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CAD-CAE IMPLEMENTATION IN CARGO SECURING SYSTEMS TESTING

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Abstract: *The paper presents a comparative analysis between numerical simulations performed in ANSYS software and the results obtained in real dynamic tests in order to observe the behavior of a cargo securing system. After a statistical analysis it can be noticed that the number of road casualties is higher when discussing about heavy goods vehicle (HGV) comparative to passenger vehicles. And one of the main reasons for accidents in traffic is the rollover effect caused by the incorrect securing of the load disposed on a truck platform. The subject of the analysis is a 6 $\times$ 6 military truck, adapted to carry onto its chassis a special platform, secured with atypical connections due to the complexity of the entire assembly. Both theoretical and practical information regarding the testing procedures are presented. The obtained results are also analyzed and the described methods could be useful for vehicle testing engineers in order to predict the possible failures during real testing.*

Key words: *cargo securing, FEM, braking, simulation, testing procedures, vehicle stability.*

1. INTRODUCTION

Nowadays, the demand of the society on the traffic safety is permanently increasing because of the growing number of the vehicles all around the world. It is obvious that transportation infrastructure cannot keep up with the rising number of vehicles so other safety measures need to be considered. One of the most important issues related to traffic safety is the presence of heavy vehicles on public roads: trucks, road tankers, trailers, buses, military vehicles, special adapted vehicles and so on.

According to [1], statistics show that accidents related to heavy goods vehicle (HGV) are more dangerous than those of passenger vehicles. Even if they constitute only 3% of vehicles in traffic, heavy vehicles are involved in 10% of accidents with fatalities. Furthermore, the fatality rate is twice as high when a HGV is implied. One of the most frequent accidents is represented by rollover (20%) and causes significant damages to the vehicles and injuries to its driver and passengers.

For a better presentation of this issue, we have analyzed a statistical release from 2012, regarding road casualties in Great Britain [2]. As it can be seen in Fig. 1 between 2007 and 2011, seven times more goods vehicle occupants were killed than bus and coach occupants in traffic accidents. Figure 2 presents the situation of seriously injured peoples in road casualties, where the average value is 1.5 higher when talking about goods vehicle occupants.

Though, we can notice that in this time interval, the overall number of road casualties is decreasing. The main reason for this phenomenon could be represented by the permanent progress in automotives and the new technologies applied on this type of vehicles in order to increase transportation safety.

Here are some possible causes of heavy vehicles implication in traffic accidents:

- overloaded mass;
- incorrect disposal of the load (see Fig. 3);
- excessive speed;
- damaged tires, suspension, or braking systems;

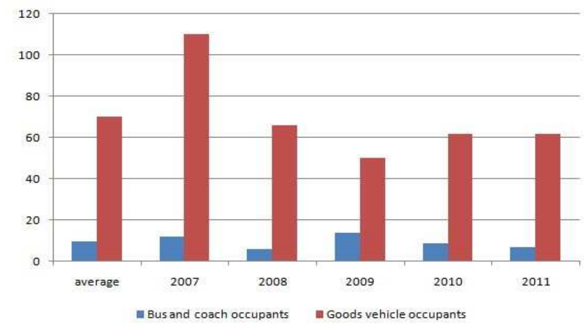

Fig. 1. Statistic of *killed* peoples in accidents in Great Britain (2007−2011).

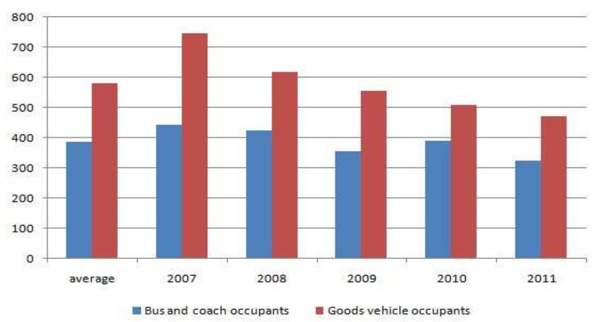

Fig. 2. Statistic of *seriously injured* peoples in accidents in Great Britain (2007−2011).

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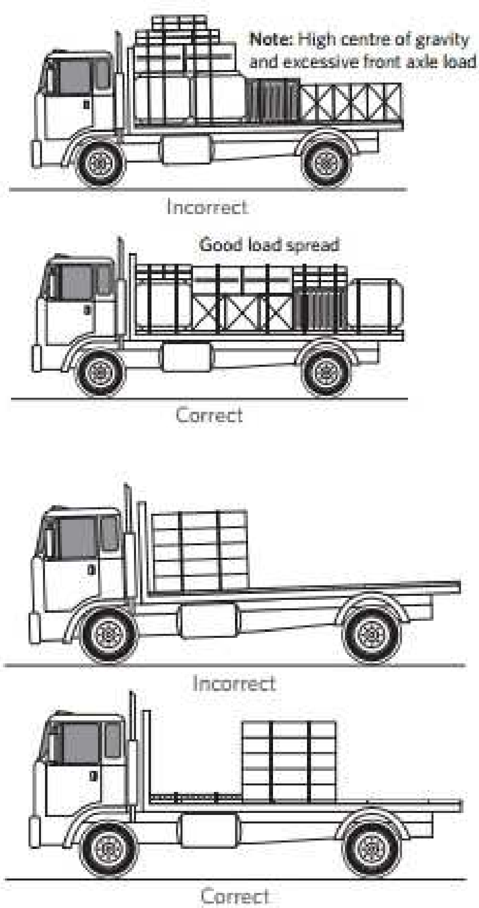


Fig. 3. Methods of disposing the load on a truck platform.

- inadequate cargo securing systems;
- traffic congestions;
- overtaking maneuvers;
- weather conditions;
- bad road infrastructure;

This paper main subject is concentrated on cargo safety issue, especially on finding alternative solutions for verifying the conformity of special securing systems adapted on trucks designed for public transportation.

2. GENERAL REGULATION

Nowadays, national regulations, standards and guidelines have been adopted all over the world because of the increasing number of truck accidents which can be attributed to inadequate cargo securing. However, even if the rules content and scope slightly differ, most of them require that cargo securing systems should be capable of withstanding the forces associated with following three decelerations/accelerations, applied separately:

- 0.8 g deceleration in the forward direction;
- 0.5 g acceleration in the rearward direction;
- 0.5 g acceleration in a lateral direction.

The first performance requirement was established taking into account the force exerted by the cargo towards the front of the vehicle during full braking [3, 4]. On the other hand, in accordance with 71/320/EEC [5], the performance of braking systems for vehicles from N category (vehicles used for the carriage of goods) is considered adequate if:

- the mean fully developed deceleration is greater than 0.5 g (type 0 test with engine disconnected);
- the mean fully developed deceleration is greater than 0.4 g (type 0 test with engine connected).

However, even if a vehicle is certified to circulate on public roads (EC type-approval certificate), it is possible not to reach a 0.8 g deceleration. This is not an impediment though in the following context:

- cargo securing equipments are always built and chosen in compliance with relevant standards and guidelines. For example, Cargo Securement Rules [4] stipulates: „*Generally, motor carriers are not required to conduct testing of cargo securing systems to determine compliance with the performance requirements. The new rules explicitly state that cargo immobilized or secured in accordance with the general securing rules, or the commodity-specific rules, are considered to meet the performance criteria.*”;
- standard vehicles bodies (side, front and rear walls) and reinforced vehicles bodies respect the basic requirements established in EN 12642 [6] and the verification of conformity to this standard is provided by static testing.

The difficulty appears when a special charge disposed o a truck platform should be secured with specific elements only, different from the standardized ones and the vehicle structure differs from the models presented in EN 12642 [6].

Therefore, this paper presents a method of verifying if a special securing system is capable of withstanding the force associated with 0.8 g deceleration in the forward direction, even if the vehicle is not capable of such deceleration. EN 12642 claims that „*the aptitude for special cargo should generally be proved by driving tests*” and „*if the vehicle brakes by themselves are unable to provide the necessary braking deceleration of 0.8 g the required deceleration shall be achieved e.g. by adding a complementary braking device independent of the track condition*”. Because the last condition is difficult to be achieved, we propose that the conformity verification to be realized through a combined method: dynamic driving tests and calculation/simulations, both accepted by EN 12642.

2. VERIFICATION OF CONFORMITY METHOD

The method consists in performing dynamic driving tests specified in annex B, EN 12642 – Testing brake deceleration in longitudinal direction, except the 0.8 g deceleration value. The vehicle is braking with maximum intensity, measuring not only the deceleration but also speed and other parameters that describe the securing systems elements behavior.

In parallel, the computational model is realized, based on geometrical model and using finite element method (FEM) for the vehicle frame, securing equipments and the load. Having the measured deceleration, a simulation of the entire assembly will be performed in ANSYS in order to determine the deformations and equivalent stress – *deceleration method*. The purpose of this procedure is to validate the computational model. If the results are favorable, another simulation should be performed for a

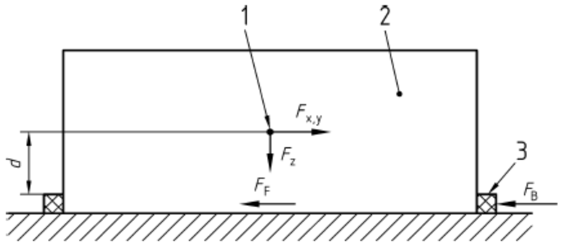


Fig. 4. Securing in longitudinal direction [7]: blocking method: 1 – centre of gravity; 2 – load; 3 – blocking device.

value of deceleration of 0.8 g in order to verify if the cargo securing equipments are capable or not of withstanding the force associated to this value of deceleration in the forward direction.

If cargo model is too complex, the method of calculating securing forces for load restraint that appear on the blocking devices can be used, as in [7] (Fig. 4).

Blocking force in the longitudinal direction is calculated with the equation below:

$$F_B = (C_x - \mu_d \cdot c_z) \cdot m \cdot g \,, \qquad (1)$$

where: F_B – blocking force;
m – the mass of the load to be secured;
g – the gravitational acceleration;
c_x – the longitudinal acceleration coefficient;
c_z – the vertical acceleration coefficient;
μ_d – coefficient of friction for dynamic friction.

Using force F_B value from equation (1), a local simulation will be performed in ANSYS, following the same steps previously presented – *force method*.

3. CASE STUDY

A case study has been developed in order to present the accuracy of cargo securing equipments verification by applying driving tests and simulations in ANSYS.

It was chosen a truck that cannot achieve the deceleration of 0.8 g but it has type-approval certificate. This situation is frequently occurred because a typical loaded vehicle would not be expected to achieve a deceleration greater than 0.6 g on a dry road [4]. The truck frame (1) was specially adapted to carry a platform (2) with different equipments on it. The blocking system (3) for cargo securing in longitudinal direction consists in a pad with bolt (4) element fixed on an angle iron (5) welded to vehicle frame (see Figs. 5 and 6).

3.1. Dynamic driving test

A dynamic driving test was performed, as specified in annex B, EN 12642 – "testing brake deceleration in longitudinal direction".

To measure the parameters of interest, a *VBOX 3i* data logging system with an inertial measurement unit *IMU 02* was used (see Fig. 7.).

As it concerns the simulations on virtual model, data acquisition was needed regarding the deformation of an element from the securing system.

Thus a *IL-600 Keyence* distance sensor (6) with analog output was mounted in front of the angle iron, with the laser point (7) at 10 mm bellow the upper margin as it can be seen in Fig. 6.

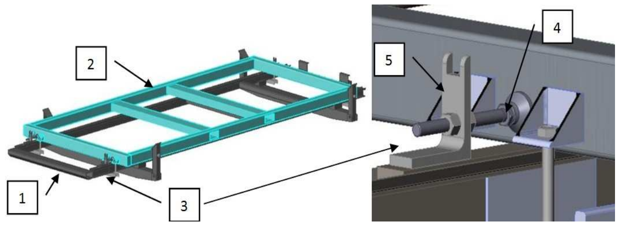


Fig. 5. Vehicle frame and platform assembly.

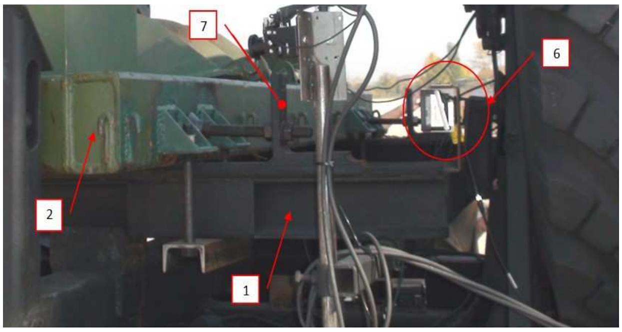


Fig. 6. Distance sensor position.

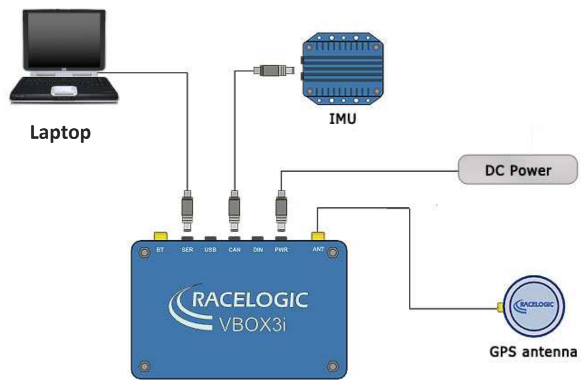


Fig. 7. *VBOX 3i* data logging system configuration.

At the braking test (Fig. 8) an average value of deceleration *X_Accel* = 0.43 g was obtained during *one second* interval (1.5−2.5 s, see the highlighted zone), with minor influences given by pitching oscillations – average value of *Z_Accel* is 0.997 g. The average distance between sensor and angle iron is 255.7 mm, with 0.401 mm lower than in vehicle static position. For these values, there were no permanent deformations on cargo securing equipments or on the vehicle frame.

3.2. ANSYS simulation

On a 3D geometric model several simulations were performed using ANSYS software in order to analyze the behavior of securing elements in longitudinal direction during a deceleration similar to real braking tests. As the studied phenomena's duration is only 1 second, a static analysis is enough to describe what happens.

The materials used for the simulations have a linear behavior: the majority of the pieces are made of S235 steel with *235 MPa* yield stress, except the bolts that are made of steel with 800 MPa yield stress. The simulations purpose is to obtain the values of equivalent stress, total deformations and safety factor.

A) *Deceleration method*. In this case, the force to be applied was generated from a value of deceleration of

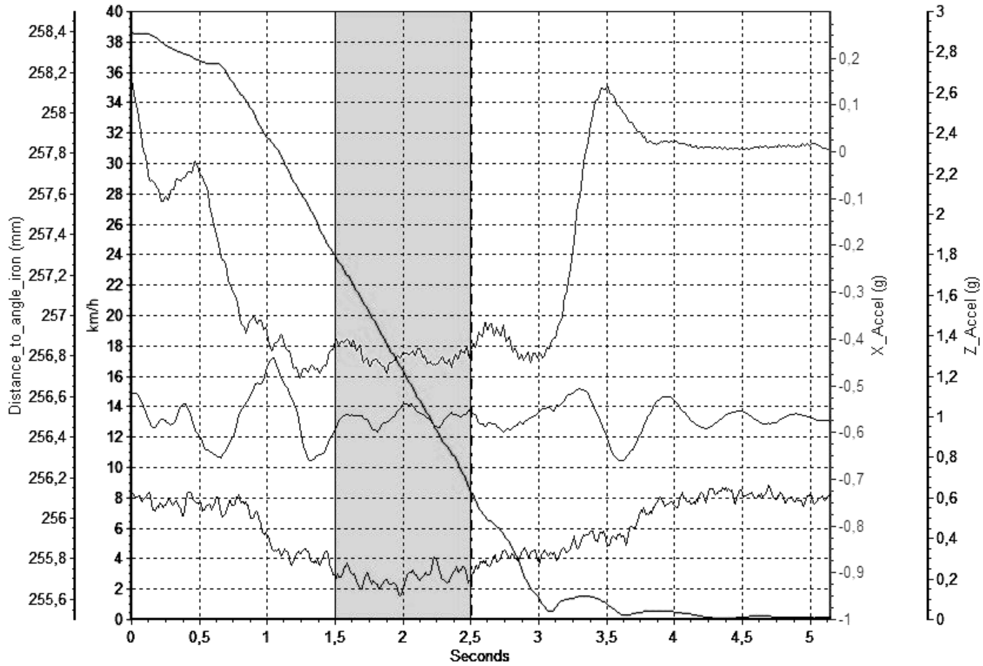


Fig. 8. Full braking tests on a level road.

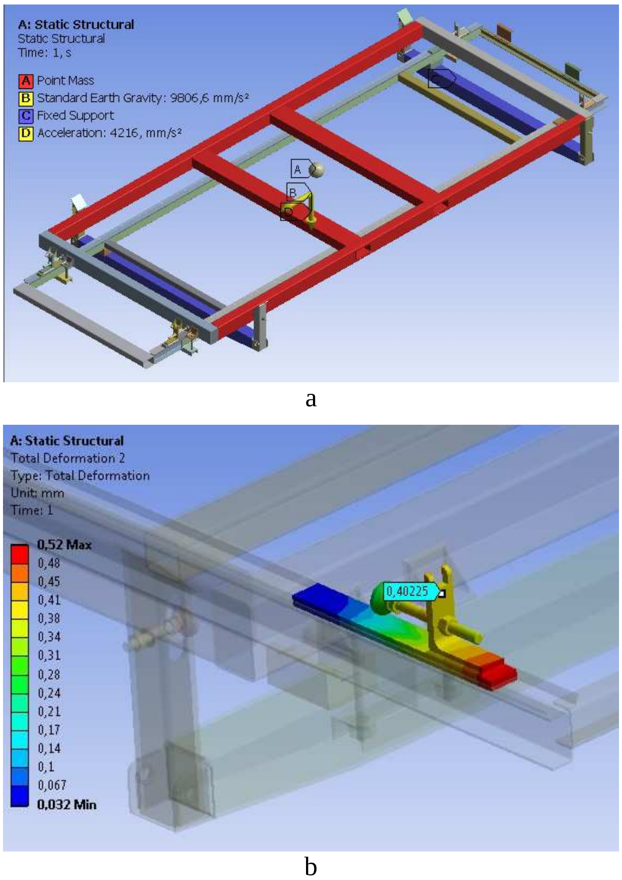


Fig. 9. *Deceleration method*: *a* − static structural representation; *b* − angle iron deformation.

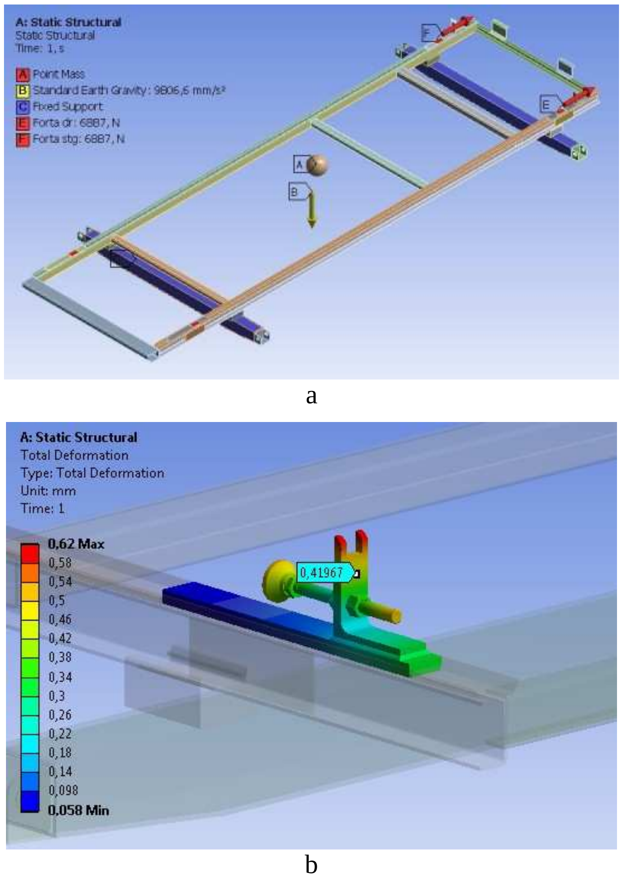


Fig. 10. *Force method*: *a* − static structural representation; *b* − angle iron deformation.

0.43 g, obtained at real braking test. Because of the complexity of the equipments disposed on the platform they were all converted to a point mass.

Figure 9 presents the static structural representation (a) and the angle iron deformation (b). According to simulations, the obtained deformation (in elastic domain) is about 0.402 mm in the interest zone (10 mm bellow the upper margin of the angle iron).

B) *Force method*. In this second case, the forces to be applied were calculated according to EN 12195-1, taking in consideration a value of 0.43 for c_x and a value of 0.1 for μ_d. Both the platform and the equipments disposed on it were converted to a point mass, maintaining the real support surfaces. The point mass definition is required because of the influence of vehicles frame deformation under load action. This method's advantage is the simplification of the 3D model and ANSYS simulation as well.

Figure 10 presents the static structural representation (a) and the angle iron deformation (b). According to simulations, the obtained deformation (in elastic domain) is about 0.419 mm in the interest zone (10 mm bellow the upper margin of the angle iron).

3.3. Model validation

Both previously mentioned methods provided close results to those obtained in real braking tests for angle iron deformation. However, *deceleration method* is more appropriate because in this case the simulation is applied to the entire assembly in comparison to *force method* where there are two actions in parallel, namely the platform mass on the vehicle frame and forces influence on the securing system in longitudinal direction.

Therefore, the analyzed model in ANSYS (especially deceleration method) is adequate and can be used to validate the case of a 0.8 g deceleration (see Fig. 11), where, at the level of studied angle iron, the interest parameters have the following values:

- maximum deformation: 0.57 mm;
- maximum equivalent stress: 92.75 MPa;
- minimum safety factor: 2.69.

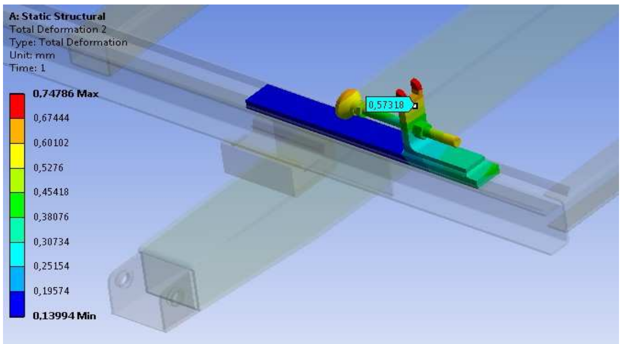
As it concerns the entire assembly (see Fig. 12), the obtained results are also satisfying:

- maximum deformation: 8.42 mm;
- maximum equivalent stress: 187 MPa;
- minimum safety factor: 1.59.

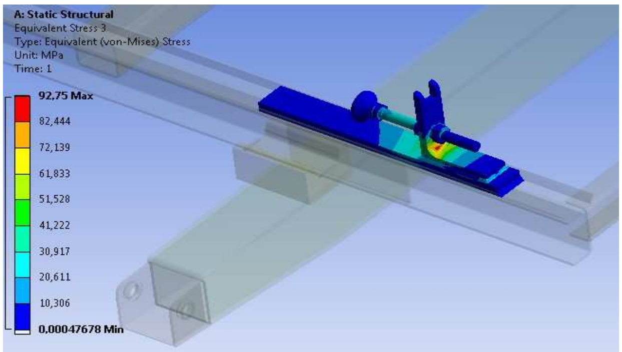
Analyzing the previously mentioned values, it can be noticed that the maximum equivalent stress does not reach yield stress value (235 MPa) so it can be considered that all the deformations are in elastic domain.

4. CONCLUSIONS

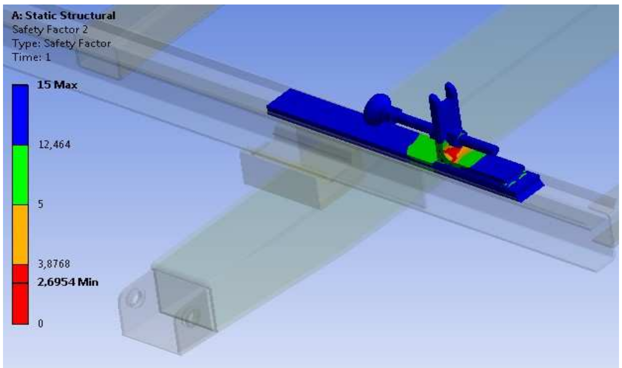
Most states have legal requirements regarding the capability of cargo securing systems to withstand the forces associated with 0.8 g deceleration in forward direction. Details about restraining methods and systems are found in EN 12195-1 and EN 12642. However, none



a

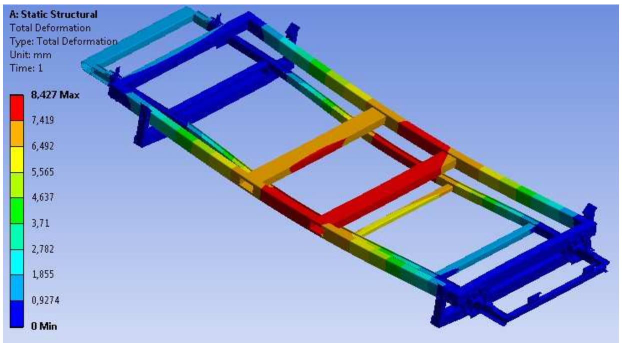


b

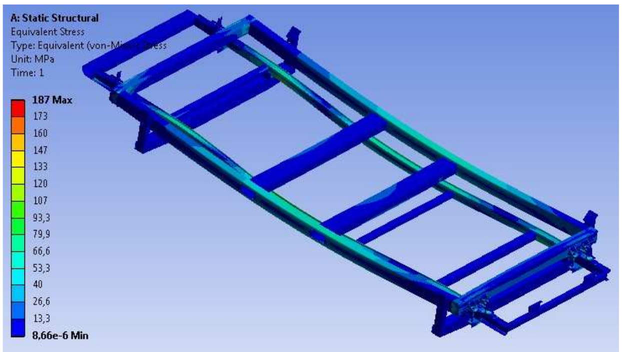


c

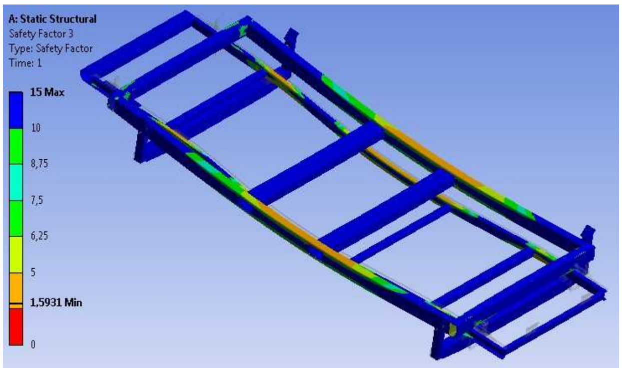
Fig. 11. Simulations results for a 0.8 g deceleration over the angle iron: *a* – Total deformation; *b* – Equivalent stress; *c* – Safety factor.



a



b



c

Fig. 12. Simulations results for a 0.8 g deceleration over the entire assembly: *a* – Total deformation; *b* – Equivalent stress; *c* – Safety factor.

of these standards refers to the special situation when the vehicle is not capable to reach a 0.8 g deceleration and the cargo securing systems are not standardized (blocking case, especially).

This paper provides a method to prove the performance criteria that combine dynamic driving test with simulation method in ANSYS. The first step was to validate a virtual model by real dynamic driving tests for the value of deceleration provided by the analyzed vehicle – in this case smaller than 0.8 g.

Comparing the measurements made in real braking driving test for 0.43 g deceleration, with the simulations on the developed model, it can be noticed that the results are satisfying. Therefore, the proposed model can be validated and afterwards the capability of meeting the performance criteria for 0.8 g deceleration is verified using the same principles.

All vehicle structures, systems, parts and components used to secure cargo must be in proper working order when used to perform that function with no damaged or weakened components that could adversely affect their performance. Therefore, in ANSYS a smaller value than the yield stress must be obtained for the equivalent stress and at least 1.5 for the safety factor.

The case study presented in this paper demonstrates that this method is viable. Moreover, a comparison between 2 methods of generating forces was performed in ANSYS:

- by applying deceleration (*deceleration method*);
- by applying forces calculated according to EN 12195-1 (*force method*).

As expected, the first method provides better results by perceiving the components as an entire assembly. The second one, though, presents the advantage of simplifying the 3D model and ANSYS simulation by reducing the entire load to a point mass.

Future research could provide even better results if creating a model in Multi-Body System (MBS) software and performing dynamic simulations to analyze the behavior of cargo securing systems when braking.

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