Special Hook Design for Hatch Cover Stocking Gantry Crane, Strength, Numerical Analysis under Static Loading

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Research Article

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Abstract

In this study, Computer-Aided Design (CAM) of special crane hooks used to close the stack type hatch covers used for sea freight transport, which is of great importance in our world, has been made. In this design, bolt and pin connections were preferred in the connections of the hook with the crane, as well as the connection with the welding performed in other studies. Thanks to these fasteners, corrosion events caused by the place of use and environmental conditions will also be prevented, and the strength values and reliability of the material will be increased. Critical sections with high-stress values on this design were determined by the Finite Element Method (FEM) with ANSYS R3 analysis program. In this design, the necessary improvements and strength calculations of the hook were made. Numerical calculations performed by the FEM and strength calculation results were compared. Results overlap: This, in turn, has been associated with the fact that the design made for us provides an optimal level of efficiency. These calculations are based on the data of St-37 structural steel. According to the results of these strength calculations, improvements were made in the design. As a result of improvements in special design and strength values for hatch cover stocking gantry Crane hooks, the design is expected to be standardized.

Introduction

Hatch covers are used to cover the cargo in the hatch/cargo area and to protect the cargo from air/sea conditions [1]. It also makes the area waterproof by closing the hatch opening. On ships, dry cargo is carried in compartments located in the hull and called warehouses. Each compartment is covered to protect from effects such as seawater, rain, solar heat and to create usable areas on the deck [1, 2]. Stacking hatch covers is used especially in European countries and in our country [3]. During loading and unloading operations, accidents and permanent damages occur due to ignoring limit values and violating the standard rules [4]. As a result of the accident analysis, the need to review international rules and design criteria was emphasized [3, 4].

Before steel hatch covers became widely used, until about the 1940s, wooden covers were used and covered with tarpaulin to ensure waterproofing [1, 3, 4]. In this context, Maritime Transport in the 21st century is the most used transport route, where 80% of World Trade occurs [5]. The most important element of this transportation route is; these are ships that are industrial structures designed and manufactured to perform a certain activity [7]. The shape of ship's hull is constantly evolving to meet requirements such as improving carrying capacity, seaworthiness, manoeuvrability, route tracking and maintaining strength depending on marine conditions [5-8]. In area studies, it was determined that these hooks were not made according to a certain standard and that work accidents occurred because strength calculations were not made.

In current literature studies, both welded connection and bolt connections were used as a connecting element in the hooks designed and manufactured [9]. In this case, the corrosion incident that occurs due to weather conditions causes major problems in the system. In this study, the eyebolt connection was attached to the ready-made box profile in the hatch cover stocking gantry crane, and the hook was connected to the ready-made box in these hatch cover stocking gantry crane by welding. In this case, the continuity of the force cannot be achieved because there is no support plate inside the box profile and the box profile is deformed and the material breaks after a certain period [10-12]. It is believed that this study will be more reliable and useful since there is no such situation. In the literature studies performed [15, 16], it was seen that only the weld connection was made in the joining directions of the eyebolt and hook. Corrosion occurring in welding connections, etc. due to the situation, breaks occur from the eyebolt and hook welding sites. This situation causes big problems and work accidents. Furthermore, although the fatigue strength and static strength formed in welding joints are equal, they are less than in non-welding material [13-16]. Fatigue strength in the weld metal of welding joints initiates the magnitude and distribution of the errors [17], the weld metal and a co-the magnitude of stress concentration in the connection of the plate [18], in the case of steel, it is determined by the region under the thermal influence and the decarburisation on the surface of the welding metal [19, 20]. The high-cycle fatigue strength of a welded high-strength steel is not greater than that of a welded low-strength steel [21, 22]. In this study, joints were provided with bolts and pins instead of welding connections. This is predicted to be a more reliable and durable system.

In this study, all force transmission will be on the hook because the eyebolt is combined with the hook. This will extend the service life of the hatch cover stocking gantry crane. A case of corrosion occurring in the hook or eyebolt or the need to replace the hook caused by careless use arises [13-24]. In this case, the hook or eyebolt will need to be cut from the welding areas and boiled again. In this case, repeatedly welding the hatch cover stocking gantry crane destroys the profile box material [25], so this crane system will be destroyed. In this study, it is believed that such situations will not occur, and a safer and more convenient operation will be performed. During maintenance and change, no change will occur in the mechanical properties of the box profile material of the hatch cover stocking gantry crane, as it will not be welded. This, in turn, found that the strength values will be higher and safer than other studies [21-23].

In this study, a special computer-aided hook design was made for special cranes designed for hatch cover stocking used for sea freight transportation. St-37 structural steel data were taken as the hook material. Calculations of the strength of the hook and numerical analysis calculations were made by the finite element method. The tension values formed in the hook were calculated and the deformations occurring in the hook were determined. In line with these calculations, improvements were made to the design. The minimum safety coefficient of the hook was kept above 2. In this way, the product to be manufactured will be reliable and its strength will be ensured at the maximum value.

Materials And Methods

2.1. Computer-Aided Design (CAM)

Currently, stocking type hatch covers are used in marine cargo transport [8]. Special cranes are designed to open and close these covers. Figure 1 shows the design of a special hatch cover crane.

SOLIDWORKS 2020 design program was used for the special hook design of the Stacking type hatch opening crane. Figure 2 shows a two-dimensional hook design and Figure 3 shows a three-dimensional hook appearance.

2.2. Mechanical Properties and Stress Types of St 37 Steel

In the strength calculations of this study, St-37 structural steel data were based, and the mechanical properties of St-37 structural steel were given in Table 1.

Table 1. Mechanical properties of St-37 structural steel [27].

Material	Density Kg/m³	Young's Modulus (MPa)	Elongation (%)	Tensile Strength (MPa)	Yield Strength (MPa)	Poisson's Ratio
St-37	7.7	210000	15	1158	355	0.3

Strength calculations are needed for the design, material selection, reliability, and structural drawings of all machine elements [26, 27]. A machine element is subjected to 6 types of stress under static and dynamic stress, the types of stress exposed according to the strain state are shown in Figure. 4.

In this study, the critical regions and types of stress exposure to the material at 62500 Newton (N) load under static loading are shown in Figure 5.

2.3. Strength Calculations Formulas

Strength calculations made (1), (2), (3), (4), (5), (6), (7), and formulas numbered (8) were used.

$$A = h * L \tag{1}$$

$$I = L * H^3 / 12 \tag{2}$$

$$\tau = F/A \tag{3}$$

$$\sigma_ç = F/A \tag{4}$$

$$\sigma_{B=} (\sigma e + 3 * \tau) \tag{5}$$

$$\sigma_B = \sigma_e + \sigma_ç \tag{6}$$

$$SF = \sigma Ak / \sigma_B \tag{7}$$

$$W = I/(05 * h) \tag{8}$$

Results And Discussion

In this study, critical areas where the stresses of the Hatch cover stocking gantry crane special hook, which was designed with computer support, were calculated by general engineering methods. Analysis operations were performed with finite element analysis.

3.1. Strength Calculations

Calculation 1.

The material has been subjected to bending and shearing. Their calculation measures are shown in Figure 6.

Bending and shearing stress occurred in this part of the Hatch Cover Stocking Gantry Crane of the hook shown in Figure 6. Machine elements exposed to bending moment are subjected to bending and shear stresses [27]. As shown in Figure 6, the material width is 53.44 mm, and the height is 100 mm.

A= h*L

A=53*100 =5300 mm^2 (Sectional Area)

I= L*H^3/12

I= 53*100^3/12 = 4416666,67 mm^4 (Moment of Inertia)

Moment Arm = L1= 62.5mm

M=L1*F

M=62.5*62500 = 3906250 N.mm (Moment)

W=Strength of Moment

W= I/(05*h)

W= 4416666,67/(05*100)= 88333,33 mm^3 (Strength Moment)

τ = F/A

τ= 62500/5300 = 11.79 N/mm^2 (Shearing Stress)

$\sigma_{e=}$ M/W

σe =3906250 / 88333.33 = 44.22 N/mm^2 (Bending Stress)

$\sigma_{B=}$ $(\sigma_e^2+3* \tau^2)^{1/2}$

σB = $(44.22^2+3*11.79^2)^{1/2}$ = 48.707 N/mm^2 (Compound Stress)

sAk= 355 N/mm^2

SF= sAk/ σBi

SF= 355/48.707 = 7.29 (Safety Factor)

Calculation 2.

Tensile and shearing stress occurred in this part of the Hatch Cover Stocking Gantry Crane of the hook shown in Figure 7. Tensile stress is the resistance of the material or system against pull [26]. The tensile stress value is obtained by dividing the force by the cross-sectional area [27, 28].

L= 60mm (Width)

H= 143mm (Height)

A= h*L
A=60*143= 8580mm^2 (Sectional Area)

I= L*H^3/12
I= 63*143^3/12 = 14621035 mm4 (Moment of Inertia)

Moment Arm= L1= 171mm
M=L1*F
M=171*62500 = 10687500 N.mm (Moment)

W= I/(0.5*h)
W= 14621035/ (0.5*143)= 204490 mm^3 (Strength Moment)

σç = F/A
σç = 62500/8580 = 7.284 N/mm^2 (Tensile Stress)

σe= M/W
σ_e = 10687500 / 204490 = 52.026 N/mm^2 (Bending Stress)
σB = σe + σç
σB = 7.28+52.026 = 59.55 N/mm^2 (Compound Stress)
sAk= 355 $_{N/mm^2}$

SF= sAk/ σ_B
$SF_=$ 355/59.055= 5.95 (Safety Factor)

Calculation 3.

In this part of the Hatch Cover Stocking Gantry Crane of the hook shown in Figure 8, only shear stress occurred in the material. The force applied parallel to the cross-section of the system or material is called the shear force. The effect of the applied shear force on the unit area is called shear stress.

Bore Diameter = D= 40mm

Number of Uses = 2

A= π*D^2/4
A= 3.14*40^2/4 = 1256,637 mm^2 (Sectional Area)
F= 62500 N
P = F/2 = 62500/2 = 31250 N (Pin Force)

$\tau = F/A$

$\tau = 312500 / 1256.637 = 24.86$ N/mm² (Shearing Stress)

sAk= 355N/mm²

SF= sAk/ σ_B

SF= 355/24.86 = 14.28 (Safety Factor)

Calculation 4.

Compressing and shearing stress occurred in this part of the Hatch Cover Stocking Gantry Crane of the hook shown in Figure 9. The eyebolt slot has been subjected to pressing stress. The top of the map hole was subjected to shear stress. Compression stress is the internal resistance to the force that tries to crush and shorten the length of the material [26-28].

Calculation 4.1. Eyebolt Slot

Bore Diameter = D= 50mm

Bore Width = L= 52mm

A= D*L

A= 50*52 = 2600 mm² (Sectional Area)

F= 62500 N

$\sigma b = F/A$

$\sigma b = 62500 / 2600 = 24.038$ N/mm² (Compressing Stress)

sAk= 355 N/mm²

SF= sAk/ σB

SF= 355/24.03 = 14.77 (Safety Factor)

Calculation 4.2. Eyebolt Hole Slot

Bore Diameter = D= 50 mm

Bore Width = L= 64 mm

A= D*L

A= 50*64 = 3200 mm² (Sectional Area)

F= 62500 N

$\tau = F/A$

$\tau = 62500 / 3200 = 19.53$ N/mm² (Shearing Stress)

sAk= 355 N/mm²

$SF = sAk/\sigma_B$

$SF = 355/19.53 = 18.17$ (Safety Factor)

The data obtained in the results of strength calculations are shown in Table 2-3-4-5-6.

Table 2. Calculation 1 bending and shear calculation results

Moment of Inertia [mm4]	Strength Moment [mm□]	Bending Stress [N/mm□]	Moment [N.mm]	Shearing Stress [N/mm□]	Compound Stress [N/mm□]	Safety according to Yield Strength
4416666.67	88333.33	44.22	3906250.00	11.79	48.71	7.29

Table 3. Calculation 2 bending and tensile calculation results

Moment of Inertia [mm4]	Strength Moment [mm□]	Bending Stress [N/mm□]	Moment [N.mm]	Tensile Stress [N/mm□]	Compound Stress [N/mm□]	Safety according to Yield Strength
14621035	204490	52.26	10687500	7.28	59.55	5.96

Table 4. Calculation 3 pin shearing calculation results

Number of uses	Shearing Stress [N/mm□]	Safety according to Yield Strength
2	24.86	14.77

Table 5. Calculation 4.1 Eyebolt Slot compression calculation results

Hole Pressing Area [mm□]	Compressing Stress [N/mm□]	Safety according to Yield Strength
2600	24.038	14.77

Table 6. Calculation 4.2. Shaft over hole shear strength results

Cross-sectional area above the hole [mm□]	Shearing Stress [N/mm□]	Safety according to Yield Strength
3200	19.56	18.17

This design is shaped according to the function to be done. In the strength calculations made, the adequacy of the design made mechanically has been proven. In Hatch Cover Stocking Gantry Crane, the strength values must be kept high for the system to be safe, as it also carries the scale prepared according to the cover size [30]. In this study, strength values were kept to a maximum. Because there are no welding connections in this special hook design, it is believed that it will not be affected by environmental conditions such as corrosion.

In other studies, the welded connection was made in the hook profile [13-31]. For this reason, corrosion occurring in welding connections, etc. cases are broken from the eyebolts and hook welding places. This causes major problems and accidents at work [32]. In this study, bolts and pins were used instead of welding connections in joints. This will solve the problems occurring in environmental conditions and connection conditions. It is envisaged that the system will be more reliable and durable.

3.2. Finite Element Analysis (FEA)

Finite element analysis (FEA) is a method for obtaining a numerical analysis of a wide range of engineering problems [28]. The analysis of the specially designed In Hatch Cover Stocking Gantry Crane hook was made with ANSYS R3 software. The ANSYS software program works synchronously with other CAD software programs. Various special hooks were designed with the Catia, Solidworks programs and transferred from there to the analysis program to be analysed [29]. In this study, a special hook design was made with SOLIDWORKS 2020 design program. The analysis of this designed hook was performed using the ANSYS R3 analysis program. St-37 structural steel data was based on the material in the analysis. Due to the ductility of the material, equivalent stress (Von Mises stress), total deformation results were examined and reliability factors of the parts of the hook were calculated. Figure 10-11-12-13-14-15 shows values on the images.

Conclusion

In this study, a computer-aided special hook design was made for special cranes designed for stacking hatch covers used for marine cargo transportation, and St-37 structural steel data was based on the hook material. Calculations of the strength of the hook and numerical analysis calculations were made by the finite element method. The tension values formed in the hook were calculated and the deformations occurring in the hook were determined. In line with these calculations, improvements were made to the design. The following results were obtained in the study.

- Quaternary mesh was used in the analysis, and the minimum edge length of 1,508 mm was selected as the optimal edge length by the program. End-of-network 201715 node point and 127973 items are created.
- Finite element analysis has shown a good fit with analytical calculation, and the results overlap with each other.
- 62500 N load was applied to the end part where the hook was subjected to the most load. It was concluded that it remained safe below the flow limits to carry the load, and the safety factor was found to be a minimum of 2.26, a maximum of 15.

- When 62500 N force is applied to the hook, the maximum stress in the system has been determined as 110.5 MPa and the total deformation as 0.556 mm.
- Improvements have been made in these areas by detecting weak (critical) areas of the hook with the ANSYS R3 software program.
- The parts where the hook is subjected to stress were determined and strength calculations were made here. Strength results and numerical analysis results performed by finite element analysis showed similar values.
- Industrial applicable feature high Hatch Cover Stocking Gantry Crane hook design was designed by SOLIDWORKS 2020 program. Critical subcomponents have been analysed with ANSYS R3 (finite element software). The suitability of stress and deformation levels was observed.
- Improvements were made to the design according to the results of these strength calculations. As a result of improvements in special design and strength values for the Hatch Cover Stocking Gantry Crane hook, the design is expected to be standardized.

Declarations

-Ethical Approval

Not applicable

-Consent to Participate

Not applicable

-Consent to Publish

Not applicable

-Authors Contributions

Not applicable

-Funding

No funding was received for conducting this study.

-Competing Interests

The authors declare no competing of interest.

-Availability of data and materials

Not applicable

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Figures

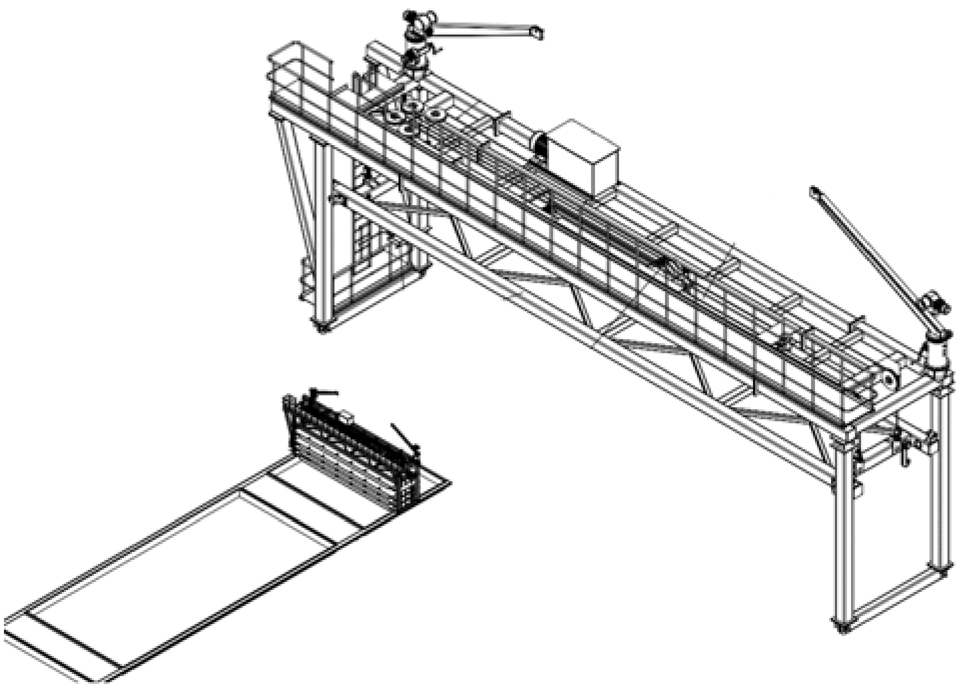

Figure 1

New Type Designed Hatch Cover Stocking Gantry Crane

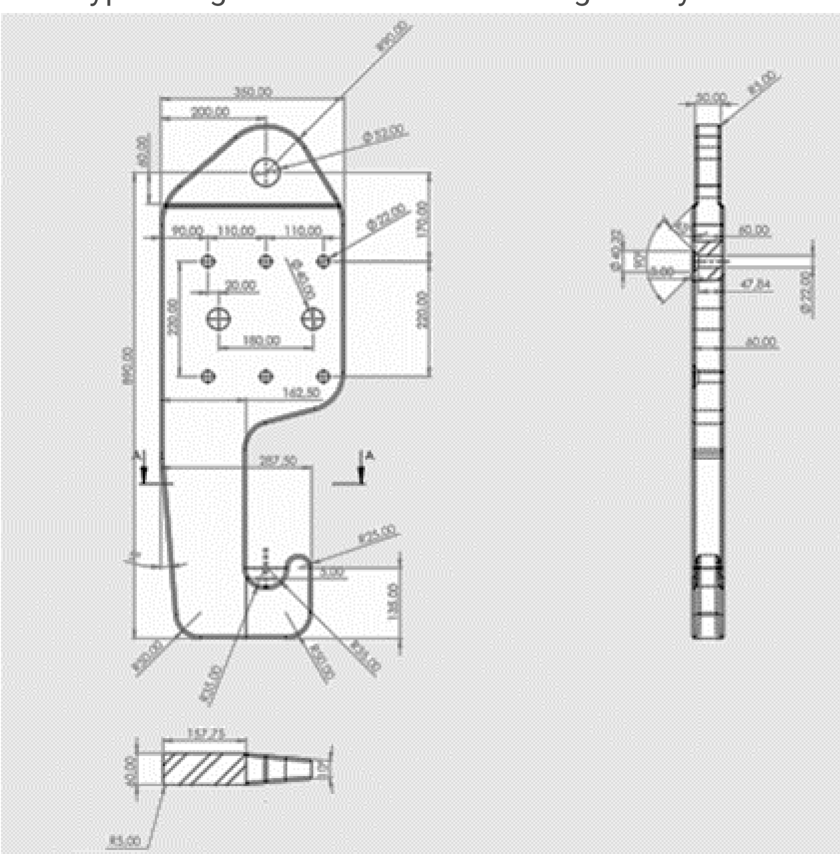

Figure 2

Design Dimensions of Hook Design

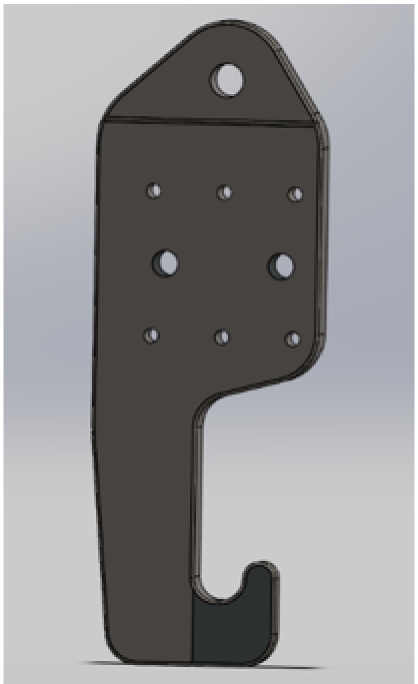

Figure 3

Modelling of Hook

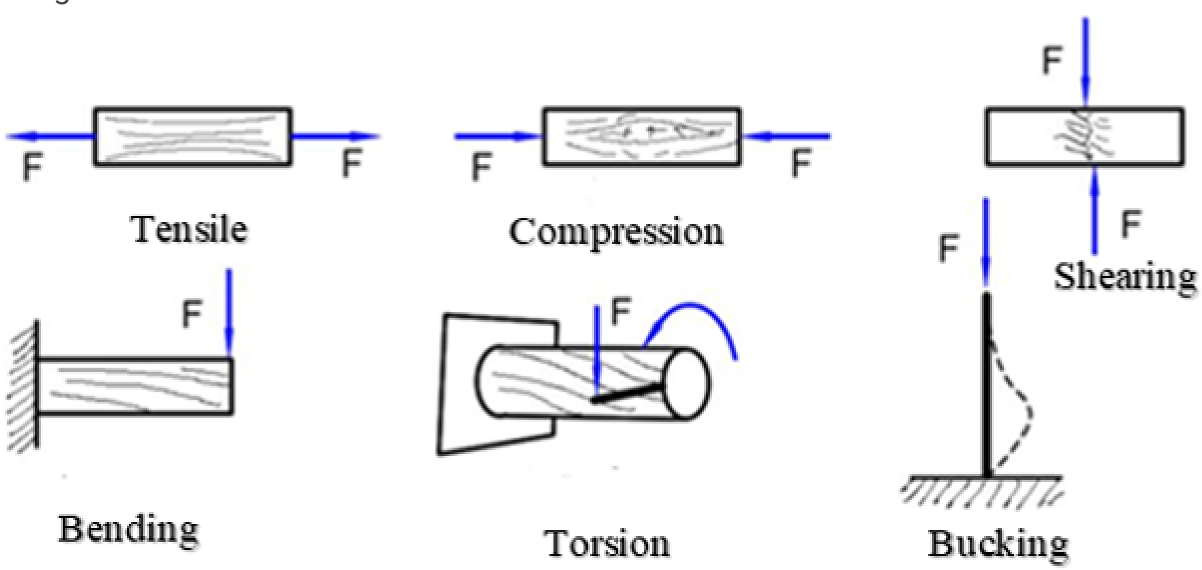

Figure 4

Stresses exposed according to the strain state [17].

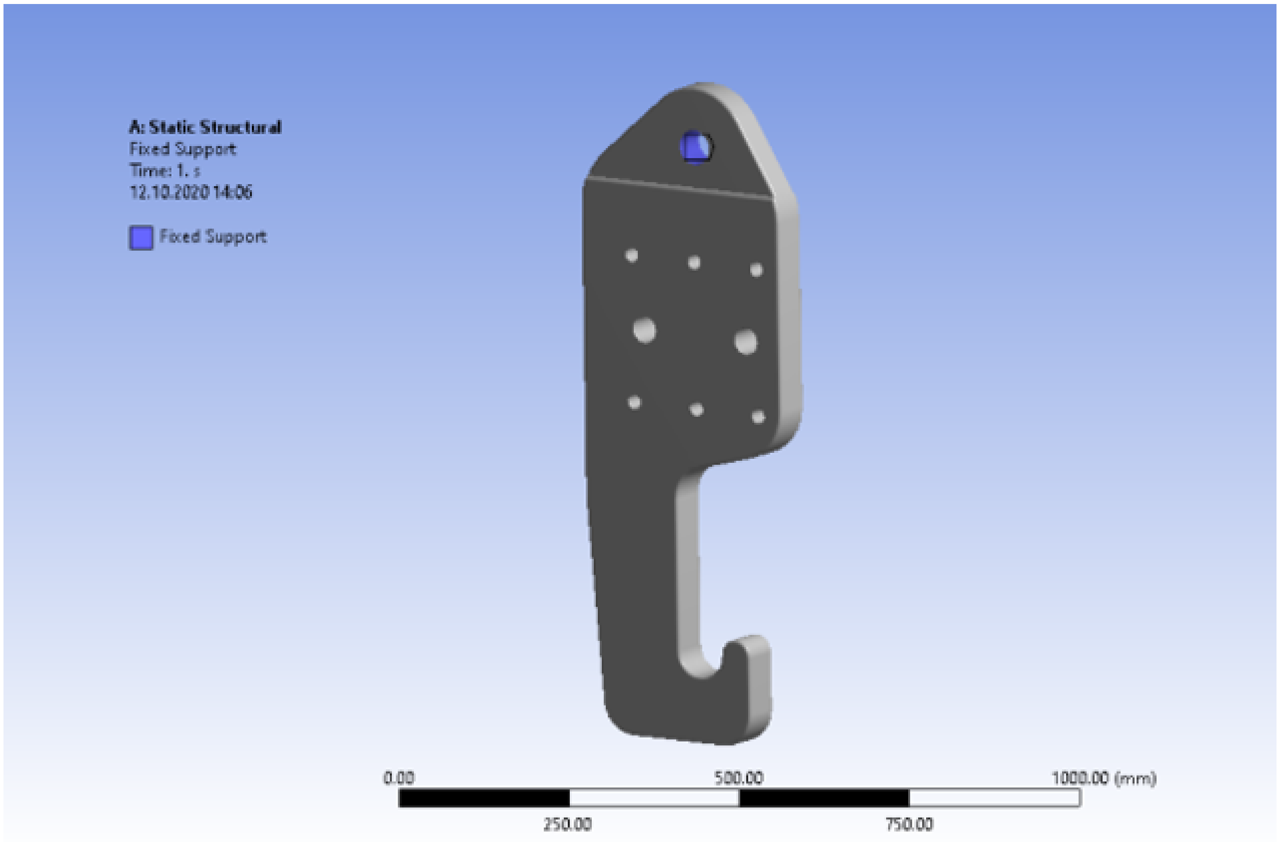

Figure 10

Connection Form of Design

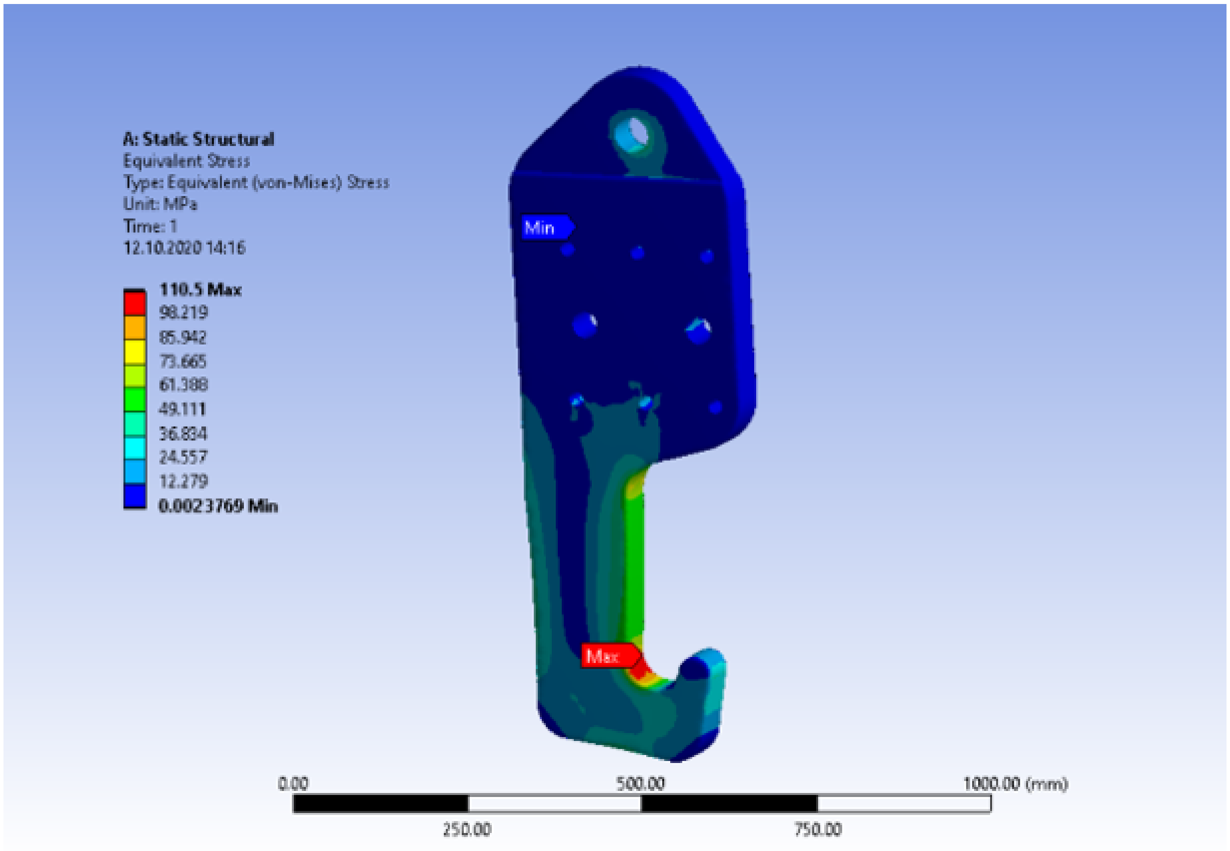

Figure 13

Von-Misses (equivalent stress) analysis result

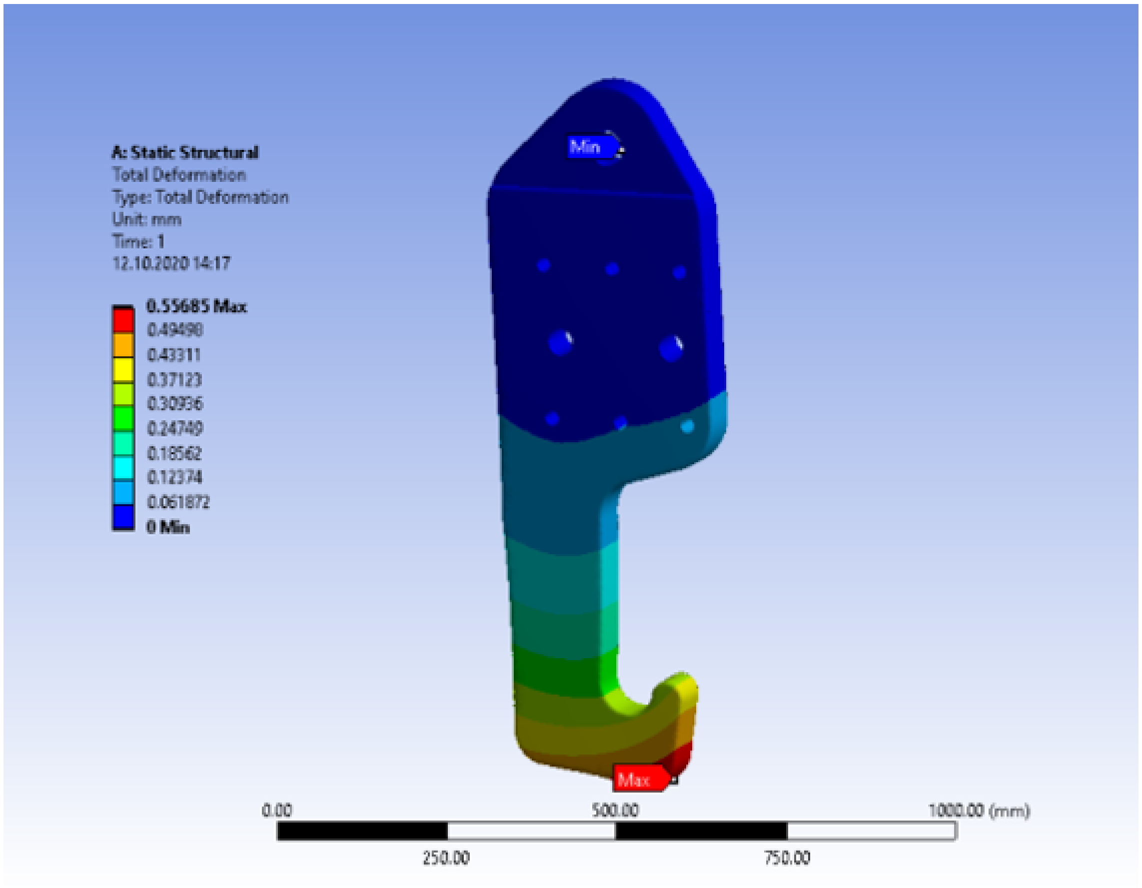

Figure 14

Total deformation analysis