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STRENGTH ANALYSIS OF INSULATED BODY WITH THE USE OF FEM

Summary

The paper presents the results of the computer analysis of strength of insulated body. Mathematical model was described. The analysis included the development of load characteristics based on exploitation conditions. Based on construction data computational models of the analyzed construction were developed. Their simulation tests and result analysis carried information about stress distribution in the semi-trailer construction. In particular, actions were focused on presenting the load implementation of trailer during driving on a bend of the road.

***Key words**: modeling, trailer, insulated body, FEM analysis, loads*

BADANIA WYTRZYMAŁOŚCIOWE MES KONSTRUKCJI NACZEPY CHŁODNI

Streszczenie

W pracy przedstawiono wyniki komputerowych analiz wytrzymałościowych konstrukcji naczepy chłodni. Opisano model matematyczny zestawu transportowego. Analiza obejmowała opracowanie charakterystyk obciążeniowych na podstawie danych dotyczących warunków eksploatacyjnych. Na podstawie danych konstrukcyjnych zostały opracowane modele obliczeniowe analizowanej konstrukcji. Ich badania symulacyjne i analiza wyników dostarczyły informacji o rozkładzie naprężeń w konstrukcji naczepy chłodni. W szczególności skupiono się na przedstawieniu implementacji obciążeń dla przypadku jazdy naczepy na łuku drogi.

***Słowa kluczowe**: modelowanie, naczepa, chłodnia, analiza MES, obciążenia*

1. Introduction

The value of transported articles in cooled or freezing conditions, in the whole world is estimated to reach over 1200 mld USD annually. A significant part of it is realized using refrigerated vehicles and in this, specialized semi-trailers. They own number of advantages comparing to standard trucks [4]. Connection of a tractor unit with a semi-trailer creates an assembly unit, ensuring convenient, long distance transport of cargo. The weight of the commodity is distributed on a larger number of axes and the assembly has high maneuverability.

Continuous progress and increasing request for commodities forces a constant decrease of transport costs with a simultaneous increase of requirements for commodity producers. This forces the improvement and search for a modern design solutions that meet the requirements of functionality but especially durability and strength. There exist many ways to check a construction's strength, inter alia: analytical strength calculations at the design stage, strain gauge measurement methods on physical objects or methods of simulation studies using mathematical modelling on computer workstation [2, 12]. The Finite Element Method is a method which uses a constructional model, discretized by finite elemtents.

2. Description of structure of the analyzed construction

The semi-trailer construction, which is the subject of the research was designed as a cargo road vehicle, without its own drive, adopted to work with a tractor unit (fig. 1). The semi-trailer is fixed to a tractor, which supports the front end, the rear part rests on three axes.

By specifying the basic components in the construction of the vehicle, the body and chassis can be distinguished.

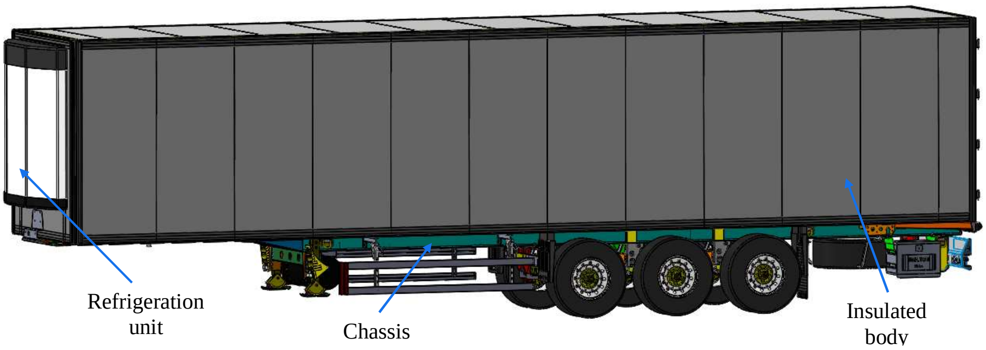

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Fig. 1. Food transporting semi-trailer
Rys. 1. Naczepa do przewozu żywności

The body is a box made of thermal-insulating materials limiting the heat transfer and being a protective element of transported goods [14]. The box construction is a self-supporting structure build by glued panels of the sandwich panel. Designed structure makes the body a closed cooling system, dust- and waterproof. The box floor, being a structure exposed to the various types of impact was designed as an element which possesses high strength and low thermal conductivity coefficient. For this reason its construction differs from the other insulating panels. Its structure, besides polyurethane filling, is characterized by a number of reinforcements in a form of wooden crossbeams.

The primary supporting structure, providing appropriate driving parameters, is semi-trailer's chassis in which the steel frame is the main structure. The frame is a rigid construction, welded from metallurgical profiles. Main task of the semi-trailer frame is to transport loads, acting on the individual assemblies. Frame also ensures the required spatial location of the vehicles assemblies, it participates in a transfer of dynamic and static loads. It constitutes a direct support for the spatial structure of the insulated body. In the designed semi-trailer a stringer-type frame was used. The structure is composed of two longitudinal beams connected by transverse beams. In the front part the stringers turn into the spatial plate structure which is the holder of the pivot that couples semi-trailer with a tractor. This is a simple and compact solution widely used in truck vehicles.

3. Construction of the computational model

The process of creating the computational model of insulated body was realized in CAD 3D system using the geometric model developed at the designing stage. By the use of graphical facilitates of pre- and postprocessors the computational model was characterized by finite elements. The following elements were used in the model:

a) one-dimensional:

- "Beams" with twelve degrees of freedom used to model the chassis structure of the vehicle,
- "Rigid" elements for mapping of suspension system

b) two-dimensional:

- "Thin-Shell" elements for modeling of sheet metal surfaces and closed profiles;

c) three-dimensional tetrahedral second order elements,

d) as a concentrated mass.

The discrete computational model is shown in fig. 2. Finite elements were used for its construction, allowing to approximate the object reaction in real condition case [9, 13]. It was decided not to model in detail some subassemblies, the construction approximation was done in a degree that ensures a compatibility of its strength parameters with construction elements geometry. In the vast majority the structure was built using two-dimensional tetragonal "Thin-Shell" elements as well as one-dimensional elements were used like "Beam", "Rigid" elements and three-dimensional second order tetrahedral elements.

Model of the vehicle chassis frame was made in details that are required for stress analysis, using primarily 2D finite elements. Connecting elements (screws, bolts, pins, rivets) were replaced with the corresponding groups of finite elements or reaction forces. Geometric features that do not affect the major loads were eliminated. In the front part of the frame, at the location of the fifth wheel's support, grid elements were applied with a contact type relationship.

Fig. 3 shows the details of a part of the semi-trailer suspension on the computational model. The suspension was modeled using "Spring" finite elements, replacing pneumatic suspension (for the purpose of the calculations definition of elements that copy the damping effects of the suspension was not necessary) and "Rigid" elements that model swing arms.

Vehicle body was modeled in a simplified manner using four-node shell elements, allowing to reflect the nature of layered composite structures of segments of semi-trailer walls. The view of discretized semi-trailer body is shown in fig. 4 where distribution of the wall panels structure is shown as well. Reinforcing elements of the body structure which are embedded in the wall segments, including the generator frame as well as floor cross-bars, were built with "Beam" elements with rectangular cross-sections. Door frames were modeled using "Beam" elements which are open spatial profiles.

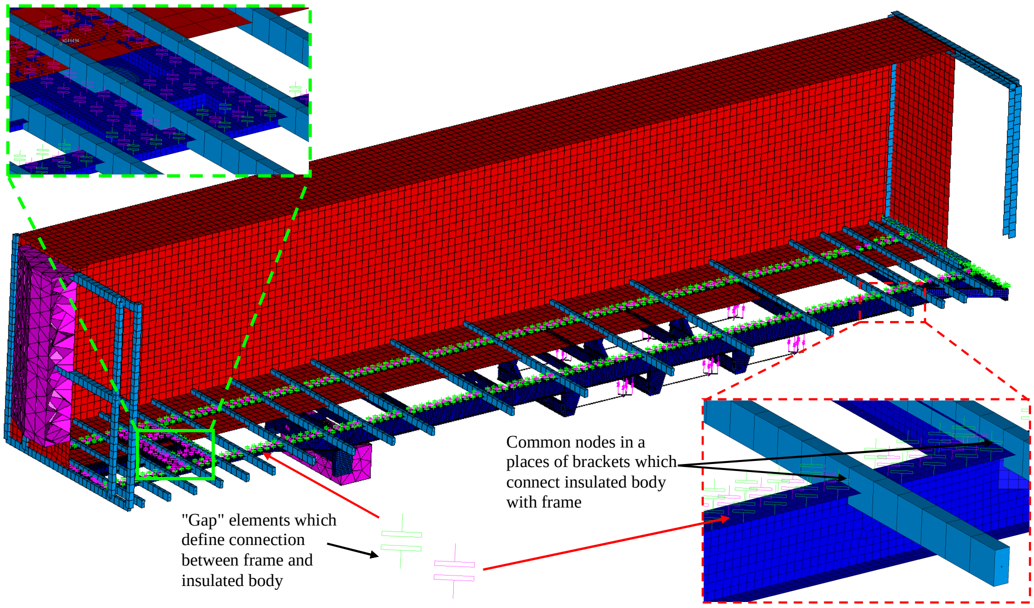

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Fig. 2. The computational model
Rys. 2. Model obliczeniowy

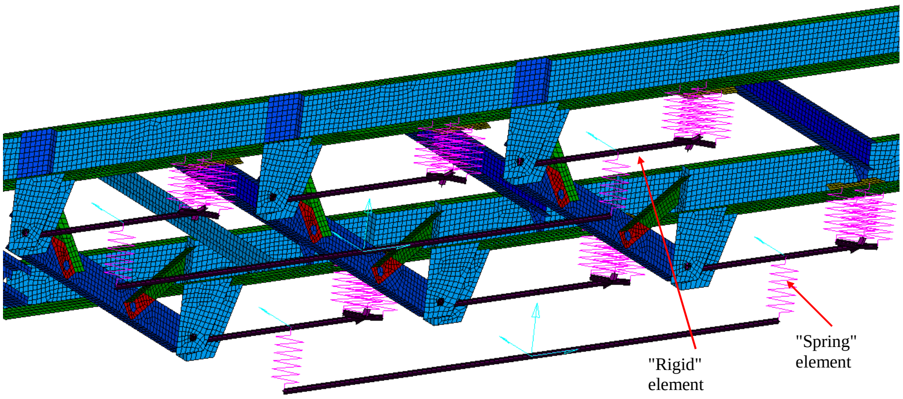

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Fig. 3. The computational model of vehicle suspension
Rys. 3. Model obliczeniowy zawieszenia

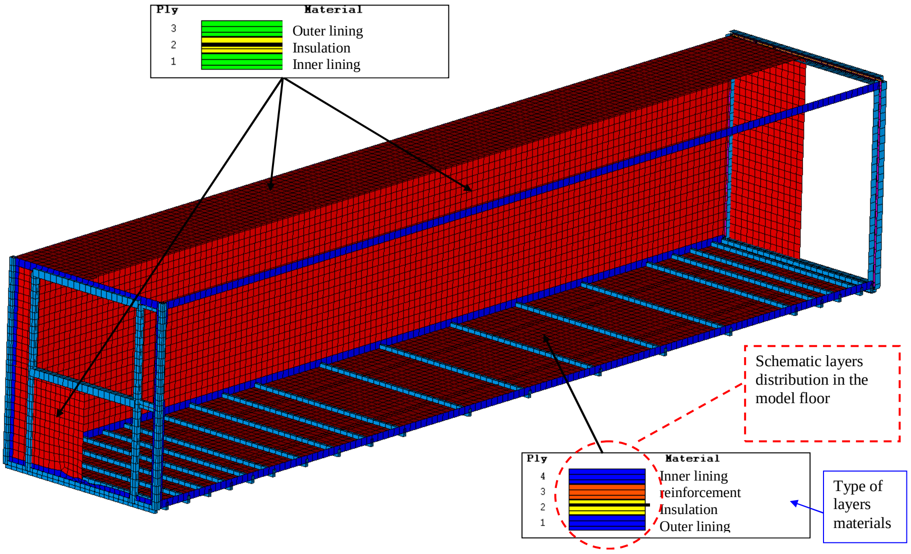

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Fig. 4. Structure of wall panels in the semi-trailer computational model
Rys. 4. Struktura paneli ściennych modelu obliczeniowego naczepy

For the purpose of development of material and physical properties of the insulated walls it was necessary to carry out laboratory tests. To this end, properly samples with formulated geometrical dimensions were prepared. During tests under the controlled conditions they were subjected to static loads. On a series of comparative samples stress and deformation states were registered. Obtained information through the experiment allowed to construct FEM computational models of analyzed objects (fig. 5).

The identification of material data and physical properties of panels that were carried out allowed to properly define the four-node shell element, by which walls of insulated body were modeled.

Relations between the body (insulating body) and vehicle frame are defined in places where screw connections exists using common nodes. The remaining connection places were connected with the use of finite elements that reflects contact condition.

4. Loads implementation in computational model of the semi-trailer

In the process of construction preparation for engineering analysis, it is very important to identify the loads, determine its type, direction and value [10].

For the purpose of stress analysis using Finite Element Method boundary conditions were specified for all verified components and assemblies of the insulated body. In the analysis of various states of motion of the vehicle, values of loading forces were calculated and degrees of freedom were defined which designate fulcrums. Defined boundary conditions were implemented into the computational models.

During the work realization, norms were taken into account (e.g. ISO/TS 20119, ISO 9815, ISO 15037-2, ISO 14792, EN 12642 [3, 5-8]), in which guidelines for proper determination of individual research can be found. On the basis of defined requirements and regulations a number of cases were defined for computational analysis in the field of static strength.

The most complex load condition was found in the case of moving vehicle on a curve of the road, where the main external load is the mass of the cargo. Movement at a certain speed V [$m \cdot s^{-1}$] on a particular curvature with the radius r [m], generates a centripetal acceleration a [$m \cdot s^{-2}$]. Weight of cargo and the own mass of a vehicle, due to the acting acceleration, generates force of inertia.

Fig. 6 shows the behavior of the vehicle during a ride on a curve of the road in a visual way. The calculations take into account weight of the construction Q_g [N] which generates centrifugal force Q_a [N] and the associated body roll φ [$\circ$].

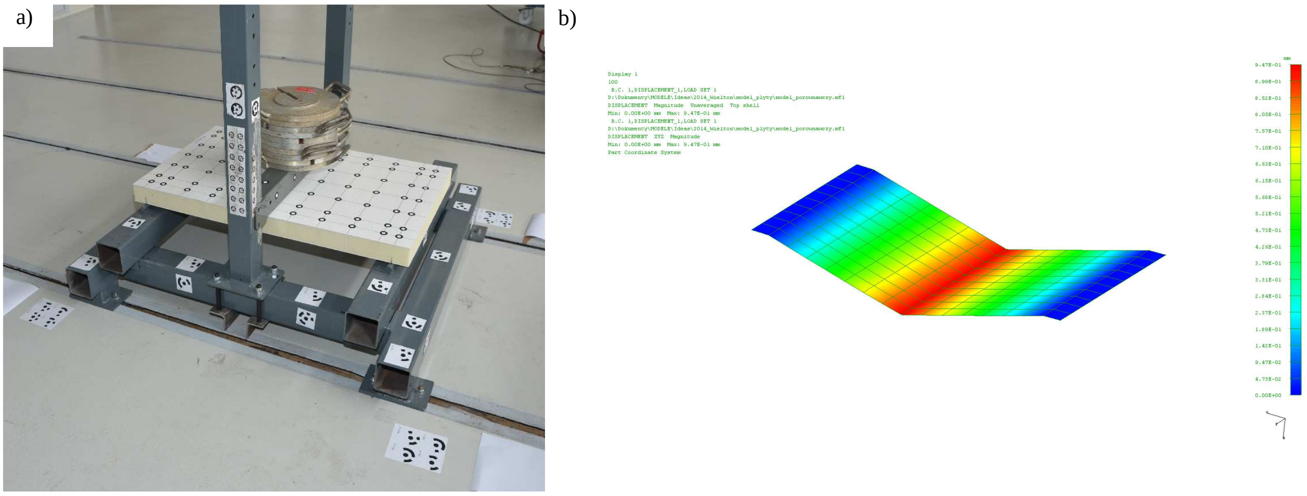

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Fig. 5. Material data identification: a - bending of a real sample, b - parameterized equivalent model
Rys. 5. Identyfikacja danych materiałowych: a - rzeczywista próbka zginana, b - sparametryzowany model zastępczy

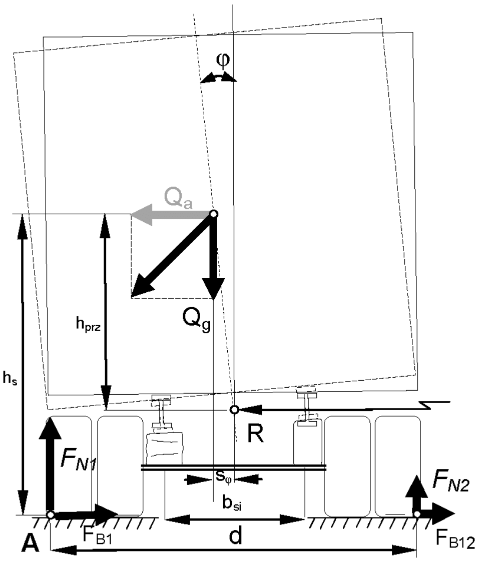

Fig. 6. Forces acting on vehicle while driving on a curved and sloped road [1]
Rys. 6. Siły działające na pojazd na łuku drogi pochylonej [1]

For the construction of computational model for the driving-around-a-curve case the load reaction on vehicle was mapped with two force components: horizontal and vertical. For the purpose of simulation of relieving effect due to inertia forces acting on one side of construction the vertical loads components were arranged unevenly. Furthermore, in accordance with the provisions of norm EN 12642 the cargo pressure on the side wall of semi-trailer was included as a form of evenly distributed pressure. The tires grip forces were introduced into the system in a form of transverse components of F_p [N], directed contrary to forces of inertia. In the present case, the alignment of forces reflects the state of vehicle movement during driving on left curve of the road.

In computational model, in the saddle support region there were removed all possible displacements in all directions (fig. 7a). Supporting system of the rear part of the model was built according to the scheme shown in fig. 7b.

Centripetal acceleration for the case of driving on an arc and for maximum speed limit was established under the Regulation of Ministry of Transport and Marine Economy on 2nd March 1999 [11]. Chosen parameters reflect the most adverse real driving conditions. For a such kind of movement the centripetal acceleration reaches a value of 2,45 $m \cdot s^{-2}$.

For all considered exploitation variants some load components in computation model were determined automatically by a computer system on the basis of adequately defined acceleration vectors. Other load components were determined based on analytical calculations.

5. Calculation results and their analysis

Computer calculations that were performed gave stress distribution for all analyzed cases. Values of the reduced stresses of the analyzed structure were obtained with the use of Huber-Mises hypothesis. For the sake of loads character (cyclic load changes) the main calculations concerned fatigue strength.

The most adverse condition of material exertion was obtained for the case of driving on a curve for which stress distribution is shown in fig. 8 and 9. Analyzing the results of numerical calculations, it was found that the maximum stresses in the support structure are located in the plate which supports the tractor fifth wheel and reach 190 MPa. Taking into account the phenomenon of stress concentration, point indicated by P5.2.3 is a material exertion point. In this case, the maximum value of stress reaches 209 MPa. The analysis of the front part of the structure showed that the external part is exerted strongly with respect to the path arc. In the stronger loaded structural which is an extension of the longitudinal frame members, the stresses reach 80 MPa. The highest values of stresses in the wooden elements of the body are found within the floor, above the wheel set and reach a value of 25 MPa.

Fig. 10 shows the displacement of the whole structure of the vehicle. The greatest displacement occurs at the rear part and is equal to 16 mm.

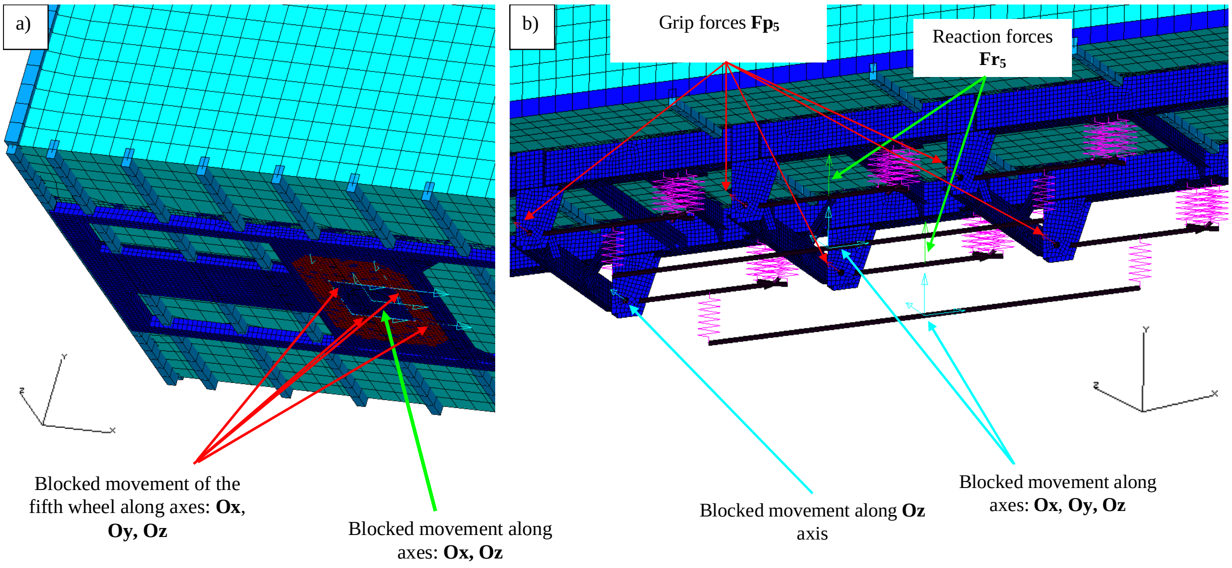

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Fig. 7. Support and forces distribution in suspension system of the semi-trailer in the driving around a curve case
Rys. 7. Podparcia oraz rozkład sił w układzie zawieszenia naczepy dla przypadku jazdy po łuku

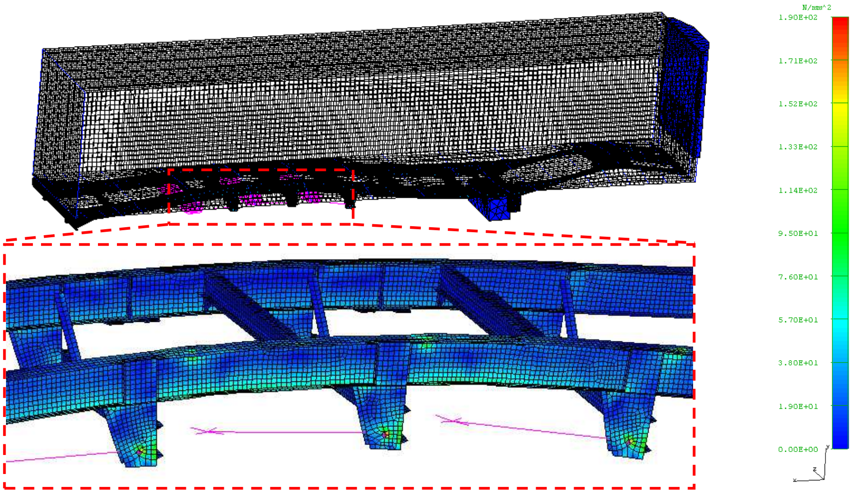

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Fig. 8. The magnitude of von Mises stress in the suspension area
Rys. 8. Mapa naprężeń zredukowanych Hubera-Misesa w obszarze zawieszenia naczepy

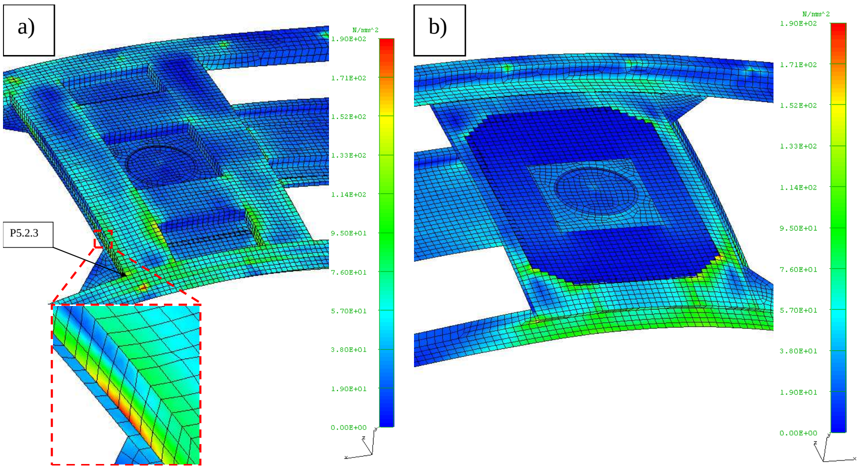

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Fig. 9. The magnitude of von Mises stress in the fifth wheel area: a - view from the right upper side, b - view from the left lower side
Rys. 9. Mapa naprężeń zredukowanych w obszarze siodła ciągnika: a - widok od prawej górnej strony, b - widok od lewej dolnej strony

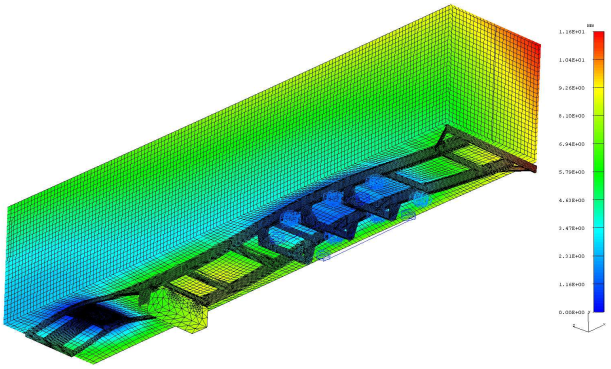

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Fig. 10. Displacements of the grid nodes for the calculation case Ps5.1 in [mm]
Rys. 10. Przemieszczenia węzłów siatki dla przypadku obliczeniowego Ps5.1 w [mm]

6. Summary

Finite Element Analysis of the insulated body construction allowed the identification of the most exposed and intensively exerted structural nodes. The analysis showed that the frame, which is the main load-bearing element, has sufficient and adequate strength. In none of the analyzed variants stresses did exceed allowable values, neither in the base material nor in the welded joints. Consequently, construction meets the fatigue strength requirements in the field of adopted loads and exploitation conditions. Displacements did not reach values which might have a negative impact on the structure functioning. Obtained stress maps are the outputs data for the planned functional tests (in the next stages of scheduled work) with the use of strain gauge measurements. The analysis results can have an important contribution in works on development and optimization of new insulated body constructions.

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