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Conference Article

Strength Comparison of Swing Tower Designs with Finite Element Method in Backhoe Loaders

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Abstract

Backhoe-Loader construction machines are exposed to several different loads within the scope of their usage areas. The degree of freedom of the attachment is one of the elements that ensures the functionality of the excavating zone. The movement of the attachment on the horizontal plane is provided with hydraulic cylinders. The forces and moments that comes from the attachment area are transferred directly to the upper chassis. It is critical that the swing tower located between the upper chassis and the attachment, can withstand these transferred loads. In this study, static structural analysis of different designs of the swing tower in the attachment area for HİDROMEK backhoe-loader machines was carried out with the finite element package program MSC Marc. The forces and moments that the HİDROMEK construction machine is exposed to due to working conditions were evaluated and applied as input in the analysis. The accuracy of the analysis method was verified by the strain gauge test performed on a model selected from the designs examined. As a result of the study; the models were compared in terms of strength, and the effects of the changes made on the designs on the strength were interpreted.

Keywords: Backhoe-Loader; Strain Gauge; Structural Analysis; Swing Tower

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1. Introduction

The effectiveness and efficiency of earth moving machines used in construction and mining sectors are directly related to the quality and performance of the equipment used in the machine. While backhoe loader construction machines serve as the backbone of these sectors, critical components such as the swing tower play a decisive role in the durability, carrying capacity and operational efficiency of the machine.

Figure 1: Backhoe Loader

The effects of the swing tower on earth moving machines should be examined in depth with structural analysis methods and tests. The swing tower is located between the upper chassis and the attachment in backhoe loader construction machines. The forces and moments coming from the attachment are directly transferred to the upper chassis through the swing tower. It is appropriate to use structural analysis package programs to understand the behavior of the swing table against the loads imposed on it. It is important to apply a strain gauge on the structure to ensure the accuracy of the applied finite element method.
In this study, structural analysis of different swing tower designs was carried out with MSC Marc, a finite element package program, and a strain gauge was applied on a model selected among the designs and the accuracy of the method applied for analysis was determined.

2. Materials and Methods

In this section, the methods used to compare the alternative designs of the HİDROMEK brand backhoe loader construction machine in terms of strength will be shared in detail. Finite element analysis was carried out for existing alternative designs, the stress values on the structure were compared, the strain gauge application was completed on a model selected among the designs, the accuracy of the analysis method was tested and the results were evaluated (Figure 2).

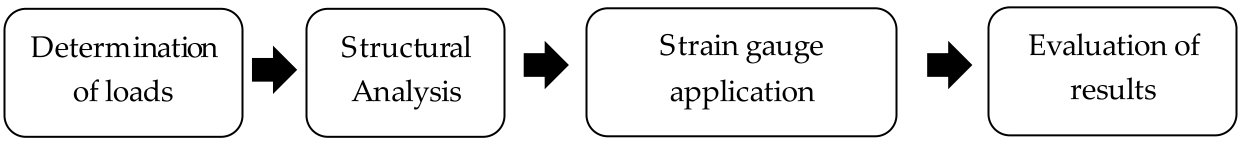

Figure 2: Strength comparison stages of swing tower

Mechanical properties of the material used for the swing tower are shared in Table 1.

Table 1: Material Properties

Elasticity Modulus (GPa)	169
Poisson Ratio	0.28
Yield Strength (MPa)	320
Elongation (%)	7

The material used has a 7% elongation rate. In the literature, materials that behave above 5% elongation rate are defined as ductile materials [1]. Examining the Von Mises equivalent stress criterion for ductile materials is an accurate method for examining the behavior of the material against applied loads. The Von Mises equivalent stress criterion is also known as the maximum strain energy criterion. In this criterion, the strain energy created on the unit volume by the multiaxial stress components existing on the structure is compared with the strain energies created on the unit volume by the stress value that causes the yield strength of the structure in the simple tensile test [2]. In order to prevent plastic deformation, the equivalent Von Mises stress value obtained through intermediate formulas is expected to be lower than the yield strength of the material. The operations embedded in the finite element package programs have the capacity to make the necessary calculations and output the stresses on the structure as equivalent Von Mises stress values.

2.1. Determination of Loads

While determining the forces to be assigned as boundary conditions to the finite element package program MSC Marc for the static strength analysis of the swing tower, the hydraulic cylinder capacity connected to the swing tower of the HİDROMEK backhoe loader construction machine and the forces transferred from the attachment.

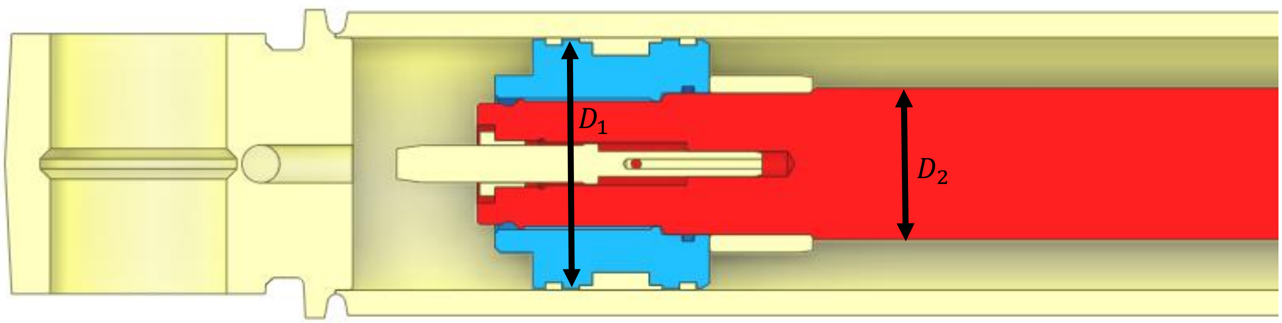

Figure 3: Hydraulic cylinder section view

$$F_i = P\frac{{D_1}^2}{4} \quad (1)$$

$$F_c = P\frac{(D_1 - D_2)^2}{4} \quad (2)$$

Here, $\boldsymbol{F_i}$ represents the pushing force, $\boldsymbol{F_c}$ represents the pulling force, $\boldsymbol{P}$ represents the cylinder pressure, $\boldsymbol{D_1}$ represents the inner cylinder diameter and $\boldsymbol{D_2}$ represents the rod. After the pressure value created by the force acting on the hydraulic cylinder exceeds a certain level, pressure leakage occurs in the region. For this reason, to ensure that the static balance condition is met, it should be checked whether the pressure created by the forces transferred from the attachment area on the hydraulic cylinder exceeds the leakage pressure.

For the position where the attachment weighs at the maximum reach, the load that the machine can carry until the moment of tipping over is compared with the cylinder capacity. While the transferred forces were calculated, the force and moment values occurring in each connection region on the attachment were calculated to keep the system in static balance. Starting from the bucket region, operations are carried out so that the sum of the horizontal and vertical forces and moments at each point is zero [3].

The pressure in the hydraulic cylinder was calculated by taking into account the magnitude and direction of the forces occurring on the hydraulic cylinder. The resulting pressure value was found to be lower than the leakage pressure of the hydraulic cylinder. Since there will be no leakage in the hydraulic cylinders, the forces created on the swing tower by the heaviest load that can be carried until the machine topples over were determined as input for the analysis. The calculated forces were applied separately for

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the position where the attachment was parallel to the wheels and for the position where the attachment was perpendicular to the wheels. Thus, it was aimed to examine the stress values on the swing tower in more detail.

2.2. Structural Analysis

Since irregularities in the cross-sectional area of the structure prevented the hexahedron mesh elements, the finite element model was created using tetrahedron elements. Fixations were made from the areas where the connection with the upper chassis is provided. Since the attachment can rotate 180° around the swing tower in backhoe loader construction machines, the analysis was carried out for two different positions of the attachment. The visual regarding the attachment locations is shared in Figure 4.

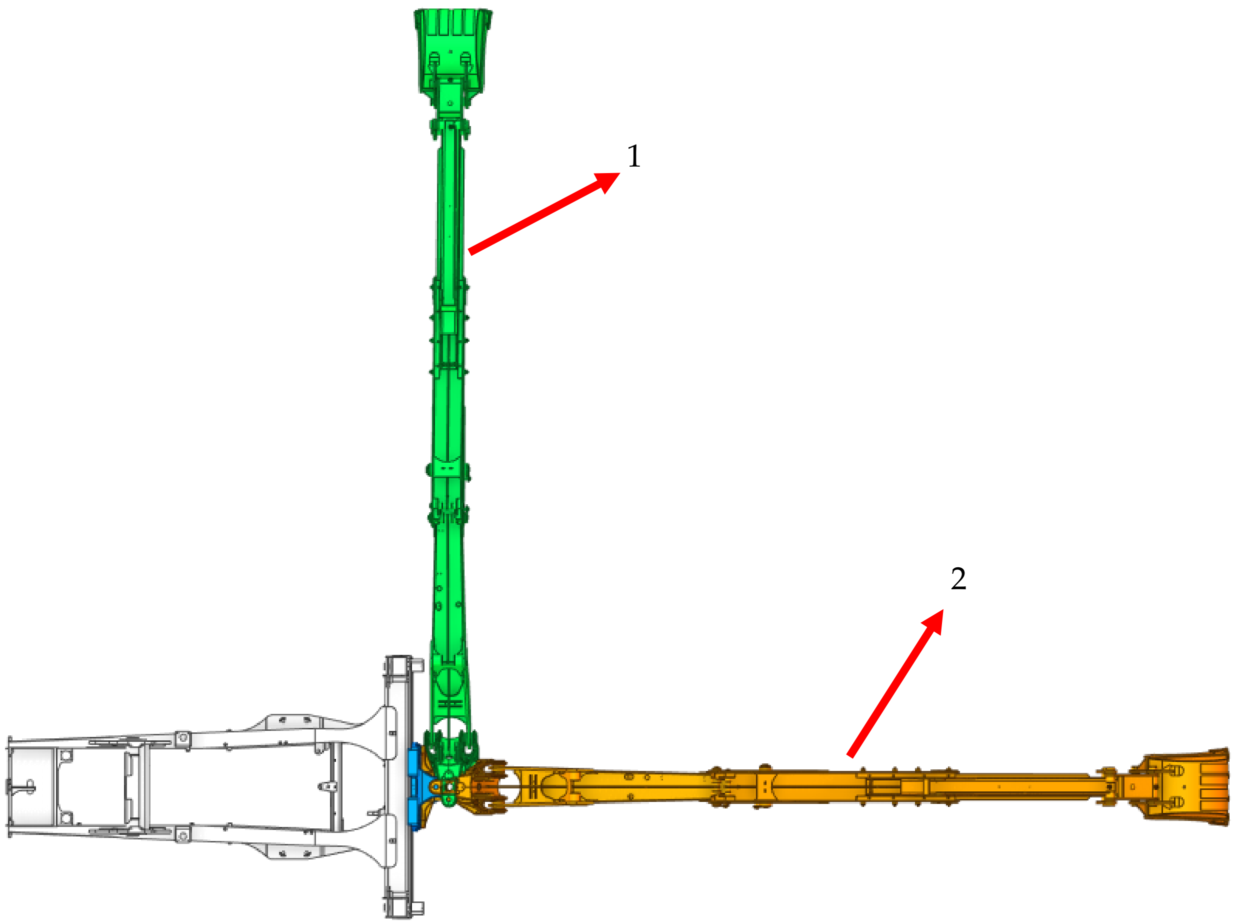

Figure 4: Attachment locations included in analysis

In position 1, the attachment is positioned perpendicular to the wheels, while in position 2, the attachment and wheels are parallel to each other. The force values calculated for

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these positions were provided as input to the analysis.

2.3. Verification With Strain Gauge Application

Strain values in a system can be easily measured with a strain gauge application. The dimensions of the strain gauge will change at the same rate as the structure on which the measurement is made during application. This causes the resistance values in the strain gauge to change and thus the strain values occurring in the system become measurable [4]. In order to verify the analysis method performed on the swing tower, strain gauges were applied on the structure. Two different applications were carried out for 2 different locations shared in Figure 3. After the backhoe loader construction machine was brought to predetermined positions, a load of known weight was hung on the bucket. Stress values were examined with strain gauges placed on the structure. Theoretical calculations were made for the load placed in the bucket area, and the loads on the swing tower were provided as input to the analysis program. The regions where data was collected with the strain gauge test are shared in Figure 5. The related application test images are shared between Figure 6 and Figure 8.

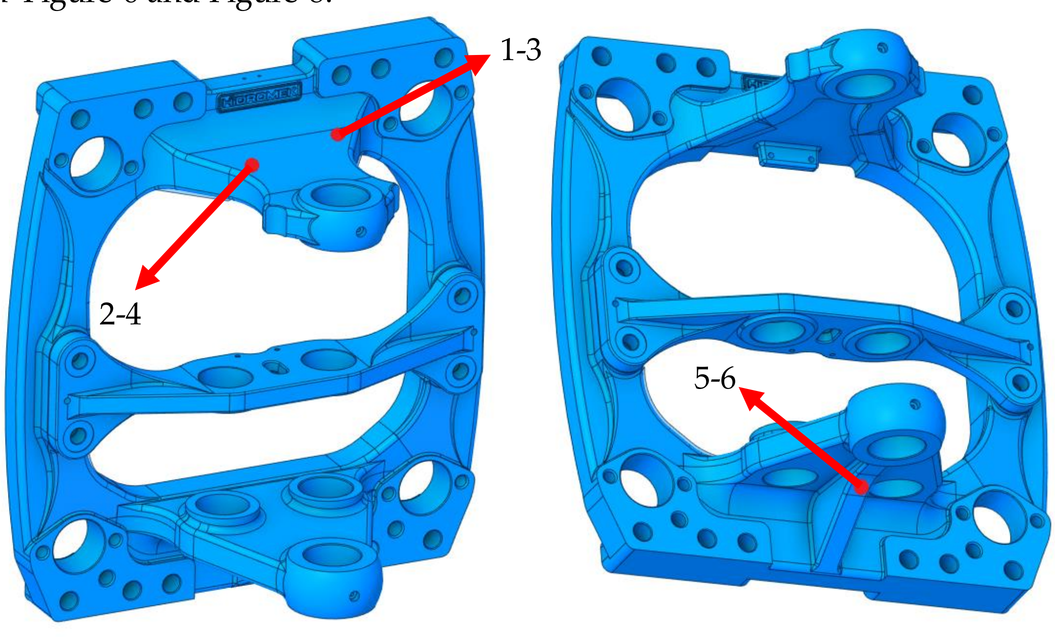

Figure 5: Measurement zones

In measurements 1, 2 and 4, the attachment is positioned parallel to the wheels; while it is positioned upright in measurements 3, 5 and 6. The test data obtained for the scenarios examined with the strain gauge application and the structural analysis package program outputs are shared comparatively in Figure 13 in the results section.

Figure 6: Strain gauge application, general view

Figure 7: Strain gauge application, bottom view

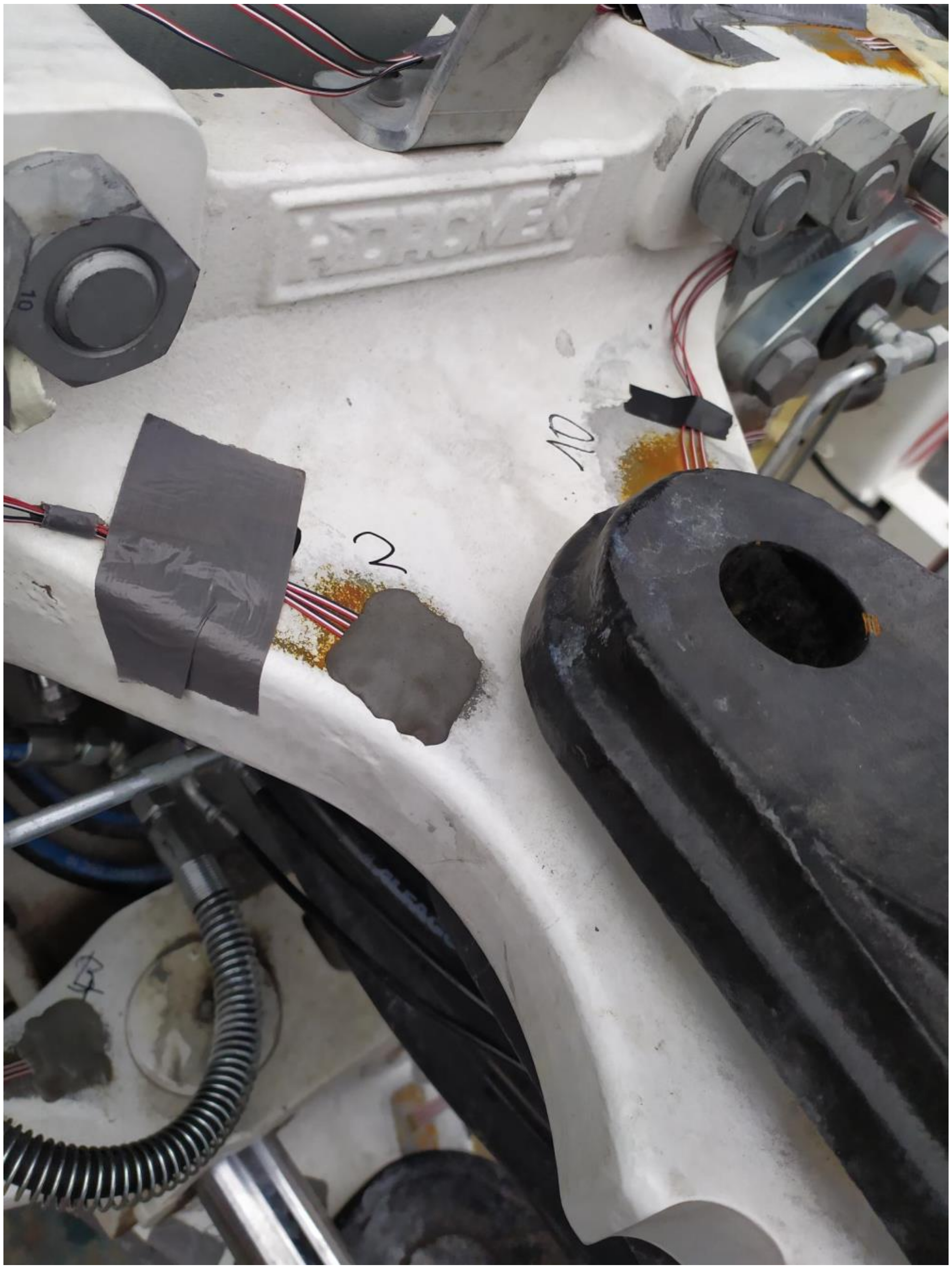

Figure 8: Strain gauge application, top view

3. Result

The stress values obtained under the boundary conditions applied on the structure in the structural analysis package program MSC Marc are shared between Figures 9 and Figure 12.

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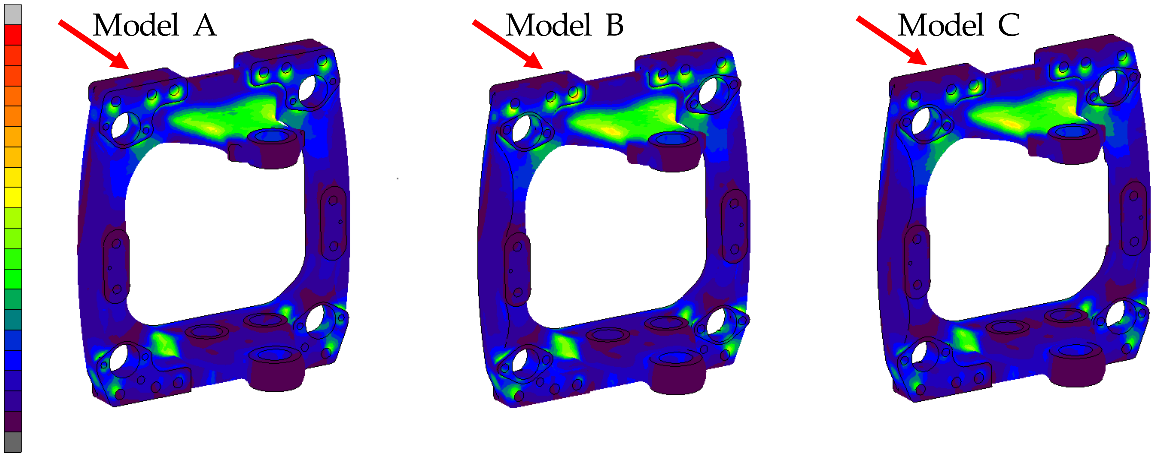

Figure 9: Stress distributions in attachment position parallel to the wheels, front view

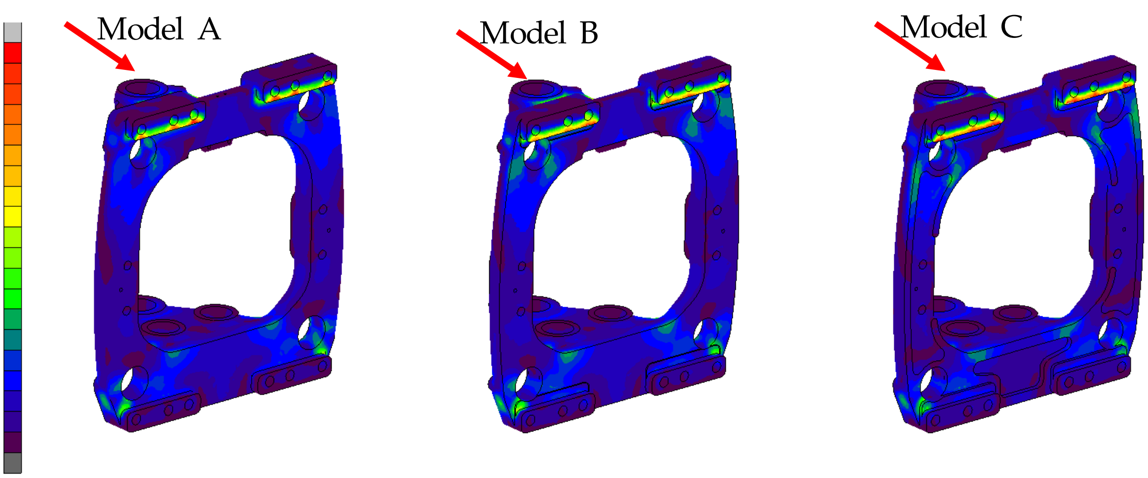

Figure 10: Stress distributions in attachment position parallel to the wheels, rear view

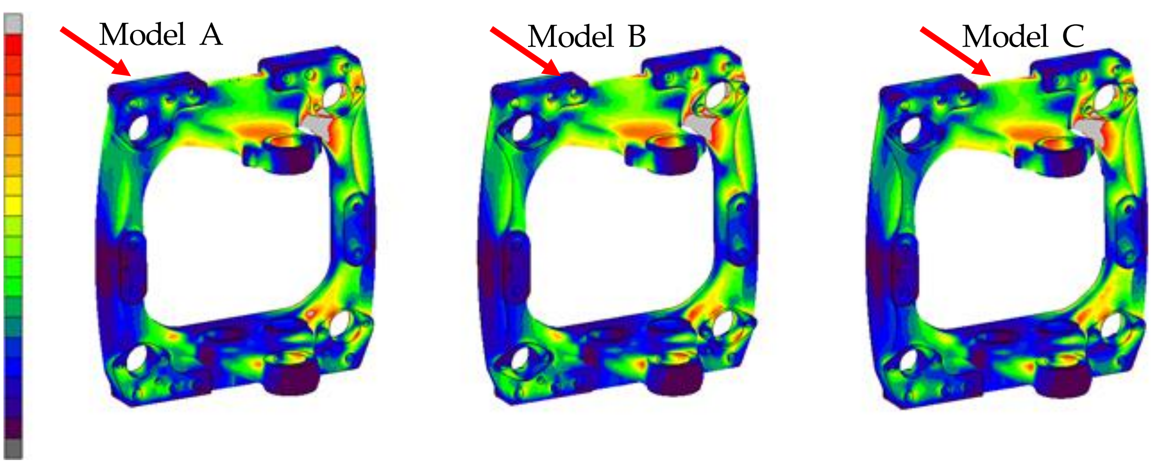

Figure 11: Stress distributions in attachment position perpendicular to the wheels, front view

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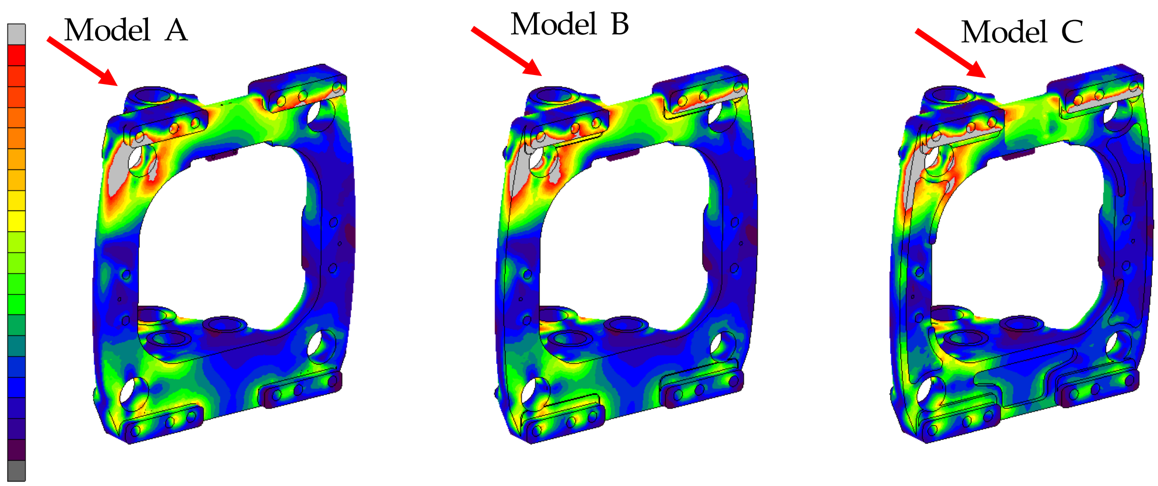

Figure 12: Stress distributions in attachment position perpendicular to the wheels, rear view

When the stress values obtained as a result of the applied boundary conditions are examined; Regional stress values on Model B and Model C increased by 7%-15% and 6%-38%, respectively, compared to Model A.

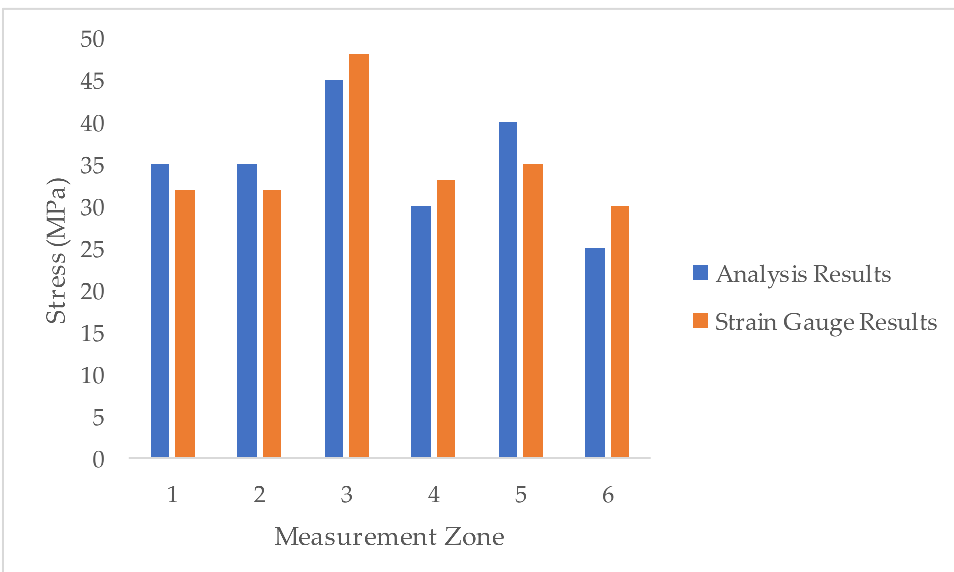

Figure 13: Analysis and Test Outputs

For the strain gauge application, a difference between the analysis results of the scenario examined and the test results was detected, varying between 6.25% and 16.67%, depending on the test data. This shows the consistency of the method applied for all models examined in this study.

4. Discussion and Conclusion

In line with the data obtained, the consistency of the structural analysis method performed on the swing tower was examined with the application of a strain gauge. The low difference between the stresses obtained as a result of the analysis and the stresses obtained in the test results showed that the structural analysis method performed on the structure was applicable. Among all the models examined, the structure with the lowest stress values was the one with the highest thickness and on which no unloading process was carried out. The structure that was weaker than the others in terms of strength was the structure with the lowest thickness. It has been observed that the material removing process causes stress concentrations in two structures with the same thickness.

5. Acknowledge

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