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COMPOSITE ABSORBER IN COLLISION SIMULATIONS OF A BUS

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ABSTRACT
This paper details the numerical modeling of composite absorbers and an assessment of the influence of such deformation elements on a bus during frontal collision with a car. The absorber itself is designed as an assembly of thin-walled composite wound tubes oriented in the vehicle direction of travel. During the impact the tubes are crushed, causing energy absorption. Crash simulations were performed at various speeds using differing scenarios with the deformational member as well as without it. Comparative diagrams of force and velocity of the car and deformation of the bus structure were assessed.
KEYWORDS: ABSORBER, CRASH, FEM, SIMULATION

SHRNUTÍ
Článek se zabývá vývojem numerického modelu kompozitního absorbéru a posouzením vlivu celého deformačního členu autobusu při jeho čelním nárazu s osobním automobilem. Absorbér je navržen jako soubor tenkostěnných vinutých kompozitových trubek orientovaných ve směru jízdy. V momentě nárazu nastane borcení těchto trubek a tím dojde k významné absorpci energie. Byly provedeny simulace nárazu při různých rychlostech ve variantách při použití deformačního členu a bez něj. Porovnáním průběhů sil, rychlostí a posuvů osobního automobilu a deformací konstrukce autobusu byla posouzena jeho funkce.
KLÍČOVÁ SLOVA: ABSORBÉR, NÁRAZ, MKP, SIMULACE

1. INTRODUCTION
Mass reduction is one of the frequently-mentioned requirements for both current and future vehicles. Substitution of various previously steel or alloy parts with composite ones is a commonly accepted approach to this problem. This article presents a numerical study of a specific kind of impact energy absorber made from composite parts. It is based on the experimentally determined response of a single energy absorbing component. The response of the complete absorber, or the vehicle-absorber assembly, has been determined numerically.

The purpose of this task was to verify the use of a thin bundle of wound composite tubes to absorb impact energy. The initial task was a series of experimental impact tests on individual tubes and small bunches of tubes in order to determine their response [3]. We have tested several layup options to find the layup that is characterized by stable crushing, a small peak force at the beginning, and a high energy absorption rate. Subsequently, we formulated a computational model at the level of the tube with a more complex material model including a description of the damage to the composite [2]. Using the Abaqus software, we were unable to create a tube model with responses consistent with the experiments. However, such a complicated model at the tube model level would not be applicable to any collision simulation with vehicles containing the absorber (which would consist of a significant number of these composite tubes). For this reason, a simplified tube model as described below was created. This model describes the crushing of the composite tube in a way that is sufficiently accurate and corresponds with the experimentally observed behavior. This tube model is adapted to simulate vehicle collisions containing several tens of composite tubes.

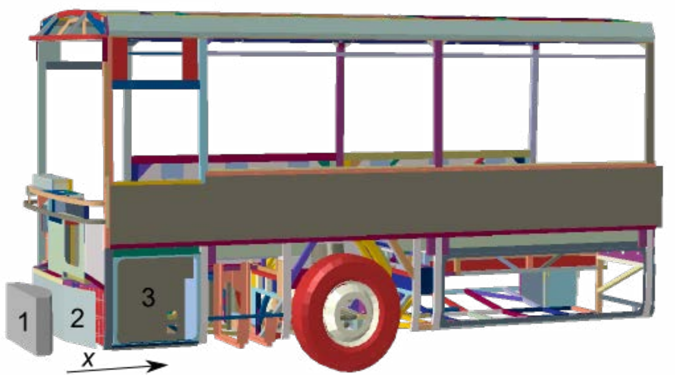

FIGURE 1: Crash simulation arrangement.
OBRÁZEK 1: Uspořádání simulace nárazu.

The objective of the car-bus frontal impact simulation is to assess the impact absorber (i.e. deformational member) composed of composite tubes that serve as deformation elements of the respective member and absorb the kinetic energy. The simulation of this impact is highly complex and thus certain simplifications of the problem are vital. Nevertheless, the situation still provides a solid functional rendition of the absorber during a frontal collision between a bus and a car. The crash simulation arrangement is shown in Figure 1, where 1 is the car, 2 is the absorber, and 3 is the bus. The simulation was performed using ABAQUS/Explicit.

2. CRASH SITUATION

The crash simulation is performed using three models of interacting bodies: the model of the bus, the model of the vehicle, and the model of the absorber. Each model includes a certain degree of simplification compared to reality. The main simplification is an absolutely rigid car model with boundary conditions that prevent it from sliding and turning in other directions than its displacement perpendicular to the bus front. Similarly, the properties and the deformation of the absorbers are enabled only in this direction – in Figure 1 depicted as the x-direction. Only the front half of the bus is used in the simulation. The car has an initial velocity and the bus was fixed at the end of its front half.

For this impact simulation, a simplified model of a car was created – Figure 1. The car is represented by an absolutely rigid block which is 1188 mm wide, 500 mm high and shaped just like the car bumper. This block is assigned a weight of 1444 kg. The front half of the standard bus model used for crash simulation in the PAM-Crash software was used. This model is based on shell elements with elastic-plastic behavior.

3. MODEL OF THE DEFORMATION ELEMENT

Deformation elements in the absorber are wound composite tubes which are located at the front of the bus. The tubes are made of carbon fiber and an epoxy matrix. Mechanical properties (force-displacement diagram) of this composite tube during crushing were obtained from dynamic experiments on a drop tester. A simplification of the recorded behavior is shown in Figure 2. The force-displacement behavior shows an apparent initial peak with the maximum force of 25 kN and the force response has a steady value of 20 kN during stable crushing.

The behavior of this deformation element can be introduced into the FEM model in ABAQUS using the connector element (Connector type Translator). Using this feature, a force-displacement response can be prescribed – but only in a limited way. In order to obtain identical force-displacement response, it is necessary to use two connector elements with different behaviors and join them together. Then we can

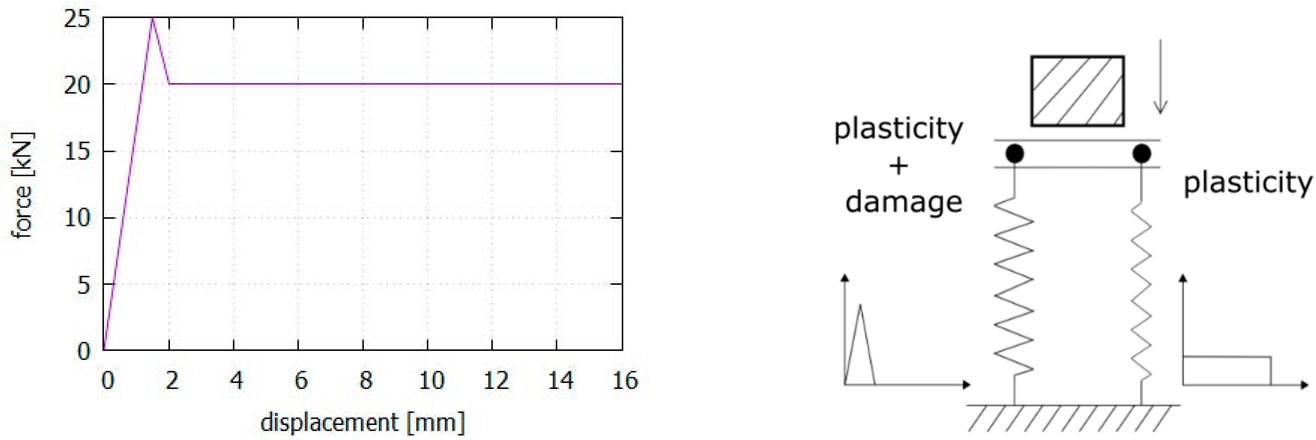

FIGURE 2: Diagram of the deformation element model and its force-displacement response.
OBRÁZEK 2: Schéma modelu a odezva deformačního elementu.

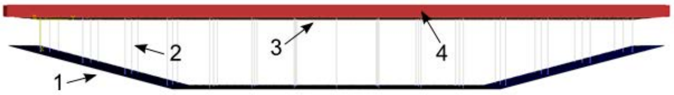

FIGURE 3: Absorber and its parts (top view).
OBRÁZEK 3: Absorber a jeho části (pohled seshora).

achieve the same deformation element behavior as obtained from the experiments.

The first connector element describes the initial peak of the force-deformation behavior, and the second connector displays stable crushing. Parallel connection of both connectors (Figure 2) ensures a model with the same force-displacement behavior as we obtained on a drop tester.

The connector element describing the first peak has the following properties. The elastic response is deactivated and all behavior derives from plasticity with some damage. The plasticity limit (yield) is set to 5 kN and initiation of damage is also set at 5 kN. A second connector element simulating stable crushing is also without elastic response and exhibits only plastic behavior, which is set to 20 kN.

4. MODEL OF THE ABSORBER

Deformation elements described above are inserted into the deformational member – the absorber (Figure 3), which is placed at the front of the bus. The absorber consists of four parts: 1 – front plate, 2 – deformation elements, 3 – rear plate, 4 – supporting structure.

The front and back plates do not have a significant impact on absorber behavior – their function is to keep the deformation elements in place and cover them. The supporting structure at the back of the absorber is an intermediate stage between the deformation elements and the bus frame. Its function is to ensure uniform transfer of the forces occurring during crushing of the deformation elements into the structure of the bus.

The absorber used in the simulations has a width of 2280 mm, a height of 480 mm and a depth between 100 mm and 250 mm. The whole absorber is divided into three parts, two outer and one central part. The central part occupies half the width of the absorber and has a constant depth of 250 mm. The depth of the outer arrays of half the size of the central part varies linearly from 250 mm inside to 100 mm at the edge of the absorber. The absorber is composed of 45 deformable elements described above, which are uniformly distributed over its area.

The proposed absorber is theoretically able to absorb an energy of approximately 200 kJ, assuming maximum deformation of the deformation elements. This absorber is placed at the frontal bottom part of the bus where it absorbs a significant part of the energy resulting from a frontal impact with a car.

5. RESULTS

Six simulations of impact with different conditions were performed: using different initial car speeds, using the absorber, or omitting the absorber. We monitored the progress of displacement, velocity and acceleration of the car. The monitored variables on the bus were logarithmic deformation and reaction forces in the restrained half of the bus.

Progress of the car velocity after impact for all variants is shown in Figure 9. For all variants velocity reduction is more significant in cases using the absorber. Therefore, the impacting bodies achieve zero velocity earlier at all initial speeds than in situations where the absorber is not used. The second graph, Figure 9, shows the progress of the reactionary forces in the half of the bus where the boundary condition is applied – these forces are transmitted in the half of the bus frame.

The following four images show the distribution of the largest main logarithmic strain in the front of the bus from the bottom view after the impact. All images have the same range of deformations – from zero to two percent of the logarithmic deformation. The displayed situation is captured at the end of the impact – the car is no longer in contact with the bus. Grey areas represent a logarithmic deformation greater than two percent.

At higher initial velocities (30 and 40 km/h), buckling of the front structure of the bus is clear. The rigidity of this part is not sufficient and thus fails before transmitting the necessary force to support the absorber during its function. This is shown in Figure 7 with the logarithmic strain for an impact with initial velocity of 40 km/h.

In the case of the 20 km/h initial speed, we could see the loading design nodes responsible for transmitting forces generated by the absorber to the rest of the structure. At this initial speed there was no significant damage, and it was therefore omitted from the list.

Based on the results, it is evident that the front part of the bus is currently designed as a deformation zone and not as a rigid part of the structure intended to transfer and distribute forces arising from an impact to the rest of the structure.

When comparing impact results with and without the absorber, the difference in energy absorption becomes very obvious. When the absorber is not installed on the bus structure (Figures 4 and 6) all of the impact energy must be absorbed by the plastic deformation of the bus frame. There is significant deformation and lower rigidity of the front part of the structure as well as a notable bending of the bus structure causing a longer energy absorption time.

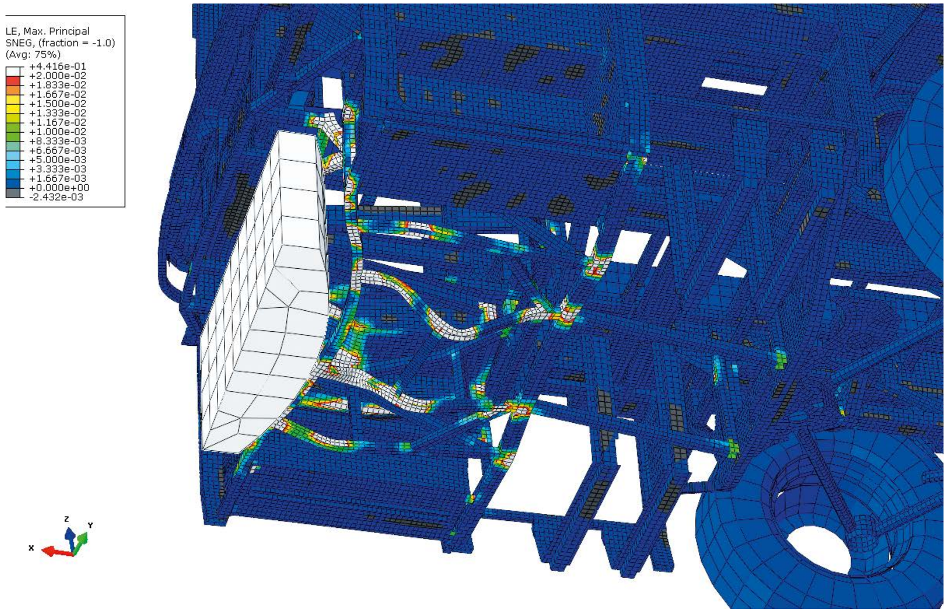

FIGURE 4: Logarithmic strain of the bus after car impact with initial velocity 30 km/h without the absorber.
OBRÁZEK 4: Logaritmická deformace konstrukce autobusu po nárazu autem rychlostí 30 km/h bez absorbéru.

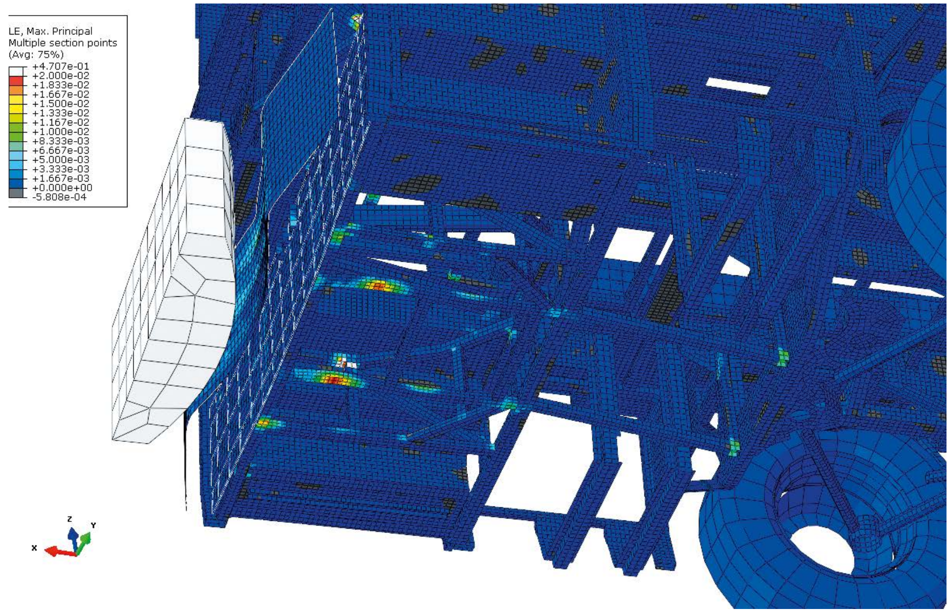

FIGURE 5: Logarithmic strain of the bus after car impact with initial velocity 30 km/h with the absorber.
OBRÁZEK 5: Logaritmická deformace konstrukce autobusu po nárazu autem rychlostí 30 km/h s absorbérem.

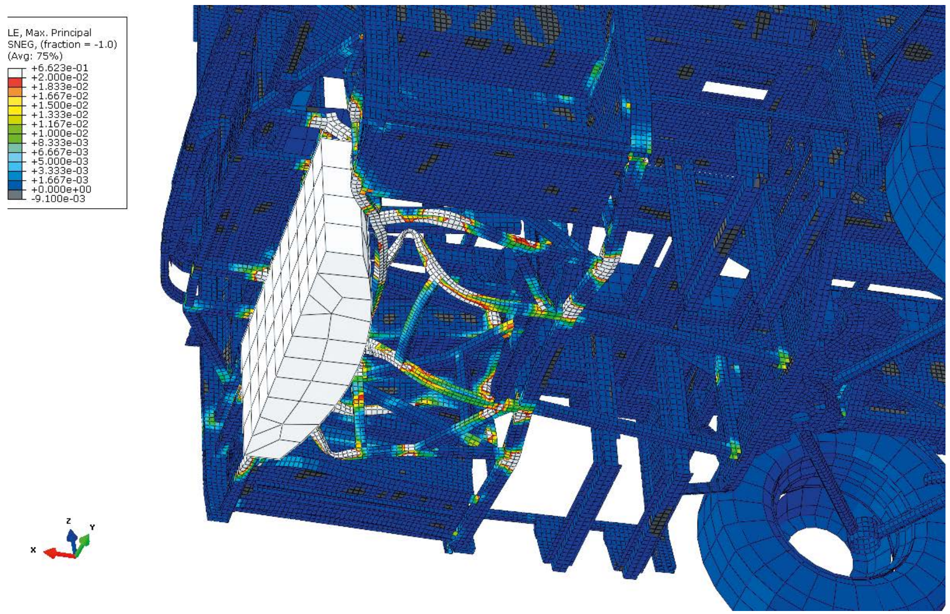

FIGURE 6: Logarithmic strain of the bus after car impact with initial velocity 40 km/h without the absorber.
OBRÁZEK 6: Logaritmická deformace konstrukce autobusu po nárazu autem rychlostí 40 km/h bez absorbéru.

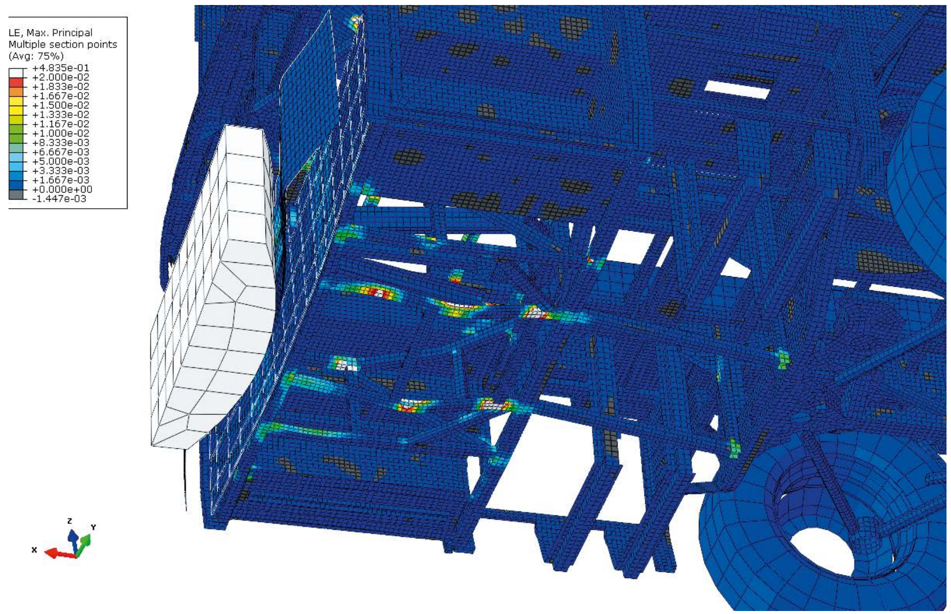

FIGURE 7: Logarithmic strain of the bus after car impact with initial velocity 40 km/h with the absorber.
OBRÁZEK 7: Logaritmická deformace konstrukce autobusu po nárazu autem rychlostí 40 km/h s absorbérem.

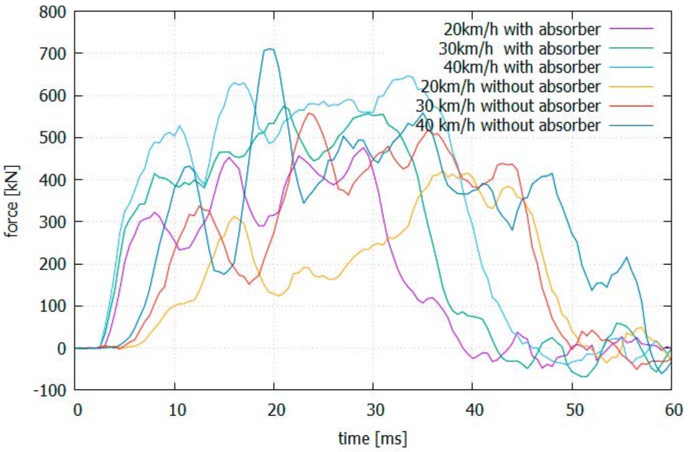

FIGURE 8: Reaction force in the half of the bus over time.
OBRÁZEK 8: Graf závislosti reakční síly ve vetknutí autobusu na čase.

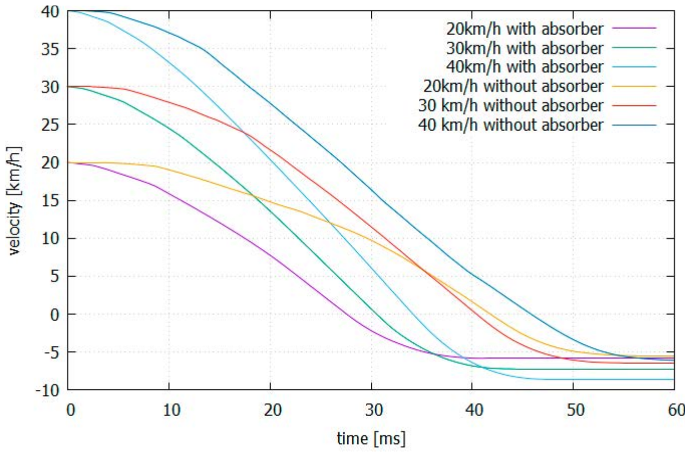

FIGURE 9: Graph of the car velocity over time for all variants.
OBRÁZEK 9: Graf závislosti rychlosti automobilu na čase pro všechny varianty.

6. CONCLUSION

Six simulations of a head-on collision between the bus and a car were performed, outlining a possible course of development of the given situation. The aim of the simulations was to assess the impact absorber installation on the front of the bus. This assessment was made by comparing the deformation and forces of the bus and velocity of the car. The simulations do not aim to cover every possible situation that might arise from the collision of a car and a bus. The special case of a direct collision using a simplified model of a car was selected in order to test the absorber effect during the collision. There is a clear positive role of the absorber as a deformation member. However, at higher velocities the rigidity of the front structure of the bus is insufficient. It is necessary to reinforce the front part of the bus structure for the real usage of the absorber on a bus.

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