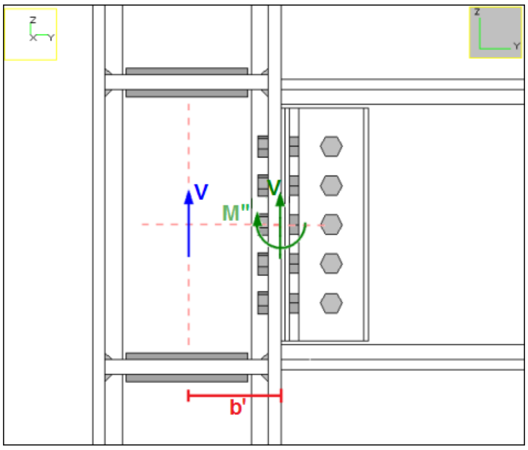


Figure B-116

Consider the forces in bolt layout plane first (Figure B-115). A force V_v parallel to the applied shear acts on each bolt. It is equal to the load applied to the layout divided by bolts number (5). Then there is a V_u shear normal to the previous one: it is due to layout reaction to torque. On each bolt, this shear depends on the distance from bolt to layout centre, as seen in previous paragraphs. Resultant force on each bolt is (*v* and *u* are bolt layout principal axes):

$$F_{b,i} = \sqrt{V_v^2 + V_u^2} = \sqrt{\left(\frac{V/2}{5}\right)^2 + \left(\frac{M' d_i}{J_p}\right)^2}$$

Distance between bolts is 54mm, so polar inertia moment is J_p=2*(54^{2}x108^2)=29160mm^2; force in each bolt is given in following table, according to previous formula.

d_i [mm]	$F_{b,i}$ [N]
108	1.001E+04
54	7.371E+03
0	6.250E+03
54	7.371E+03
108	1.001E+04

CSE computes the same values (column T_B):

```
--------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
--------------------------------------------------------------

Inst  Combi  Name Bolt -?-      NB          NTB          TuB          TvB         TB          MuB        MvB          MB       Expl  cause

    1     1    B1   1   1 -1.499e+004 -1.499e+004 -7.816e+003   6.250e+003 1.001e+004  2.811e+003 -1.473e-006  2.811e+003  0.319 resis
    1     1    B1   2   1 -7.497e+003 -7.497e+003 -3.908e+003   6.250e+003 7.371e+003  2.811e+003 -1.473e-006  2.811e+003  0.198 resis
    1     1    B1   3   1 -4.509e-007 -4.509e-007 -2.437e-007   6.250e+003 6.250e+003  2.811e+003 -1.473e-006  2.811e+003  0.102 resis
    1     1    B1   4   1  7.497e+003  7.497e+003  3.908e+003   6.250e+003 7.371e+003  2.811e+003 -1.473e-006  2.811e+003  0.198 resis
    1     1    B1   5   1  1.499e+004  1.499e+004  7.816e+003   6.250e+003 1.001e+004  2.811e+003 -1.473e-006  2.811e+003  0.319 resis

    1     1    B2   1   1 -1.499e+004 -1.499e+004  7.816e+003   6.250e+003 1.001e+004  2.811e+003 -1.473e-006  2.811e+003  0.319 resis
    1     1    B2   2   1 -7.497e+003 -7.497e+003  3.908e+003   6.250e+003 7.371e+003  2.811e+003 -1.473e-006  2.811e+003  0.198 resis
    1     1    B2   3   1  4.509e-007  4.509e-007 -2.438e-007   6.250e+003 6.250e+003  2.811e+003 -1.473e-006  2.811e+003  0.102 resis
    1     1    B2   4   1  7.497e+003  7.497e+003 -3.908e+003   6.250e+003 7.371e+003  2.811e+003 -1.473e-006  2.811e+003  0.198 resis
    1     1    B2   5   1  1.499e+004  1.499e+004 -7.816e+003   6.250e+003 1.001e+004  2.811e+003 -1.473e-006  2.811e+003  0.319 resis
```

Now consider bending due to the offset in beam axis direction (Figure B-116). Since we are not using a bearing surface here (see part C for this aspect), bending in the layout produces tension or compression in bolts. To compute axial force in bolts, we need to compute bolt layout inertia moment about considered axis (inertia moment per area unit). It is equal to the sum of two components: the first one is the sum of squared distances from each bolt to layout centre; the second one is the inertia moment (per area unit) of single bolts. We have:

$$J_{tot}=J_u+5J_b$$

where

$$J_u = \Sigma\left(d_i^2\right) = 0^2 + 2 \cdot 54^2 + 2 \cdot 108^2 = 29160mm^2$$

For M18 bolts: r=9mm and A_b=254.4mm^2, so:

$$J_b = \frac{\pi\, r^4}{4}\frac{1}{A_b} = \frac{\pi \cdot (9mm)^4}{4 \cdot 254.5mm^2} = 20.2mm^2$$

Total inertia moment is:

$$J_{tot} = J_u + 5J_b = 29169mm^2 + 5 \cdot 20.2mm^2 = 29261.2mm^2$$

Axial force in each bolt is:

$$N_i = \frac{M''}{J_{tot}} \cdot d_i$$

Central bolt has no axial force (d=0mm); we have two bolts in compression (d=54mm and d=108mm) and two bolts in tension, with the same distances. We have:

$$N_{d\pm108} = \frac{4.0625 \cdot 10^6\,Nmm}{29261.2mm^2} \cdot (\pm 108mm) = \pm 1.499 \cdot 10^4\,N$$

$$N_{d\pm54} = \frac{4.0625 \cdot 10^6\,Nmm}{29261.2mm^2} \cdot (\pm 54mm) = \pm 7.497 \cdot 10^3\,N$$

CSE computes the same values (column N_B = N_{TB} since there is no preload):

```
---------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
---------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	-1.499e+004	-1.499e+004	-7.816e+003	6.250e+003	1.001e+004	2.811e+003	-1.473e-006	2.811e+003	0.319	resis
1	1	B1	2	1	-7.497e+003	-7.497e+003	-3.908e+003	6.250e+003	7.371e+003	2.811e+003	-1.473e-006	2.811e+003	0.198	resis
1	1	B1	3	1	-4.509e-007	-4.509e-007	-2.437e-007	6.250e+003	6.250e+003	2.811e+003	-1.473e-006	2.811e+003	0.102	resis
1	1	B1	4	1	7.497e+003	7.497e+003	3.908e+003	6.250e+003	7.371e+003	2.811e+003	-1.473e-006	2.811e+003	0.198	resis
1	1	B1	5	1	1.499e+004	1.499e+004	7.816e+003	6.250e+003	1.001e+004	2.811e+003	-1.473e-006	2.811e+003	0.319	resis

Bolts utilization factor computation has been already treated in detail in previous paragraphs. Let's go on with beam web bolt layout computation.

Beam web bolt layout is "shear only". A shear equal to applied force acts on it, together with a moment of transport equal to shear by distance from layout centre to column axis (*M'*=*V***b*). In Figure B-118 are shown the components of total shear force on each bolt. Since we have 2 check sections for the bolts, in each section the shear is half of the applied one.

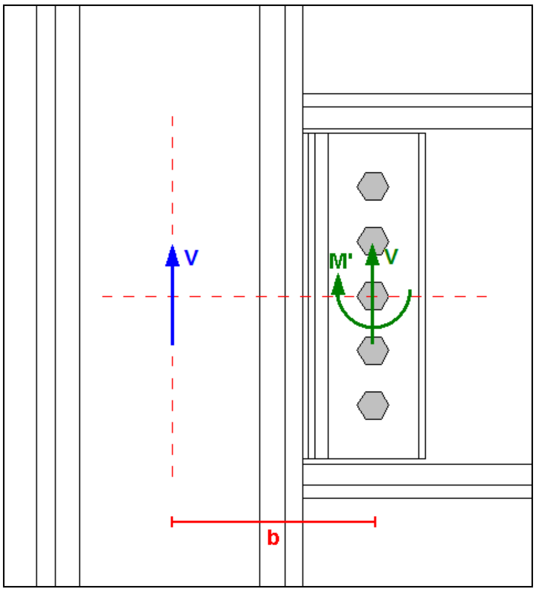


Figure B-117 Moment of transport M'=V*b

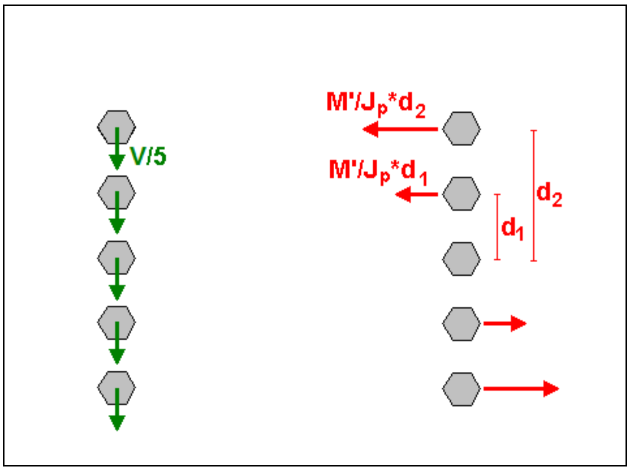


Figure B-118

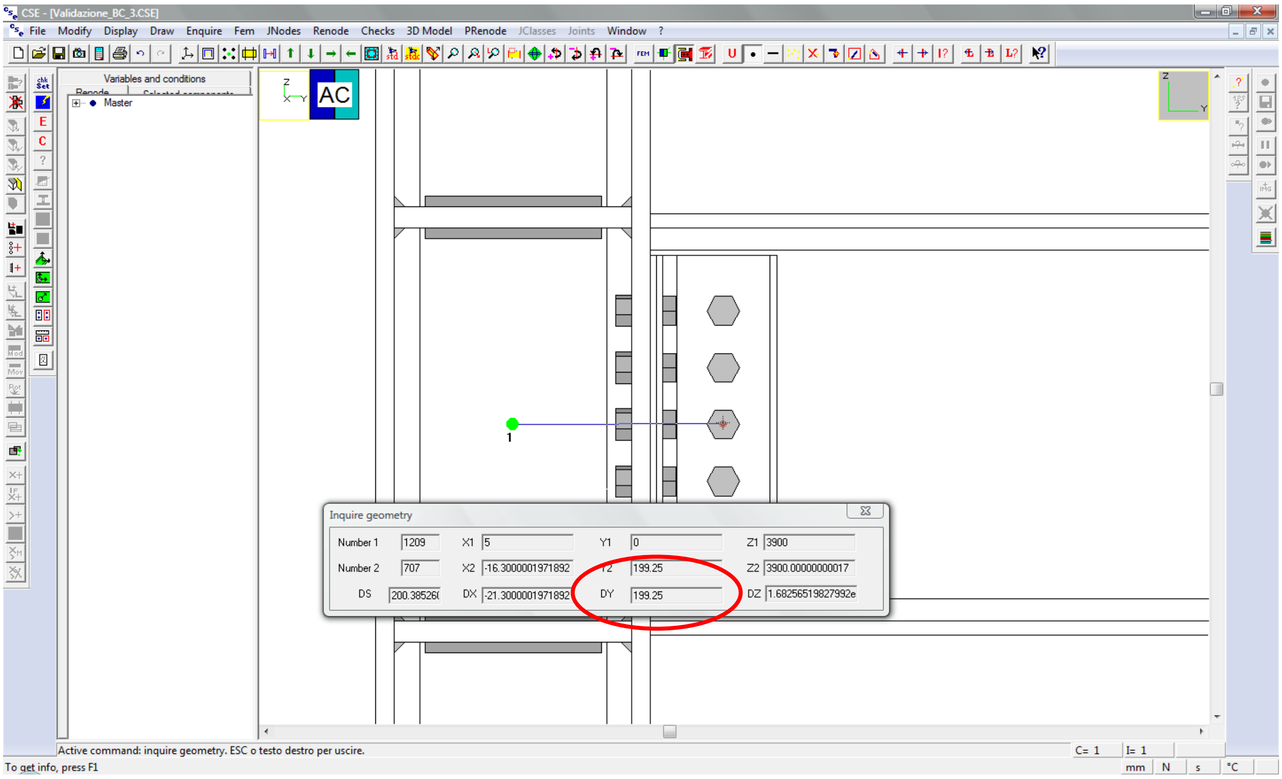


Figure B-119

Distance b is 199.25mm, as shown in previous figure. Moment is:

$$M' = 3.125 \cdot 10^4\text{N} \cdot 199.25\text{mm} = 6.226 \cdot 10^6\text{Nmm}$$

CSE computes the same value (M_{tT}).

Overall internal actions over Bolt Layouts

Id	Inst	Combi	Sec	NT	TuT	TvT	MtT	MuT	MvT
B1	1	1	1	-2.2543e-006	-1.2187e-006	3.1250e+004	-2.1102e+006	4.0625e+006	-7.3675e-006
B2	1	1	1	2.2543e-006	-1.2188e-006	3.1250e+004	2.1102e+006	4.0625e+006	-7.3675e-006
B3	1	1	1	-1.2187e-006	-2.2543e-006	-3.1250e+004	6.2266e+006	5.3846e+004	-2.3314e-004
B3	1	1	2	1.2187e-006	-2.2543e-006	3.1250e+004	-6.2266e+006	5.3846e+004	2.3314e-004

Forces composition is the same done for column flange bolt layout. Bolt distances and layout intertia moment J_p are the same. Using current shear and moment values, we have:

$$V_{b,i} = \sqrt{\left(\frac{V/2}{5}\right)^2 + \left(\frac{M' d_i}{J_p}\right)^2}$$

d_i [mm]	$T_{b,i}$ [N]
108	2.389E+04
54	1.312E+04
0	6.250E+03
54	1.312E+04
108	2.389E+04

For example, considering one of the external bolts (*d*=108mm from layout centre) we have:

$$F_{b,108mm} = \sqrt{\left(\frac{3.125 \cdot 10^4 N}{5}\right)^2 + \left(\frac{6.226 \cdot 10^6 Nmm \cdot 108mm}{29160mm^2}\right)^2} = 2.389 \cdot 10^4 N$$

CSE computes the same values (*TB*).

```
-------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
-------------------------------------------------------------

Inst  Combi  Name Bolt -?-        NB           NTB          TuB          TvB           TB          MuB          MvB           MB      Expl  cause

    1      1    B3   1   1  -2.437e-007  -2.437e-007   2.306e+004  -6.250e+003  2.389e+004   1.077e+004 -4.663e-005   1.077e+004   0.391
    1      1    B3   1   2   2.437e-007   2.437e-007  -2.306e+004   6.250e+003  2.389e+004   1.077e+004  4.663e-005   1.077e+004   0.391 resis
    1      1    B3   2   1  -2.437e-007  -2.437e-007   1.153e+004  -6.250e+003  1.312e+004   1.077e+004 -4.663e-005   1.077e+004   0.215
    1      1    B3   2   2   2.437e-007   2.437e-007  -1.153e+004   6.250e+003  1.312e+004   1.077e+004  4.663e-005   1.077e+004   0.215 resis
    1      1    B3   3   1  -2.437e-007  -2.437e-007  -4.509e-007  -6.250e+003  6.250e+003   1.077e+004 -4.663e-005   1.077e+004   0.102
    1      1    B3   3   2   2.437e-007   2.437e-007  -4.509e-007   6.250e+003  6.250e+003   1.077e+004  4.663e-005   1.077e+004   0.102 resis
    1      1    B3   4   1  -2.437e-007  -2.437e-007  -1.153e+004  -6.250e+003  1.312e+004   1.077e+004 -4.663e-005   1.077e+004   0.215 resis
    1      1    B3   4   2   2.437e-007   2.437e-007   1.153e+004   6.250e+003  1.312e+004   1.077e+004  4.663e-005   1.077e+004   0.215
    1      1    B3   5   1  -2.437e-007  -2.437e-007  -2.306e+004  -6.250e+003  2.389e+004   1.077e+004 -4.663e-005   1.077e+004   0.391 resis
    1      1    B3   5   2   2.437e-007   2.437e-007   2.306e+004   6.250e+003  2.389e+004   1.077e+004  4.663e-005   1.077e+004   0.391
```

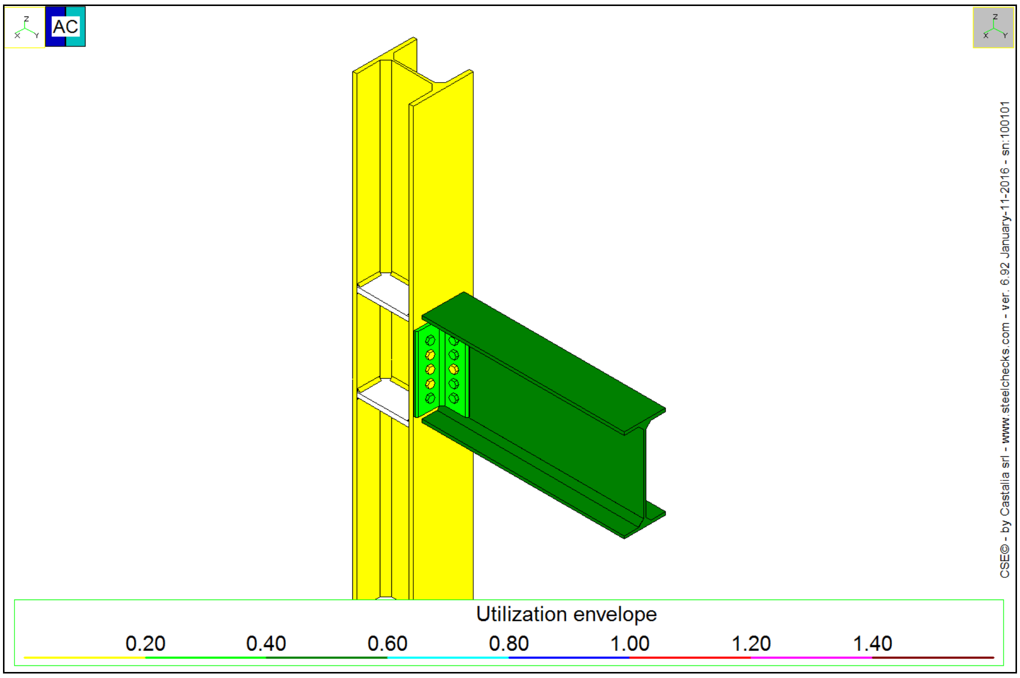


Figure B-120 Components utilization envelope

B.5.4 End plate (connection on column flange)

This example has some differences if compared with model seen in B.5.3: instead of double angle cleats, here an end plate is used.

Bolts position is the same, but now all the bolts of column flange belong to the same layout: there is no torque due to moment of transport, since there is no offset (see B.4.3). Model name is *Validation_BC_4.CSE*.

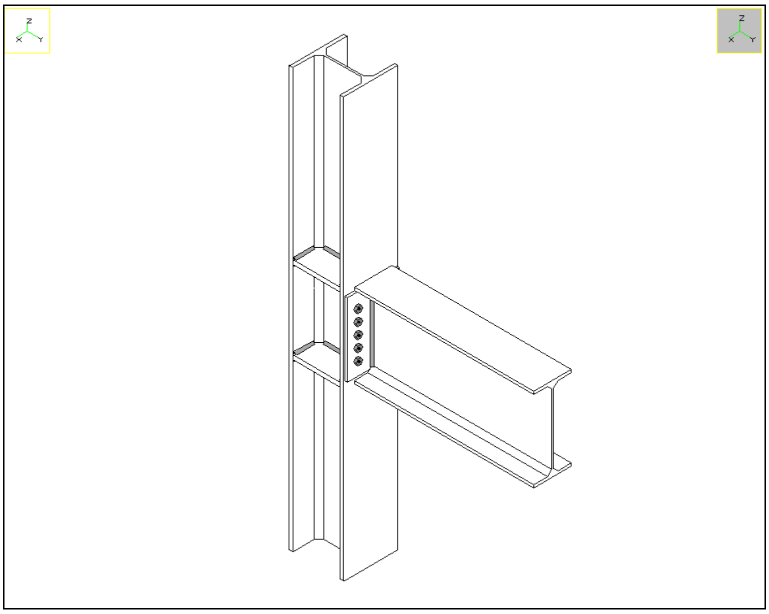


Figure B-121 3D view of the joint

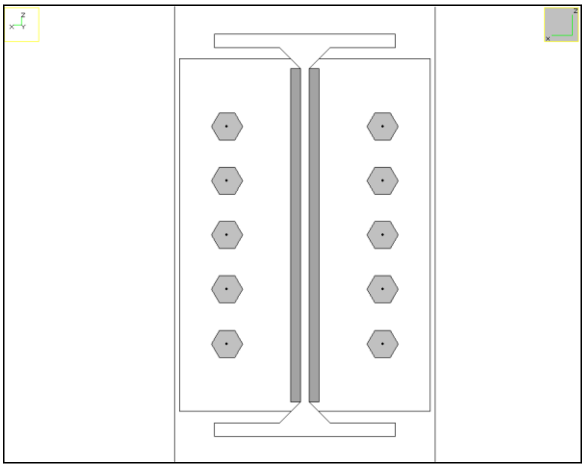


Figure B-122 Front view

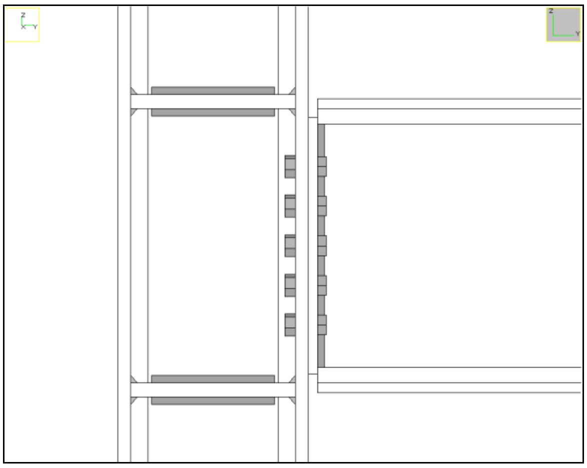


Figure B-123 Side view

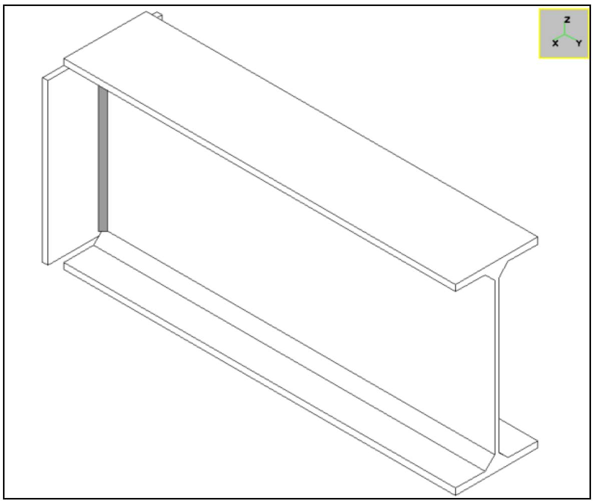


Figure B-124 Detail: end plate welded on beam

Model data: Material: S235

Column: HEB260

Beam: IPE 400

Plate 250x350x12mm

Stiffeners: thickness 20mm

Bolts: M16 class 8.8 (2 columns, 5 rows)

Fillet welds on beam web: length 331mm, throat section 7.071mm

As said, here there is no torque on bolt layout: shear on each bolt is equal to total shear divided by bolts number: 62500N/10=**6250N** (column T_B in following CSE abstract).

In addition, there are axial forces in bolts equal to those computed in previous paragraph, since offset along beam axis and applied force are the same (column N_{TB} in the abstract).

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	1.499e+004	1.499e+004	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.257	resis
1	1	B1	2	1	1.499e+004	1.499e+004	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.257	resis
1	1	B1	3	1	7.497e+003	7.497e+003	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.180	resis
1	1	B1	4	1	7.497e+003	7.497e+003	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.180	resis
1	1	B1	5	1	-4.072e-007	-4.072e-007	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.102	resis
1	1	B1	6	1	4.072e-007	4.072e-007	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.102	resis
1	1	B1	7	1	-7.497e+003	-7.497e+003	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.180	resis
1	1	B1	8	1	-7.497e+003	-7.497e+003	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.180	resis
1	1	B1	9	1	-1.499e+004	-1.499e+004	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.257	resis
1	1	B1	10	1	-1.499e+004	-1.499e+004	2.438e-007	-6.250e+003	6.250e+003	-2.811e+003	-1.063e-007	2.811e+003	0.257	resis

Now consider fillet weld layout. In addition to the applied shear, there bending moment due to the offset between weld layout and column axis. Distance is equal to half of HEB260 shape plus plate thickness.

$$d = 260\text{mm} / 2 + 12\text{mm} = 142\text{mm}$$

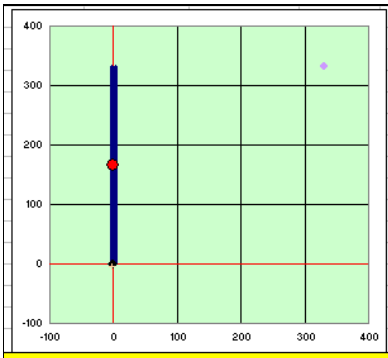
$$M = 62500\text{N} * 142\text{mm} = 8875000\text{Nmm}$$

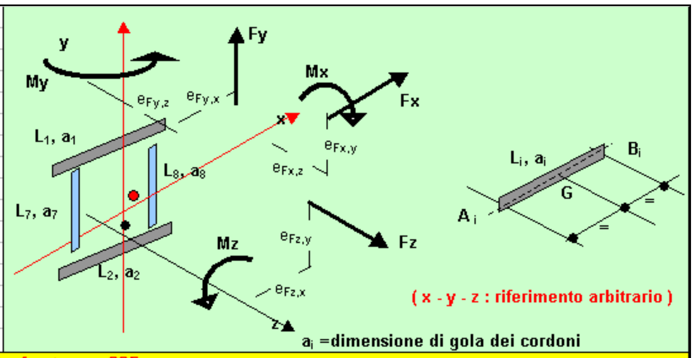
The same moment is computed by CSE (M_{uT}); T_{vT} is applied shear divided by bolts number.

Overall internal actions over Weld Layouts

Id	Inst	Combi	NT	TuT	TvT	MtT	MuT	MvT
W1	1	1	-0.0000e+000	-2.4375e-006	6.2500e+004	-0.0000e+000	8.8750e+006	3.4612e-004

To compute stress in fillet welds, we use *Saldature* application again (see A.3).





Confronto con CSE												
tutti i cordoni hanno eguale dimensione della gola pari a: mm				***7,1***	*il dato sostituisce tale valore*			riferite ad assi principali				
posizione cordoni	cordone w	a_i	L_i	$x_{A,i}$	$y_{A,i}$	$x_{G,i}$	$y_{G,i}$	A_i	$\xi_{A,i}$	$\xi_{B,i}$	$\eta_{A,i}$	$\eta_{B,i}$
		mm	mm	mm	mm	mm	mm	cm^2	mm	mm	mm	mm
cordoni paralleli ad asse x	1											
	2											
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		331,0	-3,4	0,0	-3,4	166	23,5	-3	-3	-166	166
	8		331,0	3,4	0,0	3,4	165,5	23,5	3	3	-166	166
	9											
	10											
	11											
(blu)	12											

Figure B-125 *Saldature* application: input data

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1		9.031,3			62.500,0							
2												
3												

Figure B-126 *Saldature* application: applied loads

condizione di carico 1			unità di misura degli sforzi:	N/mm2						
cordoni	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
7A	-34,37	0,0	0,0	-34,37	0,0	0,0	0,0	0,0	13,35	13,35
7B	34,37	0,0	0,0	34,37	0,0	0,0	0,0	0,0	13,35	13,35
8A	-34,37	0,0	0,0	-34,37	0,0	0,0	0,0	0,0	13,35	13,35
8B	34,37	0,0	0,0	34,37	0,0	0,0	0,0	0,0	13,35	13,35

Figure B-127 *Saldature* application: welds stresses results

CSE results are the same.

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Internal stresses in welds, exploitations
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```

Inst	Combi	Name	Weld	nPer	tPar	tPer	force	Cause	Ext	Expl
1	1	W1	1	-3.437e+001	1.335e+001	5.207e-010	2.607e+002	2	1	0.177
1	1	W1	2	3.437e+001	-1.335e+001	-5.207e-010	2.607e+002	2	1	0.177

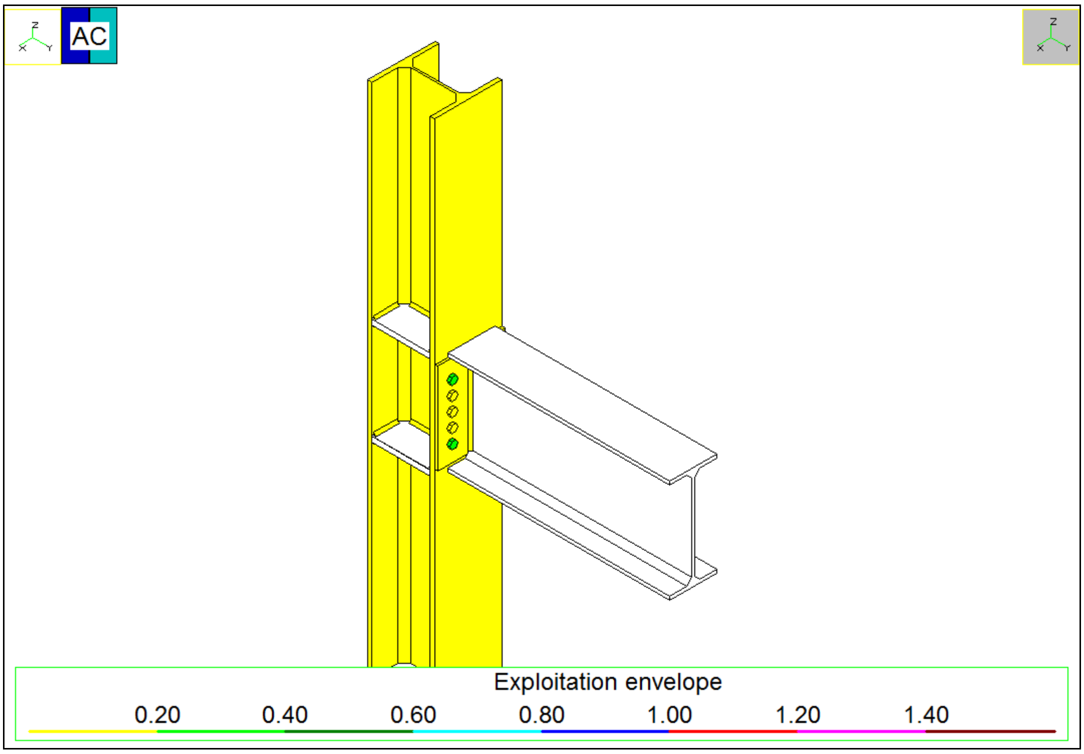

Figure B-128 Components utilization envelope

B.6 CONSTRAINTS

B.6.1 Column base

B.6.1.1 Introduction

Consider a column base joint. In order to validate also irregular bolt layout positions, apply a α=5.3° rotation to a four rows per 2 columns layout. Of course this is not a typical or common condition, but it is useful to validate CSE computations in “strange” situations.

Model is *Validation_CB_1.CSE*; material is S235 for member and base plate. Note well: anchor bolts pull-out check will be validated in part C, as well as bearing pressure check. Note well: bolts compression is not included in check settings, for this model: compression is computed, but not used for resistance checks.

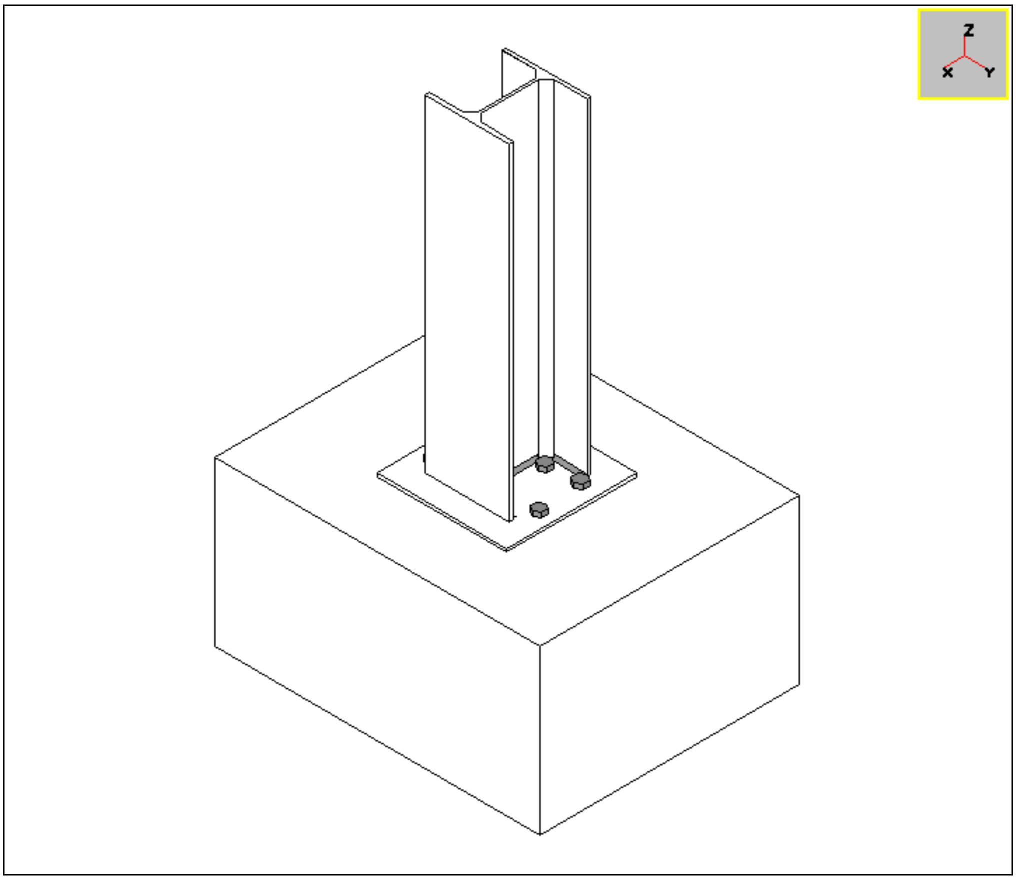

Figure B-129 3D view of the joint

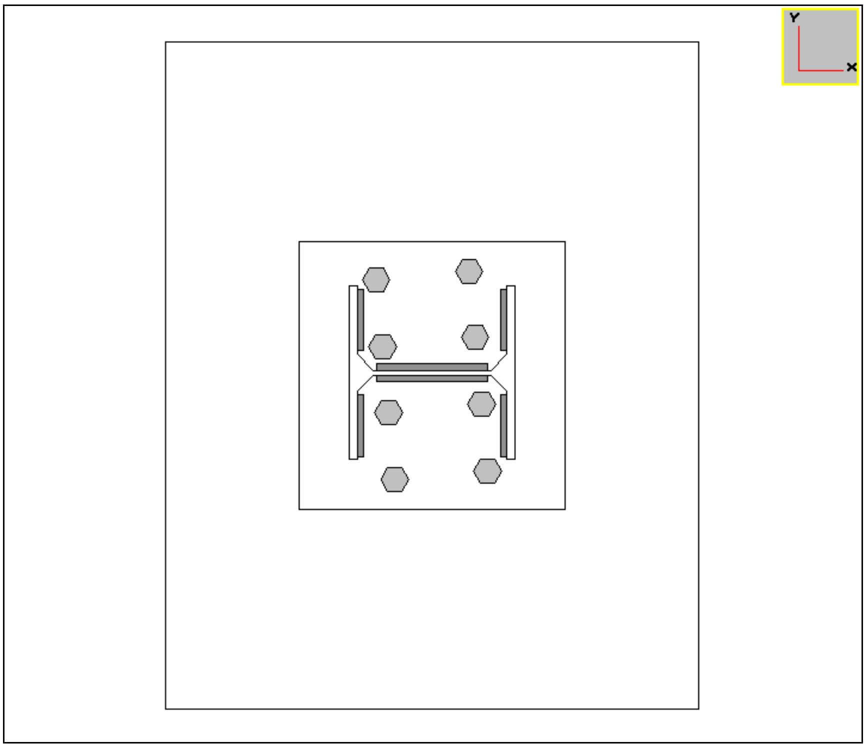

Figure B-130 Top view

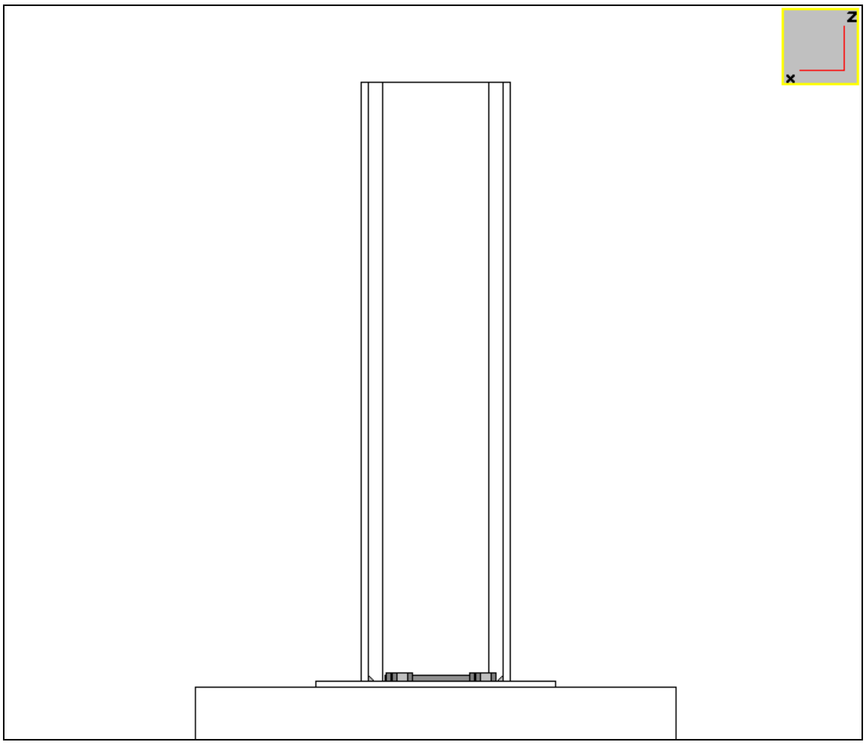

Figure B-131 Side view

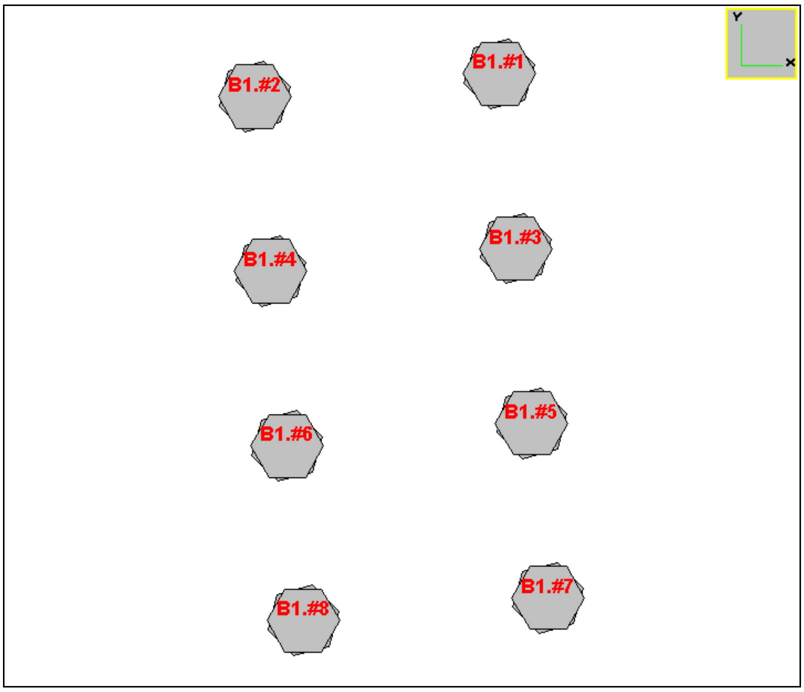

Figure B-132 Bolts numbering

B.6.1.2 Tension

This model was not imported from external FEM models: it was built directly in CSE. To define check combinations, plastic limits of joint member were used (this is one of the ways to define combinations in CSE). Using elastic limits, 24 combinations are defined for each member, including single forces (axial force, shears, torque, bending moments) and combinations between them (see program guide for more information). Amplification factors can be defined for each component. Here all limits have an amplification factor equal to 1.

First combination is tension. Plastic limit of the cross-section (HEA260, S235) is:

$$N^{+}_{pl,Rd}= A*f_y=8682\text{mm}^2 * 235\text{N/mm}^2=2.0403*10^6\text{N}$$

Next figures show bolt layout geometry.

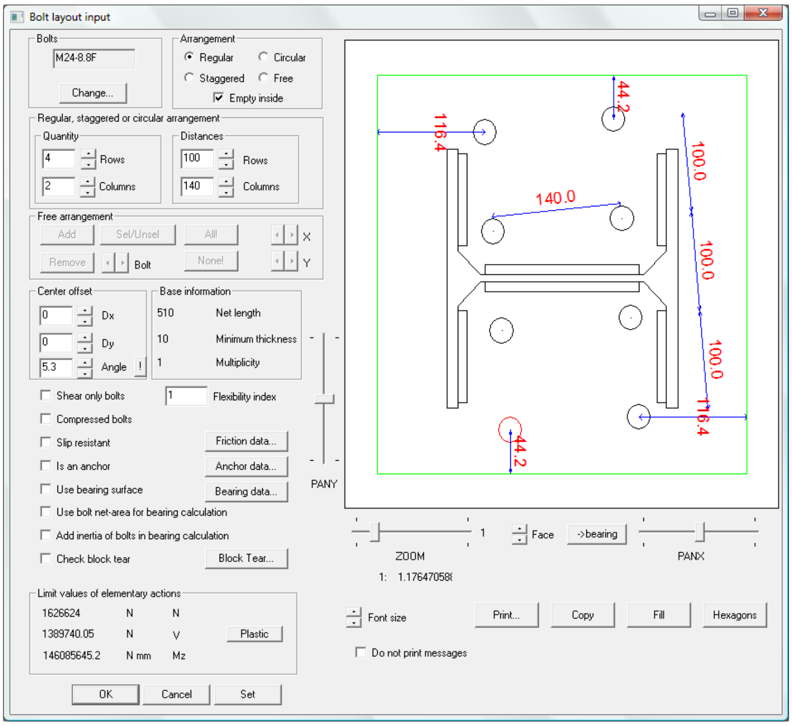

Figure B-133 Bolt layout geometry

Note well: in order to check and validate a more general condition, bolt layout and plate have been shifted along member flanges direction (see Figure B-134, where *u* and *v* are bolt layout principal axes).

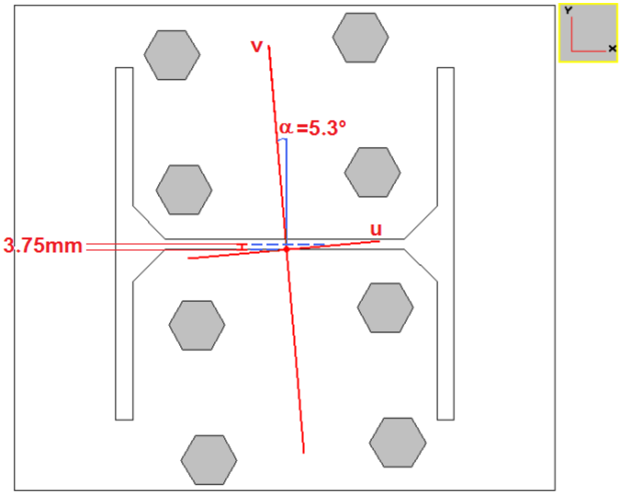

Figure B-134 Offset between bolt layout and member centres

In this way, tension applied along column axis produces two bending moments about bolt layout principal axes. Axial force (named simply N_{pl} from now on) produces these moments about u and v axes:

$$M'_u = N_{pl} * 3.75 * \cos\alpha = 7.618 * 10^6 \text{Nmm}$$

$$M'_v = N_{pl} * 3.75 * \sin\alpha = 7.066 * 10^5 \text{Nmm}$$

Where 3.75 is the offset in global reference system, and multiplying it bt cosα or sinα gives the components along bolt layout principal axes.

Inertia moments about principal axes, according to Figure B-135, are (moments per bolt area unit).

$$J_u = \Sigma(dv_i) = 4 * (50\text{mm})^2 + 4 * (150\text{mm})^2 = 1.000 * 10^5 \text{mm}^2$$

$$J_v = \Sigma(du_i) = 8 * (70\text{mm})^2 = 3.920 * 10^4 \text{mm}^2$$

Then we get:

$$M'_u / J_u = 7.618 * 10^6 \text{Nmm} / 1.000 * 10^5 \text{mm}^2 = 76.18 \text{N/mm}$$

$$M'_v / J_v = 7.066 * 10^5 \text{Nmm} / 3.920 * 10^4 \text{mm}^2 = 18.03 \text{N/mm}$$

On each bolt, resultant force is the sum of 3 components:

$$\frac{N_{pl}}{8}$$

$$\frac{M'_u}{J_u} \cdot v_i$$

$$\frac{M'_v}{J_v} \cdot u_i$$

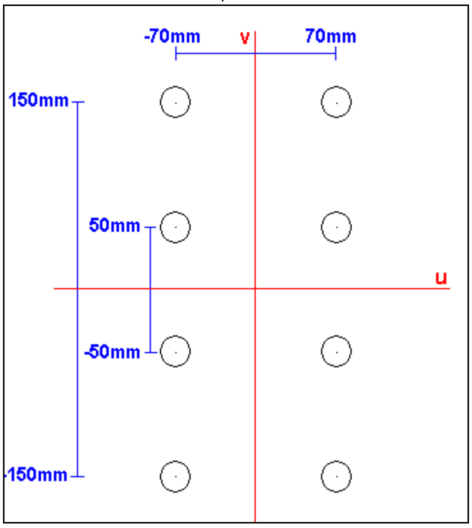

Figure B-135 Bolts distances in bolt layout principal axes ref. system

According to distances shown in previous figure, the following tables give the components of axial force in bolts due to bending moments, and the the total resultant force in each bolt (layout scheme is the same of Figure B-135 and Figure B-134):

(M'_u/J_u)*v_i [N]

1.143E+04	1.143E+04
3.809E+03	3.809E+03
-3.809E+03	-3.809E+03
-1.143E+04	-1.143E+04

(M'_v/J_v)*u_i [N]

-1.262E+03	1.262E+03
-1.262E+03	1.262E+03
-1.262E+03	1.262E+03
-1.262E+03	1.262E+03

Resultant forces are:

$$F_{tot,i} = \frac{N_{pl}}{8} + \frac{M'_u}{J_u} v_i + \frac{M'_v}{J_v} u_i \text{ [N]}$$

2.652E+05	2.677E+05
2.576E+05	2.601E+05
2.500E+05	2.525E+05
2.423E+05	2.449E+05

Now we compute bolts design resistance to tension, as seen in B.3.

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$$

with

k_2=0.9

f_{ub}=800

A_s=353

γ_{M2}=1.25

It is $F_{t,Rd}$=2.033e+05N; utilization factors are:

$F_{tot,i}/F_{t,Rd}$

1.304	○	○	1.317
1.267	○	○	1.279
1.229	○	○	1.242
1.192	○	○	1.204

Unless small roundings in hand computations, we got the same results of CSE:

```
--------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
--------------------------------------------------------------

Inst  Combi  Name Bolt -?-       NB          NTB          TuB          TvB          TB          MuB          MvB          MB        Expl  cause

    1     1    B1   1   1  2.677e+005  2.677e+005  8.034e-005  -1.349e-004  1.570e-004  -2.735e+003  6.443e+002  2.810e+003  1.316 resis !!!
    1     1    B1   2   1  2.652e+005  2.652e+005  8.034e-005  -1.316e-004  1.542e-004  -2.735e+003  6.443e+002  2.810e+003  1.304 resis !!!
    1     1    B1   3   1  2.601e+005  2.601e+005  7.796e-005  -1.349e-004  1.558e-004  -2.735e+003  6.443e+002  2.810e+003  1.279 resis ***
    1     1    B1   4   1  2.576e+005  2.576e+005  7.796e-005  -1.316e-004  1.530e-004  -2.735e+003  6.443e+002  2.810e+003  1.267 resis ***
    1     1    B1   5   1  2.525e+005  2.525e+005  7.559e-005  -1.349e-004  1.547e-004  -2.735e+003  6.443e+002  2.810e+003  1.242 resis ***
    1     1    B1   6   1  2.500e+005  2.500e+005  7.559e-005  -1.316e-004  1.518e-004  -2.735e+003  6.443e+002  2.810e+003  1.229 resis ***
    1     1    B1   7   1  2.449e+005  2.449e+005  7.321e-005  -1.349e-004  1.535e-004  -2.735e+003  6.443e+002  2.810e+003  1.204 resis ***
    1     1    B1   8   1  2.424e+005  2.424e+005  7.321e-005  -1.316e-004  1.506e-004  -2.735e+003  6.443e+002  2.810e+003  1.192 resis **
```

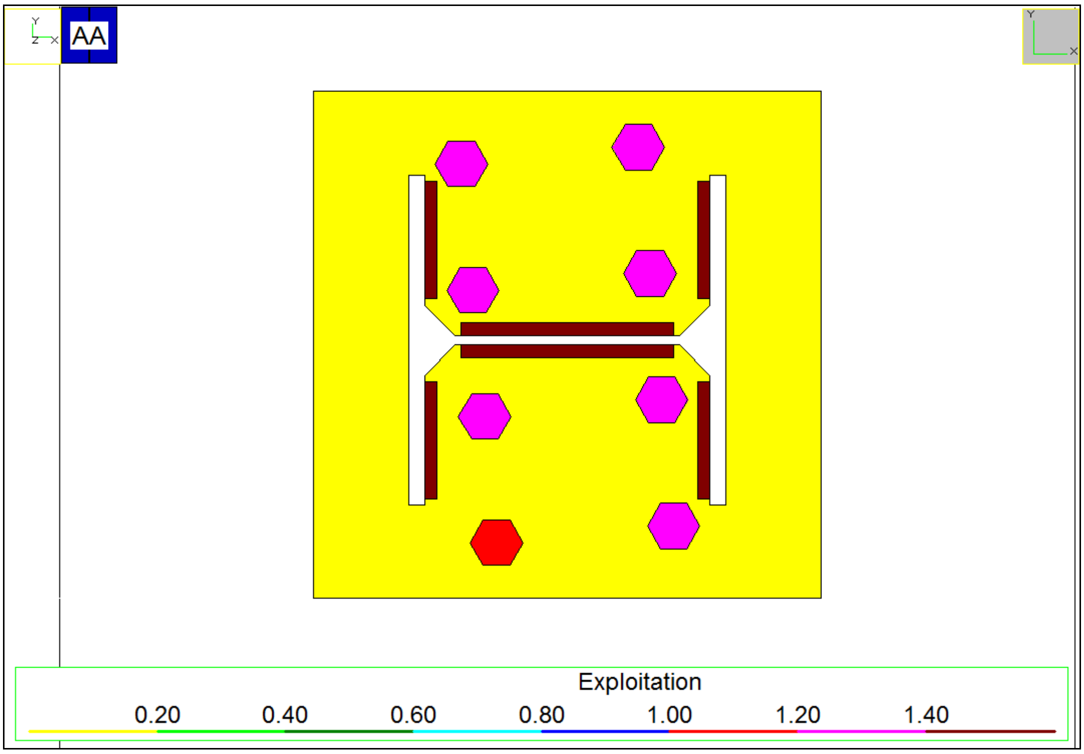

Figure B-136 Components utilization in combination 1 (tension)

Weld layout is not affected by bolt layout offset (weld layout centre lies on column axis, so the condition is similar to the one previously computed in B.3). In order to focus on bolt layout computation (which is rotated and has an offset), weld layout computation for tension and for the other forces (following paragraphs) are all reported in B.6.1.8.

B.6.1.3 Shear parallel to flanges

According to EN1993-1-1, plastic shear parallel to flanges is equal to:

$$V_{pl,f} = \frac{A_{V,f} \cdot f_y}{\sqrt{3}} = \frac{5806.25mm^2 \cdot 235N/mm^2}{\sqrt{3}} = 7.878 \cdot 10^5 N$$

with

$$A_{V,f} = 2bt_f - (t_w + 2r) \cdot t_f = 2 \cdot 260mm \cdot 12.5mm - (7.5mm + 2 \cdot 24mm) \cdot 12.5mm = 5806.25mm^2$$

Applied force lies on the line passing through bolt layout centre, since defined offset is in *y* direction (Figure B-137). For that reason, there is no moment of transport in bolt layout plane (torque), but there is a bending moment of transport causing axial force in bolts. This axial force will not be considered in our hand computations.

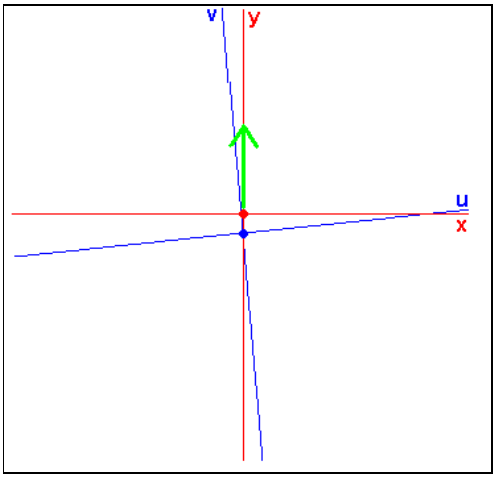

Figure B-137 x-y: cross-section ref. system; u-v: bolt layout ref. sys.

Shear components parallel to u and v are:

$$V_u = V\sin\alpha = 7.275 * 10^4 N$$

$$V_v = V\cos\alpha = 7.844 * 10^5 N$$

To get forces in each bolt, divide previous values by bolts number:

$$V_{u,bolt} = V_u/8 = 9.094 * 10^3 N$$

$$V_{v,bolt} = V_v/8 = 9.805 * 10^4 N$$

Resultant force is:

$$V_{bolt} = \sqrt{V_{u,bolt}^2 + V_{v,bolt}^2} = 9.847 \cdot 10^4 \, N$$

Now compute bolts design resistance to shear, according to formulae used in previous paragraphs and reported in appendix:

a_v	0.6
f_{ub}	800
A	452.4
γ_{M2}	1.25
$F_{v,Rd}$	1.737E+05
expl	**0.567**

As we can see in following abstract, CSE computes this value only for 4 bolts. The reason is that shear produces also bending (as explained previously) so bolts are also in tension or compression. Since, according to defined check settings, compression is not included in bolts check, CSE results for the four compressed bolts are the same of hand computation. On the other 4 bolts, tension must be also included in checks.

```
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Inst  Combi  Name Bolt -?-        NB          NTB          TuB          TvB         TB           MuB         MvB           MB      Expl  cause

   1      2    B1    1   1  -1.302e+004  -1.302e+004  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.567 resis
   1      2    B1    2   1  -1.044e+004  -1.044e+004  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.567 resis
   1      2    B1    3   1  -5.201e+003  -5.201e+003  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.567 resis
   1      2    B1    4   1  -2.621e+003  -2.621e+003  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.567 resis
   1      2    B1    5   1   2.621e+003   2.621e+003  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.576 resis
   1      2    B1    6   1   5.201e+003   5.201e+003  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.585 resis
   1      2    B1    7   1   1.044e+004   1.044e+004  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.604 resis
   1      2    B1    8   1   1.302e+004   1.302e+004  -9.096e+003  -9.805e+004  9.847e+004   2.816e+003 -6.634e+002   2.893e+003   0.613 resis
```

If we refine our hand computation of bolts utilization including also tension we have, for example considering last bolt:

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} = \frac{9.487 \cdot 10^4 N}{1.737 \cdot 10^5 N} + \frac{1.302 \cdot 10^4 N}{1.4 \cdot 2.033 \cdot 10^5 N} = 0.613$$

As computed by CSE.

Now consided bolt bearing on the plate according to Eurocode formulae (see previous paragraphs or appendix). All bolts transfer the same force, so it is the position in the layout to give different utilization values. We computed the utilization factor for one of the bolts closest to plate edges (see Figure B-138). Note well: as previously said, CSE gives as total utilization factor for bolt bearing the square root of the sum of the squares of utilizations in parallel and perpendicular direction.

F_u	9.094E+03N	F_v	9.805E+04N
$F_{b,Rd}$	9.792E+04N	$F_{b,Rd}$	9.792E+04N
k_1	2.5	k_1	2.5
α_b	0.567	α_b	0.567
f_u	360N/mm^2	f_u	360N/mm^2
d	24mm	d	24mm
t	10mm	t	10mm
d_0	26mm	d_0	26mm
e_1=e_2	44.2mm	e_1=e_2	44.2mm
p_1	140mm	p_1	100mm
p_2	100mm	p_2	140mm
$expl_u$	0.093	$expl_v$	1.001

To be on the safe side, *e1* and *e2* are assumed equal to minimum between *e1* and *e2*

$$\text{expl} = \sqrt{\text{expl}_u^2 + \text{expl}_v^2} = 1.006$$

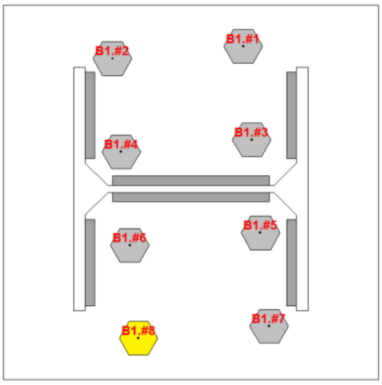

Figure B-138

Note well: see B.2.1.2.1 for a detailed step-by-step computation of design resistance forces and utilization factors.

CSE computes the same value:

```
-------------------------------------------------------------
Through whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

   Inst  Combi  Name   Boltlay   Bolt   Extr.     Sigma       Sigma M     Expl

     1     2     P1     B1        2       1    4.103e+002  4.078e+002   1.006 *
```

NOTE WELL: in EN1993-1-1 the studied cases are for rectangular plates; in general, a plate can have edges not parallel or perpendicular and plates can also have a different number of sides: CSE always divide forces in their components along bolt layout principal axes and uses minimum distance from the edges. This seems to be on the safe side.

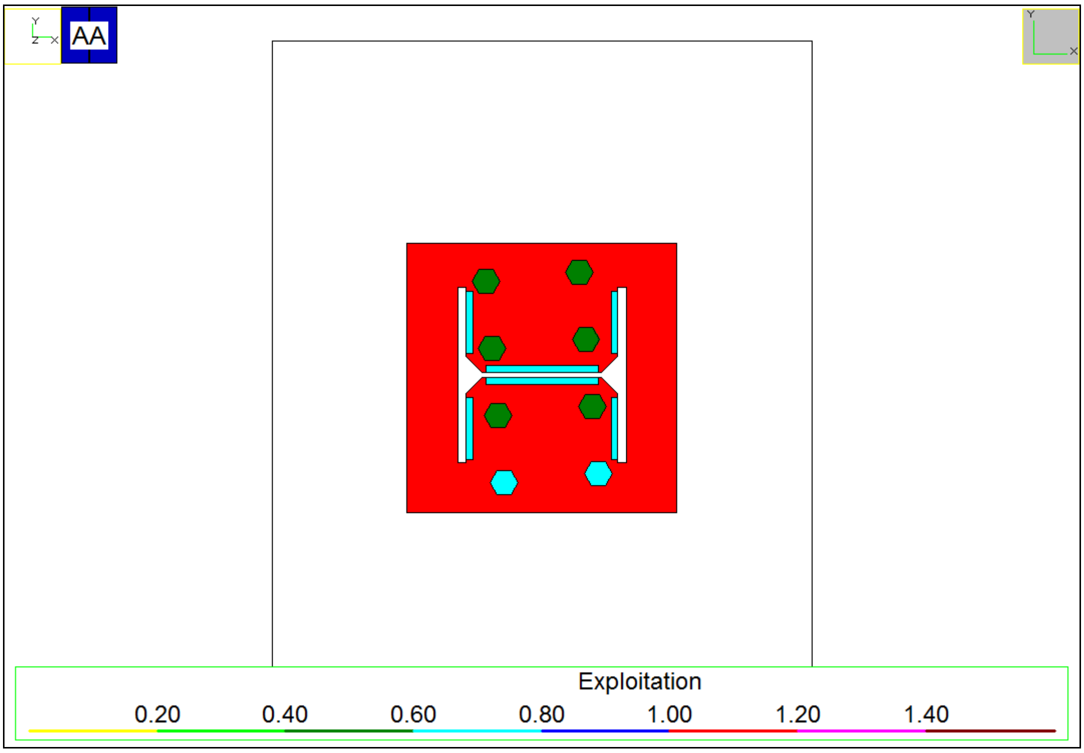

Figure B-139 Components utilization in combination 2 (shear parallel to web)

B.6.1.4 Shear parallel to the web

Applied shear is $V_{pl,3}=V=3.9017*10^5$N, oriented along column web. Shear components along bolt layout principal axes are:

$$V_u=V\cos\alpha=3.885*10^5\text{N}$$

$$V_v=V\sin\alpha=3.603*10^4\text{N}$$

Dividing them by bolts numbers, we get the forces on each bolt:

$$V_{u,b}= V_u/8=4.856*10^4\text{N}$$

$$V_{v,b}= V_v/8=4.504*10^3\text{N}$$

In addition, there are two further components (one in u and one in v direction) due to the moment of transport (torque) caused by the applied shear and the offset between its application point and bolt layout centre (d=3.75mm):

$$M'=V*d=1.4632*10^6\text{mm}$$

Force in u direction is equal to M' divided by bolt layout polar inertia (J_p=1.392*10^5N) and multiplied by bolt distance from layout centre, in *v* direction. According to each bolt distance (see Figure B-135), we have:

$(M'/J_p)*v_i$ [N]

1.577E+03	○	○	1.58E+03
5.256E+02	○	○	5.26E+02
-5.256E+02	○	○	-5.26E+02
-1.577E+03	○	○	-1.58E+03

Resultant force in *u* direction on each bolt is the composition of $V_{u,b}$ (the same for all bolts) and previously computed $(M'/J_p)*v_i$ value.

F_u [N]

5.014E+04	○	○	5.014E+04
4.909E+04	○	○	4.909E+04
4.804E+04	○	○	4.804E+04
4.699E+04	○	○	4.699E+04

We make the same computations for *v* direction:

$(M'/J_p)*u_i$ [N]

-7.36E+02	○	○	7.36E+02
-7.36E+02	○	○	7.36E+02
-7.36E+02	○	○	7.36E+02
-7.36E+02	○	○	7.36E+02

F_v [N]

3.768E+03	○	○	5.240E+03
3.768E+03	○	○	5.240E+03

3.768E+03	5.240E+03
3.768E+03	5.240E+03

And finally we get total resultant force:

$$F_{tot} = \sqrt{(F_u^2 + F_v^2)} \text{ [N]}$$

5.028E+04	5.041E+04
4.923E+04	4.937E+04
4.819E+04	4.832E+04
4.714E+04	4.728E+04

CSE computes the same values ($F_u = T_{uB}$, $F_v = T_{vB}$, $F_{tot} = T_B$).

```
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Internal actions in bolts at different planes, exploitations
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Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	3	B1	1	1	6.348e+003	6.348e+003	5.014e+004	-5.241e+003	5.041e+004	1.294e+002	3.542e+003	3.544e+003	0.313	resis
1	3	B1	2	1	-7.426e+003	-7.426e+003	5.014e+004	-3.769e+003	5.028e+004	1.294e+002	3.542e+003	3.544e+003	0.289	resis
1	3	B1	3	1	6.707e+003	6.707e+003	4.909e+004	-5.241e+003	4.937e+004	1.294e+002	3.542e+003	3.544e+003	0.308	resis
1	3	B1	4	1	-7.067e+003	-7.067e+003	4.909e+004	-3.769e+003	4.923e+004	1.294e+002	3.542e+003	3.544e+003	0.283	resis
1	3	B1	5	1	7.067e+003	7.067e+003	4.804e+004	-5.241e+003	4.832e+004	1.294e+002	3.542e+003	3.544e+003	0.303	resis
1	3	B1	6	1	-6.707e+003	-6.707e+003	4.804e+004	-3.769e+003	4.819e+004	1.294e+002	3.542e+003	3.544e+003	0.277	resis
1	3	B1	7	1	7.426e+003	7.426e+003	4.699e+004	-5.241e+003	4.728e+004	1.294e+002	3.542e+003	3.544e+003	0.298	resis
1	3	B1	8	1	-6.348e+003	-6.348e+003	4.699e+004	-3.769e+003	4.714e+004	1.294e+002	3.542e+003	3.544e+003	0.271	resis

CSE also computes the axial force in the bolts due to bending moment of transport on the layout, as seen in previous paragraph.

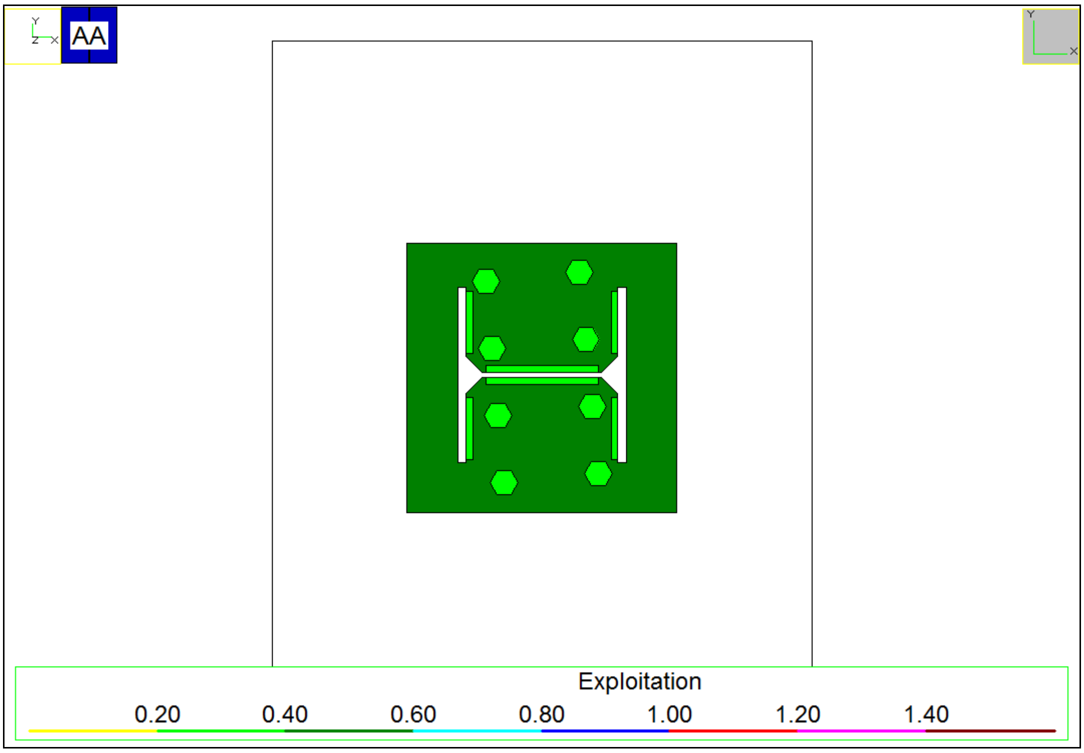

Figure B-140 Components utilization in combination 3 (shear parallel to the web)

B.6.1.5 Torque

Applied torque is M_t=8.527*10^6Nmm. The same torque is applied to bolt layout; shear forces on bolts are computed according to what was done in previous paragraphs (computations are not explained in detail again here; see previous computations).

$$F_u=(M_t/J_p)*v_i \text{ [N]}$$

9.188E+03	9.188E+03
3.063E+03	3.063E+03
-3.063E+03	-3.063E+03
-9.188E+03	-9.188E+03

$$F_v=(M_t/J_p)*u_i \text{ [N]}$$

-4.288E+03	4.288E+03
-4.288E+03	4.288E+03
-4.288E+03	4.288E+03

-4.288E+03	4.288E+03

$$F_{tot} = \sqrt{(F_u^2 + F_v^2)}\ [N]$$

1.014E+04	○	○	1.014E+04
5.269E+03	○	○	5.269E+03
5.269E+03	○	○	5.269E+03
1.014E+04	○	○	1.014E+04

Utilization factor

0.058	○	○	0.058
0.030	○	○	0.030
0.030	○	○	0.030
0.058	○	○	0.058

CSE computes the same values:

```
----------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
----------------------------------------------------------------
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Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	4	B1	1	1	5.878e-005	5.878e-005	9.188e+003	-4.288e+003	1.014e+004	1.198e-006	3.279e-005	3.282e-005	0.058	resis
1	4	B1	2	1	-6.876e-005	-6.876e-005	9.188e+003	4.288e+003	1.014e+004	1.198e-006	3.279e-005	3.282e-005	0.058	resis
1	4	B1	3	1	6.210e-005	6.210e-005	3.063e+003	-4.288e+003	5.269e+003	1.198e-006	3.279e-005	3.282e-005	0.030	resis
1	4	B1	4	1	-6.543e-005	-6.543e-005	3.063e+003	4.288e+003	5.269e+003	1.198e-006	3.279e-005	3.282e-005	0.030	resis
1	4	B1	5	1	6.543e-005	6.543e-005	-3.063e+003	-4.288e+003	5.269e+003	1.198e-006	3.279e-005	3.282e-005	0.030	resis
1	4	B1	6	1	-6.210e-005	-6.210e-005	-3.063e+003	4.288e+003	5.269e+003	1.198e-006	3.279e-005	3.282e-005	0.030	resis
1	4	B1	7	1	6.876e-005	6.876e-005	-9.188e+003	-4.288e+003	1.014e+004	1.198e-006	3.279e-005	3.282e-005	0.058	resis
1	4	B1	8	1	-5.878e-005	-5.878e-005	-9.188e+003	4.288e+003	1.014e+004	1.198e-006	3.279e-005	3.282e-005	0.058	resis

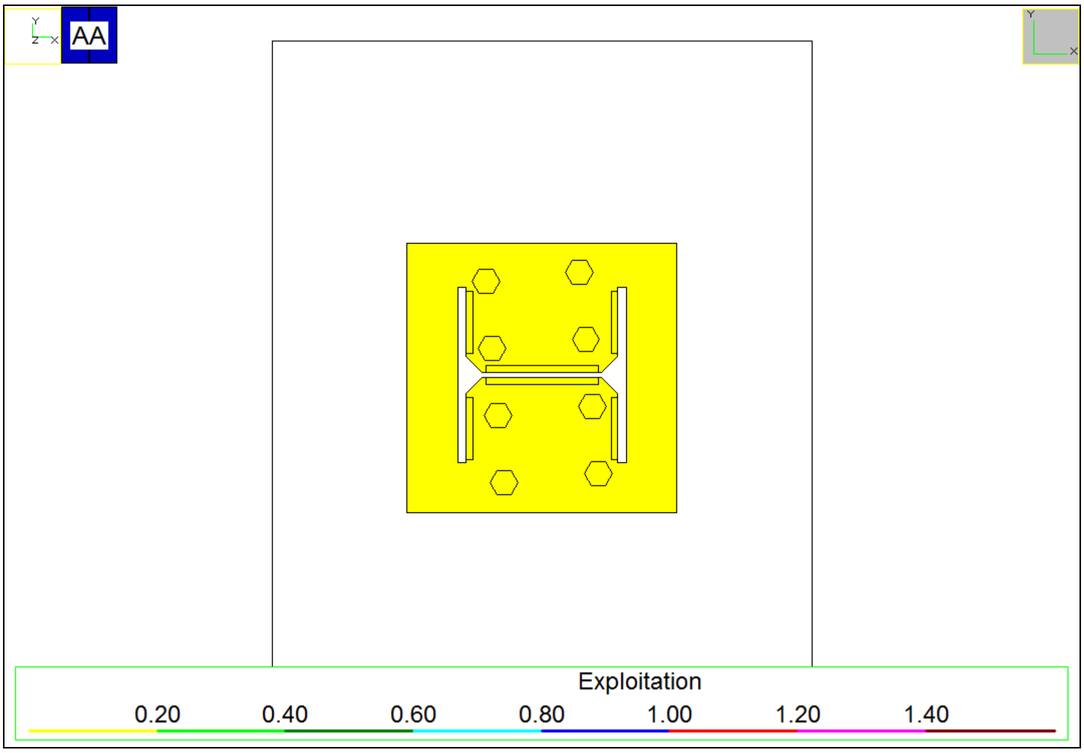

Figure B-141 Components utilization in combination 4 (torque)

B.6.1.6 Bending moment about strong axis

Plastic bending moment of the cross-section about strong axis is equal to $2.161*10^8$Nmm. It is decomposed in M_u=$-1.997*10^7$Nmm and M_v=$-2.152*10^8$Nmm. Now we are going to compute forces in each bolt, as done in B.6.1.2.

$$F_u=(M_u/J_u)*v_i \text{ [N]}$$

2.995E+04	2.995E+04
9.983E+03	9.983E+03
-9.983E+03	-9.983E+03
-2.995E+04	-2.995E+04

$$F_v=(M_v/J_v)*u_i \text{ [N]}$$

3.843E+05	-3.843E+05
3.843E+05	-3.843E+05
3.843E+05	-3.843E+05

3.843E+05	-3.843E+05

Resultant force in each bolt is (note well F_u and F_v are both axial forces; F_u is due to M_u bending moment, F_v to M_v bending moment):

$F_{tot}=F_u+F_v$ [N]

4.143E+05	-3.544E+05
3.943E+05	-3.743E+05
3.743E+05	-3.943E+05
3.544E+05	-4.143E+05

When axial force is a compression, it is not included in bolt resistance check, according to out check settings: it is assumed that compression s carried by an area around the bolt, involving the plate and the concrete block. For this reason, utilization factor of compressed bolts is null. See part C for bearing surface check.

As shown in following abstract, CSE computes lower values for the forces.

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Inst  Combi  Name Bolt -?-        NB          NTB          TuB          TvB          TB          MuB         MvB          MB      Expl  cause

    1     5    B1    1   1  -3.517e+005  -3.517e+005  -4.531e-002   5.361e-003  4.562e-002  -7.167e+003 -1.962e+005   1.963e+005   0.000 resis
    1     5    B1    2   1   4.114e+005   4.114e+005  -4.531e-002   3.714e-003  4.546e-002  -7.167e+003 -1.962e+005   1.963e+005   2.023 resis !!!
    1     5    B1    3   1  -3.716e+005  -3.716e+005  -4.413e-002   5.361e-003  4.446e-002  -7.167e+003 -1.962e+005   1.963e+005   0.000 resis
    1     5    B1    4   1   3.915e+005   3.915e+005  -4.413e-002   3.714e-003  4.429e-002  -7.167e+003 -1.962e+005   1.963e+005   1.925 resis !!!
    1     5    B1    5   1  -3.915e+005  -3.915e+005  -4.296e-002   5.361e-003  4.329e-002  -7.167e+003 -1.962e+005   1.963e+005   0.000 resis
    1     5    B1    6   1   3.716e+005   3.716e+005  -4.296e-002   3.714e-003  4.312e-002  -7.167e+003 -1.962e+005   1.963e+005   1.827 resis !!!
    1     5    B1    7   1  -4.114e+005  -4.114e+005  -4.178e-002   5.361e-003  4.212e-002  -7.167e+003 -1.962e+005   1.963e+005   0.000 resis
    1     5    B1    8   1   3.517e+005   3.517e+005  -4.178e-002   3.714e-003  4.195e-002  -7.167e+003 -1.962e+005   1.963e+005   1.730 resis !!!
```

The difference is due to a lack in hand computations, which did not consider bending in bolts shafts. We are going to refine hand computation. We previously assumed that a distribution of forces neglecting bolts own inertia in J_u and J_v inertia moments computation. Inertia moment of the 8 bolts is $J_b=\pi*r^4/4/A_b=288mm^2$ (inertia per area unit).

So we have:

$$J_{u,tot}=J_u+J_b=100288mm^2$$

$$J_{v,tot}=J_v+J_b=39488mm^2$$

Let's compute F_u e F_v with these values:

$F_u=(M_u/J_{u,tot})*v_i$ **[N]**

2.986E+04	2.986E+04
9.954E+03	9.954E+03
-9.954E+03	-9.954E+03
-2.986E+04	-2.986E+04

$F_v=(M_v/J_{v,tot})*u_i$ **[N]**

3.815E+05	-3.815E+05
3.815E+05	-3.815E+05
3.815E+05	-3.815E+05
3.815E+05	-3.815E+05

Resultant forces are:

$F_{tot}=F_u+F_v$ **[N]**

4.114E+05	-3.517E+05
3.915E+05	-3.716E+05
3.716E+05	-3.915E+05
3.517E+05	-4.114E+05

These forces are the same computed by CSE. Considering equal to zero the utilization factors for compressed bolts (according to check settings) we can compute utilization factors for bolts in tension, dividing previous resultant forces by bolts design resi stance (previously computed).

Utilization factors $F_{tot}/F_{t,Rd}$

2.023	○	○	0
1.925	○	○	0
1.827	○	○	0
1.729	○	○	0

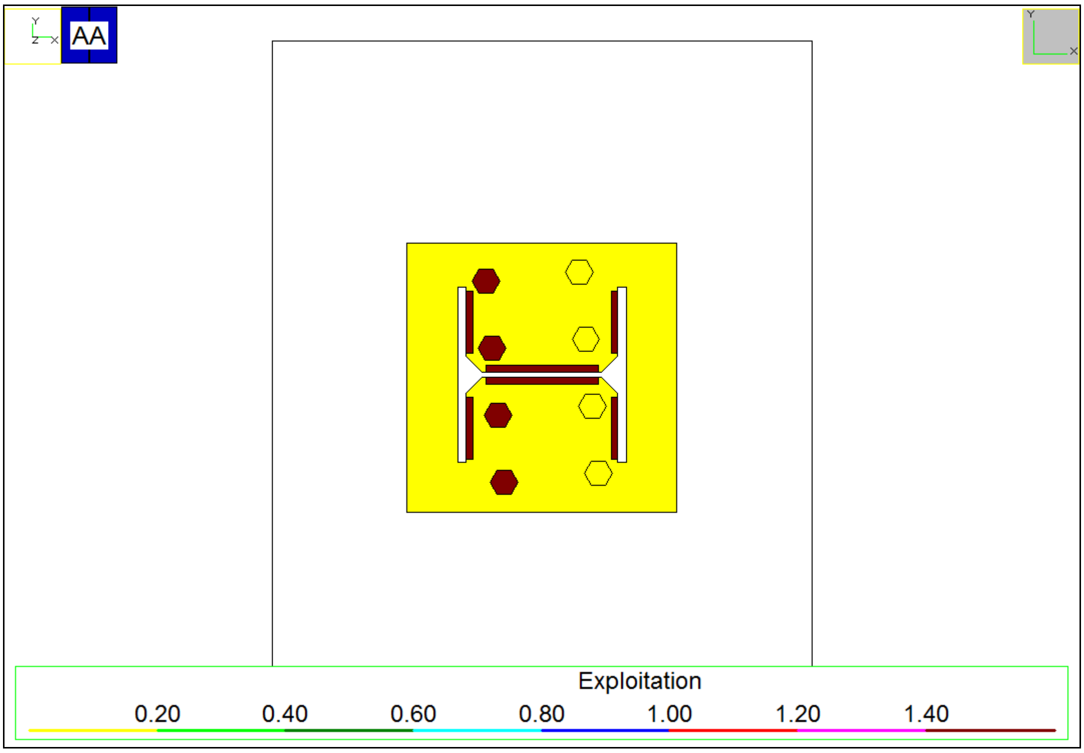

Figure B-142 Components utilization in combination 5 (bending about strong axis)

B.6.1.7 Bending about weak axis

Consider finally the bending moment about weak axis. Plastic moment is $1.011*10^8$Nmm, decomposed M_u=$1.007*10^8$Nmm and M_v=$-9.338*10^6$Nmm.

We make the same computations of previous paragraph, without explaining them in detail, but using current bending moment about weak axis.

$$F_u=(M_u/J_u)*v_i \text{ [N]}$$

-1.510E+05	○	○	-1.510E+05
-5.033E+04	○	○	-5.033E+04
5.033E+04	○	○	5.033E+04

1.510E+05	1.510E+05

$F_v=(M_v/J_v)*u_i$ [N]

1.667E+04	-1.667E+04
1.667E+04	-1.667E+04
1.667E+04	-1.667E+04
1.667E+04	-1.667E+04

Resultant force is:

$F_{tot}=\sqrt{(F_u^2+F_v^2)}$ [N]

-1.343E+05	-1.677E+05
-3.366E+04	-6.700E+04
6.700E+04	3.366E+04
1.677E+05	1.343E+05

Utilization factors

0	0
0	0
0.330	0.166
0.825	0.661

As in previous paragraph, if hand computation is made considering J_u and J_v (without bolts own inertia) there are some differences with CSE computation: bolts own inertia moment should be considered to refine hand computations (see previous paragraph).

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Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	6	B1	1	1	-1.671e+005	-1.671e+005	-9.918e-004	2.534e-003	2.721e-003	3.613e+004	-8.513e+003	3.712e+004	0.000	resis
1	6	B1	2	1	-1.340e+005	-1.340e+005	-9.918e-004	2.490e-003	2.680e-003	3.613e+004	-8.513e+003	3.712e+004	0.000	resis
1	6	B1	3	1	-6.674e+004	-6.674e+004	-9.604e-004	2.534e-003	2.710e-003	3.613e+004	-8.513e+003	3.712e+004	0.000	resis
1	6	B1	4	1	-3.363e+004	-3.363e+004	-9.604e-004	2.490e-003	2.669e-003	3.613e+004	-8.513e+003	3.712e+004	0.000	resis
1	6	B1	5	1	3.363e+004	3.363e+004	-9.290e-004	2.534e-003	2.699e-003	3.613e+004	-8.513e+003	3.712e+004	0.165	resis
1	6	B1	6	1	6.674e+004	6.674e+004	-9.290e-004	2.490e-003	2.658e-003	3.613e+004	-8.513e+003	3.712e+004	0.328	resis
1	6	B1	7	1	1.340e+005	1.340e+005	-8.977e-004	2.534e-003	2.688e-003	3.613e+004	-8.513e+003	3.712e+004	0.659	resis
1	6	B1	8	1	1.671e+005	1.671e+005	-8.977e-004	2.490e-003	2.647e-003	3.613e+004	-8.513e+003	3.712e+004	0.822	resis

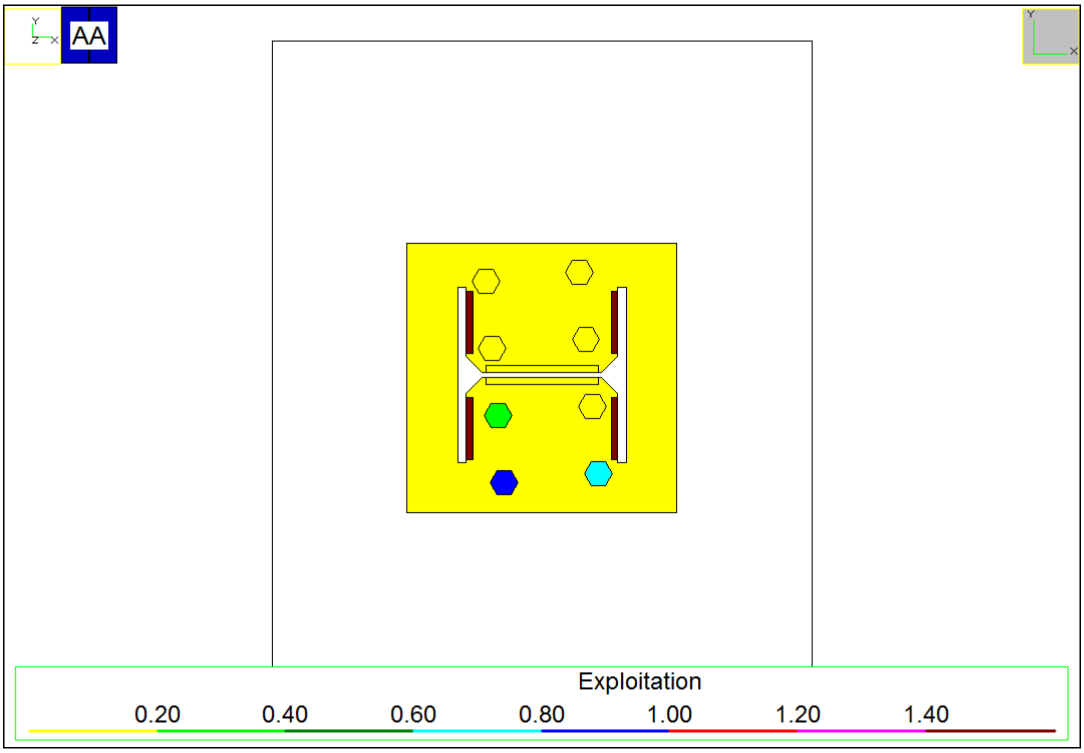
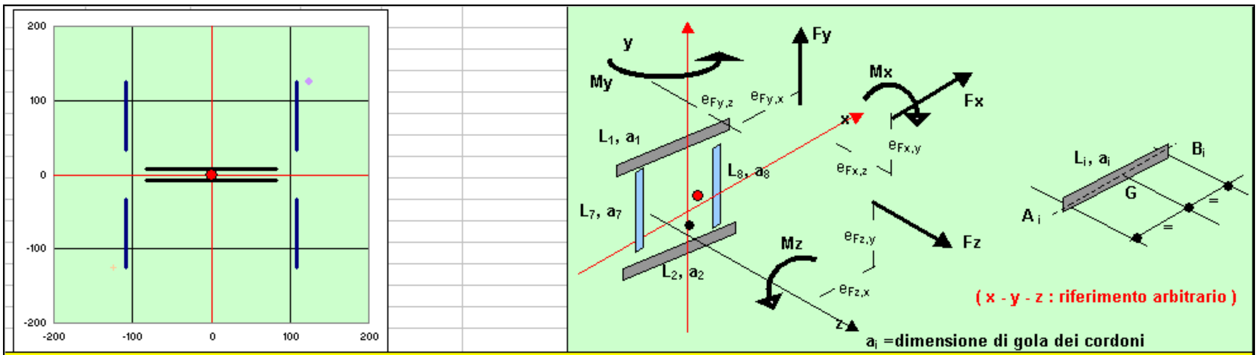


Figure B-143 Components utilization in combination 6 (bending about weak axis)

B.6.1.8 Validation of welds stresses computation

Cross-check is made using *Saldature* application again (see A.3). Following image shows the input data used.



Confronto con CSE												
tutti i cordoni hanno eguale dimensione della gola pari a: mm					7,071	il dato sostituisce tale valore			riferite ad assi principali			
posizione cordoni	cordone w	a_i mm	L_i mm	$x_{A,i}$ mm	$y_{A,i}$ mm	$x_{G,i}$ mm	$y_{G,i}$ mm	A_i cm^2	$\xi_{A,i}$ mm	$\xi_{B,i}$ mm	$\eta_{A,i}$ mm	$\eta_{B,i}$ mm
cordoni paralleli ad asse x	1		167,0	-83,5	7,3	0,0	7,3	11,8	-83,5	83,5	7,3	7,3
	2		167,0	-83,5	-7,3	0,0	-7,3	11,8	-83,5	83,5	-7,3	-7,3
	3											
	4											
	5											
(neri)	6											
cordoni paralleli ad asse y	7		92,3	-109,0	-125,0	-109,0	-79	6,5	-109	-109	-125	-33
	8		92,3	-109,0	32,8	-109,0	78,9	6,5	-109	-109	33	125
	9		92,3	109,0	-125,0	109,0	-78,9	6,5	109	109	-125	-33
	10		92,3	109,0	32,8	109,0	78,9	6,5	109	109	33	125
	11											
(blu)	12											
caratteristiche della sezione		A	x_G	y_G	I_{Gxx}	I_{Gyy}	I_{Gxy}	α		$I_{G\xi\xi}$	$I_{G\eta\eta}$	
		cm^2	mm	mm	cm^4	cm^4	cm^4	radianti	gradi	cm^4	cm^4	
		49,7	0	0	1.821	3.647	0	0,0000	0	1.821	3.647	

Figure B-144 *Saldature* application: input data

The following is welds numbering in CSE model, needed to compare results.

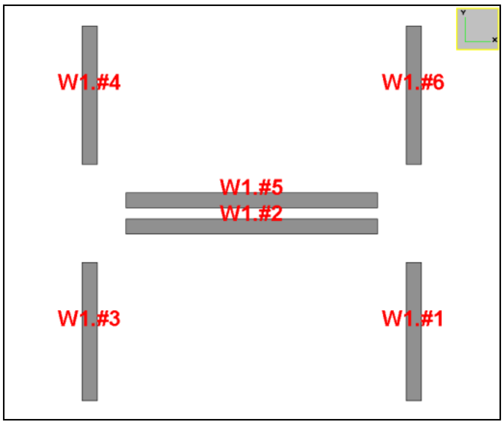


Figure B-145

B.6.1.8.1 Tension

Next image shows the loads applied to weld layout in *Saldature* application.

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1									2.040.300,0			
2												
3												

Figure B-146 *Saldature* application: applied loads

Following image shows the stresses computed for each fillet weld by Saldature application. Sforzi nei cordoni in *Saldature*. For each weld, stress value in both extremes is given (A, B). To compare with CSE results, consider maximum value.

condizione di carico 1		unità di misura degli sforzi:		N/mm2						
cordoni	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
1B	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
2A	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
2B	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
						F_x			F_y	
7A	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
7B	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
8A	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
8B	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
9A	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
9B	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
10A	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0
10B	0,0	0,0	410,4	410,4	0,0	0,0	0,0	0,0	0,0	0,0

Figure B-147 *Saldature* application: stresses in welds

Stresses in CSE are the same:

```
------------------------------------------
Internal stresses in welds, exploitations
------------------------------------------

Inst  Combi  Name Weld      nPer         tPar          tPer         force       Cause  Ext    Expl

    1      1     W1    1  4.104e+002 -4.049e-008  -1.777e-007   2.902e+003      3      1    1.975 !!!
    1      1     W1    2  4.104e+002 -1.777e-007   4.049e-008   2.902e+003      3      2    1.975 !!!
    1      1     W1    3  4.104e+002  4.049e-008   1.777e-007   2.902e+003      3      2    1.975 !!!
    1      1     W1    4  4.104e+002  4.049e-008   1.777e-007   2.902e+003      3      2    1.975 !!!
    1      1     W1    5  4.104e+002  1.777e-007  -4.049e-008   2.902e+003      3      1    1.975 !!!
    1      1     W1    6  4.104e+002 -4.049e-008  -1.777e-007   2.902e+003      3      1    1.975 !!!
```

B.6.1.8.2 Shear parallel to flanges

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica										
carico	asse x				asse y				asse z		
	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1					787.800,0							
2												
3												

Figure B-148 *Saldature* application: applied loads

condizione di carico 1	unità di misura degli sforzi:				N/mm2					
cordoni w	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	0,0	0,0	0,0	0,0	158,5	158,5	0,0	0,0	0,0
1B	0,0	0,0	0,0	0,0	0,0	158,5	158,5	0,0	0,0	0,0
2A	0,0	0,0	0,0	0,0	0,0	158,5	158,5	0,0	0,0	0,0
2B	0,0	0,0	0,0	0,0	0,0	158,5	158,5	0,0	0,0	0,0
						F_x			F_y	
7A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
7B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
8A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
8B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
9A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
9B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
10A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5
10B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	158,5	158,5

Figure B-149 *Saldature* application: stresses in welds

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-------------------------------------------
Internal stresses in welds, exploitations
-------------------------------------------

Inst  Combi  Name Weld      nPer         tPar         tPer        force       Cause  Ext   Expl

    1      2    W1   1   3.512e-005 -1.585e+002   2.779e-007   1.121e+003      3     2   0.762
    1      2    W1   2   2.050e-006  2.779e-007   1.585e+002   1.121e+003      3     1   0.762
    1      2    W1   3   3.513e-005  1.585e+002  -2.779e-007   1.121e+003      3     1   0.762
    1      2    W1   4  -3.512e-005  1.585e+002  -2.779e-007   1.121e+003      3     2   0.762
    1      2    W1   5  -2.050e-006 -2.779e-007  -1.585e+002   1.121e+003      3     1   0.762
    1      2    W1   6  -3.513e-005 -1.585e+002   2.779e-007   1.121e+003      3     1   0.762
```

B.6.1.8.3 Shear parallel to web

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1	390.170,0											
2												
3												

Figure B-150 *Saldature* application: applied loads

condizione di carico 1	unità di misura degli sforzi:			N/mm2					
cordoni	n_L dovuto a:			t_L dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	78,49	78,49
1B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	78,49	78,49
2A	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	78,49	78,49
2B	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	78,49	78,49
						F_x			F_y	
7A	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
7B	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
8A	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
8B	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
9A	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
9B	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
10A	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0
10B	0,0	0,0	0,0	0,0	0,0	78,49	78,49	0,0	0,0	0,0

Figure B-151 *Saldature* application: stresses in welds

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------------------------------------------
Internal stresses in welds, exploitations
------------------------------------------

Inst  Combi  Name Weld      nPer        tPar         tPer         force       Cause  Ext   Expl

    1      3    W1   1   1.934e-006 -2.953e-009  -7.849e+001   5.550e+002      3     2   0.378
    1      3    W1   2  -1.502e-006 -7.849e+001   2.975e-009   5.550e+002      3     1   0.378
    1      3    W1   3  -1.981e-006  2.978e-009   7.849e+001   5.550e+002      3     1   0.378
    1      3    W1   4  -1.951e-006  2.978e-009   7.849e+001   5.550e+002      3     1   0.378
    1      3    W1   5   1.502e-006  7.849e+001  -2.956e-009   5.550e+002      3     1   0.378
    1      3    W1   6   1.964e-006 -2.953e-009  -7.849e+001   5.550e+002      3     2   0.378
```

B.6.1.8.4 Torque

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1										8.526,5		
2												
3												

Figure B-152 *Saldature* application: applied loads

condizione di carico 1	unità di misura degli sforzi:				N/mm2					
cordoni	n_L dovuto a:				t_L dovuto a:			t_W dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	0,0	0,0	0,0	-13,02	0,0	-13,02	-1,136	0,0	-1,136
1B	0,0	0,0	0,0	0,0	13,02	0,0	13,02	-1,136	0,0	-1,136
2A	0,0	0,0	0,0	0,0	-13,02	0,0	-13,02	1,136	0,0	1,136
2B	0,0	0,0	0,0	0,0	13,02	0,0	13,02	1,136	0,0	1,136
						F_x			F_y	
7A	0,0	0,0	0,0	0,0	19,49	0,0	19,49	-16,99	0,0	-16,99
7B	0,0	0,0	0,0	0,0	5,107	0,0	5,107	-16,99	0,0	-16,99
8A	0,0	0,0	0,0	0,0	-5,107	0,0	-5,107	-16,99	0,0	-16,99
8B	0,0	0,0	0,0	0,0	-19,49	0,0	-19,49	-16,99	0,0	-16,99
9A	0,0	0,0	0,0	0,0	19,49	0,0	19,49	16,99	0,0	16,99
9B	0,0	0,0	0,0	0,0	5,107	0,0	5,107	16,99	0,0	16,99
10A	0,0	0,0	0,0	0,0	-5,107	0,0	-5,107	16,99	0,0	16,99
10B	0,0	0,0	0,0	0,0	-19,49	0,0	-19,49	16,99	0,0	16,99

Figure B-153 *Saldature* application: stresses in welds

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Internal stresses in welds, exploitations
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Inst  Combi  Name Weld     nPer         tPar         tPer         force       Cause   Ext    Expl

   1      4    W1    1   8.163e-009  -1.699e+001   1.949e+001   1.829e+002      3     2   0.124
   1      4    W1    2  -6.255e-009   1.136e+000  -1.302e+001   9.242e+001      3     1   0.063
   1      4    W1    3  -8.163e-009  -1.699e+001  -1.949e+001   1.829e+002      3     1   0.124
   1      4    W1    4  -8.163e-009  -1.699e+001   1.949e+001   1.829e+002      3     2   0.124
   1      4    W1    5   6.255e-009   1.136e+000  -1.302e+001   9.242e+001      3     1   0.063
   1      4    W1    6   8.163e-009  -1.699e+001  -1.949e+001   1.829e+002      3     1   0.124
```

B.6.1.8.5 Bending moment about strong axis

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1						216.146,0						
2												
3												

Figure B-154 *Saldature* application: applied loads

condizione di carico 1		unità di misura degli sforzi:		N/mm2						
cordoni w	n_L dovuto a:				t_L dovuto a:			$t_{//}$ dovuto a:		
	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	0,0	494,9	0,0	494,9	0,0	0,0	0,0	0,0	0,0	0,0
1B	0,0	-494,9	0,0	-494,9	0,0	0,0	0,0	0,0	0,0	0,0
2A	0,0	494,9	0,0	494,9	0,0	0,0	0,0	0,0	0,0	0,0
2B	0,0	-494,9	0,0	-494,9	0,0	0,0	0,0	0,0	0,0	0,0
						F_x			F_y	
7A	0,0	645,8	0,0	645,8	0,0	0,0	0,0	0,0	0,0	0,0
7B	0,0	645,8	0,0	645,8	0,0	0,0	0,0	0,0	0,0	0,0
8A	0,0	645,8	0,0	645,8	0,0	0,0	0,0	0,0	0,0	0,0
8B	0,0	645,8	0,0	645,8	0,0	0,0	0,0	0,0	0,0	0,0
9A	0,0	-645,8	0,0	-645,8	0,0	0,0	0,0	0,0	0,0	0,0
9B	0,0	-645,8	0,0	-645,8	0,0	0,0	0,0	0,0	0,0	0,0
10A	0,0	-645,8	0,0	-645,8	0,0	0,0	0,0	0,0	0,0	0,0
10B	0,0	-645,8	0,0	-645,8	0,0	0,0	0,0	0,0	0,0	0,0

Figure B-155 *Saldature* application: stresses in welds

```
-------------------------------------------
Internal stresses in welds, exploitations
-------------------------------------------

Inst  Combi  Name Weld      nPer         tPar         tPer         force      Cause  Ext    Expl

    1      5    W1   1  -6.458e+002  1.598e-007  8.804e-005  4.567e+003     3     1   3.107 !!!
    1      5    W1   2   4.949e+002  8.804e-005 -1.598e-007  3.499e+003     3     1   2.381 !!!
    1      5    W1   3   6.458e+002 -1.598e-007 -8.804e-005  4.567e+003     3     1   3.107 !!!
    1      5    W1   4   6.458e+002 -1.598e-007 -8.804e-005  4.567e+003     3     1   3.107 !!!
    1      5    W1   5  -4.949e+002 -8.804e-005  1.598e-007  3.499e+003     3     1   2.381 !!!
    1      5    W1   6  -6.458e+002  1.598e-007  8.804e-005  4.567e+003     3     1   3.107 !!!
```

B.6.1.8.6 Bending moment about weak axis

	le componenti di sollecitazione sono riferite al sistema x - y - z prescelto per la descrizione geometrica											
	asse x				asse y				asse z			
carico	F_x	M_x	e_y	e_z	F_y	M_y	e_x	e_z	F_z	M_z	e_x	e_y
	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm	[N]	[N m]	mm	mm
1		101.090,0										
2												
3												

Figure B-156 *Saldature* application: applied loads

condizione di carico 1	unità di misura degli sforzi:				N/mm2					
cordoni	n_L dovuto a:				$t_\perp$ dovuto a:			$t_{//}$ dovuto a:		
w	M_ξ	M_η	F_z	tot	M_z	F_y	tot	M_z	F_x	tot
1A	40,45	0,0	0,0	40,45	0,0	0,0	0,0	0,0	0,0	0,0
1B	40,45	0,0	0,0	40,45	0,0	0,0	0,0	0,0	0,0	0,0
2A	-40,45	0,0	0,0	-40,45	0,0	0,0	0,0	0,0	0,0	0,0
2B	-40,45	0,0	0,0	-40,45	0,0	0,0	0,0	0,0	0,0	0,0
						F_x			F_y	
7A	-694,0	0,0	0,0	-694,0	0,0	0,0	0,0	0,0	0,0	0,0
7B	-181,8	0,0	0,0	-181,8	0,0	0,0	0,0	0,0	0,0	0,0
8A	181,8	0,0	0,0	181,8	0,0	0,0	0,0	0,0	0,0	0,0
8B	694,0	0,0	0,0	694,0	0,0	0,0	0,0	0,0	0,0	0,0
9A	-694,0	0,0	0,0	-694,0	0,0	0,0	0,0	0,0	0,0	0,0
9B	-181,8	0,0	0,0	-181,8	0,0	0,0	0,0	0,0	0,0	0,0
10A	181,8	0,0	0,0	181,8	0,0	0,0	0,0	0,0	0,0	0,0
10B	694,0	0,0	0,0	694,0	0,0	0,0	0,0	0,0	0,0	0,0

Figure B-157 *Saldature* application: stresses in welds

```
-------------------------------------------
Internal stresses in welds, exploitations
-------------------------------------------

Inst  Combi  Name Weld     nPer        tPar         tPer        force      Cause  Ext   Expl

   1      6    W1    1  6.940e+002  1.749e-006  2.348e-006  4.907e+003     3     2   3.339 !!!
   1      6    W1    2  4.045e+001  2.348e-006 -1.749e-006  2.860e+002     3     1   0.195
   1      6    W1    3  6.940e+002 -1.749e-006 -2.348e-006  4.907e+003     3     1   3.339 !!!
   1      6    W1    4 -6.940e+002 -1.749e-006 -2.348e-006  4.907e+003     3     2   3.339 !!!
   1      6    W1    5 -4.045e+001 -2.348e-006  1.749e-006  2.860e+002     3     1   0.195
   1      6    W1    6 -6.940e+002  1.749e-006  2.348e-006  4.907e+003     3     1   3.339 !!!
```

C. COMPONENTS CHECKS AND FLEXIBILITY INDEX

C.1 PULL-OUT CHECK FOR BOLTS OF ANCHOR BOLT LAYOUTS

To check CSE computation for bolts pull-out, consider a column base, with HEB 260 cross-section (model *Validation_Anchor_1.CSE*).

The joint is under bending about column strong axis; at the base, moment is equal to $1.2*10^8$Nmm; in addition, at the base there is a shear parallel to column web equal to $4*10^4$N; this shear is equally distributed in the 12 bolts (M30, class 8.8).

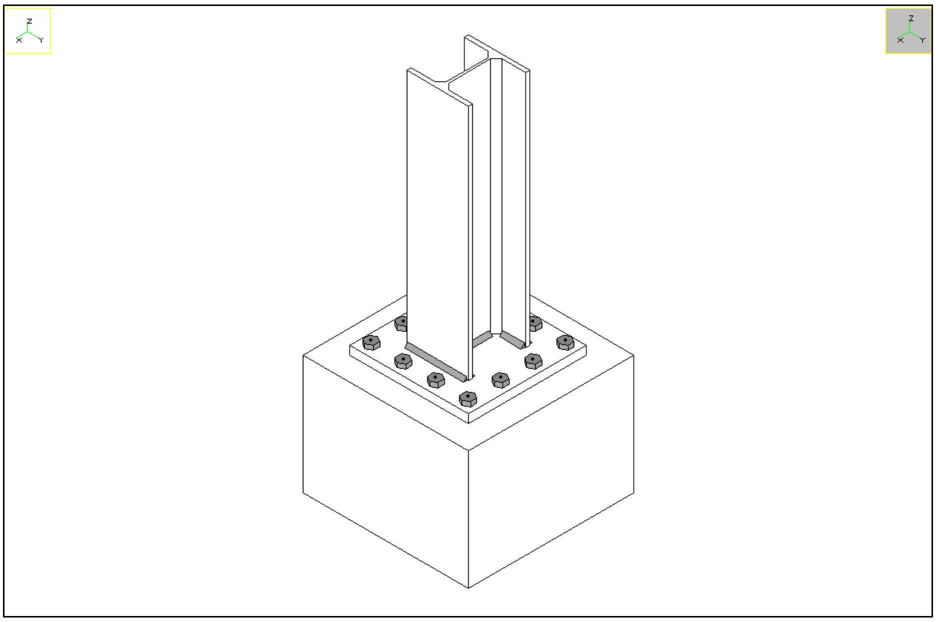


Figure C-1 3D view of the joint

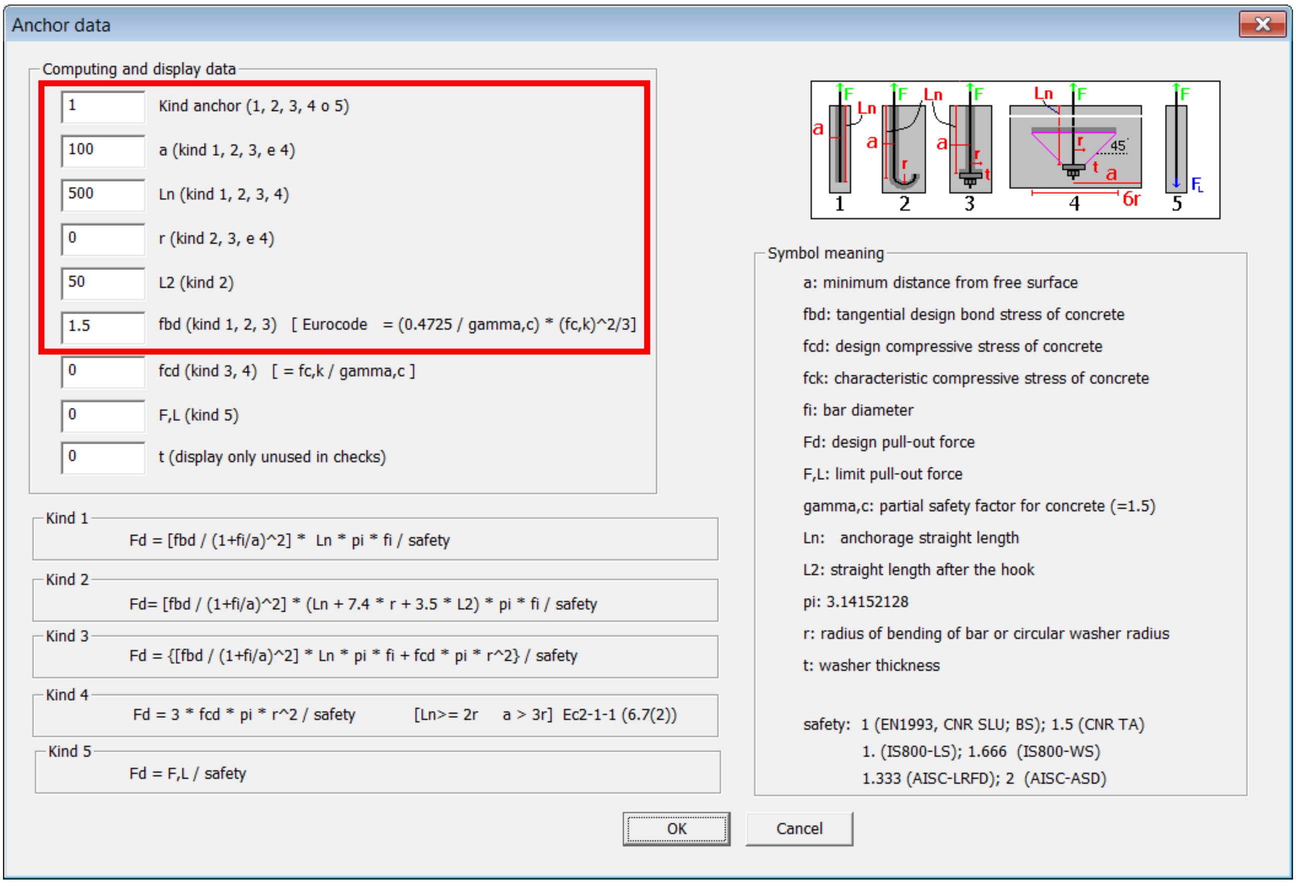


Figure C-2 Anchor bolts data

As we can see in the deformed view of following figure, there are some bolts in tension and an area in compression between base plate and constraint block. In this model, bolts do not react to compression and bearing surface check is not investigated.

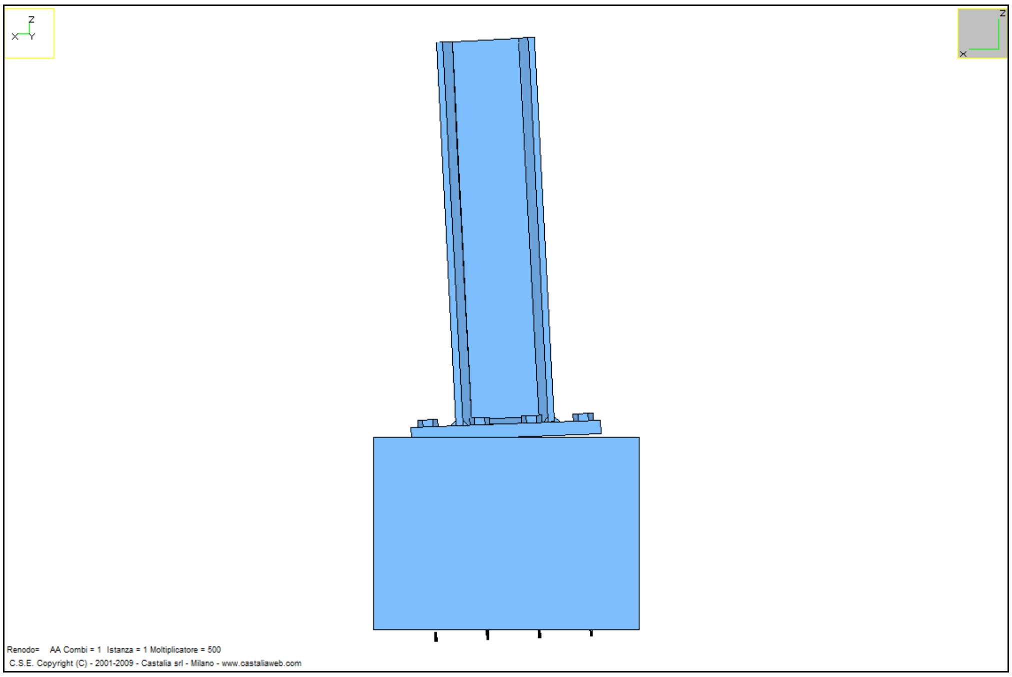


Figure C-3 Amplified deformed view (side view)

Forces distribution in bolts has been investigated in part B of this document. Considering forces computed in each bolt by CSE, we can now compute the utilization value for bolts pull-out check, to compare it with CSE result. Consider the bolt with the highest tension force (bolt number 1, see *NTB* column in following abstract). The utilization factor is the ration between axial force in bolt and limit force. If limit force is exceeded, there is a pull-out.

Internal actions in bolts at different planes, utilization ratios

Inst	Combi	Name	Bolt	-?-	NB (N)	NTB (N)	TuB (N)	TvB (N)	TB (N)	MuB (N mm)	MvB (N mm)	MB (N mm)	Expl	cause	
1	1	B1	1	1	69825.6	69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	1.669	pullo	!!!
1	1	B1	2	1	23275.2	23275.2	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.556	pullo	
1	1	B1	3	1	-23275.2	-23275.2	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.012	resis	
1	1	B1	4	1	-69825.6	-69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.012	resis	
1	1	B1	5	1	69825.6	69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	1.669	pullo	!!!
1	1	B1	6	1	-69825.6	-69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.012	resis	
1	1	B1	7	1	69825.6	69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	1.669	pullo	!!!
1	1	B1	8	1	-69825.6	-69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.012	resis	
1	1	B1	9	1	69825.6	69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	1.669	pullo	!!!
1	1	B1	10	1	23275.2	23275.2	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.556	pullo	
1	1	B1	11	1	-23275.2	-23275.2	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.012	resis	
1	1	B1	12	1	-69825.6	-69825.6	3333.3	0.0	3333.3	0.0	19112.8	19112.8	0.012	resis	

Pull-out force F_d for anchor bolts is equal to:

$$F_d = \frac{L_{eq} \cdot \tau \cdot \pi \cdot \phi}{safety} \frac{1}{\left(1 + \frac{\phi}{a}\right)^2}$$

where L_{eq} is the equivalent length of the bars, τ is tangential bond stress, ϕ is bar diameter, $a$is the distance from the free surface, and *safety* is a safety factor which is equal to 1 according to EN1993-1-8.

$$F_d = \frac{500mm \cdot 1{,}5N/mm^2 \cdot \pi \cdot 30mm}{1} \frac{1}{(1+0{,}3)^2} = 41825.9N$$

Utilization factor is the same computed by CSE:

$$\frac{NTB_{max}}{F_d} = \frac{69830N}{41825.9N} = 1.669$$

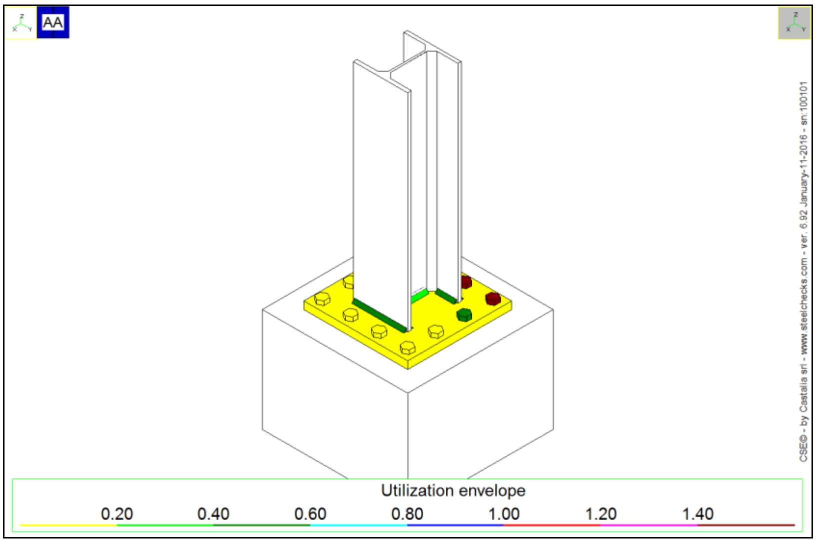


Figure C-4 Components utilization envelope

C.2 AUTOMATIC FEM MODEL CHECK

The model used here (*Validation_FEM_1.AA.P1.WSR*) is similar to the one of previous paragraph. In addition, now we include the automatic FEM model creation and analysis of the base plate (Figure C-6).

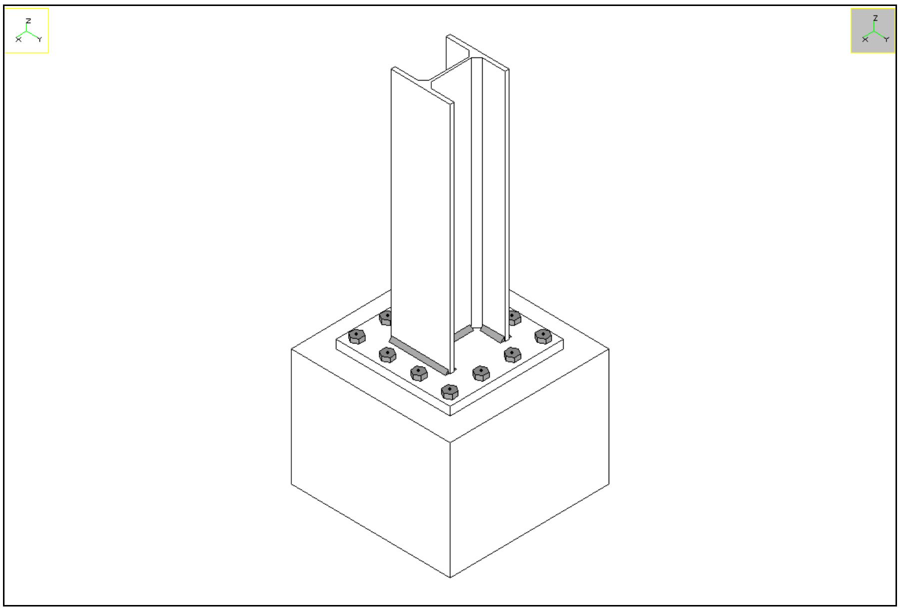


Figure C-5 3D view of the model

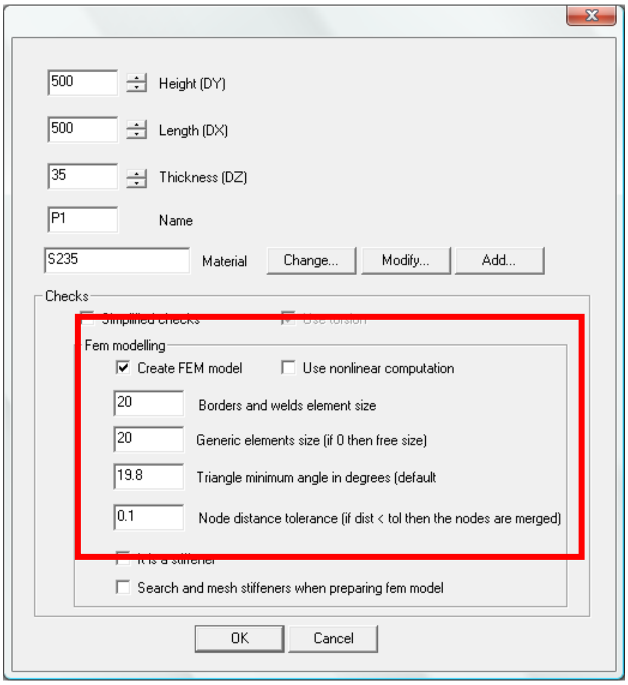


Figure C-6 Settings for automatic FEM model creation

Model settings:

- Plate-shell elements size on edges and weld lines: 20mm
- Maximum plate-shell elements size: 20mm
- Elements minimum angle: 19.8°

- Node tolerance: 0.1mm (if the distance between two nodes is smaller than 0.1, nodes are merged)

The automatically created model has the same properties (geometry and material) of the 3D component in CSE. It has a number of load cases equal to check combinations multiplied by jnode instances. Here we have only one combination and one instance, so the Fem model has just one load case.

As shown in Figure C-7, each load case has nodal forces in correspondence of the bolts and the welds which transfer forces to the plate. In addition, small nodal forces model the compression on bearing surface (see Figure C-8, where plate shell elements are hidden and forces length is the same, not scaled according to forces value).

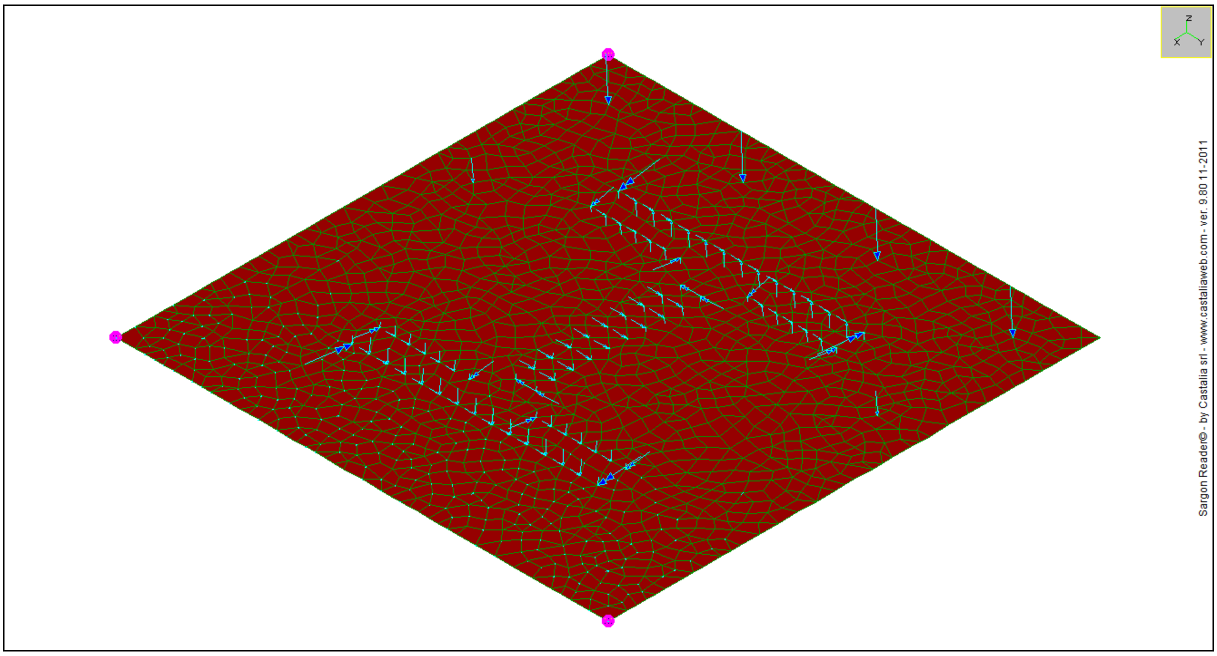


Figure C-7 Base plate FEM model automatically created by CSE

Nodal constraints are needed to solve the static problem, but since the model is self-balanced these constraints have quite null forces (the more mesh size is small, the more constraint forces are small). As expected, nodal forces resultant is shown in Figure C-9: it is quite null (0.02N) if compared to applied forces (bending moment is $1.2*10^8$Nmm, shear $4*10^4$N).

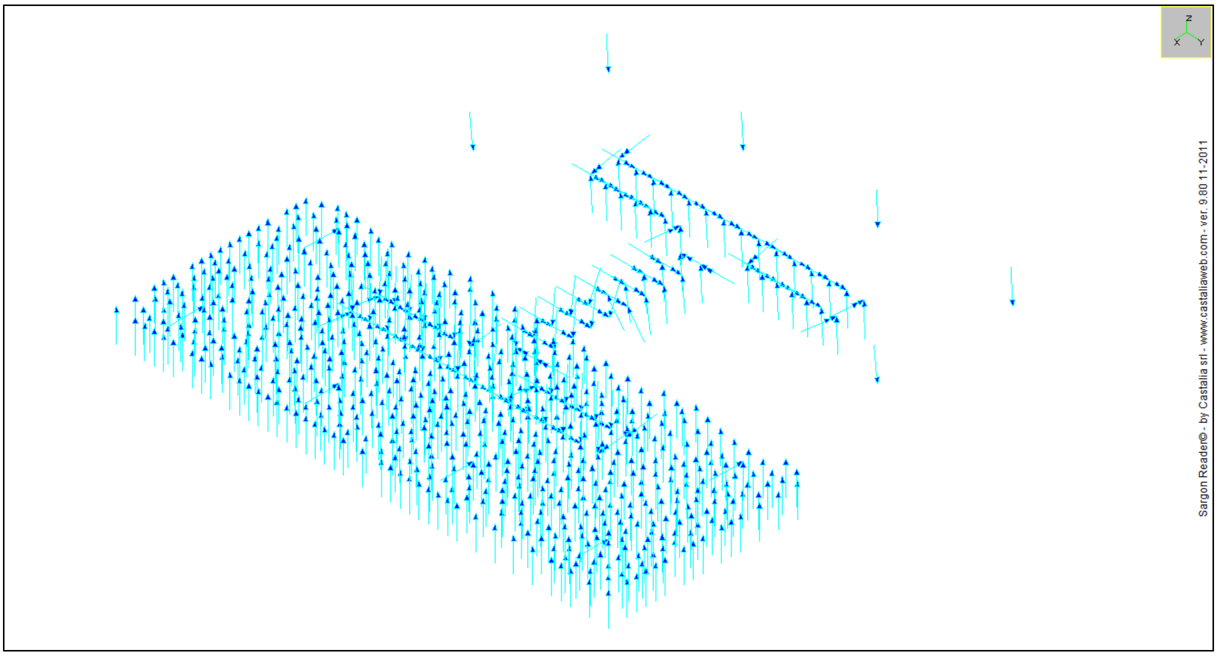


Figure C-8 Plate-shell elements hidden, nodal forces displayed with the same length

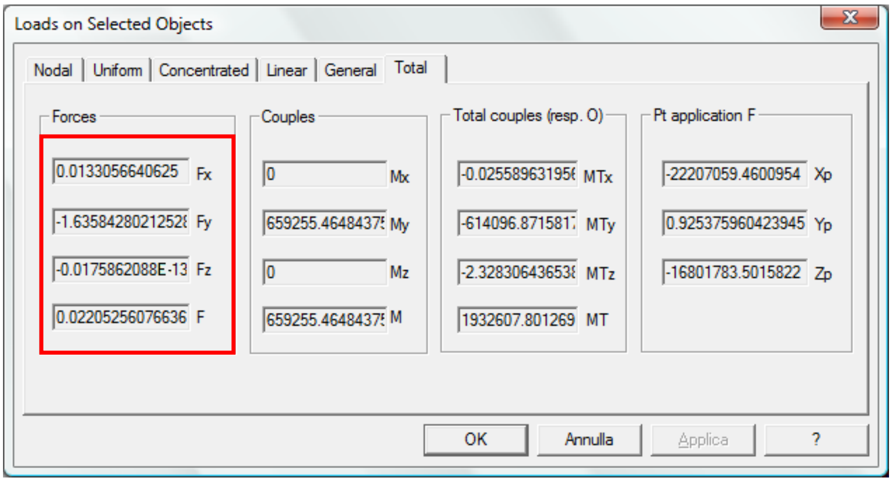


Figure C-9 Nodal forces resultant: F=0.02N

Following figures show the amplified deformed view of base plate FEM model and Von Mises stress in plate-shell elements (in the only load case of the model).

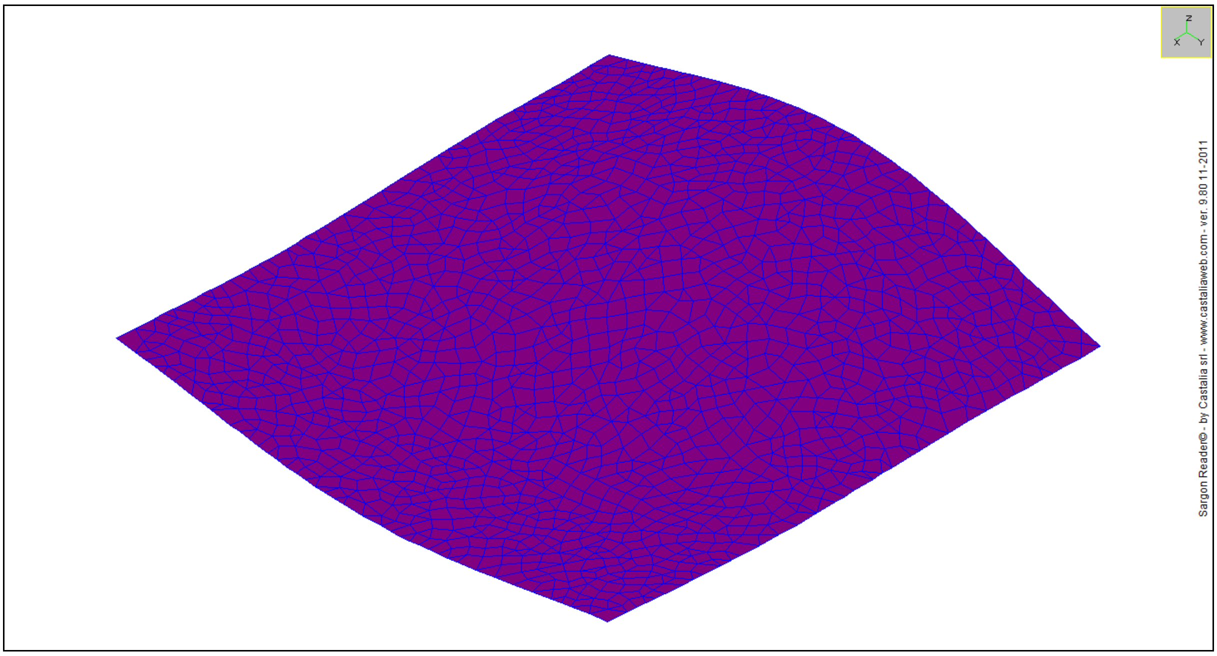


Figure C-10 Amplified Deformed View

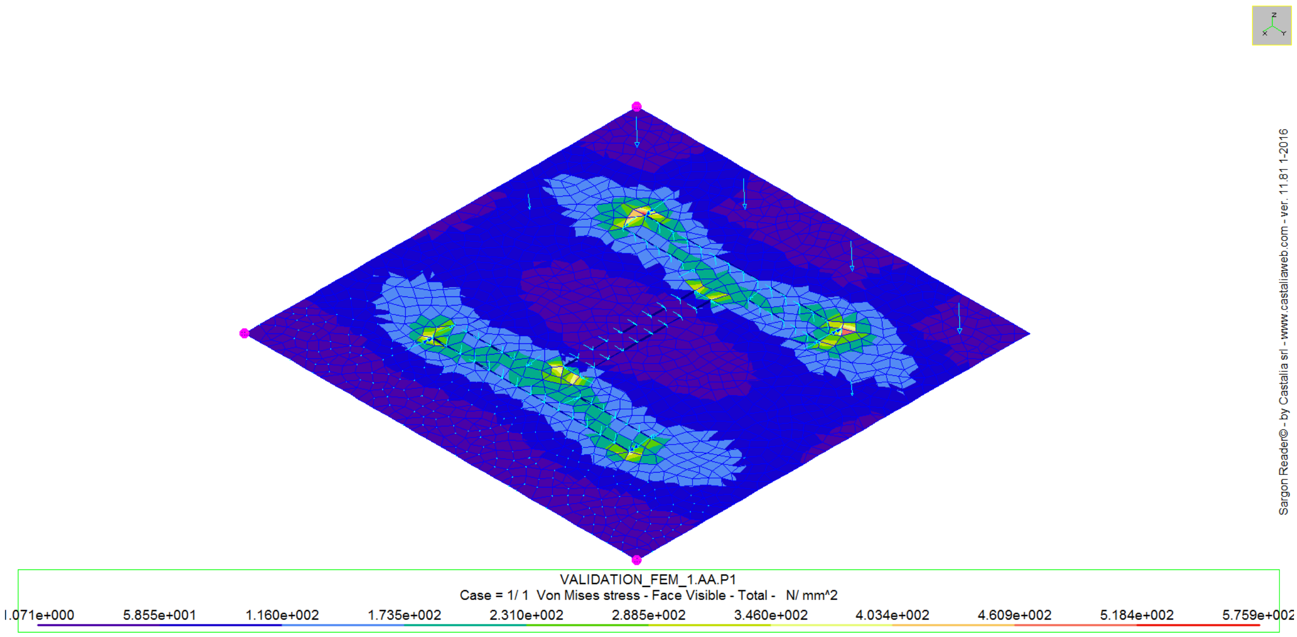


Figure C-11 Von Mises stresses on visible face (with interelement jumps); max value: 575.9N/mm^2

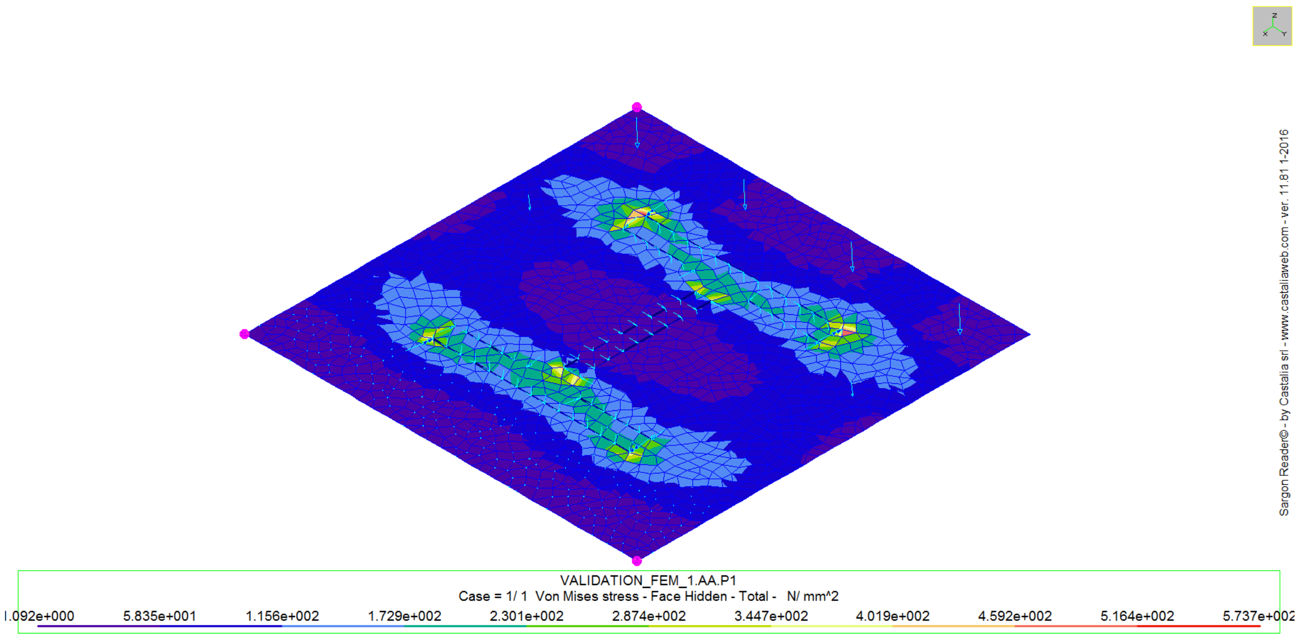


Figure C-12 Von Mises stresses on hidden face (with interelement jumps); max value: 573.7N/mm²

Maximum computed value for Von Mises stress is 575.9N/mm² on visible face. CSE uses this value to get an utilization factor: maximum Von Mises stress is divided by material yield stress and multiplied by γ_{M0} safety factor. This utilization factor is then compared to the results of other checks (bolt bearing, block tear, etc.) and maximum value is given.

Material is S235; plate thickness is 35mm<40mm so no yield stress reduction is needed according to EN1993. Utilization factor is equal to:

$$\exp 1 = \frac{\sigma_{VM,\max} \cdot \gamma_{M0}}{f_y} \frac{575.9N/mm^2 \cdot 1.0}{235N/mm^2} = 2.451$$

The same value is computed by CSE.

```
-------------------------------------------------------------------
Cleats whose worst utilization ratio is due to fem resistance checks
-------------------------------------------------------------------

  Inst   Combi    Name          VM           fd        Expl
                           (  N/  mm²)   (  N/  mm²)

    1      1        P1         575.9        235.0      2.451  !!!
```

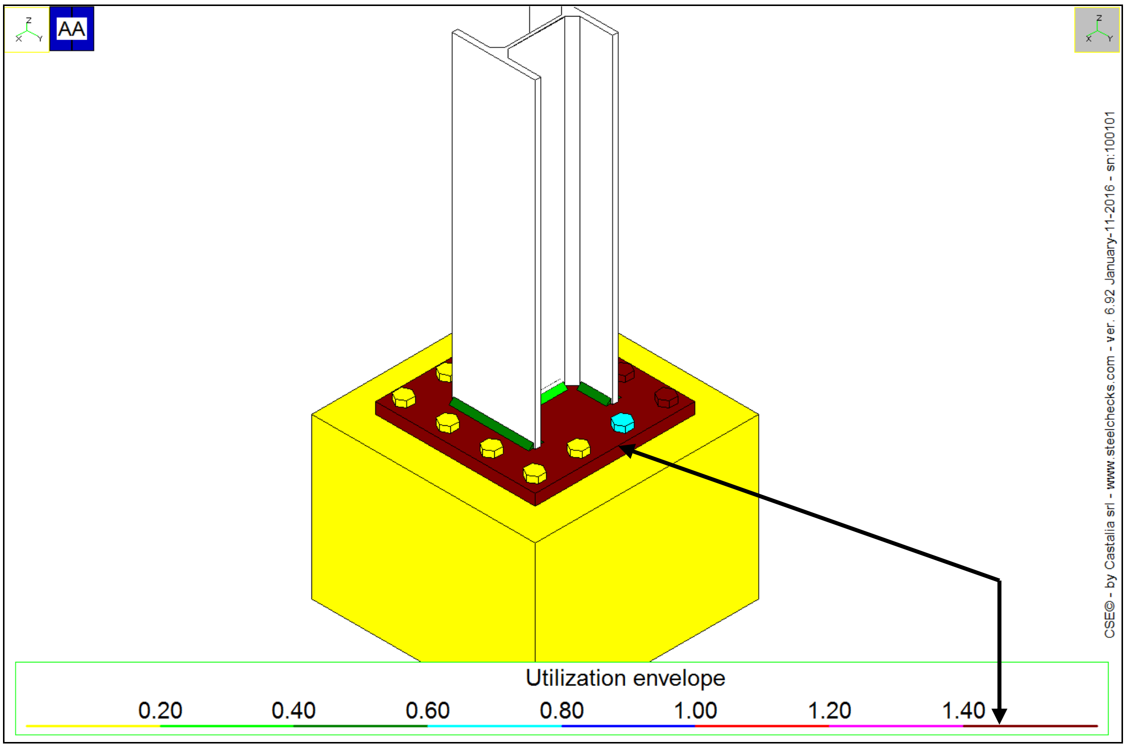


Figure C-13 Components utilization envelope

If yield stress is exceeded in some areas of the FEM model, it is up to the designer to choose one of the following conditions:

- these areas are just local peaks of stress (they can be neglected and plate can be considered checked);
- these areas are so big that plate must be considered unchecked (so stiffeners need to be added, or plate thickness must be increased, or steel grade, etc.);
- for conditions in the middle between the two previous ones, a nonlinear computation could be needed in order to see if the plate is able to carry the whole load with some plasticizations (elastic-perfectly plastic constitutive law).

NOTE WELL: in this model we required the automatic creation of plate FEM model together with its automatic analysis and automatic computation of an utilization factor according to maximum Von Mises stress; it is also possible to require the FEM model creation only, without its analysis, in order to keep FEM results separated from other checks results. Models can be created for one of the interfaced programs, and then analysed with chosen program.

C.3 SLIP-RESISTANT BOLT LAYOUTS CHECK

Some modifications were done to the model seen in previous paragraphs: bolt layout settings have been changed in order to use a slip-resistant layout (model: *Validation_Slip_1.CSE*) and loads have been set to have only shear at the base (this is not a realistic condition, but is needed to get easier and clearer hand computations).

FEM model creation is not required, and since there is not applied bending or tension, pull-out check of bars is not relevant.

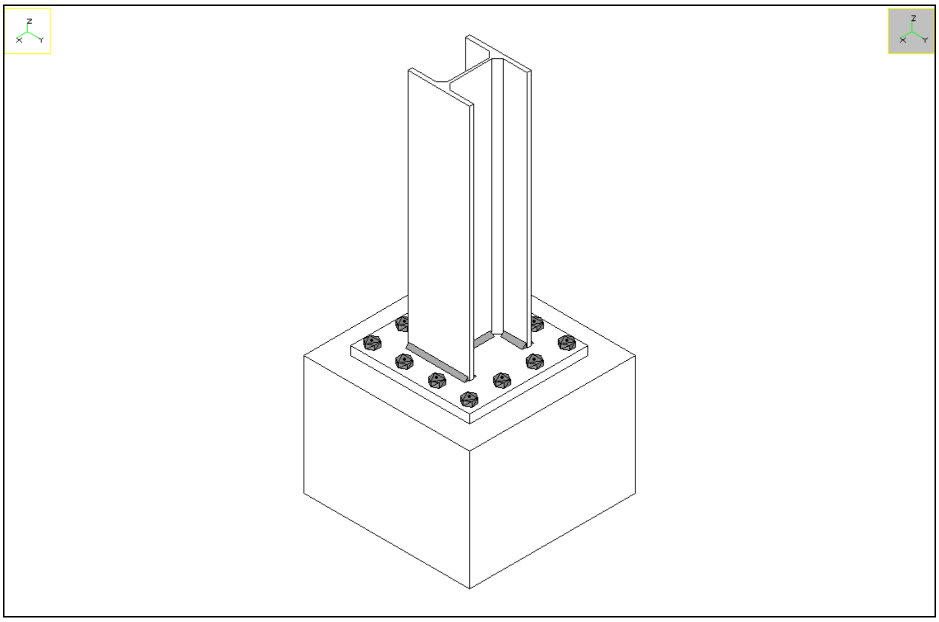


Figure C-14 3D view of the joint

The following figure shows preload and settings for slip-resistance check.

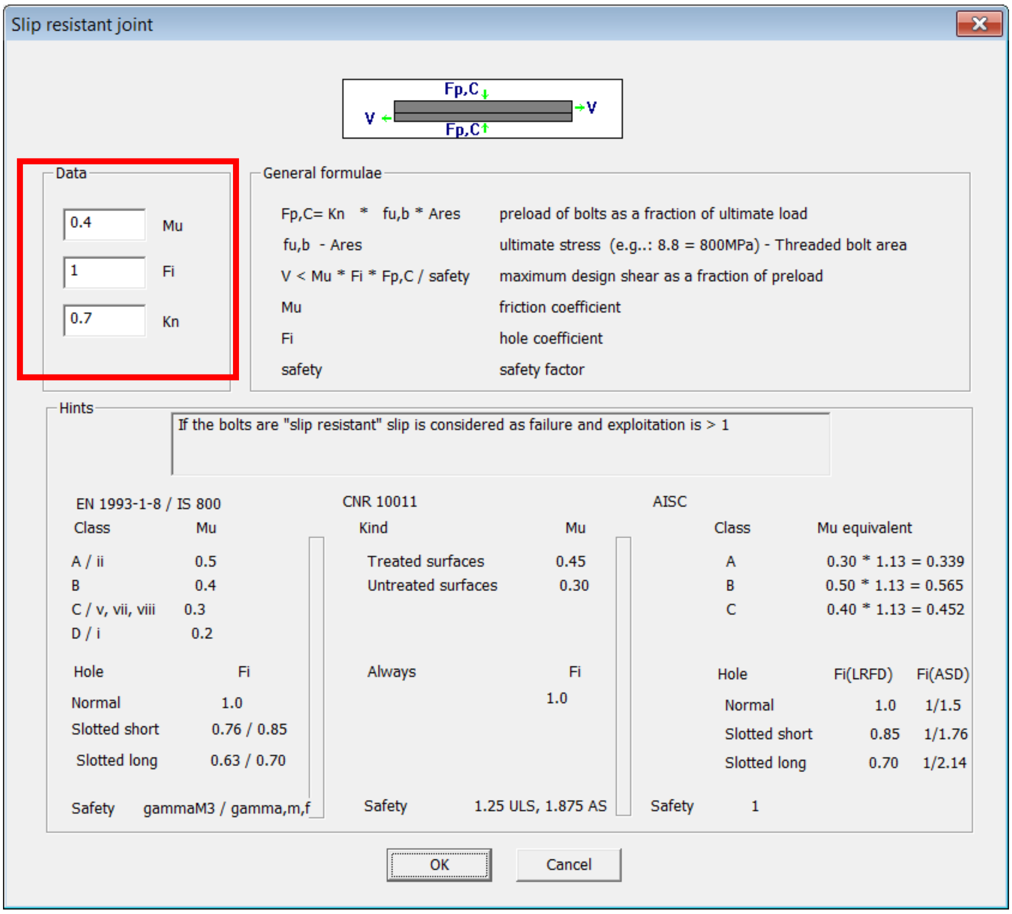


Figure C-15 Data for slip-resistance check

K_n defines the preload as a percentage of bolts ultimate load for tension. With K_n=0.7, preload is equal to:

$$F_{p,C} = K_n * f_{u,b} * A_{res} = 0.7 * 800\text{N/mm}^2 * 561\text{mm}^2 = 314160\text{N}$$

ϕ (Fi) is hole coefficient; in EN1993-1-8 it is named k_s and is equal to 1 for normal holes; μ (Mu) is friction coefficient, here defined equal 0.4 (class B surfaces). With previous value, the limit shear over which slip occurs is, for a single bolt:

$$F_{s,Rd} = \frac{k_s n \mu}{\gamma_{M3}} F_{p,C} = \frac{1 \cdot 1 \cdot 0.4}{1.1} \cdot 314160N = 114240N$$

where n=1 is the number of surfaces involved by friction (CSE automatically detects this parameter).

Since the layout is slip-resistant, resistance check of bolts shaft under shear is not required. We just need to check that applied shear on each bolt does not exceed limit value $F_{s,Rd}$. Each bolt carries a shear equal to total applied shear (V) divided by bolt number (n_B). Check is:

$$\mathrm{expl}_s = \frac{V_B}{F_{s,Rd}} = \frac{V/n_B}{F_{s,Rd}} = \frac{360000N/12}{114240N} = 0.263$$

As we can see in following abstract, CSE computes slightly different values, and we will see shortly the reason of this difference, due to simplified hand computations.

Internal actions in bolts at different planes, exploitations

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	2	1	2.416e+003	3.166e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.264	slip
1	1	B1	3	1	-2.416e+003	3.117e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	4	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	5	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	6	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	7	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	8	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	9	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	10	1	2.416e+003	3.166e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.264	slip
1	1	B1	11	1	-2.416e+003	3.117e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	12	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip

The reason ot the difference between hand computation and CSE computation is that there is not only shear in bolt layout, but also a bending moment of transport due to shear multiplied by a lever arm. This lever arm is the offset between shear application point (lower extreme of the column) and friction surface (lower face of the plate on upper face of contraint block): in practice, it is equal to plate thickness. See the deformed view in Figure C-16 and the offset in Figure C-17.

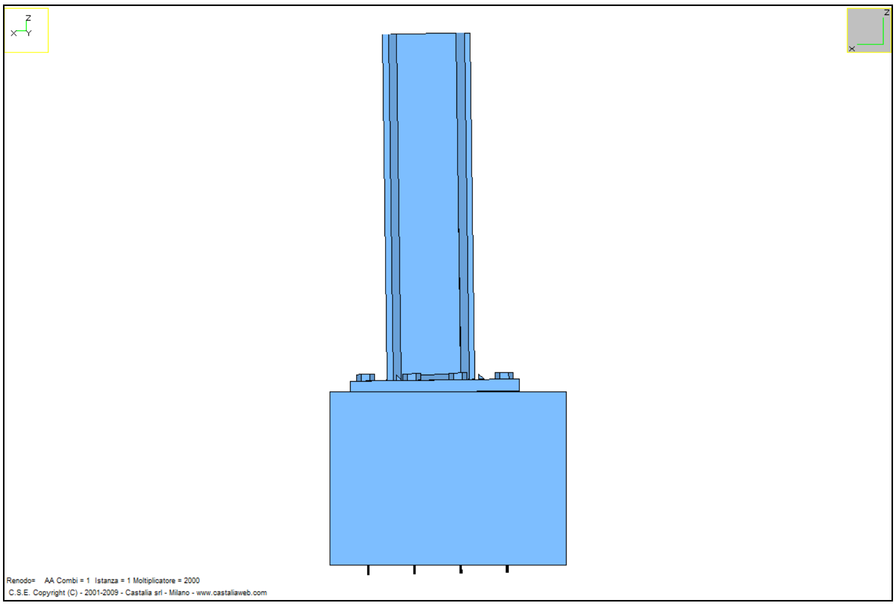


Figure C-16 Amplified deformed view: shift plus bending

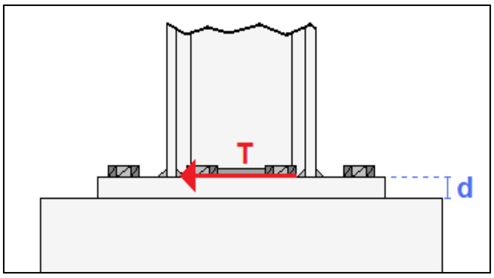


Figure C-17

The following abstract show internal forces in bolt layout.

```
------------------------------------------
Overall internal actions over Bolt Layouts
------------------------------------------
```

Id	Inst	Combi	Sec	NT	TuT	TvT	MtT	MuT	MvT
B1	1	1	1	0.0000e+000	3.6000e+005	0.0000e+000	0.0000e+000	0.0000e+000	1.2600e+007

If we divide the bending moment computed by CSE (MvT in the abstract) by the applied shear, we get exactly the thickness of the plate:

$$1.26*10^7 \text{Nmm} / 3.6*10^5 \text{N} = 35 \text{mm}$$

This bending moment of transport produces an additional tension in bolts, that must be considered when computing limit shear value for slip, according to the following formula of EN1993-1-8.

$$F_{s,Rd} = \frac{k_s n \mu (F_{p,C} - 0{,}8 F_{t,Ed})}{\gamma_{M3}}$$

Consider again the abstract previously shown:

```
--------------------------------------------------------------
Internal actions in bolts at different planes, exploitations
--------------------------------------------------------------
```

Inst	Combi	Name	Bolt	-?-	NB	NTB	TuB	TvB	TB	MuB	MvB	MB	Expl	cause
1	1	B1	1	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	2	1	2.416e+003	3.166e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.264	slip
1	1	B1	3	1	-2.416e+003	3.117e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	4	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	5	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	6	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	7	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	8	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	9	1	7.247e+003	3.214e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.268	slip
1	1	B1	10	1	2.416e+003	3.166e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.264	slip
1	1	B1	11	1	-2.416e+003	3.117e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip
1	1	B1	12	1	-7.247e+003	3.069e+005	3.000e+004	0.000e+000	3.000e+004	0.000e+000	1.984e+003	1.984e+003	0.263	slip

In column NB we have the axial force in bolts (*NTB* column is the sum of *NB* and preload). Some bolts are subjected to tension, others to compression, according to their position In the layout. For this reason, slip check on different bolts must give different results, and maximum utilization factor for slip should be on the bolt with maximum tension (bolt number 1, with *NB* = +7247N). If we compute limit shear for this bolt, we get:

$$F_{s,Rd} = \frac{k_s n \mu (F_{p,C} - 0,8 F_{t,Ed})}{\gamma_{M3}} = \frac{1 \cdot 1 \cdot 0.4 \times (314160 - 0.8 \cdot 7247)N}{1.1} = 112132N$$

And associated utilization factor is:

$$\exp1_s = \frac{V_B}{F_{s,Rd}} = \frac{30000N}{112132N} = 0.268$$

which is the same value computed by CSE.

NOTE WELL: tension in bolts produces a reduction of limit shear value, but compression in bolts does not increase limit shear value (being on the safe side).

C.4 MEMBERS NET SECTIONS CHECK

CSE automatically recognizes reductions of members gross cross-section due to bolt holes, notches, bevels, cuts or other work processes, scanning the member along its axis. In addition, CSE computes the properties of these cross sections.

If user requires it, the program automatically checks the resistance of all the net sections found, in each load combination and in each jnode instance, considering the forces acting on a given section (only the forces transferred by bolts and welds which are beyond considered section).

If net sections check gives maximum utilization factor (amont bolt bearing, bolt tearing, user’s checks, FEM check, etc.), this utilization factor is printed in the output listing and shown at screen.

Consider a single sided beam to beam joint, with a hinged supported beam connected using an end plate (model *Validation_NetSections_1.CSE*). Supported beam is double notched (see Figure C-19) and there are not bolt holes. We have net sections in correspondence of the notches.

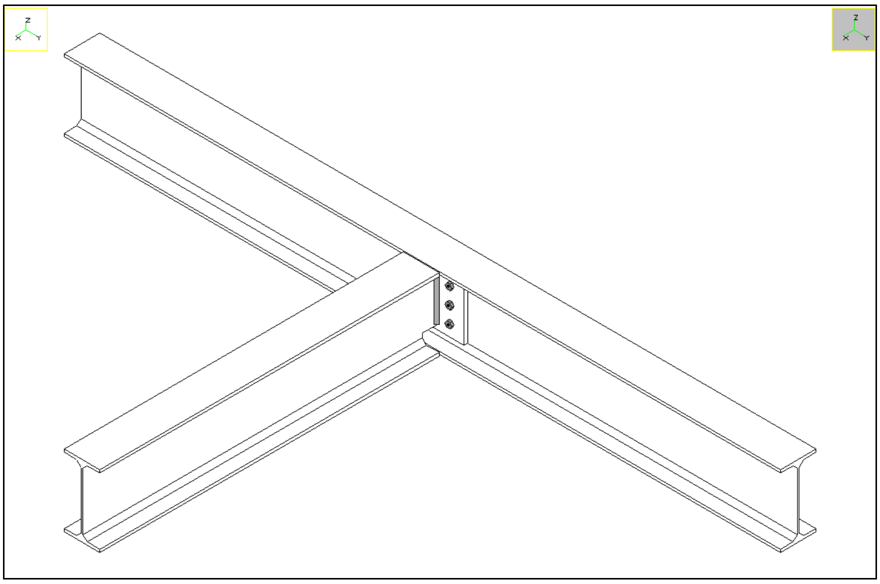


Figure C-18 3D view of the model

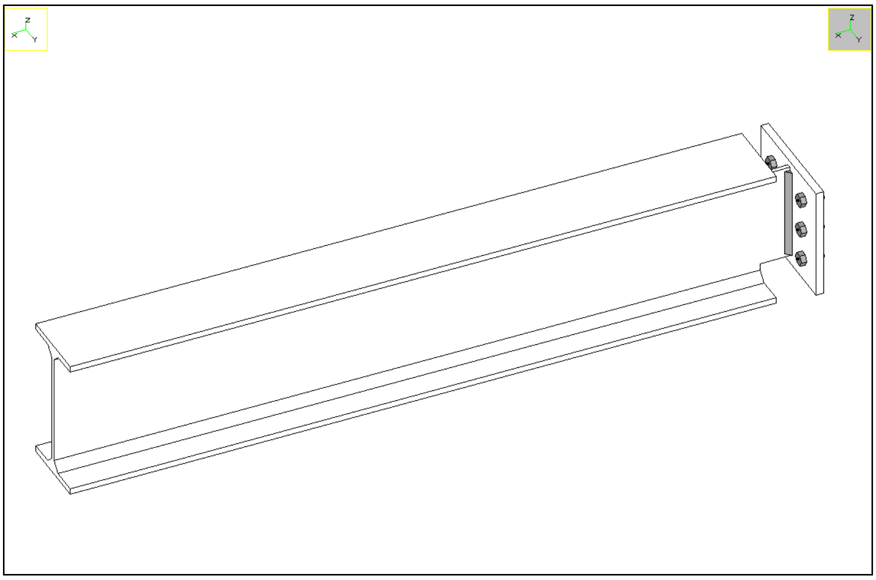


Figure C-19 Detail

In imported FEM model there is a force in supported beam middle point (Figure C-20). Since it is hinged moment distribution will be triangular (Figure C-21).

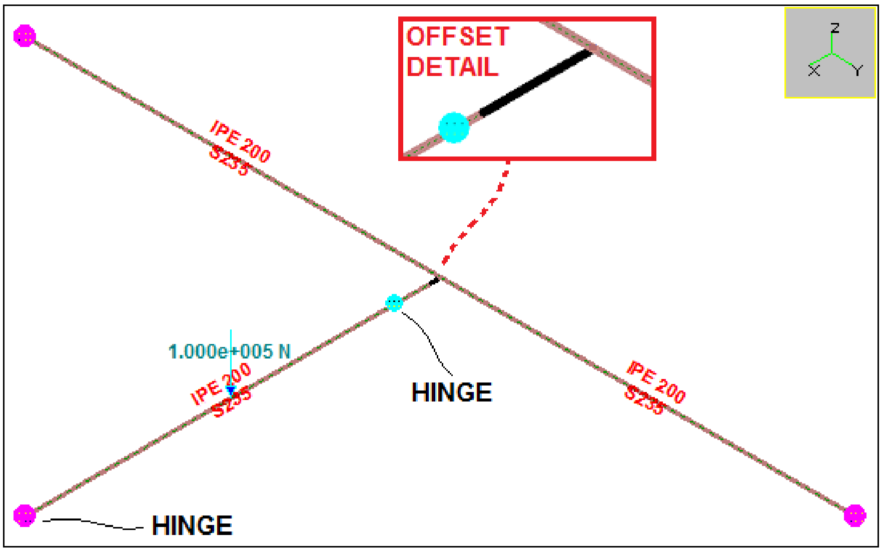


Figure C-20 Imported FEM model

Distance between the two nodes of supported beam is 1000mm, but there is a rigid offset equal to 12.8mm in the FEM model, in order to subtract plate thickness and half ow supporting beam web thickness from member total length. Supported member total length is *L*=1000mm-12.8mm=987.2mm.

Internal shear in supported beam is equal to:

$$V = F/2 = 100000\text{N} / 2 = 50000\text{N}$$

Bending moment is null at the extremes; in the middle it is equal to:

$$M_{max} = V * (L/2) = 50000\text{N} * 987.2\text{mm} / 2 = =2.468*10^7\text{Nmm}$$

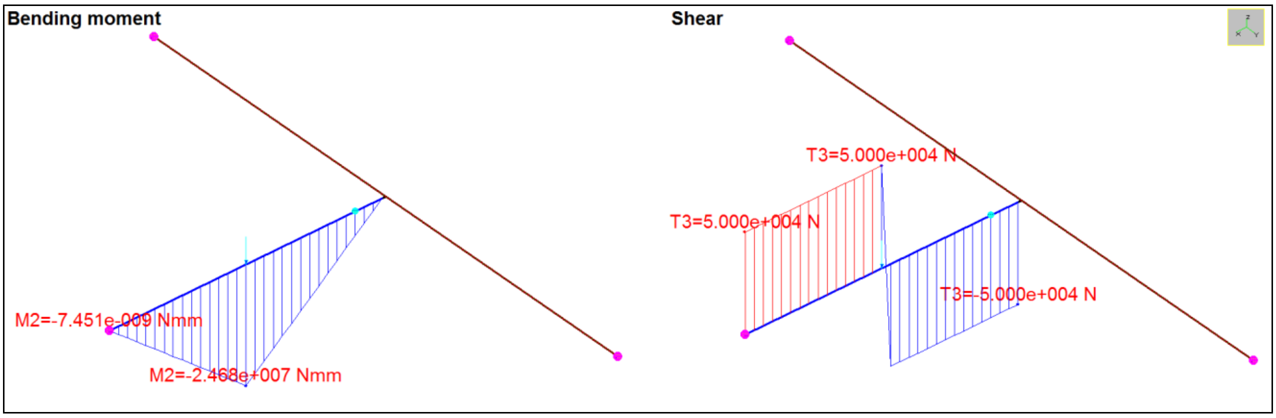


Figure C-21 Internal forces in FEM model

CSE found two net sections in supported member (see Figure C-22 and Figure C-23). The position of these net sections along member axis is shown in Figure C-24: they are at 1mm from section change.

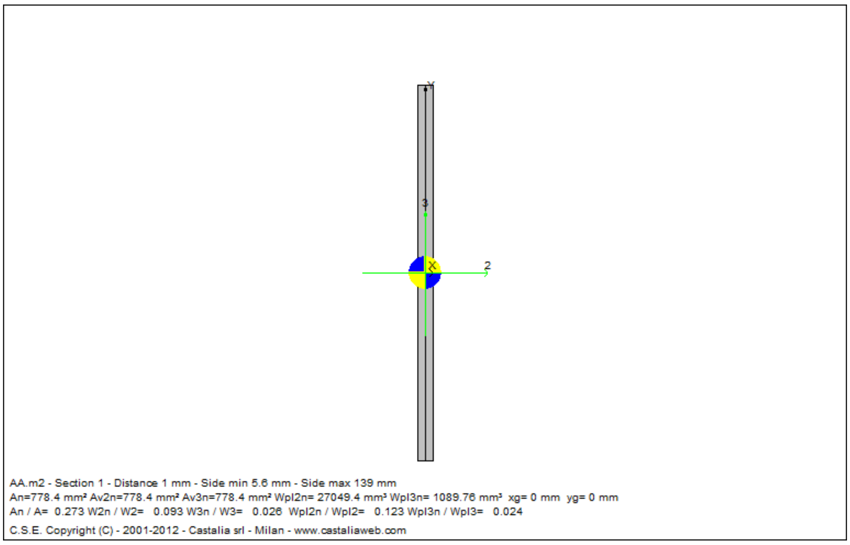


Figure C-22 Member m2, net section 1

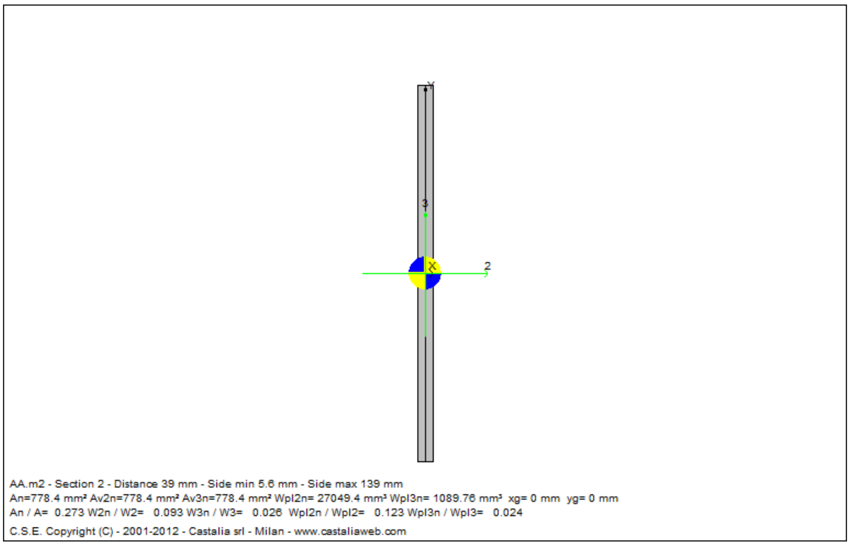


Figure C-23 Member m2, net section 2

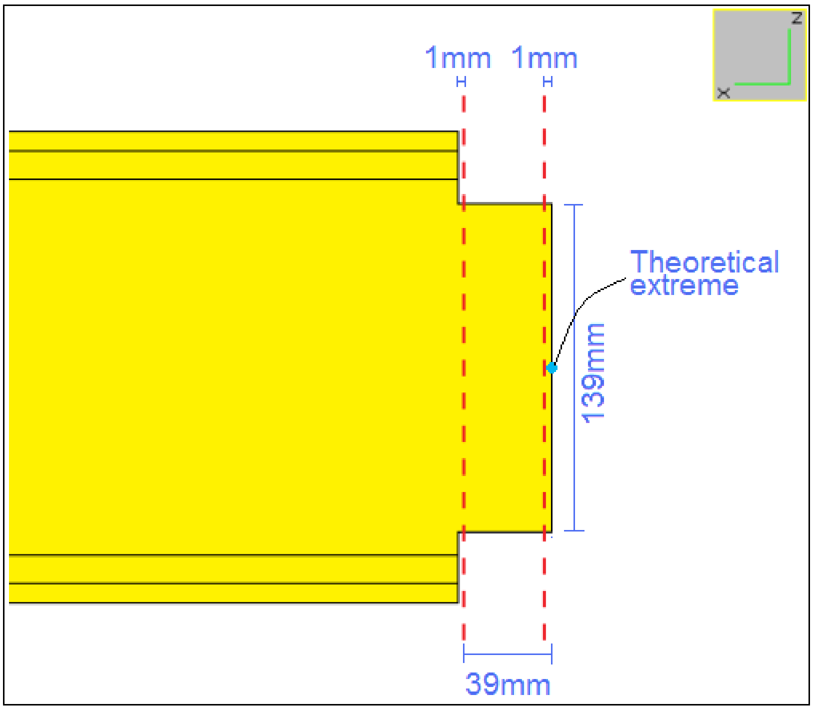


Figure C-24 Net sections position

CSE gives net sections properties, but now we are going to compute them independently from the program. We need sections area and bending moduli. Web thickness is 5.6mm; net section height is equal to 139mm (Figure C-24). Area is:

$$A_{net} = 139mm * 5.6mm = 778.4mm$$

Shear check for a rectangular section is:

$$\exp l_v = \frac{V_{Ed}}{A_{net} \cdot f_v}$$

where

$$f_v = f_y / \gamma_{M0} / \sqrt{3} = 235 N/mm^2 / 1 / \sqrt{3} = 135.7 N/mm^2$$

so:

$$\exp l_v = \frac{50000N}{778.4mm \cdot 135.7 N/mm^2} = 0.473 \quad < 0.5$$

Since utilization factor for shear is less than 0.5, resistance to bending has not to be reduced (note well: here there is not axial force). Net section inertia moment about member strong axis is:

$$J = 5.6mm * (139mm)^3 / 12 = 1253288.9mm^4$$

Bending modulus about the same axis is:

$$W = J / (L/2) = 1253288.9\text{mm}^4 * 2 / 139\text{mm} = 18032.93\text{mm}^3$$

The same values are computed by CSE:

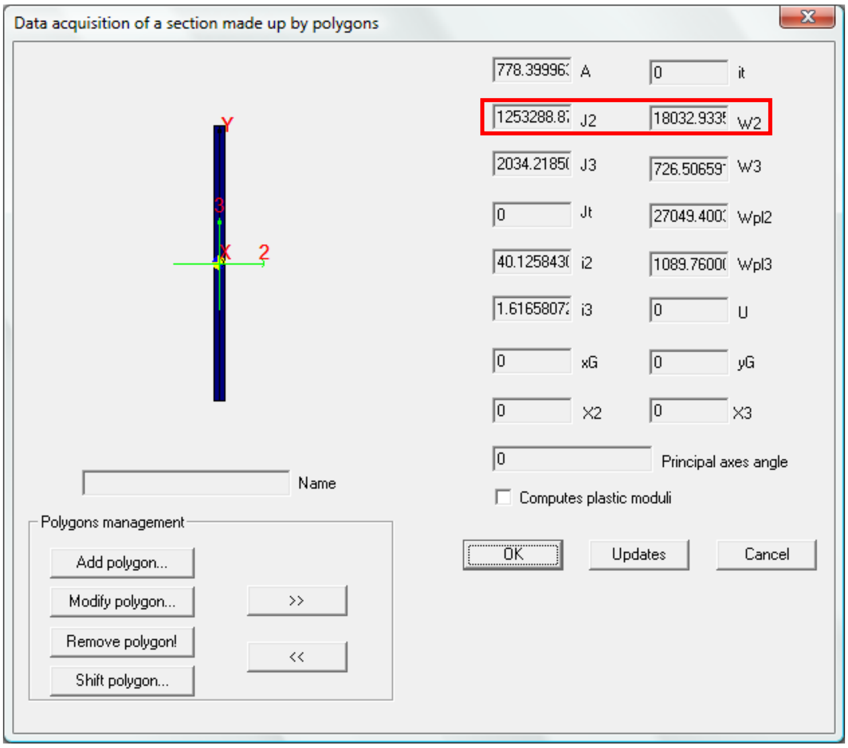


Figure C-25 Net section properties

As previously said, bending moment has a triangular shape.

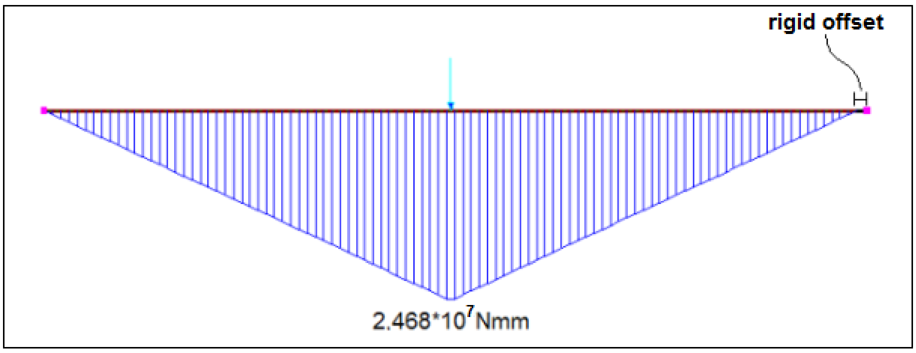


Figure C-26 Bending model (imported FEM model from Sargon)

Referring to Figure C-27, moment is quite null in section 1; in section number 2, bending moment is equal to:

$$M_{\max}\frac{d}{L/2} = 2.468\cdot 10^7\,Nmm\frac{39mm}{987.2mm/2} = 1.950\cdot 10^6\,Nmm$$

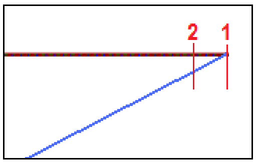


Figure C-27

Stress to be considered in bending check is:

$$f_d = \frac{f_y}{\gamma_{M0}} = \frac{235N/mm^2}{1} = 235N/mm^2$$

For net section 2, utilization factor for bending is:

$$\text{expl}_M = \frac{M}{W\cdot f_d} = \frac{1.950\times 10^6\,Nmm}{18032.93mm^3\cdot 235N/mm^2} = 0.460 \quad < \text{expl}_v$$

Maximum utilization factor is due to shear and is equal to 0.473. CSE computes the same value:

```
-------------------------------------------------------------------
Members whose relevant exploitation is due to net sections check
-------------------------------------------------------------------
```

Inst	Combi	Name	Sect	N	T2	T3	M1	M2	M3	fd	Expl
1	1	m2	2	-3.203e-013	-8.176e-012	-5.000e+004	0.000e+000	-1.950e+006	1.994e-010	2.350e+002	0.473

Following figure show CSE results for most critical net section.

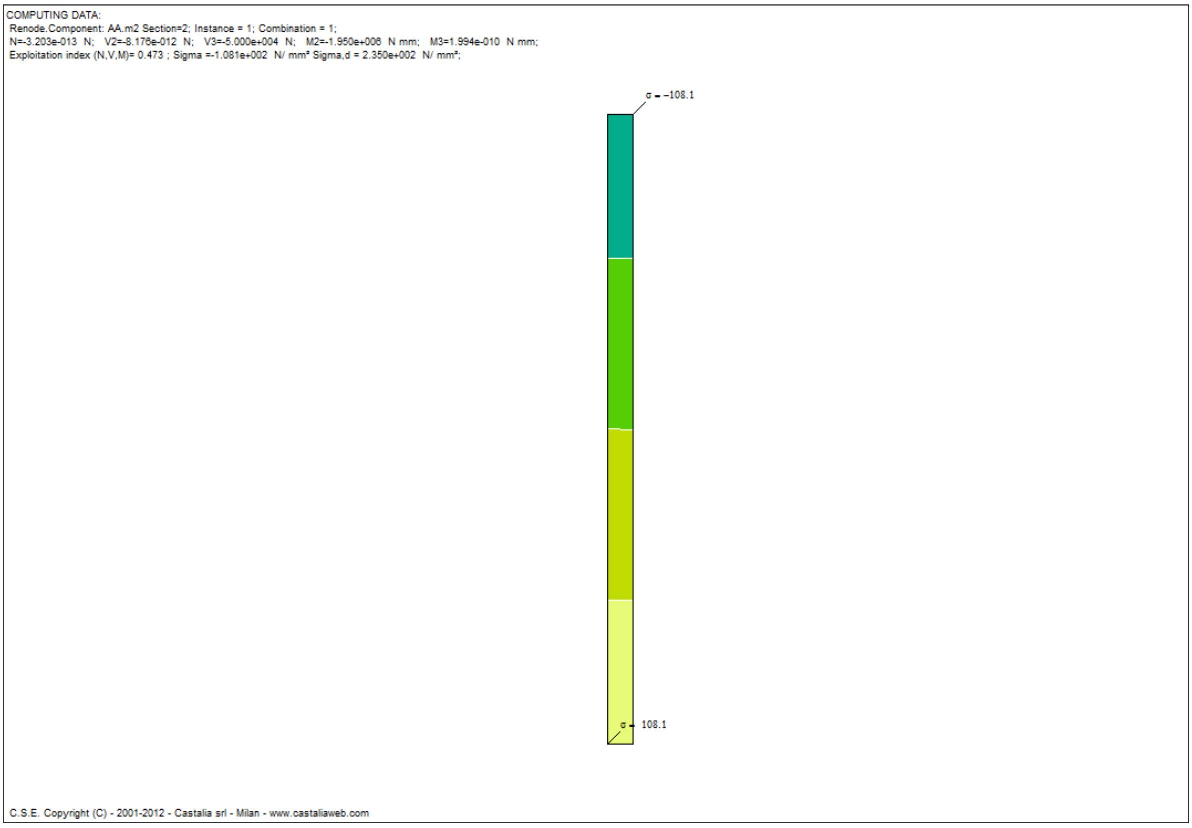


Figure C-28 Net section results

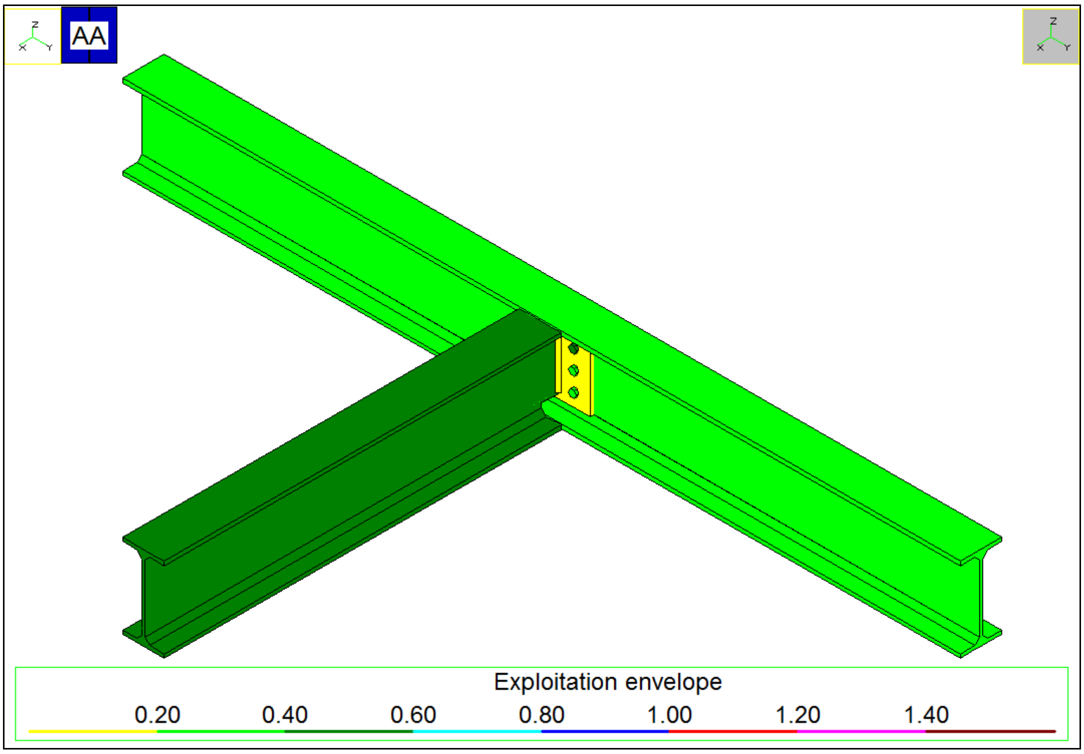


Figure C-29 Components utilization envelope

C.5 SIMPLIFIED CHECKS FOR CLEATS (STANDARD SECTIONS)

In model *Validation_Cleat_1.CSE*, which is shown in following figures, the automatic simplified check for cleats standard sections have been done by CSE. Standard sections are relevant check sections depending on component type, as explained later.

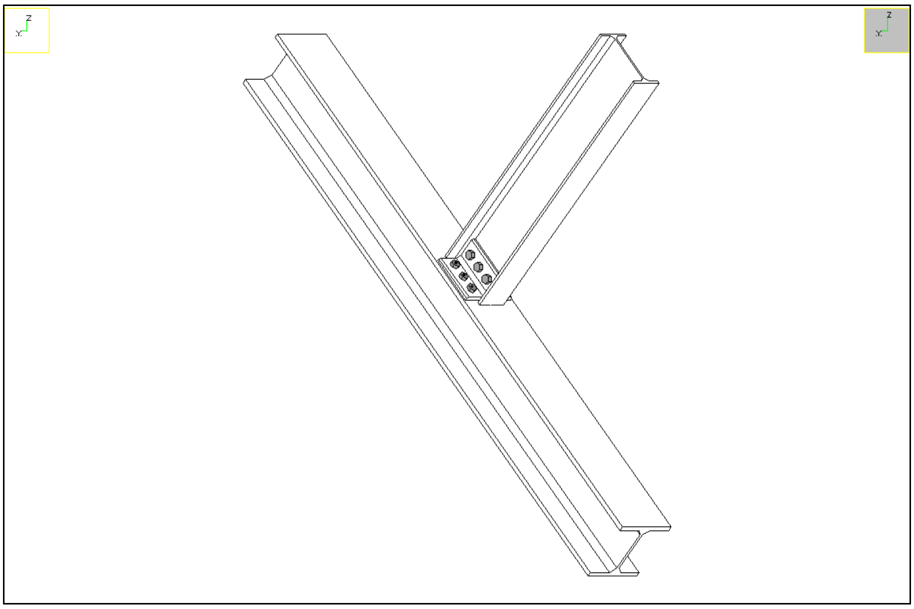


Figure C-30 3D view of the joint

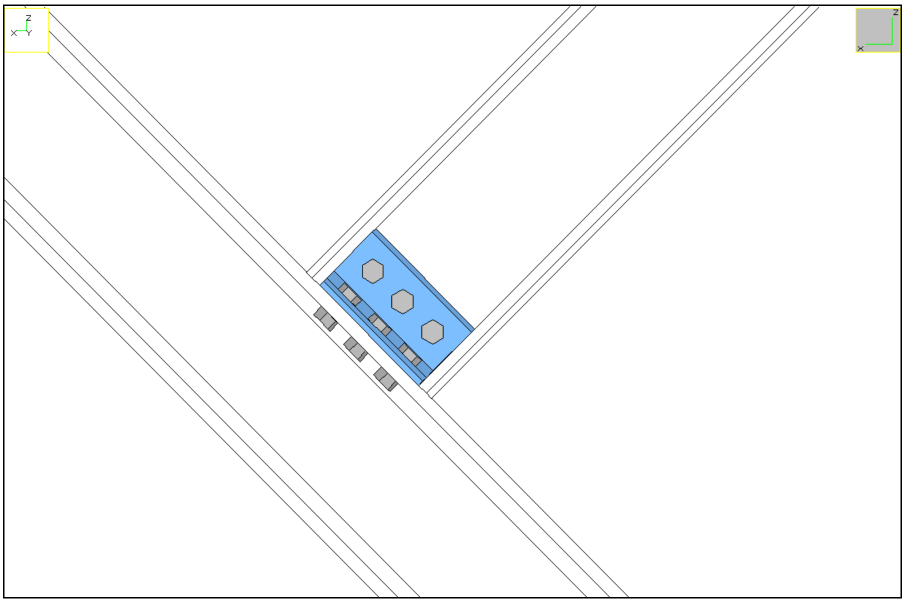


Figure C-31 Detail of the connection

Slave member is a truss, so axial force only is transferred from it to master member (tension, in this case). Applied force produces shear force on slave web bolt layout and axial force in master flange bolt layout. In addition, there is a moment of transport due to the offset between applied load and bolts. This actions are transferred to the angle cleats.

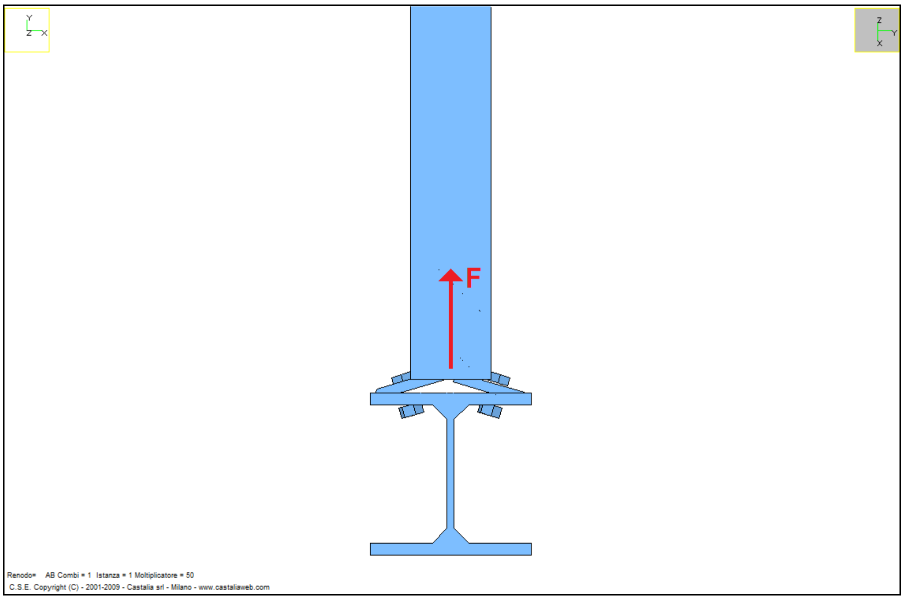


Figure C-32 Amplified deformed view

CSE checks the resistance of some sections depending on cleat shape. In case of angles, two sections are checked; those sections, which are shown in following figure, are checked through an equivalent beam model. *Note well*: since we required to neglect bolt shafts bending from resistance checks, it has not to be considered in cleats (but also members) check. CSE computes bending in shafts anyway, but user can require to not consider it during the checks.

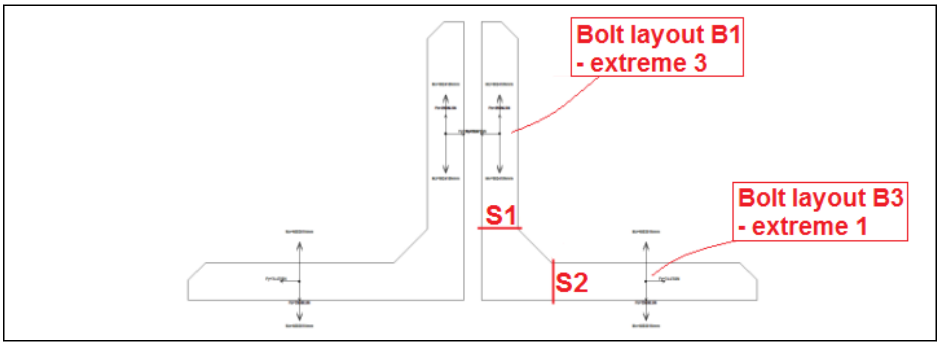


Figure C-33 Check sections S1 and S2

Forces acting on section S1 are those of extreme 3 of bolt layout B1; forces acting on section S2 are those of extreme 1 of bolt layout B3. Considering the following CSE abstract, forces computed on involved bolt layouts extremes are:

```
---------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
---------------------------------------------------------------------
```

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B1	1	1	1	4.1856e+004	-1.4881e-005	7.4475e+001	-1.0906e-004	1.1348e+006	5.2621e-005
B1	1	1	2	-8.3712e+004	3.2445e-006	-7.1054e-014	1.7462e-009	1.8626e-009	-2.3238e-005
B1	1	1	3	4.1856e+004	1.1636e-005	-7.4475e+001	-1.2429e-004	-1.1348e+006	-2.9383e-005
B2	1	1	1	1.6125e-005	7.4475e+001	4.1856e+004	8.6027e+005	9.7767e-004	1.6226e-004
B2	1	1	2	-1.6125e-005	-7.4475e+001	-4.1856e+004	-8.5926e+005	-1.1954e-003	-1.6226e-004
B3	1	1	1	7.0803e-006	-7.4475e+001	4.1856e+004	-8.6027e+005	1.1791e-003	8.7227e-004
B3	1	1	2	-7.0803e-006	7.4475e+001	-4.1856e+004	8.5926e+005	-1.2747e-003	-8.7227e-004

Section S1: Axial force equal to 4.1856*10^4N (*Fx* in the abstract)

Shear equal to –7.4475*10^1N (*Fz*)

Bending moment equal to –1.1348*10^6Nmm (*My*)

Section S2: Axial force equal to –7.4475*10^1N (*Fy*)

Shear equal to 4.1856*10^4N (*Fz*)

Bending moment equal to –8.6027*10^5Nmm (*Mx*)

As we can see, CSE computes a force normal to applied load in both extremes (*Fz* in B1 - extreme 3, which is axial force in B1 bolts, and Fy in B3 – extreme 1, which produces shear in B3 bolts. These forces are usually not considered in hand computations, but they are present and CSE computes them (see part B for forces distribution in joiners).

An axial force in bolt layout produces shear in corresponding net section and a shear in a bolt layout produces an axial force in corresponding section (see next figure).

Check sections have a rectangular section with these sizes: base is equal to angle (12mm), height is equal to angle length (159mm).

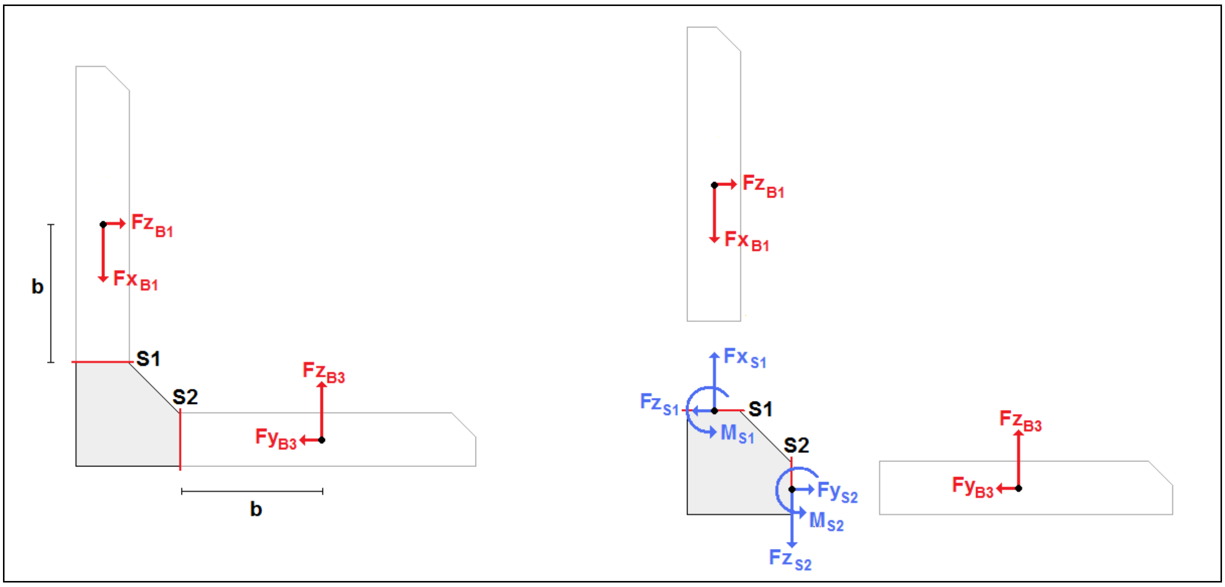


Figure C-34 Forces in bolt layouts and corresponding forces in check sections

Forces acting on check sections are printed in the following table:

Check section S1	Check section S2
Fx_{S1} = - Fx_{B1} = 41856N	Fy_{S2} = - Fy_{B3} = 74.475N
Fz_{S1} = - Fz_{B1} = 74.475N	Fz_{S2} = - Fz_{B3} = 41856N
M_{S1} = Fz_{B1} * b = 2290Nmm	M_{S2} = Fz_{B3} * b = 1287000Nmm

Check sections area A = 12mm x 159mm = 1908mm^2. Inertia modulus about the axis subjected to bending, and then its corresponding modulus, are:

$$J = 159\text{mm} * 12^3\text{mm} / 12 = 22896\text{mm}^4$$

$$W = J / t / 2 = 22896\text{mm}^4 / 6\text{mm} = 3816\text{mm}^3$$

Material is S275 abbiamo, so we have:

$$M_{res} = f_y * W = 275\text{N/mm}^2 * 3816\text{mm}^3 = 1574100\text{Nmm}$$

$$N_{res} = f_y * A = 275\text{N/mm}^2 * 1908\text{mm}^2 = 52470\text{N}$$

S1 check for axial force and bending is:

$$\text{expl}_{S1_{N+M}} = \frac{N}{N_{res}} + \frac{M}{M_{res}} = \frac{41856N}{524700N} + \frac{2290Nmm}{1574100Nmm} = 0.081$$

S2 check for axial force and bending is:

$$expl_{S2_{N+M}} = \frac{N}{N_{res}} + \frac{M}{M_{res}} = \frac{74.48N}{524700N} + \frac{1287000Nmm}{1574100Nmm} = 0.818$$

S2 check for shear is (S2 is the one with maximum shear):

$$expl_{S2_V} = \frac{V}{Af_y / \sqrt{3}} = \frac{41856N}{1908mm^2 \cdot 275N/mm^2 / \sqrt{3}} = 0.138$$

Maximum utilization factor is 0.818 for section S2, due to bending plus axial force. CSE computes the same result, as we will see later.

In addition to previous check sections, CSE considers also the mean section of the cleat along its extrusion axis, subjected only to the forces acting beyond that section (see Figure C-35, right, check section is in black). Check section is subjected only to the forces of the two upper bolts (displayed in red and yellow). Forces and moments in bolts shaft must be in equilibrium (Figure C-36) so action must produce a null resultant (obviously there is no torsion on the cleat). Since check settings neglect bending moment on bolt shafts, the forces would produce a torsion in the net section, but this torsion is not present in the component: for this reason, torsion check was not included in cleat check. Since there is no shear, axial force or bending moment in considered check section, its utilization factor is null, and previously computed value (0.818) results as maximum utilization for the component.

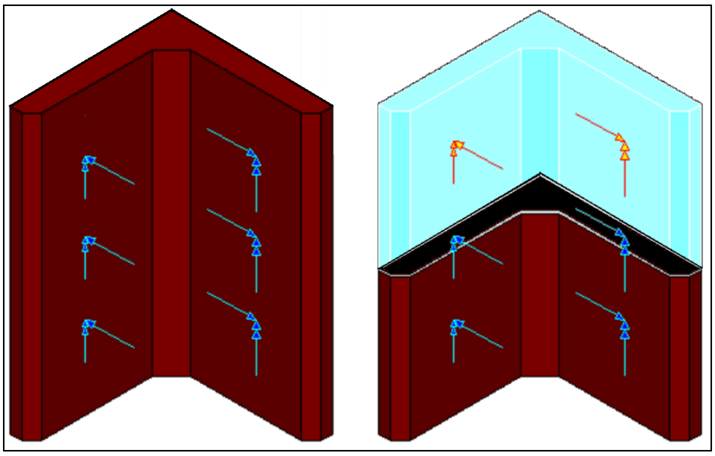


Figure C-35

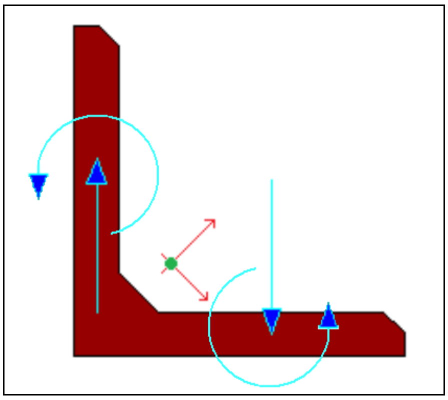


Figure C-36

CSE computes the same value.

```
--------------------------------------------------------------------------------
Throughs whose worst exploitation is due to simplified "beam" resistance checks
--------------------------------------------------------------------------------

  Inst  Combi     Name  Sect        N           T2          T3          M1          M2          M3       Expl

   1      1       L1    2    -7.448e+001 -7.080e-006  4.186e+004  1.209e-003 -1.287e+006  6.546e-004   0.818
   1      1       L2    2    -7.448e+001  1.613e-005  4.186e+004 -1.064e-003 -1.287e+006  6.581e-004   0.818
```

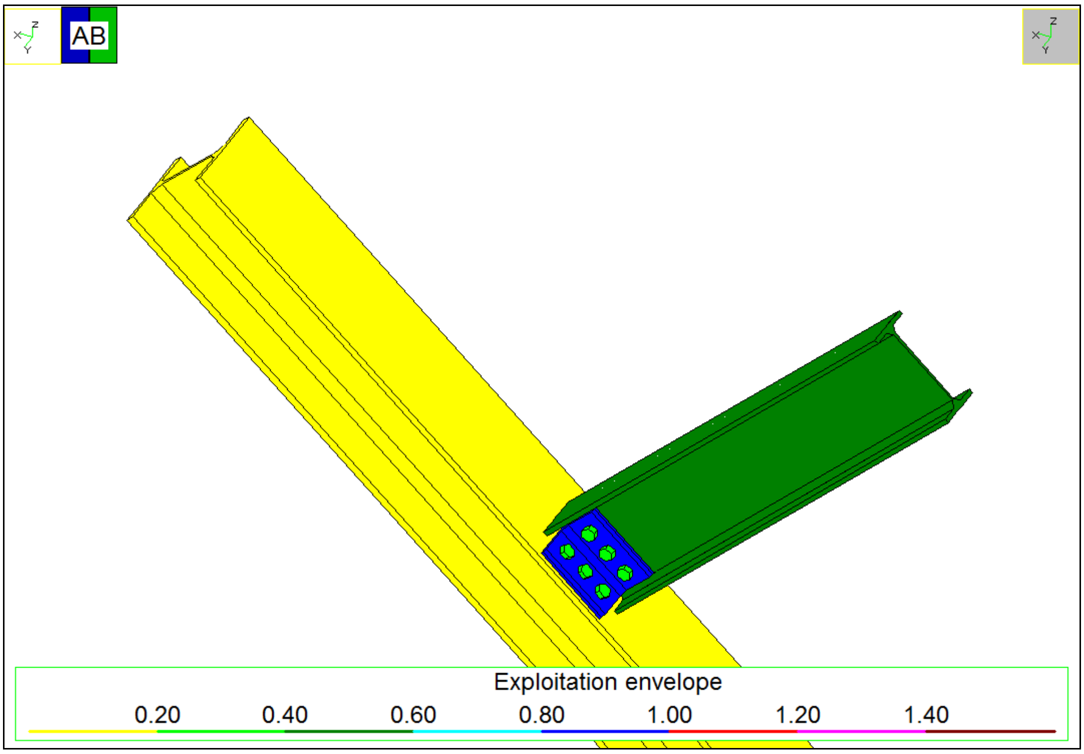


Figure C-37 Components utilization envelope

C.6 BEARING SURFACE CHECK

C.6.1 No-tension parabola-rectangle constitutive law

C.6.1.1 Combined compression and bending moment

We prepared a model of a column base in order to check the bearing stresses on concrete block with no-tension parabola-rectangle constitutive law (model *Validation_Bearing_1.CSE*).

The model is shown in following figure. Resistance check for bolts, welds, etc. see part B of the document, where these aspects have been studied in detail. Here we will consider the check of bearing surface, which is the area in compression between base plate and concrete block.

A specific non-linear algorithm (derived from those utilised in non-linear computations of reinforced concrete cross-sections) is used by CSE in order to find elastic neutral axis position and the compressive stresses acting over the reactive part of the bearing surface, as well as the tensile stresses in the tensile bolts.

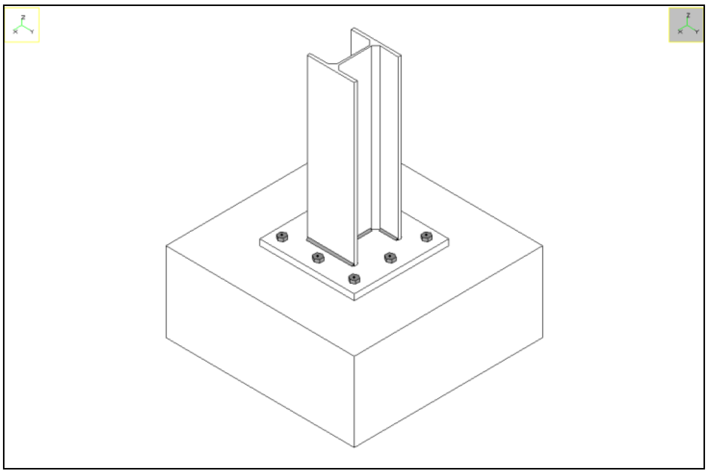


Figure C-38 3D view of the joint

Bolt layout geometry and properties are shown in next image. Bearing surface is equal to base plate footprint (600x600mm). Bearing surface check will be associated to the constraint block.

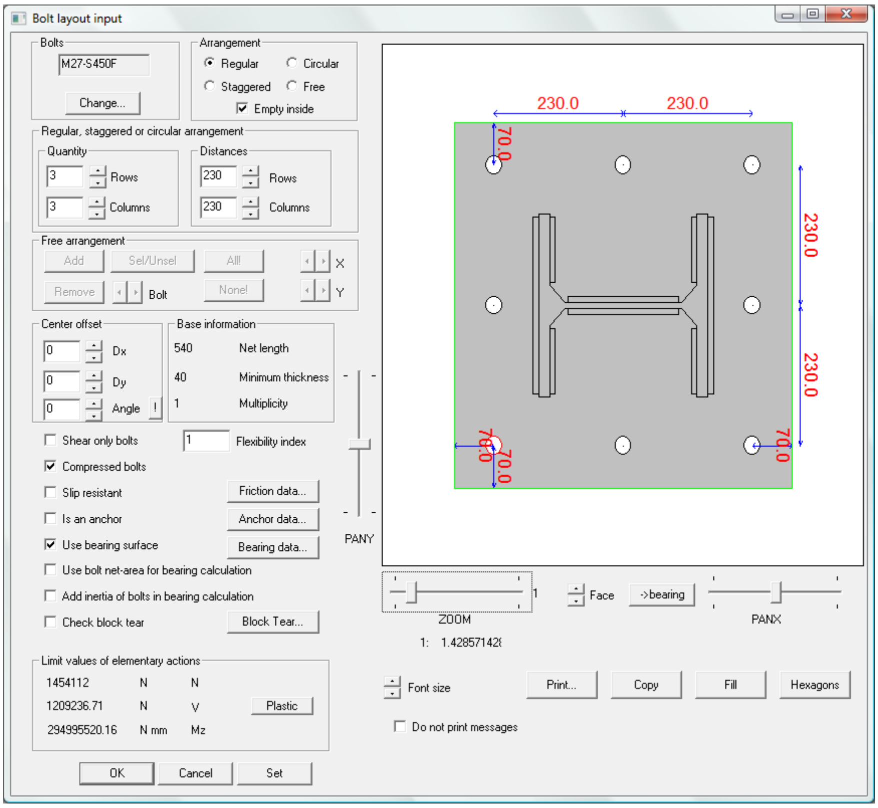


Figure C-39 Bolt layout data

NOTE WELL: here the whole plate footprint was assumed as bearing surface; in CSE it is also possible to define bearing surfaces in a general way, for example adding a border to column footprint, with border size depending on plate material, plate thickness and constraint block material, according to the Standard. If there are stiffeners, their bordered footprint can be included too.

Bolts total area is considered in the check (not threaded area, this is a choice in check settings) and single bolts own inertia is not considered in bolt layout total inertia moment (this is another check setting). To cross-check CSE results, we will use the software Lisa (see A.3).

The constitutive law defined in CSE for constraint block is shown in next image. It is a no-tension parabola-rectangle constitutive law, defined by point (s_1, e_1) (stress, deformation) and ultimate deformation e_u. γ_M factor is defined equal to 1.6 because this parameter is fixed in Lisa© to that value, and we need the same input to compare results.

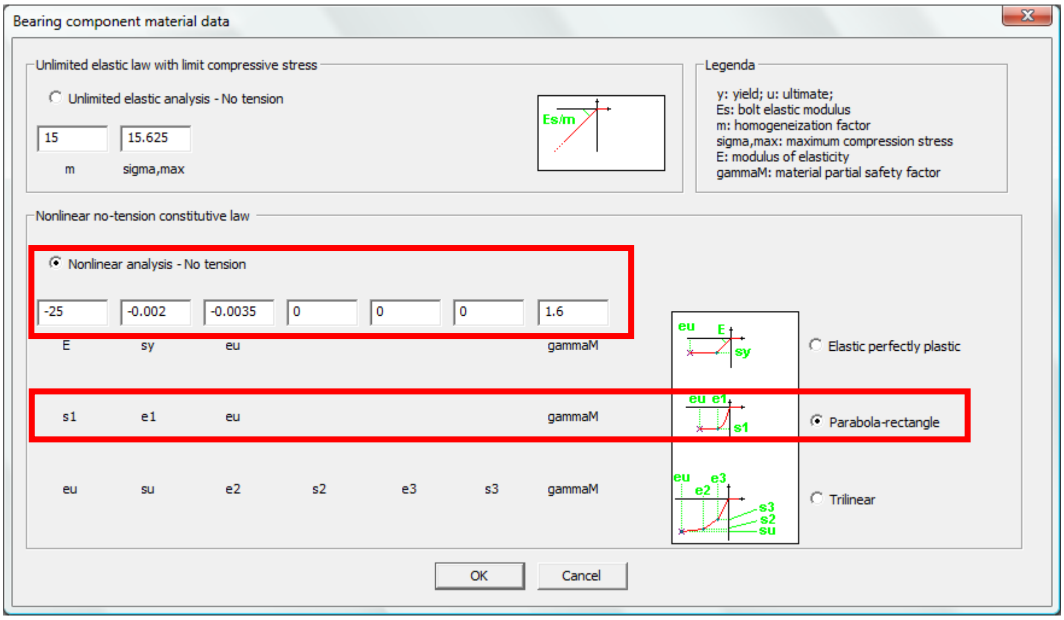


Figure C-40 Bearing surface constitutive law (units: N, mm)

Forces at column lower extreme: - compression = $3*10^5$N;

- bending about strong axis = $8*10^7$Nmm

The following figure shows bearing surface results computed by CSE.

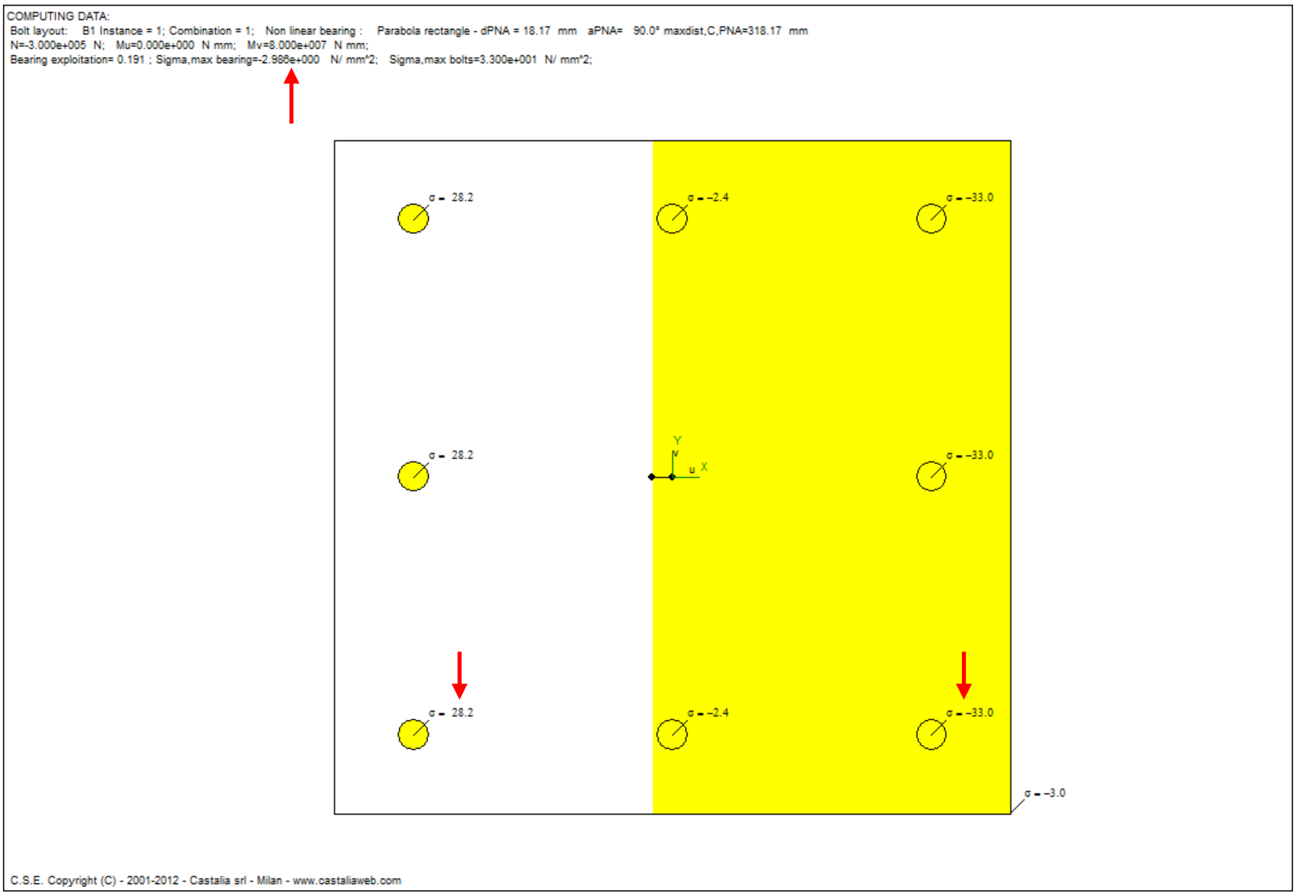


Figure C-41 Bearing surface check results

σ_c^- maximum compression stress in concrete block: -2.986N/m**m²**

σ_b^+ maximum stress in bolts: +28.2N/mm^2

σ_b^- minimum stress in bolts: -33.0N/mm^2

A computation with the same loads and geometry was done with Lisa©, through a limit state computation according to DM2006, Sections II and III (Italian Standard). The following listing reports computed results for maximum positive normal stress in bolts and compression stress in concrete. The figure of defined geometry is given after the listing.

```
Programma LISA      Ver. 3.5                                   Copyright © Castalia s.r.l.
(http://www.castaliaweb.com)


Coordinate dei nodi della sezione:

           X  [cm]     Y  [cm]
   1*       30.00       30.00
   2*      -30.00       30.00
```

```
   3*      -30.00    -30.00
   4*       30.00    -30.00

Posizione ed area delle armature:

           Xs[cm]    Ys[cm]   As[cm²]
   1*      -23.00    -23.00      5.72
   2*      -23.00      0.00      5.72
   3*      -23.00     23.00      5.72
   4*        0.00    -23.00      5.72
   5*       23.00    -23.00      5.72
   6*       23.00      0.00      5.72
   7*        0.00     23.00      5.72
   8*       23.00     23.00      5.72

Caratteristiche meccaniche dei materiali:

Resistenza di calcolo del calcestruzzo.......=      15.625   [N/mm²]
Deformazione EPSILONco del calcestruzzo......=       0.002000
Deformazione ultima del calcestruzzo.........=       0.003500
Resistenza di progetto a rottura dell'acciaio
ordinario (ftk/Gammas).......................=     373.91    [N/mm²]
Resistenza di progetto allo snervamento dello
acciaio ordinario (fyk/Gammas)...............=     373.91    [N/mm²]
Modulo di Young dell'acciaio ordinario.......=  200000.00    [N/mm²]
Deformazione ultima di calcolo...............=       0.010000
Deformazione caratteristica ultima...........=       0.120000

Condizione di carico N°  1:

Azioni interne:
Nz=      300.00 [kN]  (positiva di compressione)
Mx=        0.00 [kNm] (positivo se comprime le fibre per x>0)
My=       80.00 [kNm] (positivo se comprime le fibre per y>0)

Posizione dell'asse neutro:  Xn  =      infinito
                             Yn  =         -1.51  [cm]
                             beta=          0.000 [rad]

Deformazione massima nel calcestruzzo........=       0.000204
Tensione massima nel calcestruzzo............=       3.024   [N/mm²]
Deformazione minima nell'armatura ordinaria..=      -0.000139
Tensione minima nell'armatura ordinaria......=     -27.82    [N/mm²]

La misura della sicurezza è positiva.


Nota:  Si assumono positive le tensioni e le deformazioni di compres-
       sione. Pertanto, con la dicitura 'Tensione minima nell'armatu-
       ra ordinaria' si intende la tensione dell'armatura piu' solle-
       citata a trazione.
       Xn  = intersezione dell'asse neutro con l'asse x;
       Yn  = intersezione dell'asse neutro con l'asse y;
       beta= inclinazione dell'asse neutro rispetto all'asse x(angolo
             acuto, misurato dall'asse x all'asse neutro, positivo se
             antiorario).
```

Steel Young's modulus equal to 200000N/mm2: this value cannot be changed in Lisa©

Maximum compression stress in concrete block

Maximum tension in bolts

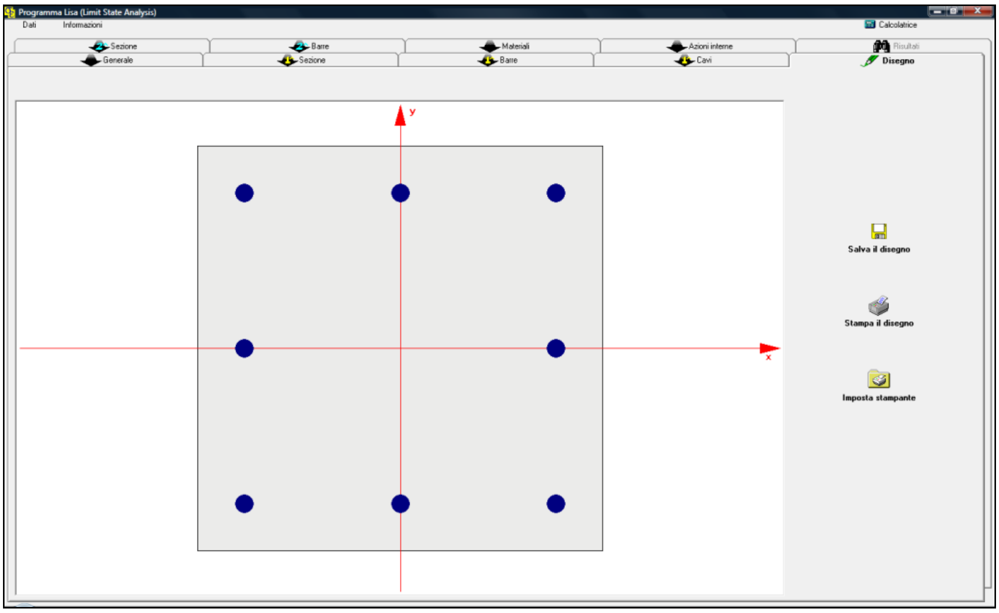


Figure C-42 The section defined in Lisa©

Results are slightly different from CSE to Lisa©, because the second program uses a Young's modulus for the steel equal 200000N/mm^2 (as shown in previous listing) while CSE uses 210000N/mm^2. This difference produces different forces distribution between steel and concrete. We will see shortly the case with no-tension linear elastic law, where E modulus is not used and the results of the two programs are equal.

[N/mm^2]	**CSE**	**Lisa**	**% diff**
Steel Young's modulus	210000	200000	-5.0%
σ_{max} concrete	2.986	3.024	1.3%
σ_{max} steel	28.2	27.82	-1.4%

% diff is the percentage difference between the values of CSE and Lisa: $\frac{x_{Lisa}-x_{CSE}}{x_{Lisa}}\times 100$

C.6.1.2 Combined compression and two bending moments

In a copy of the previous model (*Validation_Bearing_2.CSE*) we add also a bending moment about column weak axis, equal to 10^{7}Nmm. CSE results are given in following figure.

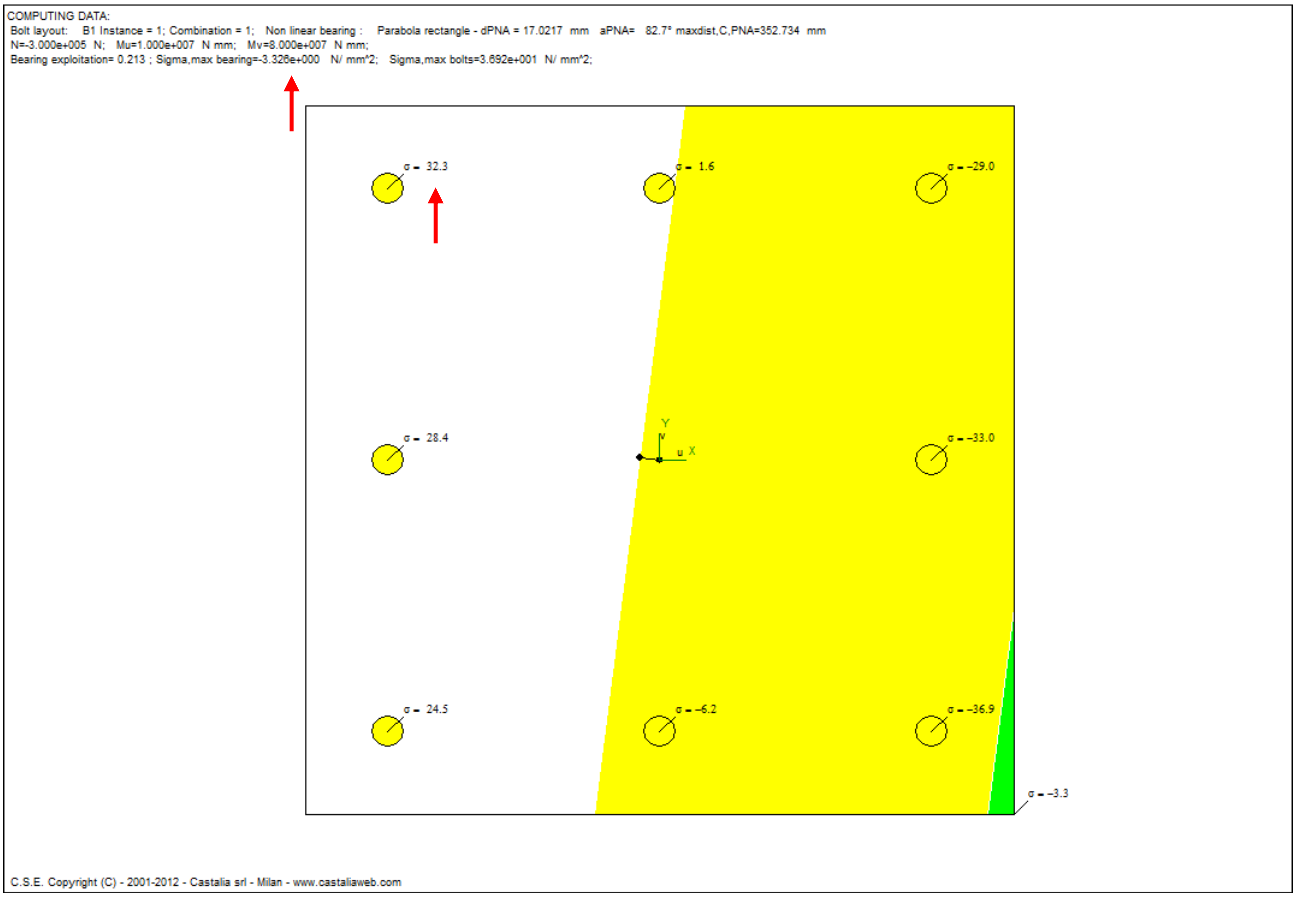


Figure C-43 Bearing surface check results

σ_c^- maximum compression stress in concrete block: 3.326N/mm^2

σ_b^+ maximum stress in bolts: 32.33N/mm^2

The following listing gives Lisa© results (see previous paragraph for more explanations).

```
Programma LISA     Ver. 3.5                              Copyright © Castalia s.r.l.
(http://www.castaliaweb.com)

Validazione CSE


Coordinate dei nodi della sezione:

           X [cm]     Y [cm]
   1*       30.00      30.00
   2*      -30.00      30.00
   3*      -30.00     -30.00
   4*       30.00     -30.00


Posizione ed area delle armature:

           Xs[cm]     Ys[cm]    As[cm²]
   1*      -23.00     -23.00       5.72
   2*      -23.00       0.00       5.72
```

```
   3*      -23.00     23.00      5.72
   4*        0.00    -23.00      5.72
   5*       23.00    -23.00      5.72
   6*       23.00      0.00      5.72
   7*        0.00     23.00      5.72
   8*       23.00     23.00      5.72


Caratteristiche meccaniche dei materiali:

Resistenza di calcolo del calcestruzzo.......=      15.625   [N/mm²]
Deformazione EPSILONco del calcestruzzo......=       0.002000
Deformazione ultima del calcestruzzo.........=       0.003500
Resistenza di progetto a rottura dell'acciaio
ordinario (ftk/Gammas).......................=     373.91     [N/mm²]
Resistenza di progetto allo snervamento dello
acciaio ordinario (fyk/Gammas)...............=     373.91     [N/mm²]
Modulo di Young dell'acciaio ordinario.......=  200000.00     [N/mm²]
Deformazione ultima di calcolo...............=       0.010000
Deformazione caratteristica ultima...........=       0.120000



Condizione di carico N°  1:

Azioni interne:
Nz=      300.00 [kN]  (positiva di compressione)
Mx=       10.00 [kNm] (positivo se comprime le fibre per x>0)
My=       80.00 [kNm] (positivo se comprime le fibre per y>0)

Posizione dell'asse neutro:  Xn  =        -11.00  [cm]
                             Yn  =         -1.41  [cm]
                             beta=         -0.127 [rad]

Deformazione massima nel calcestruzzo........=       0.000229
Tensione massima nel calcestruzzo............=       3.374    [N/mm²]
Deformazione minima nell'armatura ordinaria..=      -0.000159
Tensione minima nell'armatura ordinaria......=     -31.89     [N/mm²]

La misura della sicurezza è positiva.


Nota:  Si assumono positive le tensioni e le deformazioni di compres-
       sione. Pertanto, con la dicitura 'Tensione minima nell'armatu-
       ra ordinaria' si intende la tensione dell'armatura piu' solle-
       citata a trazione.
       Xn  = intersezione dell'asse neutro con l'asse x;
       Yn  = intersezione dell'asse neutro con l'asse y;
       beta= inclinazione dell'asse neutro rispetto all'asse x(angolo
             acuto, misurato dall'asse x all'asse neutro, positivo se
             antiorario).
```

As for the previous case, there are slightly different results due to the difference in Young's modulus (210000N/mm^2 for CSE, 200000N/mm^2 for Lisa).

[N/mm^2]	**CSE**	**Lisa**	**% diff**
Steel Young's modulus	210000	200000	-5.0%
σ_{max} concrete	3.326	3.374	1.4%
σ_{max} steel	32.3	31.89	-1.3%

% diff is the percentage difference between the values of CSE and Lisa: $\frac{x_{Lisa} - x_{CSE}}{x_{Lisa}} \times 100$

C.6.2 No-tension linear elastic constitutive law

In the following cases, we will use a different constitutive law for the constraint block; a no-tension linear elastic constitutive law with a maximum compression limit.

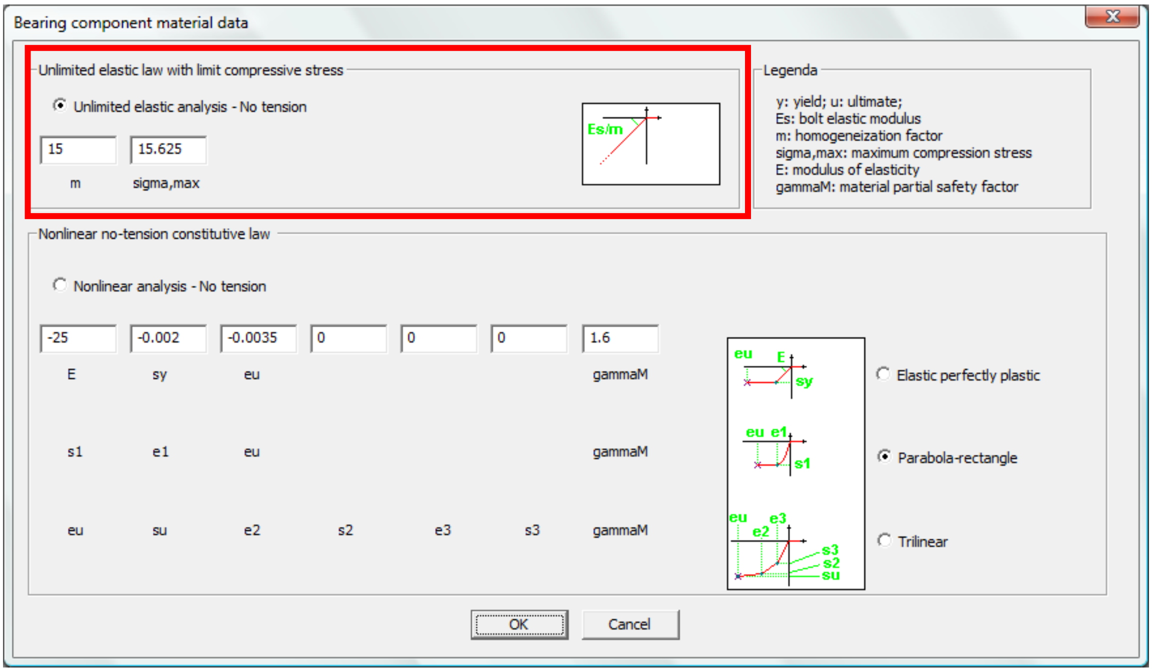


Figure C-44 Bearing surface constitutive law (units: N, mm)

Concrete elastic modulus is defined dividing bolts modulus (steel) by a homogenization factor *m*. With the defined value (*m*=15) concrete modulus is 1/15 of steel modulus. Limit compression in concrete is defined as 15.625N/mm^2.

C.6.2.1 Combined compression and bending moment

The model used here (*Validation_Bearing_3.CSE*) is a copy of the one used for combined compression and bending with no-tension parabola rectangle law (*Validation_Bearing_1.CSE*, compression 3*10^{5}N and bending moment about column strong axis 8*10^{7}Nmm). In current model the constitutive law was modified, according to Figure C-44, to define a no-tension linear elastic constitutive law. CSE results are shown in next figure.

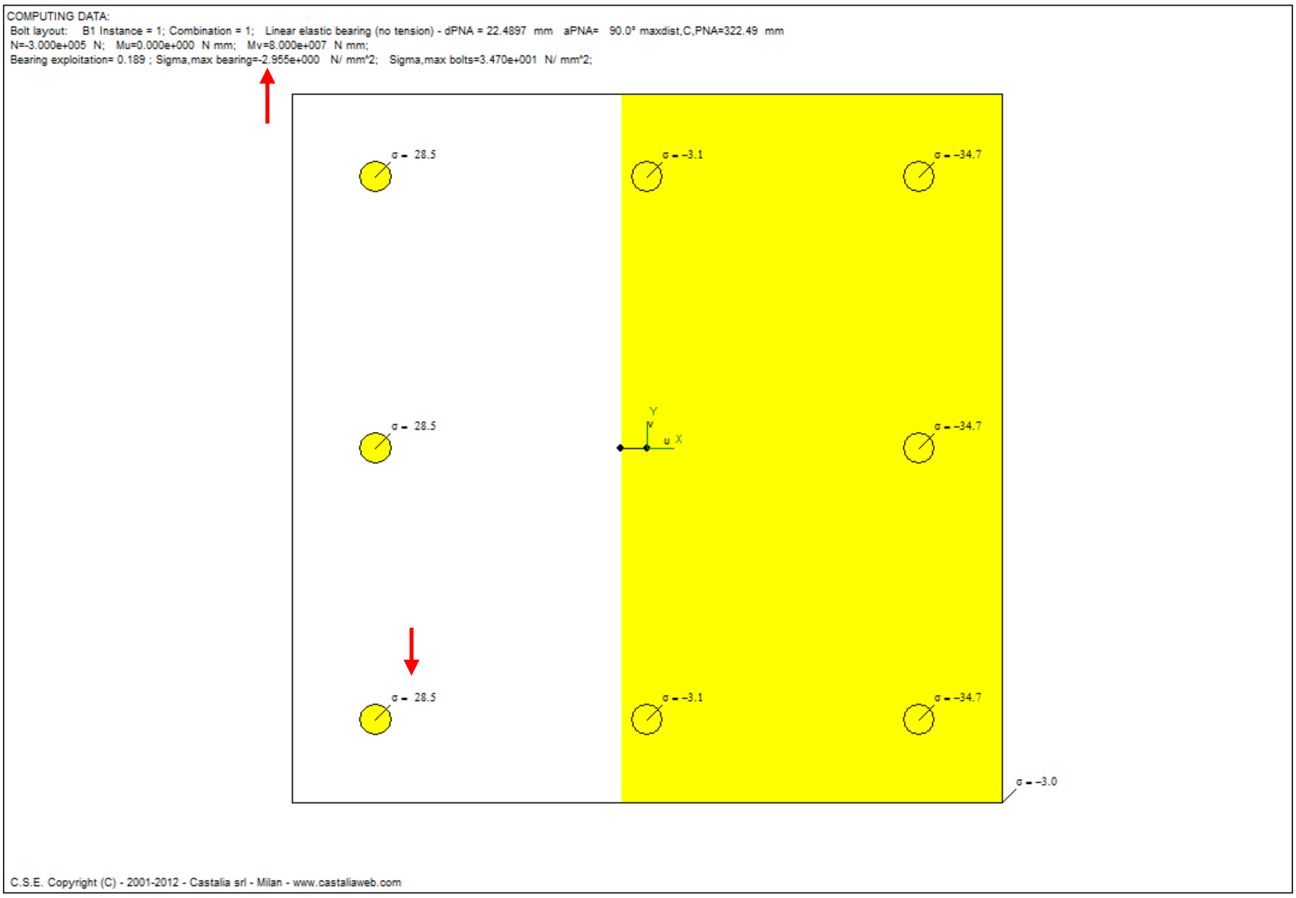


Figure C-45 Bearing surface check results

σ_c^- maximum compression stress in concrete block: 2.955N/mm^2

σ_b^+ maximum stress in bolts: 28.5N/mm^2

The following listing prints Lisa© results, computed through an analysis in cracked condition.

```
Programma LISA     Ver. 3.5                                    Copyright © Castalia s.r.l.
(http://www.castaliaweb.com)

Validazione CSE


Coordinate dei nodi della sezione:

           X [cm]     Y [cm]
   1*       30.00      30.00
   2*      -30.00      30.00
   3*      -30.00     -30.00
   4*       30.00     -30.00


Posizione ed area delle armature:

           Xs[cm]     Ys[cm]    As[cm²]
```

```
   1*      -23.00    -23.00      5.72
   2*      -23.00      0.00      5.72
   3*      -23.00     23.00      5.72
   4*        0.00    -23.00      5.72
   5*       23.00    -23.00      5.72
   6*       23.00      0.00      5.72
   7*        0.00     23.00      5.72
   8*       23.00     23.00      5.72


Caratteristiche meccaniche dei materiali:

Coefficiente di omogeneizzazione n .........=      15.00



Condizione di carico N°  1:

Azioni interne:
Nz=      300.00 [kN]  (positiva di compressione)
Mx=        0.00 [kNm] (positivo se comprime le fibre per x>0)
My=       80.00 [kNm] (positivo se comprime le fibre per y>0)

Posizione dell'asse neutro:  Xn  =      infinito
                             Yn  =         -2.25  [cm]
                             beta=          0.000 [rad]

Tensione massima nel calcestruzzo...........=       2.954    [N/mm²]
Tensione minima nell'armatura ordinaria......=     -28.51    [N/mm²]


Nota:  Si assumono positive le tensioni e le deformazioni di compres-
       sione. Pertanto, con la dicitura 'Tensione minima nell'armatu-
       ra ordinaria' si intende la tensione dell'armatura piu' solle-
       citata a trazione.
       Xn  = intersezione dell'asse neutro con l'asse x;
       Yn  = intersezione dell'asse neutro con l'asse y;
       beta= inclinazione dell'asse neutro rispetto all'asse x(angolo
             acuto, misurato dall'asse x all'asse neutro, positivo se
             antiorario).
```

The results of the two programs are the same:

[N/mm^2]	**CSE**	**Lisa**	**% diff**
σ_{max} concrete	2.955	2.954	-0.03%
σ_{max} steel	28.5	28.51	-0.04%

% diff is the percentage difference between the values of CSE and Lisa: $\frac{x_{Lisa} - x_{CSE}}{x_{Lisa}} \times 100$

C.6.2.2 Combined compression and two bending moments

The model used (*Validation_Bearing_4.CSE*) is similar to the one used previously for combined compression and two bendings with no-tension parabola-rectangle law (*Validation_Bearing_2.CSE*). In current model the constitutive law was modified, according to Figure C-44, to define a no-tension linear elastic constitutive law. CSE results are shown in next figure.

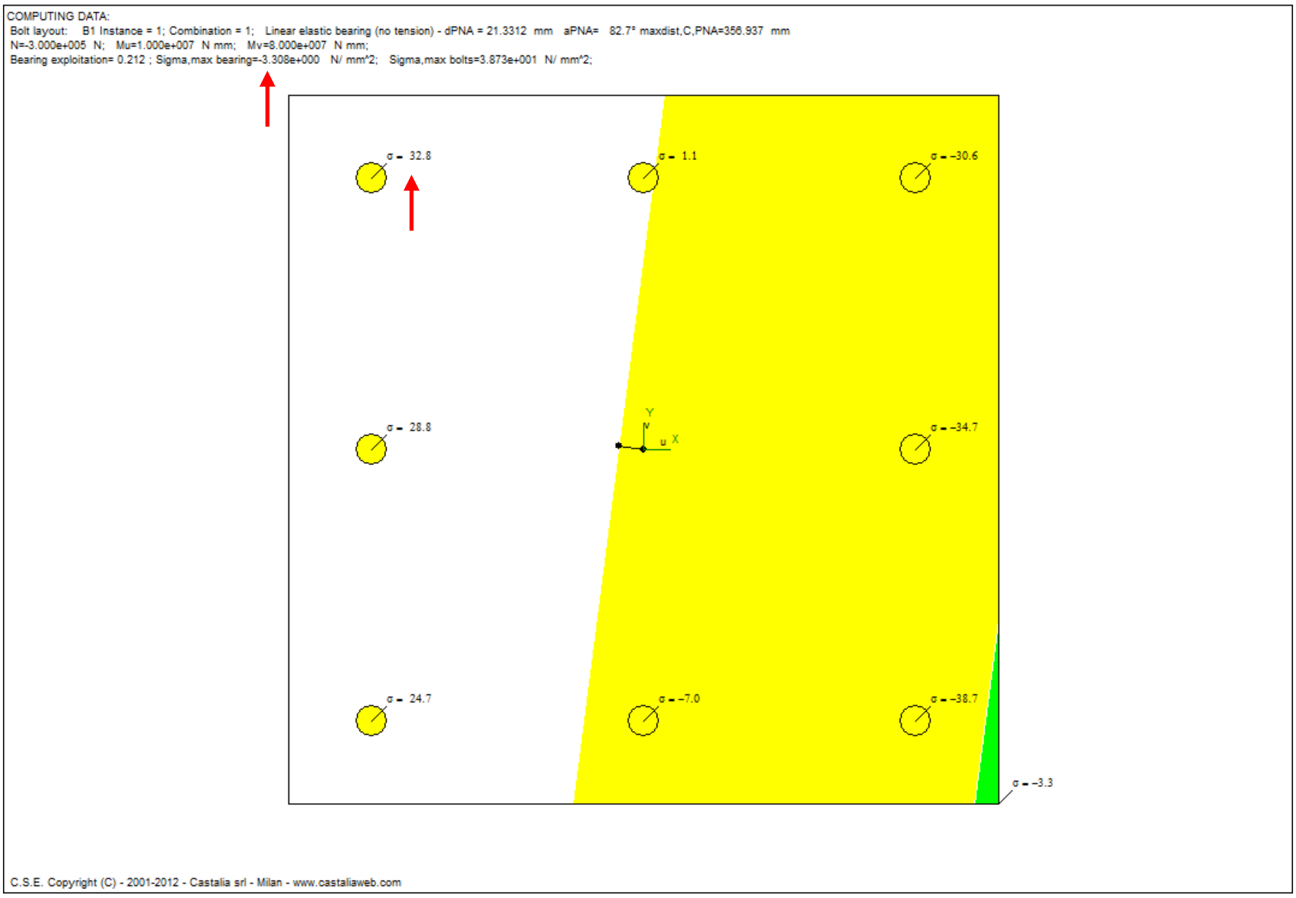


Figure C-46 Bearing surface check results

σ_c^- maximum compression stress in concrete block: 3.308N/mm^2

σ_b^+ maximum stress in bolts: 32.8N/mm^2

The following listing prints Lisa© results, computed through an analysis in cracked condition.

```
Programma LISA     Ver. 3.5                              Copyright © Castalia s.r.l.
(http://www.castaliaweb.com)

Validazione CSE


Coordinate dei nodi della sezione:

          X [cm]    Y [cm]
   1*      30.00     30.00
   2*     -30.00     30.00
   3*     -30.00    -30.00
   4*      30.00    -30.00


Posizione ed area delle armature:

          Xs[cm]    Ys[cm]   As[cm²]
```

```
   1*      -23.00    -23.00      5.72
   2*      -23.00      0.00      5.72
   3*      -23.00     23.00      5.72
   4*        0.00    -23.00      5.72
   5*       23.00    -23.00      5.72
   6*       23.00      0.00      5.72
   7*        0.00     23.00      5.72
   8*       23.00     23.00      5.72


Caratteristiche meccaniche dei materiali:

Coefficiente di omogeneizzazione n .........=      15.00



Condizione di carico N°  1:

Azioni interne:
Nz=      300.00 [kN]  (positiva di compressione)
Mx=       10.00 [kNm] (positivo se comprime le fibre per x>0)
My=       80.00 [kNm] (positivo se comprime le fibre per y>0)

Posizione dell'asse neutro:  Xn  =        -16.83  [cm]
                             Yn  =         -2.15  [cm]
                             beta=         -0.127 [rad]

Tensione massima nel calcestruzzo...........=       3.308    [N/mm²]
Tensione minima nell'armatura ordinaria.....=     -32.80     [N/mm²]


Nota:  Si assumono positive le tensioni e le deformazioni di compres-
       sione. Pertanto, con la dicitura 'Tensione minima nell'armatu-
       ra ordinaria' si intende la tensione dell'armatura piu' solle-
       citata a trazione.
       Xn  = intersezione dell'asse neutro con l'asse x;
       Yn  = intersezione dell'asse neutro con l'asse y;
       beta= inclinazione dell'asse neutro rispetto all'asse x(angolo
             acuto, misurato dall'asse x all'asse neutro, positivo se
             antiorario).
```

The results of the two programs are the same:

[N/mm^2]	CSE	Lisa	diff %
σ_{max} concrete	3.308	3.308	0.00%
σ_{max} steel	32.8	32.8	-0.00%

% diff is the percentage difference between the values of CSE and Lisa: $\frac{x_{Lisa}-x_{CSE}}{x_{Lisa}}\times 100$

C.7 USER'S CHECKS

C.7.1 Introduction

Users can add conditions to CSE models. These condition can be *preconditions* or *additional checks*; they are inequalities that are automatically checked by the program.

Preconditions are checked before all the other automatic checks, they can be geometrical checks or other controls that user wants to test.

Additional checks are associated to a component (member, cleat or joiner) and are computed by CSE in each load combination and jnode instance, giving an utilization factor which is compared to those due to other checks, to find the maximum one. User can define formulae to add new check criteria parallel to other automatic checks (cross-check) or additional checks to test some particular conditions, maybe not covered by the Standards. Internal forces in members or joiners can be used to define additional checks.

C.7.2 Preconditions

Consider a single sided beam to beam (*Validation_User_1.CSE*) similar to the one used in B.4.1. In current model we add a precondition, and enable user checks in check settings. This precondition will control if supported beam total height is less than supporting beam web net height (Figure C-48). Note well: CSE has an automatic check for overlapping between components, so this additional control is defined only to check CSE computation.

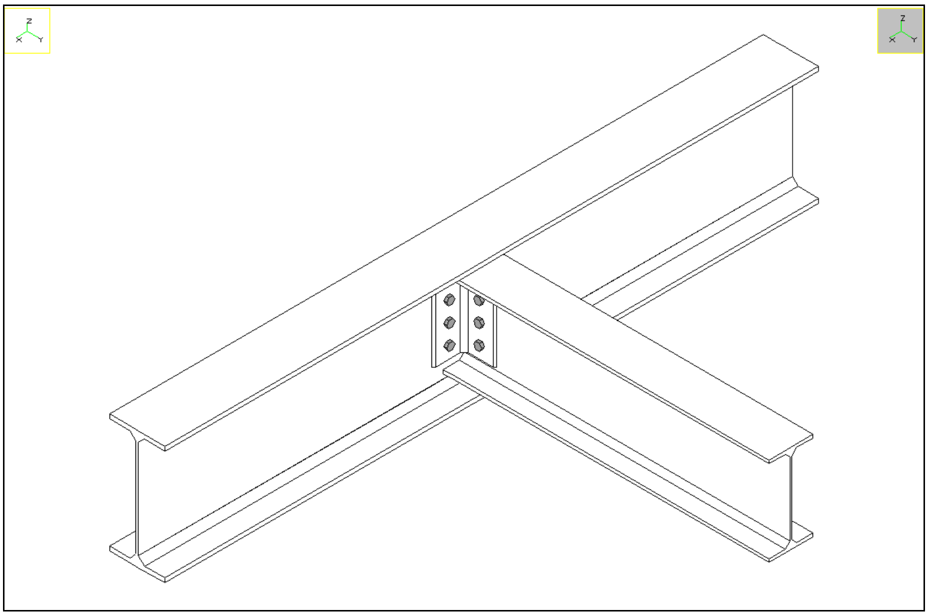


Figure C-47 3D view of the joint

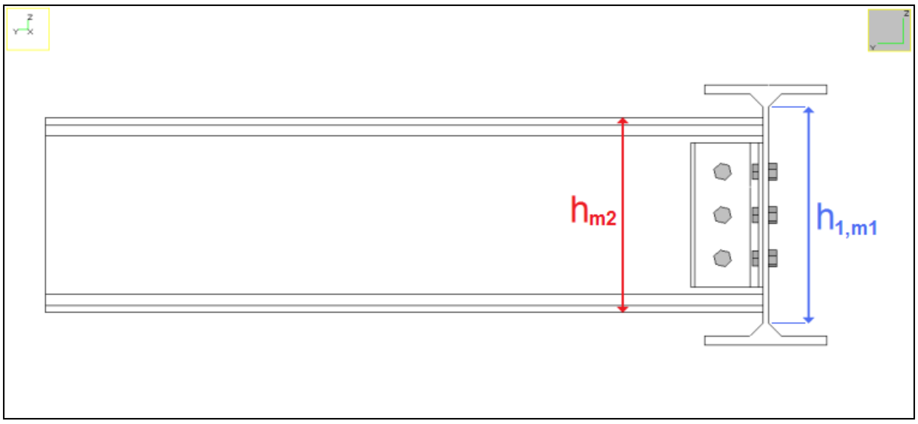


Figure C-48 Supported beam total height and supporting beam web net height

Following figure shows the precondition `m2.h < m1.h1` added in CSE (*m2.h* is supported beam total height, *m1.h1* is supporting beam web net height).

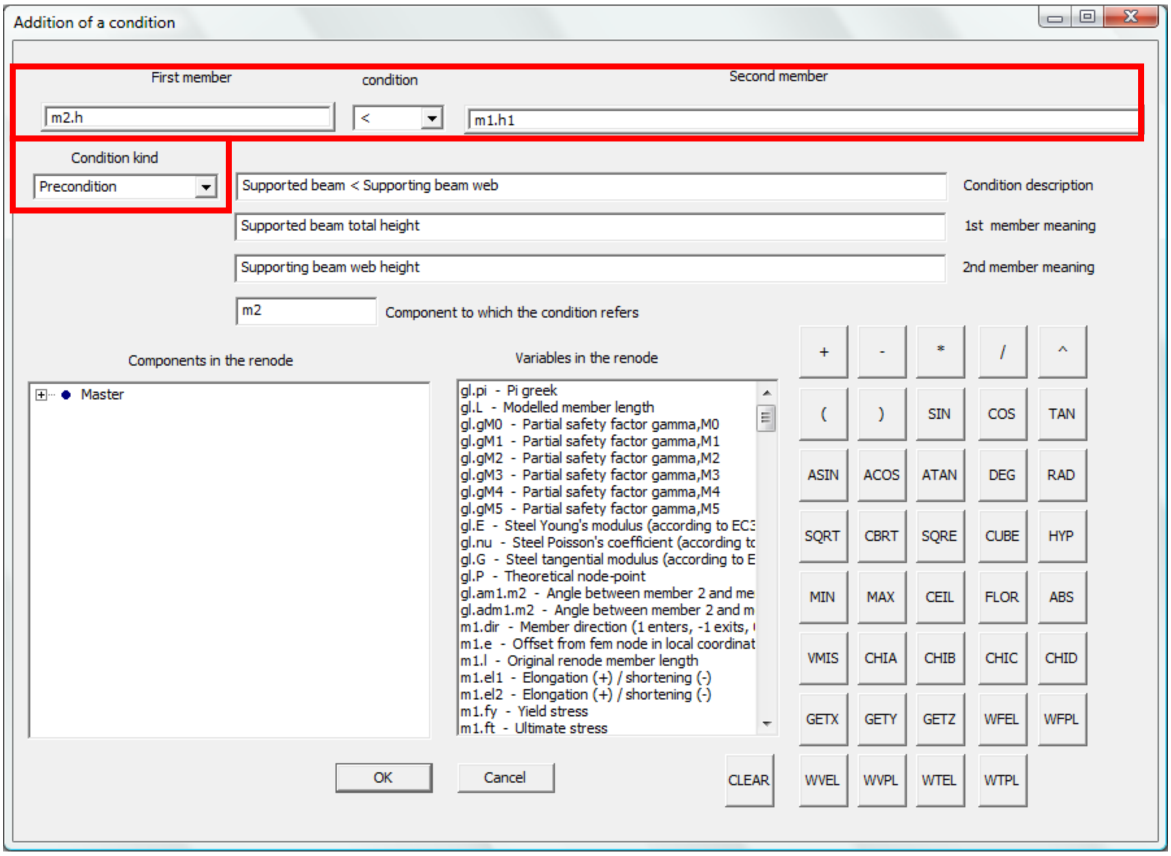


Figure C-49 Dialog box for precondition definition

It is easy in this case to hand compute the precondition, according to these sizes.

Supported beam (m2): IPE 270 total height: $\boldsymbol{h_{m2}}$ **= 270mm**

Supporting beam (m1): IPE 360 total height: h_{m1} = 360mm
flange thickness: $t_{f,m1}$ = 12.7mm
radius: r_{m1} = 18mm
web net height: $\boldsymbol{h_{1,m1} = h_{m1} - 2t_{f,m1} - 2r_{m1} = 298.6\text{mm}}$

Supported beam total height (270mm) is less than supporting beam web net height (298.6mm). Precondition is checked, with a ratio equal to 270/298.6=0.9.

If a precondition is not checked (ratio >1), the analysis of the joint stops and CSE asks the user if analysis must be continued or interrupted. In this case precondition is checked and the analysis ends normally. Precondition computation is printed in output listing, at the beginning of automatic checks section.

```
------------------------
User checks description
------------------------

---1--- Precondition of component (if null general precondition) m2

               m2.h < m1.h1
               Supported beam total height < Supporting beam web height
               Supported beam < Supporting beam web

*****************************
Beginning of automatic checks
*****************************

----------------------------
Users's preconditions check
----------------------------

Check                          Description          vL           vR        Expl

  1       Supported beam < Supporting beam web  2.700e+002  2.986e+002   0.904
```

C.7.3 User's additional checks

In *Validation_User_2.CSE* some modifications were made to the model used in C.5 for cleats check: bolt bearing check and cleats simplified check are not included in checks settings, while user's checks are enabled.

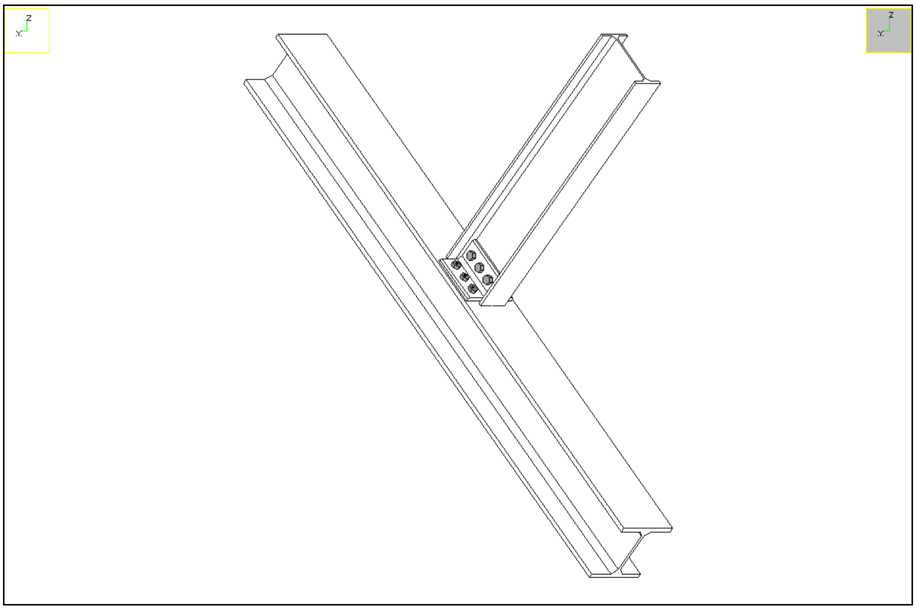


Figure C-50 3D view of the model

The additional condition we are going to define is a simplified check for cleat net section resistance under axial force (we will not consider bending moment of transports in this simplified check). Considered net section is shown in Figure C-51.

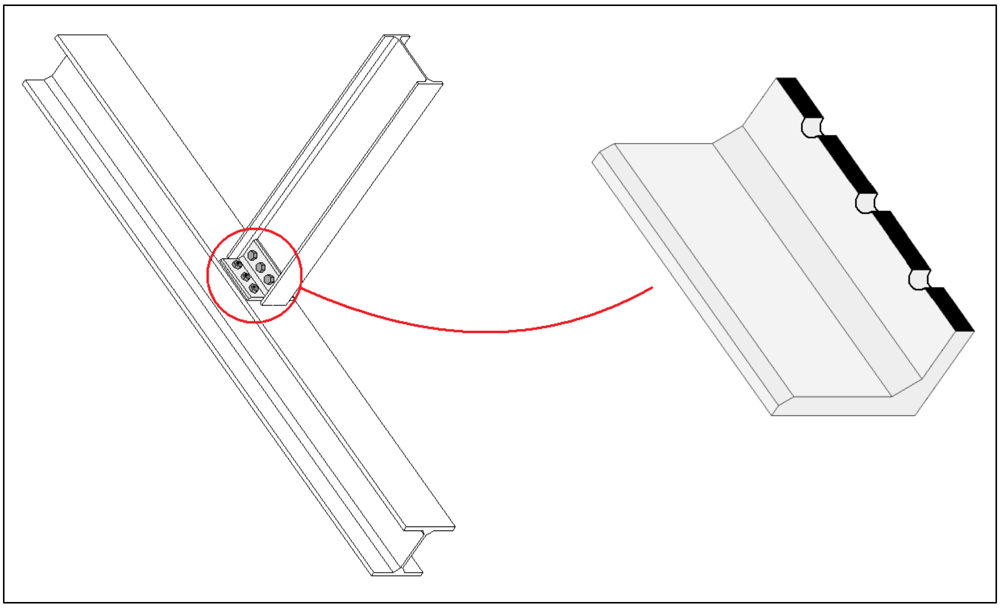


Figure C-51 Net section (in black)

The simplified check we are going to add is:

$$\frac{N}{A_{net} \cdot f_y} < 1$$

Axial force in net section must be less than net sections resistance to axial force (assuming a safety factor equal to 1). Net area is equal to total are less bolt holes area.

$$A_{net} = (L1.L - B1.n * B1.dh) * B1.a$$

where *B1.n* = 3 is the number of bolts in B1 bolt layout, *B1.dh* = 18mm is hole diameter for M16 bolts, *L1.L* = 159mm is cleat length and *L1.a* = 12mm is cleat thickness. We get:

$$A_{net} = (159\text{mm} - 3 * 18\text{mm}) * 12\text{mm} = 1260\text{mm}^2$$

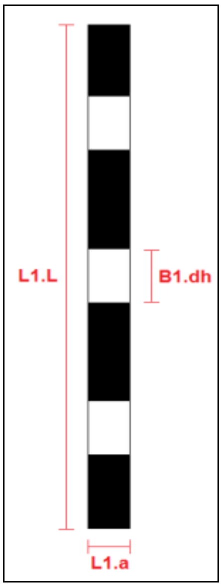


Figure C-52

Net section resistance to axial force is:

$$A_{net} * f_y = 1260\text{mm}^2 * 275\text{N/mm}^2 = 346500\text{N}$$

Since there are two symmetrical angle cleats, axial force in considered net section is equal to half of axial force in slave member (m2).

$$N = N_{m2} / 2 = 83712\text{N} / 2 = 41856\text{N}$$

Utilization factor is equal to:

$$\frac{N}{A_{net} \cdot f_y} = \frac{41856N}{346500N} = 0.121$$

We add the following condition in CSE:

```
m2.N / 2 < Nmax.L1net
```

where *m2.N* is the axial force in m2 in each combination and instance (here we have just 1 combination and 1 instance), *Nmax.L1net*, is an additional variable defined as follow:

```
Nmax.L1net = ( L1.L - B1.n * B1.dh ) * L1.a * L1.fy
```

It is net section resistance to axial force (parameters have been previously explained).

NOTE WELL: the additional variable was used in order to check also this feature of the program, but the condition could be also added without the additional variable, defining directly the whole formula: `m2.N / 2 < ( L1.L - B1.n * B1.dh ) * L1.a * L1.fy`

The following figures show CSE dialog boxes used to add the variable and the condition, to define the desired check. Condition is associated to component L1: computed utilization factor will be associated to this cleat.

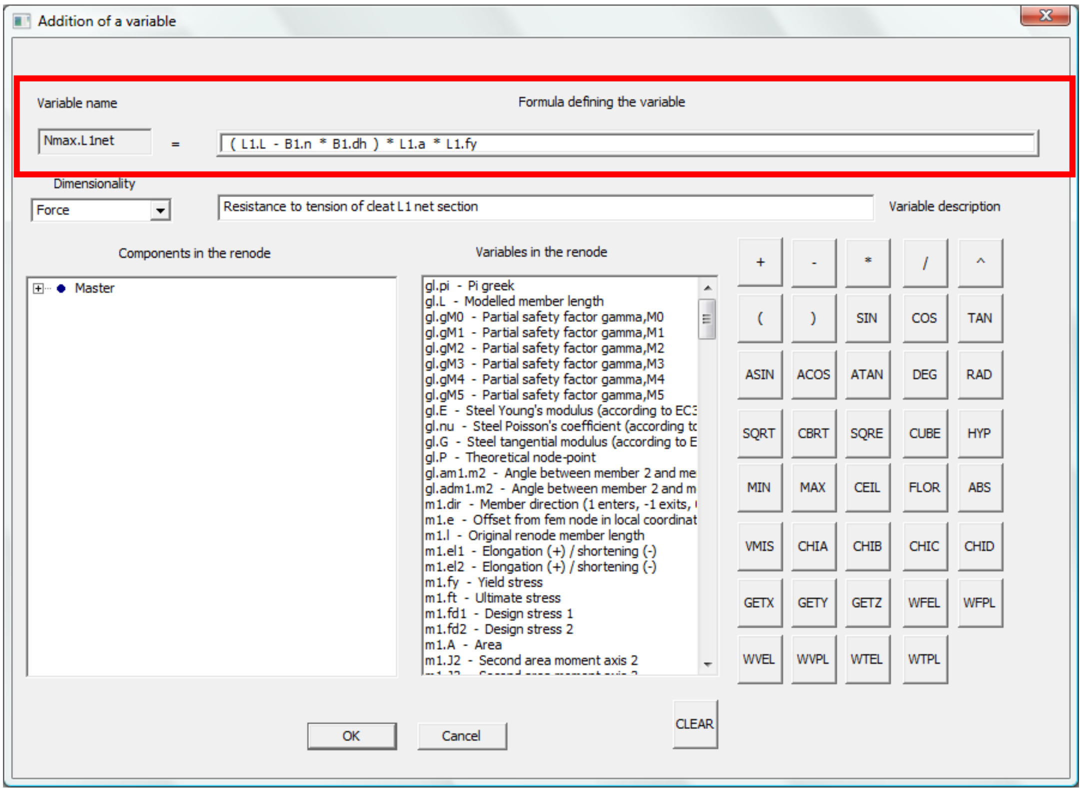


Figure C-53 Additional variable

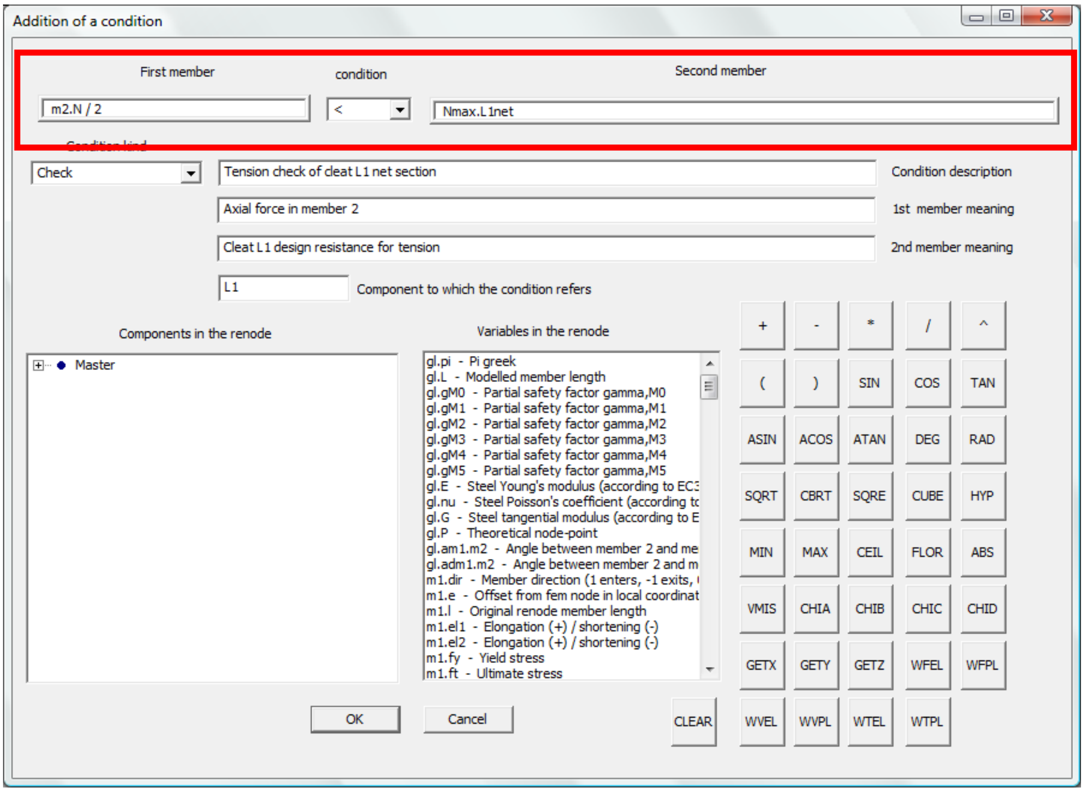


Figure C-54 Additional check condition

CSE result is the same of our hand computation.

```
---------------------------------------------------------
Throughs whose worst exploitation is due to user's checks
---------------------------------------------------------

 Inst  Combi  Name  Check          Description                        vL          vR         Expl

    1      1    L1      1    Tension check of cleat L1 net section  4.186e+004  3.465e+005    0.121
```

C.8 BOLT LAYOUTS FLEXIBILITY INDEX

C.8.1 Introduction

The translational stiffness of a bolt layout without bearing surface depends on bolts number (*n*), bolts radius (*r*) and bolts net length (*l*), with the following relationships:

- translational stiffness is proportional to: *n* and r^4
- and it is inversely proportional to l^3

In CSE it is possible to increase or reduce the translational stiffness of a bolt layout through the *flexibility index* (*f*). In addition to previous relationships, the translational stiffness is also

- inversely proportional to f^3

In part B of this document, all the tests were made with f=1. Now we are going to see what happens when flexibility index is modified.

Flexibility index can be used to drive forces distribution in different bolt layouts. Consider, for example, a bolted cover plate splice joint between two H sections, with shear only bolt layouts: to model bolt bearing on the web and subsequent increment of the force carried by bolts on the flanges, it is possible to define f>1 for web bolt layouts, to reduce their translational stiffness.

C.8.2 Axial force

Consider the bolted cover plate splice joint in tension used in B.2.1.4 (model *Validation_SP_1_3.CSE*).

As computed in B.2.1.4, distribution of applied axial force in web and flanges bolt layout is not proportional to web and flanges area, because force distribution depends also on bolt layouts stiffness.

Applied force is 4.204*10^6N; HEB300 total area is A=14908mm^2; flanges area is A_f=2bt_f=2*300mm*19mm=11400mm^2. If we assume the force on flanges as proportional to A_f/A ratio, we get the following force acting on flanges bolt layouts:

$$N_f = N\frac{A_f}{A} = 4.204\cdot10^6\,N\cdot\frac{11400mm^2}{14908mm^2} = 3.215\cdot10^6\,N$$

As seen in B.2.1.4, total force carried by the two bolt layouts on member flange is equal to 2*1.082*10^6N=2.164*10^6N, in CSE computation (see mentioned paragraph for more explanations). This value is less than the one computed according to A_f/A ratio. If we want to drive forces distribution to be proportional to areas (assuming bolt bearing on the web) we can modify the flexibility index of web bolt layouts (see Figure C-55).

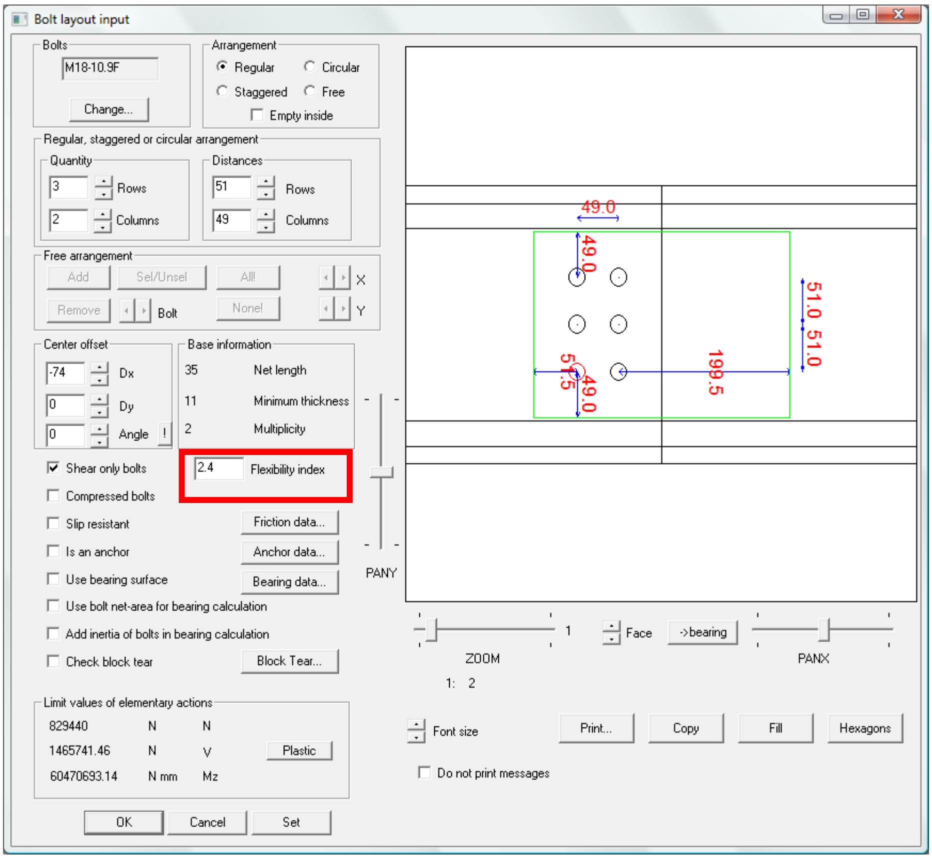


Figure C-55 Bolt layout data: flexibility index highlighted

Copies of the original model were made, with different flesibility index values for web bolt layouts (f_w).

$$f_w = 1 \rightarrow 1.7 \rightarrow 2.4 \rightarrow 5 \rightarrow 10 \rightarrow 20$$

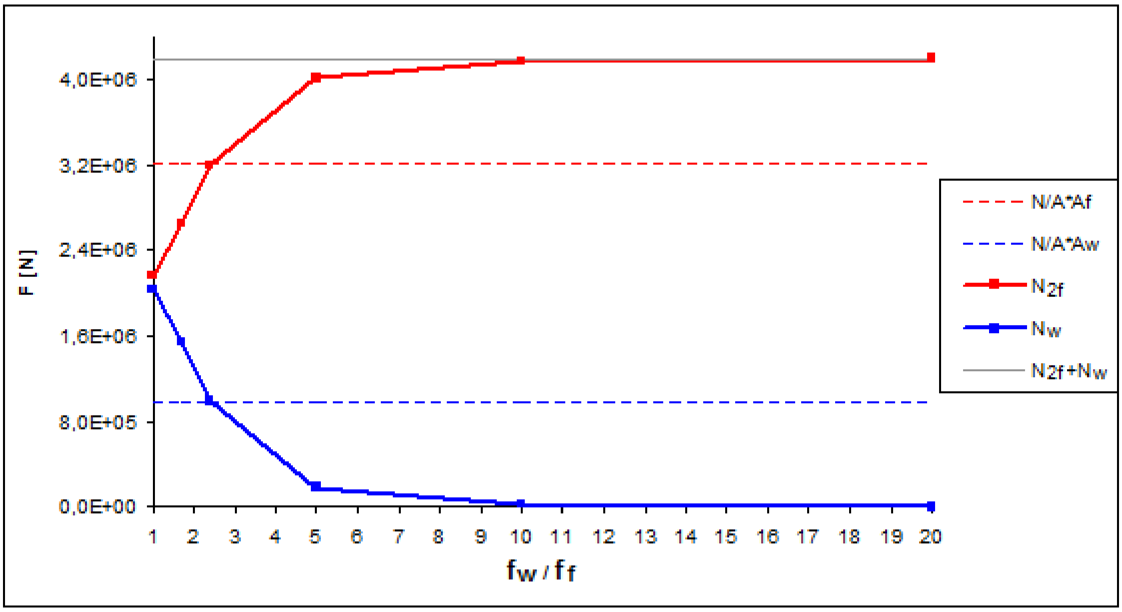
Flexibility index for flanges bolt layouts is fixed (f_f=1). When f_w increases, translational stiffness of web bolt layouts reduces, and load carried by bolt layouts increases, as shown in following table.

f_w / f_f	N_{2f}	N_w	Model name
1	2.164E+06	2.040E+06	*Validation_SP_1_3.CSE*
1.7	2.658E+06	1.546E+06	*Validation_SP_1_3_002.CSE*
2.4	3.207E+06	9.967E+05	*Validation_SP_1_3_003.CSE*
5	4.021E+06	1.834E+05	*Validation_SP_1_3_004.CSE*
10	4.179E+06	2.471E+04	*Validation_SP_1_3_005.CSE*
20	4.201E+06	3.119E+03	*Validation_SP_1_3_006.CSE*

Table C-1

N_{2f} is load carried by flanges bolt layouts (two layouts), N_w is the load carried by web bolt layout). These are the values computed by CSE and depend on flexibility index of bolt layouts. In following graphic, N_{2f} and N_w values according to different f_w values are shown.

N/A^*A_f and N/A^*A_w would be the force carried by flanges and web bolt layouts if distribution was proportional to A_f and A_w areas. $N_{2f}+N_w=N$ is applied force.



Graphic C-1

If flexibility index of web bolt layouts is f_w=2.4, forces distribution on flanges and web bolt layouts is proportional to flanges and web area (f_f=1 for flanges bolt layouts, because it is f_w/f_f ratio to drive forces distribution).

If f_w=10 (or more than 10, always with f_f=1), quite the whole force is carried by flanges bolt layouts, since web bolt layout translational stiffness is too small.

In the initial condition (f_w=1) members utilization is very high (>>1); the cause is bolt bearing due to web bolt layout (see components utilization envelope in Figure C-56). Following figures show components utilization envelope with f_w=1, 1.7, 2.4, 5, 10 and 20: members utilization start decreasing, because when f_w increases bolt bearing on web becomes smaller. Minimum exploitation is for f_w=5. After that value, member utilization start to increase, because bolt bearing due to flanges bolts layout becomes relevant, and it increases when translational stiffness of web bolt layouts decreases.

With f_w=10 and f_w=20 the exploitation is quite the same, because the load is carried by flanges only, and bolt bearing due to flanges bolt layouts is the most critical one.

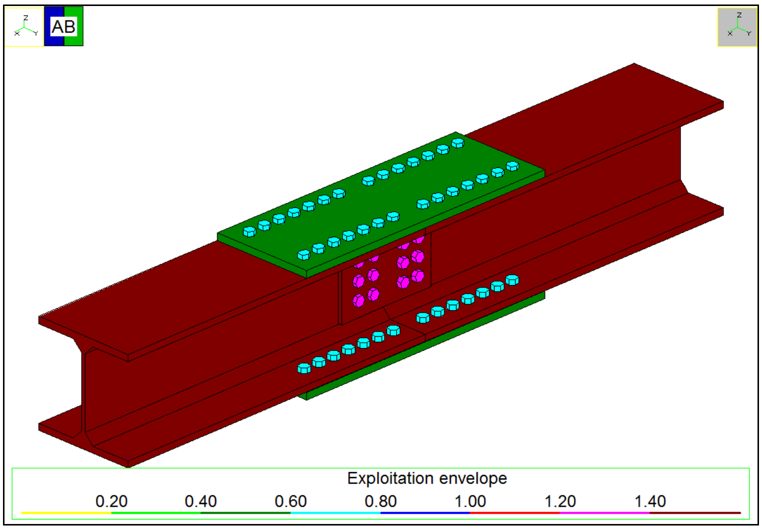


Figure C-56 Components utilization with f_w=1

```
-------------------------------------------------------------
Members whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

    Inst  Combi  Name    Boltlay   Bolt   Extr.     Sigma        Sigma M      Expl

    1      1      m1     B5         3       2    1.717e+003   4.443e+002   3.865 !!!
    1      1      m2     B6         3       2    1.717e+003   4.443e+002   3.865 !!!
```

B5 is web bolt layout.

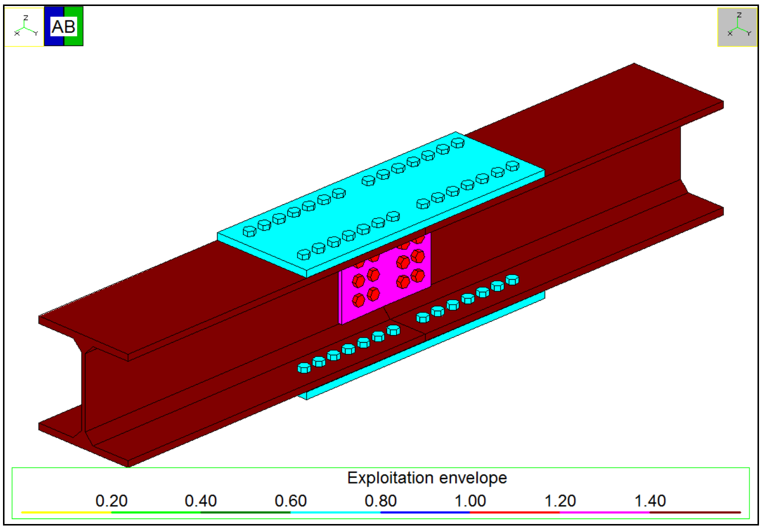


Figure C-57 Components utilization with f_w=1.7

```
-------------------------------------------------------------
Members whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

    Inst  Combi  Name    Boltlay   Bolt   Extr.     Sigma        Sigma M      Expl

    1      1      m1     B5         3       2    1.302e+003   4.443e+002   2.929 !!!
    1      1      m2     B6         3       2    1.302e+003   4.443e+002   2.929 !!!
```

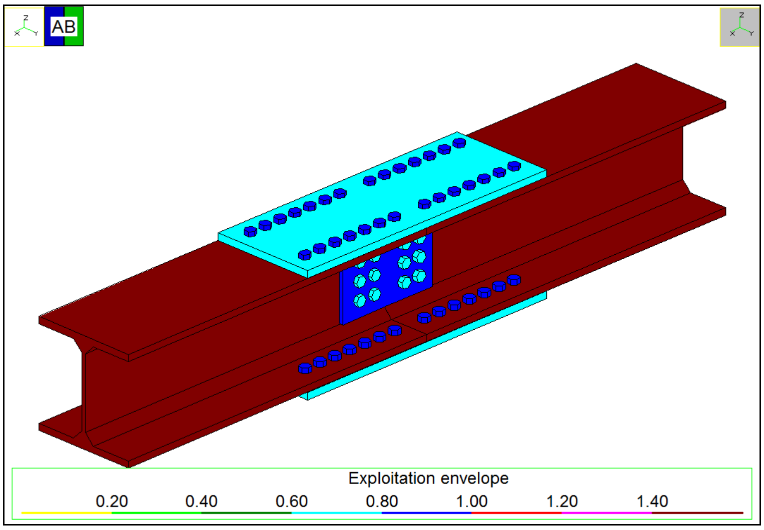


Figure C-58 Components utilization with f_w=2.4

```
-------------------------------------------------------------
Members whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

    Inst  Combi  Name   Boltlay   Bolt   Extr.     Sigma        Sigma M      Expl

    1      1     m1      B5        3        2    8.389e+002    4.443e+002    1.888 !!!
```

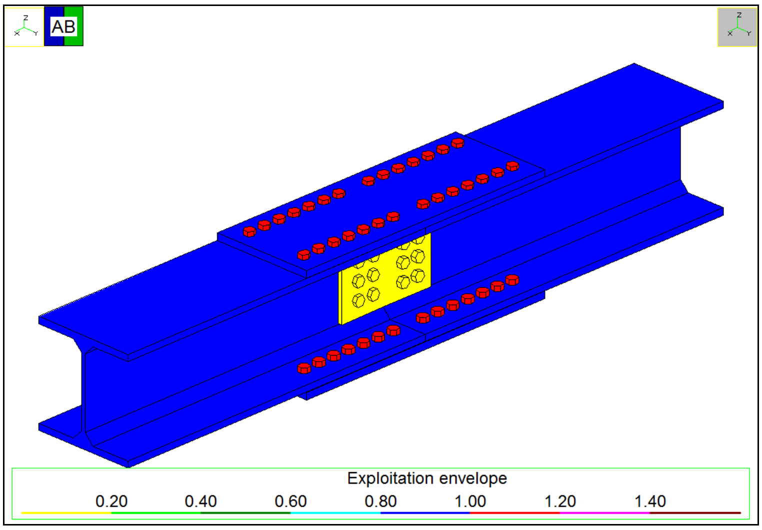


Figure C-59 Components utilization with f_w=5

```
-------------------------------------------------------------
Members whose maximum exploitation is due to bearing stresses
-------------------------------------------------------------

    Inst  Combi  Name   Boltlay   Bolt   Extr.     Sigma        Sigma M      Expl

    1      1     m1      B2        4        2    4.199e+002    4.200e+002    1.000
```

(B2 is flange bolt layout)

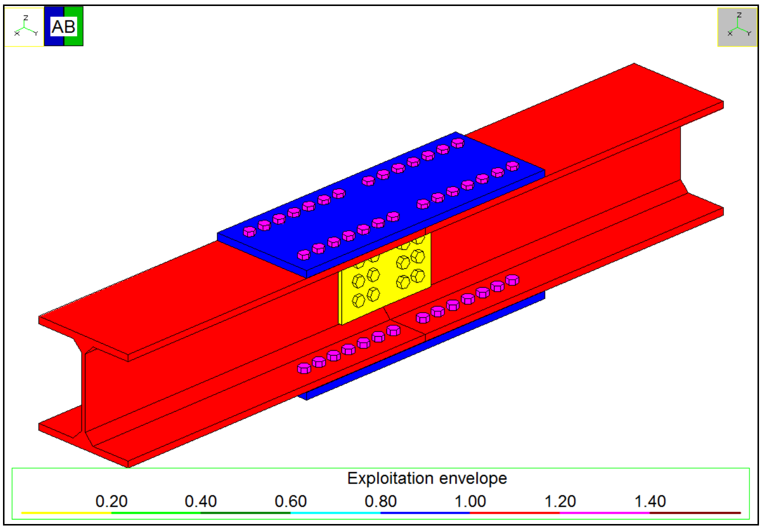


Figure C-60 Components utilization with f_w=10

Members whose maximum exploitation is due to bearing stresses

Inst	Combi	Name	Boltlay	Bolt	Extr.	Sigma	Sigma M	Expl	
1	1	m1	B2	4	2	4.364e+002	4.200e+002	1.039	*

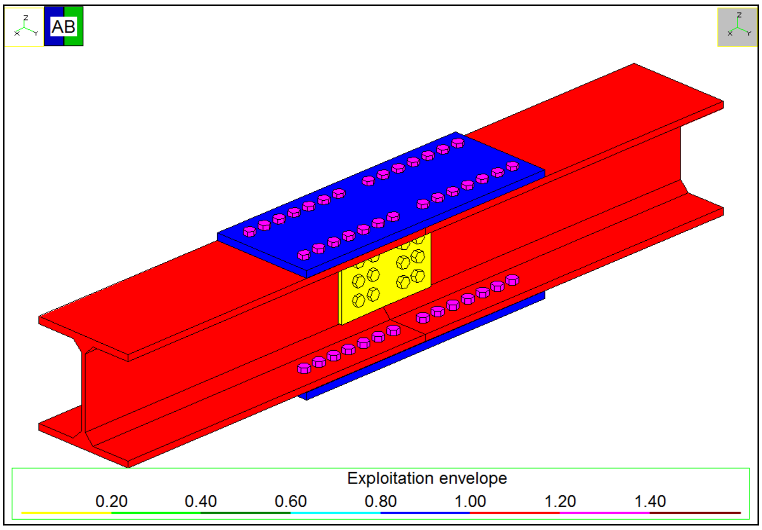


Figure C-61 Components utilization with f_w=20

Members whose maximum exploitation is due to bearing stresses

Inst	Combi	Name	Boltlay	Bolt	Extr.	Sigma	Sigma M	Expl	
1	1	m1	B2	3	2	4.387e+002	4.200e+002	1.045	*

A proper setting of bolt layouts flexibility index can provided the desired condition among different possible conditions; **all these possible conditions guarantee equilibrium**. User can set proper flexibility indexes to model the reduction of stiffness for some parts of the joint, driving forces to be carried by other parts.

C.8.3 Bending

A copy of the model used in paragraph B.2.1.2 was made (model *Validation_SP_1_1_FlexInd_2.4.CSE*). The splice joint is subjected to bending moment, and its geometry is the same of previous paragraph models. In current model, web bolt layouts flexibility index is set equal to 2.4, to see how CSE computes forces distribution for bending moment. The flexibility index assumed is the one providing an applied axial force distribution proportional to flanges and web area (see previous paragraph).

In the original model (see B.2.1.2) flanges bolt layout carried the 88% of applied load. A simplified computation of elastic moment distribution between flanges and web would give a 95.6% (see B.2.1.2). With flexibility index f_w=2.4 for web bolt layout, we have the following load carried by flanges bolt layout:

$$2 \cdot 1.6585 \cdot 10^6 N \cdot \frac{h}{2} = 2 \cdot 1.6585 \cdot 10^6 N \cdot \frac{300}{2} = 4.976 \cdot 10^8 Nmm$$

where $1.6585*10^6$N is the shear carried by flange bolt layout, in CSE computation:

```
------------------------------------------------------------------
Forces acting over bolt layouts at different extremes, global system
------------------------------------------------------------------
```

Id	Inst	Combi	Ext	Fx	Fy	Fz	Mx	My	Mz
B3	1	1	1	1.0687e-006	-1.6585e+006	2.1023e-006	-1.5176e+007	-8.9636e-006	-2.1371e-004
B3	1	1	2	-1.0687e-006	1.6585e+006	-2.1023e-006	-1.7166e+007	-1.1876e-005	2.1371e-004
B1	1	1	1	1.0687e-006	1.6585e+006	-2.1023e-006	1.5176e+007	-8.9634e-006	-2.1371e-004
B1	1	1	2	-1.0687e-006	-1.6585e+006	2.1023e-006	1.7166e+007	-1.1876e-005	2.1371e-004
B2	1	1	1	-1.0687e-006	1.6585e+006	1.8720e-006	1.5176e+007	8.9634e-006	-2.1371e-004
B2	1	1	2	1.0687e-006	-1.6585e+006	-1.8720e-006	1.7166e+007	1.1876e-005	2.1371e-004
B4	1	1	1	-1.0687e-006	-1.6585e+006	-1.8720e-006	-1.5176e+007	8.9634e-006	-2.1371e-004
B4	1	1	2	1.0687e-006	1.6585e+006	1.8720e-006	-1.7166e+007	1.1876e-005	2.1371e-004
B5	1	1	1	-4.5109e-006	-4.4711e-004	3.5405e-020	-2.5914e-003	2.5937e-005	1.3357e+007
B5	1	1	2	9.0217e-006	9.5804e-004	2.1018e-019	3.8112e-004	9.4483e-016	-2.6713e+007
B5	1	1	3	-4.5109e-006	-5.1093e-004	-2.4559e-019	2.9443e-003	-2.5937e-005	1.3357e+007
B6	1	1	1	-4.5109e-006	5.1315e-004	-2.4524e-019	2.9443e-003	2.5937e-005	1.3357e+007
B6	1	1	2	9.0217e-006	-9.6743e-004	2.0985e-019	3.2401e-004	9.3996e-016	-2.6713e+007
B6	1	1	3	-4.5109e-006	4.5429e-004	3.5387e-020	-2.5914e-003	-2.5937e-005	1.3357e+007

This distribution assigns to flanges bolt layouts the 94.4% of applied load; this distribution is close to the 95.6% computed considering distribution in cross section according to an elastic range (which is one of the possible ways to compute distribution).

Note well: in hand computations, there is not a single method to evaluate forces distribution in different bolt layouts. Flexibility index provides in CSE the possibility to drive forces distribution in order to get desired configuration. Assumptions must be coherent with the model: for example, we cannot assume that flanges bolt layout carrie the 90% of the load if we have only 2 bolts on the flanges and 20 bolts on the web.

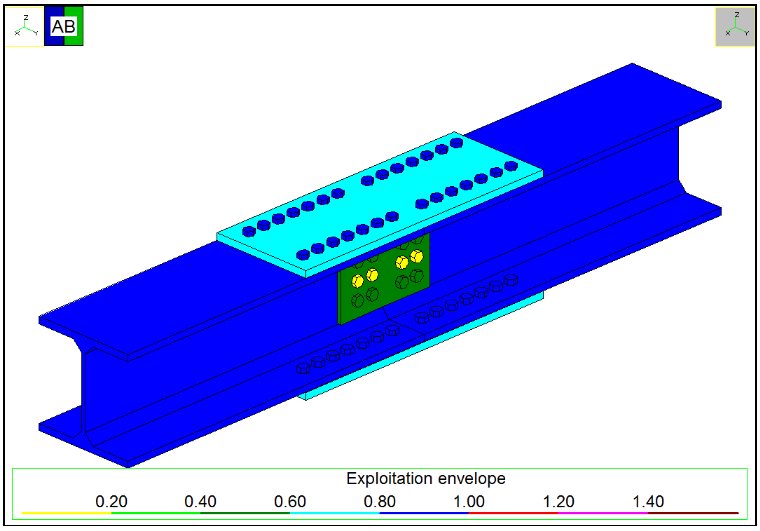


Figure C-62 Components utilization factor

C.9 BLOCK TEAR CHECKS

Now we are going to study block tear on supported beam in a single sided beam to beam joint (model *Validation_BlockTear_1.CSE*). Supported beam cross-section is IPE200, material is S235. Supported beam is double notched. Tension in supported member 133856N (see Figure C-65). There is no other applied force.

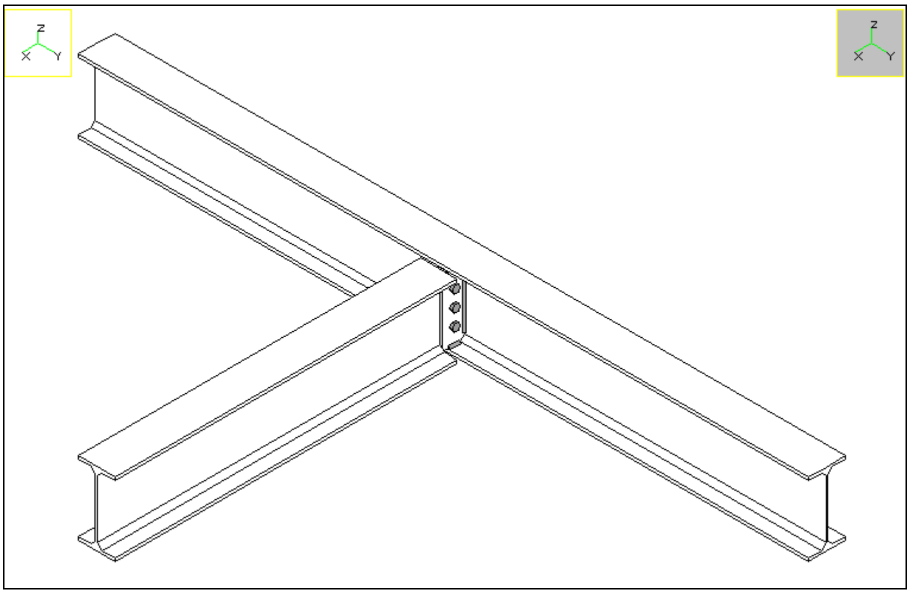


Figure C-63 3D view of the model

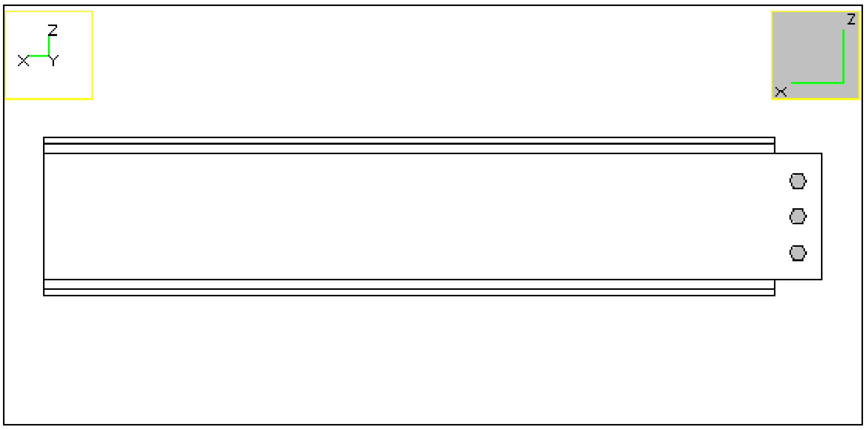


Figure C-64 Double notched supported beam

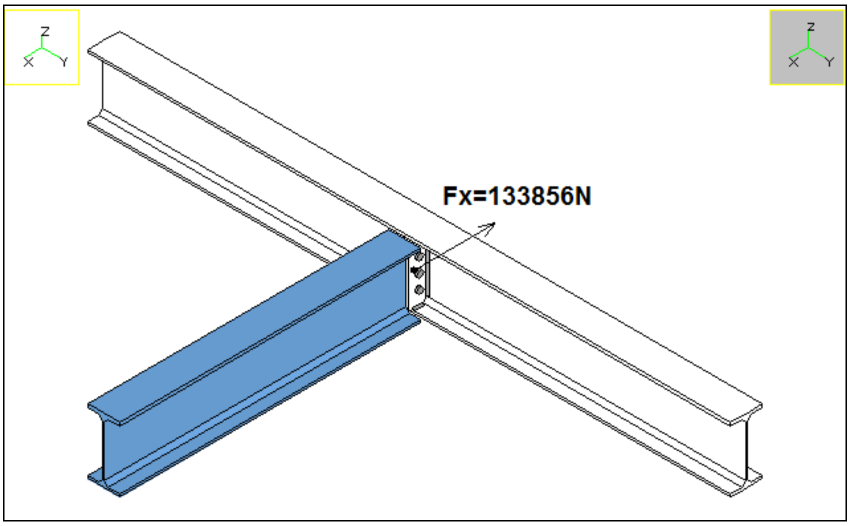


Figure C-65 Force exchanged between bolt layout and supported member

Tension in supported beam is equally distributed on the 3 bolts of the layout.

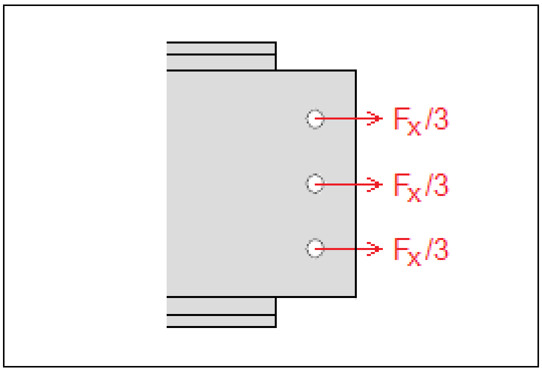


Figure C-66 Forces transferred by single bolts

Possible failure paths for block tearing are shown in Figure C-68; in addition to paths 2, 4 and 5 there are corresponding symmetrical paths, but it is not needed to compute twice the same conditions.

We will compute the design resistance of each path ($V_{eff,1,Rd}$) and we will compare it to applied force (F_a), finding the failure path with the higher $F_a/V_{eff,1,Rd}$ ratio. Design block tearing resistance according to EN1993-1-8:2005 is:

$$V_{eff,1,Rd} = f_u \cdot A_{nt} / \gamma_{M2} + \left(1/\sqrt{3}\right) \cdot f_y A_{nv} / \gamma_{M0}$$

Failure path 1 is subjected only normal stresses, since the path is exactly normal to applied force; all the other paths are subjected to both normal stresses and shear stresses, since paths have parts normal to applied force and parts parallel to applied force. Limit stresses on these surfaces are, according to the previous formula:

$$\sigma_l = \frac{f_u}{\gamma_{M2}}; \qquad \tau_l = \frac{f_y}{\sqrt{3}} \frac{1}{\gamma_{M0}}$$

Since the Eurocode 3 formula does not cover the condition of inclined forces (not normal or parallel to a surface), the following general formula has been implemented in CSE in order to consider also the limit stresses on inclined surfaces:

$$\sigma_{eq} = \frac{\sigma_l \cdot \tau_l}{\sqrt{\sigma_l^2 \cos^2 \alpha + \tau_l^2 \sin^2 \alpha}}$$

where α is the angle shown in following figure; for α=0° we get $\sigma_{eq}=\tau_l$, for α=90° it is $\sigma_{eq}=\sigma_l$ (that is, if force is normal or parallel to considered failure path, it gives the same value of Eurocode formula).

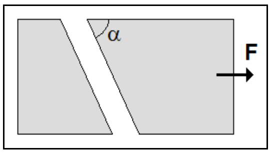


Figure C-67

In other words, **CSE can check forces in any direction**, and the case under study is just **one of the possible general cases for CSE**. If paths are subjected to shear and/or tension only, as in this case, we expect from CSE the same results provided by EN1993-1-8:2005, whose formula covers this condition only.

Referring to Figure C-68, the following results for each failure path according to Eurocode formula are given in Table C-2: design block tearing resistance, applied force and utilization factor. In this case all the parts of each path are normal or parallel to the applied force, so σ_l and τ_l can be used in hand computations. As previously said, for CSE, parallel and normal are just particular conditions of a general case.

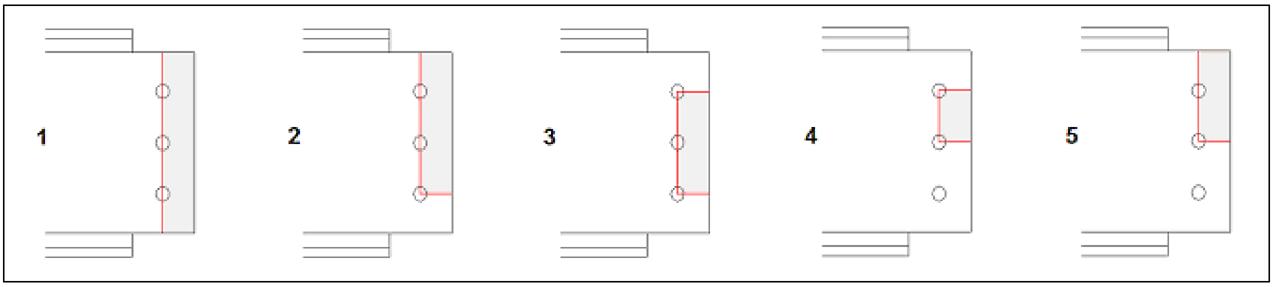


Figure C-68 Hand computed failure paths

path	L_v [mm]	A_{nv} [mm^2]	τ_l [N/mm^2]	L_t [mm]	A_{nt} [mm^2]	σ_l [N/mm^2]	$V_{eff,1,Rd}$ [N]	F_a [N]	$\frac{F_a}{V_{eff,1,Rd}}$
1	/	/	/	120	672.0	288	193536	133856	0.692
2	23.8	133.3	135.7	92	515.2	288	166464	133856	0.804
3	47.6	266.6	135.7	64	358.4	288	139391	133856	0.960
4	**47.6**	**266.6**	**135.7**	**32**	**179.2**	**288**	**87782**	**89237**	**1.017**
5	23.8	133.3	135.7	60	336.0	288	114854	89237	0.777

Table C-2 Results of hand computations on considered failure paths

- L_V is the length of the part of failure path subjected to shear (considering bolt holes).
- $A_{nv} \cdot = L_v \cdot t$ is the net area subjected to shear.
- t = 5.6mm is supported beam web thickness (IPE 200).
- L_t is the length of the part of failure path subjected to axial force.
- $A_{nt} \cdot = L_t \cdot t$ is the net area subjected to tension.
- $V_{eff,1,Rd} = A_{nt} \cdot \sigma_l + A_{nv} \cdot \tau_l$ is the design block tearing resistance of considered failure path.
- F_a is the resultant force of involved bolts only $F_a = F/3 * n_b$.
- n_b is the number of bolts involved in the considered path.

Most critical path is number 4. It is subjected to the force of 2 bolts only, but it is also the one with minimum ultimate force, resulting the one with the highest $F_a / V_{eff,1,Rd}$ ratio.

Most critical failure path is shown in Figure C-69: a part of supported beam web is torn from the rest of the member. Resultant on involved bolts is 2/3 of total applied load.

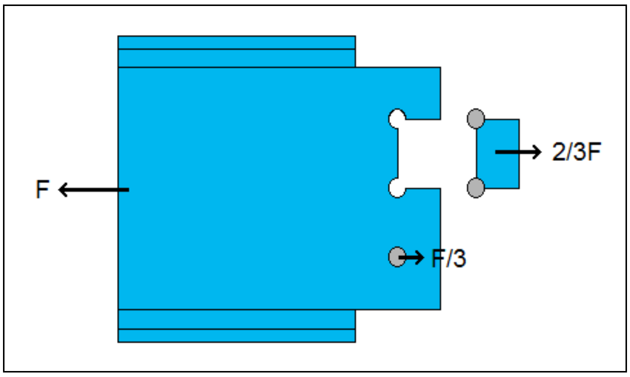


Figure C-69 Failure path number 4

Step-by-step computation of $F_a/V_{eff,1,Rd}$ for most critical failure path is shown now (only the results were printed in Table C-2). Reader could easily hand compute the other paths, if desired. First of all, we compute limit stresses value for S235 with γ_{M0}=1 and γ_{M2}=1.25.

$$\sigma_l = \frac{f_u}{\gamma_{M2}} = \frac{360N/mm^2}{1.25} = 288N/mm^2$$

$$\tau_l = \frac{f_y}{\sqrt{3}}\frac{1}{\gamma_{M0}} = \frac{235N/mm^2}{\sqrt{3}}\cdot\frac{1}{1} = 135.7N/mm^2$$

According to following figure, we can compute the length of each part of the path.

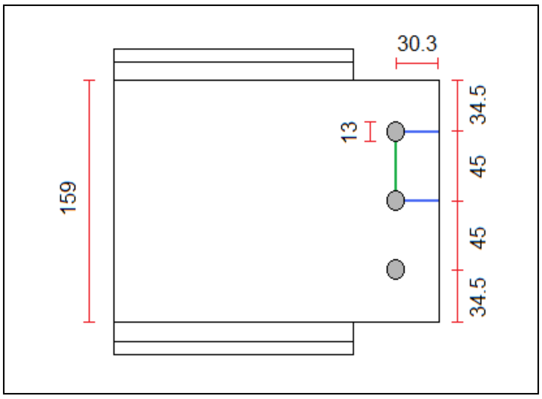


Figure C-70 Relevant distances [mm]

We get[5]

$$L_t = 45mm - 2\cdot\frac{13mm}{2} = 32mm$$

$$L_v = 2\cdot\left(30.3mm - \frac{13mm}{2}\right) = 47.6mm$$

$$A_{nt} = L_t \cdot t = 32mm\cdot 5.6mm = 179.2mm^2$$

$$A_{nv} = L_v \cdot t = 47.6mm\cdot 5.6mm = 266.6mm^2$$

$$V_{eff,1,Rd} = A_{nt}\cdot\sigma_l + A_{nv}\cdot\tau_l = 179.2mm^2\cdot 288N/mm^2 + 266.6mm^2\cdot 135.7N/mm^2 = 87782N$$

Resultant on failure path 4 is due to 2 bolts only:

$$F_a = \frac{2}{3}F = \frac{2}{3}\cdot 133856N = 89237N$$

[5] hole diameter d_0=13mm for M12 bolts

Utilization factor of failure path 4 is:

$$expl = \frac{F_a}{V_{eff,1,Rd}} = \frac{89237N}{87782N} = 1.017$$

The following figure shows the results computed by CSE. Most critical failure path is the same computed as most critical in our hand computations (see figure). Utilization factor is **1.0159**, very close to the one hand computed (-0.1%). The difference is due to a slight difference in $F_{ultimate}$ (design block tear resistance) computation. Applied force is exactly 2/3 of total applied force.

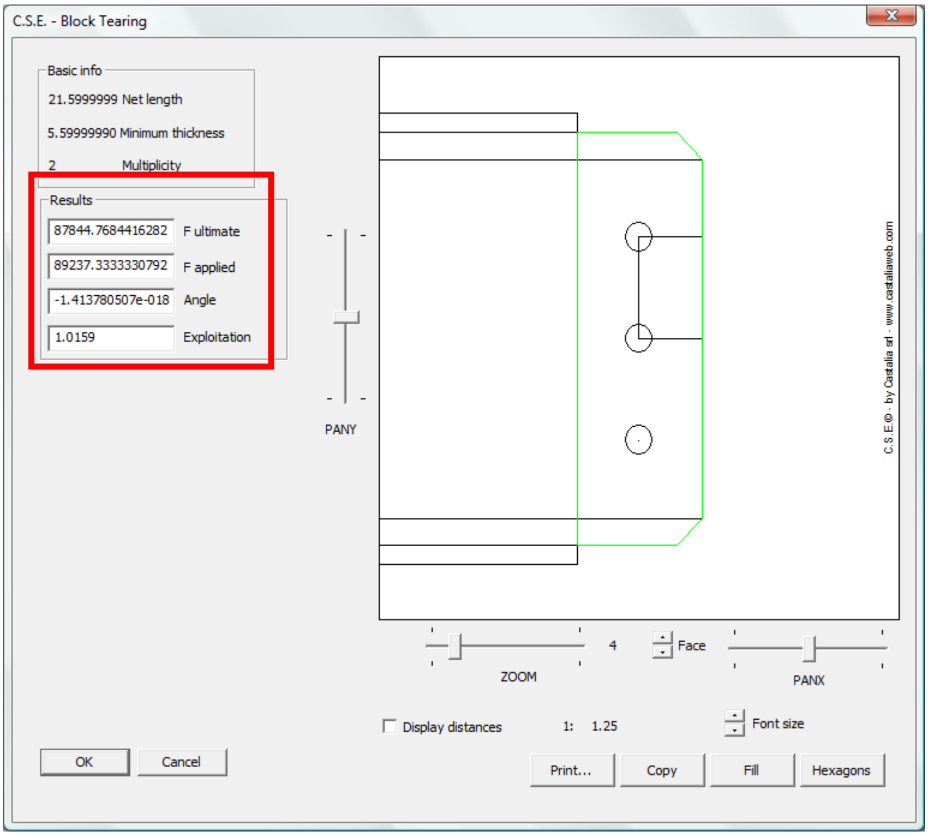


Figure C-71 CSE results for block tear check

```
---------------------------------------------------------------------
Members whose relevant exploitation is due to block tear checks
---------------------------------------------------------------------

 Inst   Combi   Name    Blayout    Angle      Force U       Force A       Expl

    1     25     m2        B1      -0.000    8.784e+004    8.924e+004    1.016 *
```

D. APPENDIX: ABSTRACTS FROM EN 1993-1-1: 2005

Table 3.1: Nominal values of the yield strength f_{yb} and the ultimate tensile strength f_{ub} for bolts

Bolt class	4.6	4.8	5.6	5.8	6.8	8.8	10.9
f_{yb} (N/mm^2)	240	320	300	400	480	640	900
f_{ub} (N/mm^2)	400	400	500	500	600	800	1000

NOTE: The National Annex may exclude certain bolt classes.

Figure D-1 Abstract from EN1993-1-8: bolts f_{yb} and f_{ub}

Table 3.3: Minimum and maximum spacing, end and edge distances

Distances and spacings, see Figure 3.1	Minimum	Maximum 1) 2) 3)		
		Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5		Structures made from steels conforming to EN 10025-5
		Steel exposed to the weather or other corrosive influences	Steel not exposed to the weather or other corrosive influences	Steel used unprotected
End distance e_1	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Edge distance e_2	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Distance e_3 in slotted holes	$1,5d_0$ 4)			
Distance e_4 in slotted holes	$1,5d_0$ 4)			
Spacing p_1	$2,2d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm
Spacing $p_{1,0}$		The smaller of $14t$ or 200 mm		
Spacing $p_{1,i}$		The smaller of $28t$ or 400 mm		
Spacing p_2 5)	$2,4d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm

1) Maximum values for spacings, edge and end distances are unlimited, except in the following cases:

- for compression members in order to avoid local buckling and to prevent corrosion in exposed members and;
- for exposed tension members to prevent corrosion.

2) The local buckling resistance of the plate in compression between the fasteners should be calculated according to EN 1993-1-1 using $0,6\ p_1$ as buckling length. Local buckling between the fasteners need not to be checked if p_1/t is smaller than $9\ \varepsilon$. The edge distance should not exceed the local buckling requirements for an outstand element in the compression members, see EN 1993-1-1. The end distance is not affected by this requirement.

3) t is the thickness of the thinner outer connected part.

4) The dimensional limits for slotted holes are given in 1.2.7 Reference Standards: Group 7.

5) For staggered rows of fasteners a minimum line spacing of $p_2 = 1,2d_0$ may be used, provided that the minimum distance, L, between any two fasteners is greater or equal than $2,4d_0$, see Figure 3.1b).

Figure D-2 Abstract from EN1993-1-8: Bolts spacing, end and edge distances

Spacing and distances according to next figure.

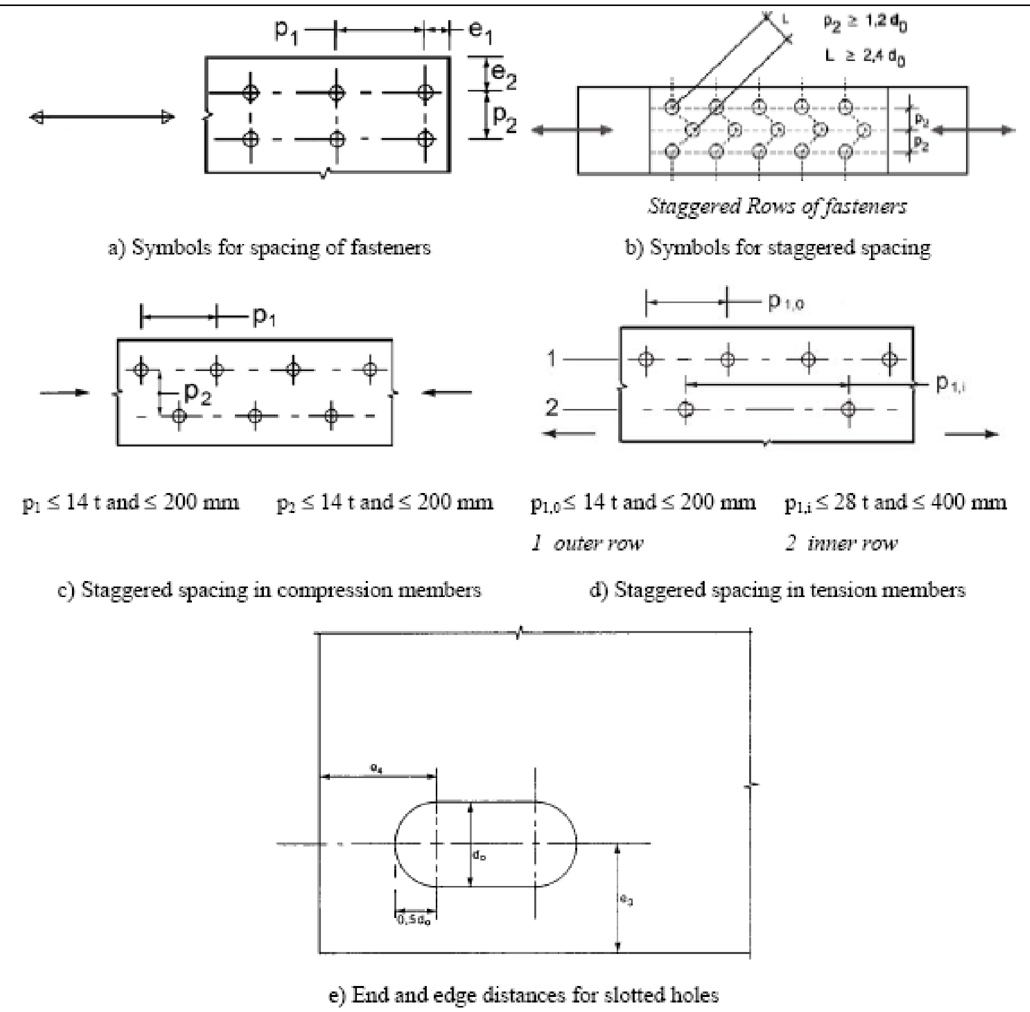


Figure 3.1: Symbols for end and edge distances and spacing of fasteners

Figure D-3 Abstract from EN1993-1-8: Bolts spacing, end and edge distances

Table 3.4: Design resistance for individual fasteners subjected to shear and/or tension

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{v,Rd} = \dfrac{\alpha_v \; f_{ub} \; A}{\gamma_{M2}}$ - where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt A_s): - for classes 4.6, 5.6 and 8.8: $\alpha_v = 0{,}6$ - for classes 4.8, 5.8, 6.8 and 10.9: $\alpha_v = 0{,}5$ - where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt): $\alpha_v = 0{,}6$	$F_{v,Rd} = \dfrac{0{,}6 \; f_{ur} \; A_0}{\gamma_{M2}}$
Bearing resistance [1), 2), 3)]	$F_{b,Rd} = \dfrac{k_1 \, a_b \, f_u \, d \, t}{\gamma_{M2}}$ where α_b is the smallest of α_d ; $\dfrac{f_{ub}}{f_u}$ or 1,0; in the direction of load transfer: - for end bolts: $\alpha_d = \dfrac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \dfrac{p_1}{3d_0} - \dfrac{1}{4}$ perpendicular to the direction of load transfer: - for edge bolts: k_1 is the smallest of $2{,}8\dfrac{e_2}{d_0} - 1{,}7$ or 2,5 - for inner bolts: k_1 is the smallest of $1{,}4\,\dfrac{p_2}{d_0} - 1{,}7$ or 2,5	
Tension resistance [2)]	$F_{t,Rd} = \dfrac{k_2 \; f_{ub} \; A_s}{\gamma_{M2}}$ where $k_2 = 0{,}63$ for countersunk bolt, otherwise $k_2 = 0{,}9$.	$F_{t,Rd} = \dfrac{0{,}6 \; f_{ur} \; A_0}{\gamma_{M2}}$
Punching shear resistance	$B_{p,Rd} = 0{,}6 \, \pi \, d_m \, t_p \, f_u \, / \, \gamma_{M2}$	No check needed
Combined shear and tension	$\dfrac{F_{v,Ed}}{F_{v,Rd}} + \dfrac{F_{t,Ed}}{1{,}4\,F_{t,Rd}} \leq 1{,}0$	

1) The bearing resistance $F_{b,Rd}$ for bolts

- in oversized holes is 0,8 times the bearing resistance for bolts in normal holes.
- in slotted holes, where the longitudinal axis of the slotted hole is perpendicular to the direction of the force transfer, is 0,6 times the bearing resistance for bolts in round, normal holes.

2) For countersunk bolt:

- the bearing resistance $F_{b,Rd}$ should be based on a plate thickness t equal to the thickness of the connected plate minus half the depth of the countersinking.
- for the determination of the tension resistance $F_{t,Rd}$ the angle and depth of countersinking should conform with 1.2.4 Reference Standards: Group 4, otherwise the tension resistance $F_{t,Rd}$ should be adjusted accordingly.

3) When the load on a bolt is not parallel to the edge, the bearing resistance may be verified separately for the bolt load components parallel and normal to the end.

Figure D-4 Abstract from EN1993-1-8: Design resistance for individual fasteners

Table 4.1: Correlation factor β_w for fillet welds

Standard and steel grade			Correlation factor β_w
EN 10025	**EN 10210**	**EN 10219**	
S 235 S 235 W	S 235 H	S 235 H	0,8
S 275 S 275 N/NL S 275 M/ML	S 275 H S 275 NH/NLH	S 275 H S 275 NH/NLH S 275 MH/MLH	0,85
S 355 S 355 N/NL S 355 M/ML S 355 W	S 355 H S 355 NH/NLH	S 355 H S 355 NH/NLH S 355 MH/MLH	0,9
S 420 N/NL S 420 M/ML		S 420 MH/MLH	1,0
S 460 N/NL S 460 M/ML S 460 Q/QL/QL1	S 460 NH/NLH	S 460 NH/NLH S 460 MH/MLH	1,0

Figure D-5 Abstract from EN1993-1-8: Correlation factor β_w for fillet welds