Research Article

Structural Analysis of Different Types of Chassis Designs for a Multi-Axle Heavy Commercial Vehicle

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Abstract

In recent years, the increasing capacity observed in air transportation requires enhanced security measures. The Aircraft Rescue and Fire Fighting (ARFF), which is one of the measures that are excessively taken in aviation, is constantly developing along with the sector, and it follows the technology closely, consequently increases its capacity day by day. In order to provide both civil and military air transportation safety, ARFF vehicles, which are specifically designed to operate in unusual boundary conditions with an ease. ARFF vehicles have high engine power in order to reach the crash site as soon as possible, aside from the high-power engine, they are equipped with all-wheel drive system (AWD) to increase mobility in rough terrain. Also, they are equipped with off road compatible tires, and it has high carrying capacity to carry extinguishing agents to be used to effectively respond to fire. In order for the vehicle to operate under these unusual boundary conditions, the frame component which works as carrier of the vehicle must be manufactured with materials which have high strength, and low weight and the frame should be as modular as possible. In this study, two different chassis designs were examined. The designs were created with the PTC Creo 3D modelling program for a multi-axle driven ARFF vehicle. Numerical calculations of the loads on the chassis were made with reference to the contact points of the chassis, rectangular-circular hollow section and different types of critical stress conditions. Finite element (FE) analysis for two different chassis conducted according to the calculation results. The main purpose of this study is to evaluate the stress *conditions of different types of ladder chassis under static axle load according to two different critical loads and to determine the stresses acting on the chassis. As a result of the determination, engineering evaluations were made by evaluating the suitability of the chassis for production.*

Keywords: 6x6 Vehicle, Heavy Duty Vehicle, Fire Fighting Vehicle, ARFF Trucks, CAE, FEA, Ladder Chassis, Static Axle Load.

1. Introduction

ARFF vehicles, which are generally used for early intervention and fire fighting at civil and military airports, are designed according to the National Fire Protection Association (NFPA) standards. These vehicles designed and manufactured in a unique way considering to different types and technical features for the purpose they serve for airports. These vehicles have a modular superstructure (shown in Figure 1) and due to both equipment weight and operating conditions, they need to reach higher speeds and functionality compared to other vehicles. In this context, static and dynamic conditions had observed when the chassis of ARFF vehicles working at fully load. Within the scope of these effects; The vehicle is exposed to its own weight and load, cornering force, braking force, torsion force and impact loads. The design and analysis of the contact points of the longitudinal and lateral carriers of the chassis under different road conditions and critical loading is very important [1-2]. The basis of the study is to solve the problems with taking into consideration the stress and deformations which are observed in the critical regions under different stress conditions [3-4].

For this purpose, the models of the chassis were created with the PTC Creo CAD program, in addition stress and deformation analyses were conducted based on different stress conditions within the scope of the finite element method using the Ansys Workbench 21 simulation program. The chassis of the LION ARFF vehicle supported by 6 helical progressive springs in addition to two longitudinal and two lateral carriers, which show resistance to bending strength and torsional rigidity, designed as a closed box rectangular hollow section ladder chassis type [5-6]. The dimensions of the longitudinal and lateral carriers were evaluated considering the bending and torsional strength.

Figure 1. 6x6 Lion ARFF Truck

2. Materials and Methods

High yield strength structural steel used as chassis material. This material is suitable for heavy vehicle chassis that are subjected to high forces and forced into bending and torsion. Lateral carrier, longitudinal main carrier, axle link and suspension link towers of the chassis made of structural steel used in the existing 6x6 ARFF vehicle were designed in 3D in PTC Creo CAD program. Chassis designed; As a modular superstructure, the connection of the cabin, water tank, rear module and front module to the chassis with bolts from the support brackets at certain points, the welded connection of the lateral-longitudinal carriers and the axle-suspension connection towers have been connected in accordance with the production and the assembly has been completed. Detailed structural elements of different types of chassis are shown in Figure 2-3.

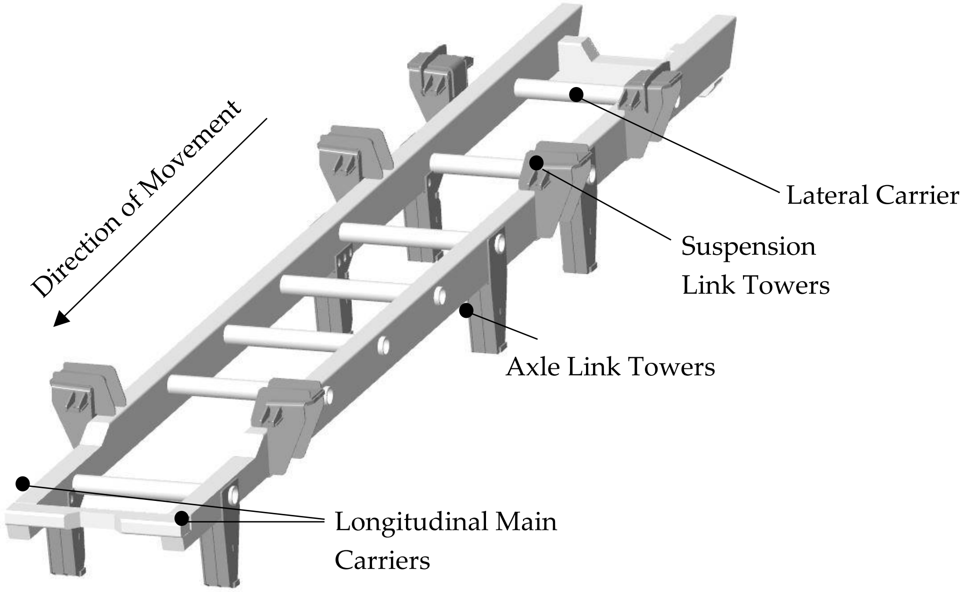


Figure 2. 6x6 Lion ARFF Truck Ladder Type Chassis-1 Structural Elements

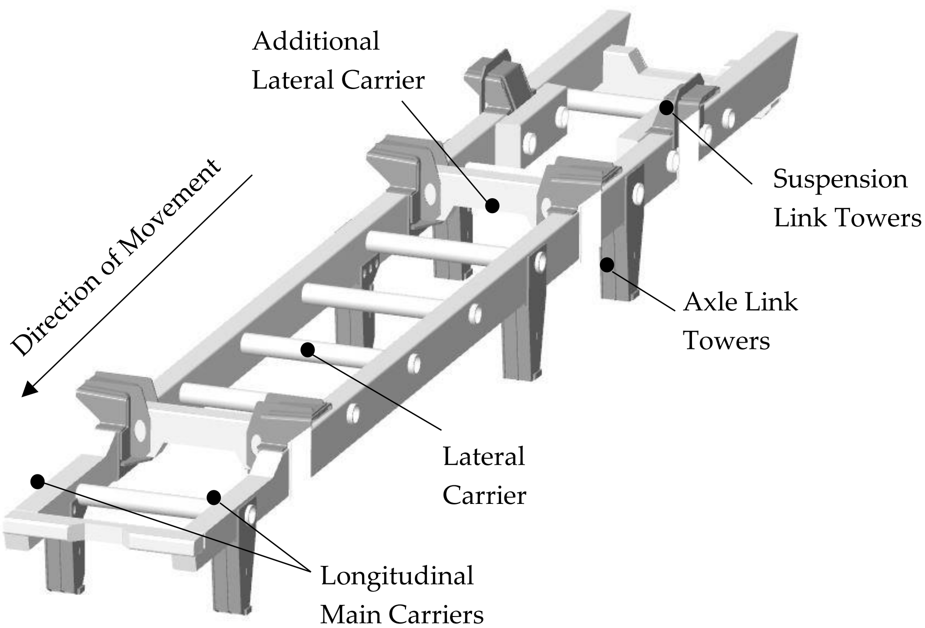
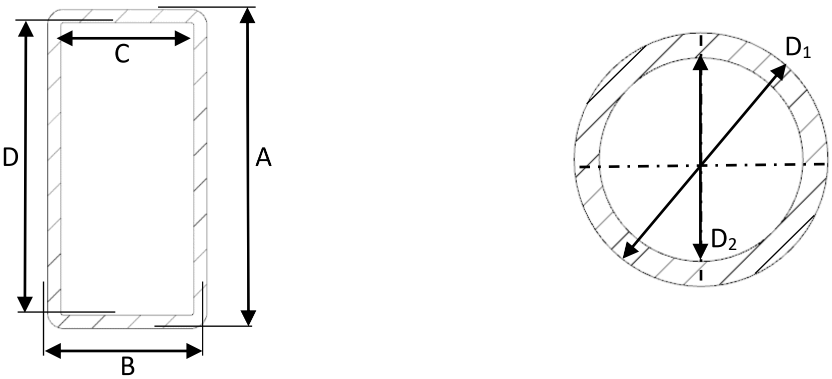


Figure 3. 6x6 Lion ARFF Truck Ladder Type Chassis-2 Structural Elements

It is predicted that the torsional and bending strength of the vehicle will be strained due to inertia in the direction of the forces coming from the longitudinal, lateral and vertical directions. The main carrier in the longitudinal direction has a certain size and cross-section; A is named long outside edge, B short outside edge, D long inside edge, and C short inside edge. It is shown in Figure 4.a. Lateral carriers are of certain size and cross-section. D_1 is called the outer diameter and D_2 is the inner diametter. Lateral carrier section is shown in figure 4.b. In this context, the inertia of the dimensions of the critical sections of the longitudinal and lateral carriers has been evaluated and the appropriate size has been selected.



a. Longitudinal main carrier box rectangular hollow

b. Lateral carrier circular hollow section

Figure 4. Cross-Section Area of Carriers

Having a modular design, Lion causes stresses on the chassis due to its weight. In order to perform chassis analysis, the loads on the axle must be calculated. The analyzes were carried out by considering the maximum and real conditions stated in Table 1.

Table 1. Input Parameters

Design Number		**Chassis-1**	**Chassis-2**	**Load Cases** %	**Velocity** km/h	**Max. Acc.** m/s^2
Max Condition	Total Mass (kg)	39 000	39 000	100	0	0
	Front Axle Load (kN) (z)	130	130	100	0	0
	Central Axle Load (kN) (z)	130	130	100	0	0
	Rear Axle Load (kN) (z)	130	130	100	0	0
Real Condition	Total Mass (kg)	35 780	35 780	100	0	0
	Front Axle Load (kN) (z)	123.150	123.150	100	0	0
	Central Axle Load (kN) (z)	115.250	115.250	100	0	0
	Rear Axle Load (kN) (z)	112.590	112.590	100	0	0

The weights and centers of gravity of the modules in the vehicle superstructure are shown in Figure 5. The vehicle center of gravity was calculated using this information.

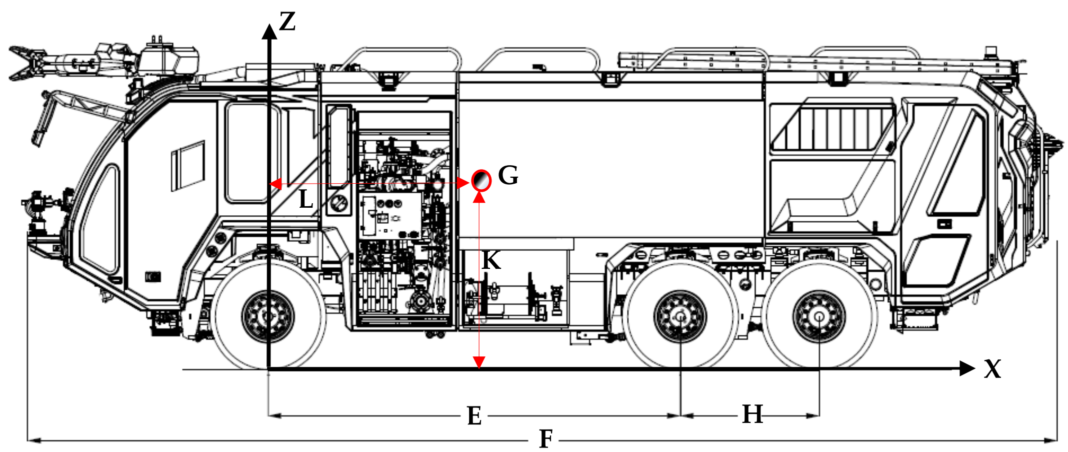


Figure 5. Representation of Static Axle Load Parameters of ARFF Lion Truck

By using the distances between the center of gravity and the axles themselves, the load distributions on the axles are calculated. Axle load distribution image is shown in Figure 6. A multi-axle vehicle mathematical model has been developed and matrix models have been created for dynamic and static axle loads by taking advantage of suspension rigidity in order to reduce the number of unknowns. [7]

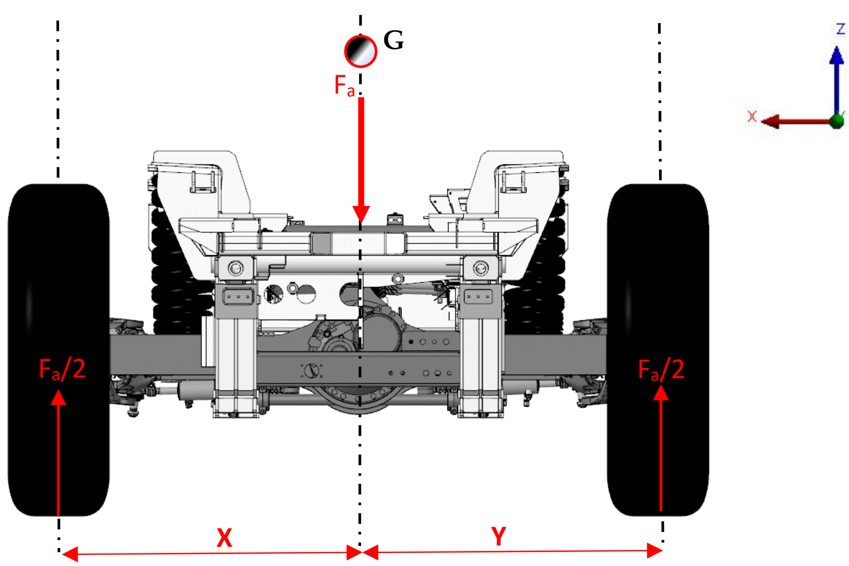
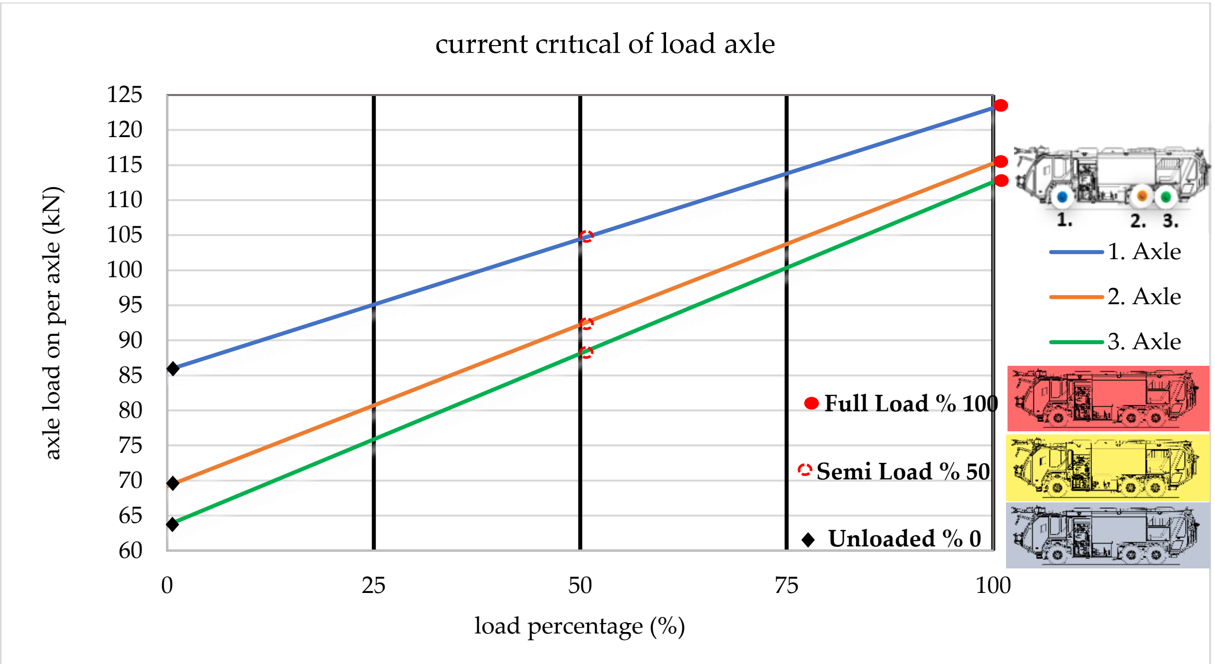
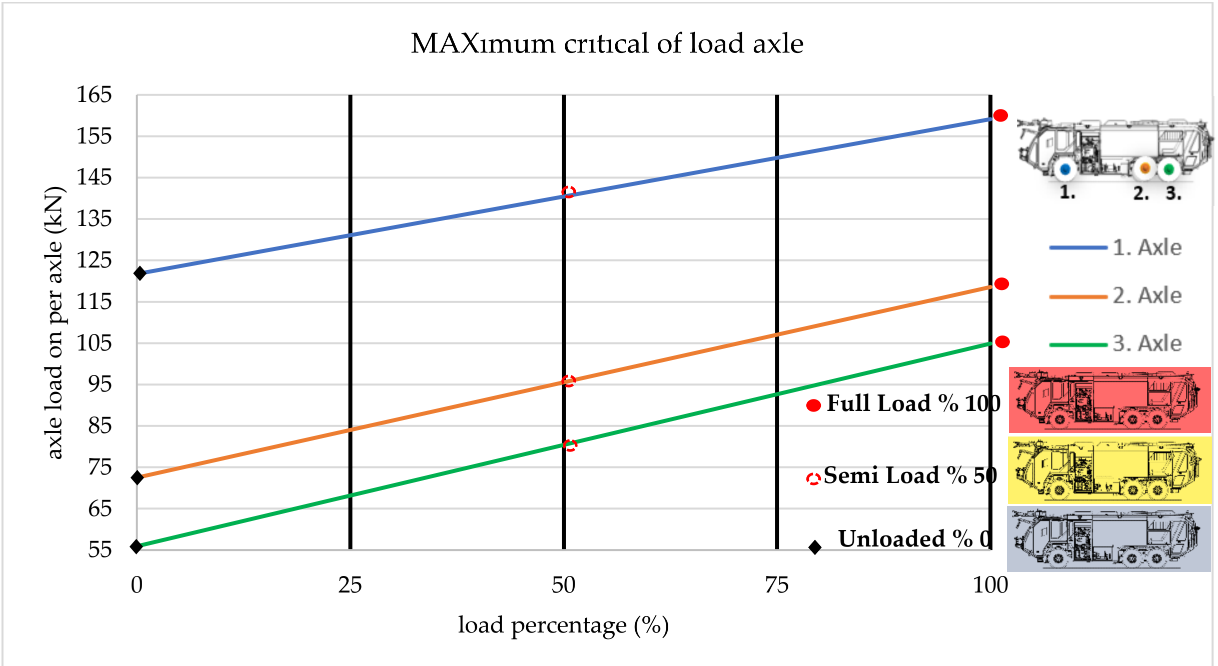


Figure 6. Static Axle Load Distribution Parameters of ARFF Lion Truck

The mathematical model is transferred onto the algorithm. Then, the load distribution graphs on the axles were obtained according to the changing payloads in graphic 1-2. The calculation is made by assuming that there is no acceleration and the vehicle is on a straight road.



Graphic 1. Current Critical Condition of Load Axles



Graphic 2. Maximum Critical Condition of Load Axles

Static axle load and the designed chassis were analyzed in the ANSYS Workbench analysis program within the scope of the design methodology. Critical stresses were evaluated in the design considering the analysis boundary conditions. As a result of the evaluation, the design improvements were renewed and the FE analysis was performed. The sequence of operations used in the design and analysis methodology is given in Figure 7.

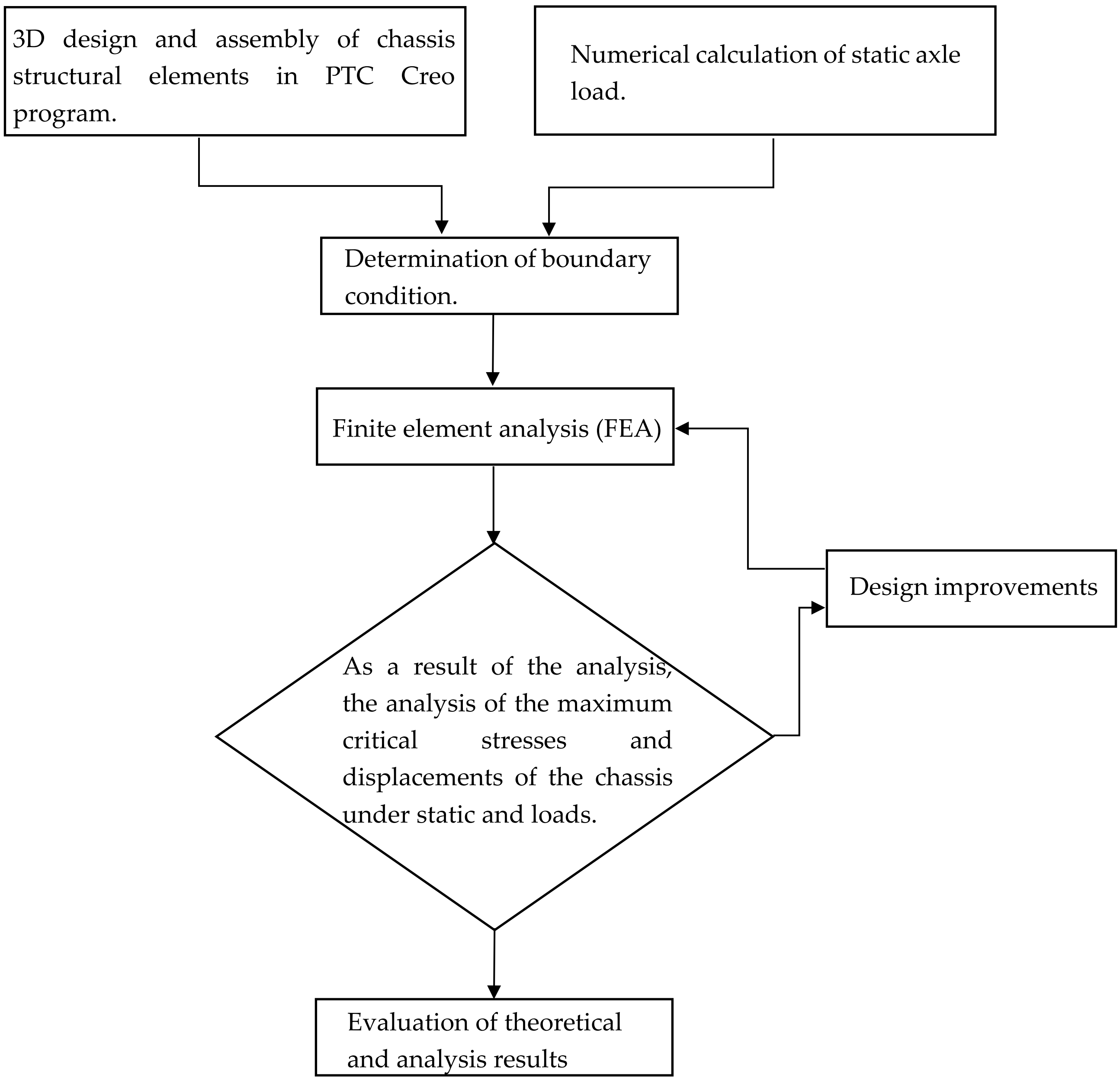
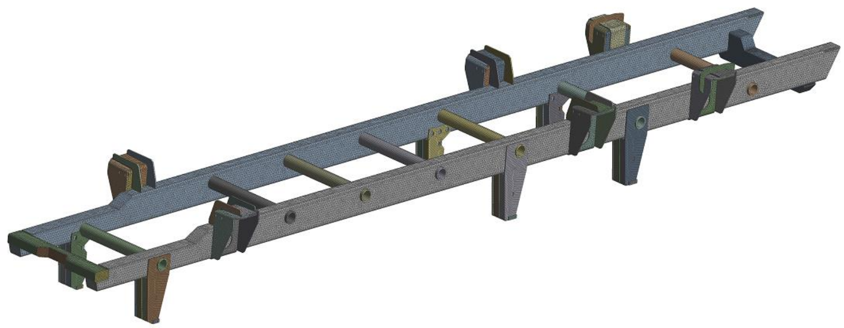


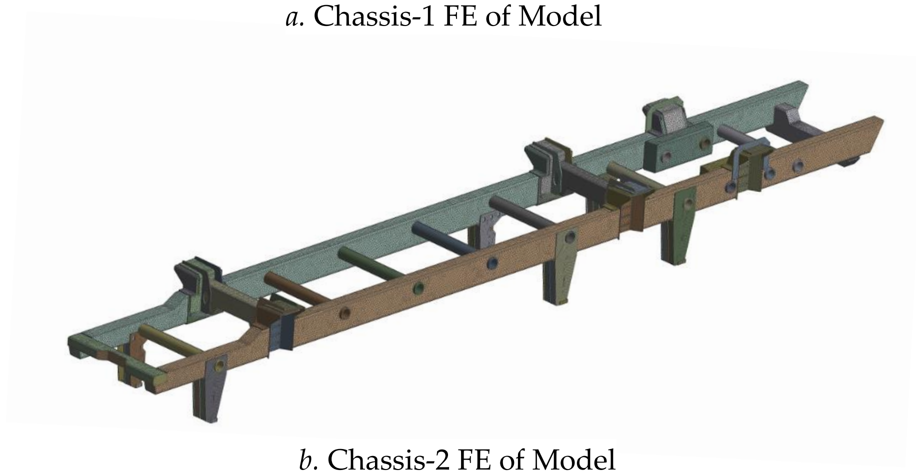
Figure 7. Design Methodology

3. Analysis

Ansys Workbench FE model of chassis with different design is shown in figure 8 a and b.



a. Chassis-1 FE of Model



b. Chassis-2 FE of Model

Figure 8 a. Chassis-1 FE of Model b. Chassis-2 FE of Model

In the ANSYS Workbench 21 package program used for analysis, mesh was made in accordance with certain mesh qualities and the mesh information is shown in Table 2.

Table 2. Mesh Information of FE Models

Design Number	Element Number	Nodes Number	Mesh Quality
Chassis-1	465027	1232356	0.71022
Chassis-2	879858	2407617	0.70101

Input parameters for analysis of ladder type chassis with two different designs are shown in Table 3.

Table 3. Analysis Input Parameters

Case Number	Analysis State	Design No	Weight (kg)	Force (N)	Critic Joint Force (N)
Case 1	Max. Load	Chassis-1	2.600	390 000	65 000
Case 2	Current Load	Chassis-1	2.600	357 800	61 575
Case 3	Max. Load	Chassis-2	2.900	390 000	65 000
Case 4	Current Load	Chassis-2	2.900	357 800	61 575

Two different ladder type chassis are defined as rigid, and the connection parts are provided with frictionless support from 12 points where the axle link arms are located for each chassis. Then, contact points were evaluated based on the thickness and joint distances of the parts in accordance with the welded joint. Connection type and contact points were selected in accordance with the production conditions of structural steel welded ladder type chassis, and the structural elements of the chassis were assembled and associated.

Boundary conditions were created by making engineering comments according to the strain condition of the longitudinal wefts and sleepers. According to the forces applied within the boundary conditions, analyzes were made for a total of 4 different cases for two different ladder type chassis. For all analyses, stress distribution value and displacement changes of structural steel welded ladder type chassis were investigated.

Exaggerated images of the stress distributions of the analyzes are shown in figures 10-13-16 and 19, while detailed images are shown in figures 9-12-15 and 18. The displacement values are shown in figures 11-14-17 and 20.

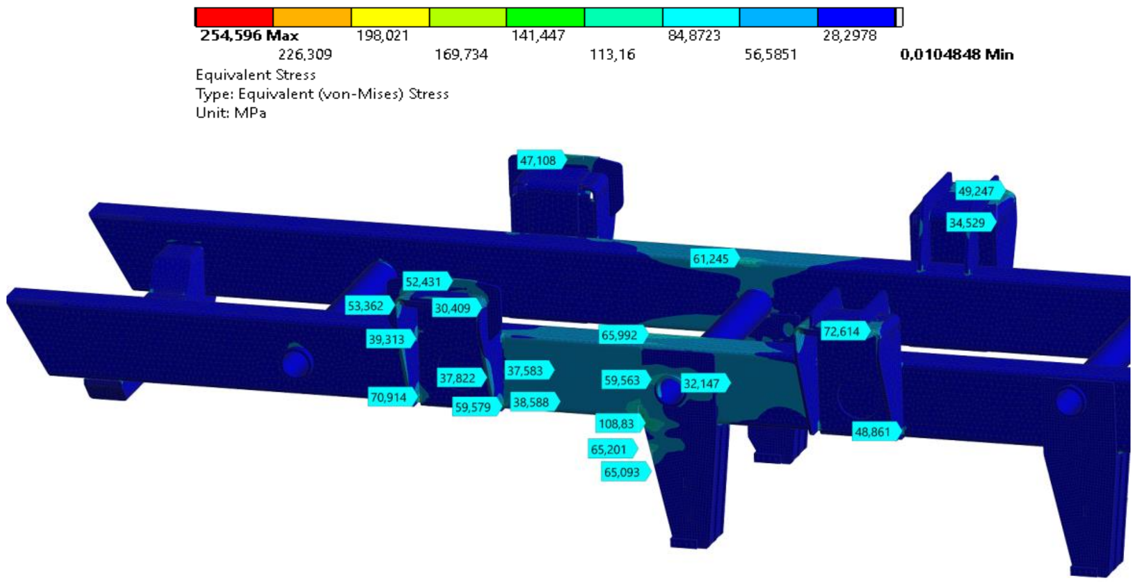


Figure 9. A′ Detail Stress Distribution of Chassis-1 Structure Under Maximum Critical Load

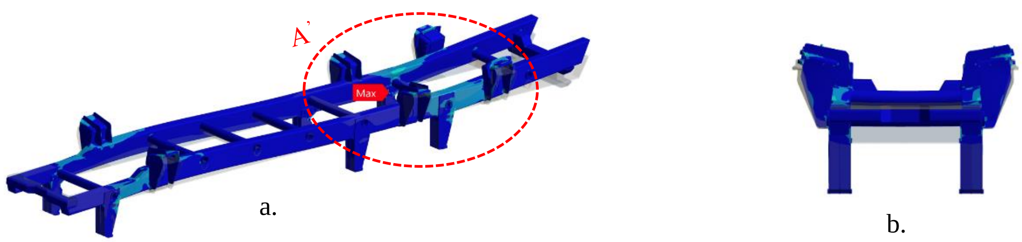


Figure 10. Stress Distribution of Chassis-1 Structure Under Maximum Critical Load
a. Isometric view b. Front view

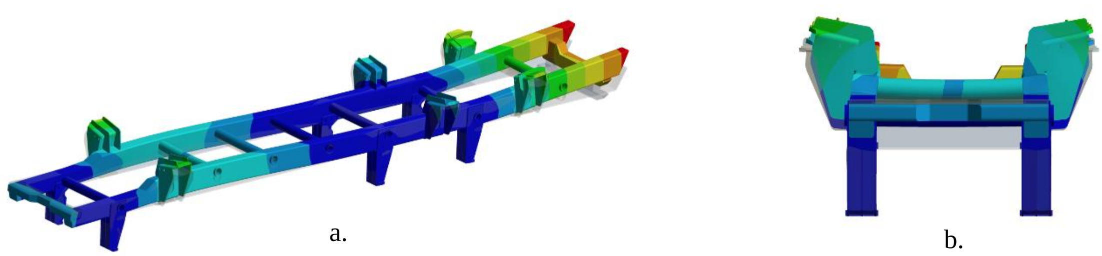


Figure 11. Displacement of chassis-1 Structure Under Maximum Critical Load
a. Isometric view b. Front view

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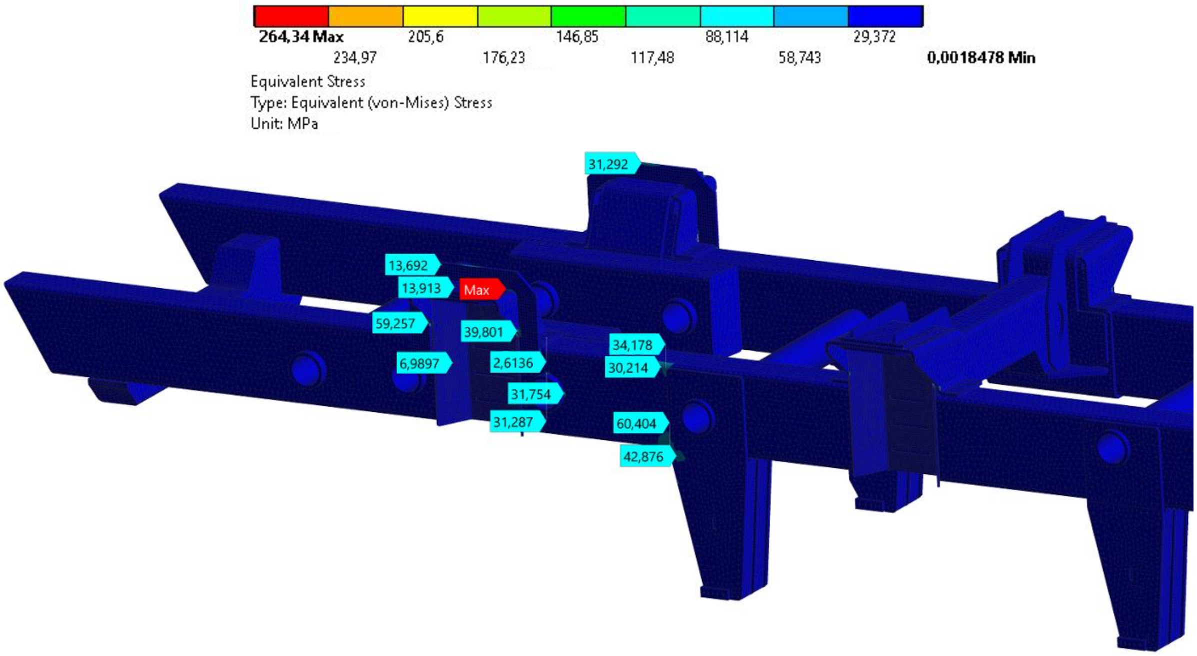


Figure 12. B′ detail Stress Distribution of Chassis-2 Structure Under Maximum Critical Load

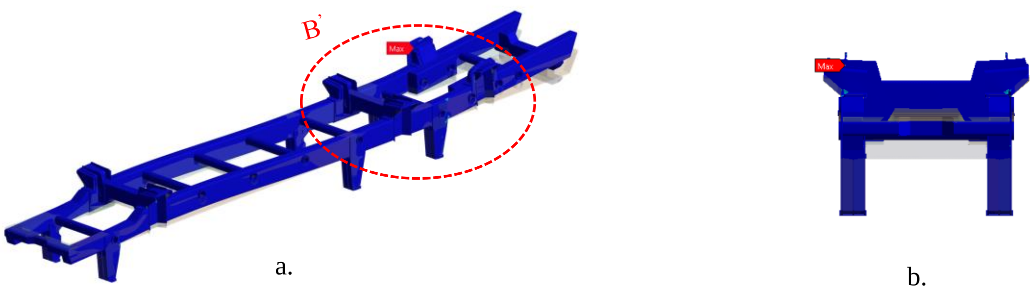


Figure 13. Stress Distribution of Chassis-2 Structure Under Maximum Critical Load
a. Isometric view b. Front view

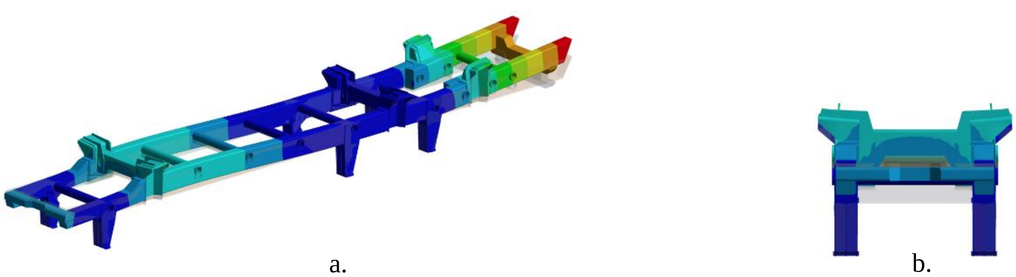


Figure 14. Displacement of Chassis-2 Structure Under Maximum Critical Load
a. Isometric view b. Front view

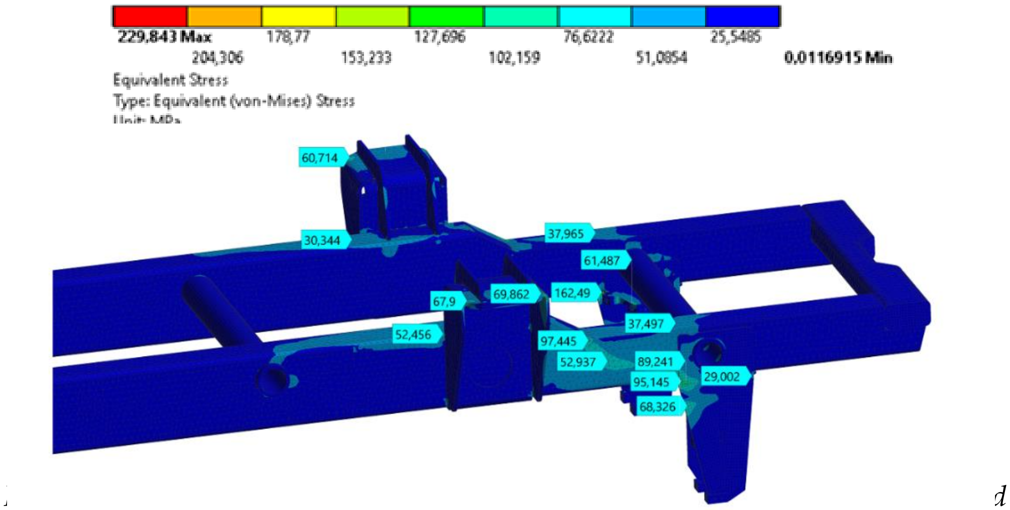


Figure 15. C′ detail Stress Distribution of Chassis-1 Structure Under Current Load

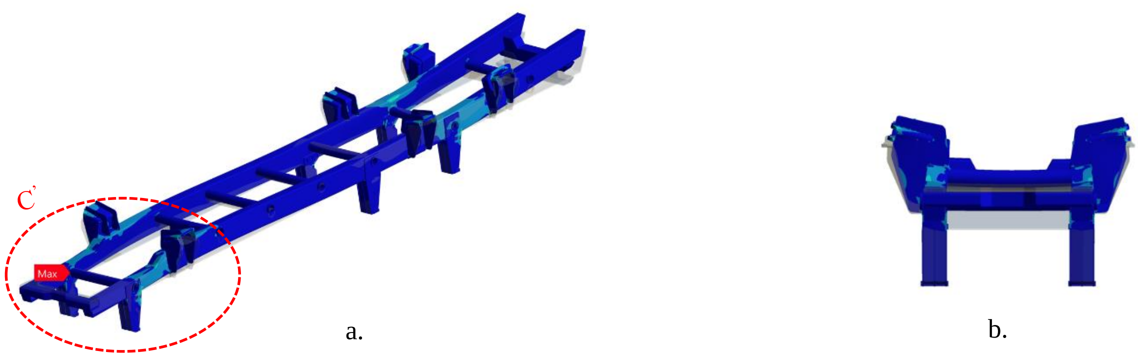


Figure 16. Stress Distribution of Chassis-1 Structure Under Current Load
a. Isometric view b. Front view

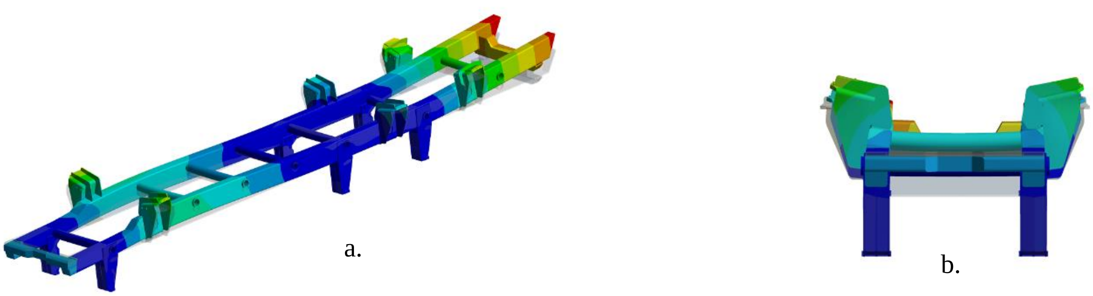


Figure 17. Equivalent Total Displacement Distribution on the Full Chassis-1 Structure
a. Isometric view b. Front view

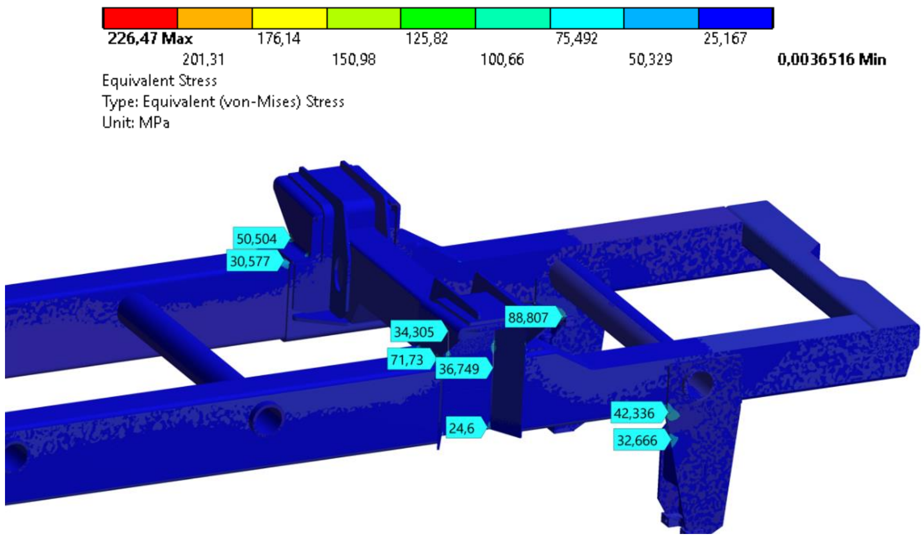


Figure 18. D′ Detail Stress Distribution of Chassis-2 Structure Under Current Load

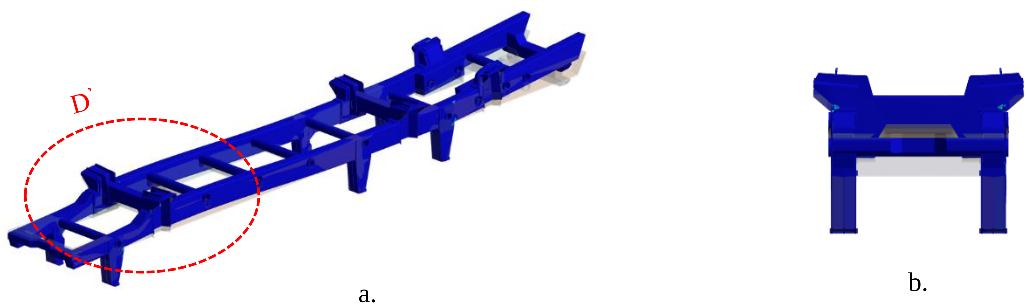


Figure 19. Stress Distribution of Chassis-2 Structure Under Current Load
a. Isometric view b. Front view

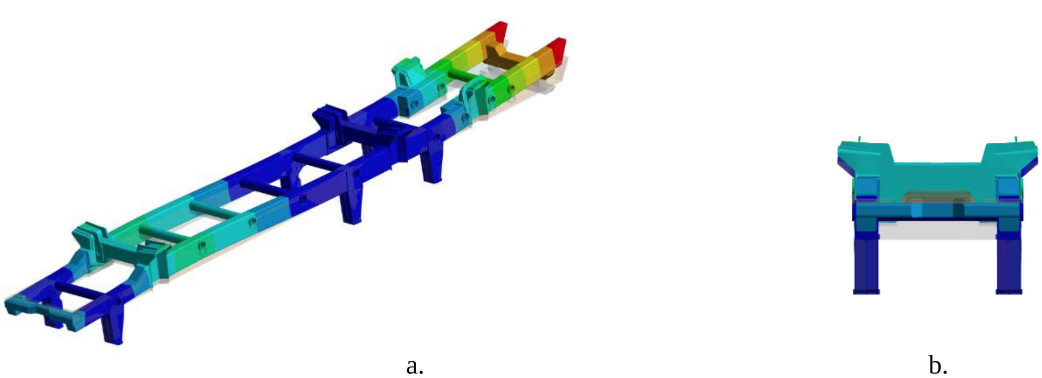


Figure 20. Equivalent Total Displacement Distribution on the Full Chassis-2 Structure
a. Isometric view b. Front view

4. Results

In this study, the stress conditions of the 6x6 ARFF vehicle were examined in detail considering that it was operating under heavy loads in static condition. Afterwards, the boundary conditions of the chassis, which are of great importance for the infrastructure framework are examined in detail. In this context, the finite element (FE) method was applied for the structural elements of two different chassis under critical and current loads. Stress and deformation values were evaluated based on 4 different types of structural analysis. While the stress values under maximum critical load are in the spring towers of the 2nd and 3rd axles, which include the engine compartment of the chassis and the water tank, are in the brackets of the axle connecting arms, the stress values under the current load, cabin section and front module suspension arm and draw-compressive of the 1st axle the connection of the arms has been detected.

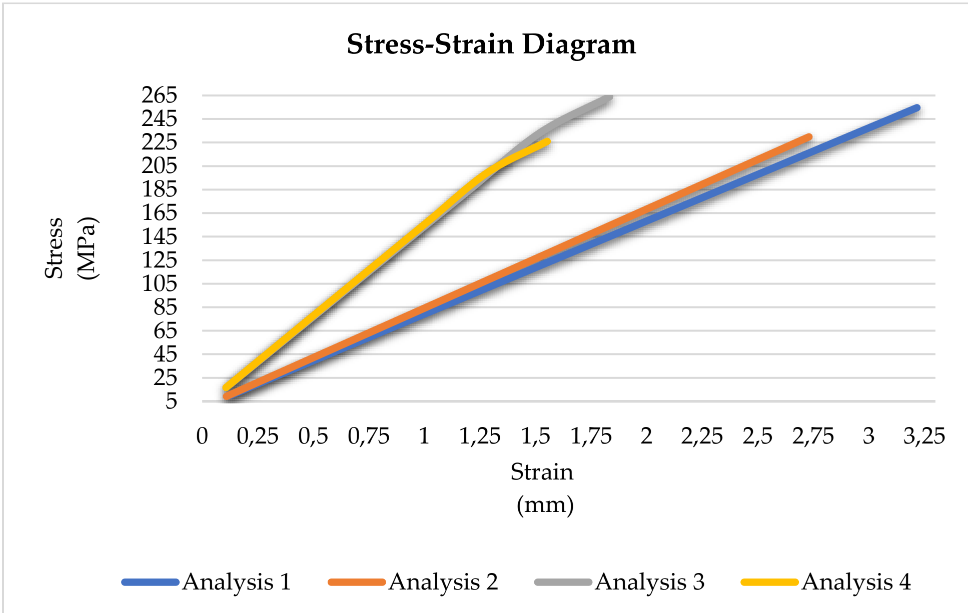
Isometric and front view images of the stress and displacement analysis results of chassis-1 and chassis-2 designs under maximum critical load are shown in exaggerated views in Figures 10, 11, 13 and 14. For Chassis-1, it the stress values varies between 20 MPa and 108 MPa, on the other hand, stress values of 13 MPa-60 MPa were observed for chassis-2. Under current load, isometric and front view images of the stress and displacement analysis results of chassis-1 and chassis-2 designs are shown in exaggerated views in Figures 16, 17, 19 and 20. For Chassis-1, the stress values varied between 29 MPa-162 MPa, while values between 24 MPa-88 MPa were observed for chassis-2. A' stress distribution is shown in detail in Figure 9 for Chassis-1 under maximum critical load, and B' stress distribution is shown in detail in Figure 12 for chassis-2. The C' stress distribution is shown in detail in Figure 15 for Chassis-1 under current load, and the D' stress distribution in Figure 18 for Chassis-2.

Table 4. Output Parameters of FEA

Case Number	Analysis State	Design No	Analysis No	Max Stress (MPa)
Case 1	Max. Load	Chassis-1	Analysis-1	254
Case 2	Current Load	Chassis-1	Analysis-2	264
Case 3	Max. Load	Chassis-2	Analysis-3	229
Case 4	Current Load	Chassis-2	Analysis-4	226

Analysis conditions, maximum stress result values are shown in Table 4 in detail.

The stress and strain change graph of the Chassis-1 and Chassis-2 designs are shown in Graphic 3.



Graphic 3. Stress-Strain Diagram of Analysis-1, Analysis-2, Analysis-3 and Analysis-4

5. Discussion and Conclusion

Stress variation is observed in following parts at two different ladder type chassis; welded joints of cross-members, suspension arm, and axle connection brackets. The lateral and longitudinal carrier's cross-section and size have a great importance for the multi-directional forces acting on the chassis. In addition, for the welded process of the carriers, part thickness, part geometry and thermal effects, welding types are important factors as well. While designing the chassis of the vehicle, the structural conditions of the structural elements should not be ignored under static and dynamic axle load conditions.

6. Acknowledgements

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