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Structural Strength Analysis and Design Improvement on Excavator Dollies

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Abstract **- Excavator Dollies are tools used in heavy equipment. Excavator dollies help the excavator move from one place to another. The presence of Dollies is very helpful and makes moving the excavator easier, one example of which is in mining. In mining, excavators move several times to dig from one pit to another. This tool is very much needed because the undercarriage section of the excavator, especially the track shoe, is not made to move long distances, but only short or close distances. With the presence of these excavator dollies, maintenance costs for the excavator undercarriage, especially the track shoe, can be saved because using this tool can save up to 50% in undercarriage maintenance. Another advantage of using dollies is saving fuel and time efficiency because they can move faster than without them. With the load lifted by the excavator dollies, it is necessary to know the structural strength and safety factor of the excavator dollies. By using the finite element method (FEM), several parameters, such as deformation, stress, and force that occur on the excavator Dollies can be determined.**

Keywords: Finite Element Method; displacement; Von Misses stress.

I. INTRODUCTION

An excavator is heavy equipment that is the main construction machine, widely used in construction, mining, agriculture, and transportation for digging and loading materials [1]. Excavators face special challenges in every job and have a dangerous working environment [2]. This tool has a strong structure and is equipped with an arm, boom, and bucket system that can be used for excavation work, loading materials, or also pruning [3]. Excavators have wheels that can wear out under high pressure on the rolls and pins [4]. Excavators used in mining are usually used for digging and loading in mining [5]. Excavators in mining are very much needed for the excavation process because excavation of the ground is required to reach the coal layer. During mining, excavators often move. However, if it moves a long distance, it is not recommended because it can damage the track shoe and is less efficient. The appearance of the excavator can be seen in Figure 1.

Figure 1: Excavator (KOMATSU & PT. HPU)

Excavator dollies are tools designed to move an excavator more easily and efficiently from one place to another. In mining, they are used to move excavation sites from one pit to another. Dollies are used with the help of dump trucks to place the excavator bucket. The excavator bucket/boom will be lifted by placing the excavator bucket/boom on the dump truck [6]. This excavator dollies is an improvement of the lowboy, which has the same function, namely to move excavators or heavy equipment, but this excavator dollies has a more compact size and is more efficient in its use than the lowboy. This is similar to semi-trailers, dump trucks, or dumpers. Dollies are used with the help of dump trucks to place the excavator's bucket. Track shoes on excavators are not designed for long journeys but only for moving short distances. The appearance of the Excavator Dollies can be seen in Figure 2.

Figure 2: Dollies Excavator (PT. HPU)

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Using excavator dollies can add time efficiency. Using these excavator dollies in transport operations, they can travel up to 15 km/h. In addition, because the time used is faster, productivity increases compared to not using excavator dollies. Fuel consumption is also more efficient because the transfer is carried out with the help of excavator dollies and dump trucks. Suppose we always move the location of the excavator. In that case, it can damage or shorten the life of the undercarriage or track shoe on the excavator, which will be damaged or worn out faster than the time or number of working hours of the excavator [7]. By using excavator dollies, service or maintenance on the undercarriage and track shoes on the excavator will last 1.5 times longer, from 3000 to 4500 hours, because using excavator dollies reduces wear time [8].

Hardox steel is a product with extraordinary wear resistance. It also has the advantage of high durability and productivity even when used in quite harsh environments [9]. Hardox steel is widely used in heavy machinery, trucks, and containers. Several factors influence the strength of the steel, such as composition, microstructure, and material properties [10]. Hardox 400 is widely used in harsh areas such as roads, construction, agriculture, excavation, mining, recycling, cement, and concrete production. Hardox steel is also known as wear plate. Hardox is also produced through bars, pipes, and tubes [11]. Hardox 400 is often used by well-known manufacturers such as Hitachi, Komatsu, and Caterpillar to make truck bodies [12].

In finite element analysis (FEA) complex substances are divided into several finite units which are then connected by nodes. These elements are processed computationally to study their characteristics. FEA adapts the model to each geometry, material properties, and loading conditions [13]. Finite elements are one of the good methods to solve numerical problems of crack and fracture strength [14]. This study aims to find answers to a problem regarding the structural analysis process using the Solidworks application to obtain the displacement, stress, and safety factor strength indices and improve the Dollies excavator.

II. ANALYSIS METHOD

The methods used in data collection to determine the strength of excavator dollies are:

1. Data and design observation
   In this data observation stage, we work directly with the excavator manual and review the excavator's heavy equipment. Design observation is the stage of creating dollies' shapes according to their needs.
2. Excavator dollies design using Solidworks 2023
   This stage is the stage for creating the design of the excavator dollies.
3. Performing a simulation using Solidworks 2023
   Performing this simulation helps determine the structural strength of the designed excavator dollies.

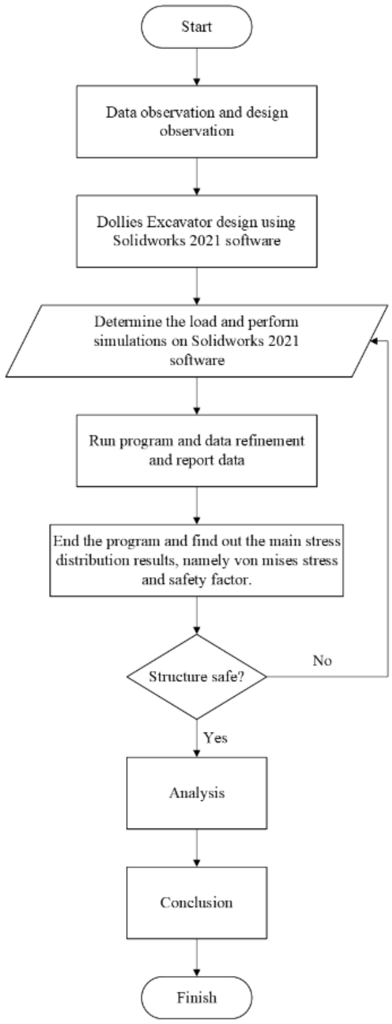

Figure 3: Flow Chart of Study

This study uses an FEA simulation approach by utilizing the Solidworks 2023 software. SolidWorks is an advanced computer-aided design (CAD) software that facilitates the creation, simulation, and analysis of 3D models across various engineering and design disciplines. The combination of a user-friendly interface and powerful functionality makes it recommended for both educational and professional environments. SolidWorks supports parametric modeling, allowing designers to easily change dimensions and features and update the entire design automatically. This feature will enable us to visualize and analyze changes before physical production, significantly improving the efficiency and accuracy of the design process, ultimately saving time and reducing costs. The analysis process is carried out with the help of the Solidworks 2023 application and can display

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output according to the analysis carried out [15]. After that, it can be known how much displacement, safety factors, and stress occur in the frame.

2.1 Troubleshooting Procedure

This solving procedure was performed to analyze the strength value or know the factor of safety (FOS) and displacement of the specified structure, the process in the analysis, and CAD using software. Several variations of excavator loads were given at the simulation stage.

2.2 Validation of Simulation Results

From the simulation results with an improved design at a load of 104,917.95 N, a von Mises stress of 41.68 MPa was obtained. Meanwhile, using the von Mises calculation according to Hibbeler, it is known that the von Mises stress that can be accepted by the Dollies Excavator is 39.89 MPa. If the von Misses results in the simulation and these calculations are compared, an error of 4% is found. Figures 4 to 6 compare the von Mises results from the simulation and the results from theoretical calculations.

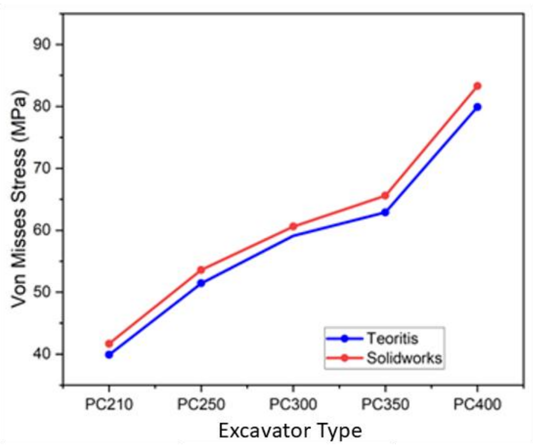


Figure 4: The Burden on Von Mises

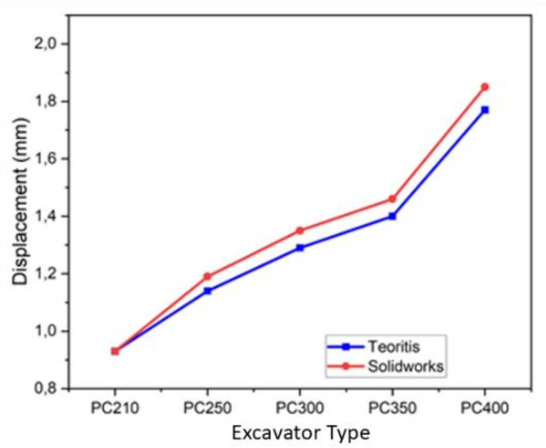


Figure 5: Effect of Loading on Displacement

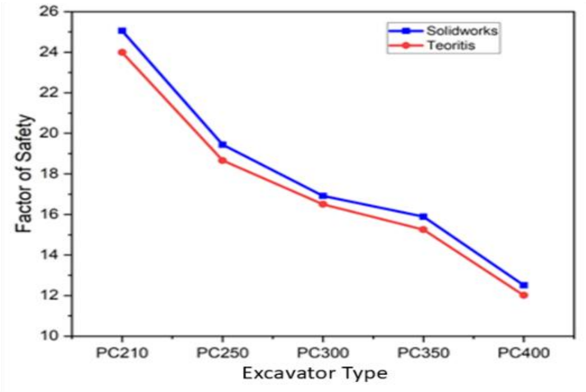
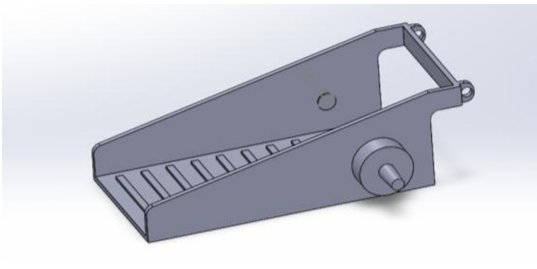


Figure 6: Effect of Loading on Safety Factor

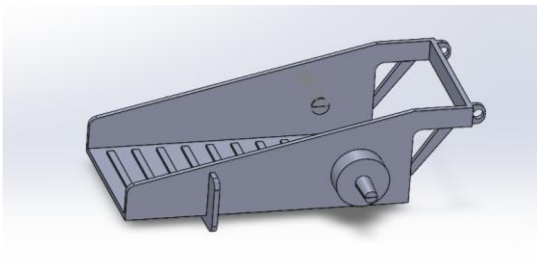
III. RESULTS AND DISCUSSION

3.1 Data

The research data used to conduct the analysis is the design of the Dollies Excavator. The design of the Dollies Excavator uses the characteristics of the Hardox 400 material and several excavators from Komatsu PC210, PC250, PC300, PC350, PC400. Several variations of Dollies excavator with their structural strengths were obtained by performing several load variations in the simulation. Several functions were found by making improvements to the Dollies excavator. The addition of iron to the bottom of the frame prevents the tool from moving forward when the excavator rides the Dollies. And the addition of iron on the back of the Dollies serves to avoid collision with the frame of the excavator Dollies when the excavator bucket lifts the tool. Figure 7 describes the design of the Dollies excavator before and after the improvement.



(a)



(b)

Figure 7: (a) Design before Improvement, and (b) Design after Improvement

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The characteristics or properties of Hardox 400 material shown in Figure 8 were used for simulation.

Property	Value	Units
Elastic Modulus	1.9e+11	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	7.5e+10	N/m^2
Mass Density	8000	kg/m^3
Tensile Strength	1250000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	1000000000	N/m^2
Thermal Expansion Coefficient	1.8e-05	/K
Thermal Conductivity	16	W/(m·K)
Specific Heat	500	J/(kg·K)

Figure 8: Characteristics of Hardox 400 Material

A Dollies excavator is used to move excavators from one place to another. In this analysis, several variations of excavator loads were applied. The modeling simulation using the finite element method (FEM) was based on the actual condition approach of the Dollies excavator to calculate the loading value at each condition, so that the stress analysis that occurs in the structure was obtained to determine the stress value, displacement, and safety factor. The load variations are shown in Table 1.[16, 17, 18, 19]

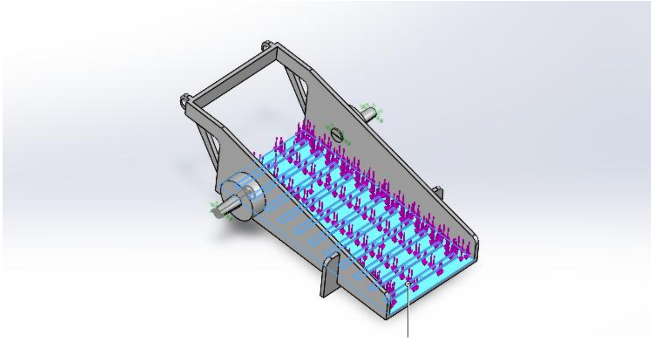
Table 1: Types and Loads of Excavators

Excavator type	Force (N)
PC210	104.917,95
PC250	134.887,5
PC300	152.545,5
PC350	165.102,3
PC400	209.639,7

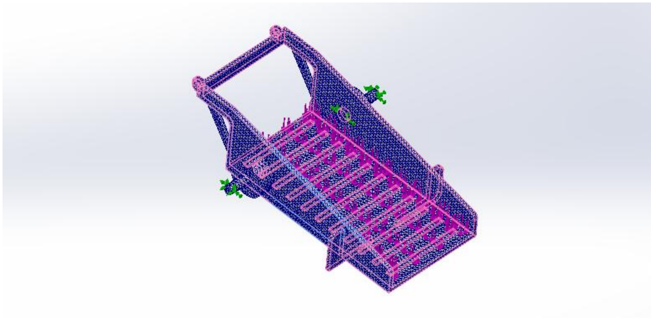
3.2 Excavator Dollies Analysis and Discussion

The results of the analysis of both designs with static simulation of the Chassis frame using Solidworks 2023 software produced values of stress, displacement, and safety factors for the Hardox 400 material used in both designs.

The stages carried out to find stress, displacement, and safety factors through FEM analysis from Solidworks 2023 are divided into three parts, namely pre-processing, analysis preprocessing, and post-processing. Pre-processing is the initial stage, which includes drawing and modeling the geometry to be analyzed. This stage was carried out to ensure the geometry's accuracy and conformity to actual conditions. The next stage was analysis preprocessing. In this stage, numerical analysis of the structural model was performed. This analysis was used to predict and calculate loads, stress, and displacement on structures. The post-processing stage was carried out after the analysis was complete. In this stage, the results of the analysis of stress, displacement, and safety factors were displayed [20]. Figure 9 is a view of the applied loads and a view of the geometry meshing.



(a)

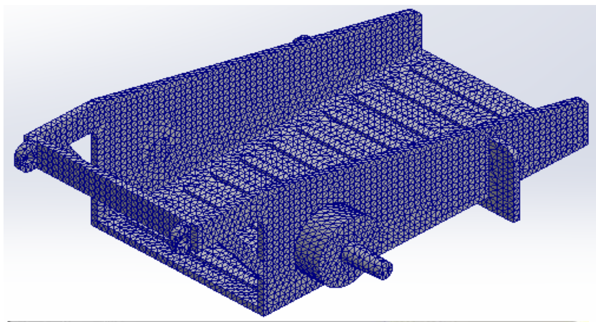


(b)

Figure 9: (a) Display of Applied Load, and (b) View of the Geometry Meshing

3.3 Meshing

The meshing step of the analysis is crucial. Meshing is a process that is done by dividing complex geometry into small elements called meshes for numerical analysis. Meshing in SolidWorks automatically determines the perfect mesh shape for analysis of a given model. Smart meshing has no restrictions in choosing the mesh shape [21]. In this simulation, the meshing used has an element length of 26.78 mm and a number of elements of 46389.



Total nodes	82947
Total elements	46389
Maximum Aspect Ratio	7,2177

Figure 10: Meshing

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Based on Figure 10, the maximum aspect ratio value is 7.2177. In SolidWorks, a good Jacobian ratio aspect ratio is between 1 and 10, and if the value is more than 10, then the mesh cannot be used, as shown in Figure 11.

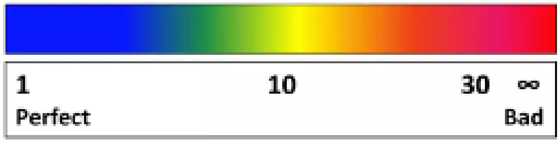

Figure 11: Jacobian Ratio

Figures 12 to 26 describe the simulation results for stress, displacement, and safety factor values in actual designs with several loads from the excavator.

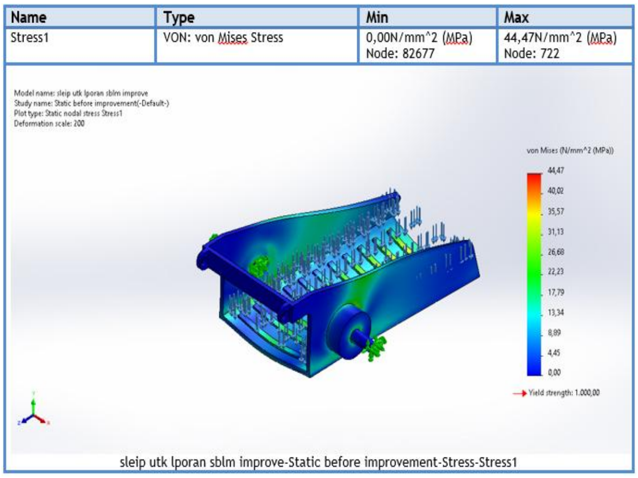

Figure 12: Stress on the actual design of the PC210 excavator

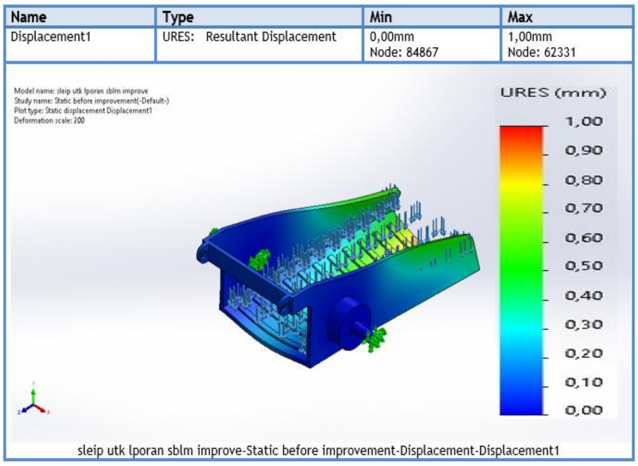

Figure 13: Displacement of the actual design of the PC210 excavator

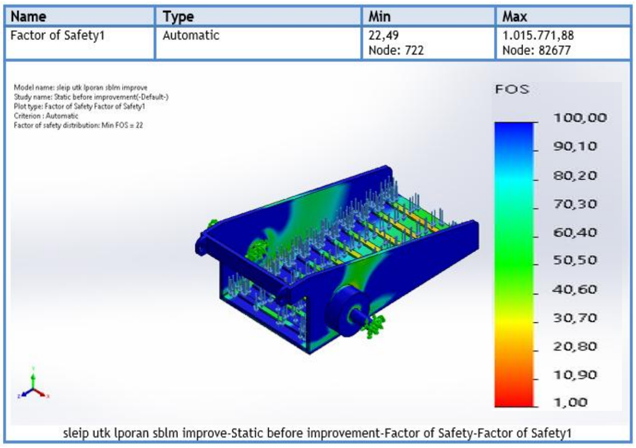

Figure 14 : Safety factor of the actual design of the PC210 excavator

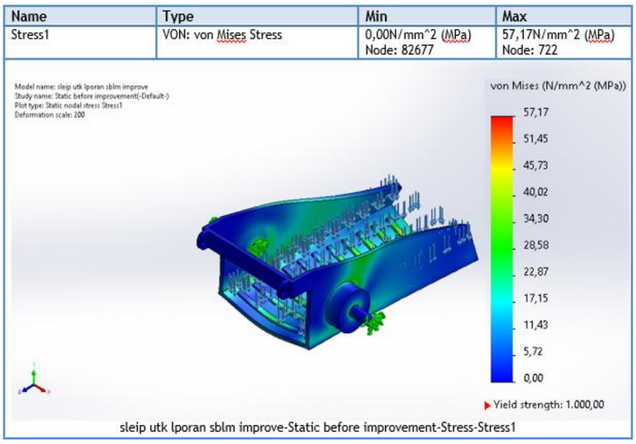

Figure 15: Stress on the actual design of the PC250 excavator

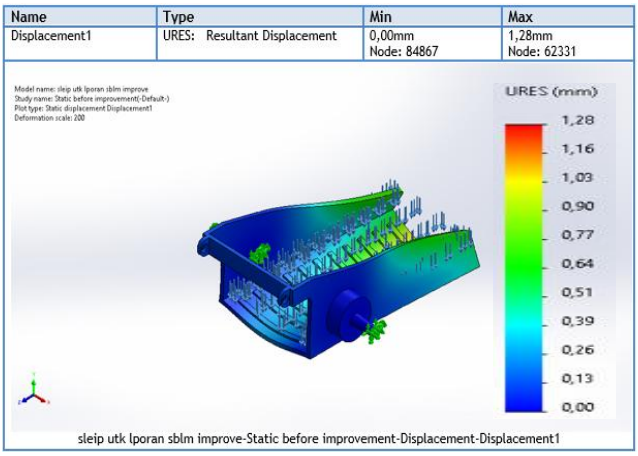

Figure 16: Displacement of the actual design of the PC250 excavator

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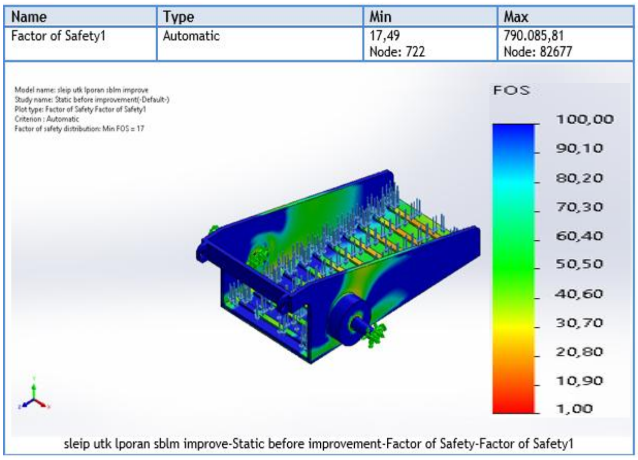

Figure 17: Safety factor of the actual design of the PC250 excavator

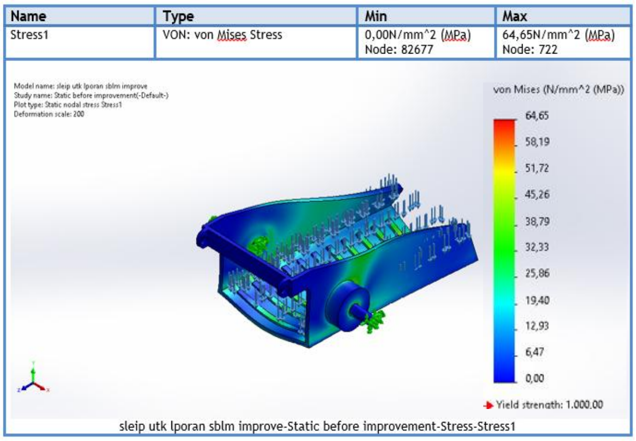

Figure 18: Stress on the actual design of the PC300 excavator

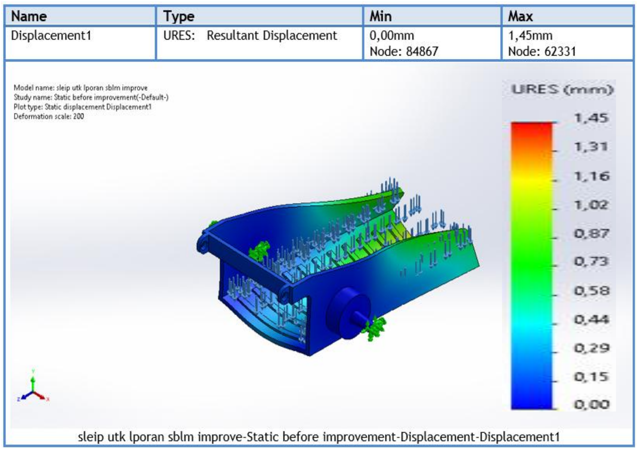

Figure 19: Displacement of the actual design of the PC300 excavator

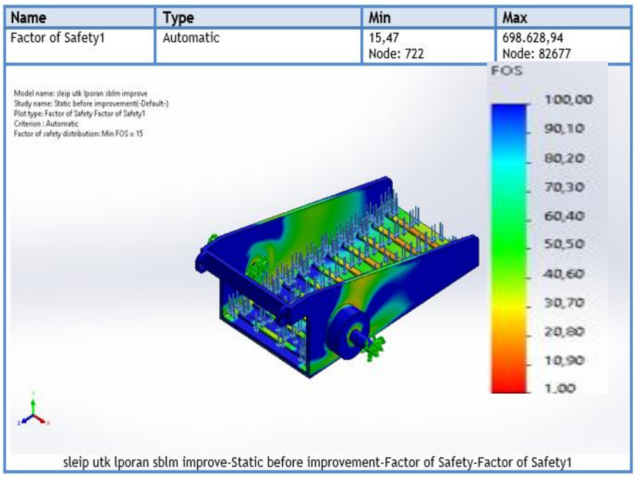

Figure 20: Safety factor of the actual design of the PC300 excavator

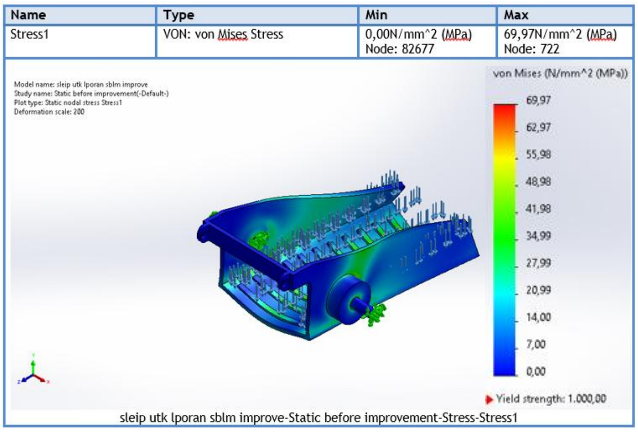

Figure 21: Stress on the actual design of the PC350 excavator

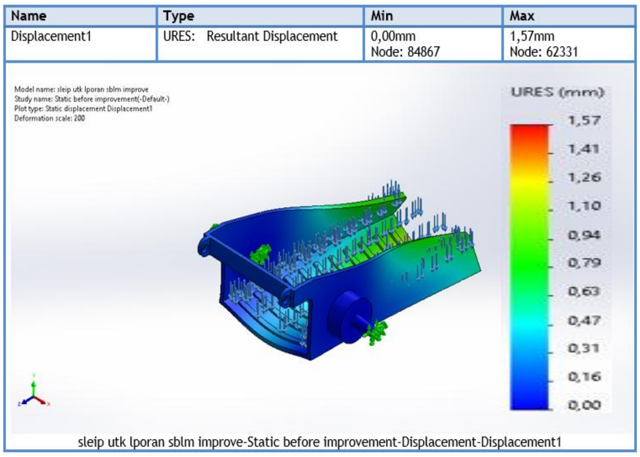

Figure 22: Displacement of the actual design of the PC350 excavator

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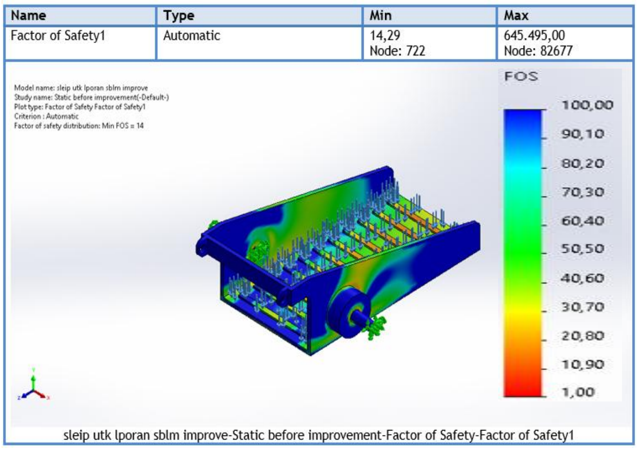

Figure 23: Safety factor of the actual design of the PC350 excavator

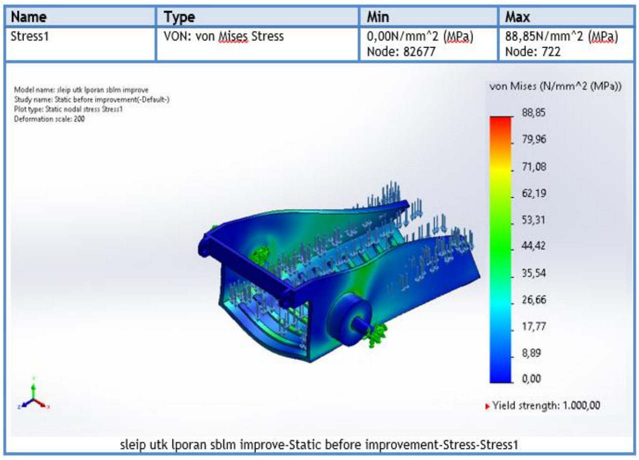

Figure 24: Stress on the actual design of the PC400 excavator

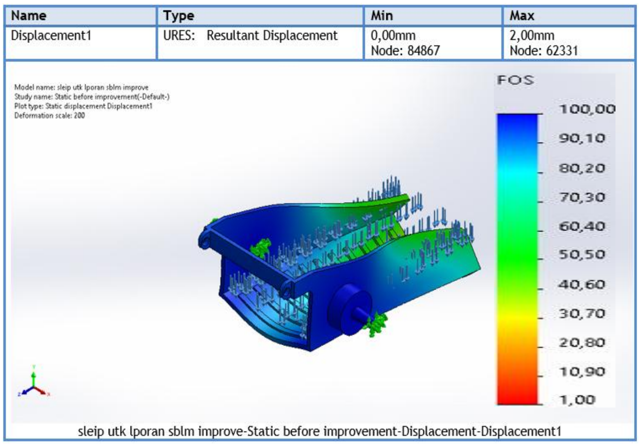

Figure 25: Displacement of the actual design of the PC400 excavator

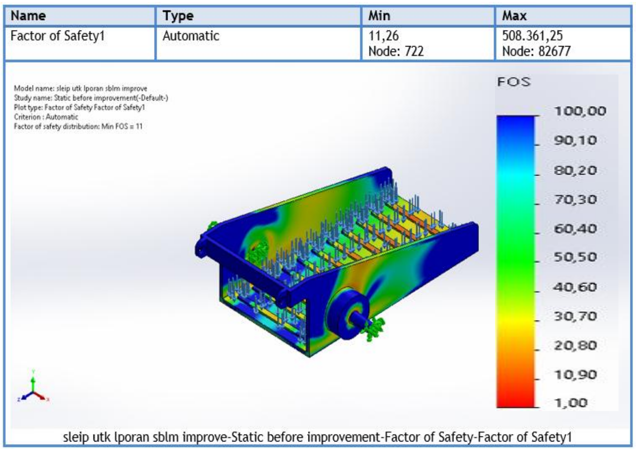

Figure 26: Safety factor of the actual design of the PC400 excavator

Figures 27 to 41 show the stress, displacement, and safety factor analysis for design improvement.

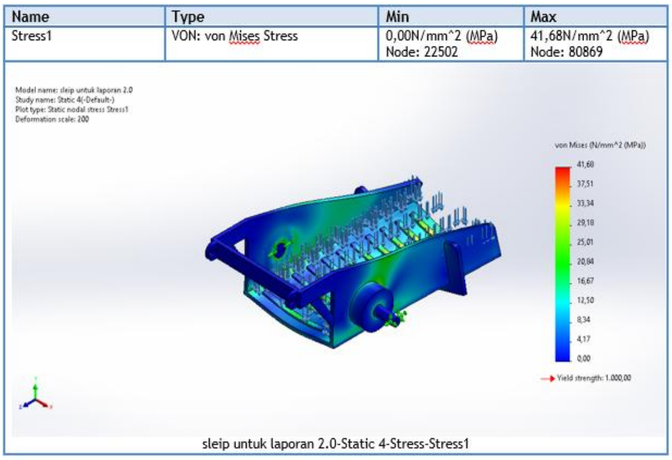

Figure 27: Stress on the actual design of the PC210 excavator

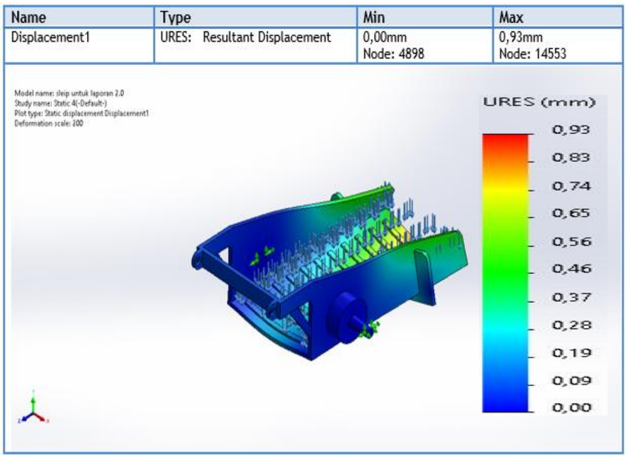

Figure 28: Displacement of the actual design of the PC210 excavator

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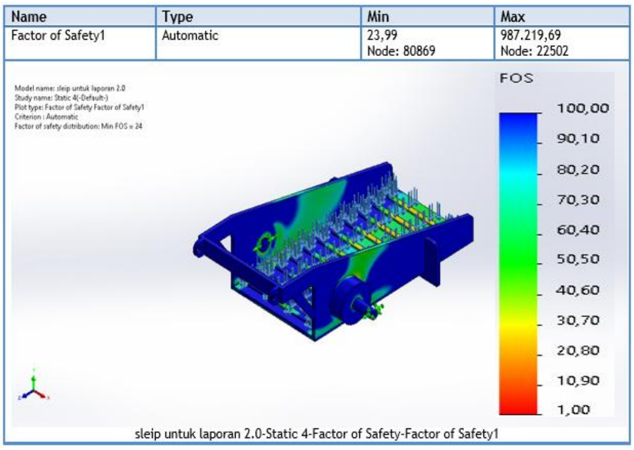

Figure 29: Safety factor of the actual design of the PC210 excavator

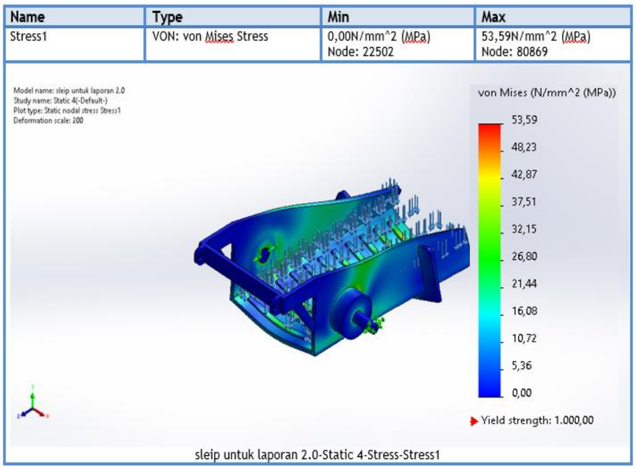

Figure 30: Stress on the actual design of the PC250 excavator

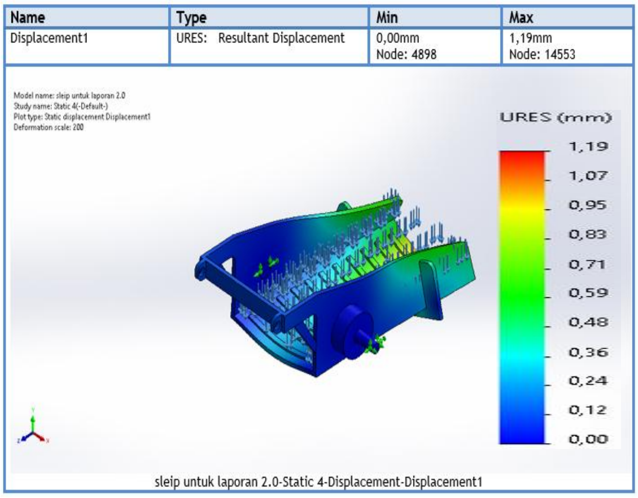

Figure 31: Displacement of the actual design of the PC250 excavator

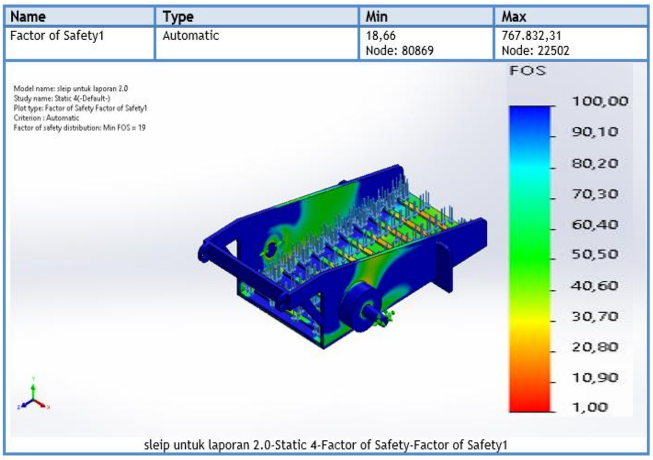

Figure 32: Safety factor of the actual design of the PC250 excavator

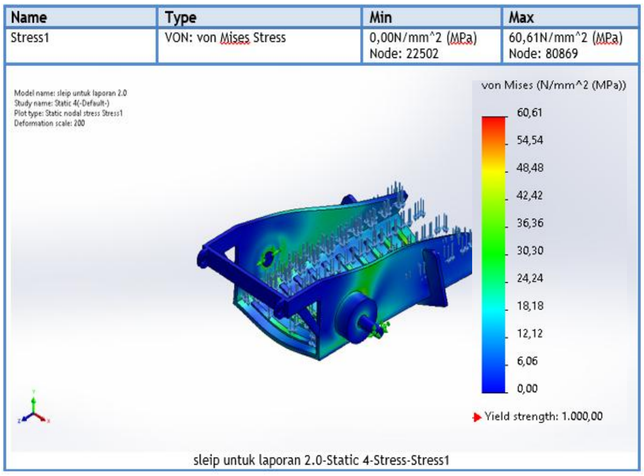

Figure 33: Stress on the actual design of the PC300 excavator

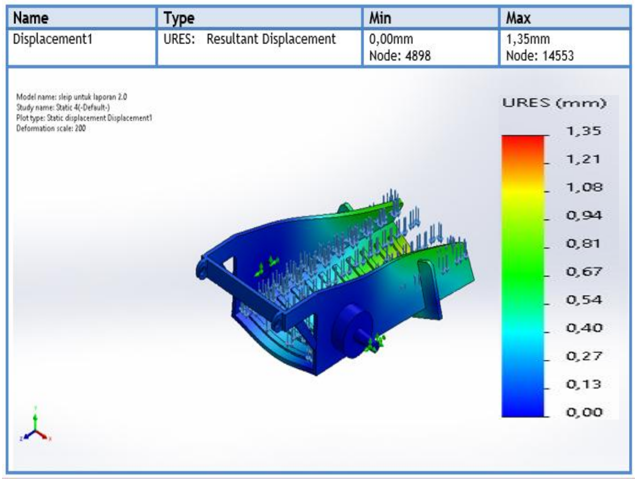

Figure 34: Displacement of the actual design of the PC300 excavator

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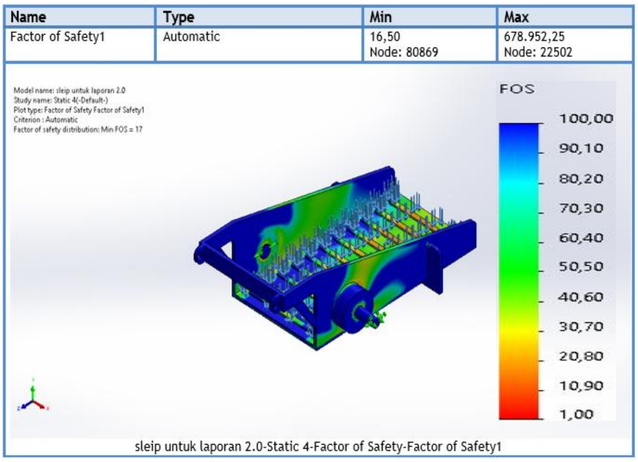

Figure 35: Safety factor of the actual design of the PC300 excavator

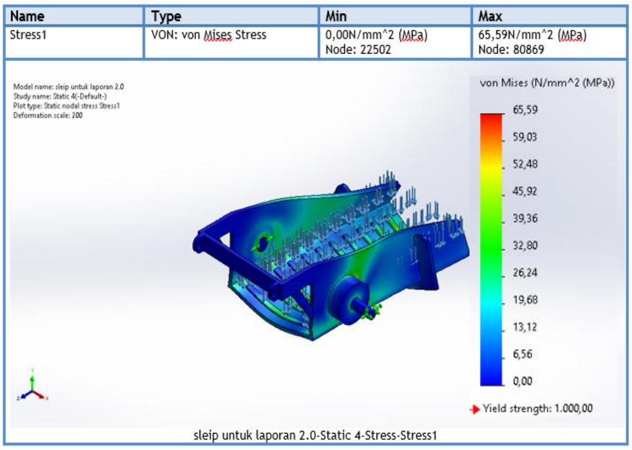

Figure 36: Stress on the actual design of the PC350 excavator

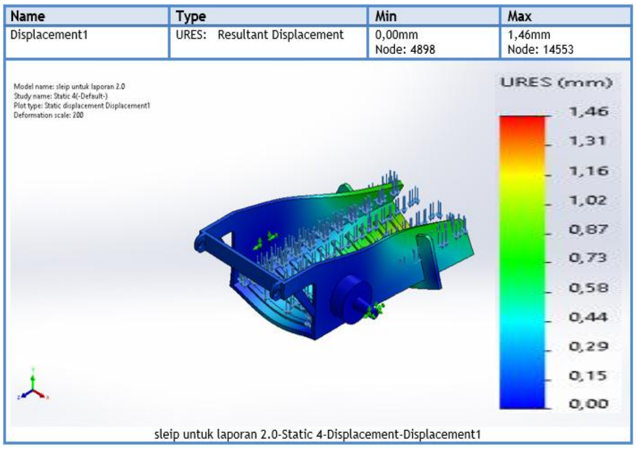

Figure 37: Displacement of the actual design of the PC350 excavator

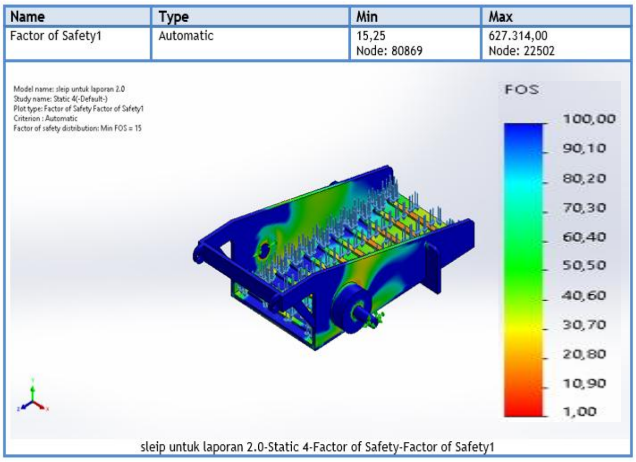

Figure 38: Safety factor of the actual design of the PC350 excavator

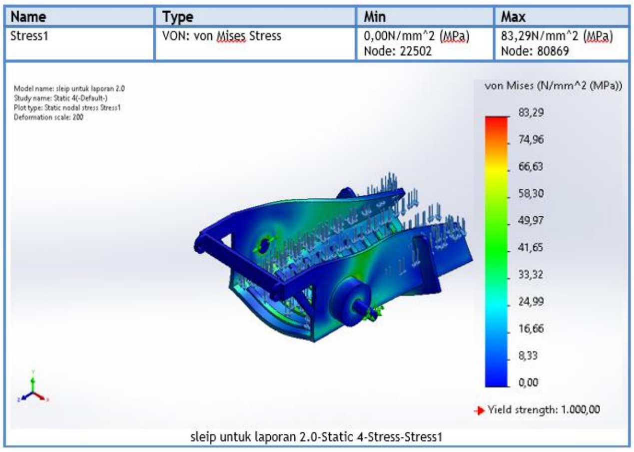

Figure 39: Stress on the actual design of the PC400 excavator

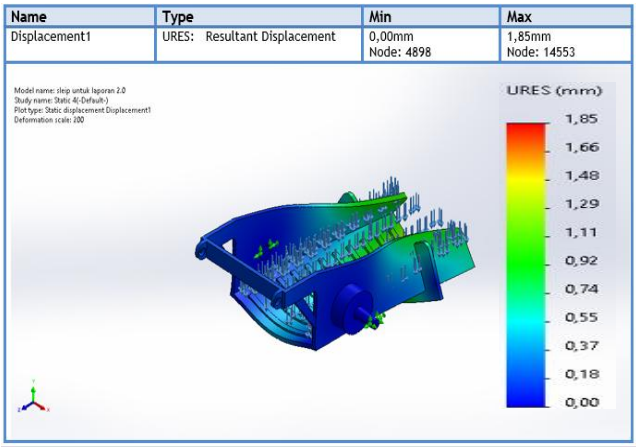

Figure 40: Displacement of the actual design of the PC400 excavator

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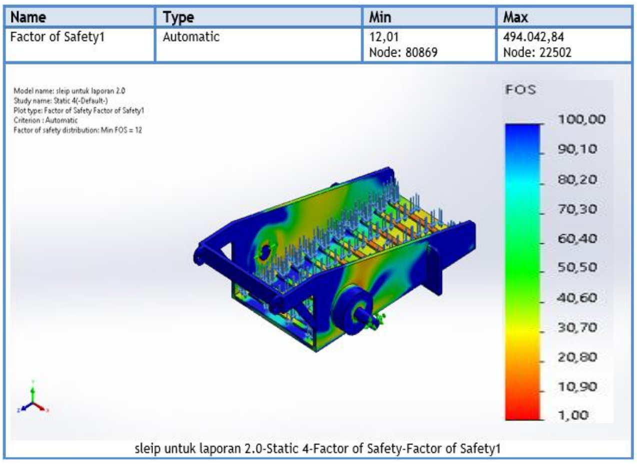

Figure 41: Safety factor of the actual design of the PC400 excavator

Based on the stress analysis results on the frame, the stress value, displacement, and safety factor were found to have different values for each variation of loading obtained, and the results between the actual design and the improved design had different values. The stress analysis results for the Dollies Excavator on the actual design found higher stress than that from the improved design. This shows that the actual design is more likely to fail than the improved design. The improved design is more recommended for its use. In this stress analysis, it was found that if the size of the excavator load given is heavier, the results of the stress analysis are higher. The results of the stress analysis can be seen in Figure 42.

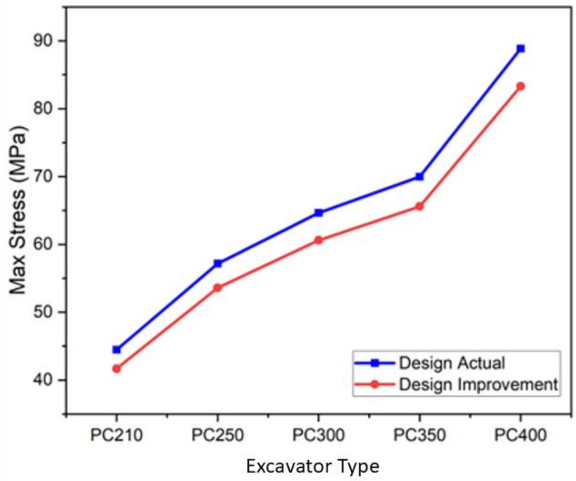

Figure 42: Maximum Stress for Various Excavators

The results of the displacement analysis for Dollies Excavator found that actual design has a higher value than design improvement, which means that actual design is easier to deform when given weight than design improvement. The displacement results in the design improvement were lower, which showed that the design had stronger resistance. The results of the analysis graph can be seen in Figure 43.

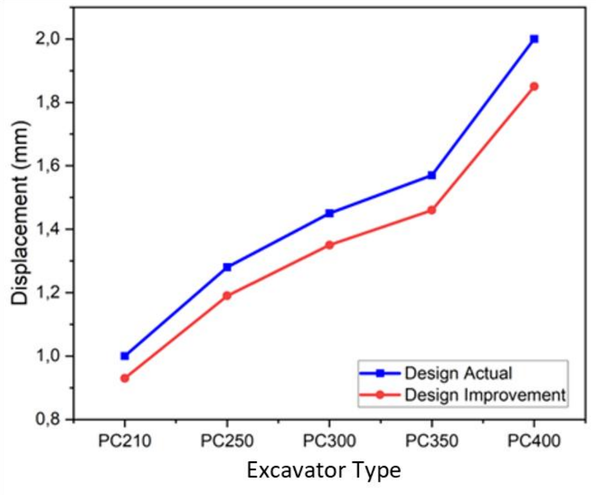

Figure 43: Displacement for Several Excavators

The safety factor for the actual design is lower than that of the design improvement. This shows that the actual design has a smaller safety margin and is more at risk of failure. The high safety factor of design improvement indicates a stronger ability to withstand greater loads without failure, as shown in Figure 44.

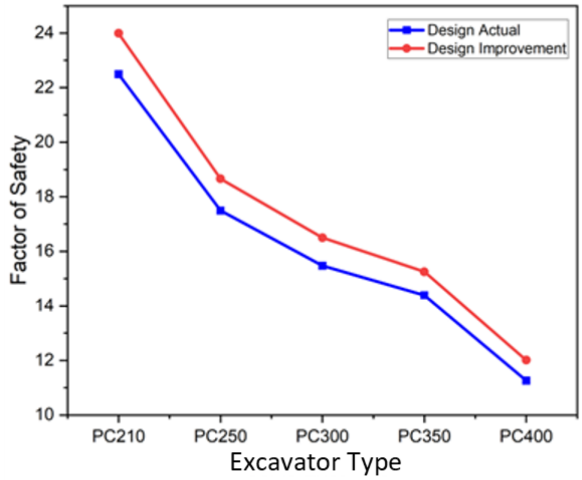

Figure 44: Safety Factor for Different Excavators

IV. CONCLUSION

From the analysis of stress data, displacement, and safety factors, the following conclusions can be drawn:

1. The analysis is carried out sequentially so that all the requirements can be met by considering the problem limitations, and no errors occur in the simulation run process.
2. The structural analysis concludes that the design improvement is superior to the actual design.

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3. The structural strength simulation obtained several results of stress analysis, displacement, and safety factors for several excavator variations.
4. From the simulation, a safety factor of 23.99 was obtained.
5. This simulation concludes that the Dollies Excavator can support PC210, PC250, PC300, PC350, and PC400 loads.

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