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Technology, Lappeenranta
Degree Programme in Civil and Construction Engineering

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Calculation and analyzing of braces connections

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ABSTRACT

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Saimaa University of Applied Sciences, Lappeenranta
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The main purpose of the thesis was to calculate and analyze five the most common for Russian design types of steel brace joints according to Russian norms. The research has been performed for roll-welded rectangular hollow sections. In addition, it was required to develop a simple-in-use program in Excel in order to realize the analysis. The working process was organized for needs and with the help of "EnergoProject" company designers.

The second part is a review of general information about the types, constructions and using of braces in steel structures. For these goals, materials of the research papers, scientific works, textbooks and publications were studied.

The third part includes research of calculation method for brace connections and developing of the Excel program that helps check and choose the main parameters of joint: thickness and dimensions of plates, quantity of bolts and length of weld. Creating and results of working of this program were inspected and verified by the company tutor.

In the last part of the thesis I present two examples of calculation of brace joints to use in practice a knowledge received during the research. Checking focused on strength resistance of all joint elements. In addition the work examined functioning and correctness of the Excel program.

Keywords: brace, brace joint, roll-welded rectangular hollow section,

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1 INTRODUCTION

A Braced Frame is a structural system that is designed primarily to resist wind and earthquake forces. Members in a braced frame are designed to work in tension and compression, similar to a truss. Braced frames are almost always composed of steel members.

Braced frames are a very common form of construction, being economic to construct and simple to analyze. Economy comes from the inexpensive, nominally pinned connections between beams and columns. Bracing, which provides stability and resists lateral loads, may be from diagonal steel members or, from a concrete 'core'. In braced construction, beams and columns are designed under vertical load only, assuming the bracing system carries all lateral loads.

Braced frames resist gravity load in bending and axial compression, and lateral load in axial compression and tension by triangulation, much like trusses. The triangulation results in great stiffness an advantage to resist wind load, but increases seismic forces, a disadvantage to resist earthquakes. Triangulation may take several configurations, single diagonals, A-bracing, V-bracing, X-bracing and etc. considering both architectural and structural criteria. In braced frames the efficiency is improved by adding truss members such as diagonals between the floor systems. (1)

The positioning of braces, however, can be problematic as they can interfere with the design of the façade and the position of openings. Buildings adopting high-tech or post-modernist styles have responded to this by expressing bracing as an internal or external design feature. (2)

2 GENERAL INFORMATION

In this chapter basic data about braces, their applying, properties and classification are presented.

2.1 Common definitions and properties

In typical buildings the beams and columns that form the frame carry vertical loads and a braced frame is a structural system commonly used in structures subject to lateral loads such as wind and seismic pressure. The members in a braced frame are generally made of structural steel, which can work effectively both in tension and compression (2).

Coupled with other frame members braces provide:

- consolidation of plane frames to the three-dimensional system by creating stable frameworks in different planes inside one building or temperature unit
- redistribution of local loads acting on one plane frame between the neighboring frames and involving them into the team-working
- accommodation and transmission of lateral wind loads, brakeage crane loads and other loads acting along of the building to the foundations
- ensuring the stability of compressed frame elements by reducing their effective lengths
- ensuring the load-carrying ability, stability and fixation in permanent position of structure elements during the erection procedure

During design of braces it is necessary to provide sequenced load transmission from point of load application to the foundations through the simplest method and the shortest way.

In each temperature unit and each level independent brace system should be provided (3).

2.2 Applying of braces in industrial building

Applying and functions are considered by an example of braces in a classic Russian industrial building like manufacturing workshop with transverse frames consisting of columns and truss, braces and crane beams.

2.2.1 Vertical braces between columns

The system of vertical braces between columns during operation and installation provides:

- stability of geometrical shape of the frame
- bearing capacity of the frame and its rigidity in the longitudinal direction
- the perception of longitudinal wind loads in the end of the building and the crane brakeage loads
- stability of the columns from the plane of the transverse frames.

There is distinction between the upper tier of the vertical braces between the columns (links located above the crane beams) and the lower tier (below the crane beams). (4)

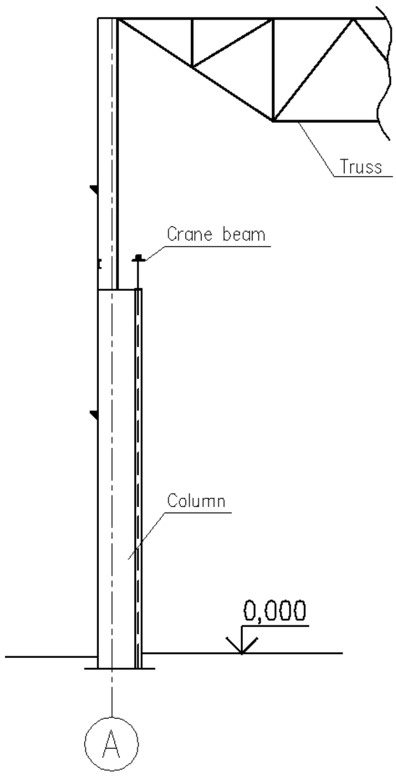

Figure 1. Fragment of transverse frame

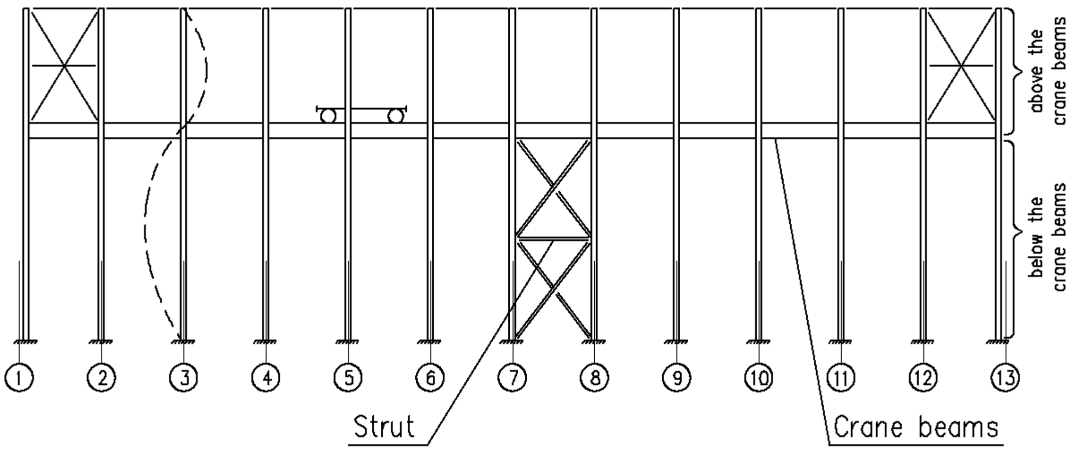

Figure 2. Scheme of vertical braces between columns

The braces of the upper tier have the following purposes:

- forces from the wind, directed to the end of the building, are transmitted to the braces of the upper tier from the end transverse braces, located in the plane of the lower truss chord, and then, along the stretched struts, these efforts are transmitted to crane girders;
- the braces of the upper tier ensure the stability of the columns "out of plane" of the frames. Thus, the design length of the above-crane-beam part of the column (Fig. 9, dashed line) from the plane of the frame is equal to the height of this part of the column;
- together with the lower tier of braces during installation keep the columns not fixed by anchors from overturning.

The communication of the lower tier is assigned to the functions:

- transmit wind forces from the braces of the upper tier and from the longitudinal braking of the cranes to the foundation;
- ensure the stability of the under-crane-beam part of the column from the plane of the frame;
- serve as erection braces during columns installing. In high-rise buildings, lower tier braces have an additional strut between the columns (Fig. 9). Its purpose is to reduce the design length of the under-crane part of the column from the plane of the frame. This arrangement is used when checking the stability of the column "out of plane" does not give satisfactory results due to the great slenderness of the column (5).

2.2.2 Horizontal roofing braces

Horizontal braces are located in the planes of the lower and upper chords of the trusses. Horizontal braces consist of transverse and longitudinal.

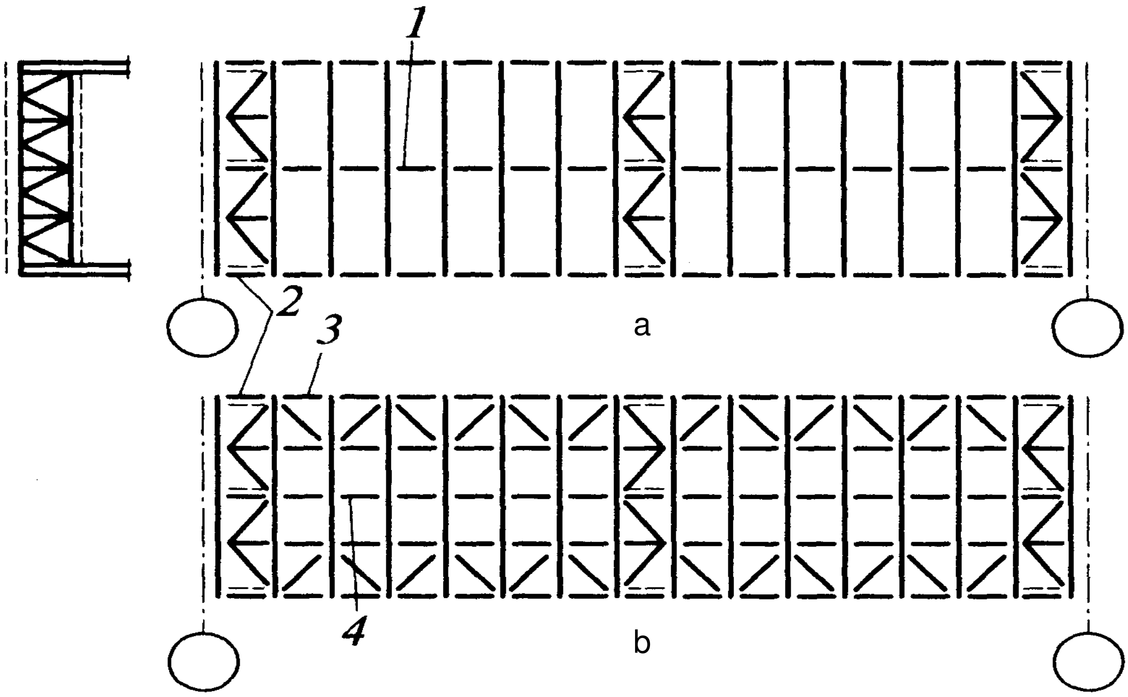

Figure 3. Braces between trusses: a - on the upper chords; b - on the lower chords (5)

Braces between the upper chords of trusses consist of transverse brace units (Fig. 10 – 2) and longitudinal struts (Fig. 10 – 1). These components have the following purposes:

- provide stability of compressed truss upper chords from the plane of trusses;
- combine the upper chords of the trusses into a single system. Wherein each of the transverse brace unit serves as a closing block;
- struts fix upper chords of trusses against displacements, ensuring their stability, and transverse brace units, in turn, fix these struts against displacements.

Also in the process of installation (before installing the floor slabs or purlins), the flexibility of the upper chord from the plane of the truss should not be more than

220. If the ridge strut does not provide this condition, an additional strut is placed between it and the strut in the plane of the columns.

Braces between the lower chords of trusses consist of transverse (Fig. 10 – 2) and longitudinal (Fig. 10 – 3) brace units and longitudinal struts (Fig. 10 – 1).

In single-span high-rise buildings (H > 18 m), in buildings with cranes with a lifting capacity Q ≥ 10 tons, a system of longitudinal braces along the lower chords of trusses is obligatory because of:

- horizontal forces from cranes act in the transverse direction on one frame and two or three adjacent ones. Longitudinal brace units ensure the team-work of the system of frames, as a result of which the lateral deformations of the framework due to the action of a concentrated force are significantly reduced;
- elements of the lower chords of the trusses adjacent to the columns, especially when the truss is fixed to the column rigidly, can be compressed. In this case, the longitudinal brace units ensure the stability of the lower chord from the plane of the trusses;
- cross brace units fix longitudinal, and at the ends of the building they are also necessary for the perception of wind load directed at the end of the building;
- in order to avoid vibration of the lower chord of the truss due to the dynamic effect of cranes, it is necessary to limit the flexibility of the stretched part of the lower chord from the frame plane. In order to reduce the free length of the stretched part of the lower chord, it is necessary in some cases to provide struts securing the lower chord in the lateral direction.

In long buildings consisting of several temperature blocks, transverse brace-units along the upper and lower chords are placed at each temperature block (as at the ends of one building), bearing in mind that each temperature block is a complete spatial complex (5).

2.2.3 Vertical roofing braces

Vertical braces between trusses are installed in the same axes in which horizontal transverse trusses are placed.

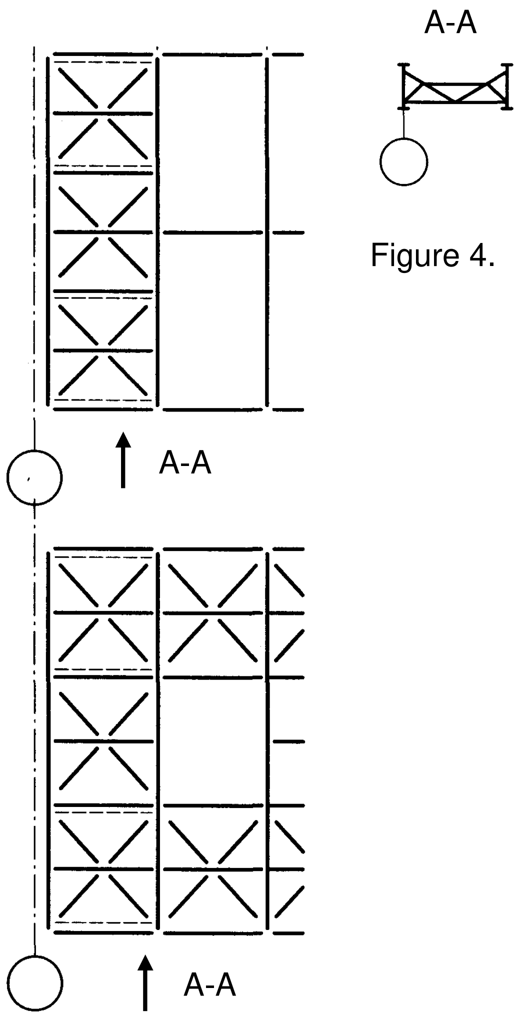

Figure 4. Vertical braces between trusses (5)

Vertical brace units are installed in the spatial brace blocks in the planes of the vertical posts of trusses along their ends and along the ridge. Also in the span, one or two vertical brace units are established across the span width (after 12–15 m).

Vertical braces impart the stability of a spatial block consisting of two trusses and horizontal cross braces along the upper and lower truss chords.
When truss consists of several pre-fabricated elements, vertical braces in rigid blocks should also be placed at the junction points of pre-fabricated elements. In buildings with overhead crane equipment, especially with its large carrying capacity, it is advisable to place vertical braces in the planes of the crane tracks (5).

2.3 Classification

Classification of braces by shape (2):

- Single diagonals
- Cross-bracing
- K-bracing
- V-bracing
- Eccentric bracing

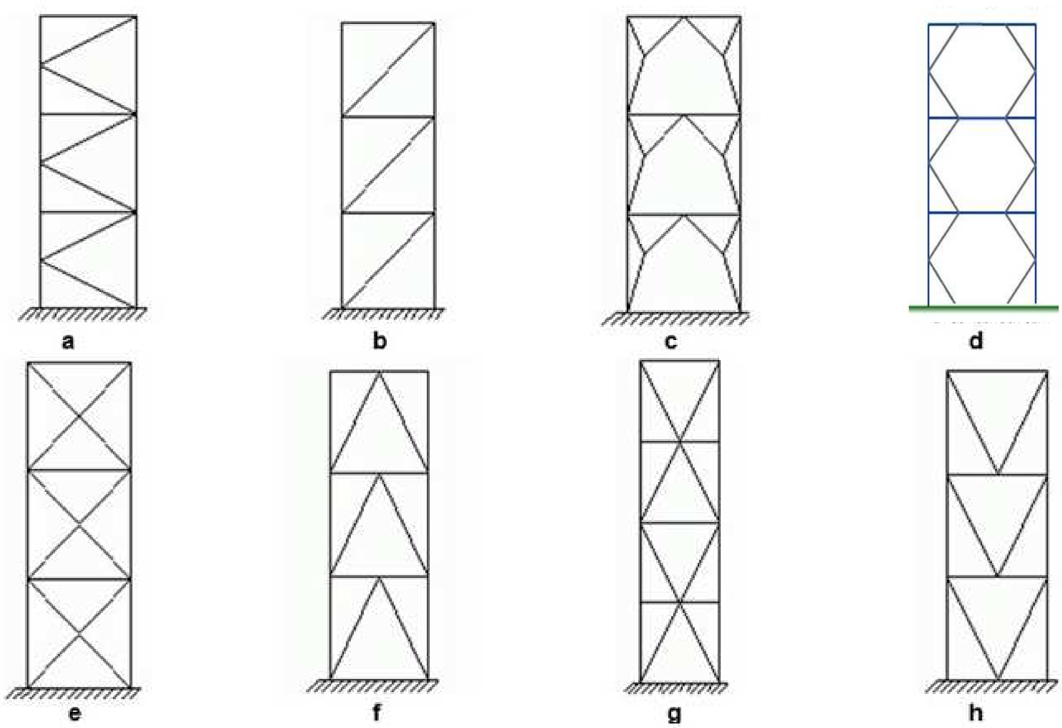

Figure 5. Shapes of braces (6)

a, b – Single diagonals; c – Eccentric bracing; d – K-bracing; f, h – V-bracing; e, g – Cross-bracing

Single diagonals

Single diagonals, trussing, or triangulation, are formed by inserting diagonal structural members into rectangular areas of a structural frame, helping to stabilize the frame. If a single brace is used, it must be sufficiently resistant to tension and compression. (2)

Cross bracing

Cross bracing (or X-bracing) uses two diagonal members crossing each other. These only need to be resistant to tension, one brace at a time acting to resist sideways forces, depending on the direction of loading. As a result, steel cables can also be used for cross-bracing. However, cross bracing on the outside face of a building can interfere with the positioning and functioning of window openings. It also results in greater bending in floor beams. (2)

<u>K-braces</u>

K-braces connect to the columns at mid-height. This frame has more flexibility for the provision of openings in the facade and results in the least bending in floor beams. K-bracing is generally discouraged in seismic regions because of the potential for column failure if the compression brace buckles. (2)

<u>V-shape</u>

Two diagonal members forming a V-shape extend downwards from the top two corners of a horizontal member and meet at a centre point on the lower horizontal member (left-hand diagram). Inverted V-bracing (right-hand diagram, also known as chevron bracing) involves the two members meeting at a centre point on the upper horizontal member. Both systems can significantly reduce the buckling capacity of the compression brace so that it is less than the tension yield capacity of the tension brace. This can mean that when the braces reach their resistance capacity, the load must instead be resisted in the bending of the horizontal member. (2)

<u>Eccentric bracing</u>

Eccentric bracing is commonly used in seismic regions. It is similar to V-bracing but bracing members do not meet at a center point. This means there is a space between them at the top connection. Bracing members connect to separate points on the horizontal beams. This is so the 'link' between the bracing members absorbs energy from seismic activity through plastic deformation. Eccentric single diagonals can also be used to brace a frame (2).

Classification of braces by cross-section (3):

- Arc-welded pipe
- Roll-welded rectangular hollow section
- Rolled open section

- Hot rolled profile

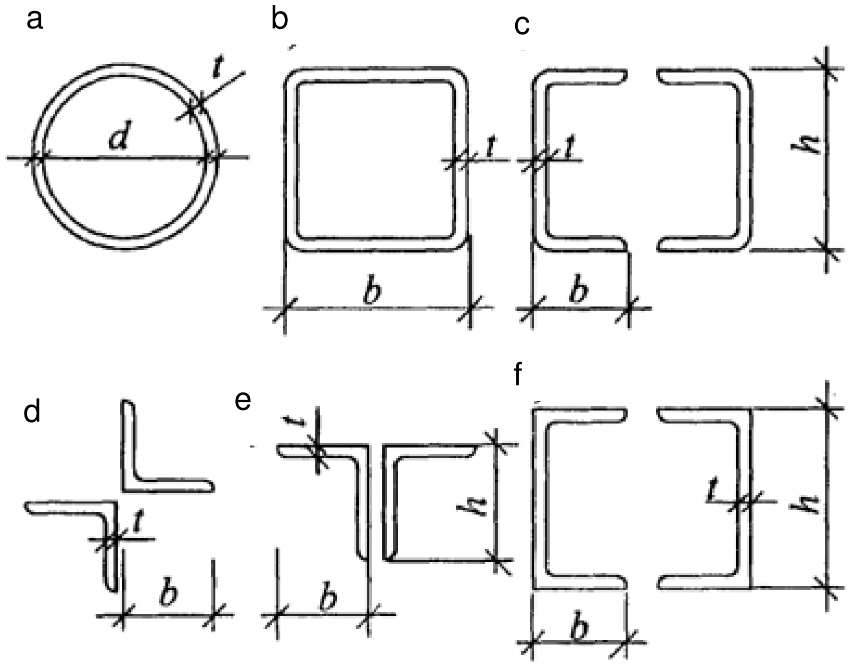

Figure 6. Types of brace sections (3)

a – Arc-welded pipe; b – Roll-welded rectangular hollow section; c – Rolled open section; d-f – Hot rolled profile

2.4 Advantages of using of roll-welded hollow section

Due to simple shape and good strength properties providing a lightweight and affordable construction solution rolled-welded profiles play a significant role in modern structure design. Of the advantages can be identified:

1. Maximum saving of metal

First of all, this is a decreasing of the metal intensity of the objects being built by 25-30%. The use of shaped tubes allows getting savings in transport costs because the weight of the required volume of profile pipes for the installation of structures is significantly less than the weight of the required volume of high-quality hot-rolled metal.

2. More affective applying of fire-proof, anticorrosion and other coatings

The surface area of structures made of shaped pipes is 30-40% smaller than the area of similar objects constructed using other types of rolled metal. This significantly reduces high cost of fire-proof coating. Also in the structures of tubular elements there are no cracks and cavities, which are the cause of the accumulation of dirt and the expansion of corrosion.

Structural elements made of RHS have the outer surface easily accessible to perform painting work. Such places, difficult to paint, are in the profiles with corners and channels like I-beams or doubled angles.

3. The minimum number of parts in the structure

Connections in the structures of elements in the form of angles and PFC are made using additional parts made of sheet steel. So, for example, joints made of RHS profiles contain 3 elements, while joints made of corner profiles contain at least 11 parts.

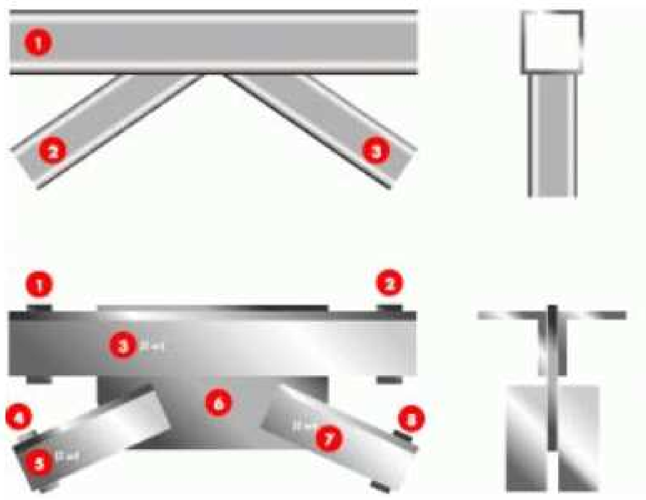

Figure 7. Amount of joints parts

4. Simplicity of manufacturing of parts with the use of equipment common for all metal structures factories

For the manufacture of parts from rolled-welded profiles it is required only equipment for mechanical cutting able to cut off the tubular profile at a given angle.

5. Reducing the size of the foundation and the cost of foundation works

Reducing the metal weight of the frame as a result of the use of roll-welded profiles allows to reduce the load on the foundation from frame weight, which leads to savings on the foundation of up to 10% of the total cost of construction.

6. Wide range of products

The stiffness, strength and weight of the tube profiles can be easily controlled by wall thicknesses without altering the outer dimensions of the profile.

2.5 Types of joints of RHS elements

Due to high buckling strength and high torsional stiffness of rectangular hollow section profiles, it is allowed to use them as braces very effectively.
Additionally, the tubular structures can be joined with simple joint details.
Joints can be welded or bolted but the preference is given to bolted joints. Bolted joints are quick and easy to install on site. All parts of the joint that require welding are made at the workshop and have high quality.
It is important that the joint moves the loads with respect to the profile as centrally as possible and that all joining components are homogeneous in regard to stiffness. Standard types of connections used in Russian practice meet the above requirements.
Generally in such types of joints bolts of diameters M12, M16, M20, M24, M30 are used. In addition, the bolts are divided into strength classes, the most common of which are classes 8.8 and 10.9. The strength class determines the values of the nominal yield strength of the bolt and the tensile strength.

- Type "F" (joint with flange welded to brace, brace plate and joint plate)

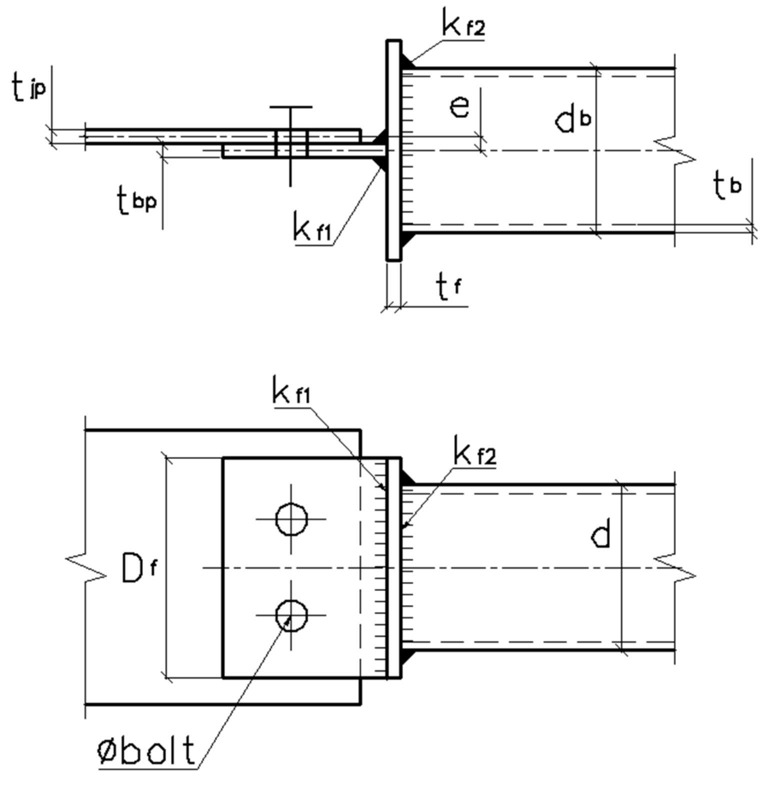

Figure 8. Type "F"

- Type "Fsp" (joint with flange welded to brace, brace plate, joint plate and two additional stiffening plates on brace section)

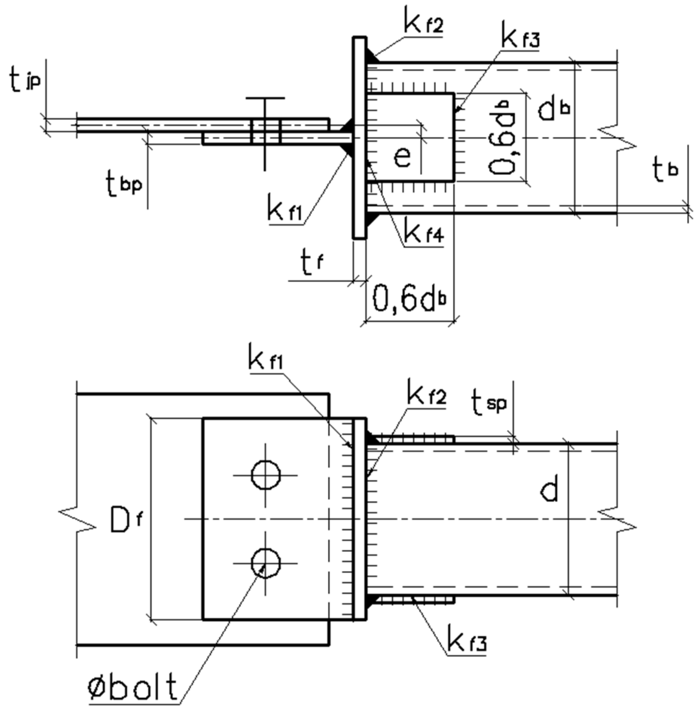

Figure 9. Type "Fsp"

- Type "Fr" (joint with flange welded to brace, brace plate, joint plate and additional stiffening rib on brace plate)

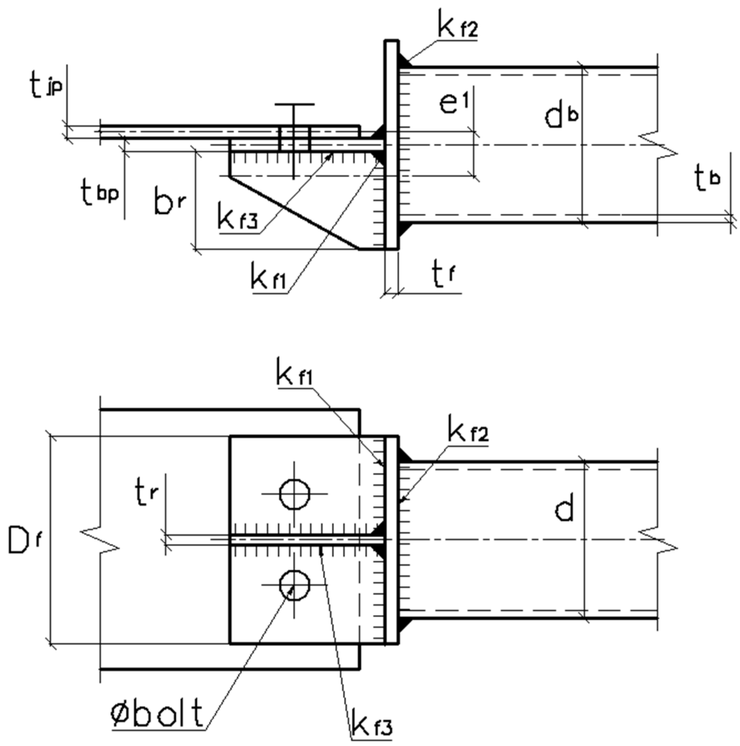

Figure 10. Type "Fr"

- Type "C" (joint with flanges welded to brace, cut-in brace plate and joint plate)

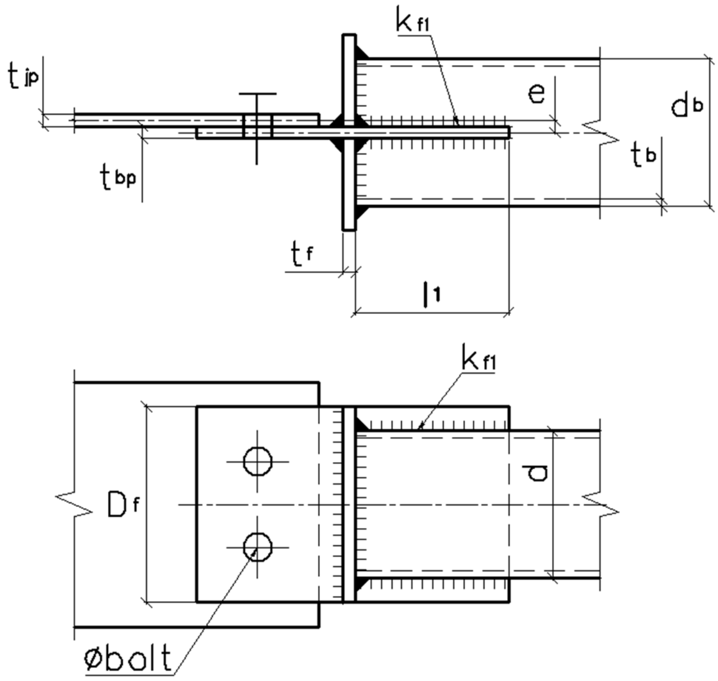

Figure 11. Type "C"

- Type "Cr" (joint with flange welded to brace, cut-in brace plate, joint plate and additional stiffening rib on brace plate)

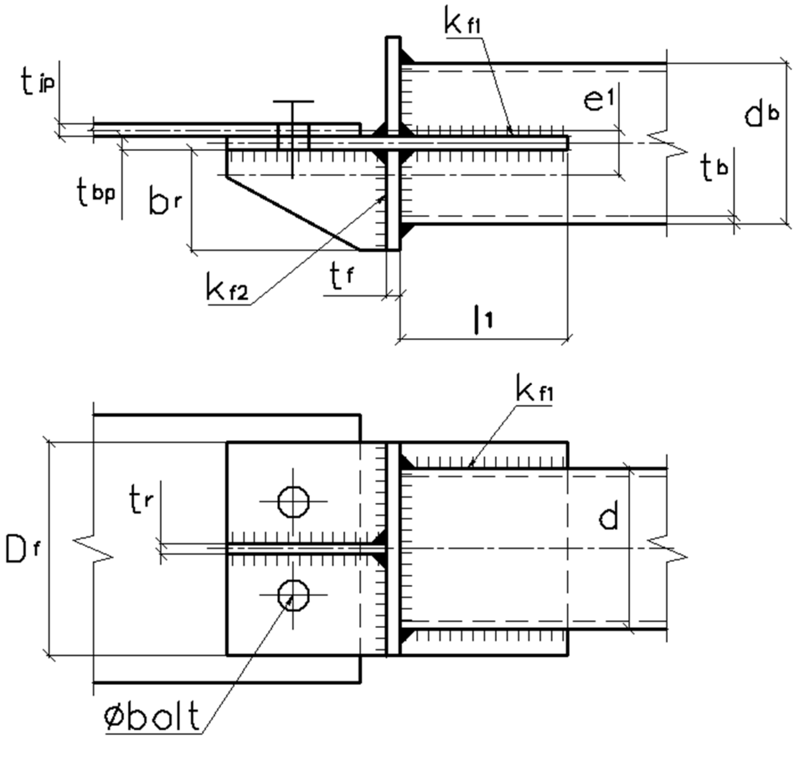

Figure 12. Type "Cr"

3 THEORETICAL PART

3.1 Information about norms

Since 2017 in Russia a new normative document has been introduced. It is SP 294.1325800.2017 “Steel Structures. Design Rules”.

This rulebook establishes requirements and applies to design and calculation of steel buildings and structures of various purposes, operating at a temperature not higher than + 100 ° C and not lower than minus 60 ° C.

SP 294.1325800.2017 is non-regulatory and used as addition to the main Russian normative document SP 16.13330.2011 “Steel Structures”.

This set of rules is made to improve the level of safety of people in buildings and structures and the preservation of material values, as well as to harmonize regulatory requirements with European and international regulatory documents, the use of common methods for determining performance characteristics and evaluation methods.

3.2 Rules of geometry design of joints

Design instructions are detailed in paragraphs 14.1 and 14.2 SP 16.13330.2017. Dimensions of corner weld (butt-welded joints and lap-welded joint are not used in considering brace connections) and construction of weld joint should meet the following requirements:

- weld leg k_f should not exceed value $1.2 \cdot t$, where t is the least of thicknesses of welded elements;
- minimum k_f is 4 mm;
- design length of corner weld should be not less than $4 \cdot k_f$ and not less than 40 mm;
- design length of weld directed along the acting load should be not more than $85 \cdot \beta_f \cdot k_f$;
- during calculation it is necessary to take away from the length 10 mm from each end because of fusion breaks at the beginning and finishing of welding.

The size of the screw holes and their edge and center distances are essential to the durability and breakage mechanisms of the connection plates.

Bolts should be placed according to the requirements of the following table (SP16.13330.2017 p. 14.2.8 table 40):

Characteristic distance and yield strength (R_{yn}) of connected elements	Distance at bolt placement
1) The distance between the centers of the bolt holes in any direction	
a) minimum	
$R_{yn} \leq 375\ N/mm^2$	$2.5 \cdot d$
$R_{yn} > 375\ N/mm^2$	$3 \cdot d$
b) maximum in the extreme rows	$8 \cdot d$ or $12 \cdot t$
c) maximum in the middle rows	
tensile	$16 \cdot d$ or $24 \cdot t$
press	$8 \cdot d$ or $12 \cdot t$
2) The distance from the center of the bolt hole to the edge of the element	
a) minimum along the stress	
$R_{yn} \leq 375\ N/mm^2$	$2 \cdot d$
$R_{yn} > 375\ N/mm^2$	$2.5 \cdot d$
b) minimum across the stress	
with cut edges of element	$1.5 \cdot d$
with rolling edges of element	$1.2 \cdot d$
c) maximum	$4 \cdot d$ or $8 \cdot t$

Bolts of accuracy class B used in considered connections should have holes of diameter $d = d_{bolt} + (1, 2\ or 3)mm.$

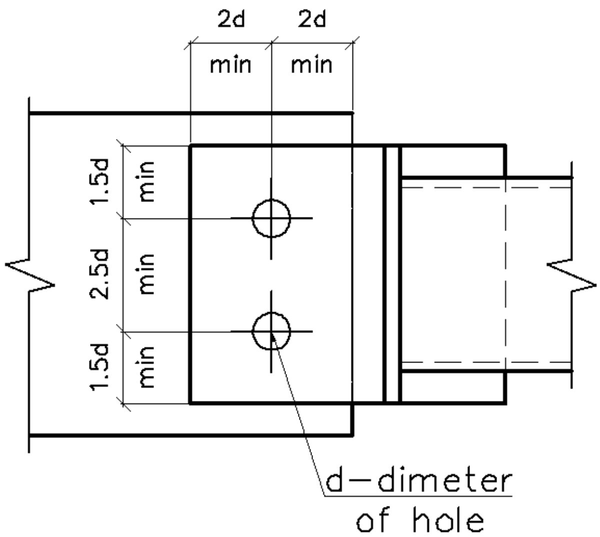

Figure 13. Distance at bolt placement for standard considered types of brace connections

3.3 Calculation method

Joints of roll-welded rectangular hollow section braces are checked:

- to strength and stability of joint parts and the nearest to the joint brace section area
- to strength of bolts and weld

All checking formulas are correct if: (SP 294.1325800.2017 p.14.4.3)

- ratio of cross-section dimensions is $0.75 \leq d_b/d \leq 1.1$
- ratio of the biggest dimension (d_b or d) to the section thickness is ≤ 45

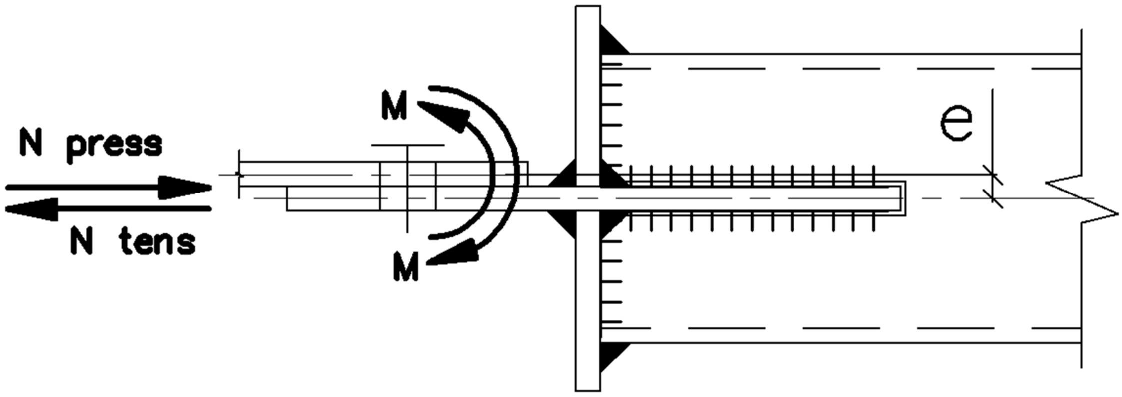

Figure 14. Scheme of loads acting

3.3.1 Calculation of Joint Type “F”

Tensile strength for Joints Type “F” should be checked with the use of two formulas:

1. Formula for overall section of flange and brace (SP 294.1325800.2017 p.14.4.2 formula 93)

$$\frac{N_{tens}}{R_{yf} \cdot t_f^2 \cdot \dfrac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} < 1 \qquad (1)$$

N_{tens} – tensile stress

R_{yf} – design strength of flange steel (SP 13.13330.2017 Annex B table B.3)

t_f – thickness of flange

D_f – flange length along plate of brace

d_b – section dimension across plate of brace

t_{bp} – thickness of brace plate

R_{yb} – design strength of brace steel (SP 13.13330.2017 Annex B table B.3)

t_b – thickness of brace section

2. Formula for section of brace plate, taking into account a Moment appearing because of eccentricity of normal force (SP 294.1325800.2017 p.14.4.2 formula 95)

$$\frac{N_{tens}}{A_{bp} \cdot R_{ybp}} + \frac{N_{tens} \cdot e}{W_{bp} \cdot R_{ybp}} < 1 \quad (2)$$

e – excentricity of normal force

A_{bp} – brace plate cross-section area

W_{bp} – brace plate section modulus

R_{ybp} – design strength of brace plate steel (SP 13.13330.2017 Annex B table B.3)

Analogous formulas for design resistance from EN-1993-1-1 are consisted in p.6.2.3. The stress N in Russian norms accord with stress F_{Ed}.
Part of the study explored that in Russian SP there is not a division to different cases: calculation of tension elements without including weakness by bolt holes and with it. But during discussion of this question with the tutor from the company we decided to take into account decreasing of brace plate cross-section area because of bolt holes.

<u>Press strength</u> for Joints Type "F" should be checked with the use of three formulas:

1. Formula for overall section of flange and brace

$$\frac{N_{pres}}{R_{yf} \cdot t_f^2 \cdot \frac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} < 1 \quad (3)$$

2. Formula for section of brace plate, taking into account a Moment appearing because of eccentricity of normal force

$$\frac{N_{pres}}{A_{bp} \cdot R_{ybp}} + \frac{N_{pres} \cdot e}{W_{bp} \cdot R_{ybp}} < 1 \quad (4)$$

3. Formula for section of brace, taking into account compression of brace area near the joint by using of special coefficient γ_f:

$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} + \frac{N_{press} \cdot e}{W \cdot R_{yb} \cdot \gamma_f} < 1 \quad (5)$$

γ_f – conditions-of-use factor (SP 294.1325800.2017 p.14.4.3):

- $\gamma_f = 0.6$ if $\bar{\lambda} \leq 0.45$
- $\gamma_f = 0.54 + 0.15 \cdot \bar{\lambda}$ if $\bar{\lambda} > 0.45$ but $\gamma_f \leq 1$

$\bar{\lambda}$ – nominal brace slenderness

So length and slenderness of brace can be taken into account only in formula (5) by factor γ_f.

It is important to note that long and thin plates as all other elements having great slenderness are able to buckle in different ways. But in the considered kinds of joints plates are rather short and their thickness is sufficient for avoiding the buckling. Taking into account of press influence is important only for profile of brace because of using RHS with thin webs. This is done by adding of conditions-of-use factor γ_f.

Load bearing capacity of bolts should be checked with the using of formula:

$$\frac{N_{max}}{N_{b\,min} \cdot n_b} < 1 \quad (6)$$

N_{max} – maximum stress (tensile or press)

$N_{b\,min}$ – minimal design resistance: shear resistance per shear plane (N_{bs}) or bearing resistance (N_{bp}) of brace/joint plate (SP 13.13330.2017 p.14.2.9 formulas 186, 187).

$$N_{bs} = R_{bs} \cdot A_b \cdot n_s \cdot \gamma_b \cdot \gamma_c$$

$$N_{bp} = R_{bp} \cdot d_{bolt} \cdot \sum t \cdot \gamma_b \cdot \gamma_c$$

R_{bs}, R_{bp} – shear and bearing resistance of one-bolt connection (SP13.13330.2017 annex Г. table Г.5)

A_b – area of bolt section (SP 13.13330.2017 annex Г. table Г.9)

n_s – amount of shear planes for one bolt

d_{bolt} – diameter of bolt

$\sum t$ – minimal sum of thicknesses of elements are damaged in one direction

γ_c – conditions-of-use factor of structure (SP 13.13330.2017 p.4.3.3 table 1)

γ_b – conditions-of-use factor of one-bolt joint (SP 13.13330.2017 p.14.2.9 table 41)

n_b – amount of bolts

Analogous formulas for design resistance from EN-1993-1-8 are consisted in table 3.4. The stress N in Russian norms accord with stress F_{Ed}.

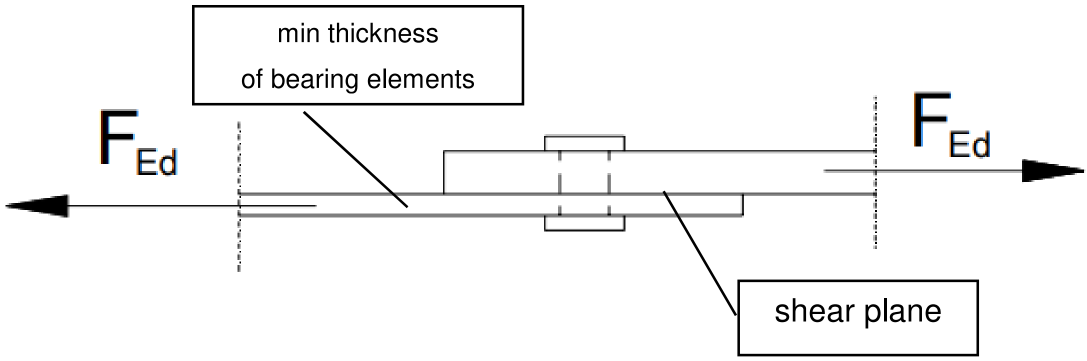

Figure 15. Scheme of one-bolt connection

Doing the research, it was discovered that, in accordance with Russian norms, the tear calculation of edge of brace plate or joint plate can be avoided if the edge distances are observed.

Damage of weld can happen immediately by weld material when its bearing capacity is not enough for acting force or along board between structure element and weld material when the leg of the weld is too small.

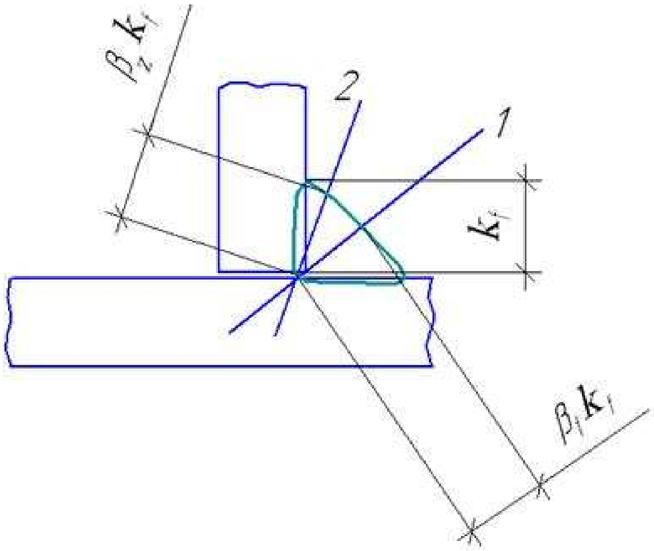

Figure 16. Parts of weld seam

1 – metal of weld; 2 – weld board

<u>Load bearing capacity of weld</u> should be checked for two different welds: brace plate to flange (k_{f1}) and flange to brace section (k_{f2}). Checking should be done according to the formulas (SP 13.13330.2017 p.14.1.16 formulas 176, 177):

$$\frac{N_{max}}{\beta_f \cdot k_f \cdot l_w \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \tag{7}$$

β_f – coefficient of weld joint by weld metal (SP 13.13330.2017 p.14.1.7 table 39)

k_f – weld leg (min value of weld leg is in SP 13.13330.2017 p.14.1.7 table 38)

l_w – weld length

R_{wf} – design strength by weld metal (SP 13.13330.2017 annex Г. table Г.1)

γ_c – conditions-of-use factor of structure

γ_{cf} – conditions-of-use factor of weld joint

$$\frac{N_{max}}{\beta_z \cdot k_f \cdot l_w \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \tag{8}$$

β_{fz} – coefficient of weld joint by weld board

R_{wz} – design strength by weld board: min between characteristic strength of flange steel and characteristic strength of brace plate steel (SP 13.13330.2017 annex B. table B.3)

$$\frac{N_{max}}{k_f \cdot l_w \cdot R_{th} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \qquad (9)$$

R_{th} – design strength by metal of weld board with flange along plate thickness (calculation depends on characteristic strength of flange steel)

3.3.2 Calculation of Joint Type "Fsp"

Sometimes only strength of RHS cross-section area can not meet the requirements for example because of too thin web. If the web could not be increased additional stiffening plates can be used.
Dimensions of stiffening plates usually are assigned equal to 0,6 of RHS width.
Steel of plates should be the same as brace material.
Checking formulas for bolts and weld of type "Fsp" are the same as for type "F" (see formulas 2, 4-9) except formulas for calculation of strength.
During strength checking the thickness of stiffening plates is also taken into consideration. In formulas 1 and 3 t_b is changed to $t_b + 0.6 \cdot t_{sp}$:

$$\frac{N_{tens/press}}{R_{yf} \cdot t_f^2 \cdot \dfrac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot (t_b + 0.6 \cdot t_{sp}) \cdot d_b} < 1 \qquad (10)$$

3.3.3 Calculation of Joint Type "Fr"

Stiffening rib can be added to increase the rigidity, cross section area and value of section modulus of the brace plate in joint. In this manner supportive of moment appearing because of eccentricity of normal force happens more efficiently.
The rib is taken into account by using its characteristics during calculation of section modulus in formulas 2 and 4 when the section of brace plate is checked. This section modulus is calculated for T-section consisting of brace plate in the form of flange of T-section and rib as web of T-section.
Also it is necessary to consider two checkings: applying section modulus of T-section relative to brace plate and relative to rib.

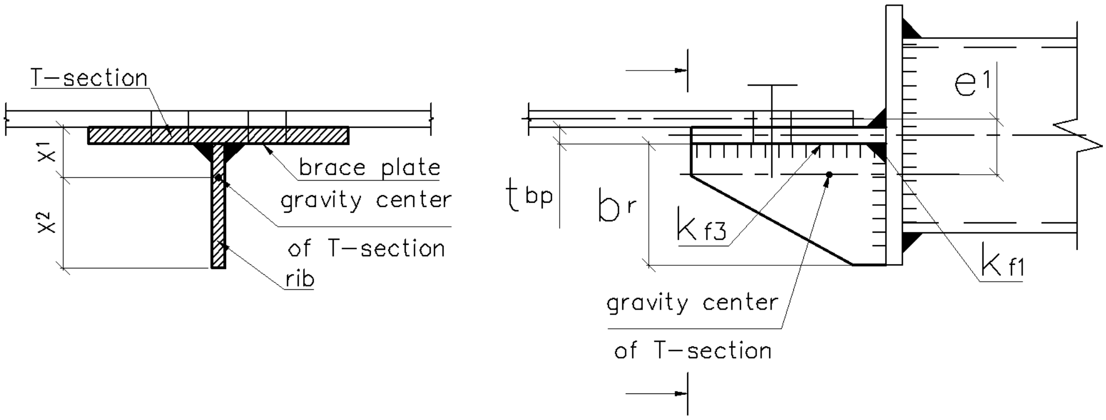

Figure 17. T-section of brace plate and rib

As the result formulas 1, 3, 5, 6 stay the same but others are changed:

$$\frac{N_{tens/press}}{A_{T-s} \cdot R_{ybp}} + \frac{N_{tens/press} \cdot e_1}{W_{1-1} \cdot R_{ybp}} < 1 \qquad (11)$$

W_{1-1} – section modulus of T-section relative to brace plate

A_{T-s} – cross-section area of T-section (plate of brace + rib)

R_{ybp} – design strength of brace plate steel

e_1 – eccentricity of normal force

$$\frac{N_{tens/press}}{A_{T-s} \cdot R_{yr}} + \frac{N_{tens/press} \cdot e_1}{W_{2-2} \cdot R_{yr}} < 1 \qquad (12)$$

W_{1-1} – section modulus of T-section relative to rib

R_{yr} – design strength of rib

Weld of type “Fr” joint also has new gravity center and bears the load by a bit different way. In this kind of joints weld has to be checked to moment appearing because of eccentricity of normal force as T-section.

Formulas acquire the following form:

$$\frac{N_{max}}{A_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \qquad (13)$$

A_{wf}, W_{wf} – cross-section area of weld kf1 by weld metal

$$\frac{N_{max}}{A_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \qquad (14)$$

A_{wz}, W_{wz} – cross-section area of weld kf1 by weld board

$$\frac{N_{max}}{A_{wth} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \qquad (15)$$

A_{wth}, W_{wth} – cross-section area of weld kf1 by metal of weld board with flange along plate thickness.

3.3.4 Calculation of Joint Type "C"

A common case is when bearing capacity requirements are not assured by weld flange to brace or more often brace plate to flange. It is usually happened by the reason of limitation of perimeter of brace section and dimensions of brace plate. So the length of weld is limited too.

The weld leg also can not be increased as much as it is required by calculation because of using not so thick webs in RHS. Generally webs thickness of standard RHS using as braces do not exceed 6-8 mm.

The solution to these problems is to lengthen the weld by cutting-in of brace plate into profile of brace. For this purpose, a rectangular cutout is made in the profile, the width is equal to the thickness of the connection gusset.

Clearances are often provided to facilitate insertion of plate into the brace. When a brace plate is installed it is welded. In this way bearing capacity can be regulated by the length of cutting-in.

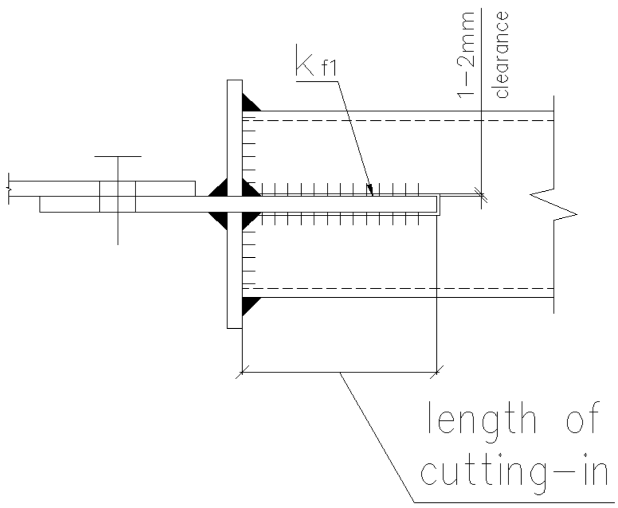

Figure 18. Cutting-in

<u>Tensile and press strength</u> for Joints Type "C" should be checked with the use of two formulas:

1. Formula for section of brace

$$\frac{N_{tens/press}}{A \cdot R_{yb} \cdot \gamma_f} < 1 \tag{16}$$

A – brace cross-section area

γ_f – factor of cutting-in length influence

$\gamma_f = 0.5 \cdot \frac{l_1}{d_b} + 0.18$ if $0.8 \leq \frac{l_1}{d_b} < 1.6$

$\gamma_f = 1$ if $\frac{l_1}{d_b} > 1.6$

If $0.8 > \frac{l_1}{d_b}$, length of cutting-in is not correct

l_1 – length of cutting-in

d_b – dimension of brace section (see Figure 11)

2. Formula for section of brace plate, taking into account a Moment appearing because of eccentricity of normal force

$$\frac{N_{tens/press}}{A_{bp} \cdot R_{ybp}} + \frac{N_{tens/press} \cdot e}{W_{bp} \cdot R_{ybp}} < 1 \tag{17}$$

Load bearing capacity of bolts should be checked by using the same formula:

$$\frac{N_{max}}{N_{b\,min} \cdot n_b} < 1 \tag{18}$$

Load bearing capacity of weld should be checked by weld material (formula 19) and along weld board (formula 20):

$$\frac{N_{max}}{\beta_f \cdot k_{f1} \cdot l_w \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \tag{19}$$

$$\frac{N_{max}}{\beta_z \cdot k_{f1} \cdot l_w \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1 \tag{20}$$

3.3.5 Calculation of Joint Type “Cr”

Type “Cr” is most commonly used in practice. Specially when tensile or press load is significantly large and plates of big thickness are used that leads to appearing of intense Moment caused by eccentricity of normal force.

The method of calculation is something common between the type “C” and type “Fr” calculation methods.

Formulas that are used: 16, 11, 12, 5, 18- 20, 13-15.

3.4 Degree of influence of basic factors and characteristics

Different characteristics of joint like the chosen kind of steel, the dimensions of plates, the diameter and amount of bolts and the presence of additional stiffening elements act on the results and resistance of joint in whole with different degree of influence.

To research the main factor some diagrams were composed. Each of the diagrams differ by changing of value one of influencing parameters.

Research is performed for standard connection of "C" type with cut-in brace plate.

Brace is pressed with stress $N_{press} = 300\ kN.$ For brace section a tube of RHS 120x120x5 is chosen.

Result factors:

1. Press strength of brace
2. Press strength of brace plate
3. Load bearing capacity of bolts in regard to shear resistance per shear plane
4. Load bearing capacity of bolts in regard to bearing resistance of brace plate
5. Load bearing capacity of weld by weld metal
6. Load bearing capacity of weld by weld board

All result factors are got in the form of strength utilization ratios in other words ratio of acting stress to resistance of considered element (plate, bolts or weld). This ratio should be less then 1. The closer the value is to 1, the smaller the strength reserve.

<u>Influence of steel kind:</u> C245 and C355

Initial data:

Brace: RHS 120x120x5, $l = 6\ m$

Brace plate: $t_{bp} = 12\ mm$, length of cut-in $l_1 = 100\ mm$

Joint plate: $t_{jp} = 10\ mm$

Bolts: 2 bolts M20, strength class 8,8

Weld: $k_f = 6\,mm$, weld material Э42

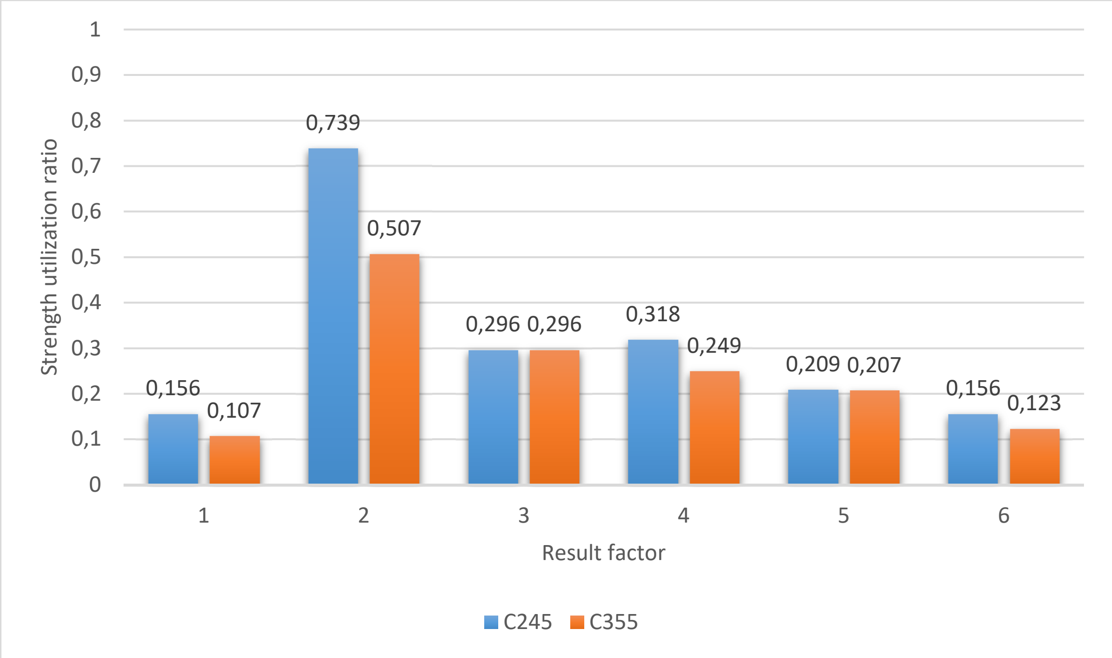

Diagram 1. Influence of steel kind

The diagram shows that kind of steel and accordingly value of design and characteristic steel strength makes the greatest impact to resistance of brace plate. Also a little influence is on durability of bolts and weld but only when they are calculated with regard to characteristics of plates.

The press strength of brace increases too but not so much as the strength of brace plate.

It is important to note that kind of steel was changed from C245 to C355 for all elements of connection. If the steel is changed only for one of the elements, for example only for brace plate, so there is no influence at the brace strength utilization ratio at all.

<u>Influence of brace plate thickness:</u> 12 mm and 16 mm

Initial data:

Brace: RHS 120x120x5, $l = 6\,m$, C245

Brace plate: C245, length of cut-in $l_1 = 100\,mm$

Joint plate: $t_{jp} = 10\ mm$, C245

Bolts: 2 bolts M20, strength class 8,8

Weld: $k_f = 6\ mm$, weld material Э42

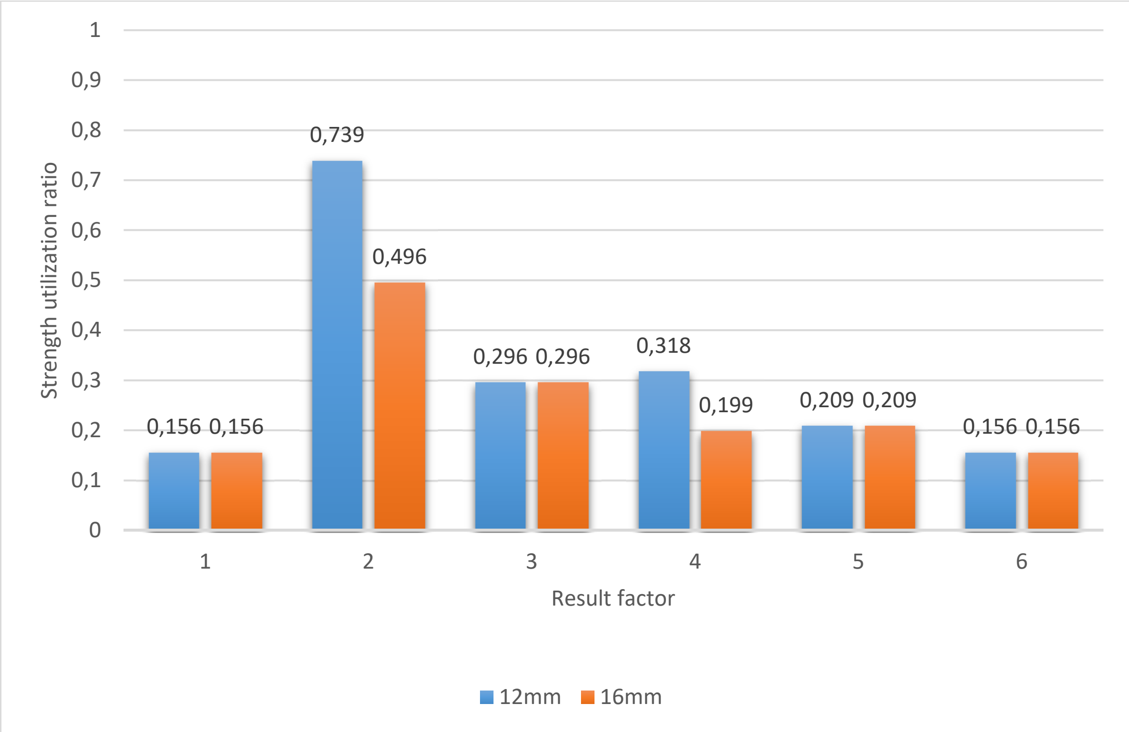

Diagram 2. Influence of brace plate thickness

Variation of the brace plate thickness first of all in the example leads to increasing of cross-section area. So changings occur only in brace plate strength and in load bearing capacity of bolts in regard to bearing resistance of brace plate.

Influence of cutting-in length: 100 mm and 200 mm

Initial data:

Brace: RHS 120x120x5, $l = 6\ m$, C245

Brace plate: $t_{bp} = 12\ mm$, C245

Joint plate: $t_{jp} = 10\ mm$, C245

Bolts: 2 bolts M20, strength class 8,8

Weld: $k_f = 6\ mm$, weld material Э42

The following diagram 3 compares the situations in which the value of brace plate cutting-in length is varied from 100 mm to 200 mm. Along with increasing cutting-in length weld length is increasing too. So strength utilization ratio of weld resistance gets smaller and strength reserve rises proportionally to cutting-in length.

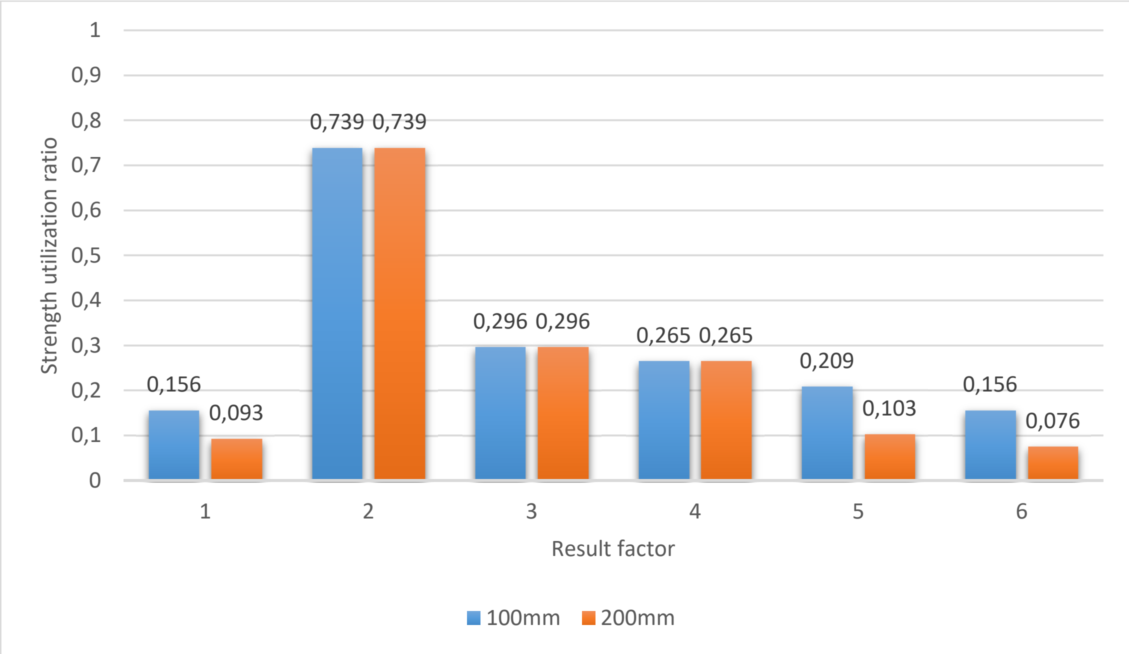

Diagram 3. Influence of cutting-in length

In addition, the diagram shows changings in press strength of brace. This is due to dependency of brace resistance on factor of cutting-in length influence (see Formula 16). So the larger the cutting-in, the less its influence.

<u>Influence of diameter of bolts:</u> M16 and M20

Initial data:

Brace: RHS 120x120x5, $l = 6\ m$, C245

Brace plate: $t_{bp} = 10\ mm$, C245, $l_1 = 100mm$

Joint plate: $t_{jp} = 10\ mm$, C245

Bolts: 2 bolts, strength class 8,8

Weld: $k_f = 6\ mm$, weld material Э42

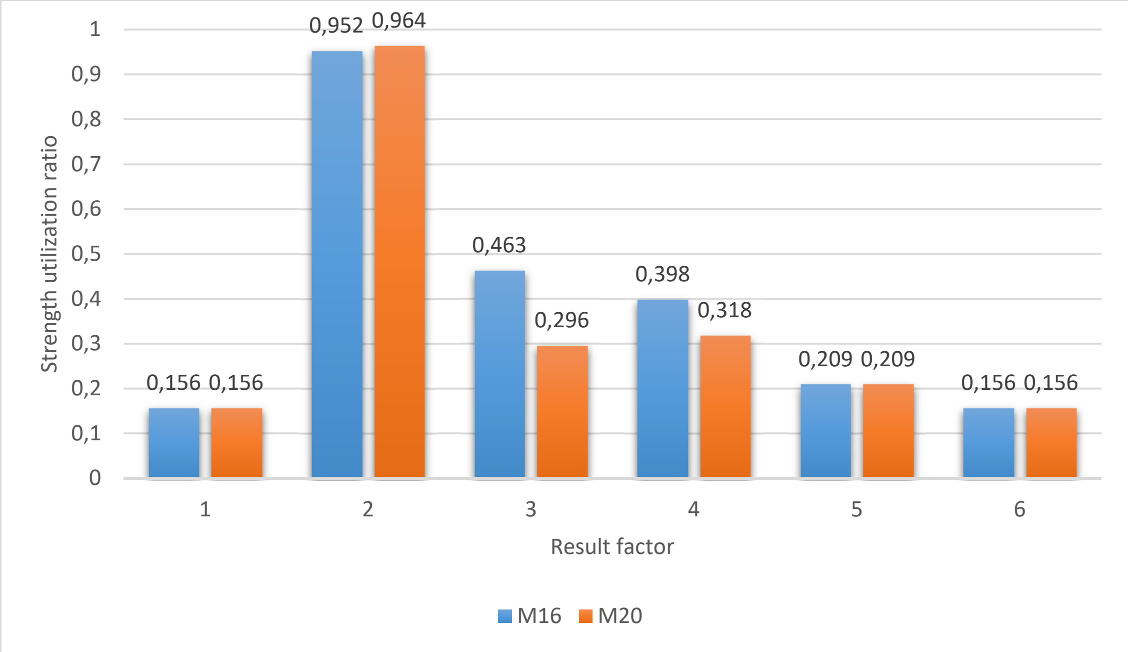

Diagram 4. Influence of diameter of bolts

Obviously, with increasing of bolts diameter, resistance of bolt connection gets higher. It is shown in diagram 4.

In addition, it can be noticed that the strength utilization ratio of brace plate becomes nearer to 1 with increasing of diameter of bolts. It happens because of increasing of bolt holes in the brace plate, that leads to weakening of the brace plate cross-section.

An important fact is also that the load bearing capacity of bolt connection with using of bolts M16 should be finally calculated with the aid of shear resistance of bolt per shear plane (N_{bs}) because it is less then bearing resistance (N_{bp}) of brace plate (see formula 6). However, with using bolts M20 on the contrary calculation should be performed with regard to brace plate bearing resistance.

<u>Influence of amount of bolts:</u> 2M20 and 4M20

Initial data:

Brace: RHS 120x120x5, $l = 6\ m$, C245

Brace plate: $t_{bp} = 12\ mm$, C245, $l_1 = 100\ mm$

Joint plate: $t_{jp} = 12\ mm$, C245

Bolts: bolts M20, strength class 8,8

Weld: $k_f = 6\ mm$, weld material Э42

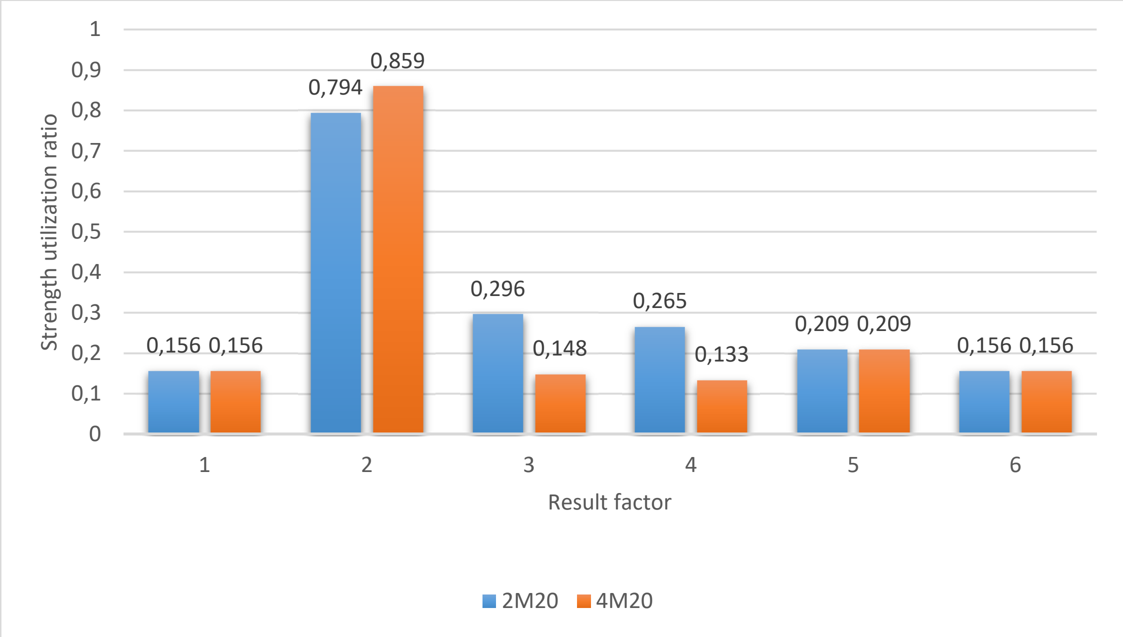

Diagram 5. Influence of amount of bolts

Same as in the case of diameter change by diagram 5 we can see that with increasing of amount of bolts the bolts resistance in relation to the shear resistance of bolt per shear plane (N_{bs}) and the bearing resistance (N_{bp}) of brace plate, both become higher. The strength durability of brace plate decreases due to weakening by bolt holes.

Influence of moment appearing because of eccentricity of normal force

As shown in formulas 4, 5 etc. according to Russian norms it is necessary to take into account additional stress appearing because of eccentricity of normal force (see figure 14). Thus the load acting on connection rises. It is important to notice that the brace plate is thicker, the eccentricity is bigger. So increasing of brace plate or joint plate thickness should be done very carefully to avoid too intense rising of stress.

4 CALCULATION PART

By agreement with the head of the designing department of the company the main goal of the work and researches is to create the program in Excel able to check easily and fast any combination of joint parameters. This application should help designers check and then choose the most rational variant by changing one or more characteristics of joint components.

The principle of program operation will be considered in the following paragraph. Then detailed examples of geometry design and calculation of two different types of connections are demonstrated to compare the chosen variants and make some inferences.

4.1 Program operation

The Excel file contains 9 sheets. The first 5 sheets are intended to joint calculation and conform to 5 basic connection types. The last 4 sheets include tables of characteristics:

- Sections – dimensions of pipe cross-sections and values of cross-section area, section modulus, radius of gyration and others according to GOST 30245-2012 “Steel closed rolled-welded square and rectangular profiles for building structures. Technical conditions”;
- Steel – design and characteristics strength and design bearing resistance of different kind of steel in accordance with SP 13.13330.2017 Annex B tables B.3-B.5 (Appendix 5);
- Bolts – cross-section area of bolts different diameters according to SP 13.13330.2017 annex Г. table Г.9 and strength characteristics for bolts of different strength classes from SP13.13330.2017 annex Г. table Г.5 (Appendix 6);
- Weld – design strength of weld metal in accordance with SP 13.13330.2017 annex Г. table Г.1 (Appendix 7).

The Excel sheet space is divided into several blocks, each of which has a certain purpose. To understand how the program works, the functions of each table in the sheet are briefly explained.

The first thing that needs to be done is to preliminarily design the geometric shape of brace connection relying on the design experience. For this it is needed to choose one of the basic variants of joins presented in paragraph 2.5 of the thesis. The same pictures corresponding to each of the connection can be seen on the Excel sheet.

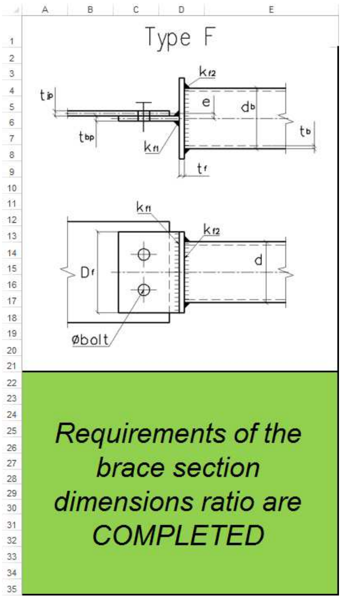

Figure 19. Principle geometric shape of joint

On the picture all symbols are shown. They mark the basic dimensions and characteristics of the chosen type of joint. In addition under the scheme note about requirements of the brace section dimensions ratio is appeared. It refers to limitation relating to brace pipe dimensions ratio (p. 3.3 of the thesis). This limitation is in order to prevent using pipe sections that are too elongated in one direction as braces.

For example RHC 300x200x8 is not desirable to be used as a brace according to SP 294.1325800.2017 p.14.4.3. because of its dimensions ratio is

$$\frac{d_b}{d} = \frac{300}{200} = 1.5 \geq 1.1$$

The table with title “DATA FOR INPUT” contains user input data such as acting stress, cross section of brace and its length, information about the other components of the joint and their characteristics such as steel mark, thickness, bolt diameter and welding characteristics. Using this table the designer after preliminary design could change one or more characteristic of joint components and select the most suitable complex of characteristics.

F	G	H	I
DATA FOR INPUT			
COMMON DATA			
Effective length of brace	l =	600.00	cm
Tensile stress	N- =	50.00	kN
Press stress	N+=	50.00	kN
FLANGE			
Steel of flange	C235 (2 mm - 4 mm)		
Thickness of flange	t_f =	16	mm
Flange length along plate of brace	D_f =	160	mm
BRACE			
Steel of brace	C255 (more 10 mm to 20 mm)		
Section of brace	300x200x8		
PLATE OF BRACE			
Steel of brace plate	C245 (from 2 mm to 20 incl.)		
Thickness of brace plate	t_{bp}=	16	mm
PLATE OF JOINT			
Steel of joint plate	C245 (from 2 mm to 20 incl.)		
Thickness of joint plate	t_{jp} =	16	mm
BOLTS			
Diameter of bolts	d =	24	
Strength class	8.8		
Amount of bolts	n_b =	2	bolts
Conditions-of-use factor of bolt joint	γ_b =	0.90	
Conditions-of-use factor of structure	γ_c =	0.90	
Amount of shear planes	n_s =	1	
WELD			
γ_{cf} =	0.8		
k_{f1} =	6		mm
β_{f1} =	0.7		
β_{z1} =	1		
Kind of welding material k_{f1}	Э42		
k_{f2} =	12		mm
β_{f2} =	0.7		
β_{z2} =	1		
Kind of welding material k_{f2}	Э46А		

Figure 20. Table “DATA FOR INPUT”

Next to this table locates a table with title “INFORMATIONAL DATA”. It contains intermediate calculations and results as well as information about characteristics taken from the tables on the last four Excel sheets and some not easy calculations of geometric characteristics like moment of inertia or Section modulus. The user does not have to input anything in this table, only review and check using information.

L M	N	O	P
INFORMATIONAL DATA			
Design strength of flange steel	R_{yf} =	230	N/mm2
Design strength of brace plate steel	R_{ybp} =	240	N/mm2
Design strength of brace steel	R_{yb} =	240	N/mm2
Design strength of joint plate steel	R_{yjp} =	240	N/mm2
Characteristic strength of flange steel	R_{unf} =	360	N/mm2
Characteristic strength of brace steel	R_{unb} =	370	N/mm2
Characteristic strength of brace plate steel	R_{unbp} =	370	N/mm2
Elastic module	E =	20600	kN/cm2
Nominal brace slenderness	λ =	2.50	
Conditions-of-use factor acc. to p.14.4.3	γ_f =	0.916	
Design bearing resistance of brace plate steel	R_{bp_bp}	485	N/mm2
Design bearing resistance of joint plate steel	R_{bp_jp}	485	N/mm2
Design shear strength of bolt	R_{bs} =	332	N/mm2
Section width along brace plate	d =	300	mm
Section width across brace plate	d_b =	200	mm
Thickness of brace section	t_b =	8	mm
Brace cross-section area	A =	75.24	cm 2
Brace section modulus	W =	503.9	cm3
Radius of gyration	i =	8.18	cm
Brace section perimeter	P =	965.664	mm
Excentricity of normal force	e=	1.6	cm
Bolt cross-section area	A_{bolt} =	4.52	cm2
Brace plate cross-section area	A_{bp} =	20.200	cm2
Brace plate section modulus	W_{bp} =	6.827	cm3
BOLTS			
Design shear stress of one bolt	N_{bs} =	121.552	kN
Design bearing stress of brace plate steel	$N_{bp\,bp}$ =	150.854	kN
Design bearing stress of joint plate steel	$N_{bp\,jp}$ =	150.854	kN
Minimal design bearing stress	N_{bp} =	150.854	kN
Minimal design shear stress of one bolt	$N_{b\,min}$ =	121.552	kN
WELD			
Design strength by weld metal kf1	R_{wf1} =	180	N/mm2
Design strength by weld board kf1	R_{wz1}=	162	N/mm2
Design strength by metal of weld board with flange along plate thickness	R_{th} =	175.610	N/mm2
Design strength by weld board kf2	R_{wz2}=	162	N/mm2
Design strength by weld metal kf2	R_{wf2} =	200	N/mm2

Figure 21. Table “INFORMATIONAL DATA”

The last block with title “CHECKING” displays the results of calculations of each checking point like plate strength and bolts or weld bearing resistance. All calculations are performed in accordance with paragraph 3.3 of the thesis and have the form of strength utilization ratio that must be less than 1 the calculation will be right.

CHECKING	
1) TENSILE STRENGTH	
$\frac{N_{tens}}{R_{yf}\cdot t_f^2\cdot \frac{D_f}{d_b-3\cdot t_{bp}}+R_{yb}\cdot t_b\cdot d_b}<1$	
0.417	YES
$\frac{N_{tens}}{A_{bp}\cdot R_{ybp}}+\frac{N_{tens}\cdot e}{W_{bp}\cdot R_{ybp}}<1$	
0.777	YES
2) PRESS STRENGTH	
$\frac{N_{pres}}{R_{yf}\cdot t_f^2\cdot \frac{D_f}{d_b-3\cdot t_{bp}}+R_{yb}\cdot t_b\cdot d_b}<1$	
0.583	YES
$\frac{N_{pres}}{A_{bp}\cdot R_{ybp}}+\frac{N_{pres}\cdot e}{W_{bp}\cdot R_{ybp}}<1$	
1.088	NO
$\frac{N_{press}}{A\cdot R_{yb}\cdot \gamma_f}+\frac{N_{press}\cdot e}{W\cdot R_{yb}\cdot \gamma_f}<1$	
0.420	YES
3) LOAD BEARING CAPACITY OF BOLTS	
$\frac{N_{max}}{N_{b\,min}\cdot n_b}<1$	
0.829	YES

Figure 22. Table “CHECKING”

4.2 Examples of calculations

The examples are calculated on the basis of real design documentations provided by the company to put into practice the skills gained through the research. The building under construction is a metal structure for industrial use for oil and gas refining. The construction of a processing complex takes place in Russia. The structures are designed by Russian norms with using characteristic and design loads appropriate for this place. Design documentation is received from the customer and contains all the main stresses in the structure elements that the designers of the company should use for joint design and calculation. Stresses in the structure elements were received during calculation of the whole frame with the aid of software complex.

The examples are taken from the part of building complex. The work and production documentation for this part was developed by the author as well as the calculation method and program.
The building is a frame structure of vertical columns, horizontal floors based on beams and vertical and horizontal bracing. The last part of the work goes through two cases of connecting vertical brace to column. In both cases, the joint plate is used in the column, and in principle, the connections work in the same way. The cases differ in profile size, acting load, brace length, thickness of plates and type of joint chosen from variants considered earlier.

In the examples I check all strength characteristics explained in paragraph 3.3 of the thesis paying particular attention to tensile capacity of plates and brace section, design resistance for individual fasteners subjected to shear and bearing resistance and capacity of welding. However, Russian calculation method of brace connections does not envisage the phenomena of block tearing in the same way as Eurocode does. Instead of this in the bolts calculation part it is performed a checking of bearing resistance of joint or brace plate, meaning capacity against plate metal damage caused by bolt pressure. This is considered sufficient with the obligatory observance of edge distances.

The task for the calculations is presented in the form of one sheet from the design documentation set received from the customer in Appendix 1.

4.2.1 Type "F" for RHS 80x80x4

In accordance with the task, initial data for the first case is the following:

- Stress $N = \pm 61.5\ kN$
- Effective length of brace $l = 330cm$
- Steel of brace C245
- Steel of joint elements C245
- Bolt strength class 8.8
- $\gamma_c = 0.9$
- $\gamma_b = 1$

Geometry design:

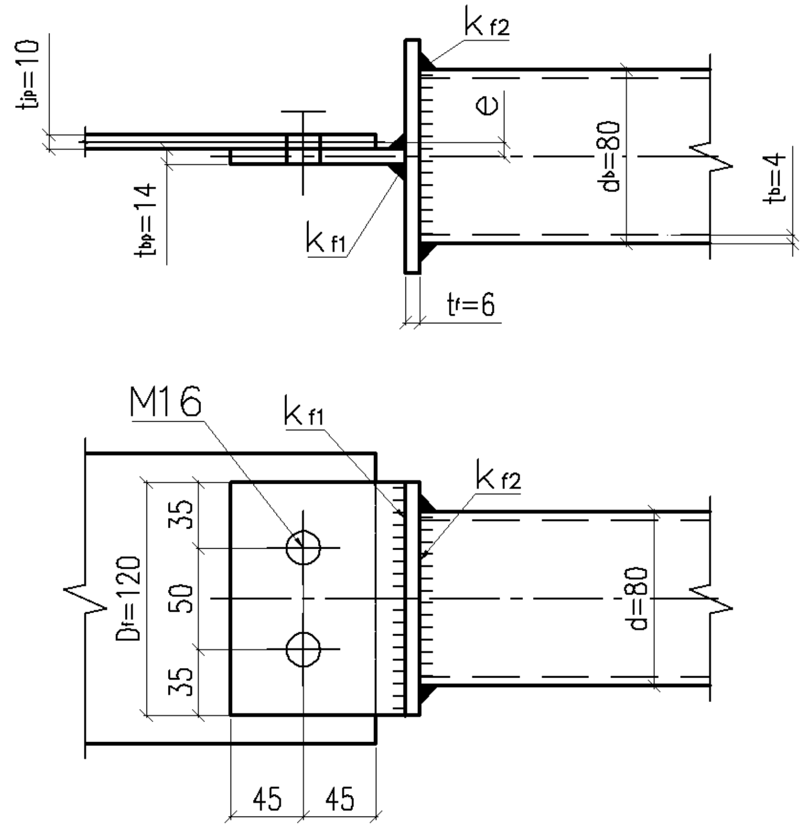

Figure 23. Type “F” for RHS 80x80x4

Checking part:

To decrease the mount of formulas and make this part of the thesis easier there are not detail calculations of geometric characteristics like cross-section areas (A) and section modulus (W). All values required in calculations are taken from the Excel program. The tutor from the company carefully checked the used data and formulas.

The whole calculation of the first example is presented Appendix 2.

1. Tensile/press strength of overall section of flange and brace

$$\frac{N_{tens/press}}{R_{yf} \cdot t_f^2 \cdot \frac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} =$$

$$= \frac{61.5\ kN}{24 \frac{kN}{cm^2} \cdot (0.6\ cm)^2 \cdot \frac{12\ cm}{8\ cm - 3 \cdot 1.4\ cm} + 24 \frac{kN}{cm^2} \cdot 0.4\ cm \cdot 8\ cm} = 0.613 < 1$$

$$\Rightarrow OK$$

2. Tensile/press strength of brace plate

$$\frac{N_{tens/press}}{A_{bp} \cdot R_{ybp}} + \frac{N_{tens/press} \cdot e}{W_{bp} \cdot R_{ybp}} =$$

$$= \frac{61.5\ kN}{13\ cm^2 \cdot 24\ kN/cm^2} + \frac{61.5\ kN \cdot 1.2\ cm}{3.92\ cm^3 \cdot 24\ kN/cm^2} = 0.982 < 1$$

$$\Rightarrow OK$$

$e = 1.4\ cm/2 + 1\ cm/2 = 1.2\ cm$ – eccentricity of normal force.

3. Press strength of brace, taking into account compression of brace area near the joint by using of special coefficient γ_f:

$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} + \frac{N_{press} \cdot e}{W \cdot R_{yb} \cdot \gamma_f} =$$

$$= \frac{61.5\ kN}{11.75\ cm^2 \cdot 24\ kN/cm^2 \cdot 1} + \frac{61.5\ kN \cdot 1.2\ cm}{27.74\ cm^3 \cdot 24\ kN/cm^2 \cdot 1} = 0.329 < 1$$

$$\Rightarrow OK$$

γ_f – conditions-of-use factor (SP 294.1325800.2017 p.14.4.3):

- $\gamma_f = 0.6$ if $\bar{\lambda} \leq 0.45$
- $\gamma_f = 0.54 + 0.15 \cdot \bar{\lambda}$ if $\bar{\lambda} > 0.45$ but $\gamma_f \leq 1$

$$\bar{\lambda} = \frac{l}{i} \cdot \sqrt{\frac{R_{yb}}{E}} = \frac{330\ cm}{3.07\ cm} \cdot \sqrt{\frac{24kN/cm^2}{20600kN/cm^2}} = 3.67$$

$\bar{\lambda}$ – nominal brace slenderness

$$\gamma_f = 0.54 + 0.15 \cdot 3.67 = 1.091 > 1 \quad \Rightarrow \quad \gamma_f = 1$$

4. Load bearing capacity of bolts

$$\frac{N_{max}}{N_{b\,min} \cdot n_b} = \frac{61.5\ kN}{60.1\ kN \cdot 2} = 0.512 < 1$$

$$\Rightarrow OK$$

$N_{bs} = R_{bs} \cdot A_b \cdot n_s \cdot \gamma_b \cdot \gamma_c = 33.2\ kN/cm^2 \cdot 2.01\ cm^2 \cdot 1 \cdot 1 \cdot 0.9 = 60.1\ kN$

N_{bs} – shear resistance per shear plane

$N_{bp\_bp} = R_{bp} \cdot d_{bolt} \cdot \sum t \cdot \gamma_b \cdot \gamma_c = 48.5\ kN/cm^2 \cdot 1.6 \cdot 1.4 \cdot 1 \cdot 0.9 = 97.8\ kN$

N_{bp_bp} – bearing resistance of brace plate

$N_{bp\_jp} = R_{bp} \cdot d_{bolt} \cdot \sum t \cdot \gamma_b \cdot \gamma_c = 48.5\ kN/cm^2 \cdot 1.6 \cdot 1.0 \cdot 1 \cdot 0.9 = 69.8\ kN$

N_{bp_jp} – bearing resistance of joint plate

$N_{b\ min} = \min\left(N_{bs}; N_{bp_{bp}}; N_{bp_{jp}}\right) = 60.1\ kN$ ⇒ it means that damage of bolts will happen earlier than damage of one of the plates.

5. Load bearing capacity of welding brace plate to flange

$k_f = 6\ mm$; kind of welding material – Э42

- by weld metal

$$\frac{N_{max}}{\beta_{f1} \cdot k_{f1} \cdot l_{w1} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$= \frac{61.5\ kN}{0.7 \cdot 0.6\ cm \cdot 2 \cdot (12 - 2)\ cm \cdot 18\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.508 \leq 1$$

$$\Rightarrow OK$$

- by metal of weld board

$$\frac{N_{max}}{\beta_{z1} \cdot k_{f1} \cdot l_{w1} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$\frac{61.5\ kN}{1.0 \cdot 0.6\ cm \cdot 2 \cdot (12 - 2)\ cm \cdot 0.45 \cdot 37\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.385 \leq 1$$

$$\Rightarrow OK$$

- by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{k_{f1} \cdot l_{w1} \cdot R_{th} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$\frac{61.5kN}{0.6\ cm \cdot 2 \cdot (12 - 2)\ cm \cdot 0.5 \cdot \frac{37}{1.025}\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.355 \leq 1$$

$$\Rightarrow OK$$

6. Load bearing capacity of welding flange to brace profile

$k_f = 4\ mm$; kind of welding material – Э42

- by weld metal

$$\frac{N_{max}}{\beta_{f2} \cdot k_{f2} \cdot l_{w2} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$= \frac{61.5\ kN}{0.7 \cdot 0.4\ cm \cdot (8 \cdot 4 - 2)\ cm \cdot 18\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.533 \leq 1$$

$$\Rightarrow OK$$

- by metal of weld board

$$\frac{N_{max}}{\beta_{z2} \cdot k_{f2} \cdot l_{w2} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$\frac{61.5\ kN}{1.0 \cdot 0.4\ cm \cdot (8 \cdot 4 - 2)\ cm \cdot 0.45 \cdot 37\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.403 \leq 1$$

$$\Rightarrow OK$$

- by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{k_{f1} \cdot l_{w1} \cdot R_{th} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$\frac{61.5kN}{0.4\ cm \cdot (8 \cdot 4 - 2)\ cm \cdot 0.5 \cdot \frac{37}{1.025}\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.372 \leq 1$$

$$\Rightarrow OK$$

The presented example shows that the weakest element of joint is the brace plate because its area of cross section depends heavily on the dimensions of the brace profile. In the example RHS tube has quite a small section that does not allow to increase the width of the brace plate (dimension D_f) sufficiently. Due to this it is necessary to increase the thickness of the brace plate, In this case only 14 mm comes enough. But in some cases applying of an element such a big thickness could seem to be not very efficient.

Appendix 3 contains calculation of another variant of joint for the same situation. All initial data is the same but the used type of joint is “Fr”. Addition of stiffening rib of 6 mm enables to decrease the thickness if the brace plate is from 14 mm to 10 mm. Maybe on the whole it does not give a great steel saving in this example, but in case with bigger sizes of brace profile and bigger thicknesses it will. In addition when the thickness of the joint plate is bigger, the eccentricity of normal force can lead to increase moment in joint and stiffening rib will be the sole solution to provide joint strength and bearing capacity.

The use of the stiffening rib has one disadvantage that is that the production of the brace at the manufacture becomes a more labor-intensive and time-taking process due to an increase in the value of welding.

4.2.2 Type “Cr” for RHS 120x120x5

In accordance with the task, initial data for the first case is the following:

- Stress $N = \pm 140.0\ kN$
- Effective length of brace $l = 496\ cm$
- Steel of brace C245
- Steel of joint elements C245
- Bolt strength class 8.8
- $\gamma_c = 0.9$
- $\gamma_b = 1$

Geometry design:

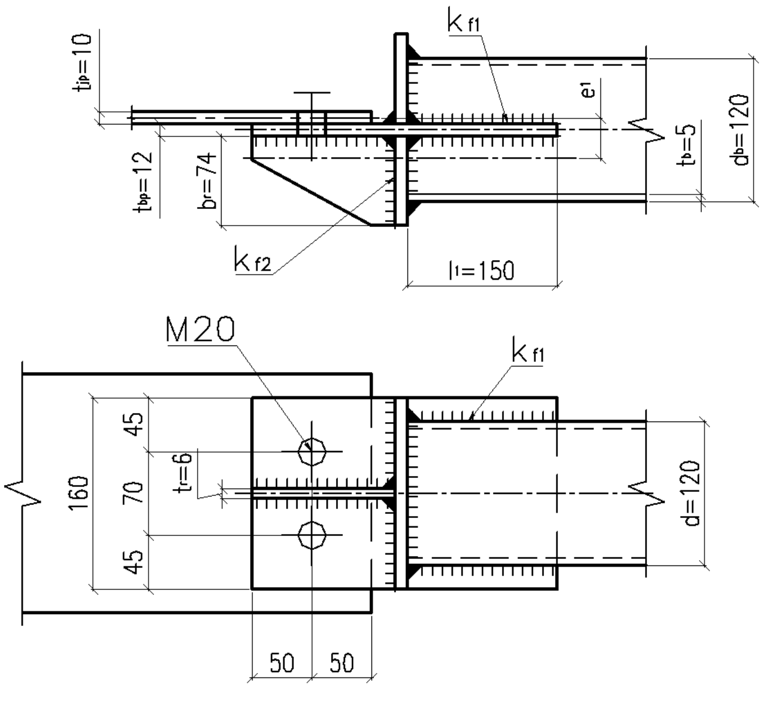

Figure 24. Type “F” for RHS 120x120x5

Checking part:

As in the previous case, there are no detail calculations of geometric characteristics like cross-section areas (A), section modulus (W), moment of

inertia (I) and coordinates of gravity center of T-section. All values required in calculations are taken from the Excel program.
The whole calculation of the second example is presented in Appendix 4.

1. Tensile/press strength of section of brace

$$\frac{N_{tens/press}}{A \cdot R_{yb} \cdot \gamma_f} = \frac{140.0\ kN}{22.36\ cm^2 \cdot 24\ kN/cm^2 \cdot 0.805} = 0.324 < 1$$

$$\Rightarrow OK$$

γ_f – factor of cutting-in length influence

$$0.8 \leq \frac{l_1}{d_b} = \frac{150}{120} = 1.25 < 1.6$$

$$\gamma_f = 0.5 \cdot \frac{l_1}{d_b} + 0.18 = 0.5 \cdot 1.25 + 0.18 = 0.805$$

2. Tensile/press strength of brace plate, taking into account a Moment appearing because of eccentricity of normal force

- in relation to edge of brace plate

$$\frac{N_{tens/press}}{A_{T-s} \cdot R_{ybp}} + \frac{N_{tens/press} \cdot e_1}{W_{1-1} \cdot R_{ybp}} =$$

$$= \frac{140.0\ kN}{25.12\ cm^2 \cdot 24\ kN/cm^2} + \frac{140.0\ kN \cdot 2.11\ cm}{70.029\ cm^3 \cdot 24\ kN/cm^2} = 0.408 < 1$$

$$\Rightarrow OK$$

- in relation to edge of rib

$$\frac{N_{tens/press}}{A_{T-s} \cdot R_{yr}} + \frac{N_{tens/press} \cdot e_1}{W_{2-2} \cdot R_{yr}} =$$

$$= \frac{140.0\ kN}{25.12\ cm^2 \cdot 24\ kN/cm^2} + \frac{140.0\ kN \cdot 2.11\ cm}{16.171\ cm^3 \cdot 24\ kN/cm^2} = 0.995 < 1$$

$$\Rightarrow OK$$

3. Press strength of brace, taking into account compression of brace area near the joint by using of special coefficient γ_f:

$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} + \frac{N_{press} \cdot e}{W \cdot R_{yb} \cdot \gamma_f} =$$

$$= \frac{140.0\ kN}{22.36\ cm^2 \cdot 24\ kN/cm^2 \cdot 1} + \frac{140.0\ kN \cdot 1.1\ cm}{80.88\ cm^3 \cdot 24\ kN/cm^2 \cdot 1} = 0.34 < 1$$

$$\Rightarrow OK$$

$$e = \frac{t_{bp}}{2} + \frac{t_{jp}}{2} = \frac{1.2}{2} + \frac{1.0}{2} = 1.1\ cm$$

γ_f – conditions-of-use factor (SP 294.1325800.2017 p.14.4.3):

- $\gamma_f = 0.6$ if $\bar{\lambda} \leq 0.45$
- $\gamma_f = 0.54 + 0.15 \cdot \bar{\lambda}$ if $\bar{\lambda} > 0.45$ but $\gamma_f \leq 1$

$$\bar{\lambda} = \frac{l}{i} \cdot \sqrt{\frac{R_{yb}}{E}} = \frac{496\ cm}{4.66\ cm} \cdot \sqrt{\frac{24\ kN/cm^2}{20600\ kN/cm^2}} = 3.63$$

$\bar{\lambda}$ – nominal brace slenderness

$$\gamma_f = 0.54 + 0.15 \cdot 3.63 = 1.085 > 1 \quad \Rightarrow \quad \gamma_f = 1$$

4. Load bearing capacity of bolts

$$\frac{N_{max}}{N_{b\ min} \cdot n_b} = \frac{140.0\ kN}{87.3\ kN \cdot 2} = 0.802 < 1$$

$$\Rightarrow OK$$

$N_{bs} = R_{bs} \cdot A_b \cdot n_s \cdot \gamma_b \cdot \gamma_c = 33.2\ kN/cm^2 \cdot 3.14\ cm^2 \cdot 1 \cdot 1 \cdot 0.9 = 93.8\ kN$

N_{bs} – shear resistance per shear plane

$N_{bp\_bp} = R_{bp} \cdot d_{bolt} \cdot \sum t \cdot \gamma_b \cdot \gamma_c = 48.5\ kN/cm^2 \cdot 2.0 \cdot 1.2 \cdot 1 \cdot 0.9 = 104.8\ kN$

N_{bp_bp} – bearing resistance of brace plate

$N_{bp\_jp} = R_{bp} \cdot d_{bolt} \cdot \sum t \cdot \gamma_b \cdot \gamma_c = 48.5\ kN/cm^2 \cdot 2.0 \cdot 1.0 \cdot 1 \cdot 0.9 = 87.3\ kN$

N_{bp_jp} – bearing resistance of joint plate

$N_{b\ min} = \min\left(N_{bs}; N_{bp_{bp}}; N_{bp_{jp}}\right) = 87.3\ kN$ $\Rightarrow$ it means that damage of joint plate will happen earlier than damage of bolts or brace plate.

5. Load bearing capacity of welding of cut-in brace plate to brace profile

$k_{f1} = 6\ mm$; kind of welding material – Э46А

- by weld metal

$$\frac{N_{max}}{\beta_{f1} \cdot k_{f1} \cdot l_{w1} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$= \frac{140.0\ kN}{0.7 \cdot 0.6\ cm \cdot 4 \cdot (15 - 2)\ cm \cdot 20\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.401 \leq 1$$

$$\Rightarrow OK$$

- by metal of weld board

$$\frac{N_{max}}{\beta_{z1} \cdot k_{f1} \cdot l_{w1} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$\frac{140.0\ kN}{1.0 \cdot 0.6\ cm \cdot 4 \cdot (15-2)\ cm \cdot 0.45 \cdot 37\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.337 \leq 1$$

$$\Rightarrow OK$$

6. Load bearing capacity of welding of rib to flange and brace plate

As rib and brace plate create T-section, welding of these elements creates the same section too. Calculation of geometric characteristics requires much time and intermediate operations. The background of these calculations is also performed in Appendix 3.

$k_f = 8\ mm$; kind of welding material – Э46А

- by weld metal

$$\frac{N_{max}}{A_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$= \frac{140.0\ kN}{26.21\ cm^2 \cdot 20\ kN/cm^2 \cdot 1 \cdot 0.8} + \frac{140.0\ kN \cdot 2.11\ cm}{28.14\ cm^3 \cdot 20\ kN/cm^2 \cdot 1 \cdot 0.8} = 0.991 \leq 1$$

$$\Rightarrow OK$$

- by metal of weld board

$$\frac{N_{max}}{A_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$= \frac{140.0\ kN}{37.44\ cm^2 \cdot 0.45 \cdot 37\ kN/cm^2 \cdot 1 \cdot 0.8} + \frac{140.0\ kN \cdot 2.11\ cm}{32.27\ cm^3 \cdot 0.45 \cdot 37\ kN/cm^2 \cdot 1 \cdot 0.8} =$$

$$= 0.969 \leq 1 \qquad \Rightarrow OK$$

- by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{A_{wth} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} =$$

$$\frac{140.0\ kN}{37.44\ cm^2 \cdot 0.5 \cdot \frac{37}{1.025}\ kN/cm^2 \cdot 1 \cdot 0.8} + \frac{140.0\ kN \cdot 2.11\ cm}{32.27\ cm^3 \cdot 0.5 \cdot \frac{37}{1.025}\ kN/cm^2 \cdot 1 \cdot 0.8} =$$

$$= 0.894 \leq 1 \qquad \Rightarrow OK$$

This example mainly shows how applying of cutting-in brace plate allows to rise the bearing capacity of welding and in addition that changing of the diameter of bolts is the primary way to increase fastener bearing capacity of joint.

A hole in RHS pipe for cutting-in brace plate and increasing of the hole`s diameter for bolts in brace plate do not lead to reducing the strength of them.

5 CONCLUSION

Nowadays, using of braced frame systems is the most common and popular solution for industrial construction of buildings like factories or storages. These structures have to be easy and fast in regard to production and installation. To achieve that all connections and joints in the structures should consist of a minimum number of parts and be simple to calculate.

In this study I consider the importance of such frame elements as braces. Firstly, definitions, properties and purposes of braces were explained. Then I focused on rectangular hollow section pipes used as braces and presented the most common types of brace connections corresponding to Russian practice. During the process of compiling the theoretical part I studied Russian norm documents in detail in relation to brace joints calculation and learned how to apply the obtained knowledge in practice. However, it is important to notice that the information contained in the Russian norms is not always complete and understandable. Many topics are not considered in sufficient detail and there are not enough clear specific methods for calculating different connections. For example, block tearing is not counted in the calculation at all. Thus, I found out that any regulatory documents need adjustments and additions.

The aim of my thesis was to study the specificity and particularity of brace joints calculation and using the acquired knowledge develop the Excel program that helps to check and choose the main parameters of joint: the thickness and dimensions of plates, the quantity of bolts and the length of weld. I think that these features are well achieved. The company tutor checked all the results. As a result of my research I performed two calculations of different types of brace joints that revealed general advantages and disadvantages of each solution. In addition, the examples proved that in different situations with diverse initial data the appropriate connection type should be chosen.

FIGURES

Figure 1. Fragment of transverse frame
Figure 2. Scheme of vertical braces between columns
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Figure 4. Vertical braces between trusses (5)
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DIAGRAMS

Diagram 1. Influence of steel kind
Diagram 2. Influence of brace plate thickness
Diagram 3. Influence of cutting-in length
Diagram 4. Influence of diameter of bolts
Diagram 5. Influence of amount of bolts

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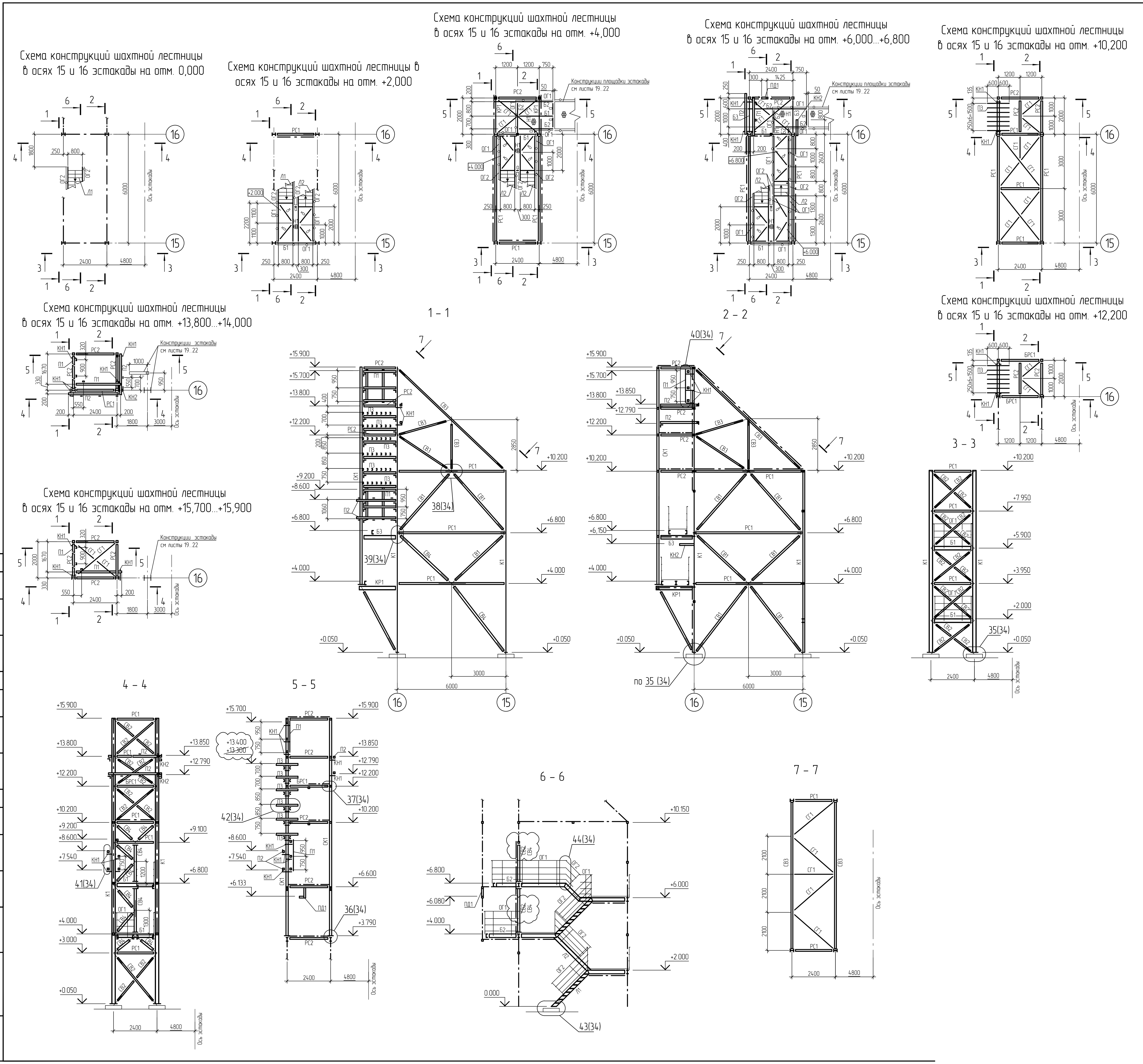
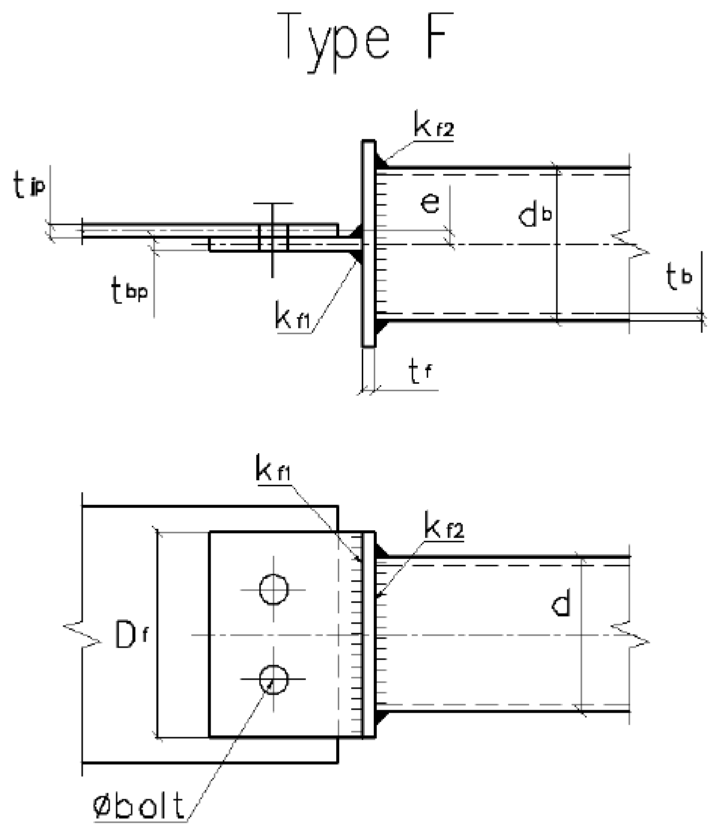


Ведомость элементов

Марка элемента	Сечение			Усилия для прикрепления			Наименование или марка металла	Примечание
	Эскиз	Поз.	Состав	A, кН	N, кН	M, кНхм		
К1			Ɪ 20Ш1	Ax=40,0 Ay=60,0	−330,0 +165,0	–	С245	
СК1			Гн. □ 120x5	Ax=0,5 Ay=0,5	−62,3	–	С245	
СВ1			Гн. □ 100x4	–	±55,0	–	С245	
СВ2			Гн. □ 80x4	–	±61,5	–	С245	
СВ3			Гн. □ 80x4	–	±28,0	–	С245	
СВ4			Гн. □ 120x5	–	±140,0	–	С245	
РС1			Гн. □ 100x4	–	±66,6	–	С245	
РС2			Гн. □ 80x4	–	±6,8	–	С245	
СГ1			L 75x6	–	±15,8	–	С245	
БРС1			Гн. □ 100x4	$A_в$=1,1 $A_г$=2,2	±34,0	–	С245	
Б1			Ɪ 20Б1	20,0	±22,0	–	С245	
Б2			[20П	2,5	±4,5	–	С245	
Б3			Ɪ 16Б2	$A_в$=5,0 $A_г$=1,1	±10,0	–	С245	
КР1		1	Ɪ 20Б1	$A_в$=5,0 $A_г$=3,4	±33,4	–	С245	
		2	Гн. □ 120x5	–	−73,2	–	С245	
П1		1	Гн. □ 100x4	$A_в$=3,0 $A_г$=3,5	–	–	С245	
		2	Гн. □ 100x4	3,5	–	–	С245	
		3	[10П	–	–	–	С245	
П2		1	Гн. □ 100x4	$A_в$=3,6 $A_г$=4,0	–	–	С245	
		3	L 50x5	–	–	–	С245	шаг ≤ 1000
П3		1	[20П	$A_в$=3,5 $A_г$=1,0	±2,0	–	С245	шаг ≤ 1000
		2	[10П	1,0	–	–	С245	
КН1			L 125x8	$A_в$=7,6 $A_г$=3,6	±4,0	$M_в$=1,2 $M_г$=0,5	С245	
КН2			Гн. □ 100x4	3,6	±4,0	1,0	С245	
ПД1			Гн. □ 100x4	$A_в$=1,4 $A_г$=0,5	±0,5	$M_в$=0,5 $M_г$=0,1	С245	
			Гн. □ 100x4	Ax=0,5 Ay=0,5	±1,4	Mx=0,1 My=0,1	С245	
а			L 50x5	–	–	–	С235	
б			L 50x5	–	–	–	С235	
Н1			ПВ510	–	–	–	Ст3пс	
Л1		1	[16П	–	–	–	С245	По типу серии 1.450.3-7.94 вып. 2
		2	ПВ510 ступень	–	–	–	Ст3пс	
		3	ПВ510	–	–	–	Ст3пс	
Л2		1	[16П	–	–	–	С245	
		2	ПВ510 ступень	–	–	–	Ст3пс	
		3	ПВ510	–	–	–	Ст3пс	
ОГ1		1	L 50x5	–	–	–	С235	
		2	L 25x3	–	–	–	С235	
		3	−150x4	–	–	–	С235	
ОГ2		1	L 50x5	–	–	–	С235	
		2	L 50x5	–	–	–	С235	
		3	L 25x3	–	–	–	С235	
		4	−100x4	–	–	–	С235	

Appendix 2. Calculation example of type “F”



Requirements of the brace section dimensions ratio are COMPLETED

DATA FOR INPUT

COMMON DATA			
Effective length of brace	*l =*	*330.00*	*cm*
Tensile stress	*N- =*	*61.50*	*kN*
Press stress	*N+=*	*61.50*	*kN*
FLANGE			
Steel of flange	*C245 (from 2 mm to 20 incl.)*		
Thickness of flange	t_f =	*6*	*mm*
Flange length along plate of brace	D_f =	*120*	*mm*
BRACE			
Steel of brace	*C245 (from 2 mm to 20 incl.)*		
Section of brace	*80x80x4*		
PLATE OF BRACE			
Steel of brace plate	*C245 (from 2 mm to 20 incl.)*		
Thickness of brace plate	t_{bp} =	*14*	*mm*
PLATE OF JOINT			
Steel of joint plate	*C245 (from 2 mm to 20 incl.)*		
Thickness of joint plate	t_{jp} =	*10*	*mm*
BOLTS			
Diameter of bolts	*d =*	*16*	
Strength class	*8.8*		
Amount of bolts	n_b =	*2*	*bolts*
Conditions-of-use factor of bolt joint	γ_b =	*0.90*	
Conditions-of-use factor of structure	γ_c =	*1.00*	
Amount of shear planes	n_s =	*1*	
WELD			
γ_{cf} =	*0.8*		
k_{f1} =	*6*		*mm*
β_{f1} =	*0.7*		
β_{z1} =	*1*		
Kind of welding material k_{f1}	*Э42*		
k_{f2} =	*4*		*mm*
β_{f2} =	*0.7*		
β_{z2} =	*1*		
Kind of welding material k_{f2}	*Э42*		

INFORMATIONAL DATA

Design strength of flange steel	$R_{y\,f}$ =	240	N/mm2
Design strength of brace plate steel	$R_{y\,bp}$ =	240	N/mm2
Design strength of brace steel	$R_{y\,b}$ =	240	N/mm2
Design strength of joint plate steel	$R_{y\,jp}$ =	240	N/mm2
Characteristic strength of flange steel	$R_{un\,f}$ =	370	N/mm2
Characteristic strength of brace steel	$R_{un\,b}$ =	370	N/mm2
Characteristic strength of brace plate steel	$R_{un\,bp}$ =	370	N/mm2
Elastic module	E =	20600	kN/cm2
Nominal brace slenderness	λ =	3.67	
Conditions-of-use factor acc. to p.14.4.3	Υ_f =	1.000	
Design bearing resistance of brace plate steel	R_{bp_bp}	485	N/mm2
Design bearing resistance of joint plate steel	R_{bp_jp}	485	N/mm2
Design shear strength of bolt	R_{bs} =	332	N/mm2
Section width along brace plate	d =	80	mm
Section width across brace plate	d_b =	80	mm
Thickness of brace section	t_b =	4	mm
Brace cross-section area	A =	11.75	cm 2
Brace section modulus	W =	27.74	cm3
Radius of gyration	i =	3.07	cm
Brace section perimeter	P =	306.265	mm
Excentricity of normal force	e=	1.2	cm
Bolt cross-section area	A_{bolt} =	2.01	cm2
Brace plate cross-section area	A_{bp} =	13.000	cm2
Brace plate section modulus	W_{bp} =	3.920	cm3
BOLTS			
Design shear stress of one bolt	N_{bs} =	60.059	kN
Design bearing stress of brace plate steel	$N_{bp\,bp}$ =	97.776	kN
Design bearing stress of joint plate steel	$N_{bp\,jp}$ =	69.840	kN
Minimal design bearing stress	N_{bp} =	69.840	kN
Minimal design shear stress of one bolt	$N_{b\,min}$ =	60.059	kN
WELD			
Design strength by weld metal kf1	R_{wf1} =	180	N/mm2
Design strength by weld board kf1	R_{wz1} =	166.5	N/mm2
Design strength by metal of weld board with flange along plate thickness	R_{th} =	180.488	N/mm2
Design strength by weld board kf2	R_{wz2} =	166.5	N/mm2
Design strength by weld metal kf2	R_{wf2} =	180	N/mm2

CHECKING

1) TENSILE STRENGTH

$$\frac{N_{tens}}{R_{yf} \cdot t_f^2 \cdot \frac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} < 1$$

0.591	YES

$$\frac{N_{tens}}{A_{bp} \cdot R_{ybp}} + \frac{N_{tens} \cdot e}{W_{bp} \cdot R_{ybp}} < 1$$

0.982	YES

2) PRESS STRENGTH

$$\frac{N_{pres}}{R_{yf} \cdot t_f^2 \cdot \frac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} < 1$$

0.591	YES

$$\frac{N_{pres}}{A_{bp} \cdot R_{ybp}} + \frac{N_{pres} \cdot e}{W_{bp} \cdot R_{ybp}} < 1$$

0.982	YES

$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} + \frac{N_{press} \cdot e}{W \cdot R_{yb} \cdot \gamma_f} < 1$$

0.329	YES

3) LOAD BEARING CAPACITY OF BOLTS

$$\frac{N_{max}}{N_{b\ min} \cdot n_b} < 1$$

0.512	YES

4) LOAD BEARING CAPACITY OF WELD kf1

by weld metal

$$\frac{N_{max}}{\beta_f \cdot k_f \cdot l_w \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.508	YES
by weld board	

$$\frac{N_{max}}{\beta_z \cdot k_f \cdot l_w \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.385	YES

by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{k_f \cdot l_w \cdot R_{th} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.355	YES

5) LOAD BEARING CAPACITY OF WELD kf2

by weld metal

$$\frac{N_{max}}{\beta_f \cdot k_f \cdot l_w \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.533	YES

by metal of weld board

$$\frac{N_{max}}{\beta_z \cdot k_f \cdot l_w \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

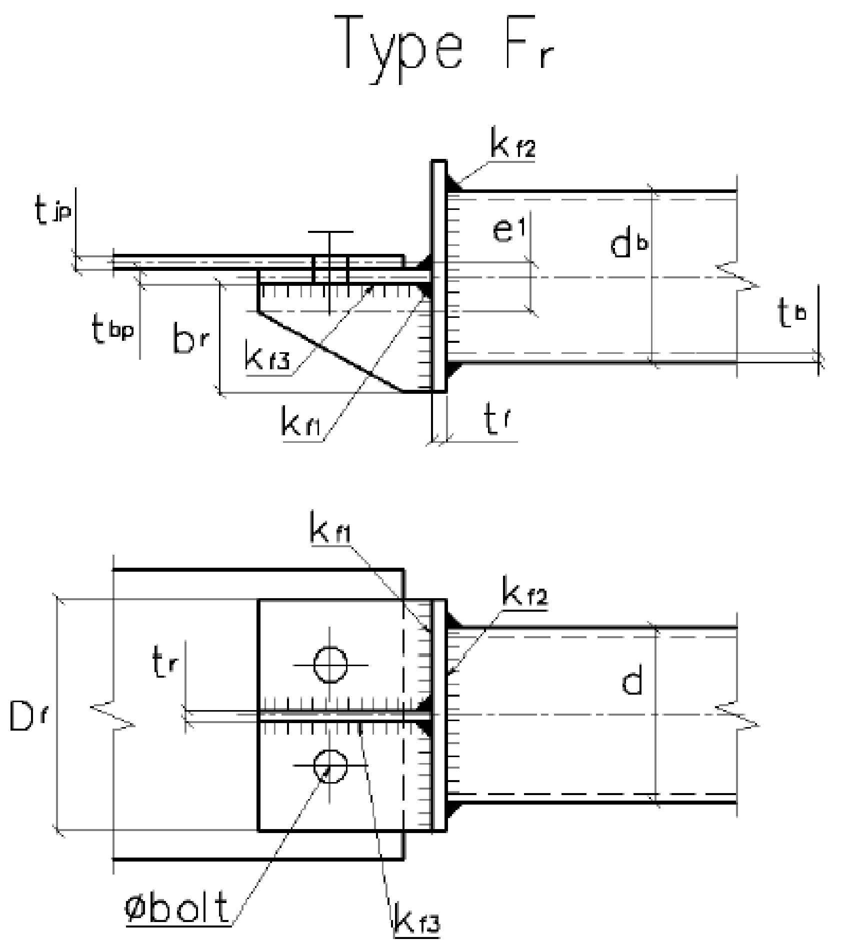
0.403	YES

by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{k_f \cdot l_w \cdot R_{th} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.372	YES

Appendix 3. Calculation example of type "Fr"



Requirements of the brace section dimensions ratio are COMPLETED

DATA FOR INPUT

COMMON DATA			
Effective length of brace	*l =*	*330.00*	*cm*
Tensile stress	*N- =*	*61.50*	*kN*
Press stress	*N+=*	*61.50*	*kN*
FLANGE			
Steel of flange	*C245 (from 2 mm to 20 incl.)*		
Thickness of flange	t_f =	*6*	*mm*
Flange length along plate of brace	D_f =	*120*	*mm*
BRACE			
Steel of brace	*C245 (from 2 mm to 20 incl.)*		
Section of brace	*180x180x7.5*		
PLATE OF BRACE			
Steel of brace plate	*C245 (from 2 mm to 20 incl.)*		
Thickness of brace plate	t_{bp} =	*10*	*mm*
PLATE OF JOINT			
Steel of joint plate	*C245 (from 2 mm to 20 incl.)*		
Thickness of joint plate	t_{jp} =	*10*	*mm*
BOLTS			
Diameter of bolts	*d =*	*16*	
Strength class	*8.8*		
Amount of bolts	n_b =	*2*	*bolts*
Conditions-of-use factor of bolt joint	γ_b =	*0.90*	
Conditions-of-use factor of structure	γ_c =	*1.00*	
Amount of shear planes	n_s =	*1*	
WELD			
γ_{cf} =	*0.8*		
k_{f1} =	*8*	*mm*	
β_{f1} =	*0.7*		
β_{z1} =	*1*		
Kind of welding material k_{f1}	*Э42*		
k_{f2} =	*4*	*mm*	
β_{f2} =	*0.7*		
β_{z2} =	*1*		
Kind of welding material k_{f2}	*Э42*		
k_{f3} =	*8*	*mm*	
STIFFENING RIB			
Steel of stiffening rib	*C245 (from 2 mm to 20 incl.)*		
Thickness of stiffening rib	t_r =	*6*	*mm*
Height of stiffening rib	b_r =	*57*	*mm*

INFORMATIONAL DATA

Design strength of flange steel	$R_{y\,f}$ =	240	N/mm2
Design strength of brace plate steel	$R_{y\,bp}$ =	240	N/mm2
Design strength of brace steel	$R_{y\,b}$ =	240	N/mm2
Design strength of joint plate steel	$R_{y\,jp}$ =	240	N/mm2
Characteristic strength of flange steel	$R_{un\,f}$ =	370	N/mm2
Characteristic strength of brace steel	$R_{un\,b}$ =	370	N/mm2
Characteristic strength of stiffening rib steel	$R_{un\,r}$ =	370	N/mm2
Elastic module	E =	20600	kN/cm2
Nominal brace slenderness	λ =	1.62	
Conditions-of-use factor acc. to p.14.4.3	γ_f =	0.782	
Design bearing resistance of brace plate steel	R_{bp_bp}	485	N/mm2
Design bearing resistance of joint plate steel	R_{bp_jp}	485	N/mm2
Characteristic strength of brace plate steel	$R_{un\,bp}$ =	370	N/mm2
Gravity center of T-section relative to flange plane of this section	x =	1.2429961	cm
Gravity center of T-section relative to rib	x1 =	5.4570039	cm
Design strength of stiffening rib steel	$R_{y\,r}$ =	240	N/mm2
Design shear strength of bolt	R_{bs} =	332	N/mm2
Section width along brace plate	d =	180	mm
Section width across brace plate	d_b =	180	mm
Thickness of brace section	t_b =	7.5	mm
Brace cross-section area	A =	49.82	cm 2
Brace section modulus	W =	268.6	cm3
Radius of gyration	i =	6.97	cm
Brace section perimeter	P =	687.810	mm
Radius of roundingof brace corner	r_b =	18.75	
Excentricity of normal force	e1 =	1.743	cm
	e=	1	cm
Bolt cross-section area	A_{bolt} =	2.01	cm2
Cross-section area of T-section (plate of brace + rib)	$A_{T\text{-}s}$ =	15.420	cm2
Moment of inertia of T-section (plate of brace + rib)	$I_{T\text{-}s}$ =	40.128	cm4
Section modulus of T-section relative to flange plane of this section	W 11 =	32.283	cm3
Section modulus of T-section relative to rib	W 22 =	7.354	cm3

BOLTS

Design shear stress of one bolt	N_{bs} =	60.059	kN
Design bearing stress of brace plate steel	$N_{bp\,bp}$ =	69.840	kN
Design bearing stress of joint plate steel	$N_{bp\,jp}$ =	69.840	kN
Minimal design bearing stress	N_{bp} =	69.840	kN
Minimal design shear stress of one bolt	$N_{b\,min}$ =	60.059	kN

WELD			
Design strength by weld metal kf1	R_{wf1} =	180.00	H/mm2
Design strength by weld board kf1	R_{wz1} =	166.50	H/mm2
Design strength by metal of weld board with flange along plate thickness	R_{th} =	180.49	H/mm2
Design strength by weld board kf2	R_{wz2} =	166.50	H/mm2
Design strength by weld metal kf2	R_{wf2} =	180.00	H/mm2
Section modulus of weld kf2 by weld metal	Wwf2	781.42	cm3
Section modulus of weld kf2 by weld board	Wwz2	1116.31	cm3
Section modulus of weld kf2 by metal of weld board with flange along plate thickness	Wth2	1116.31	cm3
Cross-section area of weld kf1 by weld metal	Awf1	19.82	cm2
Cross-section area of weld kf1 by weld board	Awz1	28.32	cm2
Cross-section area of weld kf1 by metal of weld board with flange along plate thickness	Awth1	28.32	cm2
Moment of inertia of weld kf1 by weld metal	Iwf1	61.67	cm4
Moment of inertia of weld kf1 by weld board	Iwz1	88.10	cm4
Moment of inertia of weld kf1 by metal of weld board with flange along plate thickness	Ith1	88.10	cm4
Section modulus of weld kf1 by weld metal	Wwf1	11.30	cm3
Section modulus of weld kf1 by weld board	Wwz1	16.14	cm3
Section modulus of weld kf1 by metal of weld board with flange along plate thickness	Wth1	16.14	cm3

CHECKING

1) TENSILE STRENGTH	
$$\frac{N_{tens}}{R_{yf} \cdot t_f^2 \cdot \frac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} < 1$$	
0.186	YES
$$\frac{N_{tens}}{A_{T-s} \cdot R_{ybp}} + \frac{N_{tens} \cdot e_1}{W_{1-1} \cdot R_{ybp}} < 1$$	
0.305	YES
$$\frac{N_{tens}}{A_{T-s} \cdot R_{yr}} + \frac{N_{tens} \cdot e_1}{W_{2-2} \cdot R_{yr}} < 1$$	
0.774	YES
2) PRESS STRENGTH	
$$\frac{N_{pres}}{R_{yf} \cdot t_f^2 \cdot \frac{D_f}{d_b - 3 \cdot t_{bp}} + R_{yb} \cdot t_b \cdot d_b} < 1$$	
0.186	YES
$$\frac{N_{press}}{A_{T-s} \cdot R_{ybp}} + \frac{N_{press} \cdot e_1}{W_{1-1} \cdot R_{ybp}} < 1$$	
0.305	YES
$$\frac{N_{press}}{A_{T-s} \cdot R_{yr}} + \frac{N_{press} \cdot e_1}{W_{2-2} \cdot R_{yr}} < 1$$	
0.774	YES
$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} + \frac{N_{press} \cdot e}{W \cdot R_{yb} \cdot \gamma_f} < 1$$	
0.078	YES

3) LOAD BEARING CAPACITY OF BOLTS

$$\frac{N_{max}}{N_{b\,min} \cdot n_b} < 1$$

0.512	YES

4) LOAD BEARING CAPACITY OF WELD kf1

by weld metal

$$\frac{N_{max}}{A_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.874	YES

by weld board

$$\frac{N_{max}}{A_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.661	YES

by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{A_{wth} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.610	YES

5) LOAD BEARING CAPACITY OF WELD kf2

by weld metal

$$\frac{N_{max}}{A_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.234	YES

by weld board

$$\frac{N_{max}}{A_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.177	YES

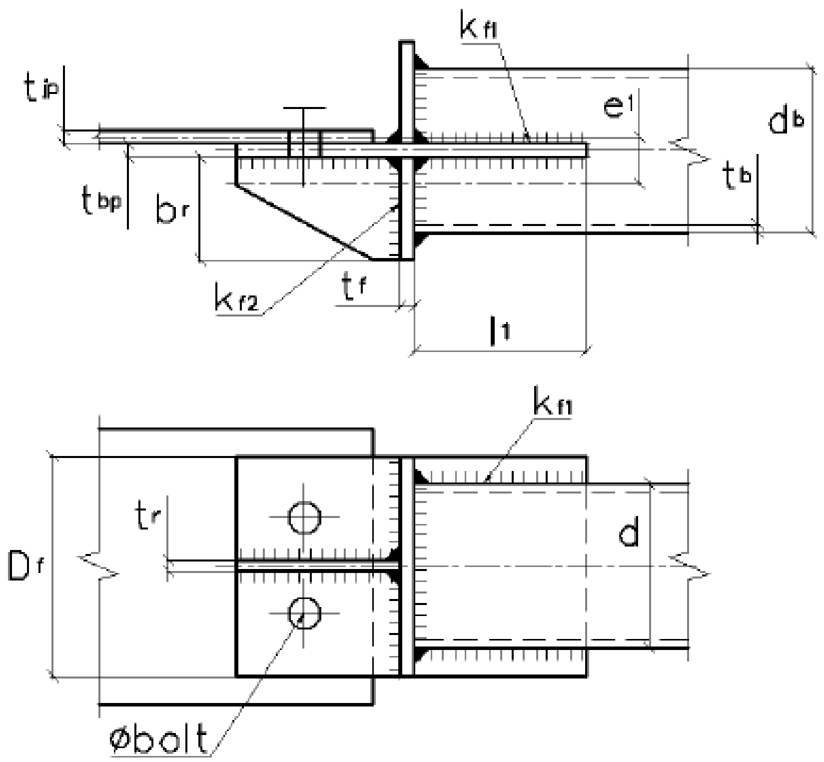
by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{A_{wth} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.163	YES

Appendix 4. Calculation example of type “Cr”

Type Cr



Requirements of the brace section dimensions ratio are COMPLETED

DATA FOR INPUT

COMMON DATA			
Effective length of brace	*l =*	*496.00*	*cm*
Tensile stress	*N+ =*	*140.00*	*kN*
Press stress	*N- =*	*140.00*	*kN*
FLANGE			
Steel of flange	*C245 (from 2 mm to 20 incl.)*		
Thickness of flange	t_f =	*6*	*mm*
Flange length along plate of brace	D_f =	*160*	*mm*
BRACE			
Steel of brace	*C245 (from 2 mm to 20 incl.)*		
Section of brace	*120x120x5*		
PLATE OF BRACE			
Steel of brace plate	*C245 (from 2 mm to 20 incl.)*		
Thickness of brace plate	t_{bp} =	*12*	*mm*
PLATE OF JOINT			
Steel of joint plate	*C245 (from 2 mm to 20 incl.)*		
Thickness of joint plate	t_{jp} =	*10*	*mm*
BOLTS			
Diameter of bolts	*d =*	*20*	
Strength class	*8.8*		
Amount of bolts	n_b =	*2*	*bolts*
Conditions-of-use factor of bolt joint	γ_b =	*0.90*	
Conditions-of-use factor of structure	γ_c =	*1.00*	
Amount of shear planes	n_s =	*1*	
WELD			
γ_{cf} =	*0.8*		
k_{f1} =	*6*	*mm*	
β_{f1} =	*0.7*		
β_{z1} =	*1*		
Kind of welding material k_{f1}	*Э46А*		
k_{f2} =	*8*	*mm*	
β_{f2} =	*0.7*		
β_{z2} =	*1*		
Kind of welding material k_{f2}	*Э46А*		
STIFFENING RIB			
Steel of stiffening rib	*C245 (from 2 mm to 20 incl.)*		
Thickness of stiffening rib	t_r =	*8*	*mm*
Height of stiffening rib	b_r =	*74*	*mm*
CUTTING-IN			
Length of cutting-in	l_1 =	*150*	*mm*

INFORMATIONAL DATA

Design strength of flange steel	$R_{y\,f}$ =	240	N/mm2
Characteristic strength of flange steel	$R_{un\,f}$ =	370	N/mm2
Design strength of brace plate steel	$R_{y\,bp}$ =	240	N/mm2
Characteristic strength of brace steel	$R_{un\,b}$ =	370	N/mm2
Design strength of brace steel	$R_{y\,b}$ =	240	N/mm2
Design strength of joint plate steel	$R_{y\,jp}$ =	240	N/mm2
Characteristic strength of stiffening rib steel	$R_{un\,r}$ =	370	N/mm2
Elastic module	E =	20600	kN/cm2
Nominal brace slenderness	λ =	3.63	
Conditions-of-use factor acc. to p.14.4.3	γ_f =	1.000	
Design bearing resistance of brace plate steel	R_{bp_bp}	485	N/mm2
Design bearing resistance of joint plate steel	R_{bp_jp}	485	N/mm2
Design shear strength of bolt	R_{bs} =	332	N/mm2
Section width along brace plate	d =	120	mm
Characteristic strength of brace plate steel	$R_{un\,bp}$ =	370	N/mm2
Section width across brace plate	d_b =	120	mm
Design strength of stiffening rib steel	$R_{y\,r}$ =	240	N/mm2
Thickness of brace section	t_b =	5	mm
Brace cross-section area	A =	22.36	cm 2
Brace section modulus	W =	80.88	cm3
Radius of gyration	i =	4.66	cm
Brace section perimeter	P =	462.832	mm
Radius of roundingof brace corner	r_b =	10	
Excentricity of normal force	e1 =	2.11	cm
	e=	1.10	cm
Bolt cross-section area	A_{bolt} =	3.14	cm2
Gravity center of T-section relative to flange plane of this section	x1 =	1.61	cm
Gravity center of T-section relative to rib	x2=	6.99	cm
Cross-section area of T-section (plate of brace + rib)	$A_{T\text{-}s}$ =	25.120	cm2
Moment of inertia of T-section (plate of brace + rib)	$I_{T\text{-}s}$ =	112.983	cm4
Section modulus of T-section relative to flange plane of this section	W 11 =	70.029	cm3
Section modulus of T-section relative to rib	W 22 =	16.171	cm3
Factor of cutting-in ifluence	γ_f	0.805	
BOLTS			
Design shear stress of one bolt	N_{bs} =	93.823	kN
Design bearing stress of brace plate steel	$N_{bp\,bp}$ =	104.760	kN
Design bearing stress of joint plate steel	$N_{bp\,jp}$ =	87.300	kN
Minimal design bearing stress	N_{bp} =	87.300	kN
Minimal design shear stress of one bolt	$N_{b\,min}$ =	87.300	kN
WELD			
Design strength by weld metal kf1	R_{wf1} =	200	H/mm2

Design strength by weld board kf1	R wz1 =	166.5	H/mm2
Design strength by metal of weld board with flange along plate thickness	R th =	180.488	H/mm2
Design strength by weld board kf2	R wz2 =	166.5	H/mm2
Design strength by weld metal kf2	R wf2 =	200	H/mm2
Gravity center of T-section relative to flange plane of this section by weld metal	X1wf =	1.90	cm
	X2wf =	6.70	cm
Gravity center of T-section relative to flange plane of this section by weld board	X1wz =	2.24	cm
	X2wz =	6.36	cm
Gravity center of T-section relative to flange plane of this section by metal of weld board with flange along plate thickness	X1wth =	2.240	cm
	X2wth =	6.360	cm
Cross-section area	As-wf =	26.208	cm2
	As-wz =	37.44	cm2
	As-wth =	37.44	cm2
Moment of inertia	Is-wf =	188.62	cm4
	Is-wz =	205.24	cm4
	Is-wth =	205.24	cm4
Section modulus	Ws-wf =	28.14	cm3
	Ws-wz =	32.27	cm3
	Ws-wth =	32.27	cm3

CHECKING

1) TENSILE STRENGTH	
$$\frac{N_{tens}}{A \cdot R_{yb} \cdot \gamma_f} < 1$$	
0.324	YES
$$\frac{N_{tens}}{A_{T-s} \cdot R_{ybp}} + \frac{N_{tens} \cdot e_1}{W_{1-1} \cdot R_{ybp}} < 1$$	
0.408	YES
$$\frac{N_{tens}}{A_{T-s} \cdot R_{yr}} + \frac{N_{tens} \cdot e_1}{W_{2-2} \cdot R_{yr}} < 1$$	
0.995	YES
2) PRESS STRENGTH	
$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} < 1$$	
0.324	YES
$$\frac{N_{press}}{A_{T-s} \cdot R_{ybp}} + \frac{N_{press} \cdot e_1}{W_{1-1} \cdot R_{ybp}} < 1$$	
0.408	YES
$$\frac{N_{press}}{A_{T-s} \cdot R_{yr}} + \frac{N_{press} \cdot e_1}{W_{2-2} \cdot R_{yr}} < 1$$	
0.995	YES
$$\frac{N_{press}}{A \cdot R_{yb} \cdot \gamma_f} + \frac{N_{press} \cdot e}{W \cdot R_{yb} \cdot \gamma_f} < 1$$	
0.340	YES

3) LOAD BEARING CAPACITY OF BOLTS

$$\frac{N_{max}}{N_{b\,min} \cdot n_b} < 1$$

0.802	YES

4) LOAD BEARING CAPACITY OF WELD kf1

by weld metal

$$\frac{N_{max}}{\beta_f \cdot k_{f1} \cdot l_w \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.401	YES

by weld board

$$\frac{N_{max}}{\beta_z \cdot k_{f1} \cdot l_w \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.337	YES

5) LOAD BEARING CAPACITY OF WELD kf2

by weld metal

$$\frac{N_{max}}{A_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wf} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.991	YES

by weld board

$$\frac{N_{max}}{A_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wz} \cdot R_{wz} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.969	YES

by metal of weld board with flange along plate thickness

$$\frac{N_{max}}{A_{wth} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} + \frac{N_{max} \cdot e_1}{W_{wf} \cdot R_{wth} \cdot \gamma_c \cdot \gamma_{cf}} \leq 1$$

0.894	YES

Appendix 5.

Steel kind	Ry, H/mm2	Ru, H/mm2	Run, H/mm2	Rbp, H/mm2
C235 (2 mm - 4 mm)	230	350	360	475
C245 (from 2 mm to 20 incl.)	240	360	370	485
C255 (from 2 mm to 3,9 mm)	250	370	380	500
C255 (from 4 mm to 10 mm)	240	370	380	500
C255 (more 10 mm to 20 mm)	240	360	370	485
C255 (more 20 to 40 mm)	230	360	370	485
C345 (more 2 to 10 mm)	340	480	490	645
C345 (more 10 to 20 mm)	320	460	470	620
C345 (more 20 to 40 mm)	300	450	460	605
C345 (more 40 to 60 mm)	280	440	450	595
C345 (more 60 to 80 mm)	270	430	440	580
C345 (more 80 to 160 mm)	260	420	430	565
C345K (from 4 to 10 mm)	340	460	470	620
C355 (more 8 to 16 mm)	350	460	470	620
C355 (more 16 to 40 mm)	340	460	470	620
C355 (more 40 to 60 mm)	330	460	470	620
C355 (more 60 to 80 mm)	320	460	470	620
C355 (more 80 to 100 mm)	310	460	470	620
C355 (more 100 to 160 mm)	285	460	470	620
C355-1 (from 8 mm to 16 mm)	350	460	470	620
C355-1 (more 16 to 40 mm)	340	460	470	620
C355-1 (more 40 to 50 mm)	330	460	470	620

C355-К (from 8 to 16 mm)	350	460	470	620
C355-К (more 16 to 40 mm)	340	460	470	620
C355-К (more 40 to 50 mm)	330	460	470	620
C355П (from 8 mm to 16 mm incl.)	350	460	470	620
C355П (from 16 mm to 40 mm)	340	460	470	620
C390 (from 8 mm to 50 mm incl.)	380	505	520	670
C390-1 (from 8 mm to 50 mm incl.)	380	505	520	670
C440 (from 8 mm to 50 mm incl.)	430	525	540	710
C550 (from 8 mm to 50 mm incl.)	525	625	640	
C590 (from 8 mm to 50 mm incl.)	575	670	685	
C690 (from 8 mm to 50 mm incl.)	650	745	785	

Appendix 6.

d, mm	Ab, cm2	Abn, cm2
16	2.01	1.57
18	2.54	1.92
20	3.14	2.45
22	3.8	3.03
24	4.52	3.53
27	5.72	4.59
30	7.06	5.61
36	10.17	8.16
42	13.85	11.2
48	18.09	14.72

Strength class of bolts	Rbun	Rbyn	Rbs	Rbt
5.6	500	300	210	225
5.8	500	400	210	-
8.8	830	664	332	451
10.9	1040	936	416	561
12.9	1220	1098	427	-

Appendix 7.

Kind of welding material	R wf , N/mm2
Э42	180
Э42А	180
Э46	200
Э46А	200
Э50	215
Э50А	215
Э60	240
Э70	280
Э85	340
Св-08	180
Св-08А	180
Св-08ГА	200
Св-08Г2С	215
Св-10ГА	215
ПП-АН-8	215
ПП-АН-3	215
Св-08Г2С*	240
Св-10НМА	240
Св-10Г2	240
Св-10ХГ2cmA	280
Св-08ХН2ГМЮ	280