Structural analysis of Formula Student vehicle chassis using Ansys software

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Abstract: *Formula Student is a student engineering competition. Students all over the world compete to build a racing vehicle. One of the main elements of this vehicle is the vehicle chassis. The chassis is one of the most important elements from the aspect of driver safety. There are different chassis design concepts. The two most common are the monocoque chassis and the tubular chassis. In this paper, a detailed structural analysis of the tubular chassis of the Formula Student vehicle was performed using the software. The chassis model was created in the CATIA software, and then the structural analysis was done in the ANSYS software. By applying modern software, it is possible to better understand the problems during construction, and significant financial and time savings can be made. ANSYS software can also be of great help in chassis optimization.*

Keywords*: STATIC STRUCTURAL, VEHICLE, CHASIS, FORMULA STUDENT, SPACE FRAME*

1. Introduction

Vehicle chassis used to be made of wood. At that time, wood was a material that had an advantage over metal, especially in the case of the need for complex shapes. After a certain time, the transition to metal chassis followed. This transition took place with the application of intermediate solutions that were a kind of hybrid chassis, that is, chassis that were made with a combination of wood and metal. At the beginning of the development of the automotive industry, chassis manufacturers were private manufacturers who were only engaged in the production of chassis that they sold to vehicle manufacturers. The integration of chassis and body production was developed in the USA and was then taken over in Europe starting in 1920 [1]. The topicality of the topic related to the design of the vehicle chassis is indicated by a large number of works on this topic [2-7]

The Formula Student competition is a student competition in the construction of vehicles. Students from various universities compete in the design and construction of a racing vehicle. One of the crucial parts of this vehicle is the chassis of the vehicle because it has a huge impact on the safety of the driver. A large number of research on the topic related to the Formula Student vehicle chassis [8-15] speaks of the importance of the mentioned topic. This paper aims to present a structural analysis of one such chassis. This work is structured into seven chapters. The first chapter is related to the introduction to the topic of the paper, while the second chapter deals with the theoretical foundations of vehicle chassis in general. The third chapter is devoted to the limitations related to the design of the Formula Student chassis. The fourth and fifth chapters present the structural analysis of the chassis and the results of this analysis. In the sixth chapter, the conclusions related to the topic of the paper are presented, while in the last, and seventh chapters, a list of references used in the paper is given.

2. Vehicle chassis

The purpose of the structure of any vehicle is to unite all the main components that make up the vehicle. These components include various vehicle systems and subsystems such as the engine, gearbox, differential, and vehicle suspension. Also, the task of the vehicle structure is to carry passengers safely and comfortably manner. Previously, vehicles were produced with a special chassis frame to which a non-structural body shell would be attached. The chassis frame must be sufficiently strong and rigid. The reason that the chassis frame must be sufficiently strong and rigid is that the chassis frame carries the load its weight, the weight of the vehicle, and the payload, but also the load due to aerodynamic loads as well as dynamic wheel loads. Most chassis frames are in the form add two longitudinal members that are connected with a certain number of transverse elements. The separate chassis frame and body shell type of construction is still a very popular construction method in the commercial vehicle industry. The reason for retaining this construction method is that different body shells can often be mounted on a common ladder-type frame. Although the principle of separate construction of the body shell and chassis frame is unfavorable due to the significantly higher weight of the chassis frame in this case, this is not so evident in the commercial vehicle industry because these vehicles have a lower own weight than the carrying capacity of the vehicle [16]. An example of a ladder-type chassis frame is shown in Figure 1.

Fig. 1 *Ladder-type chassis frame [17]*

Today, the final form in the development of mass-produced passenger car structures is the integral form of construction. This engineering solution does not have a noticeable separate chassis and the entire body shell is designed as an integral unit capable of receiving loads and providing the necessary rigidity and strength to the vehicle. This form of construction better receives and endures loads, so it can be made with less weight. Such constructions are usually made of light steel or aluminum, and very often they have to be box-type and reinforced with reinforcement. Production of this type requires very complex tools for production and assembly, so its application is justified only in mass production [16]. Figure 2 shows the integral body shell.

Fig. 2 *Integral body shell [1]*

The use of significantly more expensive materials is justified only in limited small series of vehicles. In the production of body shells for supercars and Formula 1 cars, significantly more expensive chassis made of composite materials are used, which provide sufficient strength and rigidity with very low weight.

Class small sports cars use the so-called space-frame chassis. A true space frame is a set of tubular members that are usually welded together and triangulated in such a way that the members carry loads only in tension and compression and do not suffer a significant degree of bending or torsion. An example of this type of construction is the Caterham Super Seven, which is shown in Figure 3 [16].

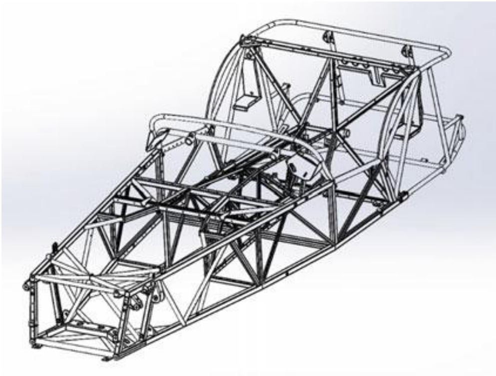

Fig. 3 *Space-frame chassis for small sports car*

3. Formula Student chassis

The design of the Formula Student car chassis must be adapted to the Rulebook [18]. According to the aforementioned regulation, the structure of the vehicle must contain:

- two roll hoops are braced
- on the front part of the shock absorber (Impact Attenuator)
- side impact protection

The minimum requirements that must be met by the chassis in terms of materials if it is made of steel tubes are given in detail in the Rulebook [18]. Alternative materials can be used for all parts of the primary structure except for the main hoop and main hoop bracing, which must be steel. The front hoop must be made of metal. All welded constructions of the primary structure must be made of steel. The front hoop can be an aluminum welded construction. Also, the primary structure of the chassis can be made of composite materials. In Formula Student, a tubular chassis is used more often than a monocoque chassis because it is much simpler to manufacture and also significantly cheaper. Figure 4 shows a space-frame chassis and Figure 5 shows a monocoque chassis.

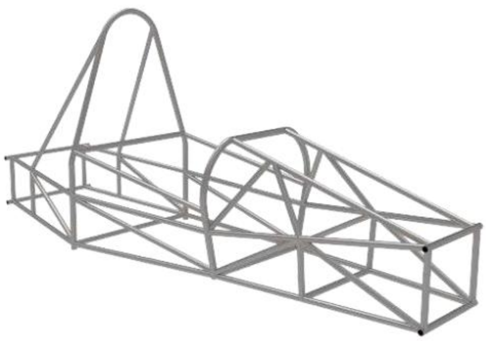

Fig. 4 *Tubular spachassisme chasis [19]*

Fig. 5 *Monocoque chassis [20]*

The front hoop construction must be fastened no lower than 50 mm below the uppermost surface of the front hoop according to Figure 6. The side impact structure design requirement is shown in Figure 7 for the tubular steel chassis, while the side impact structure design for the monocoque chassis is shown in Figure 8.

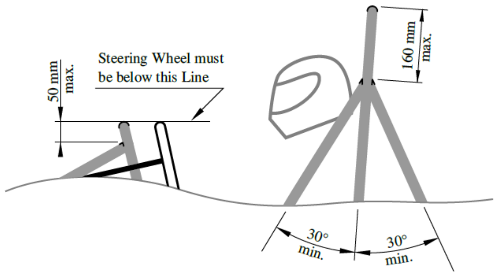

Fig. 6 *Requirements for front hoop bracing, main hoop bracing, and steering wheel bracing [18]*

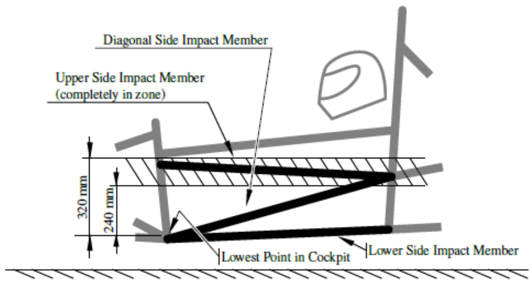

Fig. 7 *Side impact structure for tubular chassis [18]*

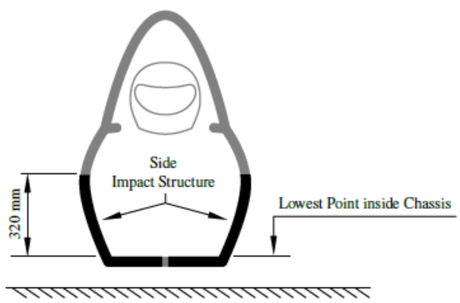

Fig. 8 *Side impact structure for monocoque chassis [18]*

As the Formula Student vehicle must be constructed for 95, the cockpit of the vehicle is precisely The cockpit. The cockpit opening template (left) and cockpit cross-section section template (right) are shown in Figure 9, while Figure 10 shows the minimum helmet clearance requirement.

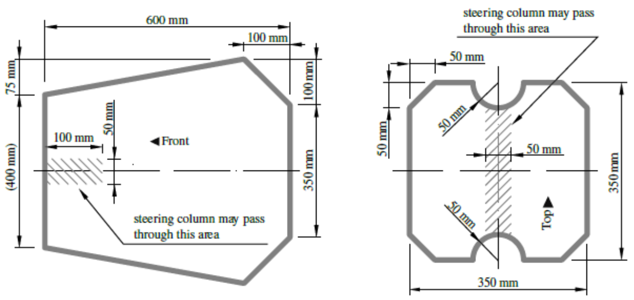

Fig. 9 *Cockpit opening template (left) and cockpit internal cross section template (right) [18]*

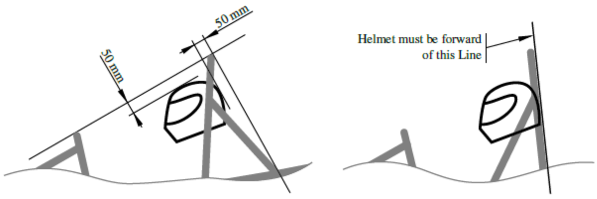

Fig. 10 *Minimum helmet clearance [18]*

Other rules related to the construction of the chassis for Formula Student vehicles, as well as all other rules for the design of Formula Student vehicles as a whole, are given in the Rulebook [18].

4. Structural analysis of Formula Student chassis

In this chapter, the 3D model of the chassis is defined and the simulation setup is performed. CATIA software is the software that was used to create a 3D model of a chassis concept. CATIA is software that is widely used in engineering practice. Some of the works in which the CATIA software was applied to solve and analyze various engineering problems are [21-27]. The geometric 3D chassis model considered in this paper is shown in Figure 11.

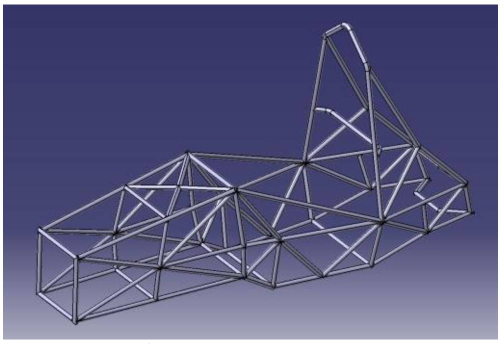

Fig. 11 *Space frame chassis – isometric view (CATIA)*

Ansys software was used for structural analysis, and the 3D model of the chassis in Ansys DesignModeler is shown in Figure 12.

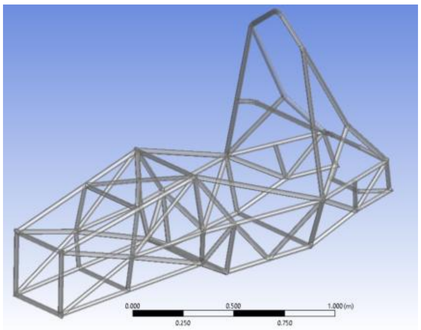

Fig. 12 *Space frame chassis – isometric view (Ansys DesigModeler)*

Ansys software was used for structural analysis. In Ref. [28] in a very good way the structural analysis of Formula Student space frame chassis was carried out under the action of different loads. Choosing the material from which the chassis will be made is a very important job. Material mechanical properties are shown in Table 1.

Table 1: *Mechanical properties of the material*

Properties	Value
Density	7850 kg/m^3
Young’s modulus	2E+05 MPa
Poisson ratio	0.3
Tensile Yield Strength	250MPa
Compressive Yield Strength	250 MPa
Ultimate tensile strength	460 MPa

After generating the 3D geometry and selecting the material, it is necessary to define the mesh of finite elements. The finite element network of the considered model is shown in Figure 13.

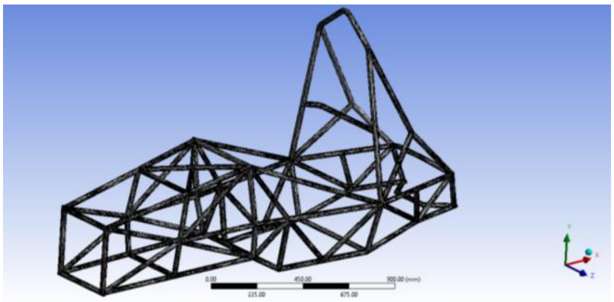

Fig. 13 *Mash of space frame chassis*

In this paper, three static tests were performed:

- static shear
- static overall bending
- lateral bending.

In the static shear, it is assumed that the space frame chassis is a cantilever beam and that one of its ends is fixed (clamped) and the other is exposed to a vertical force. The rear suspension supports were used as fixed support. A force with an intensity of 1520 N acts on the bulkhead in this case. This force represents the sum of various weights, such as the weight of the shock absorber, the driver's legs, the weight of the steering system, and the like. Boundary conditions for this case are shown in Figure 14.

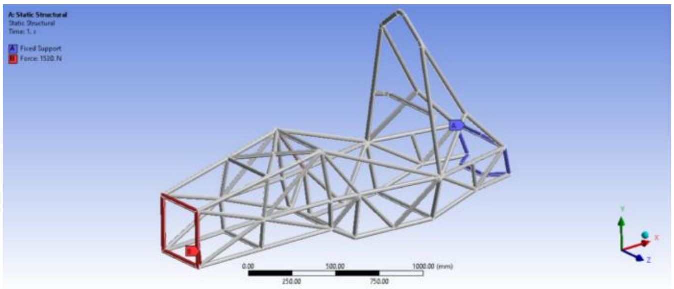

Fig. 14 *Boundary conditions for the static shear*

In the static vertical bending, it is assumed that the suspension attachment points are fixed supports and that a force of 1600 N is assumed to act at the place where the driver sits and where the engine is located. Boundary conditions for this case are shown in Figure 15.

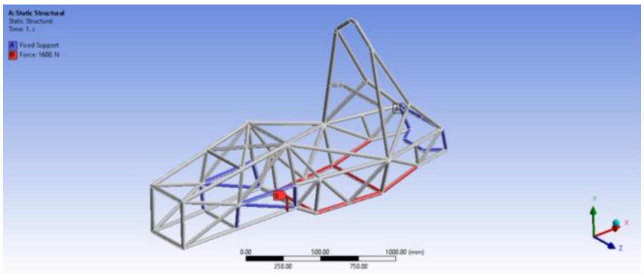

Fig. 15 *Boundary conditions for the static vertical bending*

In the lateral bending, it is assumed that the fixed supports are at the points of attachment of the front and rear suspension. Lateral force in the curve is applied on the side impact bracings of the driver cabin and engine supports. The intensity of this force is assumed to be around 2400 N. Figure 16 shows the boundary conditions for the lateral bending.

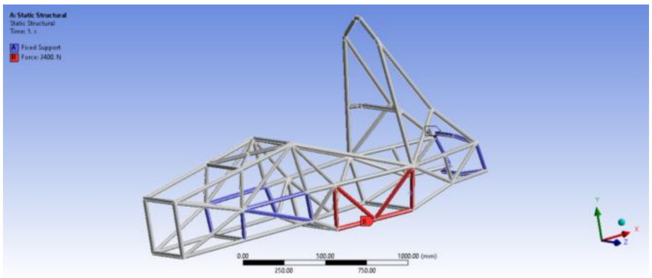

Fig. 16 *Boundary conditions for the lateral bending*

The results of the structural analysis are presented in the next chapter.

5. Results of structural analysis

The results of the structural analysis chassis should show how the loads affect the construction concept itself. They also need to answer the choice of materials. Figures 17 to 22 show the results of the structural analysis from the previous chapter. For each load that has been assumed, a graphical representation of von Misses stress and total deformation is given.

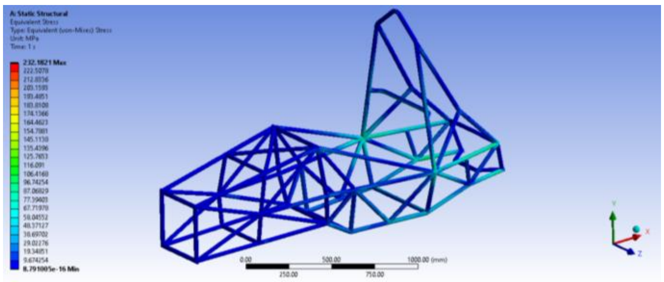

Fig. 17 *Von Mises stress as a consequence of static shear*

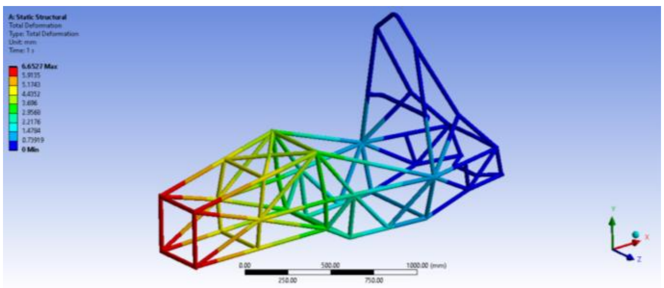

Fig. 18 *Total deformation stress as a consequence of static shear*

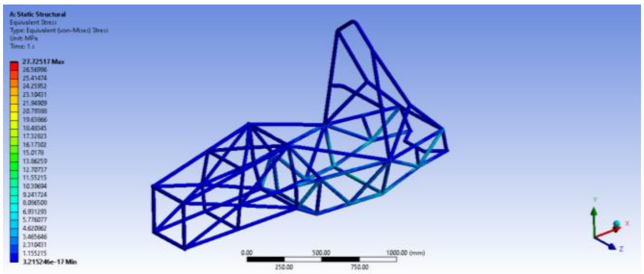

Fig. 19 *Von Mises stress as a consequence of static vertical bending*

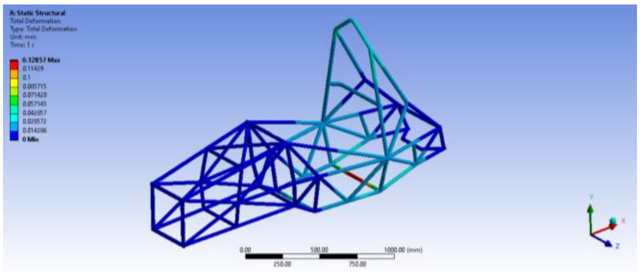

Fig. 20 *Total deformation stress as a consequence of static vertical bending*

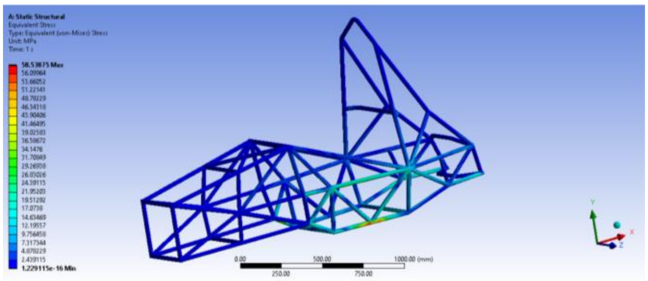

Fig. 21 *Von Mises stress as a consequence of lateral bending*

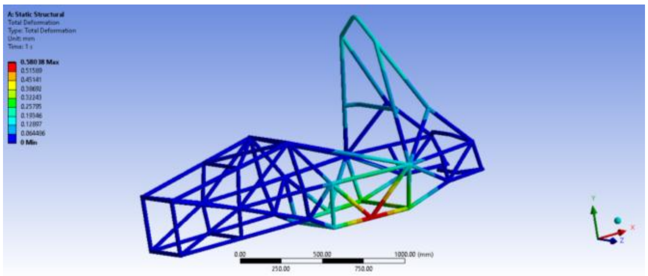

Fig. 22 *Total deformation stress as a consequence of lateral bending*

5. Conclusion

Static structural analysis is a very important analysis when designing the chassis for a Formula Student car. In the paper, only three loads were examined, i.e. static shear, static vertical bending, and lateral bending. The analysis of the impact of the torsional load from the front suspension, nor the influence of the aerodynamic forces, is not covered in this paper, but great attention should be paid to these loads when designing the chassis. Ansys is a very powerful software for structural analysis. A lot of time and money can be saved by using numerical analysis software. The reason for these savings is that in this way real conditions can be simulated, so if negative aspects of the construction are discovered, it can be redesigned before production itself. In future research, the choice of materials should be addressed in detail. We should also consider the possibility of using a monocoque chassis, although it is significantly more complicated to manufacture and also incomparably more expensive compared to a space frame chassis.

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