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Analysis the Influence of Sling Direction on Pad Eye Strength

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Abstract

One of the stages of ship production using the grand block system is the erection process, where in this process the blocks weighing up to million Tons will be lifted. This study aims to see whether the sling angle used in the block lifting process will produce different stresses, strains, and deformations in the pad eye. Sling angle variations used in this study are 45°, 60°, 75° and 90° with a tensile load of 55 tons or 539365.75 N. This research was conducted using the finite element method and assisted by ANSYS software. Based on the results of the analysis, the maximum X-axis normal stress is 57.85 MPa which occurs at a sling angle of 45°, the maximum Y-axis normal stress is 143.32 MPa which occurs at a 90° sling angle, the maximum XY shear stress is 51.712 MPa which occurs at a sling angle of 45° and a Von-Mises stress of 151.47 MPa which occurs at a sling angle of 90°. As for the shear strain XY, the maximum strain that occurs at an angle of 45° is 6.4 $x10^{-4}$and for the maximum Von-Mises strain occurs at an angle of 90° by7.4 $x10^{-4}$. And the maximum total deformation value is obtained by7,286 $x10^{-2}$mm that occurs at a sling angle of 45°.For each variation of the sling angle used, the strength of the pad eye still meets the classification requirements because the resulting value is still below the permissible value. The difference in the results obtained after using variations in the angle of the sling shows that the difference in the direction of the pull of the sling has a different effect on the strength of the Pad eye.

Keywords: Pad Eye; Lifting Angle; Strain; Stress; Deformation

1. Introduction

Currently, there are more and more medium to large-scale shipyards whose production processes have progressed. For examples in the production process of ships that use the grand block system. Construction with this system will allow shipbuilding to be faster than other systems. In this system, the erection process consists of the process of assembling, joining, moving and lifting the grand blocks, which can weigh up to millions of mN. In the lifting process, the large accident may occur [1], the supporting tools in this process, namely cranes, slings, and pad eyes.

What needs to be considered in the lifting process is the safety of the block to be lifted , as well as equipment and supplies in the lifting process. The block/structure and equipment must not be damaged during the lifting process. One of the equipment that is important in this process is the Pad eye. Pad eye is a lifting tool made of metal and welded to a plate/block, the optimum welded join was analyzed by Etio-osa, et al [2]. The number of pad eye used depends on the size and weight of the block. Pad eye used is usually 4 pieces to keep the block fixed. Determination of the location of the pad eye on the beam is in the strong point area, for ships it is usually above the bulkhead, transverse beam or longitudinal beam. One of the underlying reasons for choosing a pad eye is the sling angle, because sling angle may affect the load received by a pad eye.

Sling is a tool in lifting work, made of materials such as chains, wire, steel or synthetic materials, which are tied and tightened to the object or load to be lifted and attached to the crane hook during the lifting process. The characteristic of this sling is that one or both ends are terminated or made into an eye to be used as a means of binding accessories used to assist lifting applications such as hooks, master links, and others. In addition, there are various types of slings, depending on the function, field conditions and also the application, such as Wire Rope Slings, Chain Slings, Webbing Slings, and Round Slings. A sling angle occurs when two or more slings are attached to a crane hook, and there are several possible angles that can occur in the sling.

Based on these problems, the purpose of this study was to determine the maximum stress, strain and deformation values at the pad eye for each angle of the sling used. In addition, the change in stress strain and deformation will also be determined as a function of the angle. To facilitate this research, the ANSYS Workbench software will be used. The result was evaluated by using Bureau Veritas (BV) rules [3].

2. Literature Review

Relatively large accident risk can occur to the ship block lifting process during assembly and erection steps [1]. The factors that can cause the lifting process to fail are poor planning, equipment failure, HR that does not meet the requirements, other factors that are influenced by nature such as wind, weather, natural disasters and others. Prior to loading the block, a centre line is drawn on the floor just above the block that stands/where the joint erection is located. Its function is when the block is already above the jig (where the block stands) it is easy to see from the straightness of the block.

Pad eye is one of the most important lifting equipment in the lifting process. The pad eye serves as a link between the main load and the shackle which will later be connected to the rope (sling). Shackles are usually available in the market with a certain SWL value. The number of Pad eyes used is usually 4 Pad eyes per section, this aims to maintain the stability or balance of the block. *Lifting pad eyes* widely used in the shipbuilding and offshore industries. A good pad eye design should have high safety but also be economical [4].

Determination pad eye dimensions according to DNV OSH205 (2014) [5] are as follows:

1. The determination of the outer diameter of the Pad eye main plate must not be less than the diameter of the pin hole.
2. The Pad eye thickness in the hole area should not be less than 75% of the inner width of the shackle
3. The diameter of the Pad eye hole must be carefully determined to fit the diameter of the shackle pin. In order to be strong, the difference between the Pad eye hole spacing and the pin diameter is as small as possible
4. It is recommended that the diameter of the shackle pin is not less than 94% of the Pad eye hole diameter.

- **Description of Loading on Pad Eye**

Pad eye used to connect the construction to be lifted with a crane using a sling. Pad eye used in the field has various geometries depending on the type of load. If the load is a vertical force, the geometry used is symmetric. Meanwhile, if the style forms an angle, asymmetric/nonsymmetric geometry is used [6]. An example of a pad eye with symmetrical and non-symmetrical geometries can be seen in Figure 1. In most cases, a spreader bar is used between the crane and the lifting point. A spreader bar is used to ensure that the sling works below the allowable angle. Each lifting point has a pad eye welded to the structure and connected to the sling using a shackle [7].

Shackle connect the Pad eye and sling that work at a certain angle of the sling. Since the sling acts at an angle, the force on the Pad eye hole will act at the same angle. Therefore, the acting force can be divided into a vertical component Fz and a horizontal component Fx. The direction of these components can be seen in Figure 2.

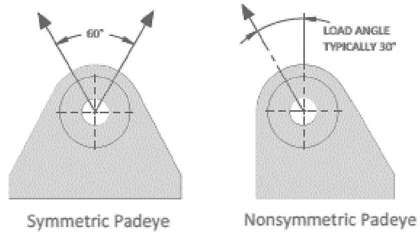


Figure 1. *Pad eyes* symmetrical and non-symmetrical [6].

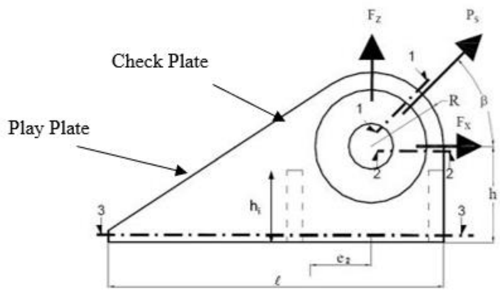


Figure 2. The direction of the force component on the Pad eye.

- **Load Resistance**

To withstand loads during operation, the pad eye consists of a main plate and sometimes has ring stiffeners. The main plate is connected to a pair of cheek plates to prevent the main plate from malfunctioning due to bearing stress. Ring stiffeners are attached to the main plate to resist radial and lateral forces and prevent excessive deformation [7].

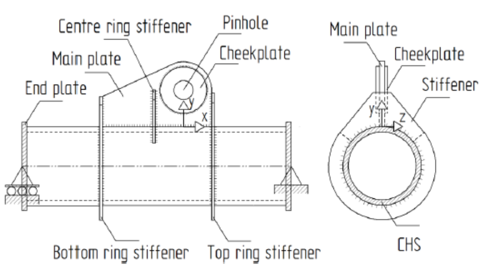


Figure 3. Pad eye Components [6].

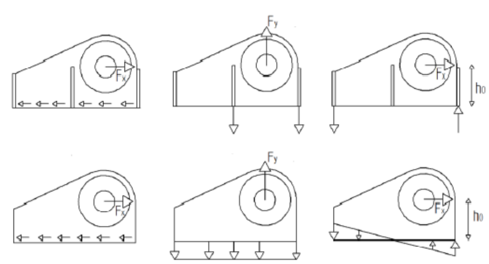


Figure 4. Force distribution with and without ring stiffeners [6].

The distribution of forces on the pad eye with additional ring stiffeners is shown in Figure 3. The distribution of forces without ring stiffeners can also be seen in Figure 4. If there are no ring stiffeners, the horizontal and vertical force components will be distributed over the entire main plate and connected to the supports. In this case the load is transferred from the Pad eye hole through the main plate to the support. The force component is transferred from the main plate to the supports as described [7]: The horizontal force component Fx is received by welding between the Pad eye main plate and the block/load, the vertical force component Fy is distributed over the base of the main plate, and Bending moments in the plane are distributed over the main plate.

Sling or wire rope are lifting tools that are usually used to connect the pad eye with the crane, especially large and heavy items in various industries. The sling angle is the angle that occurs when two or more slings are attached to one crane hook. Slings must be protected from sharp corners by means of wooden blocks and bearings when transported.

Each time the sling is used, the sling must be carefully inspected end to end to determine that the sling is in good condition [8].

- **Centre of Gravity**

The centre of gravity of an object is a point on the object or around the object where the weight of all parts of the object is centred on that point. In Figure 5. it can be seen the difference in the location of the centre of gravity on 2 different objects. It is very important for everyone involved in lifting and carrying loads to know the basics of statics and the effect of an object's centre of gravity in relation to the point of lift, or the distribution of forces on slings and objects [8].

The centre of gravity is the point in a load at which all of the load can be said to be concentrated during lifting which acts downward to bring the load to an equilibrium position just below the lifting hook, even though the load may be misaligned. Before attempting to lift a load that may be much heavier at one end than at the other, or where the pad eye may not be located with respect to the load's centre of gravity, the rigger must estimate the location of the load's centre of gravity and place the crane hook just above that theoretical point [8]. For more details can be seen in Figure 6.

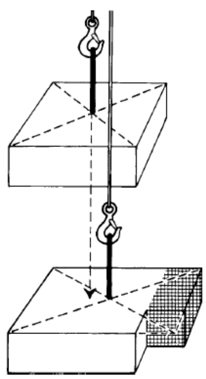


Figure 5. The Centre of gravity on the block to be lifted.

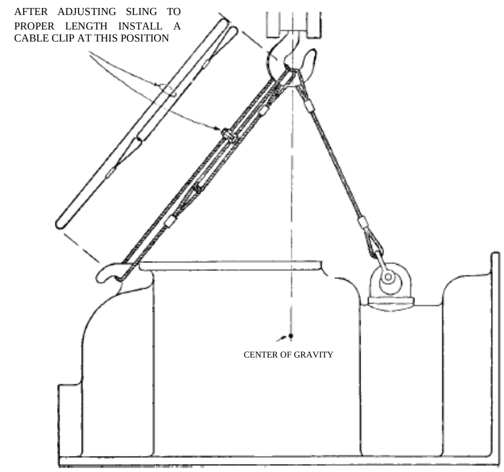


Figure 6. The center of gravity above the theoretical point.

- **Loading Analysis**

Structural loads are forces, deformations, or accelerations applied to structural members. Loads cause stress, deformation, and displacement in the structure. The calculation of the effect is carried out using the structural analysis method. Overloading can lead to structural failure, and hence such possibilities must be considered in the design or tightly controlled [9]. In modelling, analysing and designing a structure, it is necessary to have a description of the behaviour and magnitude of the loads acting on the structure.

- Static forces are force that act continuously on the structure and have the character of steady-states.
- Dynamic force is a force that acts suddenly on the structure, in general it is not steady-states and has the characteristics of large and rapidly changing locations.

- **Stress and Strain**

Stress is a quantity that shows the internal forces between the particles of a material with respect to other particles. If the pad eye is pulled with a force, then the stress is a tensile stress (tensile stress) and if the force has the opposite direction causing the rod to compress, then a compressive stress occurs. Then the normal stress can be either tensile or compressive. While the shear stress is the stress that acts in a tangential direction to the surface of the material [10].

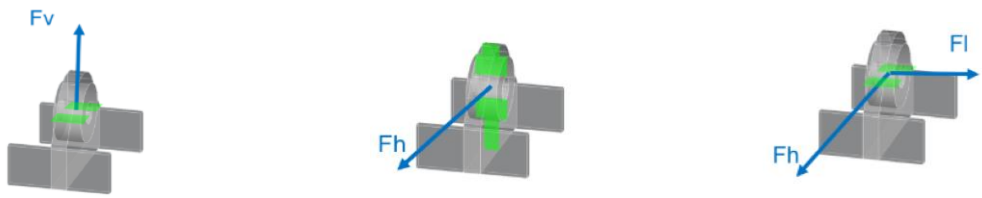
There are different types of stress that can occur in the Pad eye:

a. Tensile stress is the internal stress exerted by a material to resist the action of an external force that is perpendicular to the cross-sectional area. Tensile stress on the pad eye can be seen in Figures 7a and 7b. The equations to calculate the stress value was shows in Equations 2.1 and 2.2.

$$\textit{Tensile Stress Vertical} \qquad \sigma = \frac{Fv}{A} \qquad [2.1]$$

$$\textit{Tensile Stress Horizontal} \qquad \sigma = \frac{Fh}{A} \qquad [2.2]$$

where, Fv and Fh are working force and A is working area.



a. b. c.

Figure 7. (a) Tensile stress on the vertical axis, (b) Tensile stress on the horizontal axis, and (c) Shear stress.

b. Shear stress, the load causes a pulling effect along the surface of the cheek and main plate which causes shearing of the Pad eye and can cause deformation. The shear stress on the pad eye can be seen in Figure 7c. The equations to calculate the shear stress value was show in Equation 2.3.

$$\textit{Shear Stress} = \frac{F_Q \; x \; S}{b \; x \; I} \qquad [2.3]$$

Where F_Q is Shear force, S is area of static moment, b is cross-sectional width, and I is moment of inertia.

c. Von Mises stress (Von Mises Stress), Von Mises stress is also calculated as a combined body stress at the Pad eye.

Strain is the ratio of the deformation of a structure to its initial length due to a force whose direction is parallel to the change in the length of the structure. Straight bar will experience a change in length when loaded axially, i.e. it becomes long when it is pulled and becomes short if you hit [10]. The increase in the length of the rod is denoted by delta, where a unit length of the rod will have an elongation equal to 1/L times the total elongation. The elongation in the bar can be measured for any given increase in axial load. The concept of elongation per unit length, or so-called strain, which is given the notation (epsilon) can be calculated by the Equation 2.4.

$$\varepsilon = \frac{\Delta L}{L} \qquad [2.4]$$

where ε is strain, ΔL is the increase in length (mm), and L is original length (mm)

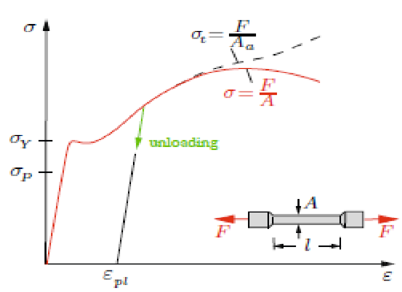


Figure 8. Stress-strain relationship curve [11].

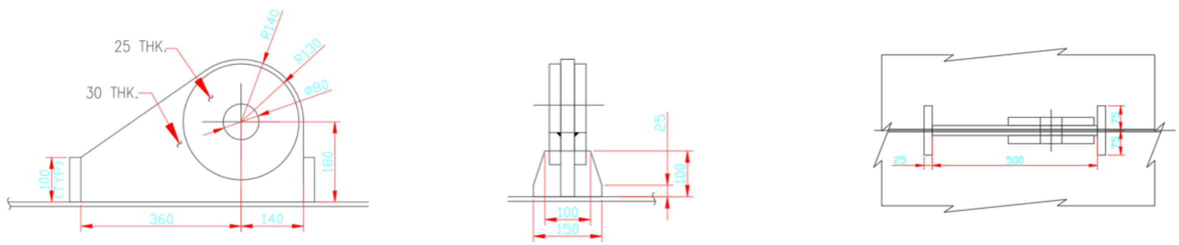
The relationship between stress-strain was show in Figure 8. The curve is the result of testing the flexural steel material [11].

2. Research Method

The steps for data processing in this study are as follows:

A. Pad eye shape and dimensions

Pad eye used in this study is a pad eye with a non-symmetrical geometry with a SWL of 55 tons. For details on the size and shape of the pad eye with SWL 55 Tons, see Figure 9.1a for detailed image lengthwise, Figure 9.1b for detailed image crosswise and Figure 9.1c for detailed image above.



a. b. c.

Figure 9. Details of Pad eye shape and size.

B. Pad eye material specifications

The material used for the pad eye construction is S355J0 with the specifications was show on Table 1.

Table 1. S355J0 Material properties

No	Property	Value	
		MPa	Pa
1	Elastic Modulus	2.1E+05	2.1×10^{11}
2	Shear Modulus	8.0E+04	8.0×10^{10}
3	Yield Strength	355	3.55×10^{8}
4	Ultimate Strength	630	6.30×10^{8}

C. Pad eye structure loading

In this study, the pad eye structure will be loaded with 4 different sling angles as show in Figure 10, namely 45º, 60º, 75² and 90º in the form of tensile forces from the crane during the lifting block process. The amount of force applied to the pad eye is 100% SWL, which is 55 Tons or 539365.75 N and 150% SWL is 82.5 Tons or 809048.63 N.

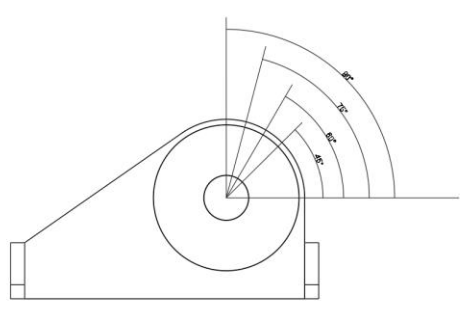


Figure 10. Variation of style angle.

The steps to analyse the strength of the pad eye structure using software are broadly as follows:

- **Making Pad eye geometry**

The process of making pad eye geometry using Autodesk AutoCAD 2017 software. At this stage the geometry modeler is made in 2D based on Figure 11, then made into 3D using the press pull and extrude commands as shown in Figure 12.

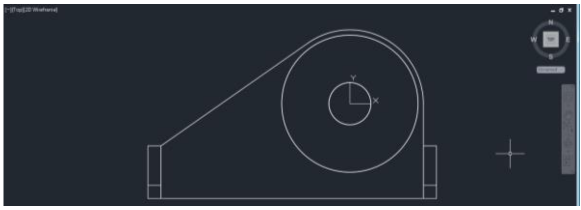


Figure 11. Geometry of the 2D Pad eye.

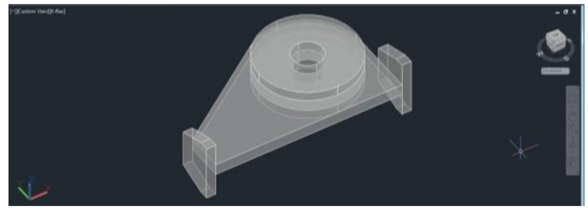


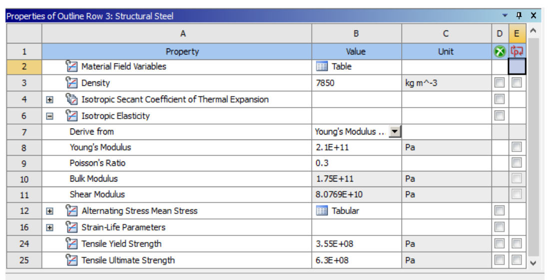
Figure 12. Geometry of the 3D Pad eye.

- **The process of importing pad eye geometry into ANSYS software**

After the pad eye geometry is created in stage 1 using Autodesk AutoCAD 2017, then the file is saved in ".iges" format by clicking on File – Export – Other Formats, then block all the geometry you want to save and press enter. Then the ANSYS Workbench software is imported by right-clicking on Geometry - Import Geometry - Browse - Then selecting the file that was saved earlier.

- **Determining the type of material and inputting material specifications**

After the geometry is imported, the next step is to determine the type of material. Material types and specifications can be inputted manually. S355J0 material specifications can be seen in Figure 13.



Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7850	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's Modulus ...			
8	Young's Modulus	2.1E+11	Pa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.75E+11	Pa		
11	Shear Modulus	8.0769E+10	Pa		
12	Alternating Stress Mean Stress	Tabular			
16	Strain-Life Parameters				
24	Tensile Yield Strength	3.55E+08	Pa		
25	Tensile Ultimate Strength	6.3E+08	Pa		

Figure 13. Material properties of pad eye (S355J0).

- **Determination of connection between geometries**

Bonded contact type is selected to connect the main plate of the pad eye with both cheek plates and the main plate of the pad eye with the stiffener plate. Contact Bonded was chosen because of the welding between these geometries.

- **Meshing process**

Meshing process aims to divide the geometry of the model into many small elements. The smaller the size of these elements, the more accurate the results will be. In the element size option, 7 mm is selected so that after meshing it forms 250576 Nodes and 167824 Elements. The meshing results can be seen in Figure 14.

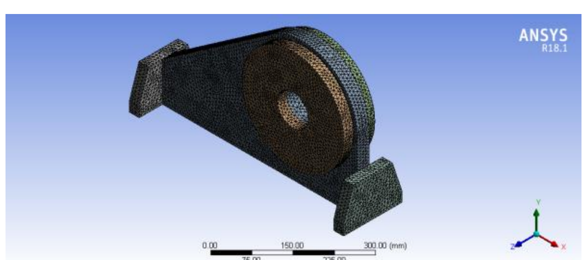


Figure 14. Meshing on the Pad eye.

- **Giving focus and burden**

The type of support used in this Pad eye is a fixed support, which holds all degrees of freedom, be it horizontal, vertical, or rotation. This fixed support is applied to the base of the Pad eye that is connected to the block to be lifted where there is welding. The application of fixed support to the geometry can be seen in Figure 15.

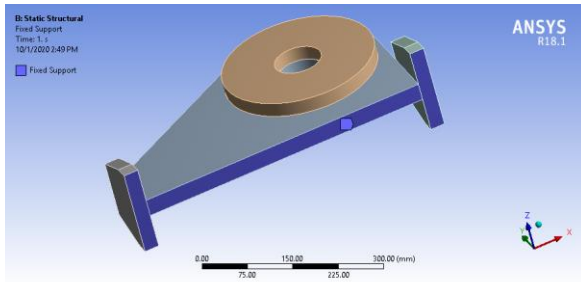


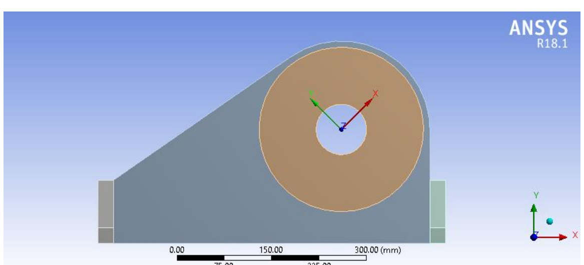
Figure 15. Fixed support on the Pad eye.

As for the loading, a force load is given to the pad eye hole of 539365.75 N as show on Figure 16 for each sling angle, including 45º, 60º, 75º, and 90º. To give a certain sling angle, it is done by doing a Z rotation with a coordinate system, then the force is input following the X axis after being rotated. The loading on the model using the ANSYS software can be seen in Figure 17.

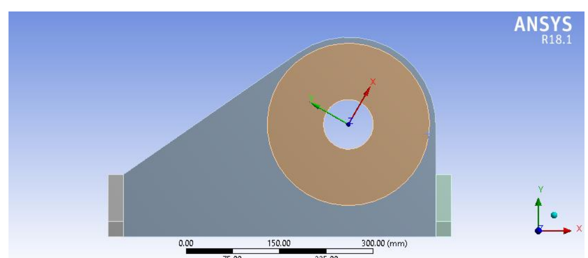
Details of "Force"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Faces
Definition	
Type	Force
Define By	Components
Coordinate System	Global Coordinate System
X Component	5.3937e+005 N (ramped)
Y Component	0. N (ramped)
Z Component	0. N (ramped)
Suppressed	No

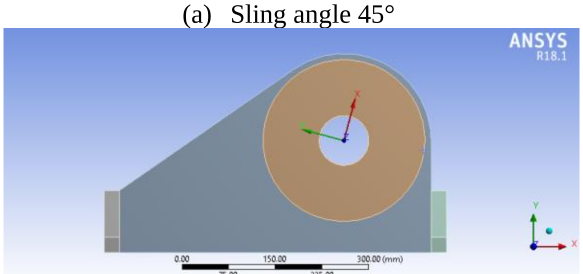
Figure 16. Details of the force load on the Pad eye.



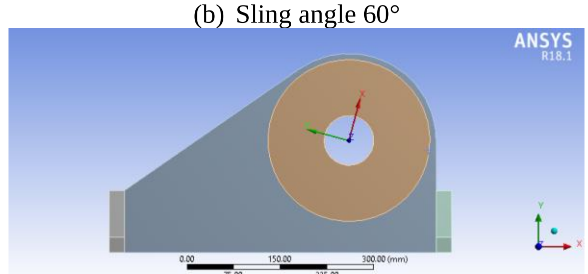
(a) Sling angle 45°



(b) Sling angle 60°



(c) Sling angle 75°



(d) Sling angle 90°

Figure 17. Overview of the direction of the load for each corner of the sling

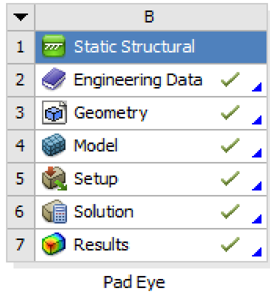


Figure 18. Solving was successful.

- **Solving process**

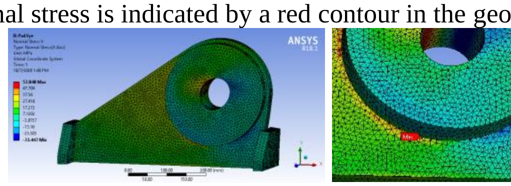
After being given the support and load on the geometry model, the next step is solving or running a simulation. If the solving process is successful without any problems, there will be a check mark next to the information as shown in Figure 18. After that, the simulation results can be seen in the Results menu.

4. Result and Discussion

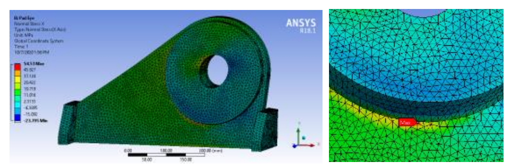
After analysing the strength of the pad eye in the form of stress, strain and deformation with sling angles of 45º, 60º, 75º and 90º, then the comparison or changes in the strength of the pad eye at each angle were analyse. The analysis was carried out by comparing two different types of materials, namely S355J0 and S500MC materials.

1. Normal Stress

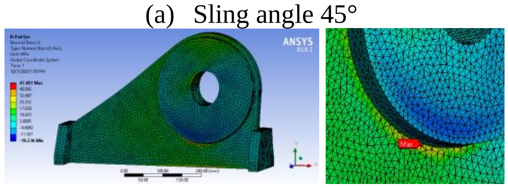
The simulation results of the normal stress on the pad eye can be seen in Figure 19 and Figure 20, where the maximum normal stress is indicated by a red contour in the geometry.



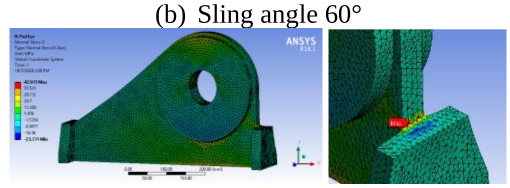
(a) Sling angle 45°



(b) Sling angle 60°

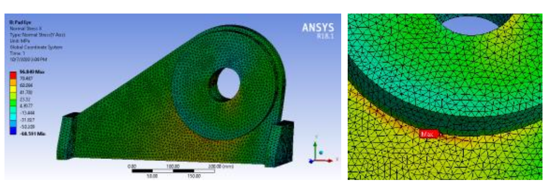


(c) Sling angle 75°

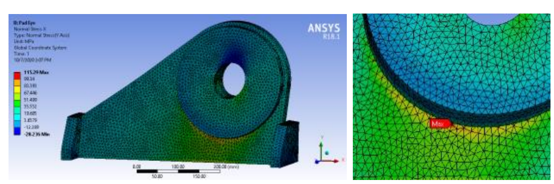


(d) Sling angle 90°

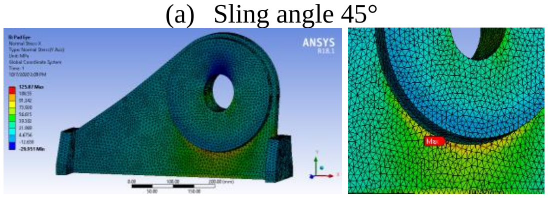
Figure 19. Simulation results of normal stress on the X axis.



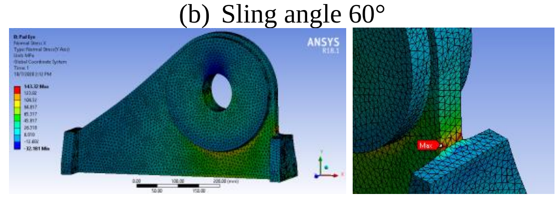
(a) Sling angle 45°



(b) Sling angle 60°



(c) Sling angle 75°



(d) Sling angle 90°

Figure 20. Simulation results of the normal stress on the Y axis.

Table 2. Normal Stress table.

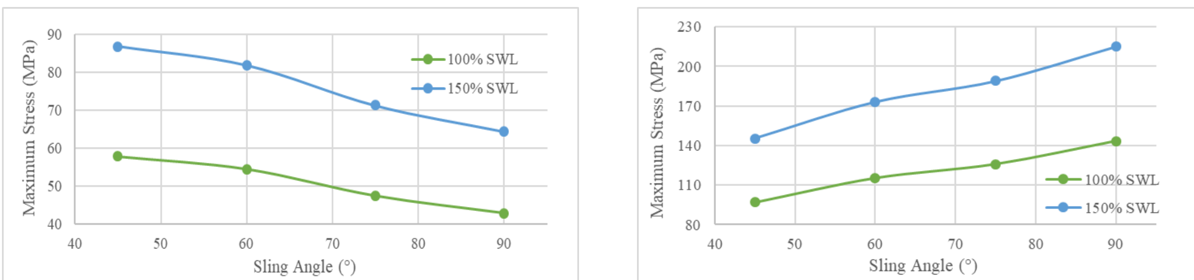
a) Maximum normal stress per angle

No.	Sling Angle	Normal Stress (MPa)			
		100% SWL		150% SWL	
		X-Axis	Y-Axis	X-Axis	Y-Axis
1.	45º	57,848	96,849	86,771	145,27
2.	60º	54,53	115,29	81,795	172,93
3.	75º	47,497	125,87	71,245	188,8
4.	90º	42,935	143,32	64,403	214,97

b) Normal stress change (100% SWL)

No.	Sling Angle	Percentage of Normal Stress Change	
		X-Axis	Y-Axis
1.	45º - 60º	-5,74%	19,04%
2.	60º - 75º	-12,90%	9,18%
3.	75º - 90º	-9,60%	13,86%

Based on Table 2, the largest maximum normal stress for the X axis occurs at the anglesling45º with a normal stress value of 57.848 MPa and the resulting stress from an angle of 45° to 90° decreases linearly, and for the Y axis it occurs at an anglesling90º with a normal stress value of 143.32 MPa and the resulting stress from an angle of 45° to 90° increases linearly. The stress for the X axis tends to decrease due to the angle of the working force, which is 45° to 90°, further away from the X axis, so that the value of the stress that occurs on the axis is getting smaller. On the other hand, for the Y axis, the angle of the acting force is getting closer to the direction of the Y axis, so the stress generated for the Y axis is getting bigger. For more details, it can be seen in Figure 21 which is a graph of the change in stress based on the variation of the angle used.



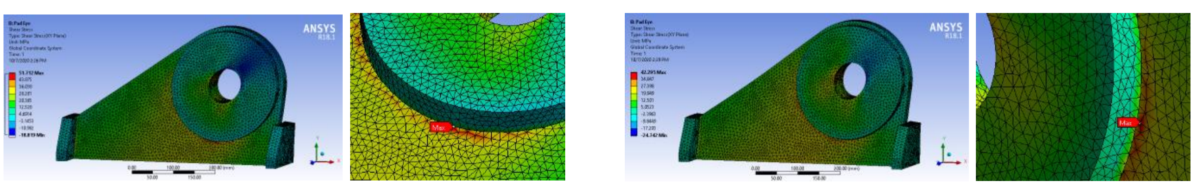
(a) Normal stress on X axis (b (c) Normal stress on Y axis

Figure 21. Graph of maximum normal stress change.

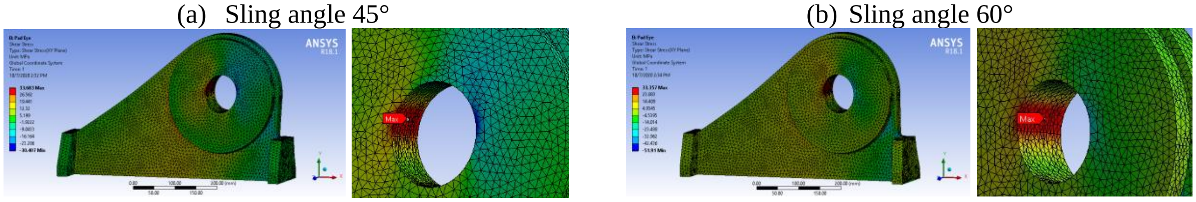
2. Shear Stress

The simulation results of the shear stress on the pad eye can be seen in Figure 22 where the maximum shear stress is marked with a red contour in the geometry.

Based on Table 3, the largest maximum XY shear stress occurs at anglesling45º with an XY shear stress of 51.712 MPa and the resulting stress from an angle of 45° to an angle of 75° decreases linearly, then from an angle of 75° to an angle of 90° tends to be constant. For more details on changes in stress based on angle variations can be seen in Figure 23.



(a) Sling angle 45° (b) Sling angle 60°



(c) Sling angle 75° (d) Sling angle 90°

Figure 22. Simulation results of XY shear stress.

Table 3. Table of shear stress

a) Maximum XY Shear Stress Per Angle

No.	Sling Angle	Shear Stress (MPa)	
		100% SWL	150% SWL
1.	45º	51,712	77,567
2.	60º	42,295	63,443
3.	75º	33,683	50,525
4.	90º	33,357	50,035

b) XY Shear Stress Change (100%)

No.	Sling Angle	Percentage Shear Stress Change
1.	45º - 60º	-18,21%
2.	60º - 75º	-20,36%
3.	75º - 90º	-0,97%

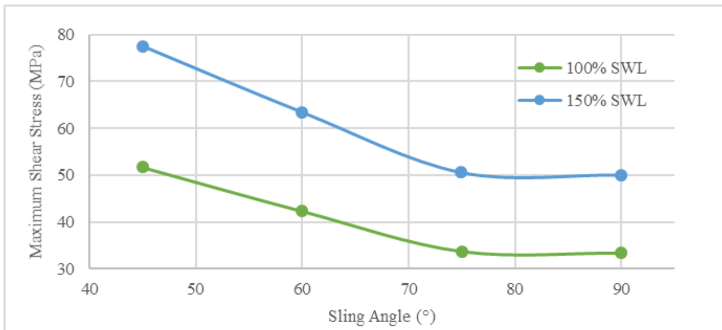
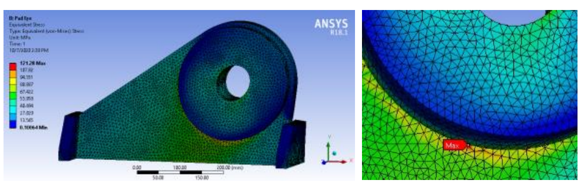


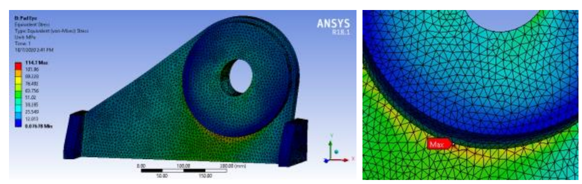
Figure 23. Graph of change in maximum XY shear stress

3. Von-Mises Stress

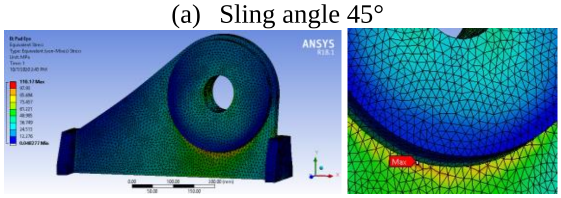
The simulation results of the Von-Mises stress on the pad eye can be seen in Figure 24 where the maximum stress is indicated by a red contour in the geometry.



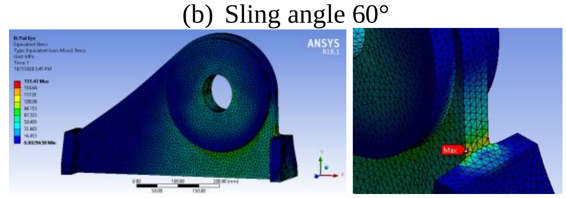
(a) Sling angle 45°



(b) Sling angle 60°



(c) Sling angle 75°



(d) Sling angle 90°

Figure 24. Simulation results of Von-Mises stress.

Table 4. Von-Mises stress

a) Maximum von-Mises stress per angle

No.	Sling Angle	Von Mises Stress (MPa)	
		100% SWL	150% SWL
1.	45º	121,28	181,92
2.	60º	114,7	172,05
3.	75º	110,17	165,25
4.	90º	151,47	227,21

b) Von-Mises stress change (100%)

No.	Sling Angle	Percentage Von Mises Stress Change
1.	45º - 60º	-5,43%
2.	60º - 75º	-3,95%
3.	75º - 90º	37,49%

Based on Table 4, the largest maximum yield stress (von-mises) occurs at angle sling 90º with a yield stress value of 151.47 MPa and the resulting stress from an angle of 45° to an angle of 75° decreased linearly then from an angle of

75° to an angle of 90° experienced a large increase. For more details on the change in stress based on the variation of the angle can be seen in Figure 25.

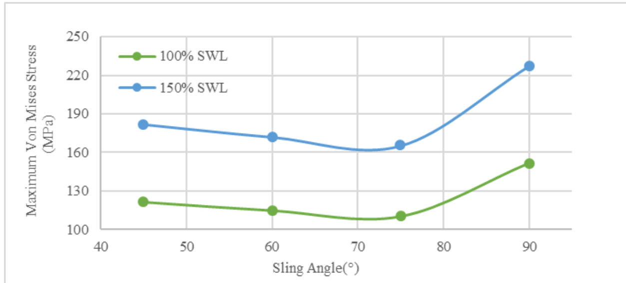
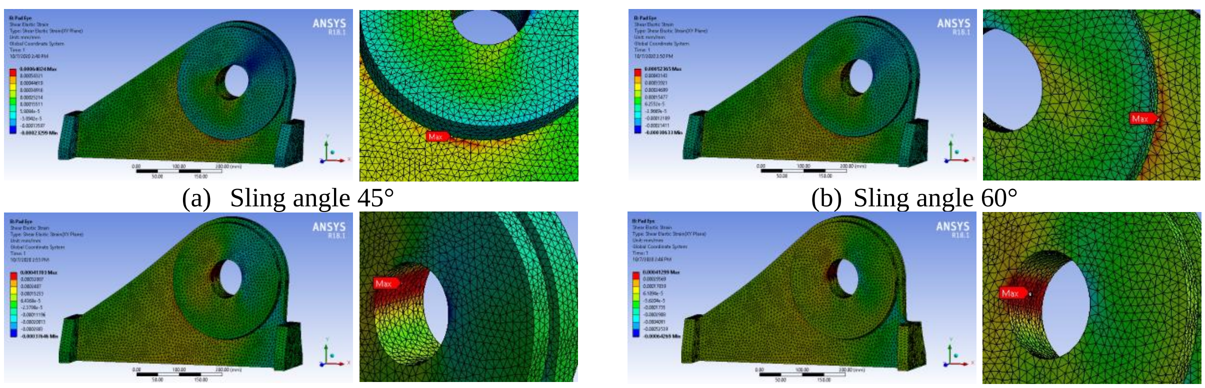


Figure 25. Graph of change in maximum von-mises stress

4. Shear Strain

The simulation results of the shear strain on the pad eye can be seen in Figure 26 where the maximum shear strain is marked with a red contour in the geometry.



(a) Sling angle 45° (b) Sling angle 60°

(c) Sling angle 75° (d) Sling angle 90°

Figure 26. Shear strain simulation results on XY.

Table 5. XY shear strain

a) Maximum XY shear strain per angle

No.	Sling Angle	Shear Strain	
		100% SWL	150% SWL
1.	45º	6,4 x 10^{-4}	9,6 x 10^{-4}
2.	60º	5,2 x 10^{-4}	7,6 x 10^{-4}
3.	75º	4,17 x 10^{-4}	6,3 x 10^{-4}
4.	90º	4,13 x 10^{-4}	6,2 x 10^{-4}

b) XY shear strain change (100%)

No.	Sling Angle	Percentage Shear Strain Change
1.	45º - 60º	-18,75%
2.	60º - 75º	-19,81%
3.	75º - 90º	-0,96%

Based on Table 5, the largest maximum XY shear strain occurs at anglesling45º with an XY shear strain value of 6.4 x $10^{-4}$and the resulting strain from an angle of 45° to an angle of 75° decreases linearly, then from an angle of 75° to an angle of 90° tends to be constant. For more details on changes in strain based on variations in angle can be seen in Figure 27.

5. Von-Mises Strain

The simulation results of the Von-Mises strain on the pad eye can be seen in Figure 28 where the maximum strain is indicated by a red contour in the geometry.

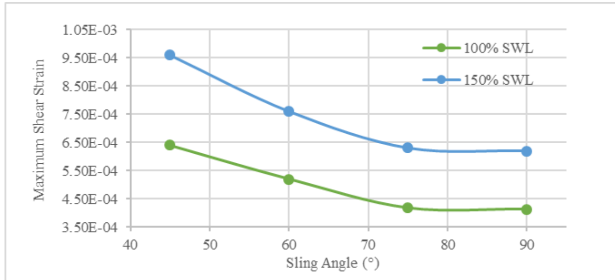
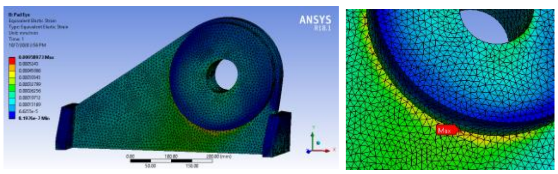
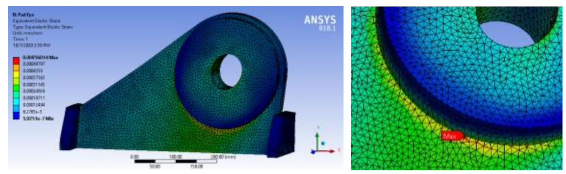


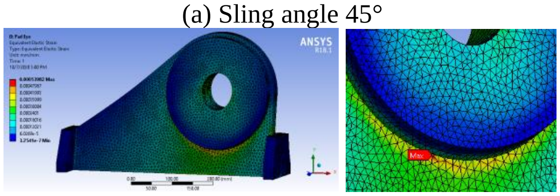
Figure 27. Graph of change in maximum XY shear strain



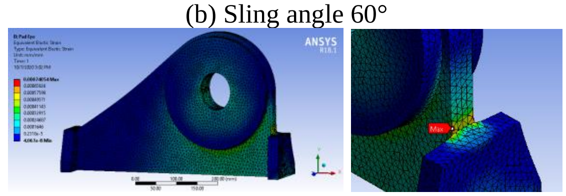
(a) Sling angle 45°



(b) Sling angle 60°



(c) Sling angle 75°



(d) Sling angle 90°

Figure 28. Simulation results of von-mises strain.

Table 6. Von-Mises Strain

a) Maximum Von-Mises Strain Per Angle

No.	Sling Angle	Von Mises Strain	
		100% SWL	150% SWL
1.	45º	5,9 x 10^{-4}	8,8 x 10^{-4}
2.	60º	5,6 x 10^{-4}	8,4 x 10^{-4}
3.	75º	5,4 x 10^{-4}	8,1 x 10^{-4}
4.	90º	7,4 x 10^{-4}	11,1 x 10^{-4}

b) Von-Mises Strain Change (100%)

No.	**Sling Angle**	**Percentage Von Mises Strain Change**
1.	45º - 60º	-5,04%
2.	60º - 75º	-3,57%
3.	75º - 90º	37,04%

Based on Table 6, the largest maximum Von-Mises yield strain occurs at anglesling90º with a von-mises yield strain value of7.4 x$10^{-4}$and the resulting strain from an angle of 45° to an angle of 75° decreases linearly then from an angle of 75° to an angle of 90° has a considerable increase. For more details, see Figure 29.

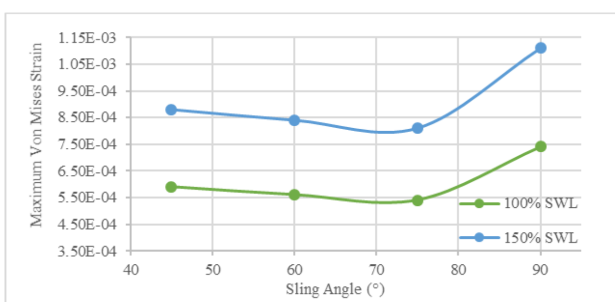
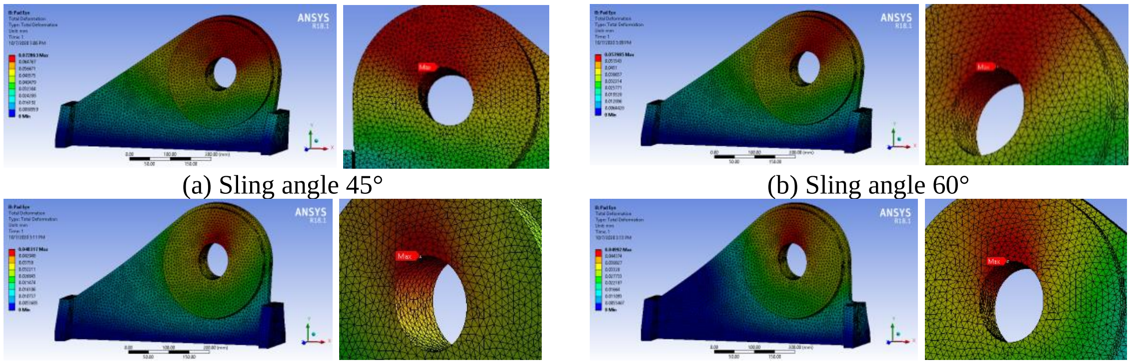


Figure 29. Graph of maximum von-mises strain change.

6. Total Deformation

The simulation results of the total deformation on the pad eye can be seen in Figure 30 where the maximum total deformation is indicated by a red contour in the geometry.



(a) Sling angle 45° (b) Sling angle 60°

(c) Sling angle 75° (d) Sling angle 90°

Figure 30. Total deformation simulation results.

Table 7. Table of Total Deformation

a) Maximum Total Deformation Per Angle

No.	Sling Angle	Deformation (mm)	
		100% SWL	150% SWL
1.	45º	7,286 x 10^{-2}	10,929 x 10^{-2}
2.	60º	5,799 x 10^{-2}	8,698 x 10^{-2}
3.	75º	4,832 x 10^{-2}	7,248 x 10^{-2}
4.	90º	4,992 x 10^{-2}	7,488 x 10^{-2}

b) Total Deformation Change (100%)

No.	Sling Angle	Percentage of Deformation Change
1.	45º - 60º	-20,41%
2.	60º - 75º	-16,71%
3.	75º - 90º	3,35%

Based on Table 7, the largest total deformation occurs at the anglesling45º with a total deformation value of 7,286 x$10^{-2}$and the resulting total deformation from an angle of 45° to an angle of 75° decreases linearly, then from an angle of 75° to an angle of 90° tends to be constant. For more details, changes in total deformation based on angle variations can be seen in Figure 31.

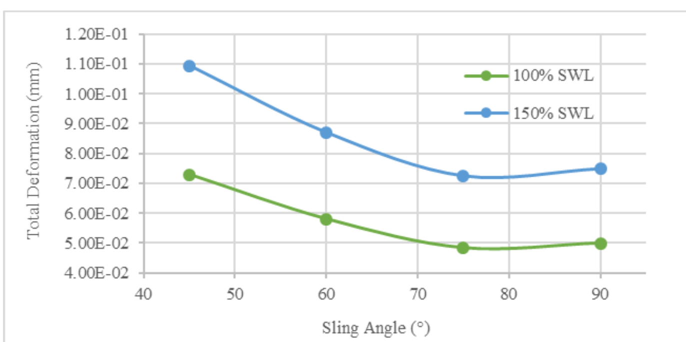


Figure 31. Graph of maximum total deformation change.

4. Conclusion

From the results of the pad eye strength analysis using the finite element method, it can be concluded:

1. Maximum stress and strain values:
   a. The maximum normal stress in the X-axis direction occurs at a sling angle of 45°, which is 57.848 N/mm², while in the Y-axis direction the maximum normal stress occurs at a 90° sling angle, which is 143.32 N/mm². This value is still below the maximum normal stress value required by class BV, which is 170 N/mm². The maximum XY shear stress occurs at a sling angle of 45°, which is 51.712 N/mm². This value is still below the maximum shear stress required by class BV, which is 110 N/mm². And the maximum von-Mises stress occurs at 90° sling angle, which is 151.47 N/mm². This value is still below the maximum stress value required by class BV, which is 235 N/mm².
   b. The maximum shear strain occurs at the sling angle of 45°, which is 6.4 $x10^{-4}$and the maximum von-Mises strain occurs at anglesling90°, which is 7.4 $x10^{-4}$.
2. The maximum total deformation is 7.286 $x10^{-2}$mm that occurs at the angle sling 45° and is located in the Pad eye hole.
3. The magnitude of the change in stress, strain, and deformation at the Pad eye:
   a. The change in normal stress for the X-axis direction from the sling angle of 45° to the sling angle of 90° is -25.78%, meaning that the greater the sling angle, the smaller the normal stress in the X direction, so that the critical point occurs at the sling angle of 45°. While the normal stress in the Y-axis direction increases in stress starting from the sling angle of 45° to the sling angle of 90°, which is 47.98%, so the critical point of normal stress in the Y-axis direction occurs at 90° sling angle. The maximum shear stress change from 45° sling angle to 90° sling angle is -35.49%, so for shear stresses the greater the sling angle, the smaller the shear stress, so that the critical point occurs at 45° sling angle. For the von-Mises stress, the magnitude of the change from 45° sling angle to 75° sling angle decreased by -9.16%,
   b. The change in shear strain from the sling angle of 45° to the sling angle of 90° is -35,47%. And for the von-Mises strain, starting from a sling angle of 45° to a sling angle of 75° it decreased by -8.43%, then from a sling angle of 75° to a sling angle of 90° it increased by 37.04%.
   c. Changes in the total pad eye deformation starting from a sling angle of 45° to a 75° which is -33.7%, then from a sling angle of 75° to 90° an increase of 3.35%.

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