Article citation info:
Witkowski D, Tarnawski P, Stefańska N. Crashworthiness of a type 228M rail vehicle. Rail Vehicles/Pojazdy Szynowe. 2022;(3-4): 37-43. https://doi.org/10.53502/RAIL-157243

Rail Vehicles/Pojazdy Szynowe

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Crashworthiness of a type 228M rail vehicle

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ARTICLE INFO

Received: 16 October 2022
Revised: 7 December 2022
Accepted: 7 December 2022
Available online: 8 December 2022

KEYWORDS

Crashworthiness
Crash
Rail vehicle
Rail safety norms

This article presents crashworthiness issues based on the design of the 228M type light rail vehicle. Meeting the requirements of the standard requires the use of appropriate components dedicated to energy absorption and ensuring adequate strength of the body. After analyzing the scenarios, it can be concluded whether type light rail vehicle. 228M meets the normative requirements for crashworthiness.

1. Introduction

Inherent in the design of a rail vehicle, is the provision of the required level of safety. According to data provided by the Office of Rail Transport UTK in 2015-2021, the average number of accidents on railroad lines was about 568 accidents per year [X]. This level, for crashworthiness, is specified in the EN 15227:2008+A1 standard [2]. The ABAQUS 6.12-12 program in the "explicit" mode of integration of the equations of motion was used for the calculations. Meeting the requirements of the standard requires the use of appropriate components dedicated to energy absorption and ensuring adequate body strength.

2. Research object

The 228M rail vehicle is a passenger vehicle that was designed to carry out journeys on regional routes. The project was implemented by Łukasiewicz Research Network – Poznań Institute of Technology along with the factory.

H. Cegielski – Fabryka Pojazdow Szynowych. The basic details of the rail vehicle are shown in Table 1. The shells of the members are made of S355J2 steel. The vehicle is equipped with two types of bogies: 41MN driving bogies and 46AN rolling bogies.

Table 1. Basic technical data of the rail vehicle

	Unit	1*	2*	3*	4*
m_o	[t]	52	50	48	150
m_1	[t]	53.2	52	50	155.2
m_2	[t]	3.32			
l_1	[mm]	26150	25000	26150	78300
l_2	[mm]	2800			
x_1	[mm]	19000			–
x_2	[mm]	2500			
v	[km/h]	160			
d	[mm]	850			

1* – first carriage of multiple unit,
2* – second carriage of multiple unit,
3* – third carriage of multiple unit,
4* – multiple unit,
m_o – tare weight of the rail vehicle,
m_1 – rail vehicle crash weight (used in calculations),
m_2 – tare weight of the bogie (used in calculations),
l_1 – total length of the body with bumpers,
l_2 – body width,
x_1 – rail vehicle base,
x_2 – bogie base,
v – rail vehicle operating speed,
d – nominal wheel diameter.

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The vehicle is equipped with devices designed to absorb crash energy. These devices include: main absorbers attached to the front end with a face that prevents the vehicle from climbing, honeycomb-type top absorbers (Fig. 2), which are mounted on the front walls of the cabs, as well as front couplers and inter-couplers.

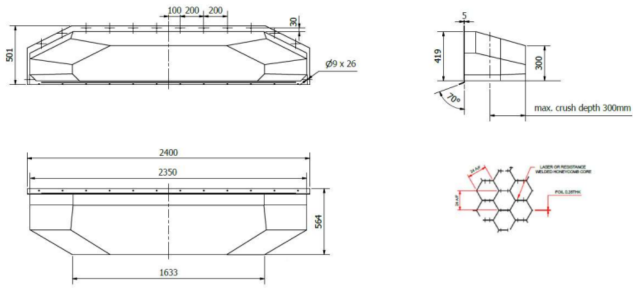


Fig. 2. Honeycomb main absorber

3. Normative requirements

Passenger safety in rail transportation is one of the key aspects of rail vehicle design.

The Type 228M rail vehicle, according to EN 15227:2008+A1 [2], which divides vehicles into four categories based on vehicle type and infrastructure, falls into category C-I. "Locomotive, train set – vehicles designed to operate on TEN, international, national and local routes (containing level crossings)". Accordingly, it was necessary to perform the following collision cases:

- scenario 1 – a collision between two identical trainsets at 36 km/h,
- scenario 2 – collision with a wagon weighing 80 t at a speed of 36 km/h,
- scenario 3 – collision with a 15 t deformable obstacle at a speed of 110 km/h,
- scenario 4 – collision with a small low obstacle.

Passive safety systems include components such as bumpers, crumple zones, survival zones, head restraints, engine and fuel system protection, and components made of non-flammable and non-toxic materials [3]. In order to minimize the impact of a collision on the condition of the passengers and the vehicle, passive safety measures are used, viz:

- reduce the risk of vehicles overlapping each other,
- absorption of impact energy,
- in a controlled manner,
- maintaining the structural unity of the vehicle with special attention to the passenger area (survival zone),
- reducing the deceleration (overloads) that occur,
- reduce the risk of derailment and the consequences of hitting an obstacle.

4. Numerical model

When using simulation for crashworthiness testing, it is necessary to calibrate the numerical model along with numerical analysis and bench tests. The method consists of three steps: bench tests of crumple zones and energy absorbers, calibration of the numerical model, and numerical simulation of collision scenarios. The model was made in the symmetry of the XOZ plane. The introduction of contact between finite elements allows the transfer of forces between colliding and deforming parts of the model. The transfer of forces between the colliding and deforming fragments of the model ensures the introduction of contact between the finite elements. Global contact was assumed, taking into account the coefficient of friction equal to 0.2. The exception is the wheel-rail contact, which was modeled as frictionless. The simulation included the force caused by the acceleration due to gravity of 9.81 m/s^2.

5. Research and results

The honeycomb absorber (Fig. 3) is a lightweight, thin-walled material with a typical multicellular structure and a good strength-to-weight ratio. [4] The force-displacement relationship for the absorber is shown in the following diagrams (Fig. 4).

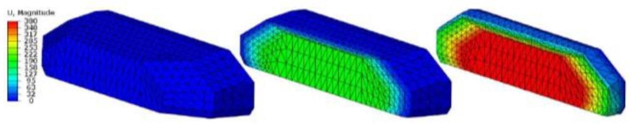


Fig. 3. Validation of the top absorber model

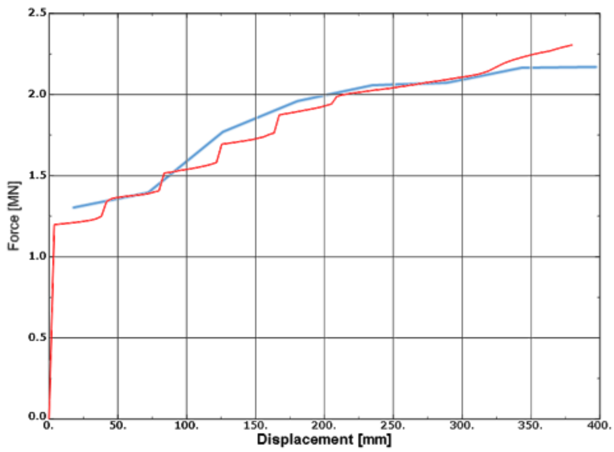


Fig. 4. The force-displacement curve obtained (blue line – research , red line – simulation)

The anti-climbing device is composed of an anti-climbing tooth, guide beam, energy absorption beam, aluminum honeycomb, reinforcing plate, mounting plate, and mounting base. A partial cross-sectional view of the anti-climbing device (Fig. 5).

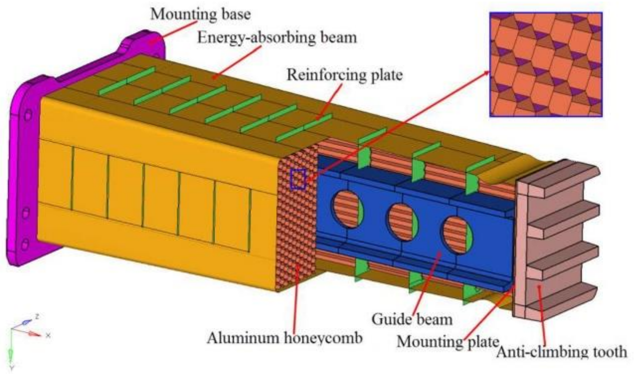


Fig. 5. The partial cross-sectional view of the example of anti-climbing device [5]

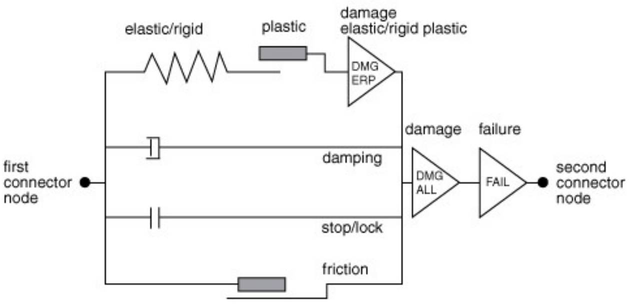


Fig. 6. Diagram of a connector type element

The diagram of the connector-type element is shown in Fig. 6. The dependence of force on displacement for the main absorber with the "anti-climbing" system is shown in the following diagrams (Fig. 7).

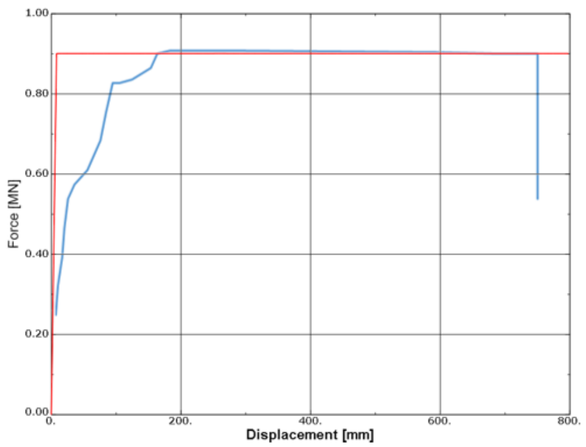


Fig. 7. Force-displacement curve (blue line – research, red line – simulation)

For the collisions between a train and large heavy obstacle at a level crossing, the equivalent deformable obstacle shall take the from of a complete numerical model represented in the specific crash simulation software (Fig. 8–10) [6].

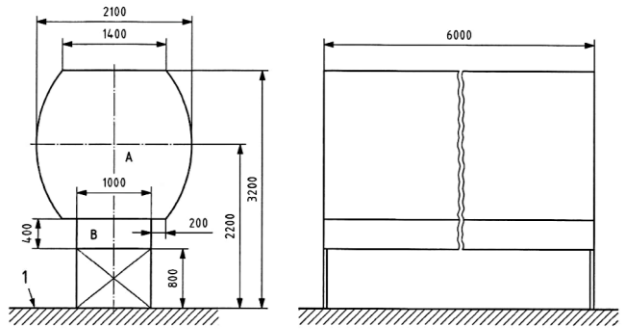


Fig. 8. Level crossing 15 t deformable obstacle

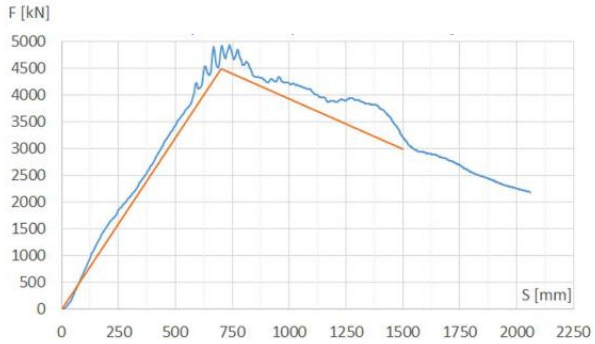


Fig. 9. Characteristics of the deformable obstacle – reference and obtained in simulation

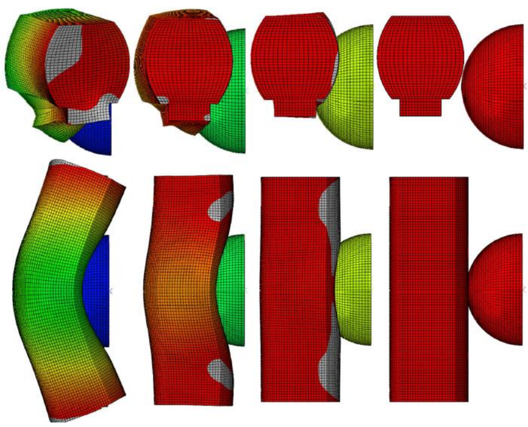


Fig. 10. Displacement stratification in successive stages of the obstacle verification test

According to the standard, the required collision cases were carried out. The first case analyzed is a collision between two identical trainsets, the first of which is moving at 36 km/h (10 m/s) and the speed of the second is 0 km/h (Fig. 11–13).

Fig. 11. Boundary and initial conditions – scenario 1

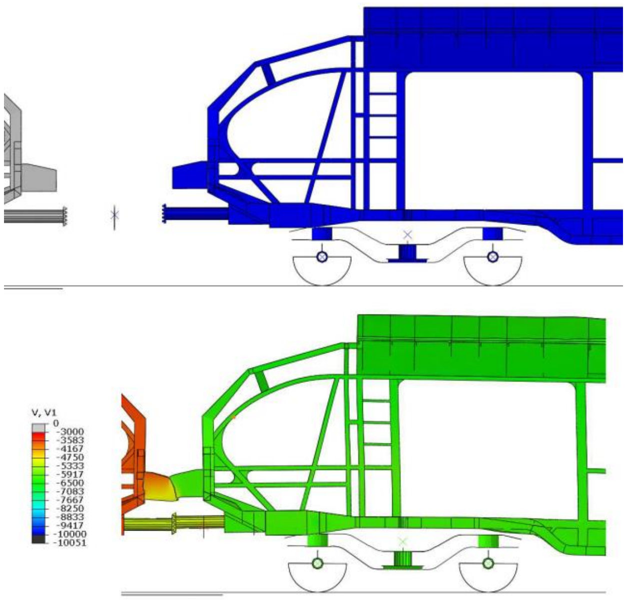


Fig. 12. The edge section of the lead vehicle at the beginning and end of the simulation (V1 – longitudinal velocity in the X axis)

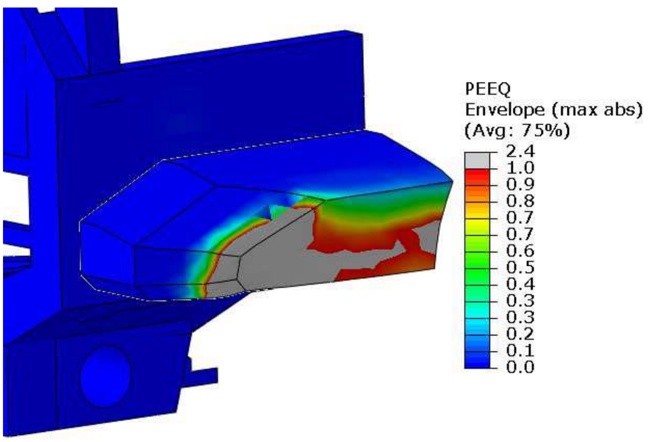


Fig. 13. Deformation of the honeycomb top absorber

The second collision scenario analyzes the impact of an 80 t freight car equipped with side buffers at a collision speed of 36 km/h. (Figs. 14–16). This wagon, according to the standard [2], was modeled as a rigid plate with bumpers with imposed characteristics.

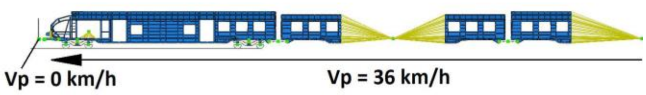


Fig. 14. Boundary and initial conditions – scenario 2

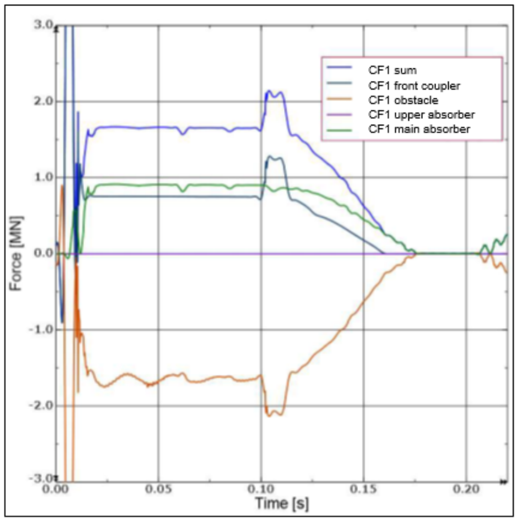


Fig. 15. Longitudinal components of the contact forces between the front end wall

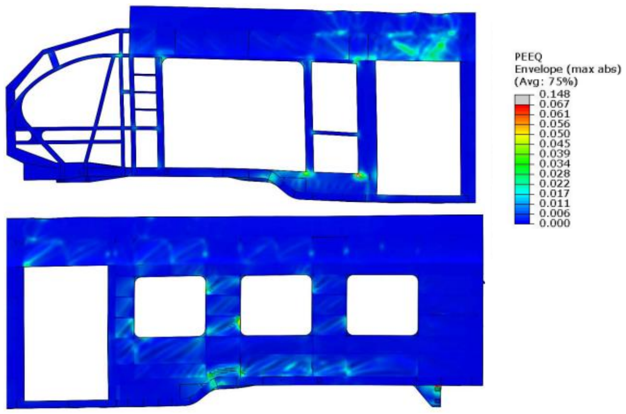


Fig. 16. Plastic deformation of the leading vehicle structure – side view

Collision scenario 3 involves a head-on collision with a deformable obstacle weighing 15 t at a railroad crossing (Fig. 17–24). [6]. According to the requirements of the standard [2] for the scenario in question, the collision speed is equal to the maximum vehicle speed minus 50 km/h (160 km/h – 50 km/h = 110 km/h).

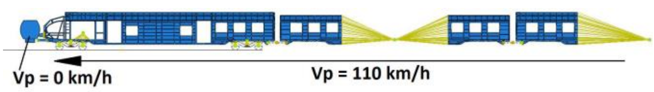


Fig. 17. Boundary and initial conditions – scenario 3

According to the graph shown in Fig. 21, the energy absorbed by the deformable obstacle and the vehicle structure is about 2.5 MJ with an initial kinetic energy of the system of 36 MJ. A plot of the longitudinal components of the contact forces between the flexible obstacle and the elements on the front wall indicates that nearly half of the longitudinal force is transferred directly to the body structure. The remainder of the contact force is distributed approximately half to the top absorber and a pair of main absorbers. Simulation studies for Scenario 3 showed significant deformation of the top absorber (Fig. 19). The intended goal is for the absorber to absorb most of the energy, which has a positive effect on the structure limiting its deformation. The use of the top absorber makes it possible to provide the required seat safety zone for the driver (Fig. 22). The plastic deformation that occurred in the structure is concentrated in the critical points, which are the front of the vehicle and around the door openings.

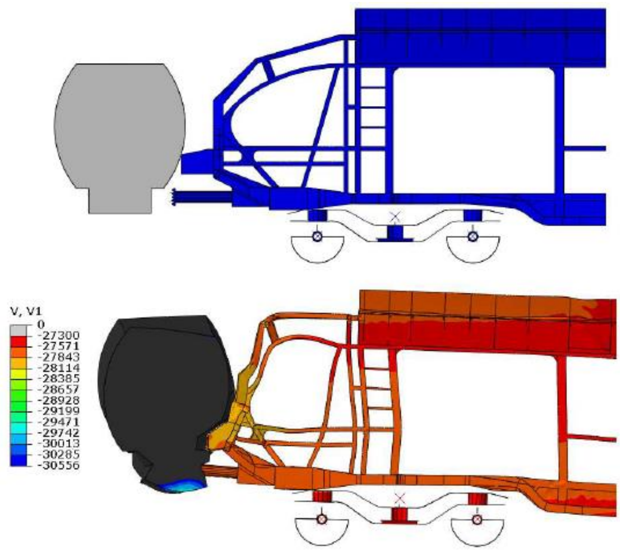


Fig. 18. The edge part of the lead vehicle at the beginning and end of the simulation

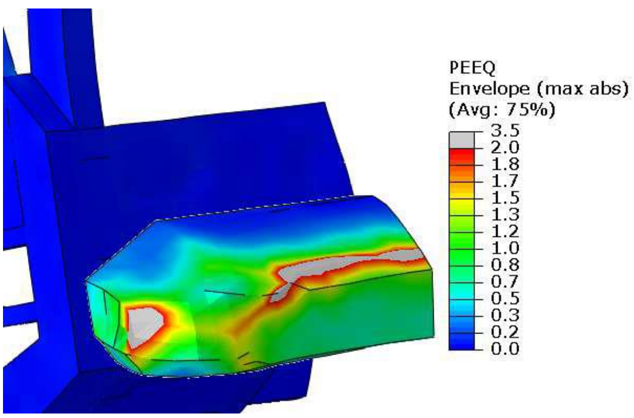


Fig. 19. Deformation of the honeycomb top absorber

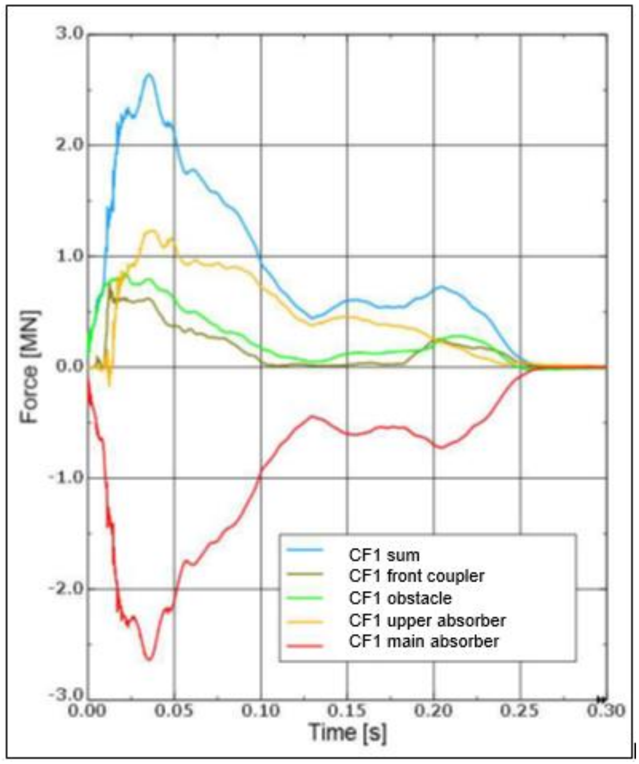
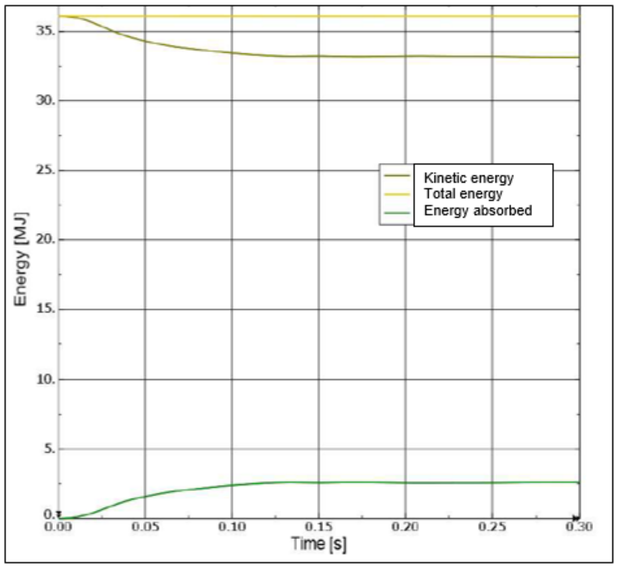


Fig. 20. Longitudinal components of contact forces between the front face of the evaluated vehicle and the flexible obstacle (180 Hz filter)



Rys. 21. Energy balance

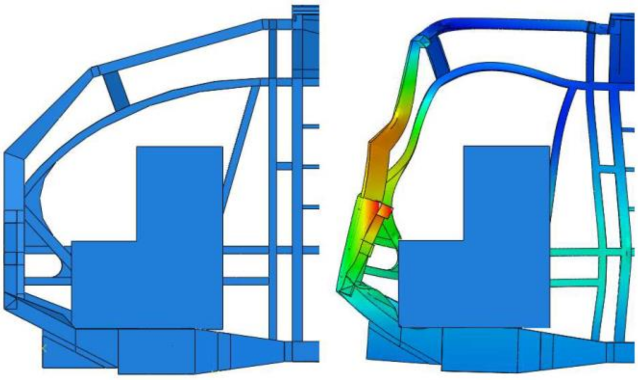


Fig. 22. Seat safety zone for the driver of the vehicle

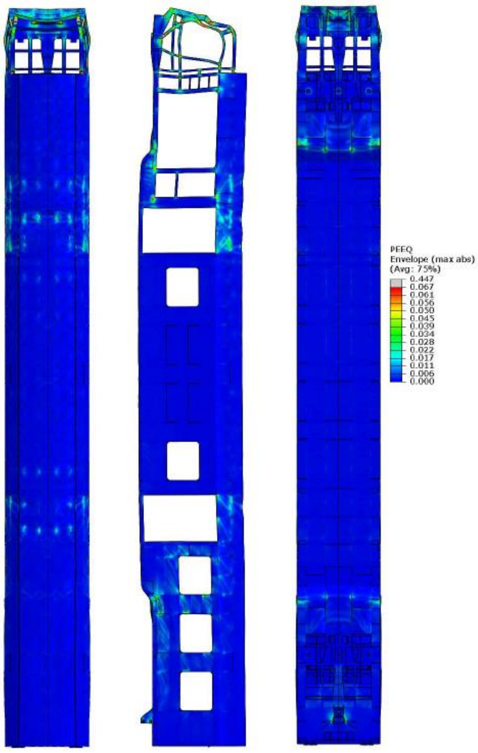


Fig. 23. Plastic deformation of the leading vehicle structure

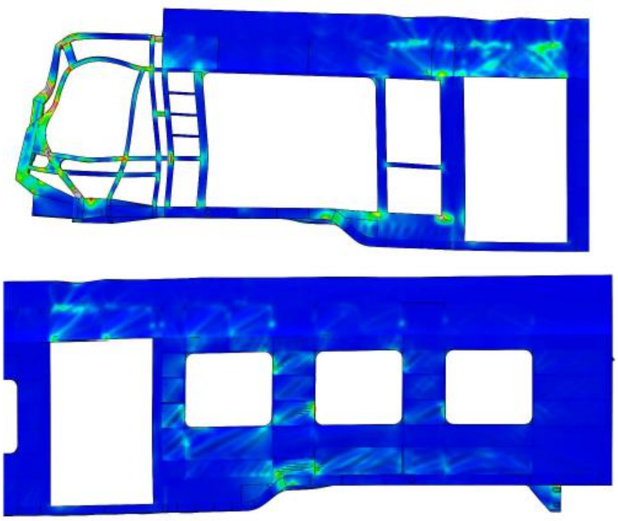


Fig. 24. Plastic deformation of the leading vehicle structure – side view

Collision scenario 4 involves a frontal collision with a small obstacle (Fig. 25) [6].

The structure of the bouncer is designed to absorb energy in an overloading in a controlled manner. The intermediate element forgives when the critical force is reached, allowing the required deformation of 120 mm to be achieved. The criterion from the standard has been replaced from geometric to energetic – this will enable the construction of scrapers with optimized mass.

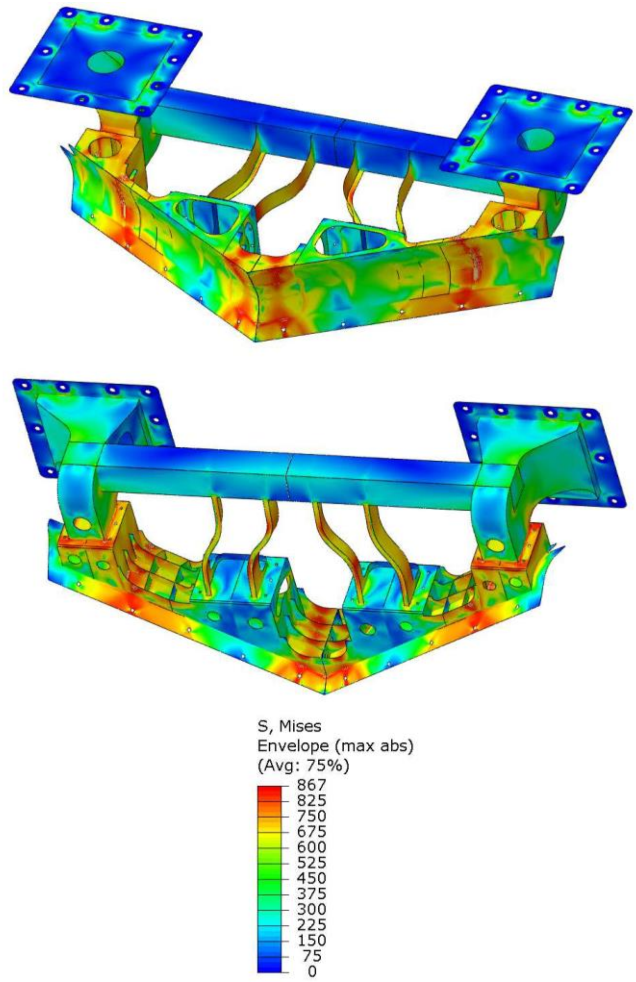


Fig. 25. Reduced stress field

6. Summary

After analyzing the scenarios, according to the standard [2], it can be concluded that the 228M type rail vehicle meets the requirements of standard for crashworthiness. In each of the four scenarios, there were no excessive deformations of the structure and no exceedances of permissible accelerations. Meeting the requirements allowed safety standards to be maintained – both in the driver's area and in the passenger section of the vehicle. The largest plastic deformations, which did not exceed the ranges presented in the in the standard, occurred in scenario 3 – collision with a deformable obstacle. In scenarios 1 and 2, most of the energy was absorbed by the main absorbers and the upper absorbers. In the case of honeycomb validation – it is possible to model with substitute elements in collision simulations.

Nomenclature

d	nominal wheel diameter
l_1	total length of the body with bumpers
l_2	body width
m_o	tare weight of the rail vehicle
m_1	rail vehicle crash weight (used in calculations)
m_2	tare weight of the bogie (used in calculations)
v	rail vehicle operating speed
x_1	rail vehicle base
x_2	bogie base

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