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STRENGTH ANALYSIS OF AN OFF-ROAD LORRY FRAME

Summary. The lorry frame is the main carrying part of a lorry, composed of several components. These components are connected by joints into one structural unit and it forms the lorry chassis. The contribution of this article is focused on the strength analyses of a backbone frame, which is used on an off-road lorry chassis. Strength analyses are carried out utilising the finite element method. This article presents a created three-dimensional model of the frame and definition of boundary conditions (loads, the definition of degrees of freedom) needed for simulation computations. Results of the numerical calculations are the main parts of

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this article. Attention is mainly centred on the distribution of stresses of the frame under defined loads and its deformations.

Keywords: frame, off-road truck, strength analysis, finite element method

1. INTRODUCTION

A lorry is a vehicle whose structure is built to transport goods. However, these vehicles are used to tow trailers of various kinds as well. Tractors of semitrailers belong to this group of vehicles.

The chassis of a lorry is the bottom as well as the carrying part of the vehicle, onto which the cabin, body and drive-train are mounted. This unit is called the vehicle underbody. Generally, it is composed of these units [23,36]:

- a frame – the basic carrying part of a lorry chassis, it is loaded by many kinds of loads reliable fixation of the manipulator to a chassis without its damage,
- a suspension system – a system of mechanisms, which transmit loads generated during driving and also as results of dynamic forces,
- axles – it is composed of a pair of wheels with significant participation on the wheel/road contact,
- a braking system – a system of mechanisms, which serve for slowing down or stopping of the lorry and ensuring of a lorry in a parking position,
- a steering system – a system of mechanisms, which allows changing the driving direction by means of a steering wheel, a system of linkages and levers.

Sufficient rigidity of the main carrying structure of a lorry chassis significantly affects its driving properties as well as loading of the frame and various lorry bodies [23,36].

2. THE LORRY FRAME DESIGN

The frame is the main carrying part of the lorry, which consists of several elements. These elements are connected by welds joints, screw connections or rivet joints to one unit. The main task of a lorry frame is its carrying ability. The lorry frame design considers among others the power drive-train type [1-3,13,16,19,34]. Therefore, the frame design has to ensure sufficient rigidity and be as light as possible [6,24,27,33]. More so, it has to ensure that the centre of gravity of the lorry be as low as possible, which affects the driving stability of the lorry. The chassis of the lorry has to allow proper guidance and ensure sufficient driving comfort.

In the case of standard lorries, a ladder frame is usually used to meet the abovementioned requirements in the best way. However, there are such operational conditions of lorries that operate in rough terrain conditions, for example, in the building industry as a tipper, concrete mixer, and likewise in forestry, agriculture, army, rescue services, etc. In these operating conditions, a lorry is submitted to the combined loads, which cause in addition to bending loads also torque [17,18,30]. From the frame strength point of view, a ladder frame structure is no longer able to withstand such difficult combined loads reliably in comparison with operation on a metalled road. Hence, a backbone chassis was developed.

The backbone chassis of a lorry is a type of vehicle chassis, which instead of a two-dimensional ladder structure, consists of a tubular backbone (usually circular cross-section). It connects the front and rear axles (lorries are often multi-axle) as well as the suspension

system. The backbone chassis is the most used by the Tatra Trucks company, which has applied this frame design to its off-road lorries for many years [22,33].

3. THE BACKBONE CHASSIS

As mentioned above, the backbone chassis is the typical characteristic of Tatra off-road lorries. These lorries are developed mainly for heavy off-road conditions, allowing high passability through terrains, high level of driving comfort, high speeds over difficult terrain, high levels of vehicle stability in turns and on slopes, minimum maintenance requirements, minimum possibility of drive-train damages, etc. [22,33].

The backbone chassis consists of these units:

- a central load-carrying tube,
- axles with independently suspended swinging half-axles bolted together into a single unit.

The central load-carrying tube can withstand high torsion and bending loads, protecting lorry bodies from transmitted loads; its modular system enables the assembly from two to multi-axle lorries with the optional all-wheel drive. Further, the shafts of a drive-train system are situated in the central tube, which protects them from external effects. Such a technical solution provides high durability together with low maintenance costs [22].

Off-road lorries Tatra equipped with the backbone chassis use independently suspended half-axles. In the basic version, they are always driven and combined with locks. Differentials are placed outside the axles in the central loading tube. Axles are equipped with a pneumatic drum brake system. There are several load-bearing capacity versions of this chassis. Lighter versions are equipped with a mechanical suspension system, which consists either of torsion rods for versions with a single steered front axle or of leaf springs for versions with two steered axles. Heavier versions are equipped with a pneumatic suspension system, which provides completely different driving characteristics. All kinds of suspension systems are combined with telescopic dampers or torsion rods [22,33].

Figure 1 shows the Tatra off-road lorry whose frame is analysed below.



Fig. 1. Tatra off-road lorry [33]

4. STRENGTH ANALYSIS OF THE BACKBONE CHASSIS FRAME

The main purpose of the strength analysis of the frame is to determine the stress distribution on the frame structure to identify critical locations with stress concentration [9].

The analysed frame is the main carrying part of the Tatra off-road lorry (Fig. 1), which is built to transport goods up to the load capacity of 15,700 kg. The total weight of the vehicle is 26,000 kg.

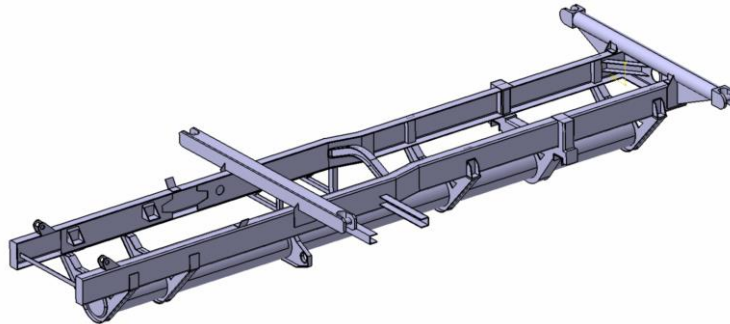


Fig. 2. A three-dimensional model of the analysed frame

The central load-carrying tube is thick-walled. It is combined with cross walls and two longitudinal U profiles.

Profiles and other components are made of structural steel S355J0 whose mechanical properties are listed in Tab. 1.

Tab. 1

Basic mechanical properties of structural steel S355J0

Material	Yield strength [MPa]	Ultimate strength [MPa]	Density [kg·m ⁻³]	Young's modulus [MPa]
Structural steel S355J0	355	470-630	7850	210,000

Strength analyses of the frame were carried out in the ANSYS software package [4,35]. It works based on the finite element method (FEM) [26,28,31]. In this software, it is possible to perform static analyses [11], modal [14,32] and other types of analyses of individual components [10,14,32], structural unit and even entire mechanical systems [7,12].

The realisation of analyses consists of several defined steps. First, the volume geometry was created and contact couples between parts of the model were defined. Afterwards, the FEM mesh was generated. Figure 3 depicts a mesh model of the frame.

The mesh model composed by quadratic tetrahedron elements with a size of 10 mm. Number of elements was 789,491 and number of nodes 1,484,614.

Another step in analysing the frame was the definition of boundary conditions. Loads were defined in the centres of gravity (CoG) as following (Fig. 4):

- an empty tipping body: 25,000 N a central load-carrying tube,
- a fully loaded tipping body: 157,000 N,
- an engine: 13,500 N,
- a cabin: 4,500 N.

The strength analyses were performed for two loading states, that is, for an empty carriage body and a fully loaded carriage body. When the empty carriage body is considered, only the net weight of the tipping body acts on the analysed structure.

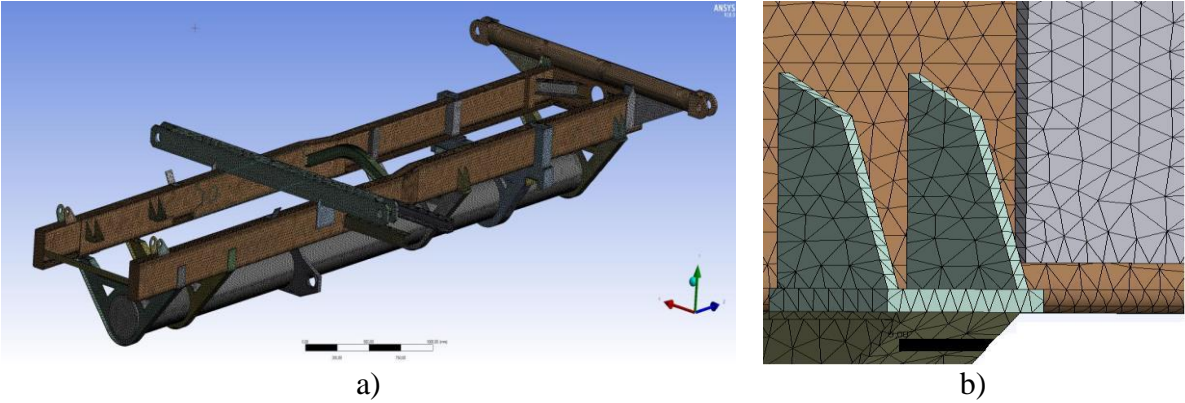


Fig. 3. (a) A mesh model of the analysed frame, (b) FEM mesh detail

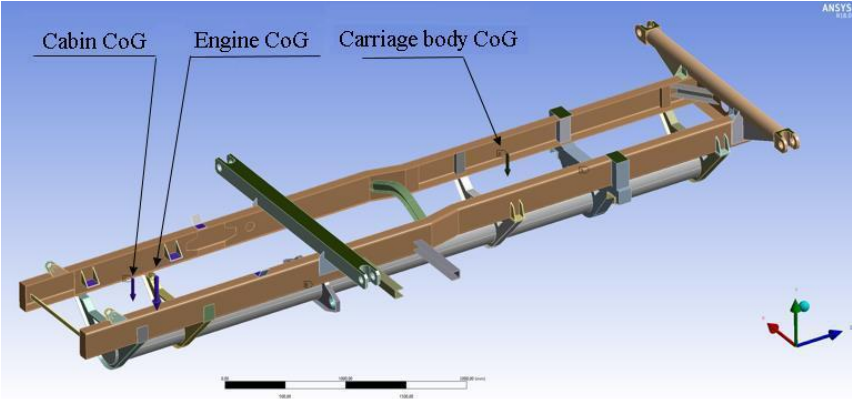


Fig. 4. Acting loads on the analysed frame

Results of strength analyses for the empty tipping body are shown in Fig. 5 and 6.

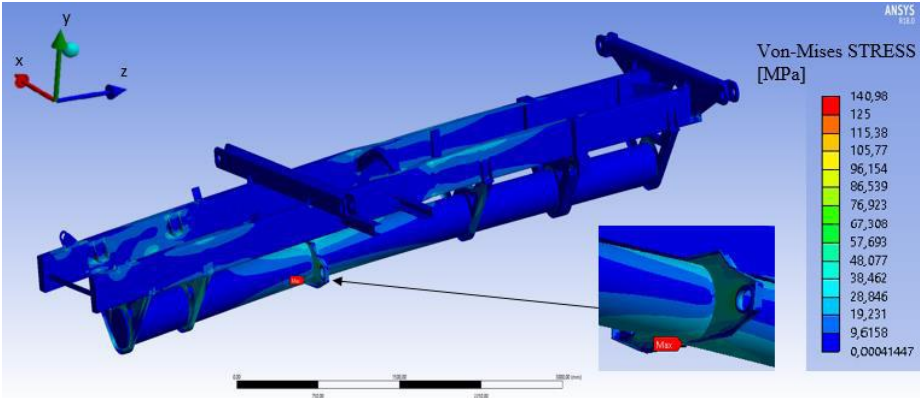


Fig. 5. Distribution of von Misses stresses in the frame structure – the empty tipping body

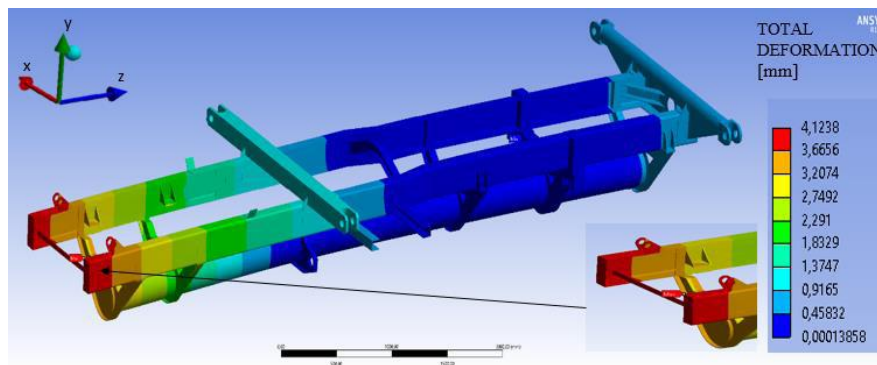


Fig. 6. Total deflection of the frame structure – the empty tipping body

As can be seen, the greatest value of the reduced stress (calculated according to the von Mises hypothesis) is identified in the locations of torsion rods joints in the plate and the location of the plate mounting to the central tube. The reduced stress reached a value of 140.98 MPa (Fig. 5).

The total deflection achieved in the frame structure for the first load case, that is, for the empty tipping body, is 4.12 mm. It is detected in the front part of the frame (Fig. 6).

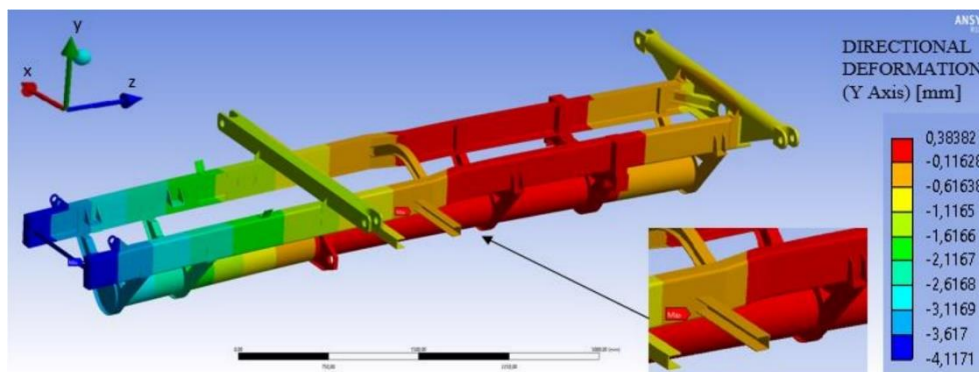


Fig. 7. Vertical deflection of the frame structure – the empty tipping body

Figure 7 shows the deflection of the frame structure for the first load case in the vertical direction (y-axis). It shows that the most loaded part of the frame is identified in the tipping body location, between the location of rear leaf springs mounting and the torsion rods plate. A part of the longitudinal profiles as well as triangular cross walls are also loaded.

The second loading case is considered for the fully loaded tipping body as aforementioned. Results of strength analyses are shown in Fig. 8 and Fig. 9.

Based on the reached results, the greatest value of the reduced stress is similarly detected in the same location as in the case of the empty tipping body. However, in the second loading case, this stress reached the value of 253.36 MPa (Fig. 8).

The total deflection of the frame structure for the second loading case reached the value of 6.36 mm (Fig. 9). It is also detected in the front part of the frame structure.

The maximal value of 0.74 mm of the vertical deflection (y-direction) of the frame structure was identified in the rear leaf springs mounting location (Fig. 10).

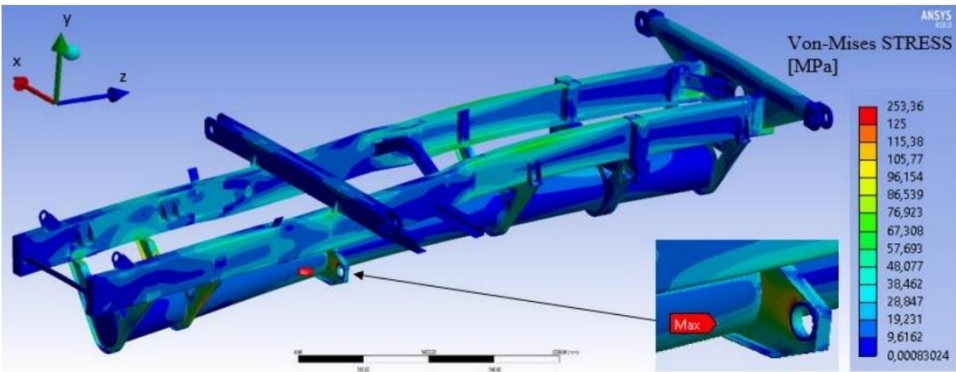


Fig. 8. Distribution of von Misses stresses in the frame structure – the fully loaded tipping body

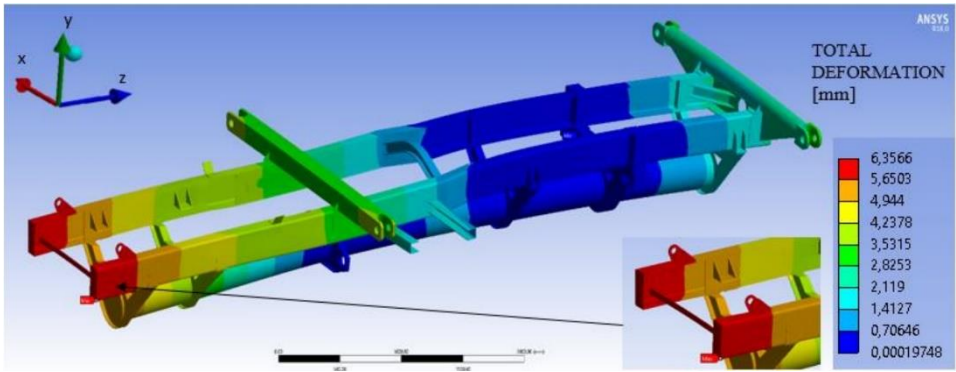


Fig. 9. Total deflection of the frame structure – the fully loaded tipping body

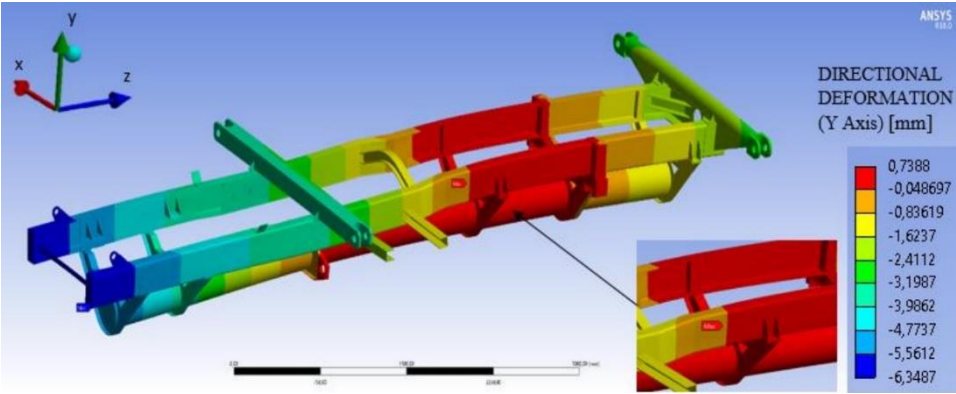


Fig. 10. Vertical deflection of the frame structure – the fully loaded tipping body

From shown results of the strength analyses of the frame structure for the first and second loading cases, it is obvious, that the value of the reduced stress calculated according to the von Misses hypothesis increased from the value of 140.98 MPa (the empty tipping body) to the value of 253.36 MPa (the fully loaded tipping body).

The determined value of the total deflection in the critical location of the frame structure increased from the value of 4.12 mm (the empty tipping body) to the value of 6.36 mm (the fully loaded tipping body).

The value of the vertical deflection (y direction) also increased, namely from the value of 0.38 mm (the empty tipping body) to the value of 0.74 mm.

The yield of strength (R_e) of the steel S355J0 used for the frame structure production is 355 MPa. The maximal value of the determined value is 253.36 MPa. Thus, the performed static analyses of the frame structure have shown that it meets the requirements of rigidity and safety material within the safety factor of 1.4.

However, the tipping lorry Tatra is designed for heavy off-road operational conditions. Therefore, the chassis including the frame is loaded with dynamic loads. Their characteristics, such amplitude and frequency are stochastic and they will cause different loads in comparison with performed static analyses [5,20,21]. Hence, future research in this field should be focused on obtaining input data, which will simulate more realistic loading of the frame structure. There are mainly loads in the location of axles mounting, where wheel forces will act on the frame. Further, efforts will be made to creating a virtual multibody model (MBS model) of the lorry chassis. It is possible to expand the MBS model using the presented FEM model of the frame [15,25,37], input dynamic loads to the structure and investigate its behaviour under these defined loads.

5. CONCLUSION

The solution of the presented problem consists of obtaining input data from a customer. Based on these data, the engineering design and functional solution of the manipulator were created. The important task was the design of the compressor setting, which has to meet all requirements in term of its dimensions and the possibility of compensation of all inaccuracies. Safety of the device, protection of health and operator and ergonomic parameters were other important aspects of the design. Compliance with the relevant standards and internal regulations of the customer was a matter of course. Designs of the rotating part of the manipulator, the control panel, the travel and the pneumatic parts of the manipulator were realised together with the compliance of the customer-required components from precisely specified manufacturers. The next step in solving this problem would be the design of the pneumatic brake, the selection of air treatment equipment, the creation of the pneumatic circuit diagram, the FEM simulation of the steel plate, the adjustment mechanism and the RPS pin console.

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