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Makale / Research Paper

Topology Optimization of Truck Chassis Under Multi Loading Conditions

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Abstract: In design stage, weight-strength balance is the most important factor to obtain minimum weight value. Try and error method is used to obtain this balance in the conventional design applications. In the last decades, topology optimization methods are used to calculate this balance. The main objective of topology optimization is to obtain strong and lightweight parts with the same characteristics as well as to reduce the amount of material in the parts. Weight of the vehicles is one of the main effective parameters in terms of fuel consumption for the structural engineering applications. Vehicles are subjected to weight load, brake load and centrifugal load when driving mode. Hence, within this study, topology optimization of truck chassis was investigated under the these loading conditions. ANSYS workbench program was used to perform the proposed study. Deformation and stress values of the chassis were investigated. Optimized model was compared with the conventional model. As a result of the study, nearly 14% mass reduction was obtained without exceed permissible stress values.

Keywords: Topology optimization; truck chassis; numerical analyses; deformation and stress values

Çoklu Yükleme Koşulları Altında Kamyon Şasisinin Topoloji Optimizasyonu

Özet: Tasarım aşamasında, ağırlık-mukavemet dengesi minimum ağırlık değerini elde etmek için en önemli faktördür. Geleneksel tasarım uygulamalarında bu dengeyi sağlamak için deneme ve yanılma yöntemi kullanılmıştır. Son yıllarda, bu dengeyi hesaplamak için topoloji optimizasyon yöntemleri kullanılmaktadır. Topoloji optimizasyonu, uygulanan yükler altında verilen sınırlamalara ve sınır koşullarına göre malzeme tasarım alanını optimize eden matematiksel model olarak tanımlanabilir. Ayrıca topoloji optimizasyonu sayesinde malzeme direngenlik açısından dengelenebilir. Topoloji optimizasyonunun temel amacı, aynı özelliklere sahip güçlü ve hafif parçalar elde etmenin yanı sıra, parçalardaki malzeme miktarını azaltmaktır Taşıtların ağırlığı, yapısal mühendislik uygulamalarında yakıt tüketimi açısından etkili parametrelerden biridir. Araçlar sürüş esnasında ağırlık yüküne, fren yüküne ve viraj yüküne maruz kalmaktadır. Bu nedenle, bu çalışma kapsamında, kamyon şasisinin topoloji optimizasyonu bu yükleme koşulları altında uygulanmıştır. Önerilen çalışmayı gerçekleştirmek için ANSYS workbench programı kullanılmıştır. Şasinin deformasyon ve gerilme değerleri incelenmiştir. Optimize edilmiş model geleneksel modelle karşılaştırılmıştır. Çalışma sonucunda kamyon şasisinde izin verilen gerilme değerleri aşılmaksızın yaklaşık %14 oranında kütle azalımı elde edilmiştir.

Anahtar kelimeler: Topoloji optimizasyonu; kamyon şasisi; numerik analiz; deformasyon ve gerilme değeri

1. Introduction

In engineering designs, the load carrying systems of the vehicles that will be designed with the aim of carrying loads are of great importance. In particularly, it must be taken to ensure, that weight balance of the vehicle and the required strength values are maintained, in the design of the main load bearing systems of vehicles in motion. Nowadays, there are standardized chassis types used as

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main carrier system in land vehicles. However, when the literature is examined, it is not seen that optimization of the chassis of these vehicles is performed.

Determination of the vibration characteristics of the truck chassis including natural frequencies and mode shapes was carried out by Fui and Rahman [1]. In this study, the stress distributions using finite element technique according to different loading conditions were examined. According to the analysis, the connection positions of the components such as engine and suspension were determined. Some modifications to increase the strength of the chassis and to reduce vibration were also proposed

Stress analyzes was performed by Aykanat according to the loads on the chassis in his thesis [2]. Natural frequency of the system was obtained by using modal analysis. According to the results of the analysis, improvements on the chassis were performed and mass reduction was realized.

Optimization of the automotive chassis by examining the concepts of maximum shear stress, equivalent stress and bending were performed by Patel *et al* [3]. In this study, finite element techniques were used. It was aimed that to reduce weight on the vehicle chassis.

Stress analysis of carrying heavy loads trucks was performed by Rahman *et al* [4]. Finite element analysis of the truck model was investigated by using ABAQUS analysis program. The connection points of the bolts with the chassis as critical stress points were obtained. It was determined that fracture start point according to the critical stress points

Torsional stiffness of heavy-duty truck chassis was determined by applying arc model, hole model, block model and multi-hole model using finite element technique by Kurdi *et al* [5]. Torsional load was applied to the chassis and the torsional rigidity was studied to design a low weight chassis. Obtained results from the study were shown that multi-hole model was found to be the most suitable in terms of torsional stiffness and minimum weight.

A model was developed for heavy vehicles to determine the fastest and best route according to the geometric and physical characteristics of the road by Kumaş *et al* [6]. In the proposed study, important factors for vehicle speed were determined. some formulations for the speed of heavy vehicles traveling on various roads on various roads were explained. In determining the best route, geographical information system was used to determine the ways in which the vehicle can move according to the loading type and physical characteristics.

Stress and dynamic analysis of ladder-type truck chassis were carried out by Mahmoodi-k *et al* [7]. After the study using ABAQUS analysis program, it was concluded that open U-shaped profiles were sufficient for weight reduction. ANSYS modal analysis was used to determine vibration and mode shapes. According to the results, the optimized chassis was improved according to driving conditions.

Stress and deformation analysis using finite element technique was carried out in the case of bending and torsional loads by Wang *et al* [8]. Stress concentration regions were determined and modal frequency analysis was performed. As a result of the low frequency values obtained, topology optimization was applied to the chassis. According to obtained results, variable cross section and type chassis design was made.

Bending and torsion analyzes were performed for the chassis density of the standard dump truck by Asker *et al* [9]. Two models, which the wheels are under zigzag block or under normal block, were formed. The analyzes were performed by using hyper elastic elements in ANSYS analysis program. According to the results, significant differences were observed between the two models.

A finite element analysis was carried out to reduce weight on a 16-ton truck chassis by Tikerar and Damle [10]. Altair Hyperworks 13.0 was used to calculate stresses and displacements on the chassis. In addition, the effects of material change on some factors were also investigated.

Load mapping technique was used to obtain low weight designs by Lowrie *et al* [11]. It was found that the hollow shaft was optimized and cavitated. As a result, 26% material saving was obtained. In addition, it was found that intensive quenching was more suitable than oil quenching in terms of both residual stresses and force and by this method found that it removed 3% of the weight of the shaft.

Element removal method, which was improved for the topology optimization, was applied to the three-dimensional parts by Kütük ve Göv [12]. A comparison was performed between obtained results and found in the literature results. Thus, the developed method was verified. The effects of the method on the solution time were also investigated.

Research on fatigue analysis techniques of truck chassis were examined by Nega and Hui [13]. In order to avoid overlap of the natural frequency of the chassis and the excitation frequency, it was found that natural frequency and vibration modes were analyzed during the loading time. It was emphasized that fatigue is one of the most important parameters to consider when designing the components used in the truck. It was understood from the studies that these components are subjected to dynamic loads during the time the truck is in motion.

2. Summary of the Literature

In the literature review conducted within the scope of this study, it was observed that there are many publications or studies related to parts or systems of heavy load vehicles. However, there was no study on the simultaneous multi-load behavior of truck chassis and subsequent optimization of the material distribution using the topology optimization method for the chassis. Therefore, in this study, it was aimed to remove the excess materials from the chassis by applying topology optimization according to the stress values when the truck chassis was subjected to weight load, brake load and centrifugal load.

3. Materials and Methods

3.1. Creation of the Three-Dimensional Truck Chassis Model and Topology Optimization

3.1.1. Creation of the chassis model

The ladder-type truck chassis, which is frequently used among truck chassis models, was formed by using U-type profiles in accordance with Kenworth model in the 3D SOLIDWORKS modeling program as shown in Fig. 1.

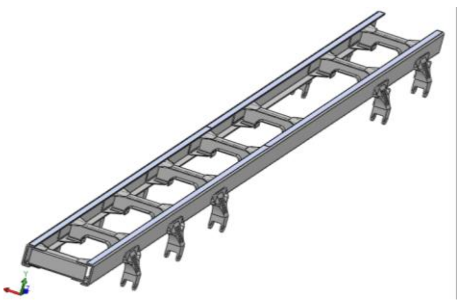

Figure 1. Isometric view of truck chassis model

3.1.2. Structural analysis of the chassis model

The structural analysis of the truck chassis created in the SOLIDWORK three-dimensional modeling program was performed using the ANSYS workbench program static structural tool. Topology optimization was performed by using structural analysis results. The static structural analysis was performed again by re-arranging the geometry generated by topology optimization (Fig. 2).

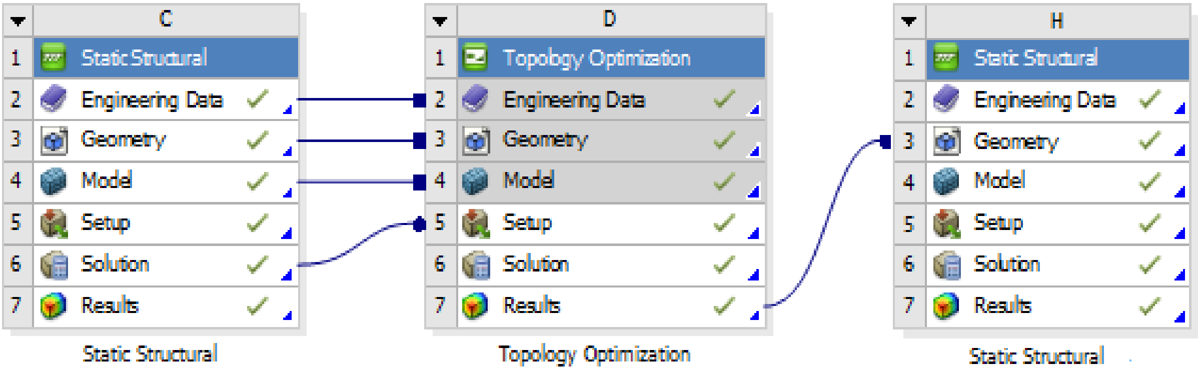

Figure 2. Structural analysis and topology optimization scheme

3.1.2.1. Structural analysis

The modeled chassis in the SOLIDWORK program for structural analysis, and the mesh model for the whole chassis was formed as shown in Fig. 3. Mesh accuracy was performed in order to verify the used mesh structure. The most suitable number of elements was determined to be 100000 elements and was shown in Fig. 4.

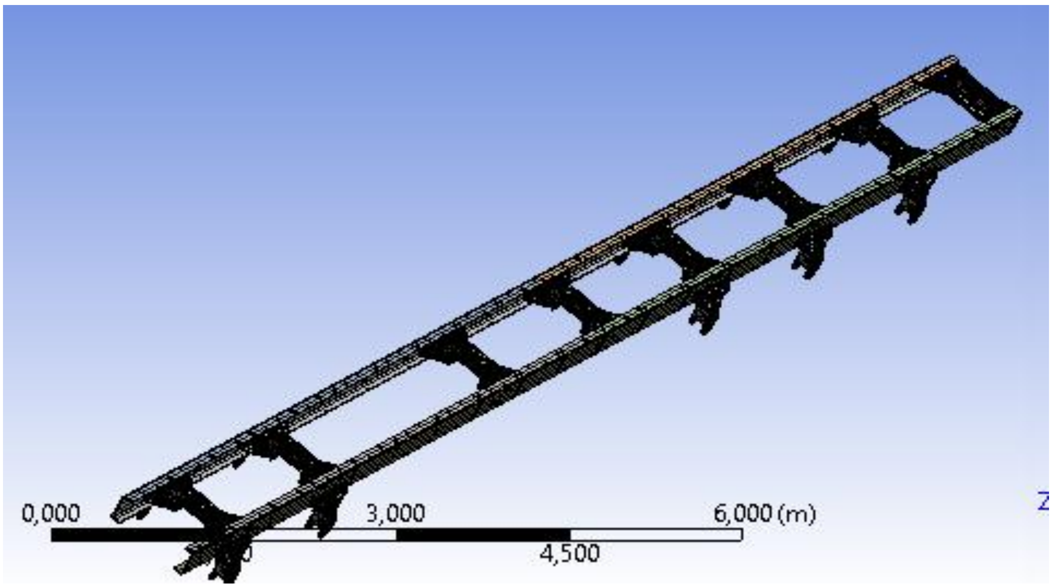

Figure 3. Mesh structure view

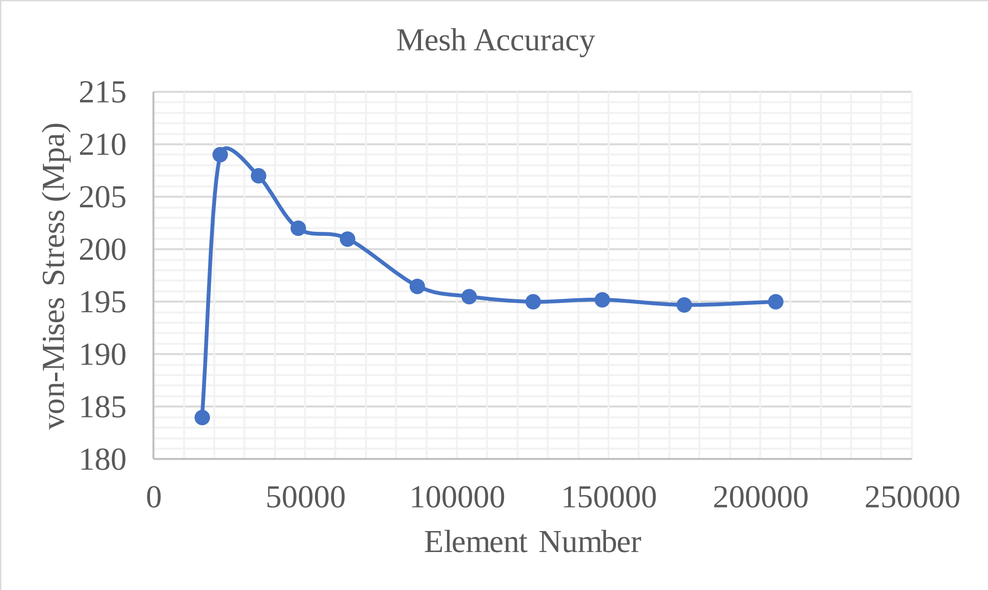

Figure 4. Mesh accuracy

In order to make the designed structural analysis to be real, the wheel was fixed by the cylindrical support through the connection holes as in Figure 5. The weight load (Fig. 6), the brake load (Fig. 7) and the cornering load (Fig. 8) were then given in Table 1.

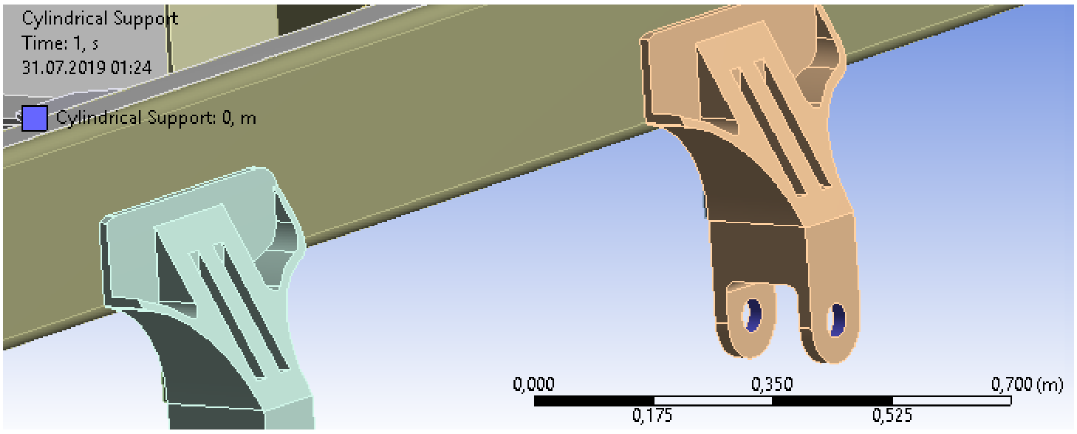

Figure 5. Cylindrical support application position.

Table 1. Load on chassis

Load type	Amount (N)
Weight load (Front axle)	95000
Weight load (Rear axle)	220000
Brake load	315000
Centrifugal load	157500

Since loads affect the front and rear axles separately, the distribution of the weight load was defined separately in the structural analysis [14].

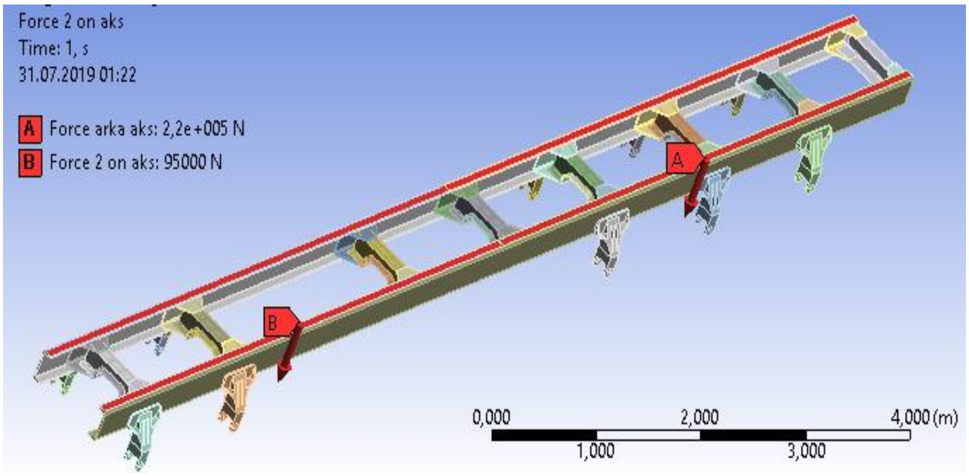

Figure 6. Weight load

For safety, the force for braking was applied as 1.g (about the weight load) as shown in Fig. 6 [2]. Again, for safety reasons, a centrifugal load of 0.5 g (half of the weight load) was used due to the centrifugal force and the lateral inclination of the road [2].

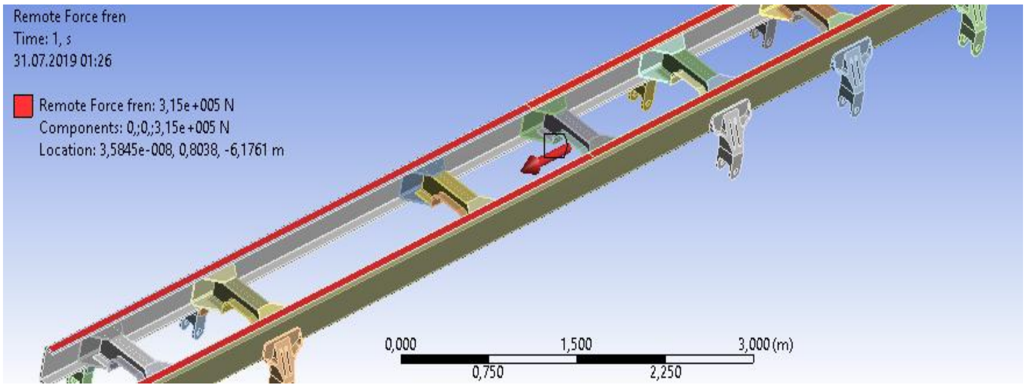

Figure 7. Brake load

In the definition of brake load (Fig. 7), Remote Force loading type was used to apply load from the center of gravity of the chassis. Likewise, in the definition of centrifugal load (Fig. 8), the Remote Force loading type was used.

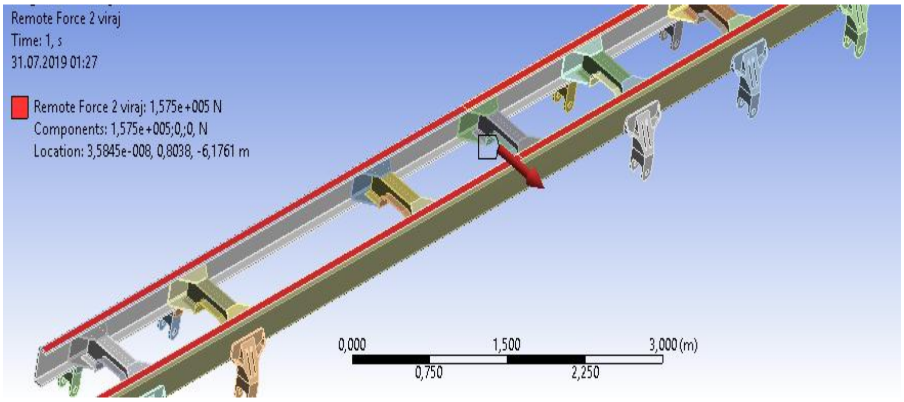

Figure 8. Centrifugal load

As a result of the structural analysis, deformation and von-Mises stress values were obtained as shown in Fig. 9 and Fig. 10.

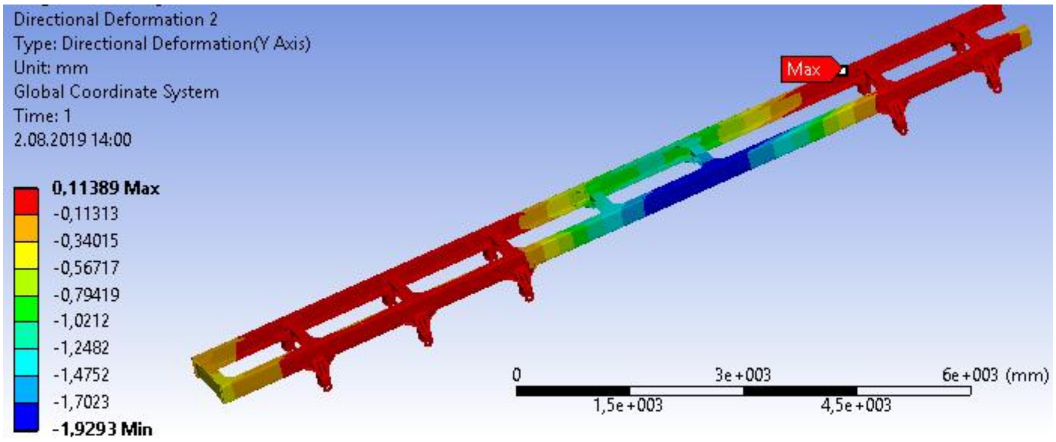

Figure 9. Deformation value

St-50 steel was defined as the chassis material and analyzes were performed. The yield point of St-50 steel is 295 MPa [15]. Since the maximum stress value obtained from the stress analysis was 194 MPa, it was aimed to lighten the chassis by applying topology optimization.

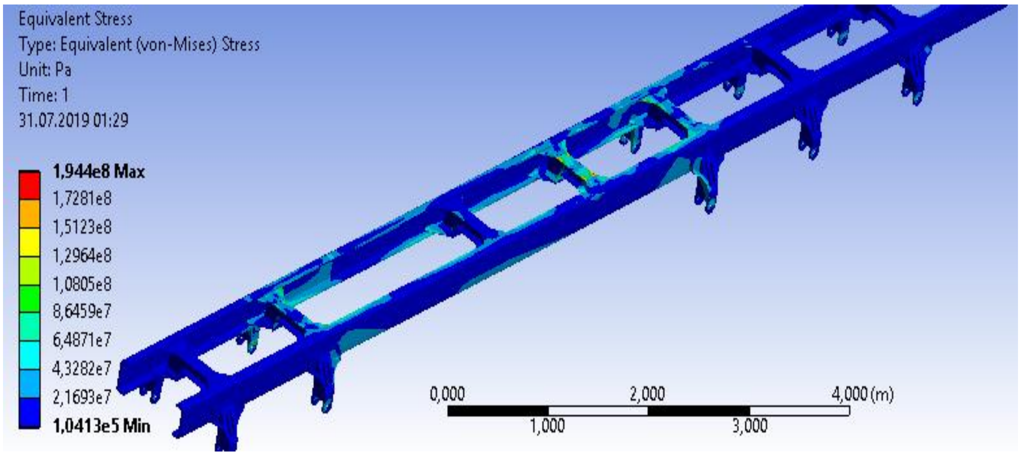

Figure 10. Von-Mises stress value

3.1.2.2. Chassis topology optimization

Topology optimization can be defined as a mathematical model that optimizes the material design area according to the constraints and boundary conditions given under applied loads. The main purpose of topology optimization is to reduce the amount of material in the parts as well as to obtain strong and light parts with the same characteristics.

The topology optimization was applied to the truck chassis and the geometry shown in Fig. 11 was obtained by using the results of the stress analysis,

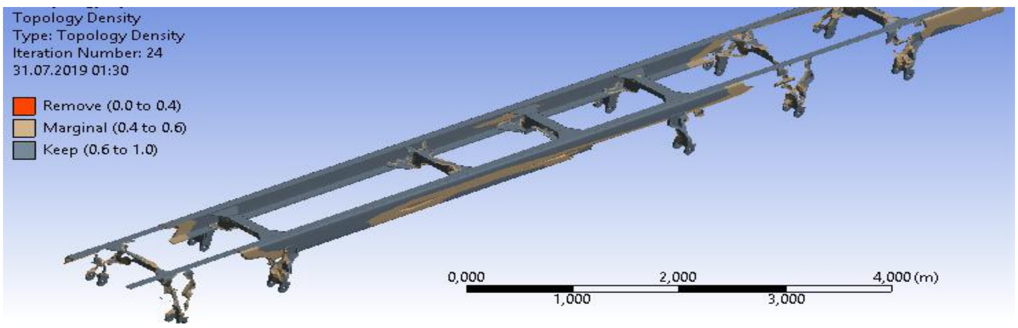

Figure 11. Topology optimization result

The optimized chassis geometry was remodeled to reduce weight by removing the stress-free zones from the chassis as shown in Fig. 12 and Fig. 13.

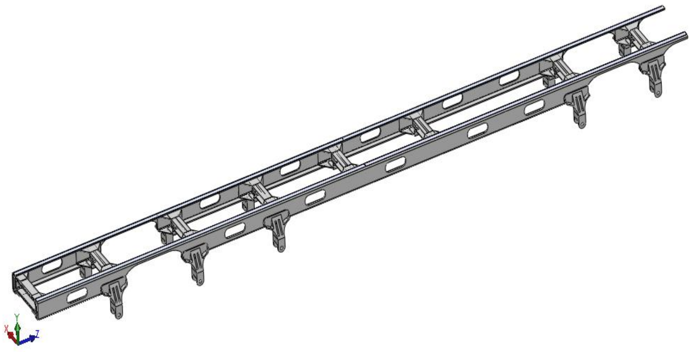

Figure 12. Optimized chassis view 1

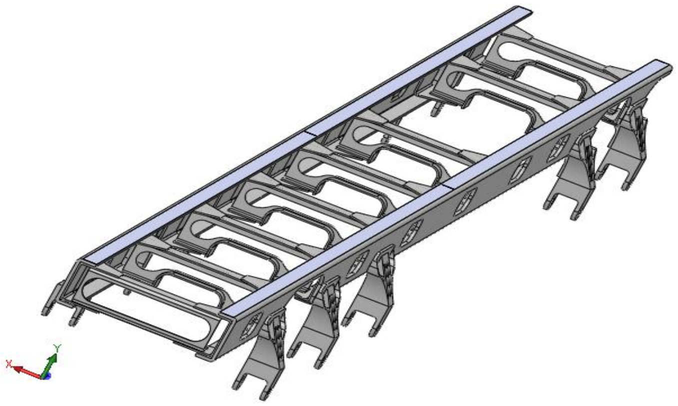

Figure 13. Optimized chassis view 2

The cylindrical support was applied at the wheel attachment points as in the first structural analysis (Fig. 14).

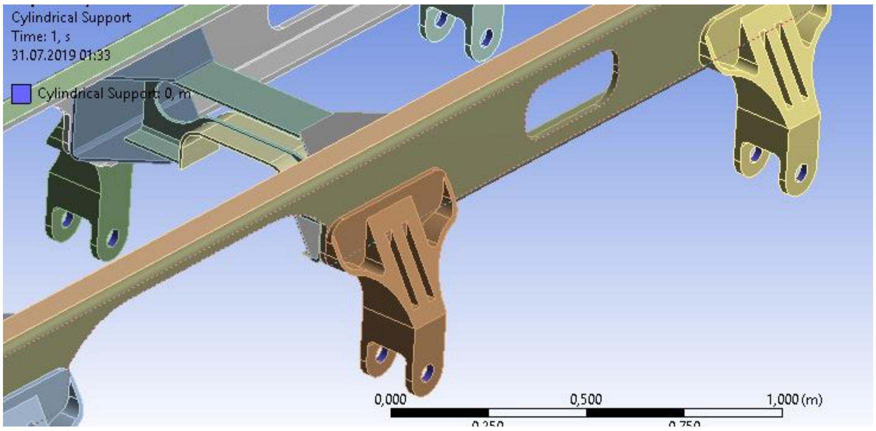

Figure 14. Cylindrical support for optimized chassis

The weight load on the optimized chassis was applied as shown in Fig. 15, the brake load in Fig. 16 and the centrifugal load in Fig. 17.

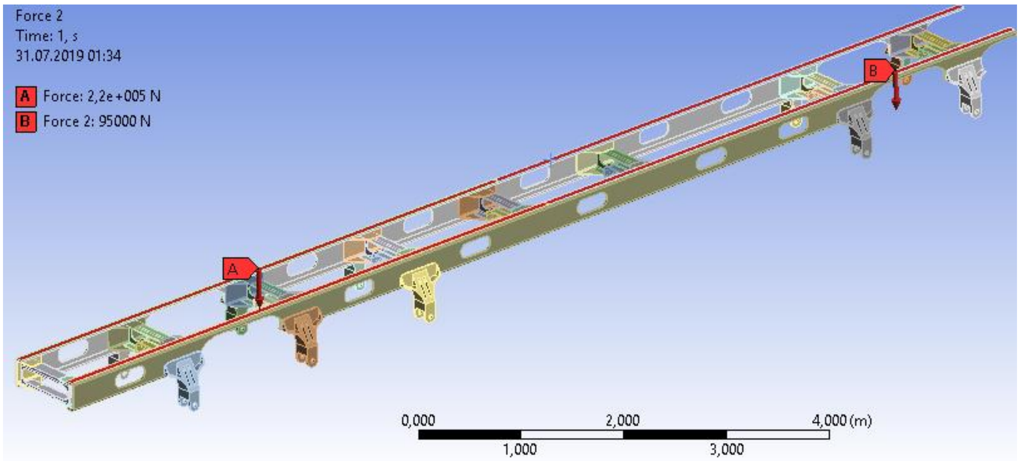

Figure 15. Weight load applied to the optimized chassis

While the structural analysis of the geometry, which was obtained after topology optimization, was performed, the loads and boundary conditions applied in the first analysis were applied in the same way and from the same places. In this way, a more meaningful comparison was performed in terms of geometry and weight.

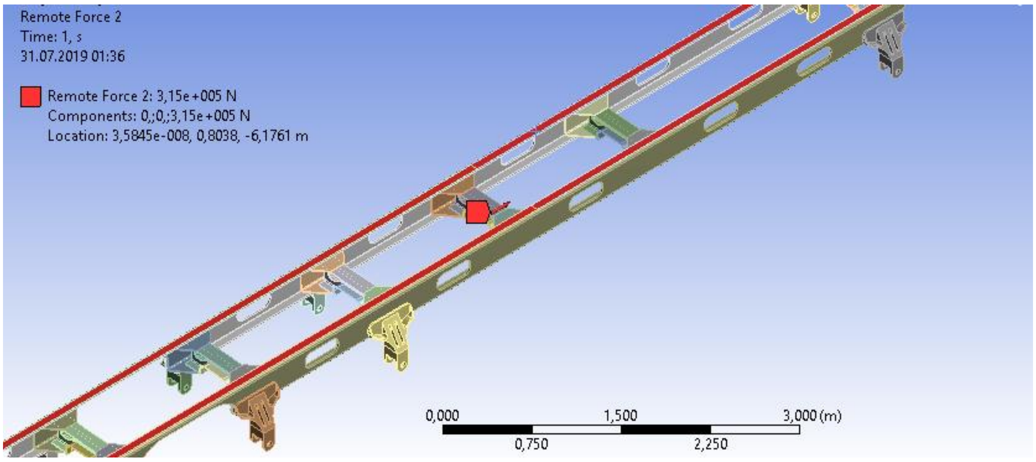

Figure 16. Brake load applied to the optimized chassis

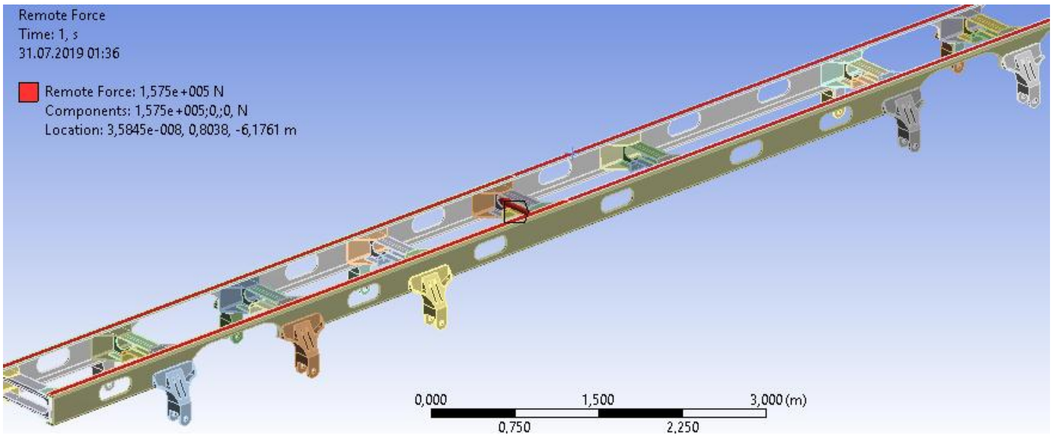

Figure 17. Centrifugal load applied to the optimized chassis.

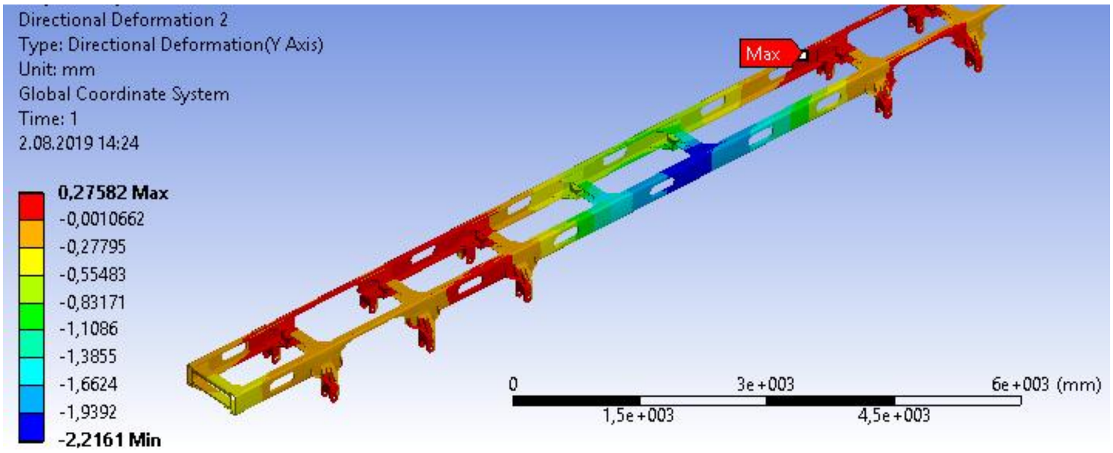

Figure 18. Optimized chassis deformation value.

According to the results of the structural analysis of the new chassis model obtained from topology optimization, the deformation (Fig.18) was observed to increase by approximately 13%. However, it was found that the von-Mises stress value (Fig. 19) increased by approximately 14%.

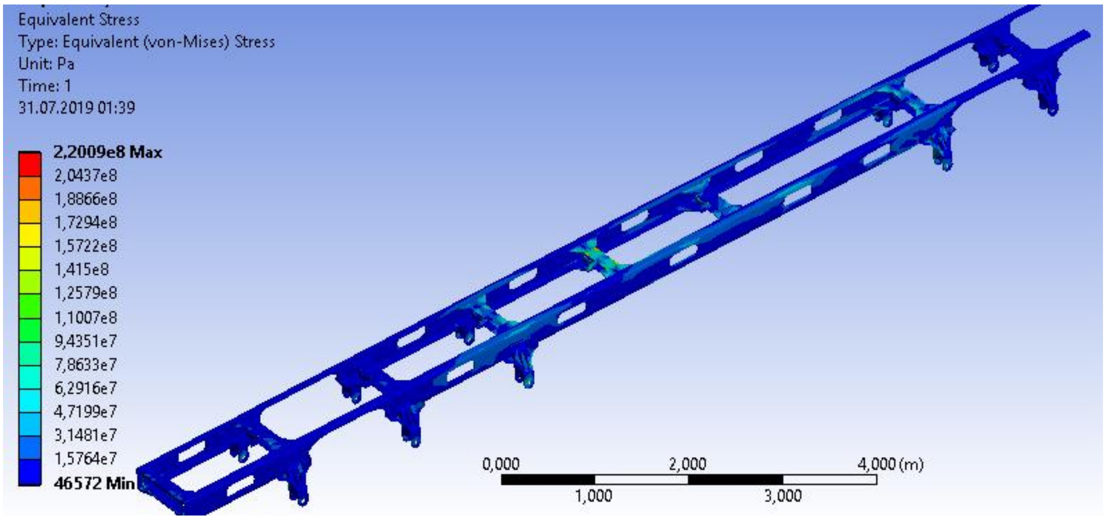

Figure 19. Optimized chassis stress value.

4. Results and Discussions

The weight of vehicles is one of the main parameters in terms of fuel consumption in structural engineering applications. The main purpose of topology optimization is to reduce the amount of material in the parts as well as to obtain strong and light parts with the same characteristics.

In this study, reduction of the chassis weight by applying topology optimization was performed for the truck chassis exposed to different loading types at the same time. It was found that the weight of the non-optimized model was 2685 kg and the structural analysis results revealed that the von-Mises stress value was approximately 194 MPa. It was concluded that the weight of the chassis obtained after topology optimization was approximately 2316 kg and the von-Mises stress value was approximately 220 MPa.

At the end of the study, it was concluded that the weight of the truck chassis was reduced by approximately 369 kg without compromising the required strength values. However, it was considered that the producibility and production costs of the new chassis geometry obtained after optimization should be examined.

5. Conclusions

Road vehicles are subjected to load types such as weight, braking and centrifugal loads while driving. Under the influence of these loads, the truck chassis must be durable. However, it is inevitable that the strength-weight balance should be optimal. Therefore, in this study, the topology optimization of the truck chassis was carried out under these loading conditions.

According to the results of the topology optimization, the weight of the recreated truck chassis decreased by approximately 14%. According to the MIT(XXX) report, trucks save 3000 liters of fuel per 200000 km, if the weight of the truck decrease nearly 300 kg [16]. Based on the fact that the trucks drive approximately 300,000 km per year, it was found that approximately 4,500 liters of fuel can be saved per year for each truck. When the trucks moving on the roads in our country are taken into account, it is revealed that this fuel saving will contribute to the national economy significantly. In another study, efficiency analysis can be made by taking into consideration the production difficulty and cost of optimized geometry.

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