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Safety device strength analysis during repair of cylinder loader up down curing machine

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Abstract: While repairing the up-down loader cylinder by the tire company engineering team, a work accident occurred. The loader fell due to movement when releasing the loader cylinder and the loader load which was hanging on the nok, because it was not strong enough to support the loader, the Nok fell off followed by the loader dropping. So then the engineering team installed a safety device to withstand the load of the loader if something similar happened, but until now its strength has not been tested. This research aims to analyze the strength of the safety device installed on the loader using calculation analysis and test simulations with Finite Element Analysis (FEA). The research began with collecting load data received by the safety device and then carrying out theoretical calculation analysis and simulations using Solidwork software. And the result it by calculating the maximum bending stress is 63,30 N/mm^2. Meanwhile, the strength of the welded joint 424,05 kN, while the actual load received by the welded joint is 6806,891 N. So it can be stated that the welded joint is safe. In the loading simulation using Solidwork software, the maximum stress (57,279 N/mm$^{2)}$, the maximum deformation (0.036mm), and the FOS (4,365). Safety loaders with ASTM A36 material are declared safe because the FOS value is > 2 (safety factor based on static load).

Keywords: Curing; loader; safety device; solidwork; FEA

1. INTRODUCTION

In tire companies, there are four stages of the production process that go through to produce tires, namely Material Section, Building Section, Curing Section, and Final Inspection. The curing process is the process of cooking green tires (semi-finished tires) into tires (finished tires) which is carried out in a mold with temperature and pressure adjusted based on product specifications [1]. The type of curing machine available at this tire company is BOM (Bag O-Matic), which is a curing machine using a motor and gearbox drive [2]. In the curing machine there is a loader component that functions as a tool to help move the green tire from the front of the machine into the mold using an up-down and in-out working process with a hydraulic cylinder drive.

While repairing the up-down loader cylinder by the tire company engineering team, a work accident occurred. The process of repairing the loader cylinder is that the loader is tied using a chain to the nok at the top end of the loader then the clevis that connects the cylinder piston to the loader is removed, and the nok at the top is locked to the loader axle with an M16 size bolt 10 mm deep. When releasing the cylinder, the Nok and the loader fell due to movement when releasing the loader cylinder and the load of the loader which was hanging on the nok. There were no fatal casualties in this incident, but it caused anxiety for the engineering team when repairing the loader cylinder. The team speculated about making a safety device that would be installed on the roof to support the loader's load if a similar incident occurred.

A safety device is a device that functions to maintain safety for the machine and the operator running it if a machine malfunction occurs. It is often also called a worker safety device which functions to maintain worker safety from the possibility of accidents occurring. The strength of safety devices is an important thing to know because each device used must have different limits to withstand the risks that occur. Until now, the safety devices that have been installed on tire company curing machine, loaders have not been tested to see whether they can withstand the load of the loader.

The researcher looked at several previous studies to then use as a reference for the author in conducting research. Testing the strength of a material by applying a force load on the same axis is the wrong test to measure the strength of the connection. The results obtained from tensile testing are very important to obtain the results of the tensile test data analysis that has been carried out, the tensile strength and stress, strain, and modulus of elasticity values are obtained [3]. Strength analysis of welded joints in air engine car construction with the result is a calculation of the forces acting on the construction, the results of calculating the cross-sectional area in the total weld area of the construction support, the shear stress that occurs, the allowable stress of the material and the results state that welding is considered safe [4]. Strength analysis of press machine component trusses for the safety analysis results, the strength of the truss designed with the allowable strength of the truss material is safe because the allowable strength of the truss material is smaller than the maximum strength of the designed truss [5].

Calculation of welded joints in the construction of mounting fn 240 weapons on zid motorcycles with the results of the analysis that has been carried out, it was obtained that the greatest stress of all components and the E6013 electrode with the maximum tensile strength is safe for use in connecting weapon mounting components [6]. Strength analysis of welded joints in multipurpose rice thresher machine frames with the results, based on welding calculations carried out on the frame of the multipurpose rice thresher machine and carrying out static simulations with solidwork, suitable results were obtained. Static simulation testing using solidwork on a multi-purpose rice threshing machine frame inputted with ASTM A36 steel material to test whether the strength of the calculated length of E6013 welding wire to withstand the specified load [7]. Simulation of frame loads on rice husk grinding machines using software based on the results of the safety factor analysis, a comparison of the three materials including AISI 1010, ASTM A36, and AISI 1045 materials shows that the best material is AISI 1045 material because it has the greatest safety factor value [8]. Based on the problems that occur and previous research references, this research aims to calculate the tensile strength of safety devices and the strength of welded joints in safety devices and to carry out load testing with Finite Element Analysis (FEA) using Solidwork 2018 software [9].

2. METHOD

Observation and literature study

A safety device is a safety device installed on the top of the loader to avoid the risk of a malfunction occurring when repairing the up and downloader cylinder. The material used is an ASTM A36 plate with a thickness of 20 mm which is joined by welding. Figure 1 is the shape of the safety device installed on the loader.

Figure 1. Safety device loader

Table 1 are the ASTM A36 material specifications used in loader safety devices, where the data will be used in calculating and analyzing the strength of the safety device.

Table 1. Spesification of ASTM A36 Materials [10][11]

Parameter	ASTM A36
Elasticity Modulus	200 Gpa
Poisson	0,3
Yield Stress	250 Mpa

Parameter	ASTM A36
Ultimate Stess	350 Mpa
Density	7850 kg/m^3
Allowable Maxsimum Stress	208,3 Mpa
Allowable Maxsimum Displacement	1 mm

Collected data

After conducting literature studies and field studies, the author collected data that will be used to carry out analysis on safety devices, namely the weight of the loader which is the load that the safety device will receive by measuring it and then processing it using solidwork software [12]. Table 2 below is the weight of loader components that have been processed with solidwork.

Table 2**.** Weight of loader component

No	**Component Name**	**Volume**	**Numbers of Component**	**Weight**
1	Body Loader	0,04192 m^3	1	3225,18 N
2	Finger	0,00115 m^3	8	89,170 N
3	Finger Mount Body	0,01270 m^3	1	977,716 N
4	Finger Stand	0,02172 m^3	1	1671,105 N
5	As Finger	0,000147 m^3	8	90,630 N
6	Finger Mount Base	0,00979 m^3	1	753,6 N
	TOTAL			6806,891 N

Analysis strength of safety device

Strength is the ability of a material to withstand plastic deformation (stress without damage). Some materials such as structural steel, wrought iron, aluminum, copper, and stainless steel have high tensile strength where the tensile strength and compressive strength are almost the same. Therefore, to determine the strength of a material, it can be done using tension, compression, or shear [13]. In this research, the strength of the safety device material will be searched for its strength level.

a) Calculation of bending stresses on components

Calculation of bending stress to determine the value of one of the forces that occur due to the tensile/compressive force on an object that has a cross-sectional area, The area (A), a moment of inertia (I), the center of gravity, and maximum bending stress of the cross-section can be calculated using the formula [14].

The Area

$$A = b \, x \, h \tag{1}$$

Moment of Inertia

$$\mathrm{I} = \frac{1}{12} \, x \, b \, x \, h^3 \tag{2}$$

Square Center Point

$$Y_{max} = \frac{h}{2} \tag{3}$$

Maximum Bending Stress

$$\sigma_{max} = \frac{M_{max} \, x \, Y}{I} \tag{4}$$

Where:

A = The Area
I = Moment of Inertia
b = wide
h = long/high
σ_{max} = Maximum Bending Stress

M_{max} = Moment Maximum
Y_{max} = Square Center Point

b) Allowable stress on components.

Allowable stress is the permitted stress or maximum stress so that the object does not fail. To determine the permissible stress, the maximum stress must be taken into account with a factor called the safety factor [15].

$$\sigma_{allowable} = \frac{\sigma t}{FOS} \tag{5}$$

Where:
$\sigma_{allowable}$ = Alowable Stress
σt = Ultimate Stress
FS = Factor of Safety

c) Factor safety

The safety factor is the comparison of the ultimate tensile stress with the permissible tensile stress, a safety factor provided so that the construction design and machine components have resistance to the load received [16].

$$FS = \frac{\text{yield strength}}{\sigma_{allowable}} \tag{6}$$

d) Butt joint welding

The tensile strength of welded joints using the butt joint welding method is [15]:

$$P = t\ x\ l\ x\ \sigma t \tag{7}$$

Where:
t = Weld thickness (mm)
l = Weld length (mm)
σt = Allowable Stress (MPa)

e) Fillet welding

If σt is the allowable tensile stress for the metal welding process, then the tensile strength for the single fillet weld method is [15]:

$$P = 0{,}707 \text{ x s x l x } \sigma \tag{8}$$

Meanwhile, the tensile strength of welded joints using the double fillet weld method is [15]:

$$P = 2 \text{ x } 0{,}707 \text{ x s x l x } \sigma \tag{9}$$

Free body diagram

A free-body diagram (DBB) is a representation of an object with all the forces acting. Free body diagrams are used to calculate the reactions of objects in mechanics problems. In Figure 2 below is a free-body diagram of the loader safety device that will be analyzed, where W is the loader load that will be received by the safety device and will support the loader shaft.

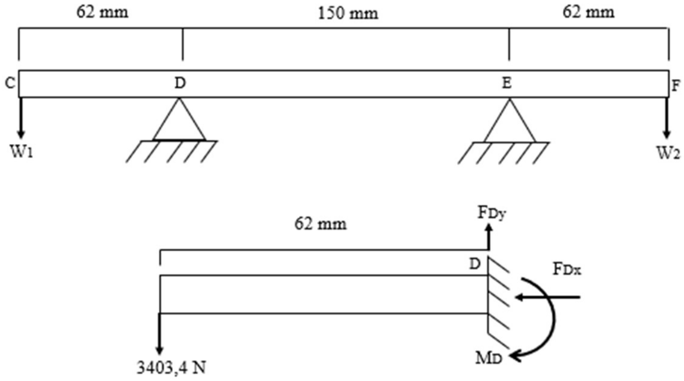

Figure 2. Free body diagram

3. RESULTS AND DISCUSSION

Determine bending stress of safety device

Based on the free body diagram in Figure 2, the reaction at the support, bending moment, moment of inertia, center point of the square, and maximum bending stress of the safety device can be calculated using the formula below.

f) Reaction at Support D and E

$$\sum V = 0;$$

$$FDy - W1 = 0$$

$$FDy = 3403{,}4 \text{ N } (\uparrow)$$

$$FEy = FDy = 3403{,}4 \text{ N } (\uparrow)$$

$$FDx = FDE = 0$$

g) Bending Moment

$$\sum Mx = 0;$$

$$- MD + W1 \times L = 0$$

$$MD = W1 \times L$$

$$MD = 3403{,}4 \text{ N} \times 62 \text{ mm}$$

$$MD = ME = 211010{,}8 \text{ N.mm}$$

h) Moment of Inertia

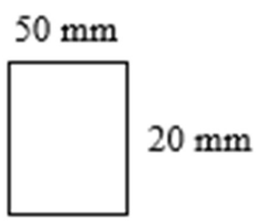

Figure 3. Safety device cross-section

Figure 3 is the shape of the cross-section of the safety device. The moment of inertia is:

$$\text{I} = \frac{1}{12}\ x\ b\ x\ h^3 \quad (2)$$

$$\text{I} = \frac{1}{12}\ x\ 50\ x\ 20^3$$

$$\text{I} = 33333{,}33\ mm^4$$

i) Square Center Point

$$\text{y} = \frac{20}{2} \quad (3)$$

$$\text{y} = 10\ mm$$

j) Maximum Bending Stress

$$\sigma max = \frac{\text{M x y}}{\text{I}} \quad (4)$$

$$\sigma max = \frac{211010{,}8 \text{ N.mm x } 10 \text{ mm}}{33333{,}33\ mm^4}$$

$$= 63{,}30\ N/mm^2$$

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The calculation above it is known that the maximum bending stress value that occurs in the safety device as a result of receiving the loader load is 63.30 N/mm^2.

Calculation of the strength of safety device welded joints

Welding is carried out on the safety loader with the top nok using an E6013 electrode type which has a tensile stress specification (σt) of 413 N/mm^2 [17]. The factor of safety (FOS) imposed is 4 because the welded joint receives a steady load and the material used is a soft and mixed material [15]. To calculate the allowable tensile stress, it can be calculated using the equation:

$$\sigma_{allowable} = \frac{\sigma t}{FOS} \quad (5)$$
$$= \frac{413 N/mm^2}{4}$$
$$= 103{,}25 \ N/mm^2$$

• Vertical plate welding to Nok

As seen in Figure 4 welding on the side of the vertical plate to Nok using parallel fillet welding as indicated by the arrow, welding using an E6013 electrode.

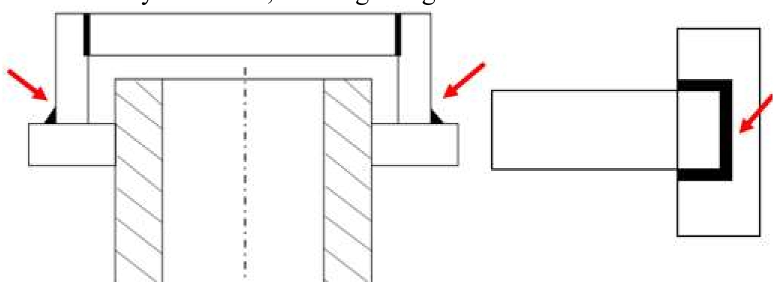

Figure 4. Vertical plate welding position

It is known that the thickness of the profile to be welded is 20 mm thick, the weld side length (l) is 50 mm, the recommended weld thickness (s) for a profile thickness of 20 mm is 10 mm. The maximum welding load can be calculated using the equation.

$$P = 0{,}707 \text{ x } s \text{ x } l \text{ x } \sigma_{allowable} \quad (8)$$
$$= 0{,}707 \text{ x } 10 \text{ x } 50 \text{ x } 103{,}25$$
$$= 36498{,}875 \text{ N} \approx 36{,}5 \text{ kN}$$

As seen in Figure 5 is welding on the other side of the vertical plate to the nok using parallel fillet welding as indicated by the arrow, welding using an E6013 electrode.

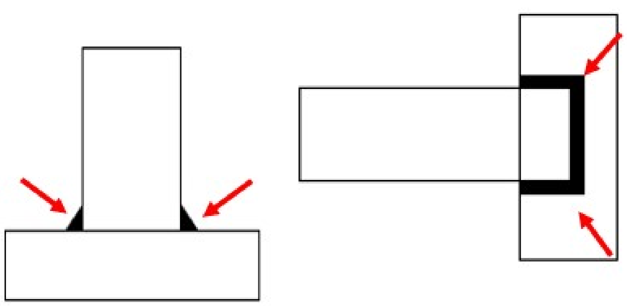

Figure 5. Vertical plate welding position

It is known that the thickness of the profile to be welded is thickness (t) of 50 mm, and the length of the weld side (l) is 20 mm, and the recommended weld thickness (s) for a profile thickness of 50 mm is 14 mm. Then the maximum welding load can be calculated using the equation.

$$P = 2 \text{ x } 0{,}707 \text{ x } s \text{ x } l \text{ x } \sigma_{allowable} \quad (9)$$
$$= 1{,}414 \text{ x } 14 \text{ x } 20 \text{ x } 103{,}25$$

$$= 40878{,}74 \text{ N} \approx 40{,}8 \text{ kN}$$

Then the total strength of the welded joint on both sides is.

$$P \text{ total} = 2 \text{ x } (36{,}5 \text{ kN} + 40{,}8 \text{ kN})$$
$$= 155{,}6 \text{ kN}$$

Based on the results obtained, the maximum allowable load on the welded joint is 155,6 kN, while the actual load received by the welded joint is 6806,891 N. Can be stated that the welded joint is safe.

k)Vertical and horizontal plate welded joints

As shown in Figure 6, welding on the side of the horizontal plate against the vertical plate uses v-butt joint welding as indicated by the arrow, welding using an E6013 electrode.

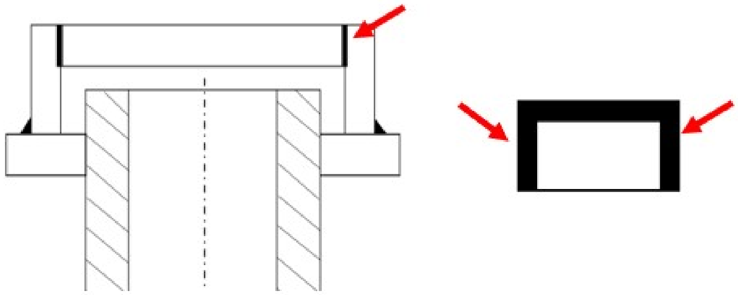

Figure 6. Horizontal plate welding position

It is known that the profile to be welded is thick (t) of 20 mm, and the length of the weld side (l) is 20 mm. The maximum welding load can be calculated using the equation.

$$P = 2 \text{ x t x l x } \sigma_{allowable} \tag{7}$$
$$= 2 \text{ x } 20 \text{ x } 20 \text{ x } 103{,}25$$
$$= 82600\text{N} \approx 82{,}6 \text{ kN}$$

As shown in Figure 7, welding on the other side of the horizontal plate against the vertical plate uses v-butt joint welding as indicated by the arrow, welding using an E6013 electrode.

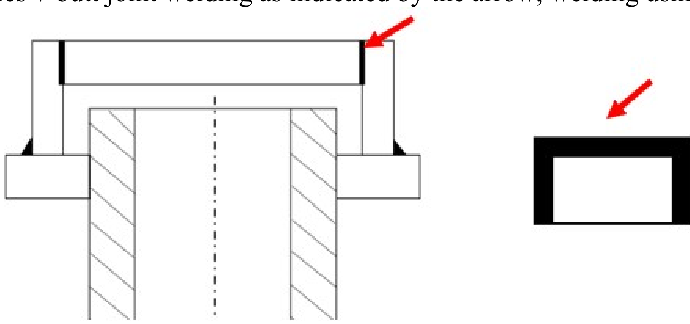

Figure 7. Vertical plate welding position

It is known that the profile to be welded is thick (t) of 20 mm, the length of the weld side (l) is 50 mm. then the maximum welding load can be calculated using the equation.

$$P = \text{t x l x } \sigma_{allowable} \tag{7}$$
$$= 20 \text{ x } 50 \text{ x } 103{,}25$$
$$= 103250 \text{ N} \approx 103{,}25 \text{ kN}$$

Then the total strength of the welded joint on both sides is

$$P \text{ total} = 2 \text{ x } (82{,}6 \text{ kN} + 103{,}25 \text{ kN})$$
$$= 268{,}45 \text{ kN}$$

Based on the results obtained, the maximum allowable load on the welded joint is 268,45 kN, while the actual load received by the welded joint is 6806,891 N. So it can be stated that the welded joint is safe.

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Finite element analysis of safety device

Finite element analysis in this research uses Solidwork 2018 software by simulating stress, deformation, and safety factors on safety devices [18].

a) Stress

Based on the results of stress on the safety device shown in Figure 8, the maximum stress value received was 57,279 N/mm^2. This result shows a value that is almost the same as the safety factor value used in theoretical calculations.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0,067 N/mm^2 (MPa) Node: 9815	57,279 N/mm^2 (MPa) Node: 10673

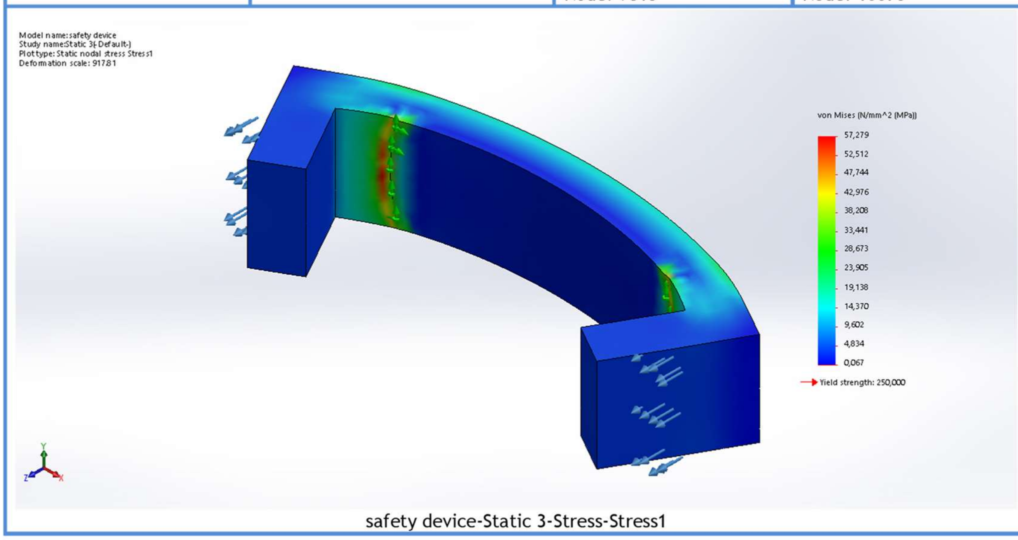

Figure 8. Stress simulation

b) Displacement

Based on the test results shown in Figure 9, the maximum deformation value was obtained at 0,036 mm. These results show that the allowable deformation for the safety device when receiving a loader load is 0,036 mm.

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0,000 mm Node: 5	0,036 mm Node: 366

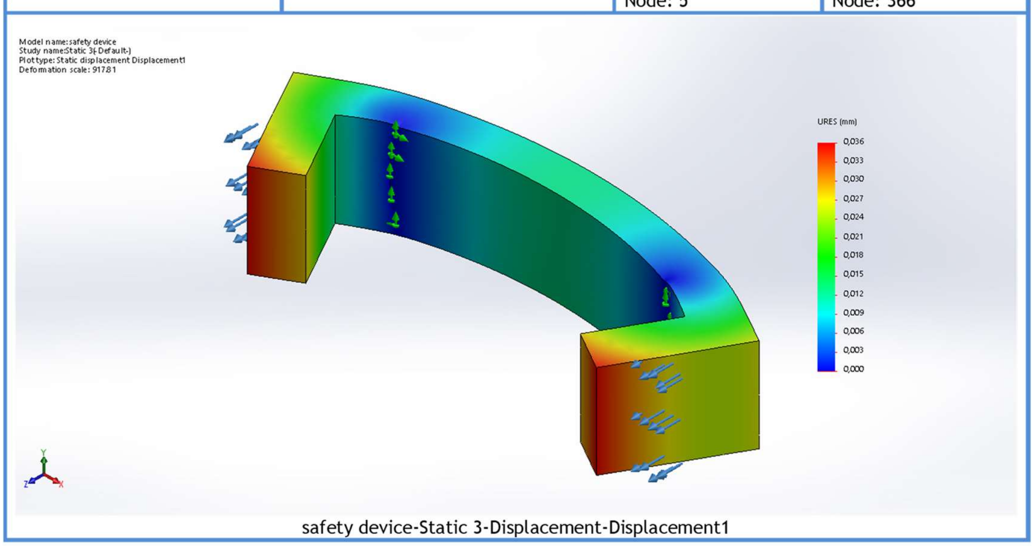

Figure 9. Deformation Simulation

c)FOS (Factor of Safety)

Based on the test results shown in Figure 10, the Factor of Safety value for the safety device with a minimum safety factor value that could be used of 4,365. This result shows a value that is almost the same as the safety factor value used in theoretical calculations.

Name	Type	Min	Max
Factor of Safety1	Automatic	4,365 Node: 10673	3.742,834 Node: 9815

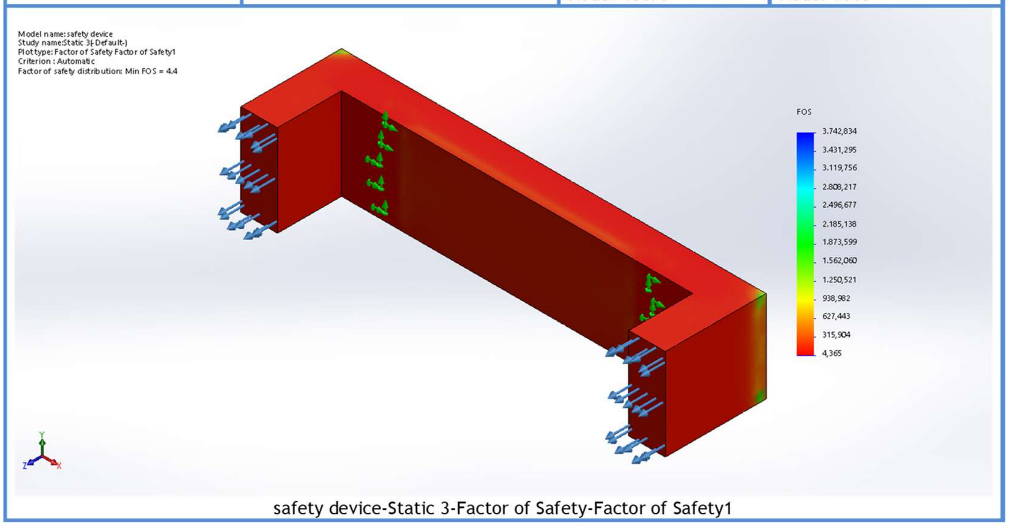

Figure 10**.** The factor of safety simulation

Factor of Safety (FOS)

The bending stress value that occurs in the safety device is 63,30 N/mm^2 while the yield stress value of ASTM A36 is 250 N/m^2. To determine the value of the factor of safety, the stress that occurs on the safety device uses the following equation.

$$FS=\frac{\text{Yield Strength}}{\sigma_{allowable}} \tag{5}$$

$$FS=\frac{250}{63,30}$$

$$FS=3,95$$

So it can be concluded that safety devices with ASTM A36 material are declared safe because the FOS value is > 2 (safety factor based on static load) [16].

Discussion

The safety device gets a loader load of 6806,891 N, the bending stress that occurs in the safety device when holding the loader load is 63,30 N/mm^2. Meanwhile, for the strength of the welded joint, based on the results that have been obtained, the maximum allowable load on the vertical and horizontal plate welded joint is 155,6 kN + 268,45 kN = 424,05 kN, while the actual load received by the welded joint is 6806,891 N. So it can be stated that the welded joint is safe. In the loading simulation using Solidwork software, the maximum stress value was 57,279 N/mm^2, the maximum deformation value was 0.036 mm, and the FOS value was 4,365. Safety devices with ASTM A36 material are declared safe because the FOS value is > 2 (safety factor based on static load).

3. CONCLUSION

The bending stress that occurs in the safety device when holding the loader load is 63,30 N/mm^2. Meanwhile, for the strength of the welded joint, based on the results that have been obtained, the maximum allowable load on the vertical and horizontal plate welded joint is 155,6 kN + 268,45 kN = 424,05 kN, while the actual load received by the welded joint is 6806,891 N. So it can be stated that the welded joint is safe. In the loading simulation using Solidwork software, the maximum stress value was 57,279 N/mm^2, the maximum deformation value was 0.036 mm, and the FOS value was 4,365. Safety devices with ASTM A36 material are declared safe because the FOS value is > 2 (safety factor based on static load).

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