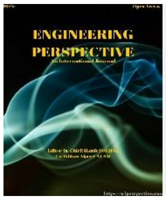

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Research Paper

Analysis of the Behavior of a Cross-Type Hydraulic Outrigger and Stabilizer Operating Under Determined Loads

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Abstract

In this study, behavior of a fully opened cross type hydraulic outrigger and stabilizer of an aerial ladder firefighting device which is on determined static load is analyzed. This hydraulic outriggers and stabilizer are designed via SOLIDWORKS 2017 software and then analyzing process is run at SIEMENS NX 11.0 NASTRAN software. The location of the center of gravity of the firefighting device and its mass at several use cases is used as input for analysis. Standard equipment's which can work with harmony are chosen for model, since design of a commercially producible model is aimed. Stress, strain values and forces acting on mills are obtained by analysis and then interpreted. When displacement of mass against gravity is -13 mm, displacement of outrigger and stabilizers system is ±4. The maximum stress at system is obtained as 190 MPa when singular values are filtered. Factor of safety is determined as 1,9 for this system. The system is decided as durable according to this study.

Keywords: Analyze, Crane, Firetruck, Hydraulic outriggers, Stabilizers

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1. Introduction

Structures such as cranes, lifting platforms, aerial ladder firefighting vehicles, and launching platforms, which serve different purposes, were shipped to the area where they would be used and made ready for use after they were assembled at the place of operation in traditional methods. In line with the requirements, these structures were transformed into mobile by mounting on trucks, and as a result, it has been provided to meet the needs more quickly [1, 2]. This situation has led to the need to stabilize and support these mobile vehicles in the different ground and environmental conditions [3, 4]. In line with this need, different stabilizers and outriggers have been developed for different vehicle superstructures. In such vehicles, to ensure the safety of the system and to ensure error-free operation continuity, the reaction forces generated in the stabilizer and outriggers should not increase to very high levels [5-7]. Stabilization of these vehicles is essential to ensure that people around, especially the operator using the vehicle, the material carried, and the vehicle itself work safely, correctly, and without any damage [8,9]. In addition to these parameters, stabilizers and outriggers are of critical importance in terms of the vehicle's ability to operate without harming the personnel and people around during its duty and not to prevent them [10-13].

In the literature, two essential criteria have been used for stabilizers and outriggers: Proper and improper use. Proper use is defined as a situation where the stabilizer and outriggers are fully extended (opened) on firm ground, and improper use is defined as use when the ground is not firm. For the stabilizer and outriggers to perform their tasks effectively, they should be operated on firm ground as much as possible, and equipment that will increase the surface area of the pad should be used in case of operation under soft ground conditions [14]. If the vehicles are not stabilized, serious problems such as rollover (tipping) can occur. Such possible problems that may arise pose a danger at a level that can lead to severe material damage and life threat for the aforementioned mobile platforms and the elements around [15-18]. A study published in 2017 determined that 72% of the crane accidents that occurred worldwide were experienced in mobile cranes. The same study determined that 45% of the accidents in mobile cranes were caused by stabilizer and outriggers, ground subsidence, and overloading [19]. In another study on mobile cranes published in 2017, it was stated that 31% of the accidents experienced in mobile cranes were caused by reasons such as lifting and lowering the load, unbalanced load distribution, load drop, and load acceleration. It has been revealed that 11% of the accidents are caused by reasons related to balancing the load, such as the failure of stabilizer and outriggers, overloading, and loss of control of the center of gravity [20]. In an older study, it was shown that more than 50% of crane accidents occurred due to improper use of the crane or stabilizer and outriggers [21]. As can be seen, in accidents that occur in superstructures worldwide, the rate of stabilizers and outriggers to cause accidents is considerably high. The dangers of such accidents, extending to death, are too severe to ignore. It is seen that stabilizers and outriggers play a significant role in these accidents.

Apart from mobile cranes, there is a need for stabilizing and supporting aerial ladder firefighting vehicles, mobile cargo lifts, and military vehicles such as launching platforms, whose operating logic is similar to mobile cranes and vehicles used in many other different areas. In this study, cross-type stabilizers and outriggers used in aerial ladder firefighting vehicles are analyzed.

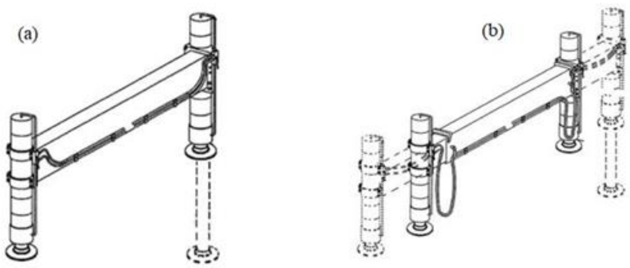

Figure 1. Frequently used stabilizer and outrigger systems

Two of the most frequently used hydraulic stabilizer and outriggers in mobile vehicles are shown in Figure 1. The stabilizing process is carried out by ensuring that the appropriate stabilizer and outrigger types, which have many more types according to the vehicle characteristics and the working area's condition, are mounted on the vehicles. Manufacturing companies use different names in identifying these stabilizer and outrigger types. In the stabilizer and outrigger type shown in Figure 1. (a), the pad parts of the hydraulic stabilizer and outriggers go down directly and become ready for use. This type is called fixed stabilizer and outrigger in the literature. In the stabilizer and outrigger type shown in Figure 1. (b), the stabilizer and outriggers are opened to the right and left before the hydraulic pads touch the ground. This type is called the (side) extending stabilizer and outrigger. According to the operating conditions, the usages in which the right and left stabilizer and outriggers are opened at different rates are also common.

Fixed type hydraulic stabilizer and outriggers are generally preferred in situations where there is a fixed and not long structure on it and does not require the superstructure to extend and rotate. This stabilizer and outrigger structure's task is to transfer the loads generated during the operation of the superstructure to the ground instead of the vehicle chassis.

In (side) extending type stabilizer and outrigger structures, in addition to the features of the fixed type, the stabilizer and outriggers can open and extend at the same rate to the right and left, or they can open and extend separately to the right or only to the left. The extending type stabilizer and outrigger structure allow rotating mechanisms, such as telescopic ladders or cranes, that change their position according to the center of gravity to operate safely without rollover. Figure 2 shows the (side) extending type outriggers in a telescopic ladder fire fighting vehicle. The most important disadvantage of this type of outriggers is that a vast area is needed to open the outriggers to the side.

Figure 2. Hydraulic stabilizer and outriggers on aerial ladder firefighting vehicle

Instead of these stabilizer and outrigger types, cross-type stabilizer and outrigger structures are frequently used in mobile vehicles. In cross-type outriggers, height differences up to 700 mm on the ground surface where the vehicle will operate can be damped thanks to the outriggers' geometric features. The most crucial feature of cross-type outrigger structures is that they can be opened to support the superstructure even in narrow spaces. In narrow streets where firefighting vehicles need to perform tasks frequently, the superstructure can be supported by extending the outriggers under the parked vehicles on the right and left sides. Another feature of the cross-type outriggers that provides an advantage over other outrigger types is that they do not prevent people and personnel from passing over them when the outriggers are open. This feature allows the personnel on duty or other people around to move quickly in emergencies.

In this study, a cross-type stabilizer and outrigger design has been made for an aerial ladder firefighting vehicle. Prior to the design, the center of gravity position and weight values were calculated for the vehicle to be used in different scenarios. Among these calculated values, scenario values that will force the outrigger structure at the maximum level were selected and used as analysis input. Static analysis of the outriggers under the determined system load has been made, and their usability has been evaluated within the firefighting vehicle whose prototype will be produced.

2. Material and Method

2.1 Determining System Components

The stabilizer and outrigger system consists of four separate outriggers, and these outriggers are mounted to each other in pairs, front, and back. The outriggers were designed in a concept that can be mounted on a two-axle class E truck. Each outrigger is driven by two separate hydraulic cylinders, one for side opening and one for ground contact, and the system assembly includes eight hydraulic cylinders in total. While designing the outriggers, considering the prototype production, standard and available materials were used as hydraulic cylinder elements, profiles, and fasteners.

Figure 3 shows the sectional view and perspective view of cylinders and profiles in an outrigger's closed and open position. The basic materials used in the construction can be listed as hydraulic cylinders, hydraulic pistons, hydraulic rods, hydraulic sealing elements, steel sheets, steel box sections, steel shafts, bronze bearings, and hydraulic valves. When the outriggers are fully open, the outriggers reach an overall size of 5475 mm, while the pads have an out-to-out distance of 5400 mm to each other. In this case, the angle of the profiles to the ground is 12˚.

Figure 3. Closed and open position solid model of cross-type outriggers

Using hydraulic load holding (over-center) valves in the pads' cylinders aims to ensure that the system can remain stabilized in case of a sudden pressure change. Using the load measurement sensor in the pads, the load on each outrigger will be measured, and the center of gravity will be kept in the safe zone electronically with this data; thus, controlling the stabilization system will be provided by electronic software.

2.2 Determination of Operating Conditions

While analyzing the structure that will serve as the stabilizer and outrigger of the ladder and rotary table mechanism of an aerial ladder firefighting vehicle, which weighs 18,000 kg with front and rear outrigger groups, the "fully open" position, which is the maximum load-bearing configuration for the outriggers, was used.

2.3 Geometries Used and Geometric Simplification

Components such as hydraulic installation, bolts, circlip, etc., are not included in the simulation model since they do not affect structural integrity. No special modeling has been performed for weld lines (for welds on the part), and continuous geometries represent the bodies. In the model created, sheet metal and profile components are represented by 2D (surface), and 3D geometries represent all other components.

2.4 Numerical Modeling

In the simulation model created for static solutions, profile and sheet metal components (2D geometries) were analyzed with CQUAD8 (8-node, parabolic, -node, parabolic, 2D NASTRAN numerical modeling element), all other 3D components were solved with CTETRA10 (10-node, tetrahedral, parabolic, 3D NASTRAN numerical modeling element) and CHEXA20 elements (20-node, hexahedral, parabolic, 3D NASTRAN numerical modeling element).

The maximum total mass of the vehicle chassis, turntable and ladder components (18 tons) is represented by the 0B CONM2 element (0B NASTRAN numerical modeling element). This element has been placed in accordance with the 45˚ angular position of the turntable as its dimensions are defined in figure 4. The point mass element is connected to the front and rear outrigger assemblies using 1B RBE2 element (1B NASTRAN numerical modeling element (rigid)), assuming that the chassis is enduring (durable). The joints' shafts are modeled with the same diameter 1B CBEAM (1B NASTRAN numerical modeling element (flexible)) numerical modeling elements. The model has a total of 200,844 elements and 732,461 nodes [22].

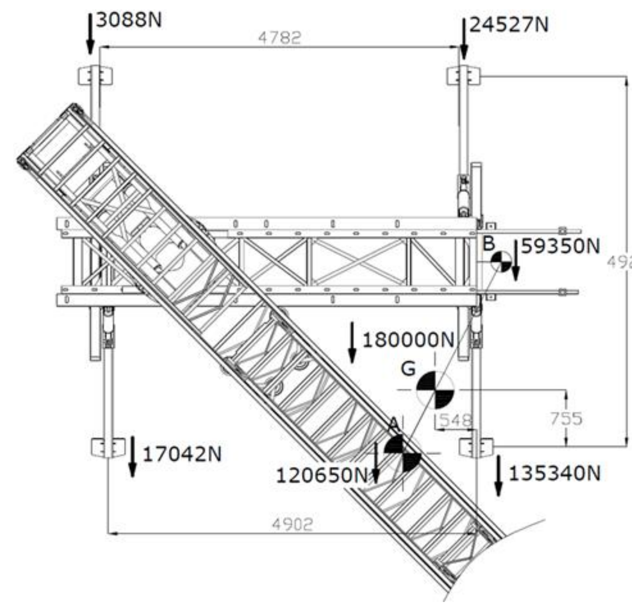

Figure 4. Firefighting vehicle center of gravity position and forces acting on outriggers

In Figure 4, the outriggers' loads can be seen in the scenario created considering the situation where the highest load affects the outriggers. In this state, the analysis was carried out according to the worst case in the load acting on the outriggers, when the firefighting vehicle ladder is synchronous 24 m open and at an angle of 45˚. In Figure 4, point A indicates the center of gravity of the superstructure, point B indicates the center of gravity of the vehicle chassis, while point G indicates the resultant center of gravity. Based on the simulation model created, a static solution was realized in the single scenario (NASTRAN solution sequence: 101). This scenario, which was chosen as the "most challenging loading condition", was prepared using the maximum load elements that the outriggers can carry, and the turntable is positioned at an angle of 45˚ relative to the vehicle chassis. Figure 5 shows the meshed view of the system and outrigger.

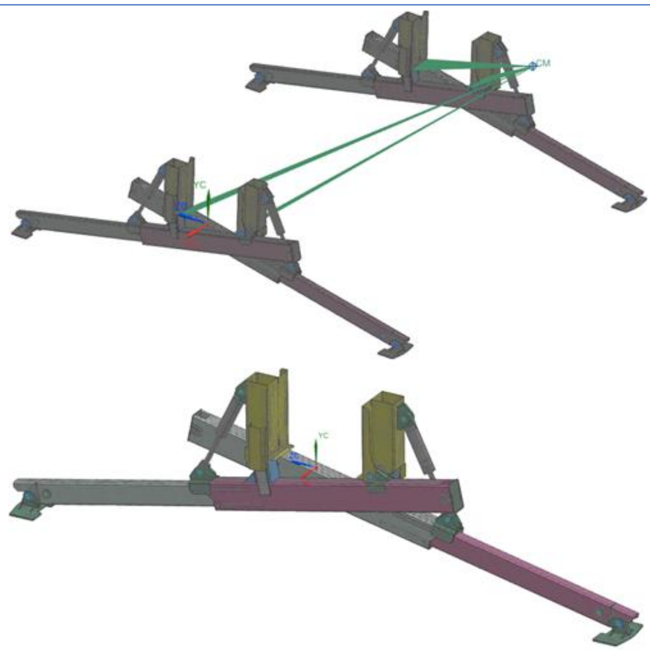

Figure 5. Numerical model of the system and outrigger assembly

2.5 Connections

Besides bolted and welded connection methods, bronze bearings for contact surfaces in friction bearings and shafts in swivel joints are used in the system. In the simulation model created for static solutions, bearing plates and counterparts contact interface connections are modeled with SSC (NASTRAN surface-to-surface contact), and all welded connections are modeled with SSG (NASTRAN surface-to-surface gluing) formulation [22].

2.6 Limiting Conditions

In the stabilizer and outriggers, since it is aimed to transfer the weight of the superstructure to the ground by the contact of the pads with the ground, in the simulation model created for static solutions, the freedom of these regions is restricted by applying "Fixed Constraint" on the base surfaces of the pads. In Figure 6, regions with restricted freedom are shown in orange.

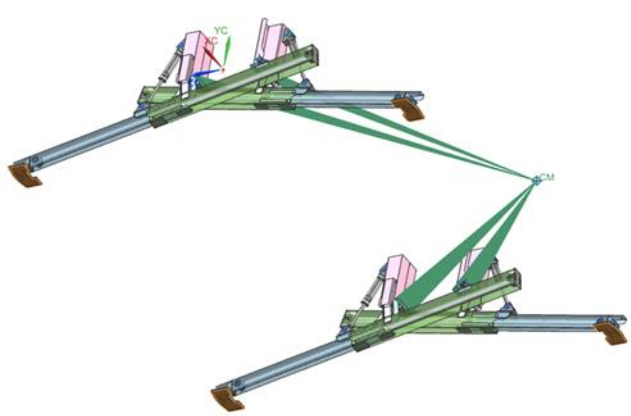

Figure 6. Simulation model limiting conditions

2.7 Material and Properties

System carrier elements consist of components such as profile, sheet metal, shaft, and bearing. In the analysis model, metal profile and sheet metal components were identified with S355 Steel, bearing components with Bronze, and shafts with AISI 4140 material. The properties of the basic materials used are shown in Table 1.

Table 1. Materials used and their main properties

Material	Type	Density (kg/m^3)	Modulus of Elasticity (Gpa)	Poisson's Ratio	Yield Strength (Mpa)
S355 Steel	Isotropic, Linear Elastic	7800	200	0.3	355
AISI 4140 Steel	Isotropic, Linear Elastic	7800	200	0.3	415
Bronze	Isotropic, Linear Elastic	8850	103.4	0.34	260

S355 steel sheet is frequently used in industry due to its low cost, high availability, ease of forming, high strength, suitable for welded and machining. In addition to the advantages of S355 steel sheets, S355 steel box sections provide product diversity with square and rectangular structures in different sizes and wall thicknesses. Thanks to their high inertia in both axes, their strength/weight ratios against axial loads are high. If the steel box section ends (outlets) are covered with a plate, the inner surfaces are easily protected from corrosion. AISI 4140 steel, on the other hand, is suitable for machining and welding processes as well as heat treatment. Therefore, it is a material frequently used in engineering applications. Bronze is a low-cost and easy-to-procure alloy that is often used in plain (sliding) bearings. Plain bearings stand out with their resistance to vibration and impacts, simple designs, easy assembly, and frequently used engineering applications.

2.8 Loading

In the single-scenario solution, since the structure's behavior under static load is examined, only 1g of gravitational acceleration is defined. In this way, the model's components and the 18-ton point mass were transformed into a static load.

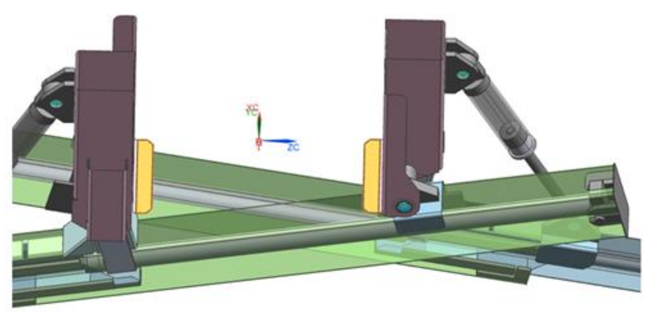

Figure 7. Load transfer interface

3. Results and discussions

In this study, the cross-type stabilizer and outriggers' design to be used on an aerial ladder firefighting vehicle was carried out, and its static analysis was performed. With the analysis performed, parameters such as displacement of the system and maximum stress were calculated, and it was evaluated whether it is suitable for prototype production.

Aerial ladder firefighting vehicle outriggers were examined in detail in the analysis program environment, and only deformation and maximum equivalent stress results were obtained for structural behavior determination in the study. An exaggerated representation is made in the visual results obtained to understand the regions with deformation more easily.

The displacement behavior of the stabilizer and outriggers in the analysis program environment was examined. Figure 8 shows the displacement results of the load application point.

According to the results obtained, the maximum displacement value of the load application point is 13-14 mm. Considering the system in general, the displacement amount is interpreted to be around 7 mm. As a result of the displacement analysis, it is concluded that the displacement is at the allowable limit value.

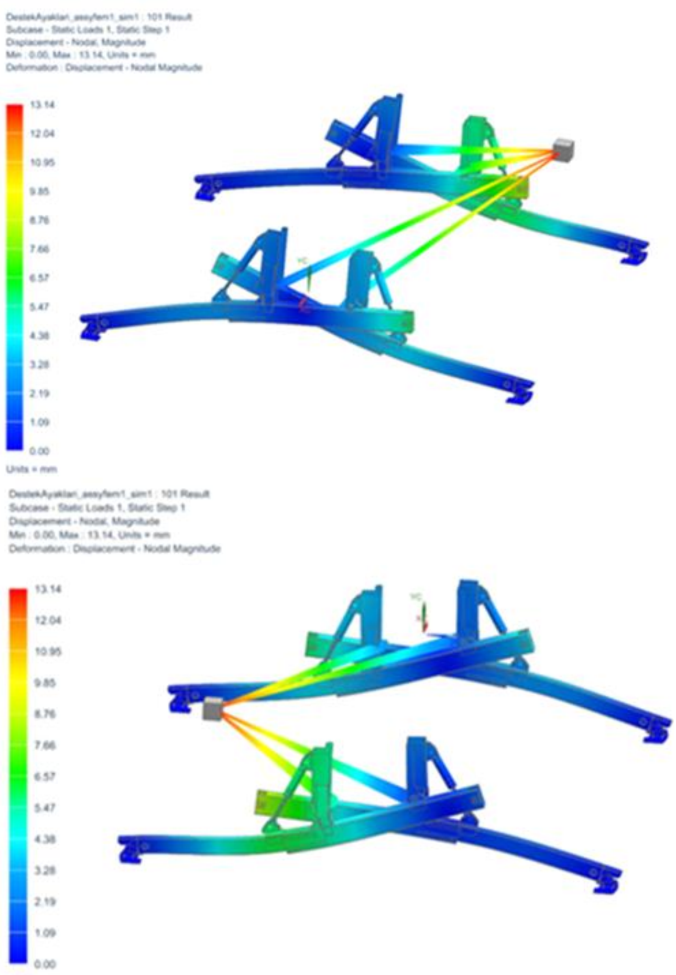

Figure 8. Rear and front view of the resulting displacement distribution

Figure 9 shows the resultant displacement results on the outriggers. According to the results, the maximum displacement on the outriggers' singular points is 4.4 and -11.78 mm. Considering the system in general, it is interpreted that the amount of displacement is around ± 4 mm. As a result of the displacement analysis, it is concluded that the displacement is at the allowable limit value.

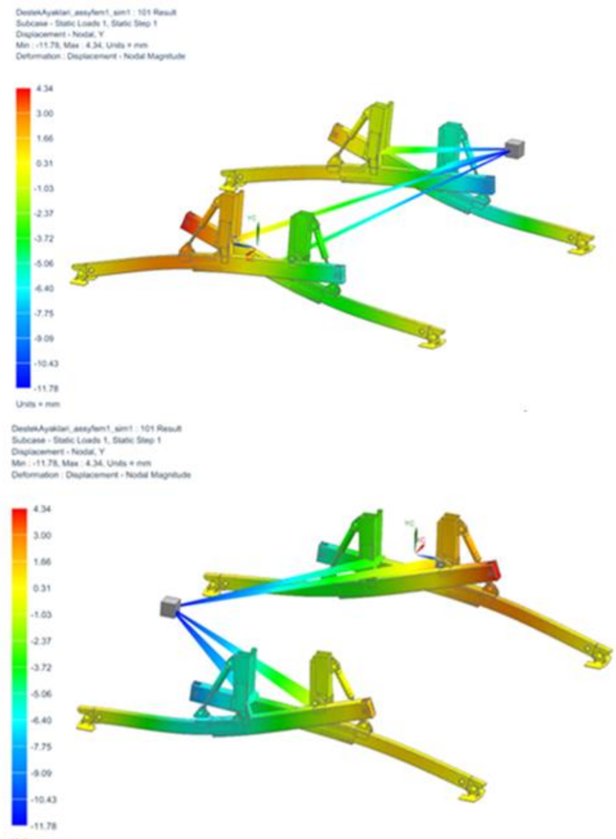

Figure 9. Y-direction displacement distribution

The stabilizer and outriggers' stress values under maximum load in the static state were examined in the analysis program environment. Figure 10 shows the stress values obtained as a result of the analysis. With reference to the yield strength of the bronze material, which has the lowest yield strength value among the materials used, the legend is limited to 260 MPa. When the stress results are examined, it is seen that the outriggers have equivalent stress values of 2500 MPa on the weld lines of the chassis connection (mounting) interfaces. These sharp edges are mathematically singular regions. These "singular" regions are formed on very short edges in the sharp geometric transition region of 2D numerical modeling elements. During the examination of the results, the values to be read from these regions do not have a physical meaning. The result is that the stress values occurring in the system are below the yield point (limit) values, except for some singular points.

The stress values of the pad region of the outriggers were examined. Figure 11 shows the equivalent stress distribution and local maximum stress values of the pad region. Because this region material is S355 JR, the legend is limited to 355 MPa. It was concluded that the stress did not exceed the yield point (limit) of the S355 JR material, except for some singular points.

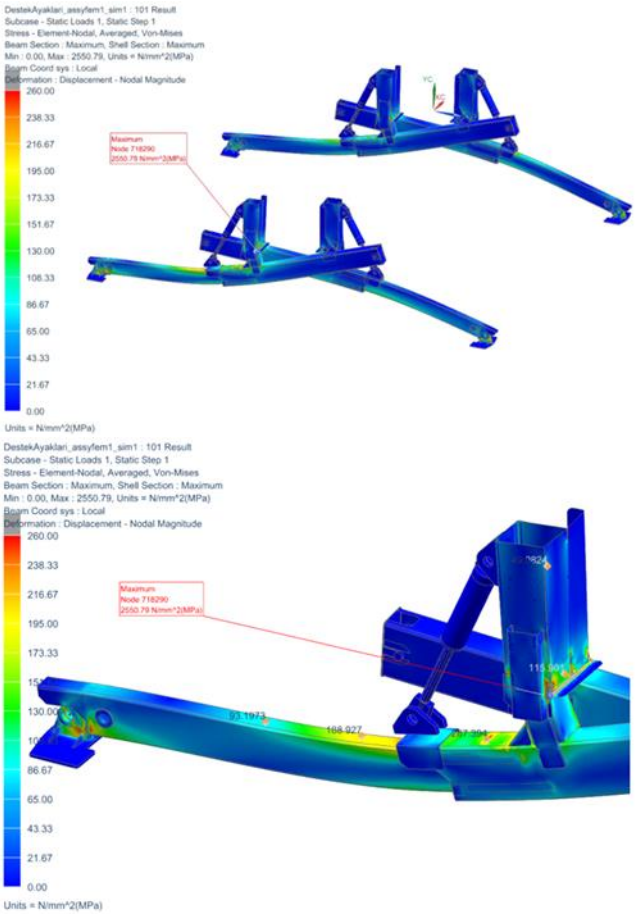

Figure 10. Equivalent stress distribution

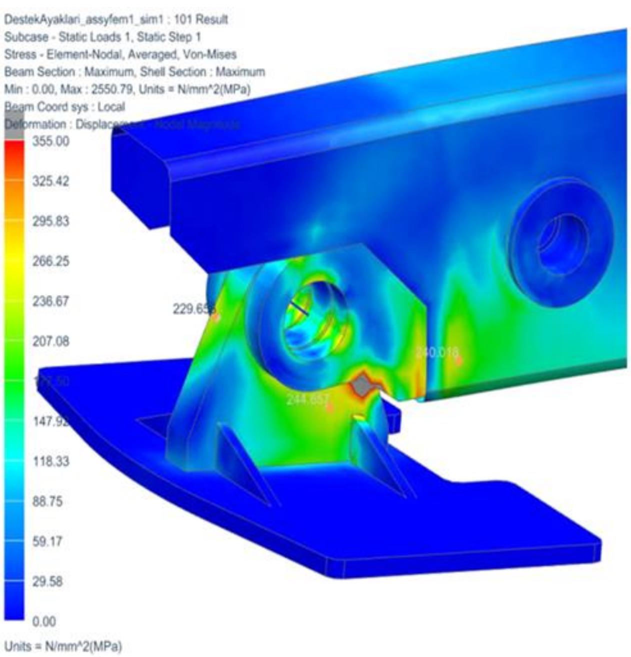

Figure 11. Equivalent stress distribution

Maximum force values affecting the shaft used in outriggers were determined in the analysis program environment. In Figure 12, it is seen that the maximum axial force on the shafts is 8138 N. The maximum axial force occurs on the front outrigger.

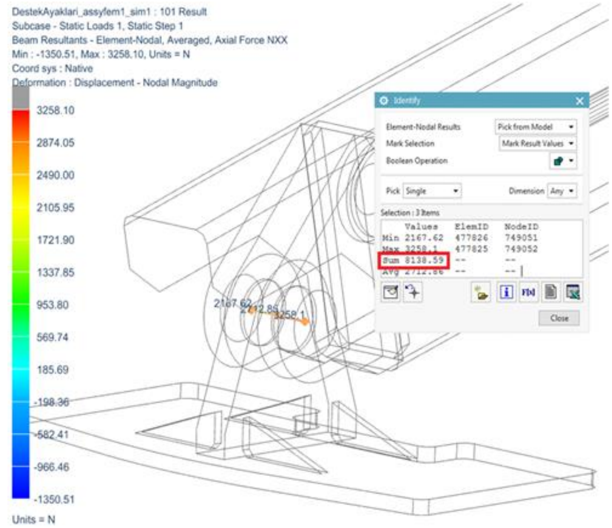

Figure 12. Maximum axial force on the front outrigger shafts

In Figure 13, it is seen that the maximum bending moment on the shafts is 226 Nm and occurs at the front outrigger. At the same time, it is seen that the maximum shear force on the shafts is 8567 N and occurs at the front outrigger.

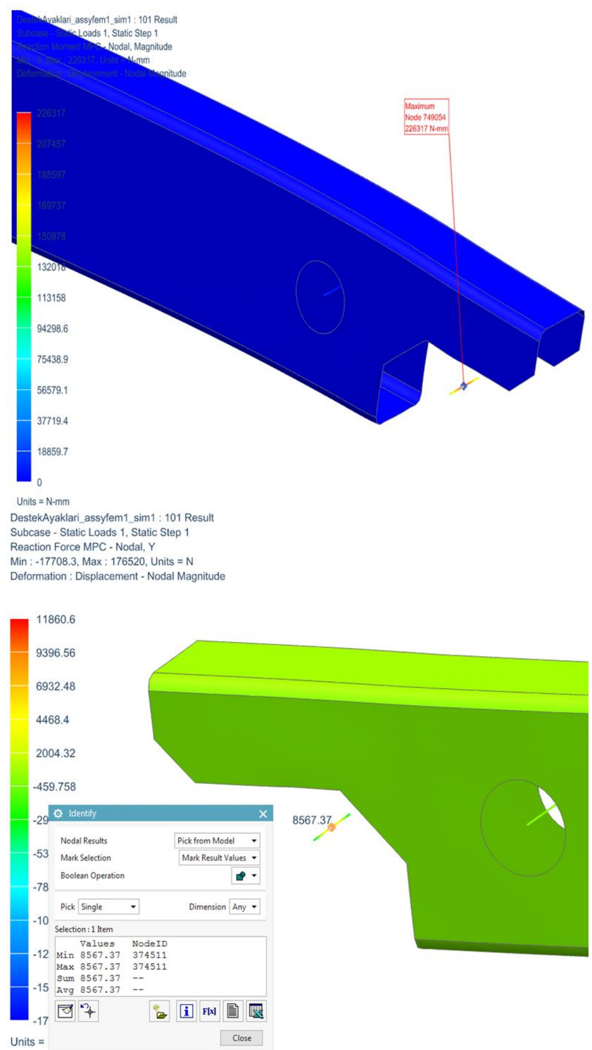

Figure 13. Maximum bending moment and shear force on shafts

Within the study's scope, the maximum loads on the connecting shafts were also calculated for the verification of the hand calculation.

According to this; the following calculations have been made.

•The maximum axial force is determined as 8138 N on the 50 mm diameter connecting rod used on the front support leg.

•The maximum bending moment was determined as 226 Nm on the 44 mm diameter front shear connecting rod.

•It has been concluded that the maximum shear force is 8567 N at the front support leg connecting rod with a diameter of 50 mm.

It has been determined that the forces acting on the shafts are well below their load-carrying capacity.

4. Conclusion

In this study, which was conducted to examine the design's resistance for the prototype production of the aerial ladder firefighting vehicle stabilizer and outrigger to the loads acting on the vehicle, the analysis results were obtained and interpreted. The results obtained for static loading cases in the analysis program environment are shown in Figures 8 to 13.

As a result of the analysis, it was seen that the load application point was displaced 13-14 mm, and the general outrigger structure was displaced approximately ± 4 mm. It is concluded that the displacement is at the acceptable (allowable) level. When the singular values are filtered, the maximum nominal stress calculated on the system is seen on the front outrigger profiles as 190 MPa (Figure 12). For this structure, which is subjected to a high degree of bending load, the maximum value location is plausible. The yield point of the profile to be produced from S355 steel material is 355 MPa. Accordingly, the system minimum factor of safety under 18 tons of loading is determined as 1.9. According to the static simulation results, it is concluded that the Outrigger design is durable (enduring) under the specified conditions.

Cross-type hydraulic outrigger and stabilizer are more ergonomic than the traditional outrigger and stabilizer type. In this study, the stresses and displacements affecting the Cross-Type Hydraulic Outrigger and Stabilizer were investigated. As a result of the examination, it was concluded that the cross-type hydraulic outrigger and stabilizer are suitable for use on the vehicle.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

CRediT Author Statement

Mustafa Karaman: Conceptualization, Supervision Analysis, Writing - review & editing, **Emre Öztürk:** Methodology, Data curation, Writing - review & editing

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