

high strength steel, dual phase steel

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## **DETERMINING THE INFLUENCE OF MATERIAL SOLUTIONS ON DURABILITY AND TARE MASS OF LIGHT CAR TRAILERS**

**Summary.** The modern light trailers constructions are expected to have considerable safety level, guaranteed by the high construction durability as well as possible low mass. The reduction of the trailer constructional mass parallel to its durability enables the increase in an acceptable capacity and contributes to fuel consumption decrease in vehicle-trailer unit. The research describes possibilities of maintenance or increase the light trailer structure durability parallel to reduction of its mass. The model of trailer behavior was simulated in various ways of load and assuming the usage of different kinds of materials such as structural steel and modern high strength steel.

## **OKREŚLENIE WPŁYWU ROZWIĄZAŃ MATERIAŁOWYCH NA WYTRZYMAŁOŚĆ I MASĘ WŁASNĄ LEKKICH PRZYCZEP SAMOCHODOWYCH**

**Streszczenie.** Od współczesnych konstrukcji lekkich przyczep samochodowych oczekuje się znacznego poziomu bezpieczeństwa, gwarantowanego poprzez wysoką wytrzymałość konstrukcji, jak też możliwe niskiej masy. Redukcja masy konstrukcji przyczepy, przy jednoczesnym zachowaniu poziomu jej wytrzymałości, umożliwi wzrost dopuszczalnej ładowności i przyczyni się do zmniejszenia zużycia paliwa przez zestaw pojazd-przyczepa. W pracy określone zostały możliwości zachowania lub zwiększenia wytrzymałości struktury lekkiej przyczepy samochodowej przy jednoczesnej redukcji jej masy. Symulowano zachowania modelu przyczepy w różnych przypadkach obciążenia i przy założeniu zastosowania różnych gatunków materiałów takich jak stal niestopowa oraz nowoczesna stal wysokowytrzymała.

### **1. INTRODUCTION**

The modern light trailers constructions are characterized by considerable diversity of solutions. It results from the necessity of optimizing them paying special attention to:

- the tare mass reduction directly influencing the fuel consumption in vehicle-trailer unit,
- ensuring the proper load supply
- minimization of costs of production and assembly,
- gaining proper exploitation stability. [1]

Complying with above requirements extorts further seeking of new construction, material and technological solutions. At present some researches are being done, associating the vehicles producers and steel manufacturers aiming the decrease of vehicle tare mass (i.e. ULSAB programme). As it was

proved in research [2], the reduction of vehicle mass (or vehicle-trailer unit) by 10% is effective in 6.5% decrease of fuel consumption.

The usage of modern CAD tools in digital prototyping allows to modify and optimize the construction and material solutions at preproduction stage simultaneously influencing the unit costs decrease. The modern CAD tools allow to examine the physical model behavior in assumed load conditions.

The goal of this research was to describe the influence of high strength steel usage on load and safety level of the light trailer. The trailer models elaborated on existing constructional solutions were simulation research objects. Prepared models were subjected to FEA numerical simulations which reflected various case of load.

Carried out simulation research allowed to describe:

- influence of the used material on constructional safety level,
- a possibility of construction mass reduction thus using lighter high strength steel elements as well as the made perforation in these elements ,
- influence of the used material and constructional solutions on material costs.

## 2. THE OBJECT PHYSICAL MODEL

As part of this research the light trailer model has been prepared (fig. 1). It was based on the following assumptions:

- the static trailer load: 500 kg,
- the load surface: 2,25 m<sup>2</sup>,
- number of unbraked axles: 1,
- type of elements connection: welding,
- constructional material of load elements: steel S355J0, steel Docol 600DP (according to table 1 [3], [4]).

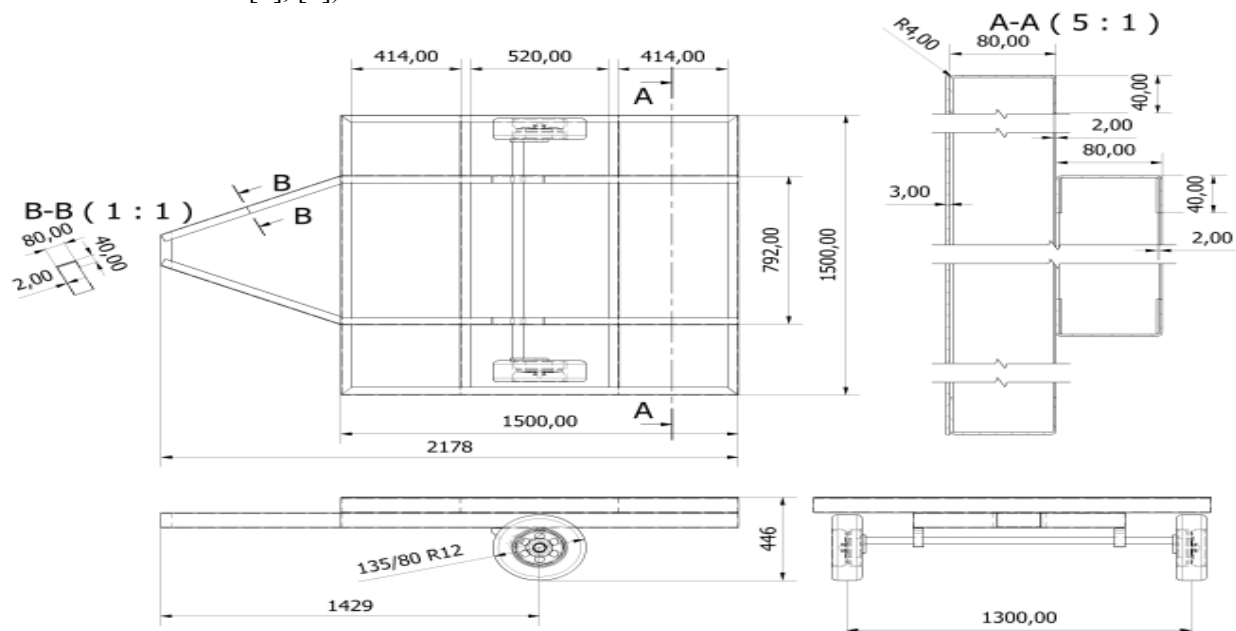


Fig. 1. Main measurements of researched object (load structure mass: 93,77kg)

Rys. 1. Główne wymiary badanego obiektu (masa struktury nośnej: 93,77kg)

Table 1

## Used steel properties

	Yield strength, $R_e$ , MPa	Tensile strength, $R_m$ , MPa	Elongation, $A_{80}$ , %	Young modulus $E$ , GPa	Poisson modulus $\nu$
S355J0	355	470÷630	27	210	0,27
DOCOL600	450	600	16	228	0,30

## 3. SIMULATION RESEARCH

Numerical simulation was made with usage of Ansys module in Autodesk Inventor application. The simulation research was done in three cases of load concerning the load during stop, load during straight line ride and load during bumpy road ride. It was assumed that there were two construction materials: structural steel and modern high strength steel (table 1.) The carried out simulations had a static character. In order to take into consideration dynamic loads, the established values of turning moments and pulling force were extended with dynamic coefficient 3 in presented works [5] and [6], multiplying the static load. The established load values are presented in table 2. They are results of following parameters [7]:

- ❖ assumed trailer load,
- ❖ pulling force as a result of resistance:
  - rolling

$$F_t = m \cdot g \cdot \mu \cdot \cos \alpha = 97 \cdot 9,81 \cdot 0,015 \cdot 0,82 = 72,04N$$

- aerodynamics

$$F_a = 0,613 \cdot c_x \cdot S \cdot v^2 = 1149,36N$$

- hill

$$F_w = m \cdot g \cdot \operatorname{tg} \alpha \cdot 100\% = 418,02N$$

where:  $m$  – trailer and load mass, kg (97kg+500kg),  $g$  – gravitational acceleration,  $m/s^2$ ,  $\mu$  – resistance coefficient of rolling for asphalt surface (established  $\mu=0,015$ ),  $\alpha$  – road gradient, ° (established  $\alpha=35^\circ$ ),  $c_x$  – air resistance coefficient, (established  $c_x=0,5$ )  $S$  – front surface of vehicle,  $m^2$  (established  $1,5m^2$ ),  $v$  – speed, km/h (established  $v=50km/h$ ).

The pulling force was calculated in relation of established dynamic coefficient 3:

$$Q_c = 3(F_t + F_a + F_w) = 3(72,04 + 1149,36 + 418,02) = 3 \cdot 1639,42 = 4918,26 \approx 5000N$$

- ❖ the turning moment resulting of one of the wheels mass in case of its vertical movement:

$$M_r = 3(m_k \cdot g \cdot \frac{1}{2}l) = 478,24 \approx 500Nm$$

where:  $m_k$  – one wheel mass with a hub, kg (established 20kg),  $g$  – gravitational acceleration,  $m/s^2$ ,  $l$  – track of wheels (according to pic. 1).

Table 2

## The simulation results list of separate constructional solution

Load case	Force on trailer surface $Q_{st}$ , N	Traction force, $Q_c$ , N	Moment of turning, $M_r$ , Nm
Static load during the stop	5000	-	-
Load during the straight line ride	5000	5000	-
Load during the bumpy ride	5000	5000	500

**The static load during stop.** In this case of load it was assumed that the trailer in rest would be loaded evenly distributed by  $Q_{st}$  load, resulting from assumed construction load. The fixing in place of linking an axle and trailer's underframe was assumed. Fig. 2 presents the diagram of load and fixing.

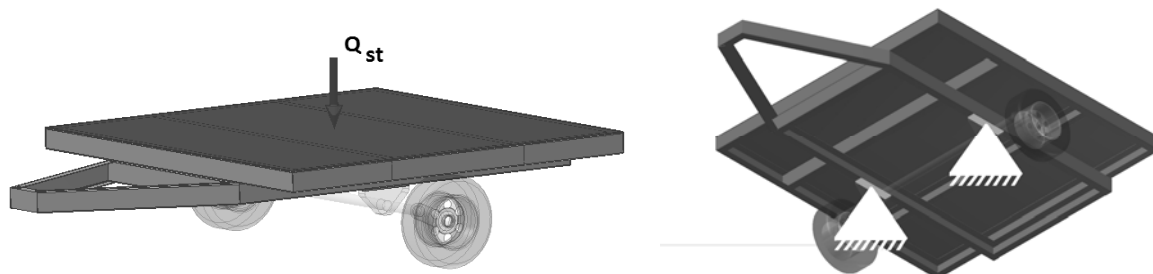


Fig. 2. Place of strength application and attaching - a case of static load during the stop  
Rys. 2. Miejsce przyłożenia siły i utwierdzenia - przypadek obciążenia statycznego na postoju

**The load during the straight line ride.** In this case of load an additional traction force  $Q_c$  was assumed (figure 3). The traction force was a result of movement resistance of moving, aerodynamics, elevation, inertia and dynamic coefficient.

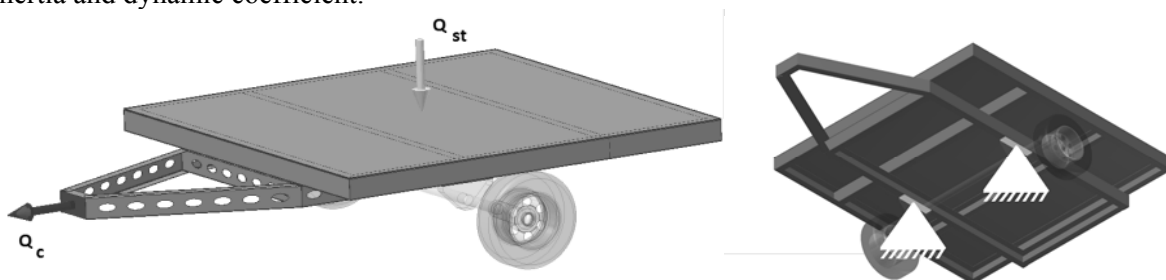


Fig. 3. Place of strength application and attaching – the case of load during straight line ride  
Rys. 3. Miejsce przyłożenia siły i utwierdzenia - przypadek obciążenia w czasie jazdy po prostej

**The load during a bumpy ride.** In this case of load an additional load was assumed with the moment of turning  $M_r$  (figure 4). The value of turning moment put to the main underframe was simulating the dynamics of the bumpy ride.

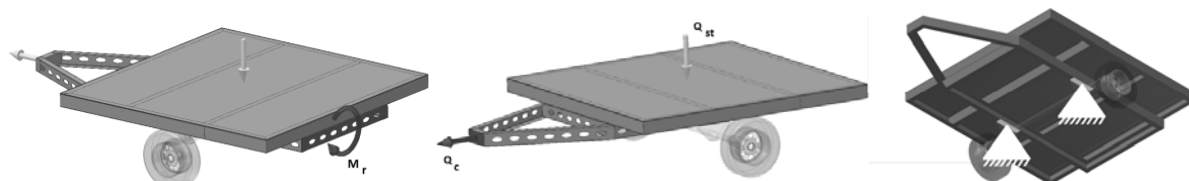


Fig. 4. Place of strength application and attaching – the case of load during the bumpy ride  
Rys. 4. Miejsce przyłożenia siły i utwierdzenia - przypadek obciążenia w czasie jazdy po nierównościach

As a result of simulation research the spatial map of stress in particular elements of the trailer and maximum values map of elements relocations were received. The view of safety coefficient values picture that was defined as acceptable stress quotient of the material and local stress appearing in individual elements was obtained. It was established that the construction will meet the requirements in case when the coefficient is in accordance with dependence:

$$n = \frac{\sigma_{dop}}{\sigma_{rz}} \geq 1,2$$

where:  $n$  – safety coefficient,  $\sigma_{dop}$  – acceptable stress in material (table 1),  $\sigma_{rz}$  – maximum stress in researched structure

#### 4. THE SIMULATION RESEARCH RESULTS

The simulation research results are presented in table 3. The selected pictures illustrating local stress are presented in tables 4-5.

Table 3

The diagram of simulation results of separate construction solutions

			<i>Static load during the stop</i>	<i>Load during the straight line ride</i>	<i>Load during the bumpy ride</i>
Steel S355J0	Von Mises stress	MPa	177,79	191,48	294,98
	Max. main stress	MPa	101,88	173,22	303,47
	Min. main stress	MPa	-186,27	-222,34	-338,53
	Max. deformations	mm	1,44	1,48	2,05
	Min. safety coefficient	-	2,00	1,86	1,20
Steel DOCL 600	Von Mises stress	MPa	188,18	190,77	294,06
	Max. main stress	MPa	199,65	176,11	308,21
	Min. main stress	MPa	-220,96	-222,92	-339,94
	Max. deformations	mm	1,36	1,36	1,89
	Min. safety coefficient	-	2,39	2,36	1,53

On account of safety of model's high reserve which was made of high strength steel, an additional physical model of trailer was decided to be worked out, in which the constructional elements were characterized by smaller thickness of sides and they were equipped with extra perforated holes that reduced the mass.

The fig. 5 present the alternative constructional solutions of trailers.

The additional model was subjected to numerical simulations according to load plan presented above. The results of research are listed in table 6 and selected maps of stress and safety coefficient are listed in table 8. The supply of safety coefficient presented in table 7 and in fig. 7 was being calculated in dependence:

$$Z_n = \frac{n - 1,2}{n} \cdot 100\% \quad ,$$

where; n – minimal safety coefficient for a particular load case.

Table 4

The numerical simulation results - the case of load during the straight line ride

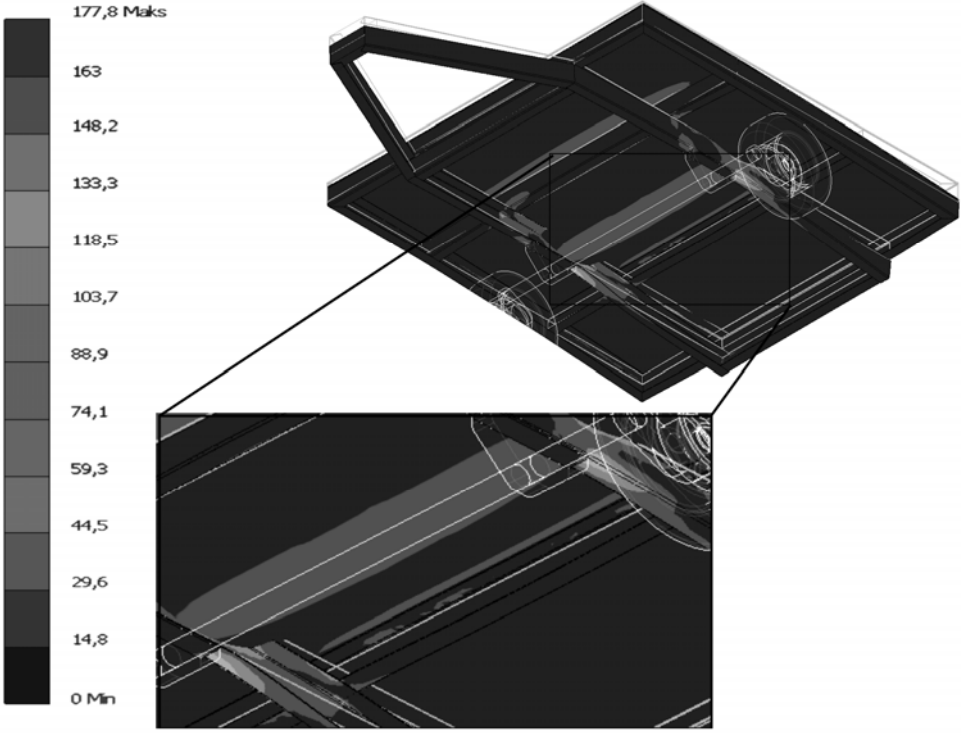
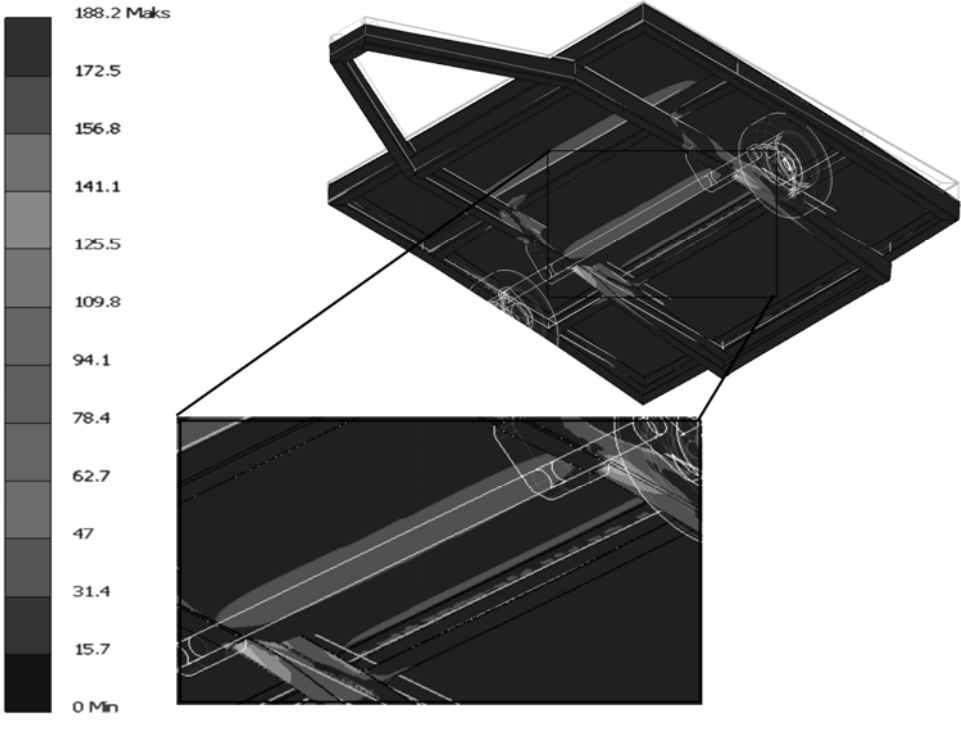
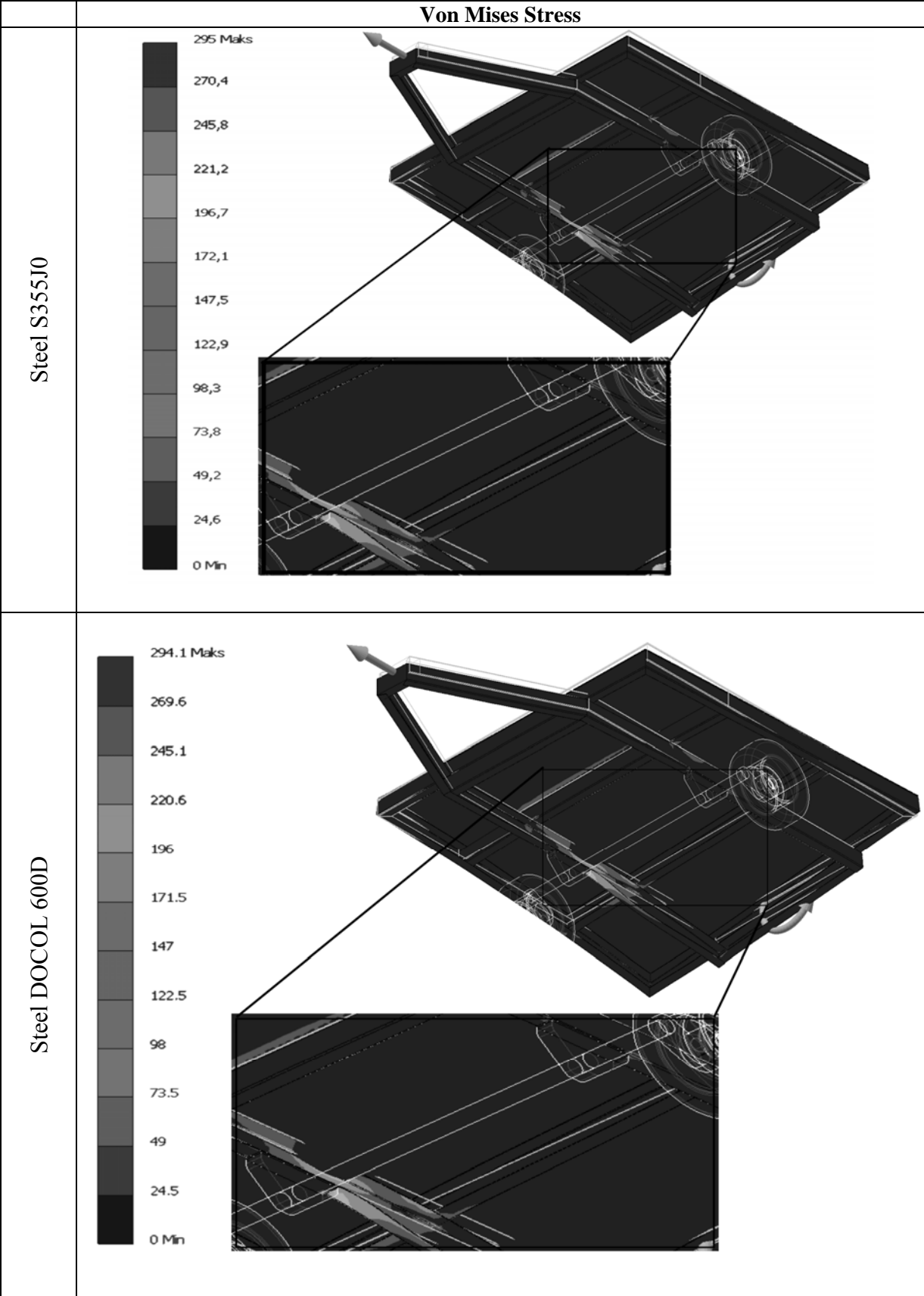
<b>Von Mises stress</b>	
Steel S355J0	
Steel DOCOL 600D	

Table 5

The numerical simulation results - the case of load during the bumpy ride



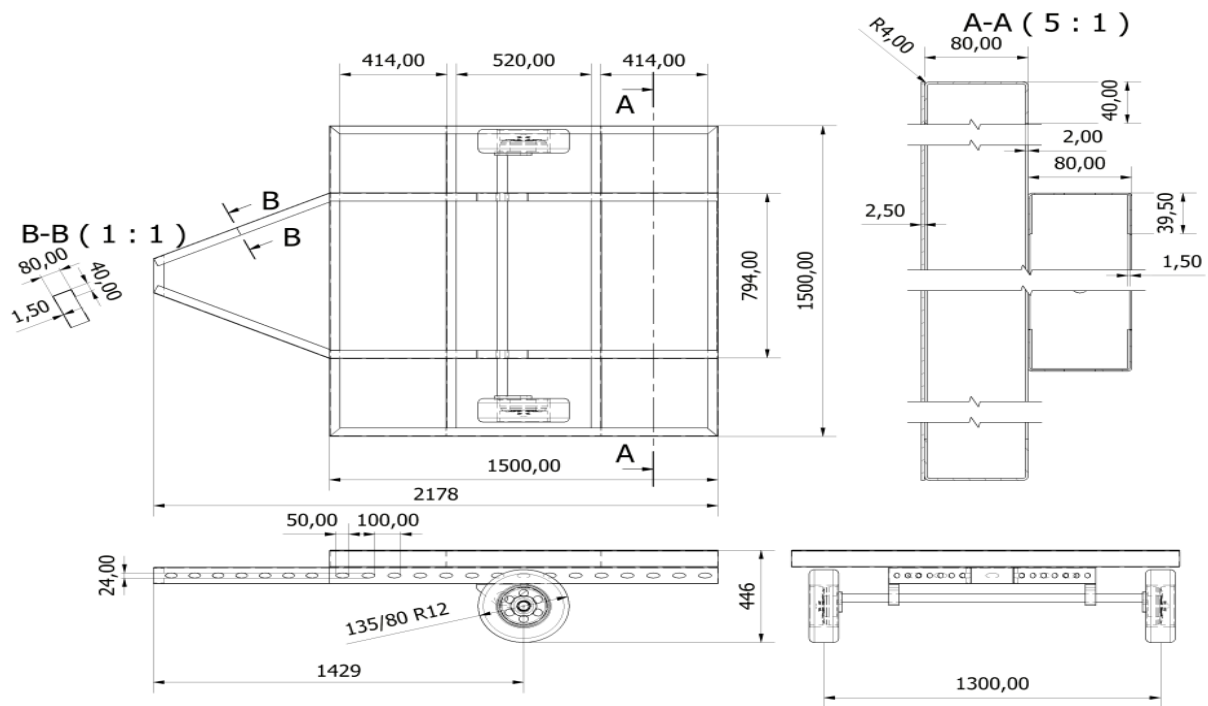


Fig. 5. Main measurements of additional model (load structure mass 75,64 kg)

Rys. 5. Główne wymiary modelu dodatkowego (masa struktury nośnej: 75,64 kg)

Table 6

			<i>Static load during the stop</i>	<i>Load during the straight line ride</i>	<i>Load during the bumpy ride</i>
Steel DOCOL 600	Von Mises stress	MPa	282,95	311,20	373,18
	Max. main stress	MPa	280,72	232,58	390,45
	Min. main stress	MPa	-113,45	-418,16	-445,95
	Max. deformation	mm	1,26	1,17	2,55
	Min. safety coefficient	-	1,59	1,45	1,20

Table 7

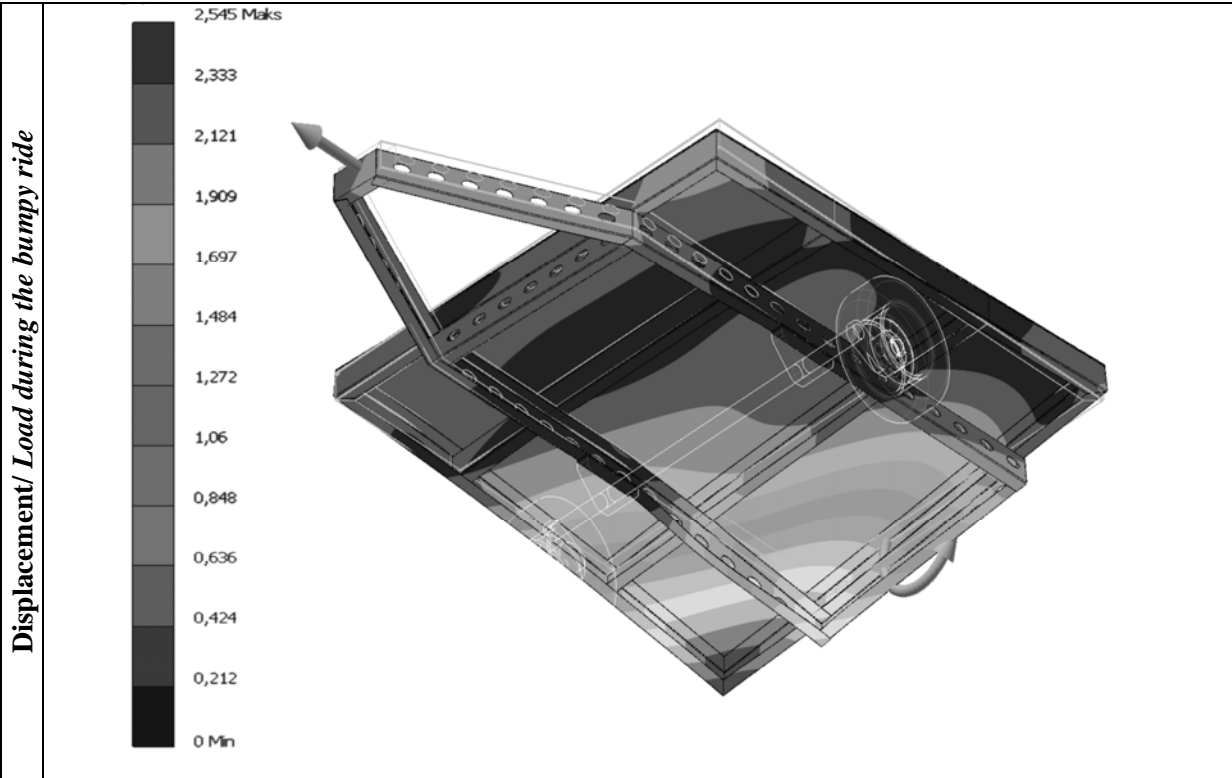
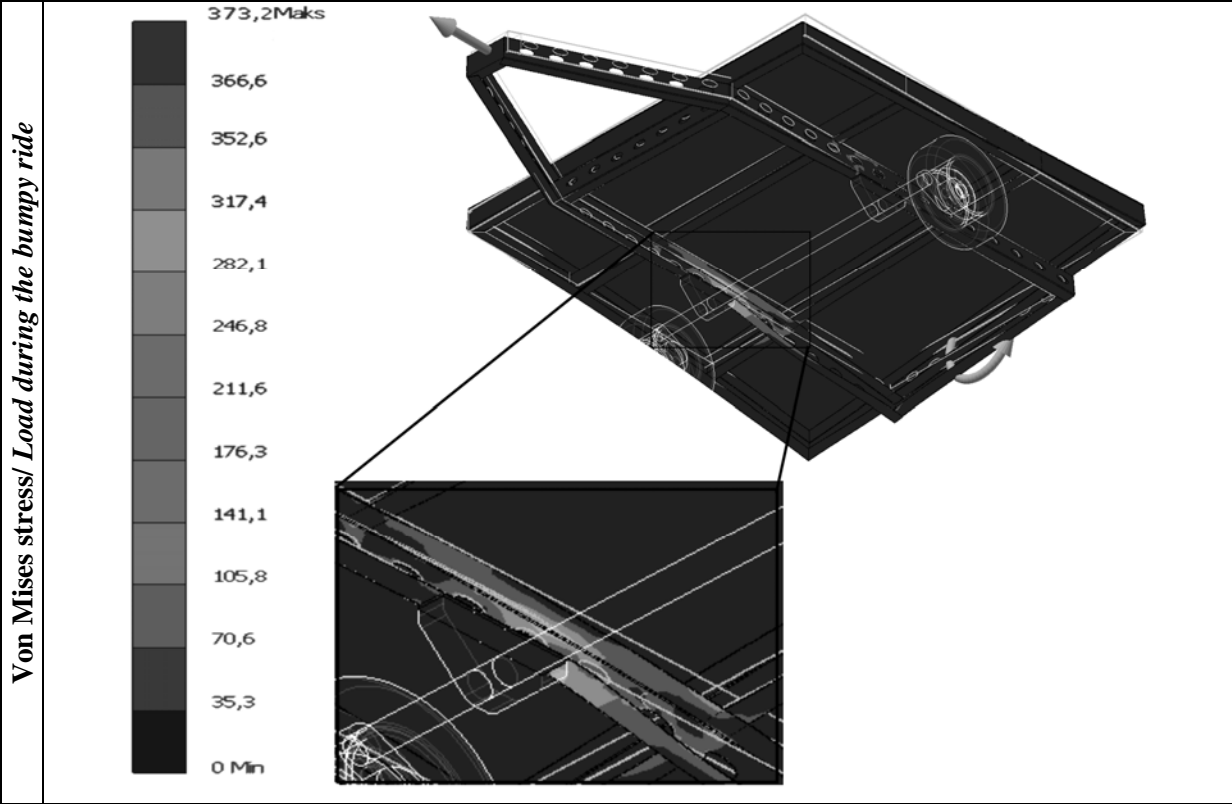
The table of selected simulation results of separate constructional solutions

	Safety coefficient reserve, $Z_n$ , %			Max. deformations, mm			Min. safety coefficient		
	Main model Steel S35510	Main model Steel DOCOL 600	Additional model Steel DOCOL 600	Main model Steel S35510	Main model Steel DOCOL 600	Additional model Steel DOCOL 600	Main model Steel S35510	Main model Steel DOCOL 600	Additional model Steel DOCOL 600
<i>Static load during the stop</i>	66,67	99,17	32,50	1,44	1,36	1,26	2,00	2,39	1,59
<i>Load during the straight line ride</i>	30,00	96,67	20,83	1,48	1,36	1,17	1,56	2,36	1,45
<i>Load during the bumpy ride</i>	0,00	27,50	0,00	2,05	1,89	2,55	1,20	1,53	1,20



Table 8

The numerical simulation results of additional model



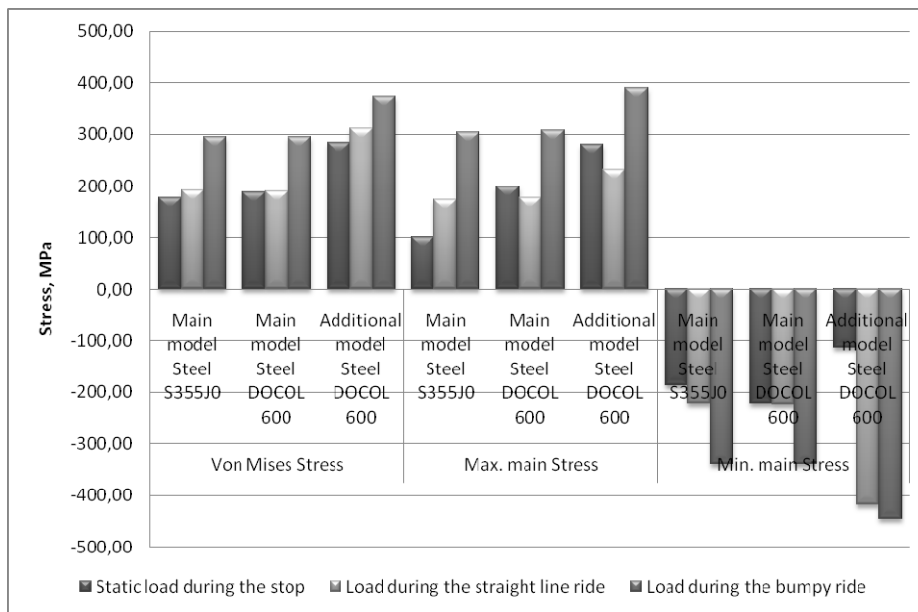


Fig. 6. The diagram of stress values in separate models  
 Rys. 6. Zestawienie wartości naprężeń w poszczególnych modelach

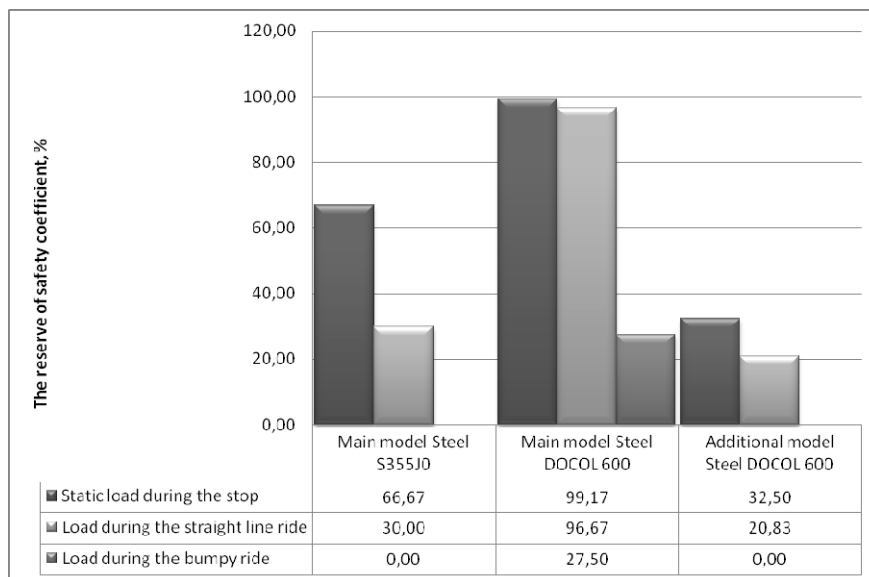


Fig. 7. The reserve of safety coefficient of separate models  
 Rys. 7. Zapas współczynnika bezpieczeństwa poszczególnych modeli

### 5. CONCLUSIONS

The carried out simulation research proved the correctness of trailers models construction and correctly established edge conditions. The defined in work dynamic coefficient allows to assume that dynamic loads existing in normal exploitation do not make any acceptable exceeding stresses. Extra established safety supply (20%) will allow to reduce an additional loads influence – e.g. resulting of the acceptable exceeding capacity-. The research proved the appropriateness of high strength steel usage in vehicles’ construction. The higher durability properties of those materials allow to reduce the thickness of profiles’ wall with appropriate capacity supply and not decreasing that supply (according to original construction).

The particular simulation research that was carried out on physical models allowed to form the following conclusions:

1. in case of both models and all set conditions of load the accepted stress was not exceeded and its values stayed in resilience range,
2. higher strength properties of used high strength steel made the increase of safety coefficient by over 27%,
3. high reverse of high strength steel model's safety coefficient allowed to decrease the load elements diameter by 25% and making the new perforations in them,
4. the usage of high strength steel in model as well as perforated elements caused the mass reduction by about 16%,
5. about 16% lower mass of the additional model allows to accept the decrease of fuel consumption by the pulling vehicle by about 10%,
6. in case of each studied physical model the assumed level of safety coefficient was done,
7. the model made of high strength steel as well as perforated elements characterized by an adequate reserve of safety coefficient parallel to lower mass,
8. some further research about possibilities of high strength steel usage in load structures of vehicles and trailers is appropriate.

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