TRUCK CHASSIS STRUCTURAL THICKNESS OPTIMIZATION WITH THE HELP OF FINITE ELEMENT TECHNIQUE

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Abstract: Heavy duty vehicles like trucks, has wide range of structural and conceptual design. In Turkey ground transportations and heavy duty works like mine and rock transportation are made with Long Vehicles and especially with middle tonnage trucks (10 – 40 tones). Many truck chassis manufacturers use thick profiles for the chassis for reliability of the frame. Using more than enough material causes expensive product manufacturing conditions. To reduce the expenses of the chassis of the trucks, the frame's structure design should be changed or the thickness should be decreased. In this study, for manufacturing reliable and inexpensive middle tonnage truck chassis, used chassis structures by some manufacturers are optimized by the thicknesses of the profiles. This study showed that the thinner chassis profiles can be reliably used in the truck chassis sections with the help of structural finite element analysis.

Keywords: Truck Chassis, Finite Element Technique, Thickness Optimization

INTRODUCTION

For more strength and reliable frame of the trucks, all manufacturers are trying to produce strong and cumbersome chassis. Every strength increase of the chassis by adding beams and structural elements makes the whole frame heavier and more expensive. The easiest technique for reducing both weight and cost of the chassis is using less chassis member or decreasing the thickness of the profiles sections. Initially, the most important part of the frame design is, the chassis reliability and safety. When decreasing the thickness of the sections the optimal design criteria should have been considered. For making a cheap truck frame might cause a destructive accident results and fatality. To make a reliable and inexpensive design thickness and cost optimization should be examined with details.

For understanding the robustness of the chassis or vehicle body by the strength tests of the members and whole frame, different studies were widely carried out as it is mentioned below.

Every vehicle has a body, which has to carry both the loads and its own weight. Vehicle body consists of two parts; chassis and bodywork or superstructure. The conventional chassis frame, which is made of pressed steel members, can be considered structurally as grillages. The chassis frame includes cross-members located at critical stress points along the side members. To provide a rigid, box-like structure, the cross-members secure the two main rails in a parallel position. The cross-members are usually attached to the side members by connection plates. The joint is riveted or bolted in trucks and is welded in trailers [1, 2].

When rivets are used, the holes in the chassis frame are drilled larger than the diameter of the rivet [2]. The rivets are then heated to an incandescent red and driven home by hydraulic or air pressure. The hot rivets conform to the shape of the hole and tighten upon cooling. An advantage of this connection is that it increases the chassis flexibility. Therefore, high stresses are prevented in critical area. The side- and cross-members are usually open-sectioned, because they are cheap and easily attached with rivets. An experimental and numerical analysis of riveted joints was studied by Fung and Smart [3]. A three-dimensional finite element model of a riveted lap joint was formulated with shell elements and elastic supports to allow for simulation of various levels of load transfer [4]. Xiong used analytical and numerical methods, for the stress analysis of riveted lap joints in aircraft structures [5]. In the numerical method, finite element analyses were conducted using some commercial packages. Nut and bolt construction are also used in chassis frame as this allows easy removal of components for repair or replacement purposes. As far as joint modeling techniques are concerned, there are many studies to determine the joint stillness in bolted connections through detailed finite element modeling or experiments [6, 7].

Different static or dynamic testing methods and variety of failure criteria are major diverging factors especially in Finite Element Method. Although the scope of these regulations does overlap for some groups of vehicles, none of the regulations specifically address paratransit style vehicles. This lack of regulation is troubling because the overall stiffness and resistance of the vehicle depend very much on the structural design solutions, applied materials, the connection to the vehicle chassis, and especially the connections between the major body components. All of these factors are dependent solely on the body builder, and as such can vary widely with the company's resources and experience [8].

The usual economic forces of reducing numbers of prototypes, minimization of testing/design iterations, optimizing gages and weight, and shortened design cycle time are driving people toward this objective. The vision is to 'drive' a computerized vehicle over a digital version of the proving grounds, observe the vehicle load responses, and 'watch' the stress histories on any or all of the elements that model the body and components of the vehicle. After geometry or thickness optimization the procedure is repeated until the achievement of the design life standard at minimum weight [9].

The body (i.e. the tray) of a large rear-dump mining truck generally accounts for 20}25% of the total empty vehicle mass and is the heaviest single item of the truck. In a typical 172-t capacity truck, the body weighs about 29 t. Therefore, one way to reduce the mass of the truck, and hence increase its load-carrying capacity, is to reduce the mass of the body [10]. The reason is of course that the designer makes an effort to reduce the mass of the structure, while limiting the deformation. It is inevitable that stress levels increase and that the deformations for the as-loaded condition increase [11].

In automotive and aerospace industries, engineers are challenged to design load-carrying components that are strong enough to sustain heavy impact, cyclic or random loads for structural integrity of the mechanical system. Such components must also contain a minimal amount of material to reduce material consumption in production and increase the efficiency of the mechanical system, such as fuel consumption. The geometry of the load-carrying components is usually complicated due to strength and efficiency requirements. Such requirements often increase manufacturing cost of the component [12].

Structural optimization research has been conducted for many decades, addressing mainly functionality aspect of the structural design [12-15]. Reliability issues have been addressed for design in recent years [16-18]. However, manufacturability, which plays a significant role in determining the cost of the engineering product, has not been widely incorporated for structural optimization [12].

In this study for manufacturing robust and economic middle tonnage truck chassis, used chassis structures by companies are optimized by the thicknesses of the profiles. In daily usage, Turkish truck chassis companies are manufacturing frames, thickness of 6mm. For determining the strength of the frame, structural analyses were performed for these frames of thicknesses of 6mm, 5mm and also 4mm. The truck chassis was modeled in Pro_Engineer and the finite element analyses were solved in Pro_Mechanica.

MATERIALS

In the chassis manufacturing technology, especially steel and its alloys are used for the material of the frame geometry. For the frame models, wide variety of materials, composite materials and different kind of alloys can be used. In the present study, manufacturer doesn't want to change its material type because of the supplier and not to changing their manufacturing methods and materials etc. Truck Chassis Company uses St 52.3 steel for the whole chassis geometry in Istanbul, Turkey. The material properties of the St 52.3 steel is given in table 1.

Table 1: Material properties of the Truck Chassis (St 52.3).

Young Modulus	199GPa
Poisson Ratio	0.27
Density	7827.08kg/m^3
Symmetry	Linear isotropic

In the finite element analysis of the truck chassis, linear isotropic material model of St 52.3 was used.

MODELING AND OPTIMIZATION ANALYSIS

The chassis manufacturer in Istanbul, Turkey wants to reduce the expenses of the company and the truck chassis structure. First step to reduce the expenses is decrease the cross members of the truck chassis. In the chassis just main members are used as needed. It is not a choice to use fewer members in frame.

The second way to decrease the cost of the frame is using thinner sections for the profiles. There should be a limit for the thickness. If the limit is exceeded, the truck chassis is no longer robust or reliable. Initial CAD part of the truck chassis was modeled in Pro_Engineer. Constrained and loaded CAD model can be seen in figure 1.

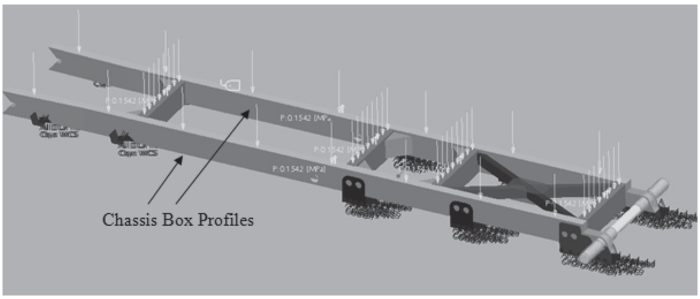

Figure 1. Truck chassis and loading condition.

For the distributed load values, manufacturer's data tables were used. 156.96kN (16t) distributed load was applied to the whole chassis geometry (Figure 2). In addition the pressure for the whole top surfaces (0.1542MPa) can be determined in figure 1. Chassis was held from the bolt holes of the brackets in All DOF.

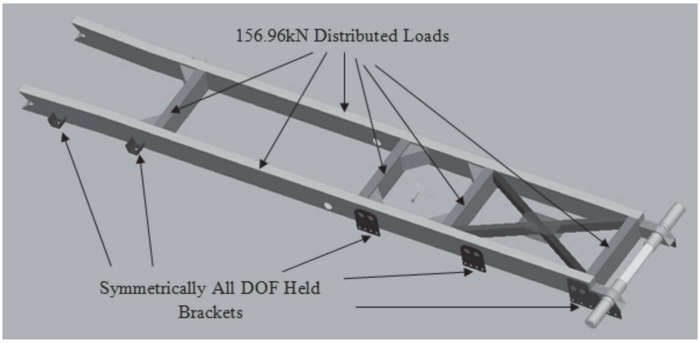

Figure 2. Distributed load and constraints.

For the structural analysis, Finite Element Model was prepared. Meshed finite element model of the truck chassis is given in figure 3.

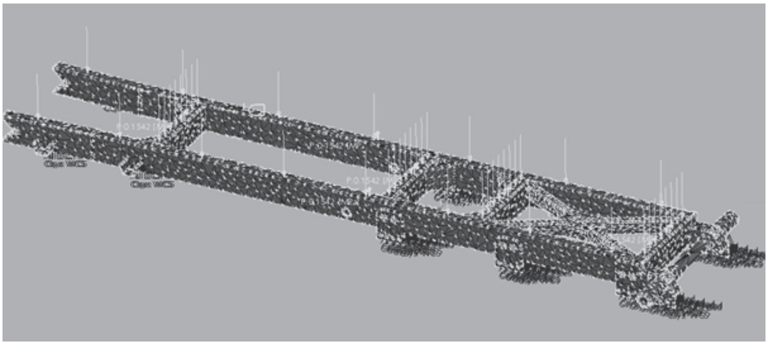

Figure 3. Truck chassis Finite Element Model.

To obtain a reliable and robust chassis design, structural simulations of thickness optimizations were carried out with the help of Pro_Mechanica code. The thickness of 6mm, 5mm and 4mm sectioned chassis structures are analyzed and evaluated. The analyses were processed with static and structural methods. The results are compared by the Von-Misses Stresses, strains and total displacements.

RESULTS AND DISCUSSION

In daily usage 6mm sectioned chassis is reliable but heavy and expensive. For decreasing the thickness of the chassis profile, structural thickness optimizations were performed for 6mm, 5mm and 4mm. The total displacements for the frame thickness of 6mm, thickness of 5mm and thickness of 4mm, can be seen in figure 4-6.

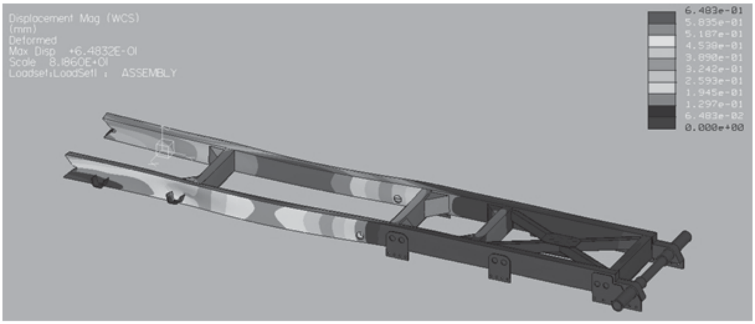

Figure 4. Total displacement results behavior for the thickness of 6mm sectioned truck chassis.

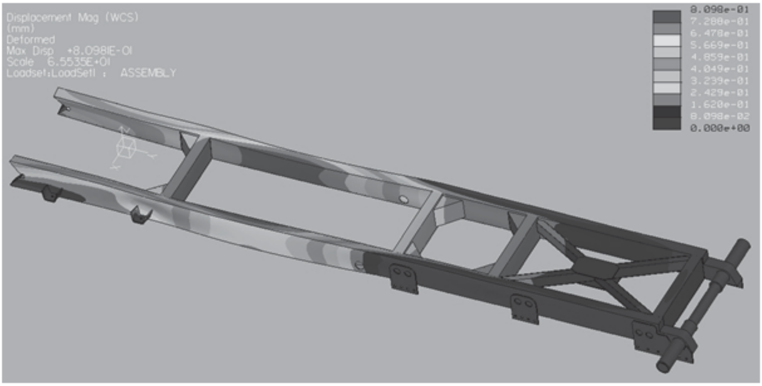

Figure 5. Total displacement results behavior for the thickness of 5mm sectioned truck chassis.

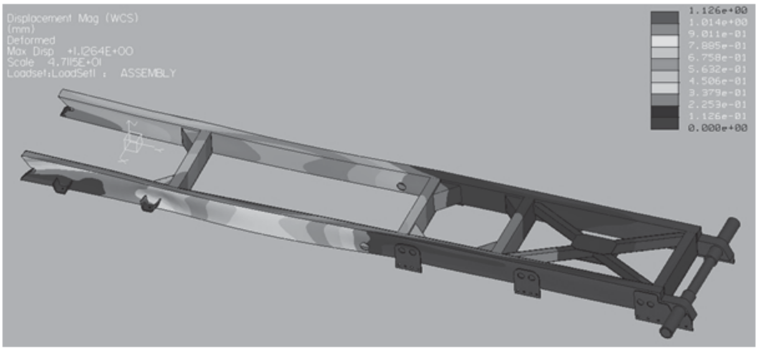

Figure 6. Total displacement results behavior for the thickness of 4mm sectioned truck chassis.

For comparing more detailed, displacement results should be supported with the help of maximum Von_Misses stresses and the strains. To see whole picture of the finite element analyses of the structural optimization max. stresses, max. strains and total displacements are given in table 2.

Table 2: Max. stresses, max. strains and total displacements of the Truck Frames.

Chassis Section Thicknesses	**Max. Von-Misses Stress (MPa)**	**Max. Principle Strain (%)**	**Total Displacement (mm)**
6mm	857.9	0.005155	0.6483
5mm	945.6	0.00566	0.8098
4mm	1045	0.006246	1.126

In the static analyses of Ford 3530 chassis, thickness of 6mm (original model), 5mm and 4mm square profile of chassis about 16t linear distributed load condition were examined.

Broken stress value of used St. 52.3 steel material is about 350-400MPa. In finite element analysis the stress values can be more than these values. The reason is the manufacturer requirements as a linear, elastic and static analysis. In the elastic analysis, stress value is getting bigger without encountering any resistance. In addition the static tensile tests are processed in the single direction and axis. In the reality loads can be effected different angles. This situation makes the max. stress value is bigger. In the chassis analyses max. Von_Misses stresses for 6mm is: 857.9MPa, 5mm: 945.6MPa and 4mm: 1045MPa.

In this structural analysis strains and displacements are more important. Strains are in mm/mm and show the deformation in %. The principle strains are in thickness of 6mm: %0.005155, in thickness of 5mm: %0.00566 and in thickness of 4mm: %0.006246. The analyses strain results for all thicknesses are acceptable in design criteria.

The total displacements are in thickness of 6mm: 0.6483mm, thickness of 5mm: 0.8098mm and the thickness of 4mm: 1.126mm. The displacement values are less than expected. If the truck loaded with 16t (that is the capacity of this chassis), thickness of 4mm chassis, is bending just about 1mm. This is tiny displacement for a heavy truck. Finally the study showed that a finite element modeling and analysis of the used truck chassis is optimized by the cross member element thicknesses.

For further studies fatigue, dynamic etc. loading conditions can be evaluated as a more realistic determination.

CONCLUSIONS

In this study following results can be drawn:

- The analyses are processed in the static and structural conditions.
- Used 6mm chassis is heavy and expensive.
- For 4mm strain and displacement results are better than expected.
- Thickness of a 4mm truck chassis section profiles can transport a load about 16t, with a 1mm bending.
- The manufacturer is gained much from their expensive chassis, by the optimization analysis of thicknesses for the truck chassis.

ACKNOWLEDGEMENTS

After these structural analyses in static conditions, the truck chassis manufacturer has changed the profiles thicknesses of their chassis. The manufacturer is selling the chassis to the popular vehicle companies around the world. In addition this project is cutting the expenses of the truck chassis manufacturer.

REFERENCES

[1] C. Karaoglu, N. S. Kuralay, Stress analysis of a truck chassis with riveted joints, Finite Elements in Analysis and Design, 38, (2002), 1115–1130.

[2] J.W. Fitch, Motor Truck Handbook, Warrandale, USA, 1994.

[3] C.P. Fung, J. Smart, An experimental and numerical analysis of riveted single lap joints, J. Aerospace Eng. 208, (1994), 70–79.

[4] G. Harish, T.N. Farris, Modeling of skin/rivet contact: application to fretting fatigue, collection of Technical Papers, Proceedings of 38th AIAA/ASME/ASCE Structures, Structural Dynamics and Material Conference, Vol. 4, 1997, pp. 2761–277.

[5] Y. Xiong, Analytical and nite element modelling of riveted lap joints in aircraft structure, AIAA J. 37, (1999), 93.

[6] M. Tanaka, H. Miyazava, E. Asaba, K. Hongo, Application of the nite element method to bolt-nut joints-fundamental studies on analysis of bolt-nut joints using the nite element method, Bull. JSME 24, (1981), 1064–1071.

[7] L. Garro, V. Vullo, Deformations car body joints under operating conditions, SAE861397.

[8] L. Kwasniewski, C. Bojanowski, J. Siervogel, J. W. Wekezer, K. Cichocki, Crash and safety assessment program for paratransit buses, International Journal of Impact Engineering, 36, (2009), 235–242.

[9] F.A. Conle and C.-C. Chu, Fatigue analysis and the local stress–strain approach in complex vehicular structures, Int. J. Fatigue Vol. 19, Supp. No. 1, pp. S317–S323, 1997.

[10] K.W. Poh, P.H. Dayawansa, A.W. Dickerson, I.R. Thomas, Steel membrane floors for bodies of large rear-dump mining trucks, Finite Elements in Analysis and Design 32, (1999), 141-161.

[11] J. Jia, A. Ulfvarson, Structural behaviour of a high tensile steel deck using trapezoidal stiffeners and dynamics of vehicle–deck interactions, Marine Structures 18, (2005), 1–24.

[12] K.-H. Chang, P.-S. Tang, Integration of design and manufacturing for structural shape optimization, Advances in Engineering Software 32, (2001), 555-567.

[13] J.S. Arora, Introduction to optimal design, New York, McGraw-Hill, 1989.

[14] R.T. Haftka, Z. Gürdal, Elements of structural optimization 3rd ed. Norwell M.A: Kluwer Academic, 1991.

[15] G. Vanderplaats, Numerical optimization techniques for engineering design 3rd ed. Colorado Springs, C.O: Vanderplaats Research & Development, Inc, 1998.