

DESIGN OF A FRAME TO A SEMI LOW-LOADER

Grzegorz Koszałka

*Lublin University of Technology
Department of Internal Combustion Engines and Transport
Nadbystrzycka Street 36, 20-618 Lublin, Poland
tel.: +48 81 5384258, fax: +48 81 5384259
e-mail: g.koszalka@pollub.pl*

Hubert Dębski

*Lublin University of Technology, Department of Machine Design
Nadbystrzycka Street 36, 20-618 Lublin, Poland
tel.: +48 81 5384201, fax: +48 81 5384200
e-mail: h.debski@pollub.pl*

Marek Dziurka, Maciej Kaczor

*Wielton SA
Baranowskiego Street 10a, 98-300 Wielton, Poland
tel.: +48 43 8434510
e-mail: m.kaczor@wielton.com.pl*

Abstract

The paper presents the process of design of a frame for a semi low loader for the transportation of oversize loads, especially wheeled and tracked machines. After considering different solutions of a frame, a central beam was chosen and an initial design was developed. The initial model of the frame was analyzed with the use of FEM and was then modified. Two final versions of the frame were prepared. One of them was used in a 4 axle trailer with a load deck that can be extended in length and width to carry oversize and heavy loads. An important advantage of the trailer is its versatility and the fact that in a non-extended state it meets the regulations for standard trailers and can carry loads without a special permission. The paper focuses on the application of FEM analysis in the design of the part of the beam where highest stresses were located.

A design solution for a ladder frame, a schematic image of a box-type central beam, a design solution for rear ramps, geometrical models of semitrailer frame with boundary conditions, stress distributions in a non-extended and extended frame model, a section of the rear part of the frame with sliding plates visible and a pin guide bar for blocking frame extension, stress distribution in the front part of the frame, single and double supporting rib, side wall supporting plate and stress distribution after the use of plates and one supporting rib, stress distribution after the employment of plates and two supporting ribs, stress distribution in the alternative gooseneck design, main dimensions of the semitrailer, extended semitrailer are presented in the paper.

Keywords: *FEM, central beam, supporting structure, extendable semi-trailer, heavy transport*

1. Introduction

There is growing demand for transportation of non-standard loads, i.e. ones that do not meet the standard legal requirements determined by traffic regulations on external vehicle dimensions, gross vehicle weight or load per axle. Heavy and oversize loads are transported by specially designed trailers. These trailers differ from one another both in allowable load limits and the degree of specialization – adjustment to the transportation of particular loads. High specialization

on the one hand facilitates transportation of specific loads but on the other hand limits the range of a trailer's applications. In Poland, there is large demand for vehicles of high versatility which enable transportation of various oversize loads. Moreover, numerous companies, especially smaller ones in sectors such as transport or construction, which do not specialize in the transportation of non-standard loads, want to have vehicles that would allow them to transport large machinery and other oversize loads and that could simultaneously be used for the rest of the time to transport standard loads. For a trailer to satisfy the expectations of such users, it should meet the requirements for standard vehicles when it is used to transport standard loads. This allows a user to avoid additional administrative procedures and costs.

The Wielton company in cooperation with the Lublin University of Technology has developed a universal semitrailer, which makes it possible to transport heavier-than-standard loads, among others, owing to the use of a larger number of axle lines, and oversize loads thanks to the possibility of extending the length and width of the load deck. At the same time, in its "unextended" state, the semitrailer meets the requirements for standard vehicles, which allows it to move on road and to transport standard loads without special permits and extra fees.

This article presents the course of research and development work on designing the supporting frame of the semitrailer, in particular the application of FEM calculations in the design process.

2. Design assumptions and a preliminary design of the frame

An analysis of the needs of the market showed that the semitrailer should be able to transport loads of min. 40 tons and should be extensible lengthwise by 5 m and widthwise by 0.5 m over the size of a standard semitrailer. Such parameters of the semitrailer would allow transportation of a greater majority of self-propelled machines and other oversize loads. Moreover, it was decided that the semitrailer would have the lowest possible load deck, whereas the coupling plate would be located in the higher, front part of the trailer, where so-called gooseneck deck – an additional, higher positioned load platform, would be located. Taking the above into account, a decision was taken that the semitrailer would be equipped with 4 axles with design loads of 10 tons and dual wheels with 17.5 inch rims and fifth-wheel load capacity of 18 tons.

Because the prospective manufacturer of the semitrailer had large experience in the production of classical ladder frames, an attempt was made to adjust this type of frame to the new vehicle. However, such a solution had many drawbacks. One of the most serious problems was that it was difficult to obtain the assumed change in semitrailer length when steerable dual wheels were used – due to the large number of axles, it was concluded that the wheels on the rear axles should be steerable (Fig. 1). For that reason, the classical conception of a ladder frame was abandoned, and a decision was taken to use a different design solution.

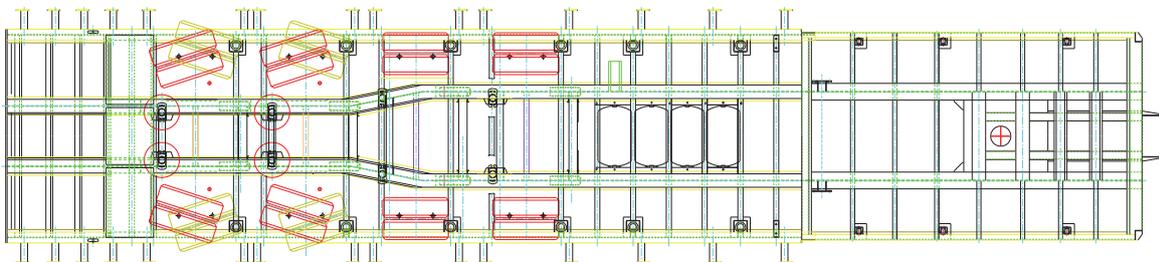


Fig. 1. A design solution for a ladder frame

After analyzing several different frame designs, a final decision was made to use a central box beam. This solution is based on a thin-wall box with a rectangular cross-section consisting of two independent parts which allow easy lengthwise extension of the frame and ensure appropriate

stiffness of the whole structure (Fig. 2). The rear, external part of the frame was to be supported by axles. At the same time this part would support the internal, front part of the frame. The front part, in turn, would have a permanently fixed coupling plate for connecting the semitrailer to a truck. The length of the frame would be changed by sliding the front part in and out of the rear part of the frame.

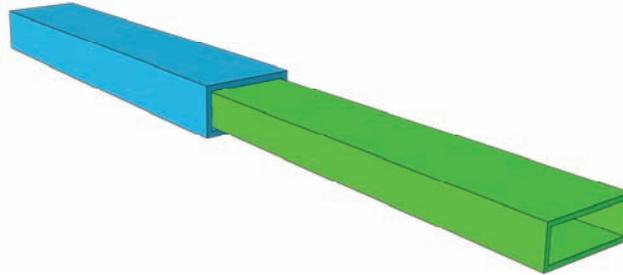


Fig. 2. A schematic image of a box-type central beam

The lengths of the individual parts of the frame were determined provisionally taking into account the design conditions: the possibility of cooperation with the semitrailer truck (mainly the length of the gooseneck – an elevated part of the frame to which the coupling plate is attached, see Fig. 12), maximum dimensions of the semitrailer in the contracted state and the assumed change in the length of the frame. The design conditions also had a decisive effect on the crosswise dimensions of the external rear part of the frame. Its width was limited by the possibility of using an axle with steerable dual wheels and its height was limited by the desire to achieve the lowest possible position of the load deck. Taking the above limitations into consideration, the external crosswise dimensions of the rear part of the frame were established. Next, the different possibilities of loading the frame with transported cargo at different lengths of the frame were analyzed. On this basis, the bending moments in the frame were determined, and the thickness of the walls of the rear part of the frame was selected taking into account the strength conditions. In preliminary calculations, it was assumed, out of technological and economic considerations, that the frame would be made of steel with yield strength of 360 MPa. The external dimensions of the front part of the frame followed from the internal dimensions of the rear part and were to ensure proper cooperation of the two components. Next, the thickness of the walls of the front part of the frame was selected taking into account the strength conditions.

On the basis of the above assumptions, a detailed design of the frame started to be developed. At this stage, a decision was taken that the rear part of the deck would tilt at an appropriate angle to eliminate the need to use folding rear ramps, preserving a small approach angle.

A small approach angle makes it easier for self-propelled machines to drive onto a trailer and reduces dynamic loads during rolling of caterpillar machines onto the deck (connected with the lowering of the machine onto the deck when its centre of gravity crosses the junction between deck and ramp). A smaller angle at a given deck height can only be obtained at the cost of increasing ramp length, which carries several adverse consequences. These include (1) higher bending stresses in the semitrailer frame and ramps and thus a need for a heavier structure; (2) excessive length of ramps after lifting up and so the necessity to use more complex, folding ramps and (3) increased length of the vehicle with lowered ramps and thus a need for more loading and unloading space. In the course of the study, it turned out that the assumed change in semitrailer length could be achieved with the rear part of the load deck tilted at an approach angle equalled to the assumed approach angle. This eliminated the problems mentioned earlier, practically without affecting the semitrailer's load transporting capability; when necessary, special wedges need only be used.

A preliminary design of the frame was developed, which contained all the components that were important from the structure strength point of view, such as support brackets for fixing the chassis assembly and holes for securing the sliding part of the frame and for securing different semitrailer components (Fig. 4). This design was subjected to a detailed FEM strength analysis.

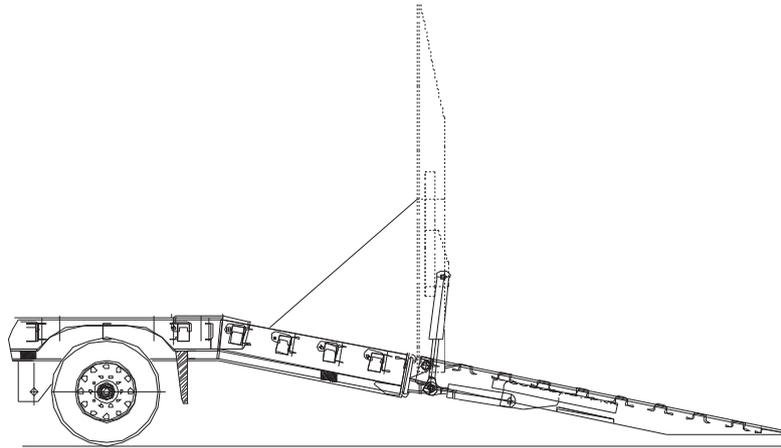


Fig. 3. A design solution for rear ramps with the rear part of the platform tilted

3. FEM calculations

Based on the geometric models (Fig. 4), discrete models of the semitrailer frame both in the non-extended and fully extended configurations were prepared. The models were turned discretely using shell elements with 6 degrees of freedom in each node. This made it possible to account for the strong bending effect in the elements of the structure under examination while simultaneously reducing the size of the numerical model [5, 6].

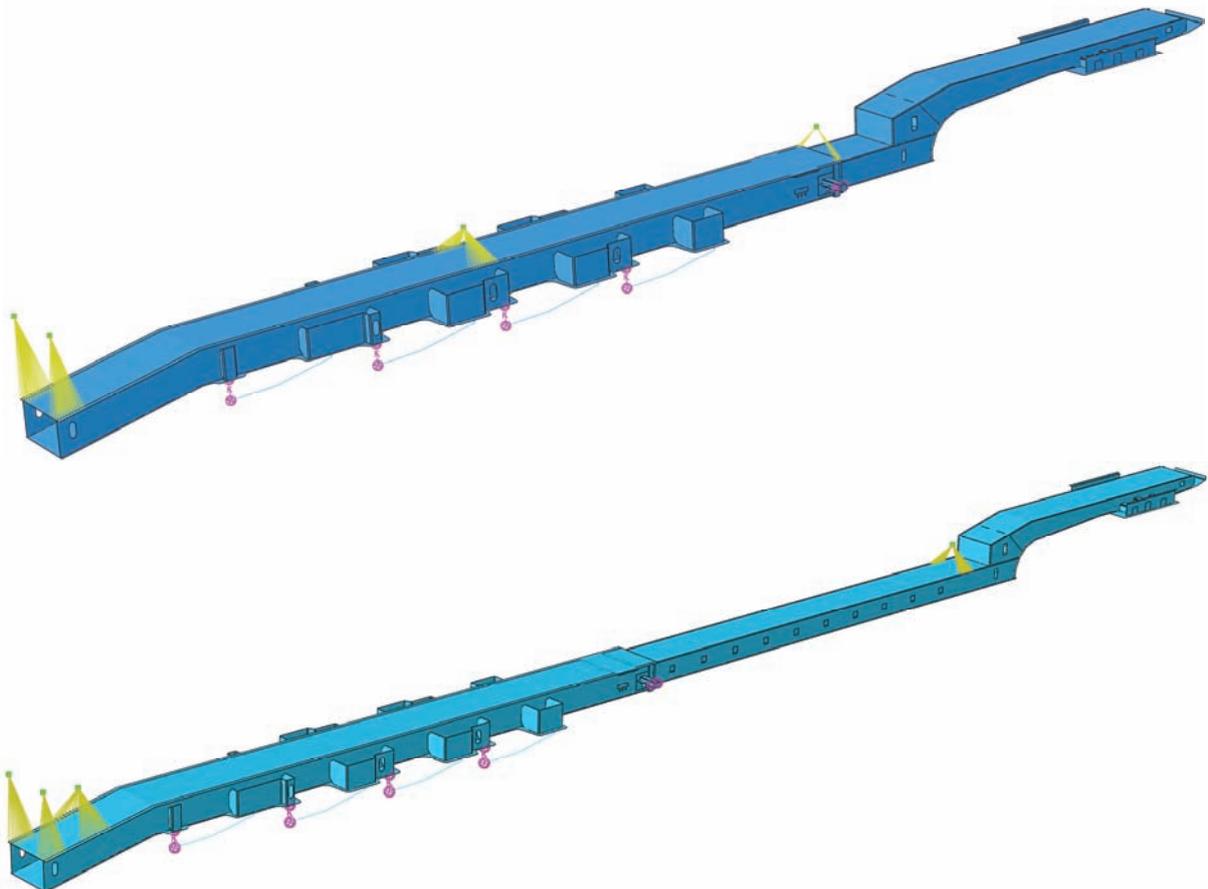


Fig. 4. Geometrical models of semitrailer frame with boundary conditions in a non-extended (top) and extended (bottom) state

Structure support and loading with its own weight and the load transported was modelled by appropriately defined boundary conditions [3]. In its front part, the frame was supported in a pin, which was modelled by appropriate reduction of movements of the pin nodes. The rear part of the frame was supported in the points where the semitrailer axles were to be fastened, as shown in Fig. 4. A single wheel suspension structure was modelled with a rigid beam element which represented the suspension arm and a flexible element which represented the pneumatic suspension cushion. The connection between the suspension arm and the frame in the front node ensured rigid transfer of the load from the suspension to the frame structure and only allowed for its rotation along the axis of the wheels. The rigidities of the flexible element were selected in such a way as to ensure similar reaction in all the axes of the semitrailer. Inertial loads resulting from the frame's own weight and point mass loads resulting from load weight were accounted for in the calculations. Ramps weight and rear support legs weight (calculation results showed that the stresses in the frame during heavy machinery entry may be very large, hence the necessity of supporting the frame during loading) also contributed to the load of the rear part of the frame which was modelled as point masses introduced to the frame structure as shown in Fig. 4. Moreover, a 20% dynamic excess was accounted for. Calculations for various placements of the loads on the semitrailer were made.

The Abakus/Standard software has been used for FEM calculations [1, 2]. After having performed the calculations, reduced stress distributions according to the Huber-Mises-Hencky hypothesis and contact pressure in the places where the front and rear part of the frame meet were analyzed.

FEM analysis revealed some imperfections in the initial design – there were areas where the reduced stress still considerably exceeded the yield stress of the material which elements of the structure were to be made of (Fig. 5). In addition, the calculations showed that in the contact places (especially the places where the front part of the frame departs from the rear part) there was very large contact pressure. In order to improve the cooperation between front and rear parts of the frame, flexible sliding plates were added. They were supposed to increase the working surface and eliminate edge pressure in the connection zone (Fig. 6). The use of sliding plates necessitated a change in the height of the front part of the frame. At the first modification stage it was also decided to dispose of the holes in the side walls of the front part of the frame which led to considerable stress concentration and to replace them with one hole in the lower wall, as shown in Fig. 7 (this hole is intended to allow the electrical and pneumatic ducts to enter the inner part of the frame).



Fig. 5. Stress distributions in a non-extended (top) and extended (bottom) frame model

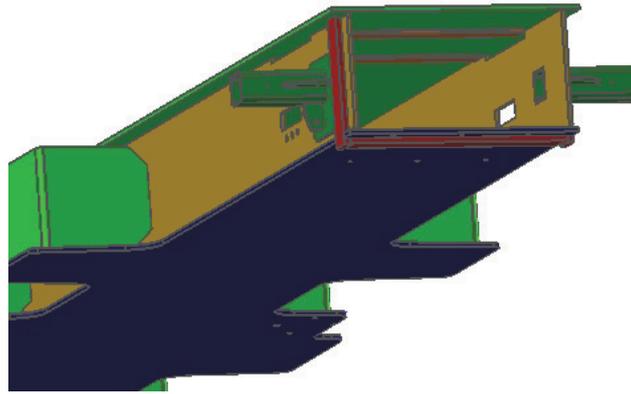


Fig. 6. A section of the rear part of the frame with sliding plates visible and a pin guide bar for blocking frame extension

After recalculation, it turned out that the reduction in height of the front part of the modified frame led to an increase in stresses in the lower and upper walls of the front part of the frame. The stresses exceeded the permissible level (Fig. 7). Therefore, the thicknesses of those walls were increased. In addition, the holes in the vertical walls of the rear part of the frame which were intended to insert polyamide sliding plates in were removed. These and some other design modifications made it possible to decrease the stresses to an acceptable level. The problem of transition of the beam into the goose-neck was still unsolved. The stresses in this area were still excessive despite the transfer of holes from the side to the lower wall (Fig. 7).

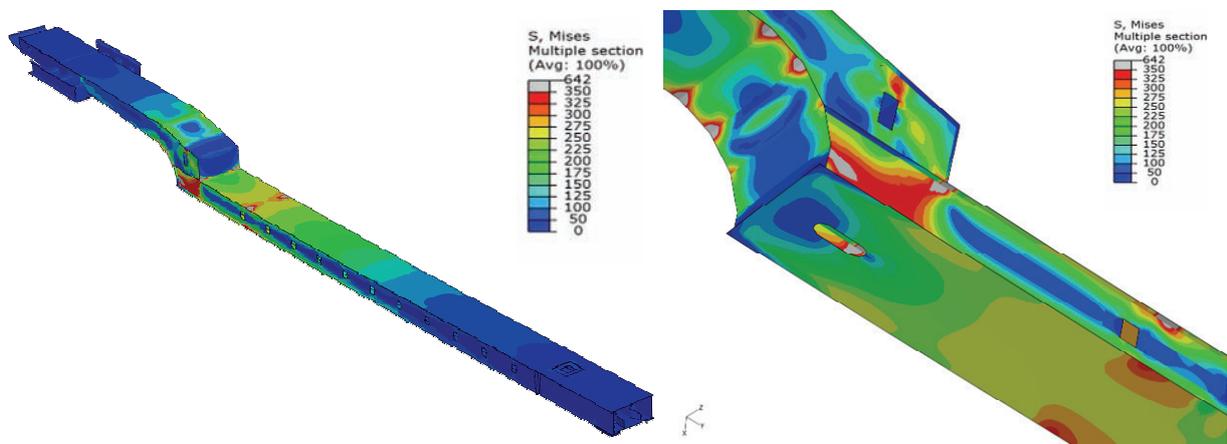


Fig. 7. Stress distribution in the front part of the frame

4. Modification of the goose-neck transition

FEM analysis showed that the area of front beam transition into the goose-neck was a critical area in the preliminary design (Fig. 5). The measures described above i.e. the transfer of holes from the side to the lower wall of frame did not result in considerable improvements. It was decided to tackle this problem in the following two ways: (1) by strengthening the structure with additional elements and (2) by complete redesigning the goose-neck transition.

While implementing the former supporting plates on the side walls (various thickness and shape variants were analyzed and finally plates were chosen as shown in Fig. 9) and one or two supporting ribs in the rear part of the gooseneck were added (Fig. 8). Calculation results showed that the use of the above mentioned measure yielded expected results (Figs. 9 and 10). In the case of two ribs the reduced stress in the analyzed area did not exceed 250 MPa.

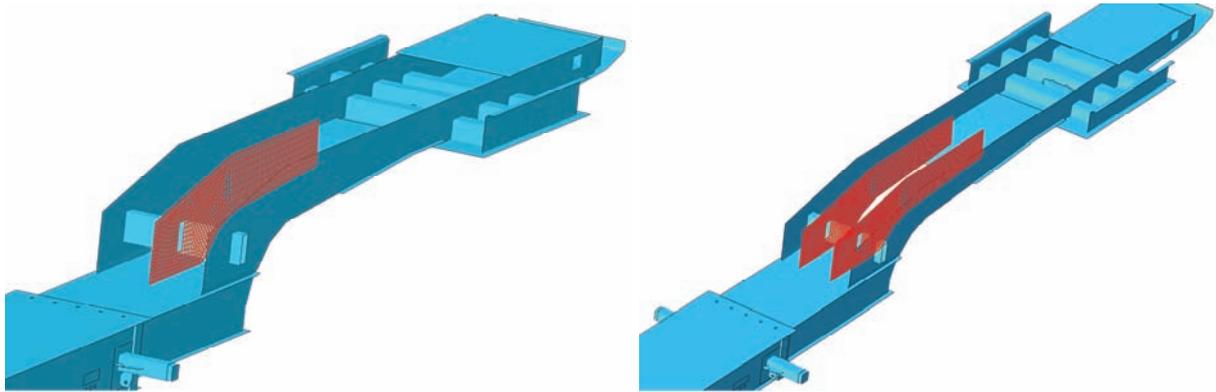


Fig. 8. Single and double supporting rib

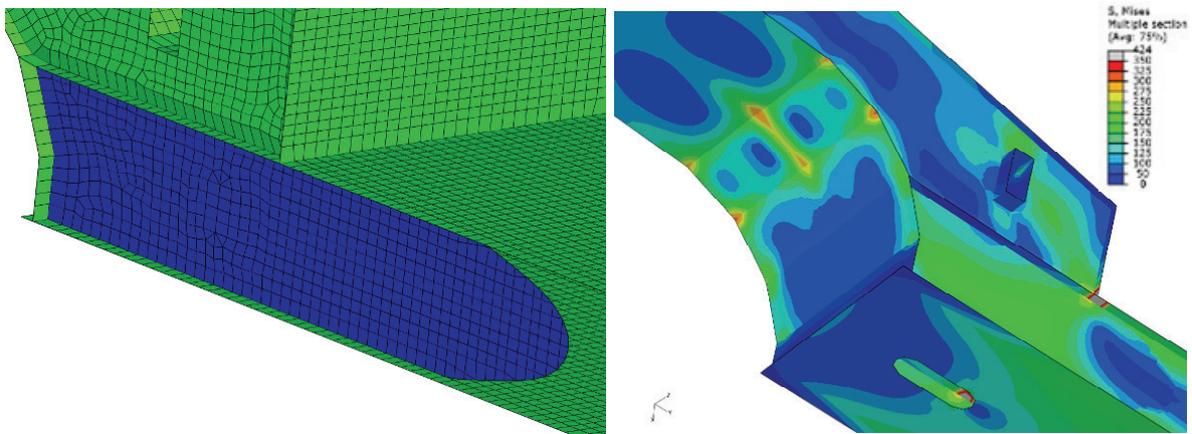


Fig. 9. Side wall supporting plate (left) and stress distribution after the use of plates and one supporting rib (right)

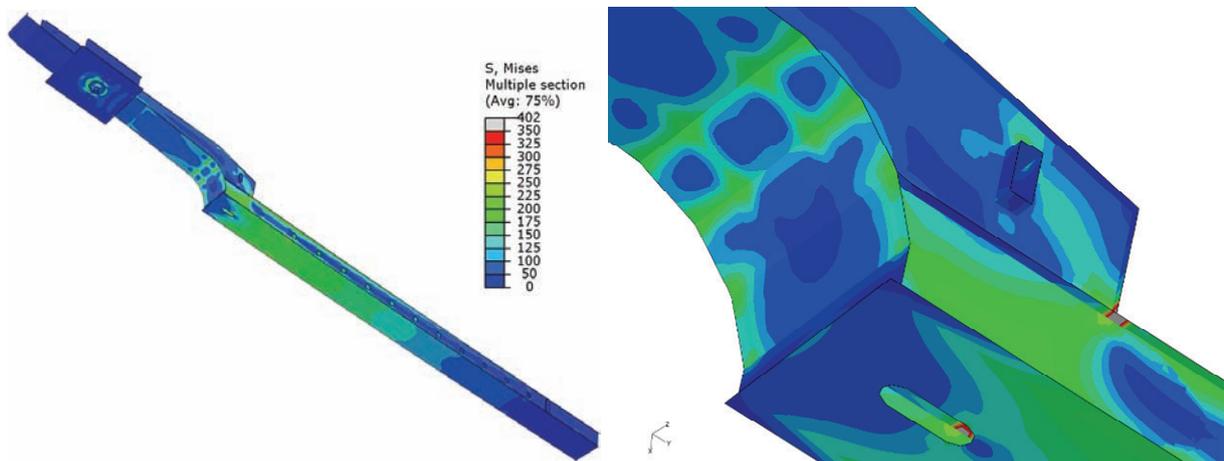


Fig. 10. Stress distribution after the employment of plates and two supporting ribs

While implementing the later method a solution in which the loads would be transferred more evenly was sought. A couple of geometrical variants of the gooseneck transition were designed preserving the required size, especially of the lower arc of the frame. Appropriate discrete models were prepared and FEM calculations performed. The best design and corresponding stress distribution are shown in Fig. 11.

The calculations showed that the new proposed gooseneck geometry considerably improved the work of the structure in this area. The strong, local concentration of stress present in the previous models was eliminated entirely without the need to employ any additional supporting elements.

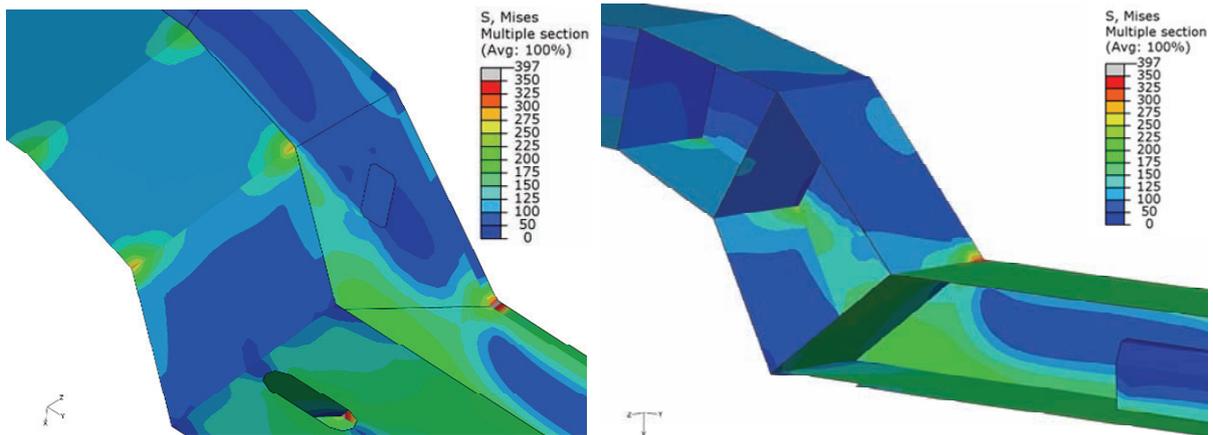


Fig. 11. Stress distribution in the alternative gooseneck design

5. Summary

The frame design presented in the paper has been employed in the newly-designed universal semitrailer for transporting non-standard loads and for self-propelled machinery in particular. Maximum total weight of the semitrailer is 58 tonnes and its kerb weight is 12.5 tonnes. The length of the semitrailer can be easily adjusted in a 5 m interval with a 0.5 m jump and the width of the load deck can be enlarged by 0.51 m (Fig. 12). The semitrailer has been equipped in one lifted axle and one steered axle, pneumatic suspension which makes it possible to adjust the height of the loading deck, and hydraulically control rear ramps with adjustable space and a braking ABS and EBS system [4].

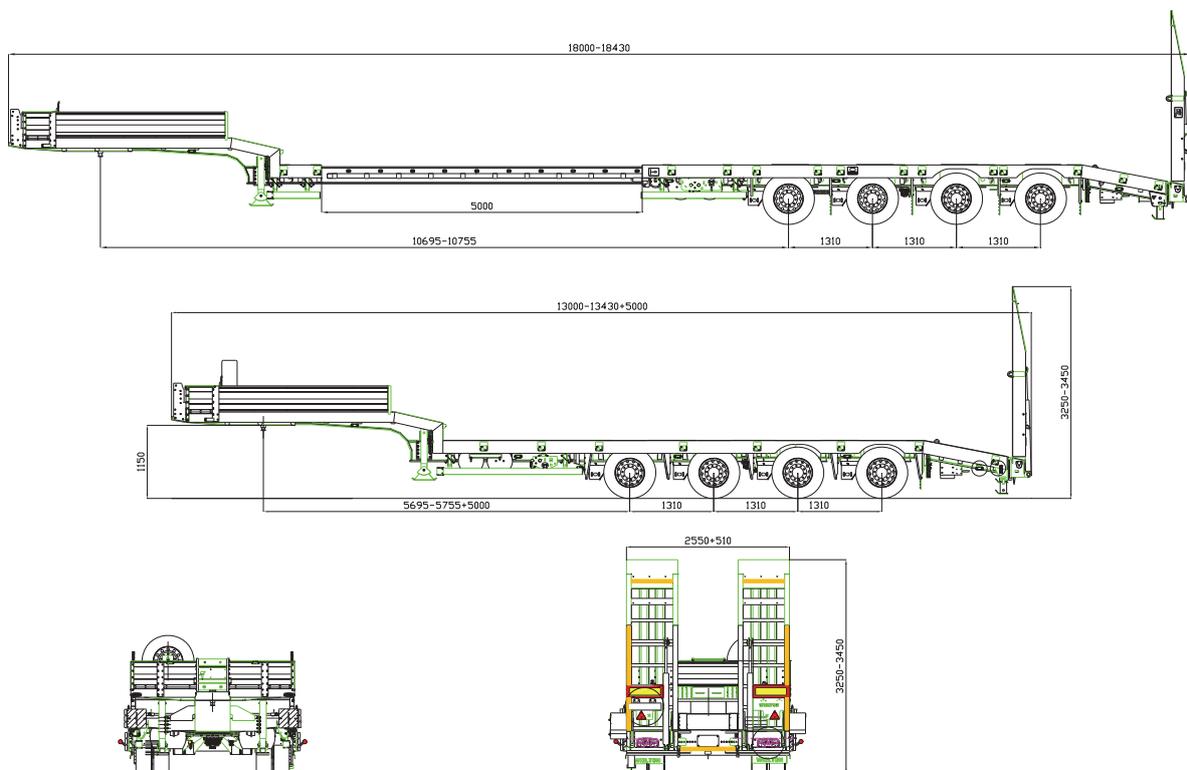


Fig. 12. Main dimensions of the semitrailer

When designing the load-bearing elements of the semitrailer, of which the main frame should be considered the most important, strength analysis with the use of FEM, has been widely

employed. It seems that the analysis made it possible to avoid design errors which could result in damage to the semitrailer during operation.

Wielton SA, the largest Polish manufacturer of trailers and semitrailers, put this semitrailer into production (Fig. 13). It has been sold to many customers and is acknowledged by them. In over twenty semitrailers in operation there has been no damage to the load-bearing structure.



Fig. 13. Extended semitrailer

References

- [1] Abaqus/Standard User's Manual version 6.5, Hibbit, Karlsson & Sorensen, 2005.
- [2] Abaqus Theory Manual version 5.8, Hibbit, Karlsson & Sorensen, 1998.
- [3] Koszałka, G., et al., *FEM analysis in design of extendable central beam for a semi-trailer*, Machine Design, Vol. 3, No. 1, pp. 47-50, 2011.
- [4] Koszałka, G., et al., *Universal extendable semi-low bed trailer for transportation of road machinery*, Proceedings of the 7th International Scientific Conference: Research and Development of Mechanical Elements and Systems, pp. 579-584, Zlatibor 2011.
- [5] Marianovic, N., Isailovic, B., Blagojevic, M., *Structural optimization in CAD software*, Machine Design, Vol. 1, pp. 27-32, 2009.
- [6] Rusiński, E., Czmochocki, J., Smolnicki, T., *Advanced finite elements methods in supporting structures* (in Polish), Wrocław University of Technology, Wrocław 2000.