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Design of Portal Supporting Structure Using FEM and Technical Standards

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Abstract The supporting structure of technological equipment captures the own gravity loading, gravity loading of mechanisms and other parts, wind effects and dynamic forces during operation. The SCIA engineering software allows to realize the final reviews of the design the supporting structure according to the relevant technical standards contained in the library program for various types of materials, but especially for steel and concrete. This applies in particular for technical standard STN EN 1993-1-(1-12) Eurocode 3 - Design of Steel Structures. Based on the preliminary results of the SCIA software is created geometric model of portal structure in SolidWorks software. This model is then subjected to static analysis performed by FEM and at the same time is subjected to analysis of price.

Keywords: *portal supporting structure, robotic arms, technical standard, structural element, design options, unity review*

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1. Introduction

The supporting structure of technical and technological equipment captures the own gravity loading, gravity loading of mechanisms and other parts, wind effects and dynamic forces during operation. The design must be sufficiently strong and rigid safety against overturning. In doing so, it must be easy, manufacturing and operationally inexpensive and it must allow for easy access to the mechanisms. The supporting structure shall comply with the principles of safety and reliability and also meet the aesthetic side [1,2].

Supporting structures typically consist of beams, columns, brackets and other elements. The individual parts of the structure are welded, riveted and are tested and bonded joints [4,6].

Design of steel structures shall be in accordance with the general rules set out in STN EN 1990's (Eurocode. Basis of structural design):

The proposed structure is:

with an appropriate degree of reliability to withstand all loads and effects, whose occurrence may be under construction and expected use;

have a small amount of damage in the event of an accident;

to be economical consumption of materials, energy and complexity of production;

have adequate durability in relation to maintenance costs.

Important role in constructing plays typification. There are taken into account the main technical parameters of the whole machine as well as its parts [5].

2. Portal Supporting Structure

The aim of this work is to design the structure and subsequent analysis of prices for material according to specified requests. In this case, it is portal supporting structure. On this construction will be placed special robotic arms as part of the production lines in the engineering industry. The design has to be a portal-type Figure 1 [11].

Figure 1. Basic scheme of the portal structure

At the backbone of the structure is fixed series of robotic arms weighing 800 kg. Distance between robotic arms during operation varies, but only sporadically. The distance between the robot axes is 2400 mm, 3000 mm and 3700 mm Figure 2. Basis on which they captured robotic arm is chosen as firmly welded to the frame structure. Attachment robotic arm on the structure of the portal is to be realized using eight screws M 24 - 100 Figure 3. Overall requested dimensions of the portal structures are height 3000 mm, a width of 5000 mm Figure 4.

3. Design Options of the Structure

Gradually was created 3 design options of the structure. These proposals differed in the types of structural elements and overall configuration. Basic design verification was carried out in the SCIA engineering software. This program allows to realize the final reviews of the design according to the relevant technical standards contained in the library program for various types of materials, but especially for steel and concrete. This applies in particular for invalid technical standard STN 73 1401 (Design of steel structures) and its replacement STN EN 1993-1-(1-12) Eurocode 3 (Design of steel structures).

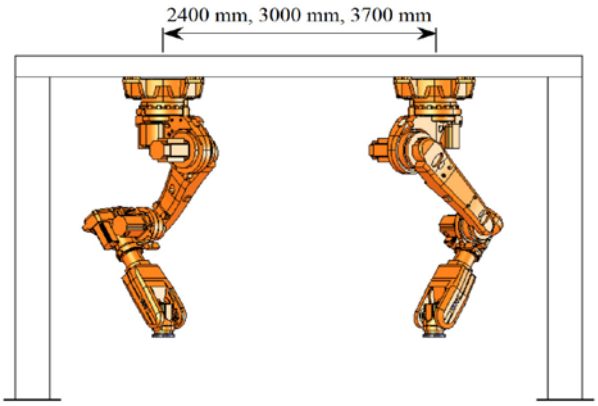

Figure 2. Pitch distance of the robotic arms

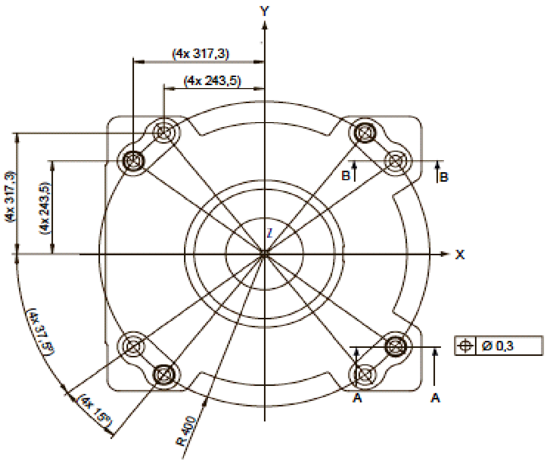

Figure 3. Gripping of the robot to the base platform

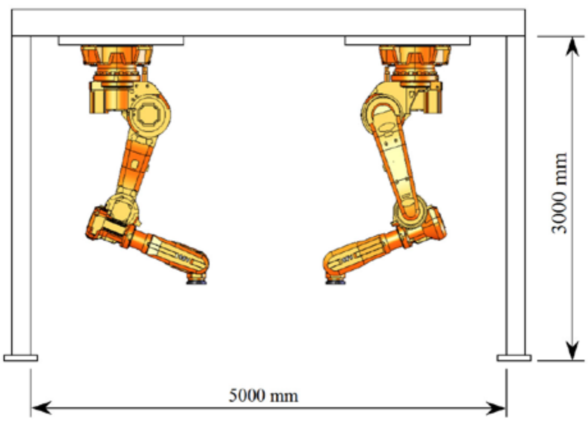

Figure 4. Base required dimensions of the portal structure

As part of a comprehensive assessment of a structural element was assessed: standard strength condition, plane buckling, lateral-torsional (spatial) buckling, lateral buckling, overall lateral stability, complex condition considering the axial thrust, bending and lateral buckling with relevant factor of reliability and with relevant information about fulfillment of the conditions. Finally was evaluated the maximum unity review (unity check).

Based on the preliminary results of the SCIA software was created geometric model of portal structure in SolidWorks software. This model was then subjected to static analysis performed by FEM.

3.1. Option No. 1

The main element of the structure of the option No. 1 is IPE profile. Base design verification was carried out in the program SCIA engineering. The simplified model consists of beams and columns both profile IPE 600 according to DIN 1025-5. Most adverse load combinations occurs under the effect of self-weight construction, and the force from the load robotic arms at individual positions Figure 5, where:

F_g is the force of gravity of the structure;

F_{b1} and $F_{b1}´$ are the forces of gravity of the robotic arms at a distance of 3700 mm;

F_{b2} and $F_{b2}´$ are the forces of gravity of the robotic arms at a distance of 3000 mm;

F_{b3} and $F_{b3}´$ are the forces of gravity of the robotic arms at a distance of 2400 mm.

The force of exerted by the load robotic arm is 8 kN.

Appropriate factors of reliability (γ_{M0} and γ_{M1}) are equal 1.15.

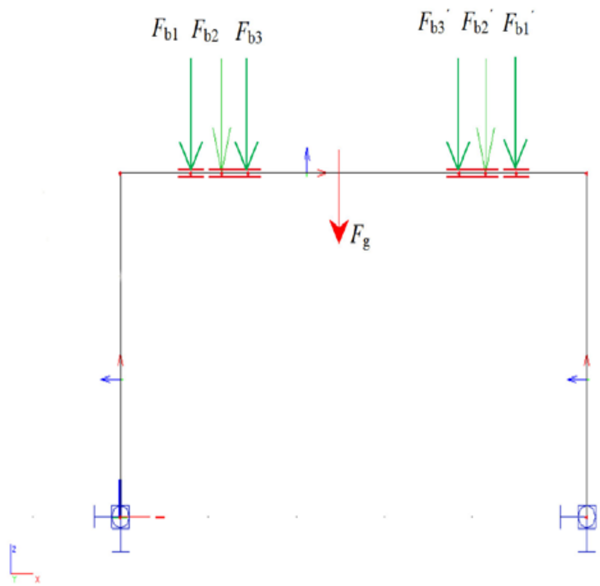

Figure 5. Adverse grouping of forces acting to the robot in SCIA engineering software (option No. 1)

The review of the steel S 235, for the individual beams IPE 600 of this simplified model were very satisfying see. Consequently, there has been a change in the geometry of the beam IPE 220 and IPE 200 for columns. Re-check was also acceptable. For individual beams and columns was changed the maximum unity review from 0.04 to 0.49, from 4 % to 49 %, the change of geometry is still relevant Figure 6.

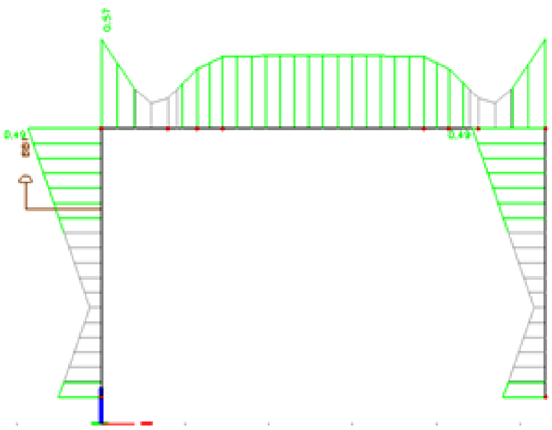

Figure 6. Display of the maximum unity review after changing cross sections (option No. 1)

Based on the preliminary results of the SCIA engineering software was created geometric model of portal structure in SolidWorks Figure 7. Contact surfaces are connected without penetration, since it is the integral welded construction. In fact, the steel columns supporting structure are attached to concrete substrate using a base screws. In addition to self-weight construction was prescribed the load of robotic arms, which was covered the entire surface of the base.

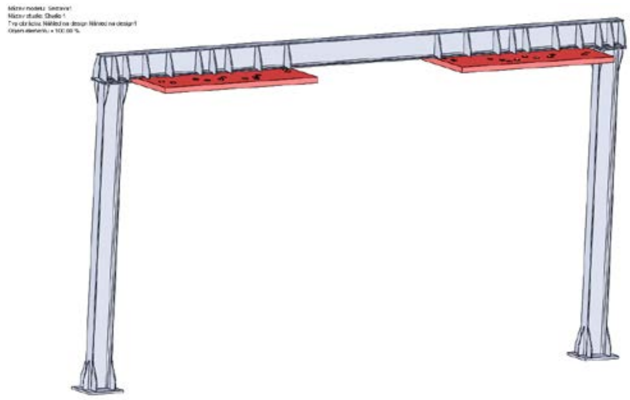

Figure 7. The geometric model (option No. 1)

On the geometric model was created the volume network of high quality, with the number of elements 524 135, with the number of nodes 960 654 and with the corresponding size of the element Figure 8.

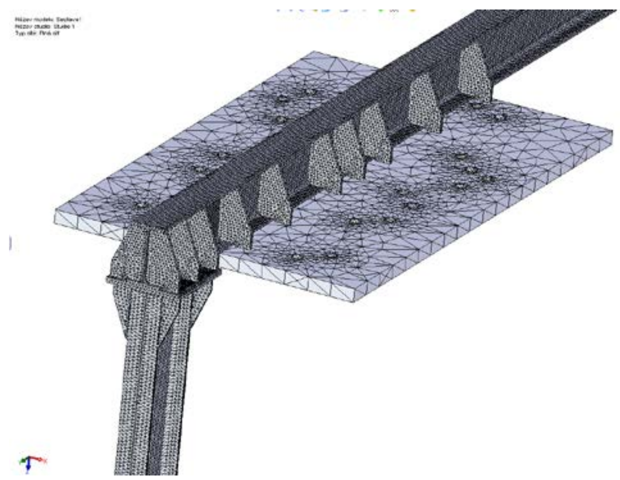

Figure 8. Volume network created on the geometric model (option No. 1)

Analytical results for option No. 1 are represented by Von Mises stress field Figure 9, by the resulting displacements field Figure 10, by field of strains Figure 11 and by layout of the safety factor Figure 12. The tables of the extreme values of reduced stress Table 1, of resulting displacement Table 2 and of strain Table 3 are also attached.

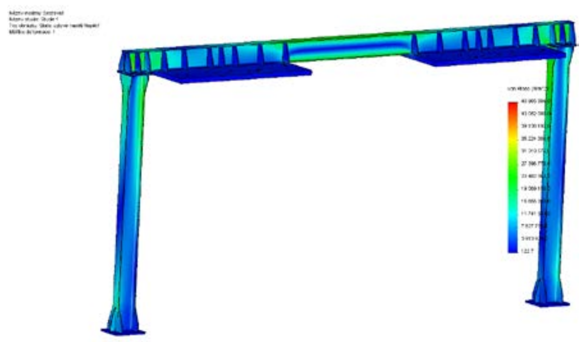

Figure 9. Von Mises stress field (option No. 1)

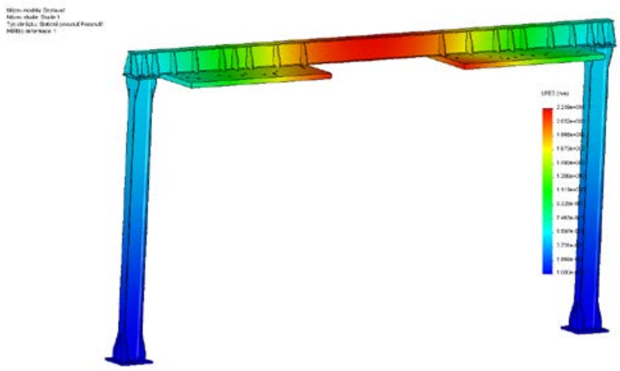

Figure 10. The resulting displacements field (option No. 1)

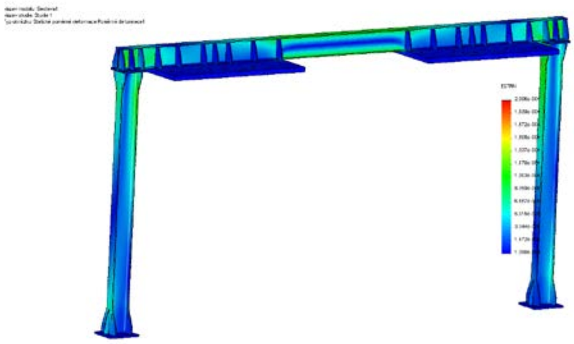

Figure 11. Field of strains (option No. 1)

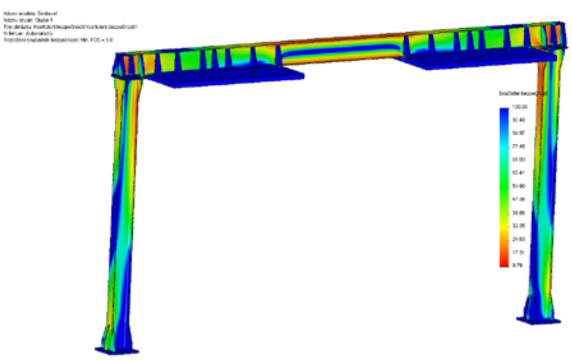

Figure 12. Layout of the safety factor (option No. 1)

Table 1. The extreme values of reduced stress

Reduced stress (von Mises) (option No. 1)		coordinates *x*; *y*; *z* of the node [mm]
$\sigma_{VM\ min}$ [MPa]	$1.227 \cdot 10^{-4}$	-1123.6; -40.3813; 2157.11
$\sigma_{VM\ max}$ [MPa]	46.9658	-1223.18; -106.837; -338.496

Table 2. The extreme values of resulting displacement

Resulting displacement (option No. 1)		coordinates *x*; *y*; *z* of the node [mm]
δ_{min} [mm]	0.0	-1423.6; -376.131; 2177.11
δ_{max} [mm]	2.23877	-1217.99; 2313.87; -780.74

Table 3. The extreme values of strain

Strain (option No. 1)		coordinates *x*; *y*; *z* of the node [mm]
ε_{min} [-]	$1.39045 \cdot 10^{-9}$	-1412.25; -39.6557; 2158.56
ε_{max} [-]	$2.00608 \cdot 10^{-4}$	-1224.77; -109.447; -340.262

3.2. Option No. 2

In this case it is the all-steel (steel S 235) framed welded portal structure Figure 13. As rods there were used the tubes of size 76.1 x 4 and 33.7 x 3.2 and as material the steel S 235. Instead of mounting base is specified continuous load on the bearing rods. There were specified external load forces of robotic arms and self weight of the structure. Preliminary analysis shows that the choice of rods of size 76.1 x 4 and 33.7 x 3.2 is satisfactory Figure 14.

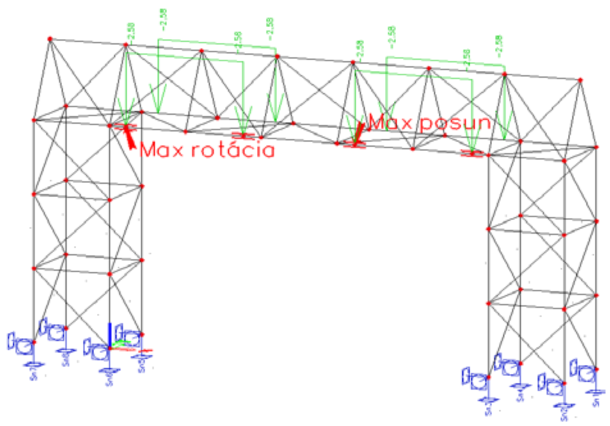

Figure 13. Simplified model of the structure for SCIA engineering software (option No. 2)

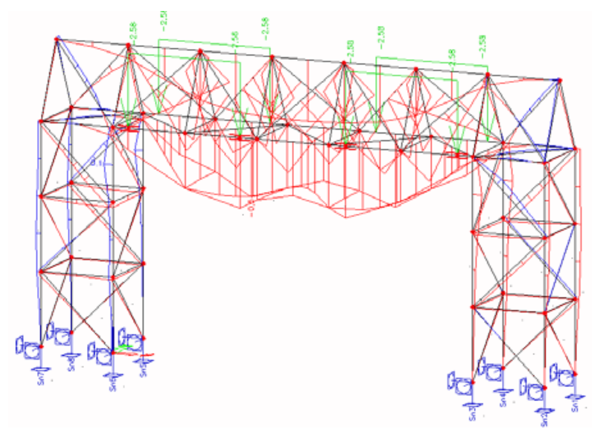

Figure 14. Deformation of the rods (option No. 2)

Static analysis of the geometric model Figure 15 was terminated unsuccessfully. The base in place of robotic arms has been separated. Thus, the whole model became unstable. Based on the results of the static analysis of the geometric model was implemented a new static study. Only the structure itself has been subjected to stability analysis. A firm grip of the structure was prescribed, self-weight and the force of size 8 kN in the selected nodes Figure 16. The geometric model itself is stable.

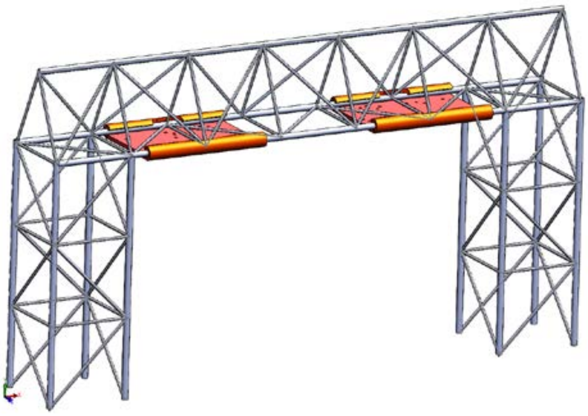

Figure 15. The geometric model (option No. 2)

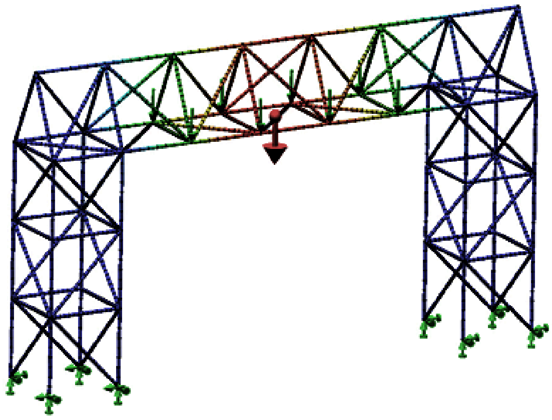

Figure 16. Modified geometric model (option No. 2)

Analytical results for option No. 2 are represented by the resulting displacements field Figure 17, by values of axial forces in the rods Figure 18 and by layout of the safety factor Figure 19. The table of the extreme values of resulting displacement Table 4 is also attached.

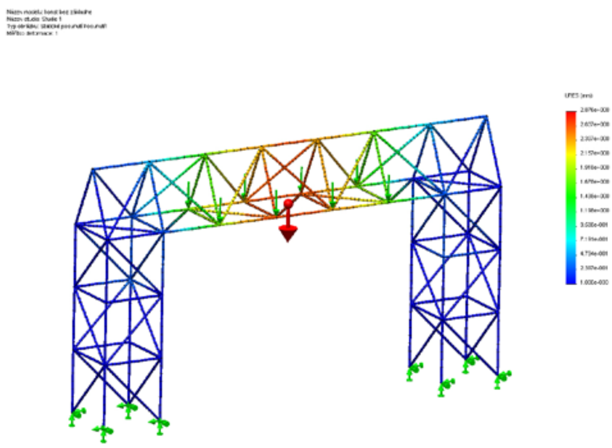

Figure 17. The resulting displacements field (option No. 2)

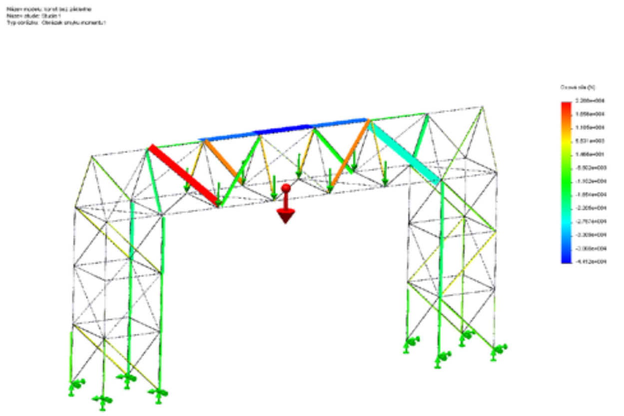

Figure 18. Axial forces in the rods (option No. 2)

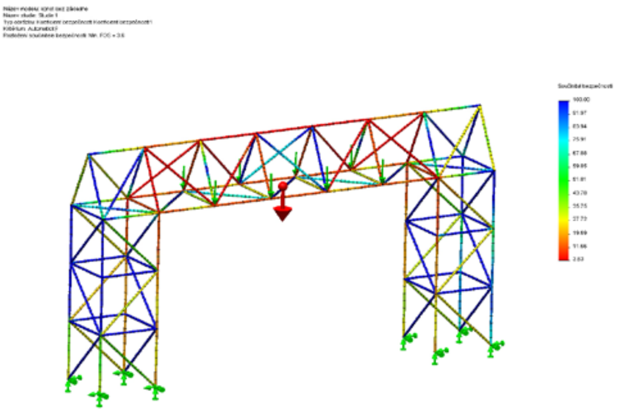

Figure 19. Layout of the safety factor (option No. 2)

Table 4. The extreme values of resulting displacement

Resulting displacement (option No. 2)		coordinates *x*; *y*; *z* of the node [mm]
δ_{min} [mm]	0.0	-
δ_{max} [mm]	2.87633	-23.536; 2997.12; -476.428

3.3. Option No. 3

Simplified model of structure consisting of beam IPE 220 (according to DIN 1025-5) and of welded hollow profiles CFRHS 180x180x8 (according to EN 10219-1) forming columns of the portal structure. The loading as an option No. 1, i.e. combination of self-weight loading of the structure and the forces of gravity of the load. Designation of the applied forces as in the option No. 1 Figure 20.

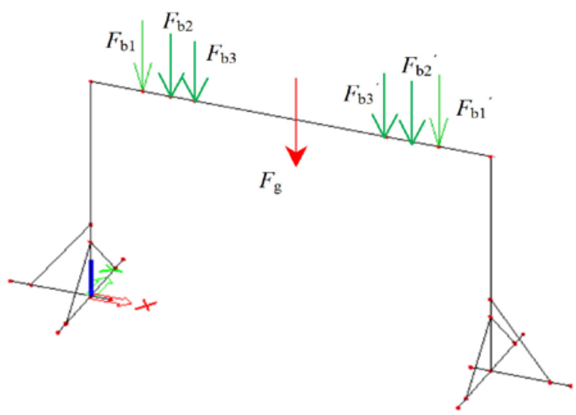

Figure 20. Adverse grouping of forces acting to the robot in SCIA engineering software (option No. 3)

According unity review in SCIA engineering software for steel S 235 were the profiles satisfactory Figure 21. Based on the preliminary results of the SCIA engineering software was created geometric model of portal structure in SolidWorks Figure 22. Power effects and material were prescribed as in option No. 1. Static analysis of the geometric model was terminated unsuccessfully. In this case the model worked unstable.

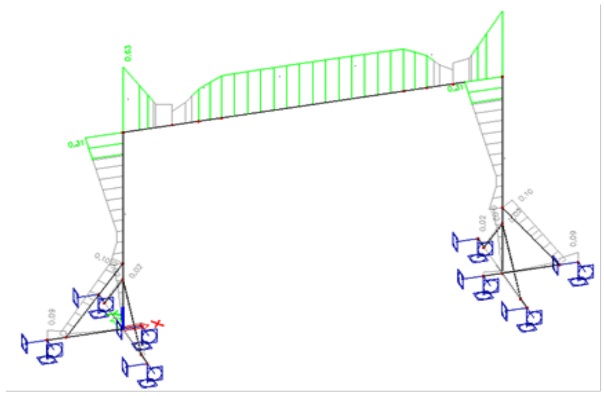

Figure 21. Display of the maximum unity review (option No. 3)

Figure 22. The geometric model (option No. 3)

4. Choice of the Material

As material to verify the total static load structure with mounted robotic arm according to STN EN 1993-1-1 Eurocode 3 has been used type of steel S 235 JR. It is a non-alloy quality structural steel, whose previous mark was also S 235 JRG2 according to EN 10025: 1990 + A1: 1993, or 11 375 according to STN, or RSt 37-2 according to DIN 17100. This steel is suitable for all commonly used welding methods. With increasing thickness of the product and increasing CEV (carbon equivalent) increases the risk of cold cracking in the weld zone. Terms of welding are set as in EN 1011-1.

Minimum yield strength for material of the products of nominal thickness ≤ 16 mm is equal to 235 MPa and for a thickness > 16 ≤ 40 mm is equal to 225 MPa. Minimum tensile strength for material of the products of nominal thickness > 3 ≤ 100 mm is equal to 360 - 510 MPa and for a thickness > 100 ≤ 150 mm is equal to 350 - 500 MPa.

5. Estimate Material Costs

After performing static analysis was determined the approximate price of the material for different options of the portal structure. For each design option is used different amounts of material, which is reflected mainly in the economics of freedom of choice of the structure. Based on a survey conducted current price of steel semi-finished and steel profiles for Slovak market and after completing the necessary calculations have been drawn the following conclusions:

For option No. 1:

The proposed model of the structure consists of beams IPE 220 and columns IPE 200. Price of beams, columns, reinforcing ribs and other elements of the all-steel structure is approx. € 2140, no fees for technological operations (welding and assembly works).

For option No. 2:

The proposed model of the structure as framed all-steel welded construction is made of tubes of size 76.1 x 4 and 33.7 x 3.2. Price of this basic structure is approx. € 420, excluding the mounting base robots. Including the mounting base robotic arm, and base mounting structure, the price of material is approx. 1943 €, no fees for technological works.

For option No. 3:

The proposed model of the structure consists of a beam IPE 200, a pair of columns created from thick walled tubes of square or rectangular profile. Other elements of the model are reinforcing ribs and base for mounting robots. The price is about. € 2406, not including the price for welding and assembly works

6. Conclusion

On the basis of performed static and price analysis of 3 options of the portal supporting structure of robotic arms it is possible to formulate the following conclusion, that option No. 1 is optimal, especially in terms of stability the structure even though the price for the material is not the lowest.

Acknowledgement

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