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Araştırma Makalesi
Research Article

Calculation of stresses of superstructure crane on fixing elements

Üstyapı vincinin sabitleme elemanlari üzerindeki gerilimlerinin hesaplanması

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Abstract: In industry load transfer plays important role for especially huge dimensional geometry. Superstructure vehicles need crane equipment to take loads to over its body. Like this upper structure crane assembly design it is important that load distribution to each assembly plate equally. It is aimed to formulate of calculating the load on the fixing plates and the fixing bolts on them according to the working conditions of the crane's carrier arms in the x and y axes. Based on this load, calculations can be done the shear stress of the plates and bolts on both sides of the vehicle. Due to the asymmetrical position of the crane on the vehicle the reaction forces have different values. According to the maximum crane carrying load defined in the crane catalog the reaction forces can be calculated. According to these calculations plates can be designed and can be chosen proper bolts.

Keywords : Crane, Moment, Shear Force, Factor of Safety

Özet: Endüstride yük aktarımı özellikle büyük boyutlu geometriler için çok önemli bir rol oynamaktadır. Üstyapı araçları, yükleri gövdesi üzerine taşıyabilmek için vinç ekipmanına ihtiyaç duyar. Bu üst yapı vinci montaj tasarımında olduğu gibi yükün her montaj plakasına eşit şekilde dağıtılması önemlidir. Vincin taşıyıcı kollarının x ve y eksenlerinde çalışma koşullarına göre sabitleme plakaları ve üzerlerindeki sabitleme cıvataları üzerindeki yükün hesaplanmasının formüle edilmesi amaçlanmaktadır. Bu yüke bağlı olarak aracın her iki tarafındaki plaka ve cıvataların kesme gerilmeleri hesaplanabilmektedir. Vincin araç üzerindeki asimetrik konumu nedeniyle reaksiyon kuvvetleri farklı değerlere sahiptir. Vinç kataloğunda tanımlanan maksimum vinç taşıma yüküne göre reaksiyon kuvvetleri hesaplanabilir. Bu hesaplamalara göre plakalar tasarlanıp uygun cıvatalar seçilebilir.

Anahtar Kelimeler : Vinç, Moment, Kesme Kuvveti, Güvenlik Katsayısı

1. Introduction

Cranes play an integral role in the construction industry. These machines are used to lift, move, lower and raise objects. Cranes have become the most essential mechanism in construction sites. Cranes which work normally work with hoists, chains, ropes, wires, and sheaves are not only fast, but they make the work easier and faster for the projection of work. Cranes are an important part of the lifting mechanism and play an important role in the overall project. Cranes help in moving materials in different directions and locations. Mobile cranes are one of the most important types of equipment in midrise building construction. They are also one of the costliest and most widely used resources when constructing midrise buildings. Cranes play a vital role in lifting several types of weights and transferring those weights from one location to another at the final placement site.[5] Industrial projects are constructed in the form of prefabricated modules that are transported to sites for installation, a process which enhances efficiency and productivity.[6]

Cranes as a mechanical system are in general closed-chain mechanisms with flexible members. In most of the techniques used for determination of the hook load, the dynamic equations of the system should be solved. However, if the hook load is obtained by measurement of wire rope tension, the solution is not necessary. In all other cases, the measurement of the load is dependent on the configuration of the crane and accuracy varies depending on the measurement technique. In the design of load control systems one of the most important points is the modelling of the crane and identification of parameters.[7]

For many centuries, power was supplied by the physical exertion of men or animals, although hoists in watermills and windmills could be driven by the harnessed natural power. The first mechanical power was provided

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by steam engines, the earliest steam crane being introduced in the 18th or 19th century, with many remaining in use well into the late 20th century. Modern cranes usually use internal combustion engines or electric motors and hydraulic systems to provide a much greater lifting capability than was previously possible, although manual cranes are still utilized where the provision of power would be uneconomic. In this study, according to safe loading and safety unloading application, the plate design and bolt specifications have been calculated and determined.

The stress is called “normal stress” because the stress acts on an area that is normal, or perpendicular, to the direction of the applied load.[1] When an external force acts on a body, the body tends to undergo some deformation. Due to cohesion between the molecules, the body resists deformation. This resistance by which material of the body opposes the deformation is known as strength of material. Within a certain limit (i.e., in the elastic stage) the resistance offered by the material is proportional to the deformation brought out on the material by the external force. Also within this limit the resistance is equal to the external force (or applied load). But beyond the elastic stage, the resistance offered by the material is less than the applied load. In such a case, the deformation continues, until failure takes place. Within elastic stage, the resisting force equals applied load. This resisting force per unit area is called stress or intensity of stress.[2] In figure 1.1 Truck mounted boom crane is shown.[3]

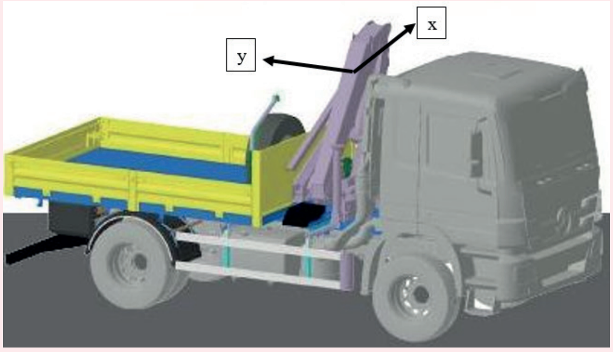

Figure 1.1 Truck Mounted Boom Crane

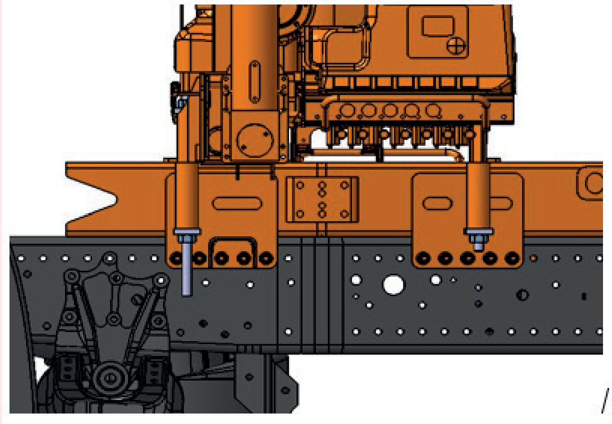

Figure 2.3 Left View

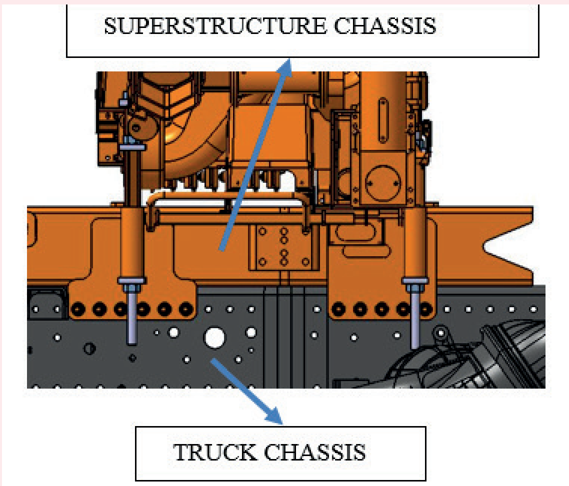

Figure 2.4 Right View

2. Materials

2.1. Crane Chassis Fitting Plates

The number of holes and thickness of the plate has been taken from Mercedes-Benz superstructure instruction in these plates. In this calculation, there are two types of plates as shown below. In this design, S355J2 high-strength structural steel has been chosen. These plates have been designed in CAD program. Below reasons can be taken into consideration for selecting this material.

- High strength
- Easy weldability
- Availability in local markets
- Easy formability

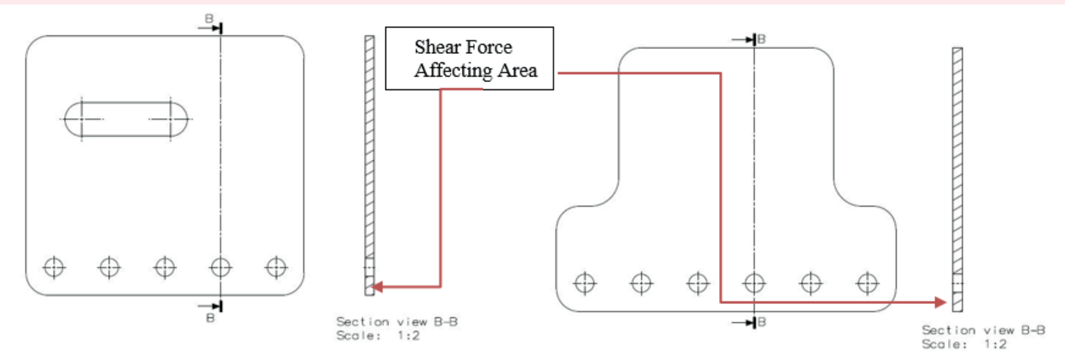

Figure 2.1 Plate Type 1

Figure 2.2 Plate Type 2

S355 is used in almost every facet of structural fabrication.[8] Typical applications include:

- Structural steelworks: bridge components, components for offshore structures
- Power plants
- Mining and earth-moving equipment
- Load-handling equipment

2.2. Fitting Bolts

Bolt standard and its quality also have been taken from Mercedes-Benz superstructure instructions. In this design, hexagon flange bolt DIN 6921 Steel Plain 10.9 grade bolt has been chosen. This material was taken into consideration due to its high strength property.

3. Calculations

In this calculation, there are two parts; One of them is a plate the other one is a bolt that should be calculated in order. After calculation, it is going to be examined which part would be exposed to design force.

In loading and unloading, the crane works in the horizontal plane with 4 axes. The boom rotation center of the crane is positioned asymmetrically when the vehicle is viewed from 4 axes. Due to this asymmetrical structure, a design calculation should be made by looking at the vehicle from the front and the side.

Machine elements are very often made from one of the metals or metal alloys such as steel, aluminum, cast iron, zinc, titanium, or bronze. This section describes the important properties of materials as they affect mechanical design. Strength, elastic, and ductility properties for metals, plastics, and other types of materials are usually determined from a tensile test in which a sample of the material, typically in the form of a round or flat bar, is clamped between jaws and pulled slowly until it breaks in tension. The magnitude of the force on the bar and the corresponding change in length (strain) are monitored and recorded continuously during the test. Because the load acts over a smaller area, and the actual stress continues to increase until failure. It is very difficult to follow the reduction in diameter during the necking down process, so it has become customary to use the peak of the curve as the tensile strength, although it is a more conservative value. [9]

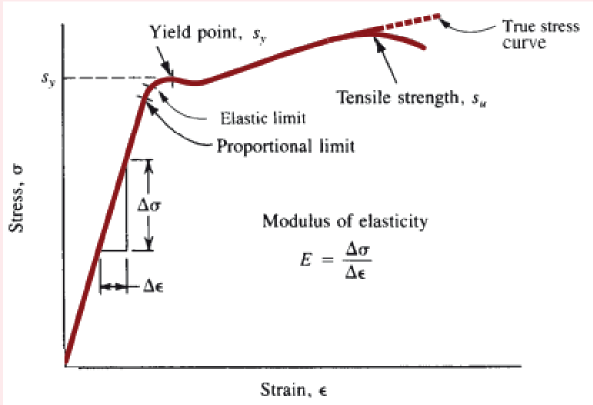

Figure 3.1 Stress-Strain

3.1. Static Analysis and Calculation When Crane Bar at Lateral Positions

From this point of view, shear stress and factors of safety can be calculated for both bolts and fixing plates at the drawing position. At the following calculation, shear stress can be obtained at bolts that are used to assemble the crane to the vehicle chassis.

3.1.1 Shear Stress Calculation for Bolts

First of all the reaction forces can be calculated from below formulas 1 and 2 according to the moment equation diagram.

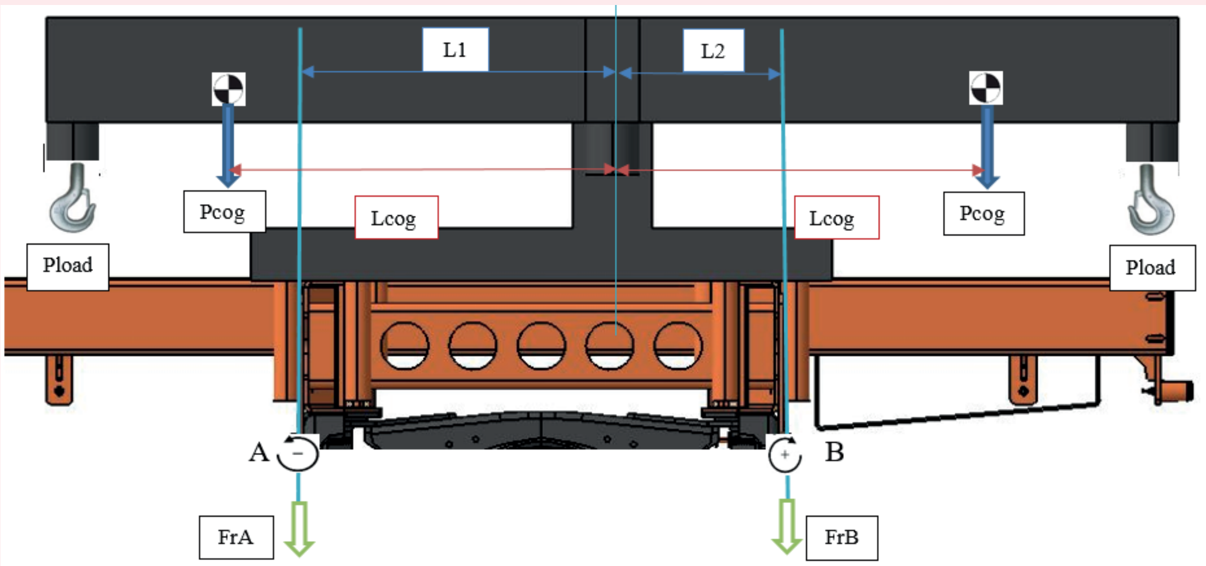

Figure 3.2 Front View

Bolt Class : BOLT HEX. CAP 10.9 M14X1.5X50 DIN6921

Plate Class : S355J2

Plate Thickness : 8 mm

$$\Sigma MB = 0$$

$$FrA * (L1 + L2) = Pcog * (Lcog - L2) + Pload * (Lt - L2) \quad (1)$$

$$FrA * (593 + 325) = 9800 * (2050 - 325) + 42000 * (4500 - 325)$$

$$FrA = 209.428 \text{ N}$$

$$\Sigma MA = 0$$

$$FrB * (L1 + L2) = Pcog * (Lcog - L1) + Pload * (Lt - L1) \quad (2)$$

$$FrB * (593 + 325) = 9800 * (2050 - 593) + 42000 * (4500 - 593)$$

$$FrB = 194.305 \text{ N}$$

After defining the reaction forces FrA and FrB, shear stresses and factor of safeties can be calculated at bolts by below formulas 3 and 4.[4] The affected area of the bolt according to the applied load is shown in figure 3.2.

$$\tau = \frac{F}{A} \quad (3)$$

$$FoS = \frac{\tau yield}{\tau} \quad (4)$$

$$\tau = \frac{209.428}{104*10} \qquad FoS = \frac{900}{201}$$

$\boldsymbol{\tau = 201}$ **Mpa** for FrA

$\boldsymbol{FoS = 4,5}$ for FrA

F is the reaction force, A is the cross-section area of the bolt. Shear stresses τA and τB at points A and B are compared with the yield stress of the bolts. FoS is the factor of safety and this must be greater than one.

$$\tau = \frac{194.305}{104*11} \qquad FoS = \frac{900}{187}$$

$\boldsymbol{\tau = 187}$ **Mpa** for FrB

$\boldsymbol{FoS = 4,8}$ for FrB

3.1.2 Shear Stress Calculation for Assemble Plates

Shear stress can be calculated at the affected area of the plates when the crane arm is at left and right position if we look from the front view. On the left side, both of the plates' cross-sectional surfaces are the same. Contract to this at the right side cross-section of the area of plates are not same. In this calculation, it is considered the working position of crane arms are at the lateral position shown in figure 3.2. Shear stress calculations can be obtained by applying reaction forces FrA and FrB. Shear stress and factor of safety can be calculated when the crane arm is at the left position in figure 3.2. We should consider S355J2 quality material property while taking in calculations. FrB taken in consideration in calculation when crane arm left position. On the other side FrA taken in consideration in calculation when crane arm right position.

Area for Plate in the figure 3.2

$$Aplate1 = h * t * n(\text{numbers of affected area}) \quad (5)$$

for right side plates shear areas

$$Aplate2 = h * t * n(\text{numbers of affected area}) \quad (6)$$

for left side plates shear areas

$$Aplate1 = (25 - 8) * 8 * 10 \qquad Aplate1 = 1360 \text{ mm}^2$$

$$Aplate2 = (25 - 8) * 8 * 12 \qquad Aplate2 = 1632 \text{ mm}^2$$

Calculation of FoS for right side;

At this side FrB taken in consideration and 2 plates mounted with 10 holes

$Aplate1 = 1360 \text{ mm}^2$ 2 plates mounted at this side, so for two plate total area is;

$$Aplate1 = 2720 \text{ mm}^2$$

$\tau = \frac{F}{A}$ F means FrB divided by total area, so

$$\tau = \frac{194.305}{2720} \qquad \boldsymbol{\tau = 72 \text{ Mpa}}$$

$FoS = \frac{\tau yield}{\tau}$ τyield is 355 Mpa

$$FoS = \frac{355}{72} \qquad \boldsymbol{FoS = 5}$$

Calculation of FoS for left side;

At this side FrA taken in consideration and 2 plates mounted with 11 holes

$$Aplate1 = 1360 \text{ mm}^2 \qquad Aplate2 = 1632 \text{ mm}^2$$

Total Area : Aplate1+Aplate2

$\tau = \frac{F}{A}$ F means FrA divided by total area, so

$$\tau = \frac{209.428}{4080} \qquad \boldsymbol{\tau = 52 \text{ Mpa}}$$

$FoS = \frac{\tau yield}{\tau}$ τyield is 355 Mpa

τyield is 355 Mpa $FoS = \frac{355}{52}$ $\boldsymbol{FoS = 7}$

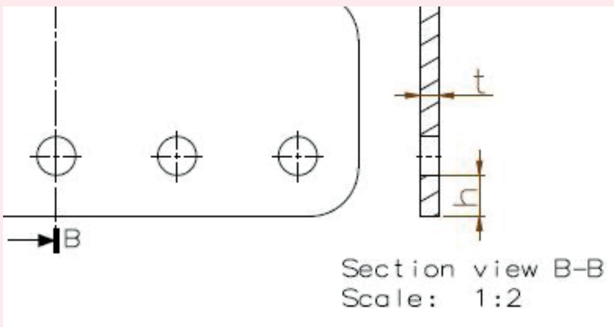

Figure 3.3 Plate Cross Section

3.2. Static Analysis and Calculation When Crane Bar at Drawing Positions

From this point of view, shear stress and factors of safety can be calculated for both bolts and fixing plates at the lateral position. At the following calculation, it will be obtained that shear stress at bolts that are used to assemble the crane to the vehicle chassis.

However in the case, the case of getting maximum stress value is directly related to carrying the maximum load in any direction. Differences between the center of moment with respect to four axis are major effects of calculating the reaction forces.

3.2.1 Shear Stress Calculation For Bolts (Right View)

First of all the reaction forces can be calculated at below formulas

$\Sigma MC = 0$ When Crane Arm At Right Position

$$FrD * (L3 + L4) = Pcog * (Lcog - L4) + Pload * (Lt - L4) \quad (9)$$

$$FrD * (224 + 346) = 9800 * (2050 - 346) + 42000 * (4500 - 346)$$

$$FrD = 335.381 \text{ N}$$

$\Sigma MD = 0$

$$FrC * (L3 + L4) = Pcog * (Lcog - L3) + Pload * (Lt - L3) \quad (10)$$

$$FrC * (224 + 346) = 9800 * (2050 - 224) + 42000 * (4500 - 224)$$

$$FrC = 346.468 \text{ N}$$

After defining the reaction forces FrC and FrC, shear stresses and factor of safeties can be calculated at bolts by below formulas 3 and 4. The affected area of the bolt according to the applied load is shown in figure 3.2.

$$\tau = \frac{346.468}{104*10} \qquad FoS = \frac{900}{333}$$

$\boldsymbol{\tau = 333}$ **Mpa** for FrC

$\boldsymbol{FoS = 2,7}$ for FrC

F is the reaction force, A is the cross-section area of the bolt. Shear stresses τA and τB at points A and B are compared with the yield stress of the bolts. FoS is the factor of safety and this must be greater than one.

$$\tau = \frac{335.381}{104*11} \qquad FoS = \frac{900}{322}$$

$\boldsymbol{\tau = 322}$ **Mpa** for FrD

$\boldsymbol{FoS = 2,8}$ for FrD

F is the reaction force, A is the cross-section area of bolt. Shear stresses τA and τB at points A and B are compared with the yield stress of the bolts. FoS is the factor of safety and this must be greater than one.

3.2.2 Shear Stress Calculation for Assemble Plate

Affecting shear stress on plates can be calculated when the crane arm is in the driving direction and reverse of the driving direction looking from the front view. The plate area can be calculated according to both crane arm directions. In the figure 2.3 and figure, 2.4 show the plates' hole numbers are different. So, the front and back-plate areas affected by shear force are different. In this calculation, it can be considered that the working position of crane arms are at the lateral position shown in figure 3.1.

Shear stress calculations can be obtained by applying reaction forces FrC and FrD.

Calculation of FoS for right side;

At this side FrC taken in consideration and 2 plates mounted with 11 holes

$Aplate1 = 1360 \text{ mm}^2$ $Aplate2 = 1632 \text{ mm}^2$ Total Area : Aplate1+Aplate2

$Aplate = 2992 \text{ mm}^2$

$\tau = \frac{F}{A}$ F means FrC divided by total area, so

$$\tau = \frac{346.468}{2992} \qquad \boldsymbol{\tau = 116 \text{ Mpa}}$$

$FoS = \frac{\tau yield}{\tau}$ τyield is 355 Mpa

$FoS = \frac{355}{116}$ $\boldsymbol{FoS = 3}$

Calculation of FoS for left side;

At this side FrD taken in consideration and 2 plates mounted with 10 holes

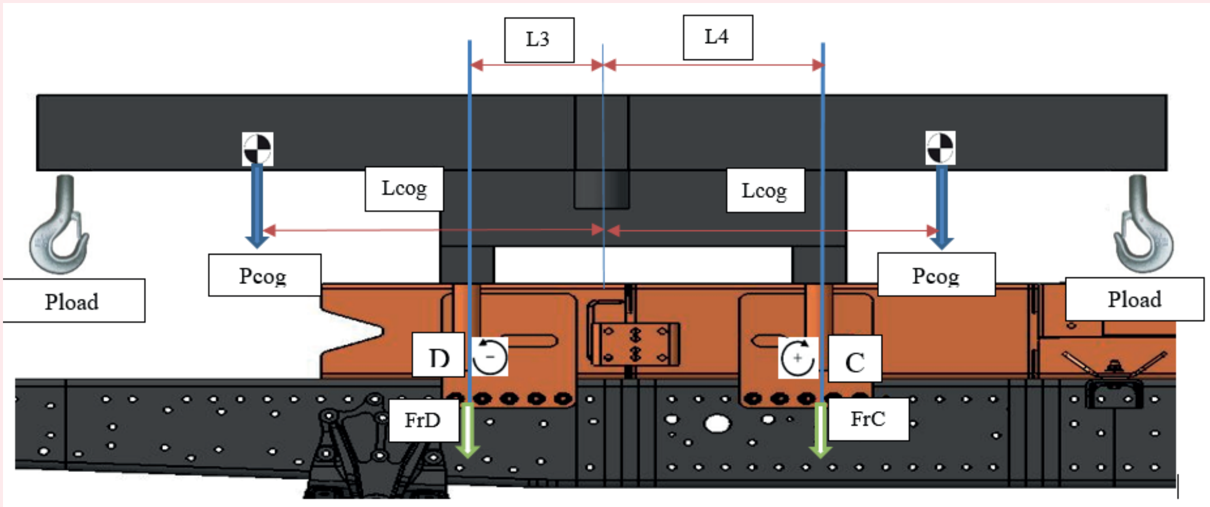

Figure 3.4 Left View

$Aplate1 = 1360\ mm^2$ 2 plates mounted at this side, so for two plate total area is;

$$Aplate1 = 2720\ mm^2$$

$$\tau = \frac{F}{A}$$ F means FrA divided by total area, so

$$\tau = \frac{355.381}{2720} \quad \boldsymbol{\tau = 131\ Mpa}$$

$$FoS = \frac{\tau yield}{\tau}$$ τyield is 355 Mpa

$$FoS = \frac{355}{131} \quad \mathbf{FoS = 2,7}$$

4. Conclusion

In this study, it is aimed to find weakest plate and bolt according to crane arm direction. There are two design criteria; the first one is shear stress at bolts, and the other one is shear stress on plates. The important point is that changing the direction of the crane arm at any direction directly affect the moment at reaction points A, B, C, and D. By getting moment values each Factor of Safety of the plates and bolts can be calculated. FoS for mechanical design should be greater than 1. So, comparing all FoS, the lowest value is 2,7 and this is greater than 1. This value shows us this design is acceptable. Beside that all FoS values show us which plate and bolt are critical for crane position. The stresses can be calculated on bolt and plates according to the crane boom when it is at four positions (left, right, driving way, counter driving way).

Statement of Conflict of Interest:

Author has declared no conflict of interest.

Author's Contributions:

All processes were carried out by the Author.

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