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SIMULATION OF THE FALL OF A STANDING PASSENGER AGAINST THE COMPOSITE DOORS OF THE ŠKODA 14 TR M TROLLEYBUS DURING AN UNEXPECTED AVOIDANCE MANOEUVRE

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Summary: *ŠKODA OSTROV Ltd. will introduce composite doors into the vehicles of its basic production program in the nearest future. Verification of the applicability of their supposed structural design was carried out in ŠKODA RESEARCH Ltd. (ŠKODA VÝZKUM s.r.o.). In order to assess the dynamic impact force during the fall of a standing passenger against the composite doors simulation of driving with the multibody ŠKODA 14 Tr M trolleybus model with a standing passenger was used applying* ***alaska*** *software.*

1. Introduction

ŠKODA OSTROV Ltd. is a traditional manufacturer of road vehicles of municipal public transport in the Czech Republic. ŠKODA RESEARCH Ltd. (ŠKODA VÝZKUM s.r.o.) has been participating significantly in developing and improving these means of transport for several decades (Kepka et al., 1999).

Fig.1 The ŠKODA 14 Tr M trolleybus

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In the framework of a so-called “plastic program” ŠKODA OSTROV Ltd. will introduce composite doors into the vehicles of its basic production program in the nearest future. Verification of the applicability of their supposed structural design was carried out in ŠKODA RESEARCH Ltd. by means of both experimental tests on the real prototype of composite doors and computer simulations.

Simulation approach towards the determination of the dynamic impact force during the fall of a standing passenger against the composite doors is presented on the ŠKODA 14 Tr M trolleybus (Fig. 1). In order to assess time history and extreme of the impact force the trolleybus driving and the fall of a standing passenger were simulated using **alaska** mechatronic software (Maißer et al., 1998).

2. Requirements for the Doors of Means of Transport

One of the criteria of public transport vehicles safety are strong enough and properly working doors. Doors as well as other parts of the vehicle bodywork come into contact with an aggressive environment intensively (especially in winter, when chemical spread is used for the treatment of especially city roads). Using composites is a possible solution. Easier achievement of the shape proposed by the designer and less expensive production are advantages of their using.

Boarding space in a public transport vehicle is overcrowded very often, especially during rush hours. Complicated driving with frequent passages through sharp curves, avoidance manoeuvres and road unevenness are characteristic of city traffic. Doors must resist not only a static force but also dynamic forces appearing in connection with the vehicle operation and they must ensure passengers safety in an unexpected traffic situation, in which a passenger may fall against the doors.

Before introducing composite doors into vehicles in serial production it is necessary to carry out operational, fatigue life and strength tests and impact force resistance tests. In tests of doors resistance against the impact force it is necessary to determine the maximum dynamic force, which should be transferred by the doors. It can be determined during an unexpected avoidance manoeuvre, experimentally by a spontaneous fall of a dummy or by means of using computer simulations. Computer simulations are more economical compared with the experiment and at the same time their use prevents from the occurrence of critical situations, in which a real test may be dangerous or practically impossible. It can be supposed that the fall of a human being is much more complicated dynamic process than the fall of a rigid body. Force calculating must be carried out considering the biomechanics of a human being.

3. Multibody models

The **alaska** program (**a**dvanced **la**grangian **s**olver in **k**inetic **a**nalysis) is intended for the investigation of kinematic quantities and dynamic behaviour of three-dimensional constrained mechanical systems consisting of the system of bodies. In addition to rigid bodies it is also possible to use a special element, so called “superelement”, which approximates a dynamic behaviour of an elastic beam. The program includes the modules, which enable to model a tyre and a wheel - rail contact. In simulating movement with multibody models in the **alaska** program non-linear movement equations are made out by means of Lagrange’s method. The equations are solved by means of a numerical time integration (results given in this report were obtained using Shampine-Gordon integration algorithm - in Maißer et al., 1998 reference to Shampine & Gordon, 1984).

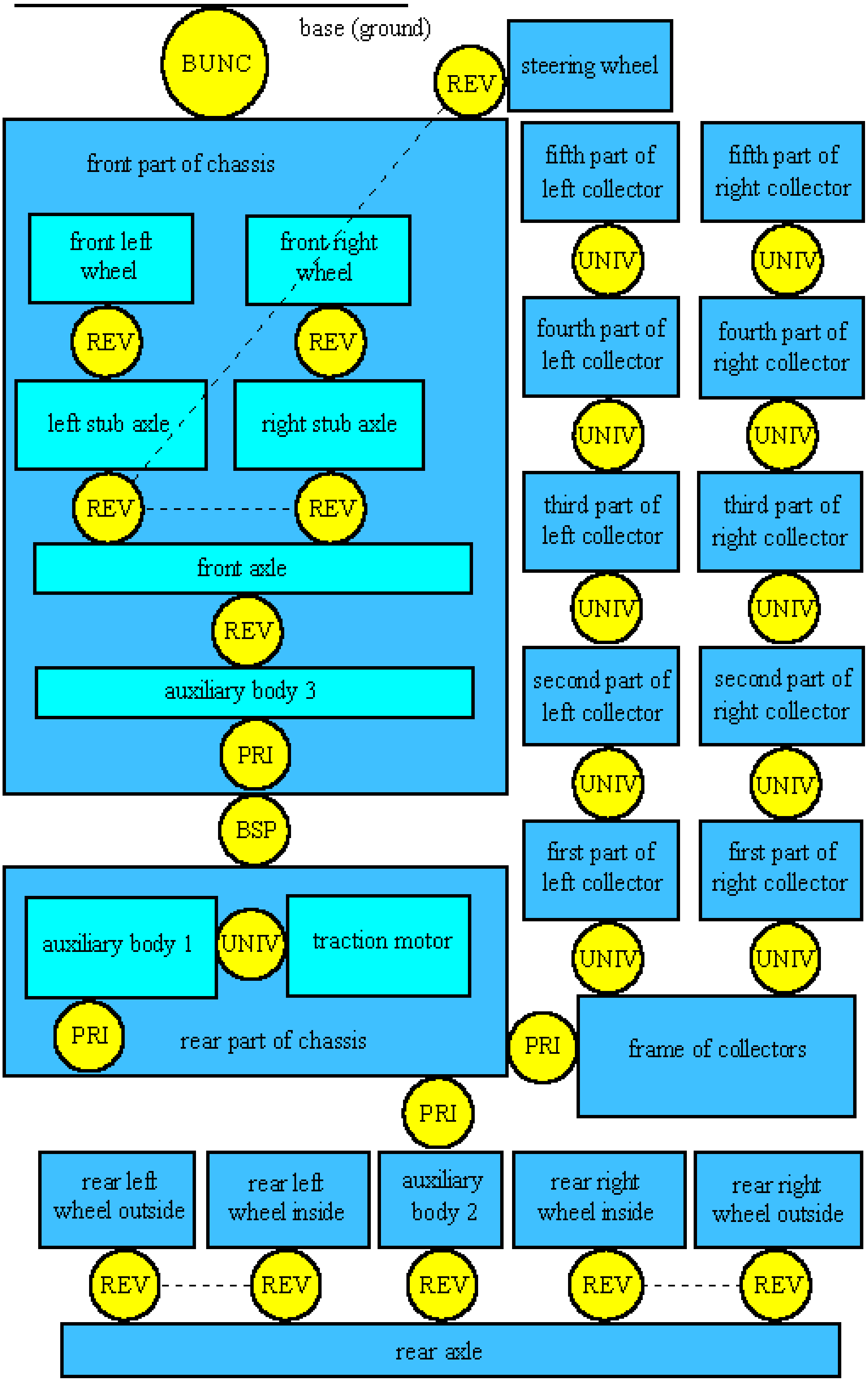

Fig.2 Kinematic scheme of a trolleybus multibody model

Multibody model of the ŠKODA 14 Tr M trolleybus (Polach, 2001) was created on the basis of numerical data and structural drawings provided by the producer, i.e. ŠKODA OSTROV Ltd. company. It is formed by 28 rigid bodies (corresponding to individual trolleybus structural parts or “auxiliary” bodies are concerned), which are mutually coupled with 28 kinematic joints. The model has 46 degrees of freedom. Individual bodies are defined by inertial properties (mass, co-ordinates of centres of gravity and mass moments of inertia). Air springs, shock absorbers and silentblocks are modelled by coupling corresponding rigid bodies with spring-damper elements. Tyres are modelled applying the *Tire Module*. Kinematic scheme of a trolleybus multibody model is shown in Fig. 2. Rectangles represent rigid bodies; circles represent kinematic joints (BUNC = unconstraint, REV = revolute, PRI = prismatic, BSP = spherical, UNIV = universal, i.e. Cardan joint). Dashed lines connect mutually depending kinematic joints.

Multibody man model is created on the basis of knowledge gained from IfM Chemnitz. It corresponds to a simplified anatomy of a movement system aiming at giving true picture of basic kinematic and dynamic properties of a human body. Multibody man model can be applied e.g. in modelling a driver or a passenger in means of transport (for the investigation of their behaviour in various traffic situations - Bikowski, 1997, Dac & Hendel, 1997, Hendel & Jödicke, 1999, Polach et al., 2002), or a pedestrian (for the simulation of collision with a car), etc. The target of simulations with multibody man model is the calculation of time histories or FFT results of time histories of kinematic and dynamic quantities acting on a human body.

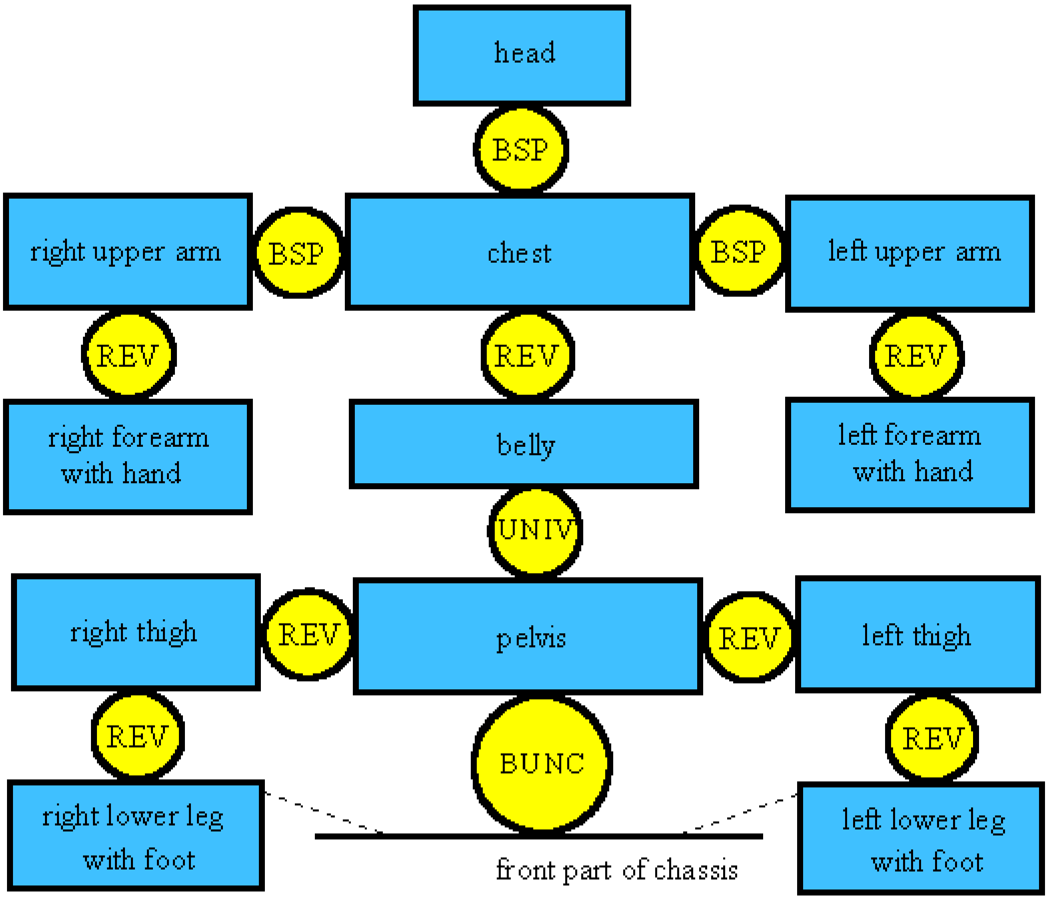

Fig.3 Kinematic scheme of a multibody man model

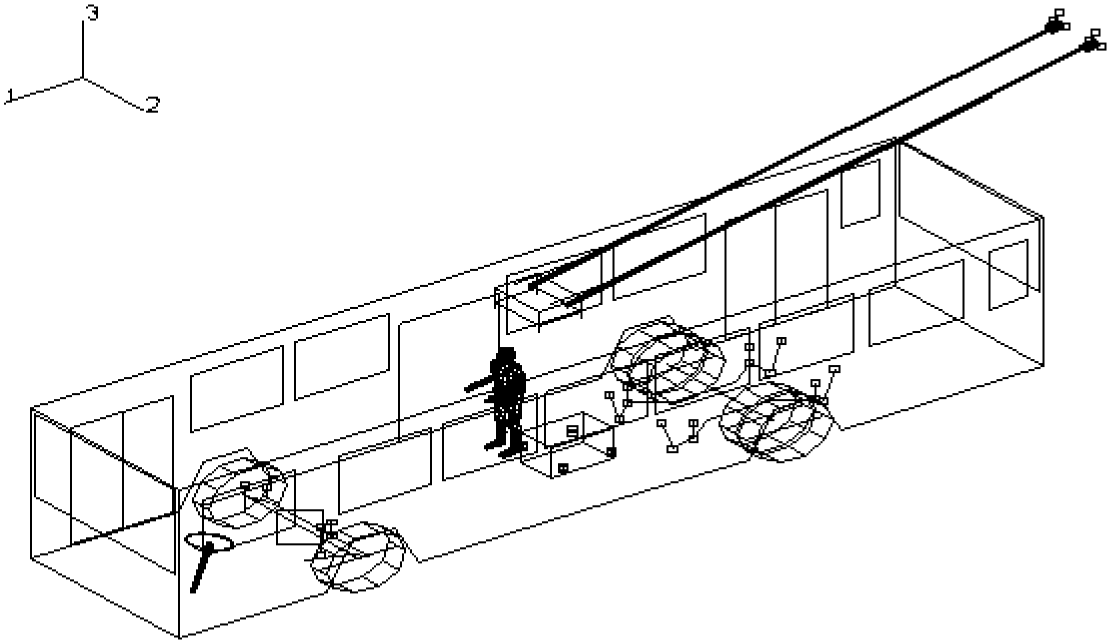

Fig. 4 Trolleybus multibody model with a standing passenger

Multibody man model is formed by 12 rigid bodies, which are mutually coupled with 12 kinematic joints with 24 degrees of freedom (Polach, 2002a). On the basis of the choice of parameters (man height and mass) geometric dimensions and inertial properties of rigid bodies modelling the individual parts of human body (from the point of view of kinematics) are automatically determined in the module multibody model. Constraints in bending and spontaneous bending in joints considered in multibody man model are realized by means of spring-damper elements. Kinematic scheme of multibody man model is in Fig.3.

Multibody ŠKODA 14 Tr M trolleybus model with a standing passenger was created by putting together multibody trolleybus model and multibody man model (see Fig. 4). There is an unconstraint kinematic joint between the front part of trolleybus chassis and the pelvis of passenger, contact between his soles and trolleybus floor is realized by means of eight spring-damper elements.

Linear stiffness of composite doors was calculated on their FEM model (Kindelmann, 2001) in COSMOS/M program (SRAC, 1999). In the trolleybus multibody model with a standing passenger the calculated stiffness is realized again by a spring-damper element, which is active only in case of a passenger - doors contact. FEM model of the composite doors right wing (left wing is axially symmetrical) is formed by 12000 shell (doors themselves) and beam (doors guide rods) elements in COSMOS/M program (see Fig. 5). Composite materials properties required for the creation of FEM model have been determined applying the tests on samples carried out

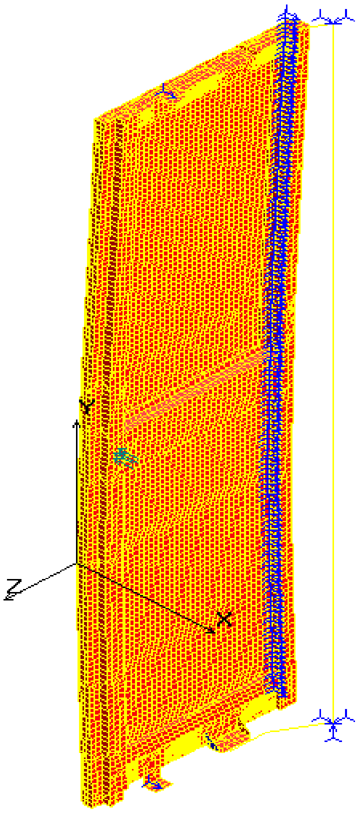

Fig.5 FEM doors model

in the Accredited Mechanical Testing Laboratory of ŠKODA RESEARCH Ltd. (Kindelmann, 2001), material properties of glass were defined by means of *Glass* material in COSMOS/M program. Boundary conditions correspond to the attachment of the doors to the bodywork frame and “locking-up” the doors during driving.

4. Simulation with a multibody model

In order to determine the time history and the extreme force acting on the doors, which was excited by the fall of a standing passenger, an unexpected avoidance manoeuvre in various driving speeds (graph in Fig.8) and with various front wheels angles (graph in Fig.9) was simulated with the multibody model. The fall against the least stiff spot in the doors was considered. The following "parameters" of the passenger were changed: distance from the doors (graph in Fig. 10), mass (graph in Fig. 11) and height (graph in Fig. 12). In the simulations a quick response of the passenger was not considered (alleviation of the fall consequences by leaning the hand on the doors, crouch, etc.), back or shoulder impact was considered (Polach, 2002b).

The basic setting of the „parameters“ in the calculations was selected on the basis of the results of the less favourable variant of the simulation conditions: maximum front wheel angle 15° during the avoidance manoeuvre, trolleybus driving speed 40 km/h, passenger mass 85 kg, distance from the doors 0.825 m and the passenger height 1.8 m. With the basic setting of „parameters“ time history of the force acting on the doors during the passenger shoulder impact is in Fig.6 (its maximum magnitude is 5 289 N), time history of the force during the back impact is in Fig.7 (its maximum magnitude is 5 501 N). Time histories of forces when the „parameters“ are changed do not differ in their character from those given in Figs. 6 and 7.

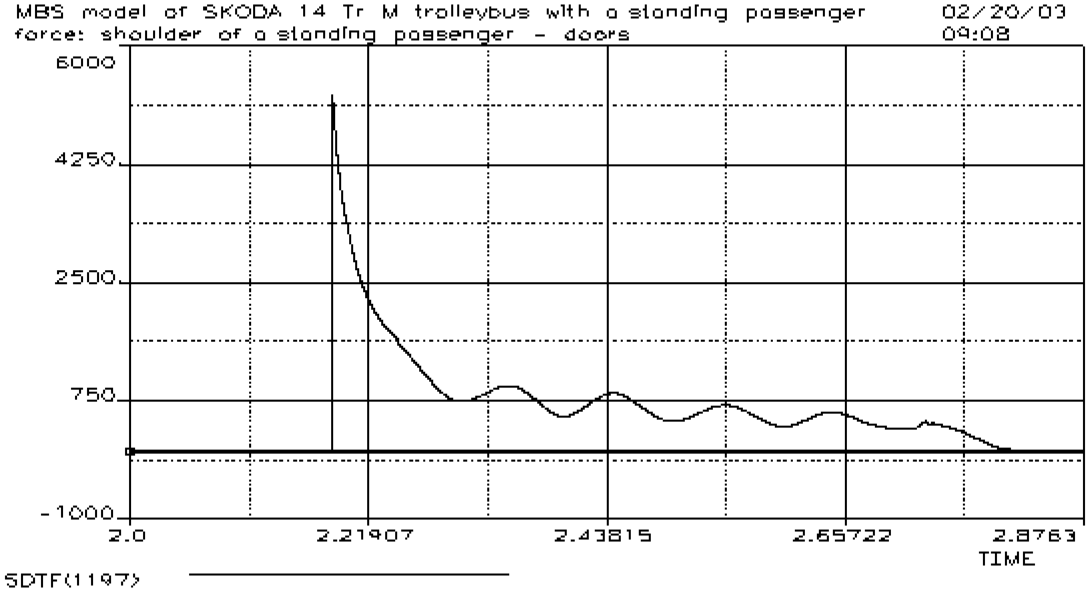

Fig.6 Impact force during the passenger shoulder impact on the doors

Carried out calculations confirmed the expected results: the magnitude of the impact force excited by the fall of the standing passenger against the composite doors increases with the increasing trolleybus driving speed (graph in Fig. 8), with the increasing maximum front wheels angle during the avoidance manoeuvre (graph in Fig. 9), with the increasing distance of the standing passenger from the doors (graph in Fig. 10) and with the increasing passenger mass (graph in Fig. 11). The influence of the passenger height (graph in Fig.12) is not quite unambiguous. Greater forces arise during the back impact of the passenger on the doors. The magnitude of the impact force excited by the fall of the standing passenger against the composite doors is influenced to a large extent especially by the distance of the standing passenger from the doors, the influence of the trolleybus driving speed and of the passenger mass is not so considerable. The maximum front wheels angle during the avoidance manoeuvre influences the impact force magnitude only to a certain extent.

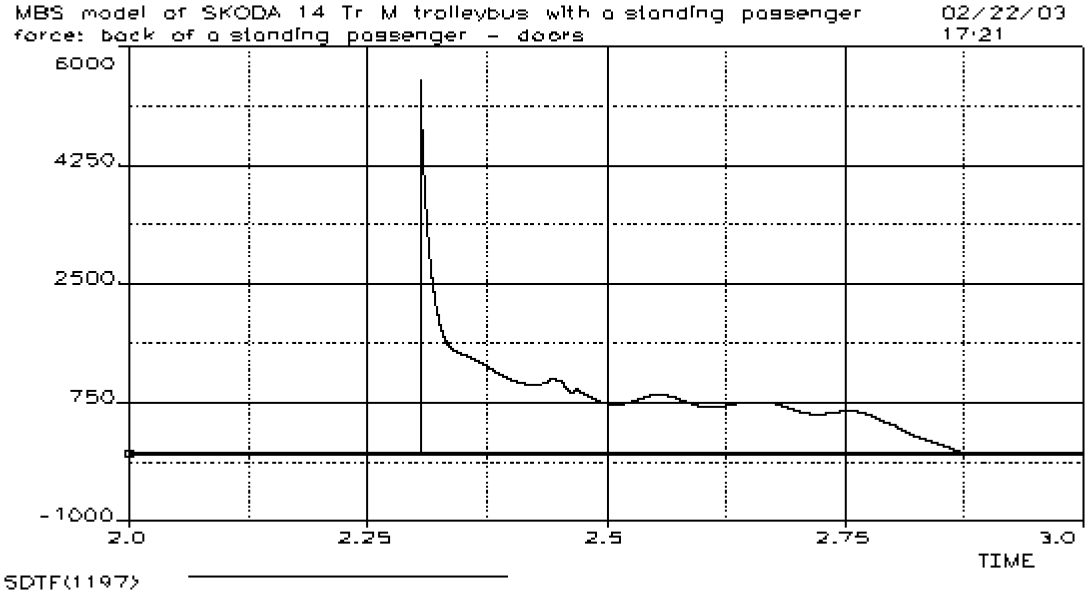

Fig.7 Impact force during the passenger back impact on the doors

In fact determined maximum impact forces excited by the fall of the standing passenger against the doors are greater than in reality and correspond to the extreme situations. In the simulations the passenger respond was not considered (alleviation of the fall consequences by leaning the hand on the doors, crouch, etc.). At the impact only the composite doors flexibility was considered, both shoulder and back of the passenger were considered to be rigid bodies. Further, in comparison with reality, only point contact of shoulder or back and the doors was taken into account during the simulations.

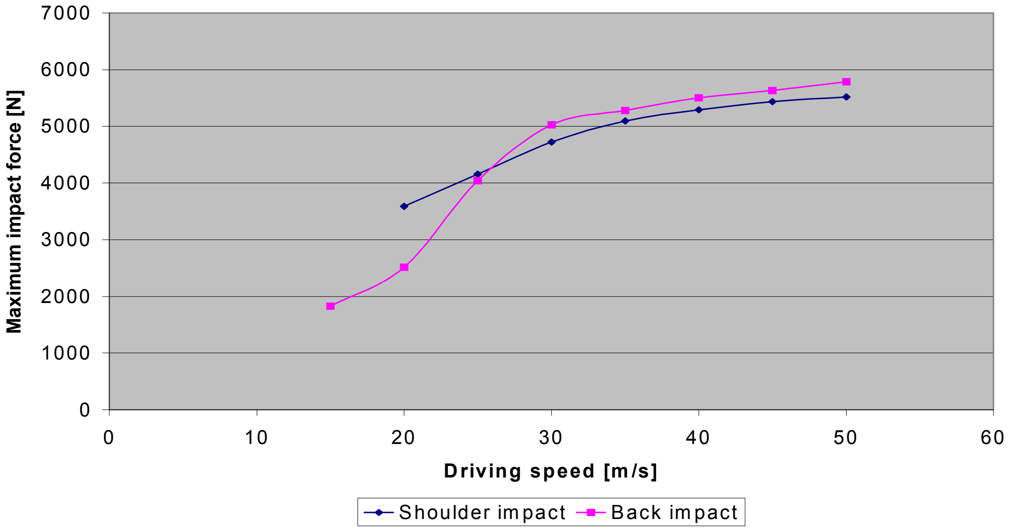

Fig.8 Dependence of the maximum impact force on a driving speed

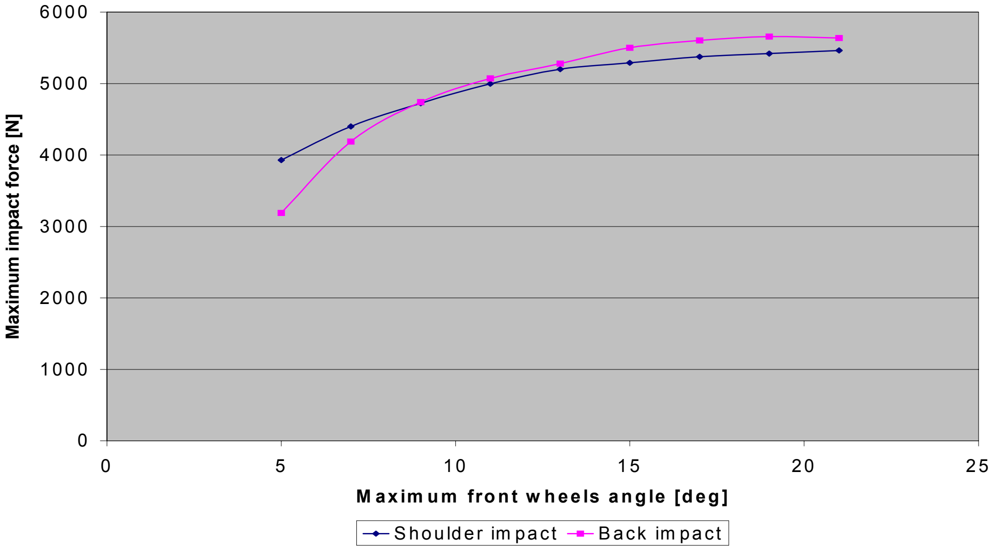

Fig.9 Dependence of the maximum impact force on the maximum front wheels angle

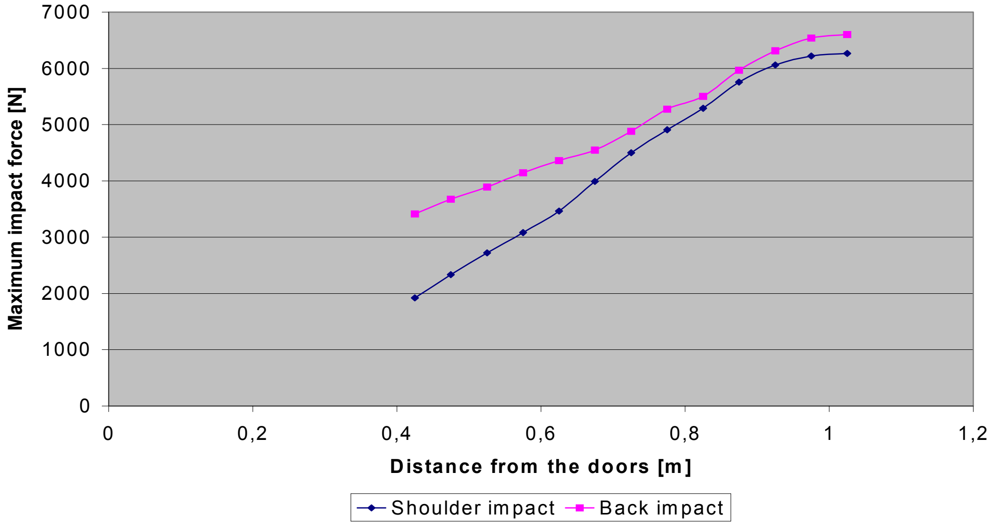

Fig.10 Dependence of the maximum impact force on the distance from the doors

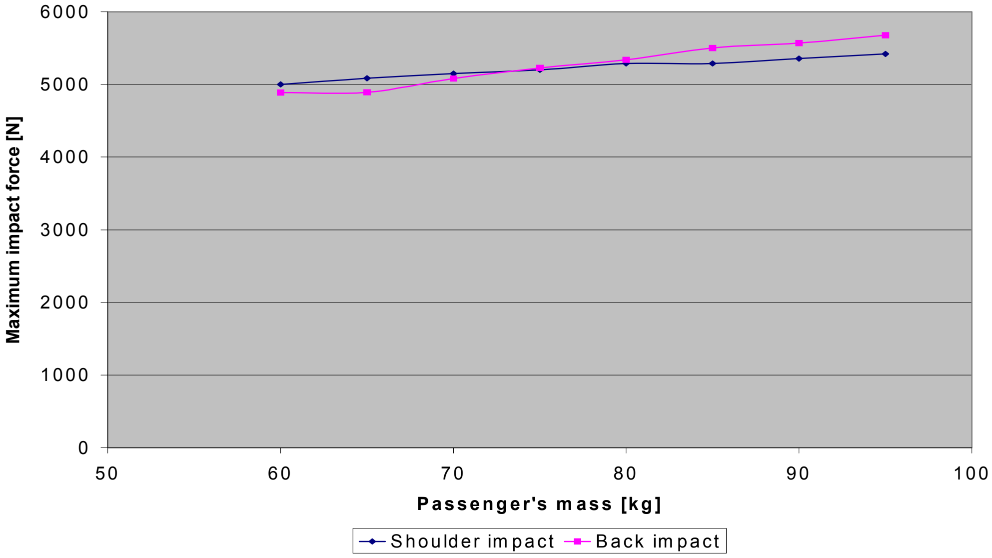

Fig.11 Dependence of the maximum impact force on the passenger mass

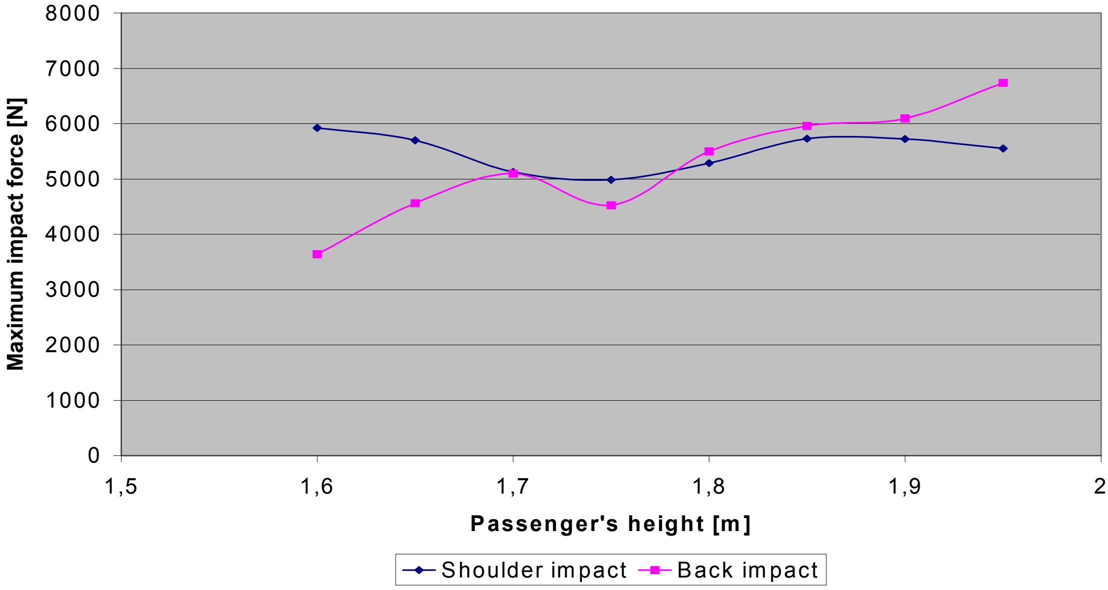

Fig.12 Dependence of the maximum impact force on the passenger height

5. Conclusion

Using the multibody simulations of unexpected avoidance manoeuvre the extreme of impact force during the fall of the standing passenger against the composite doors of the ŠKODA 14 Tr M trolleybus was determined. The structure of doors must be resistant at least to the impact force of this magnitude.

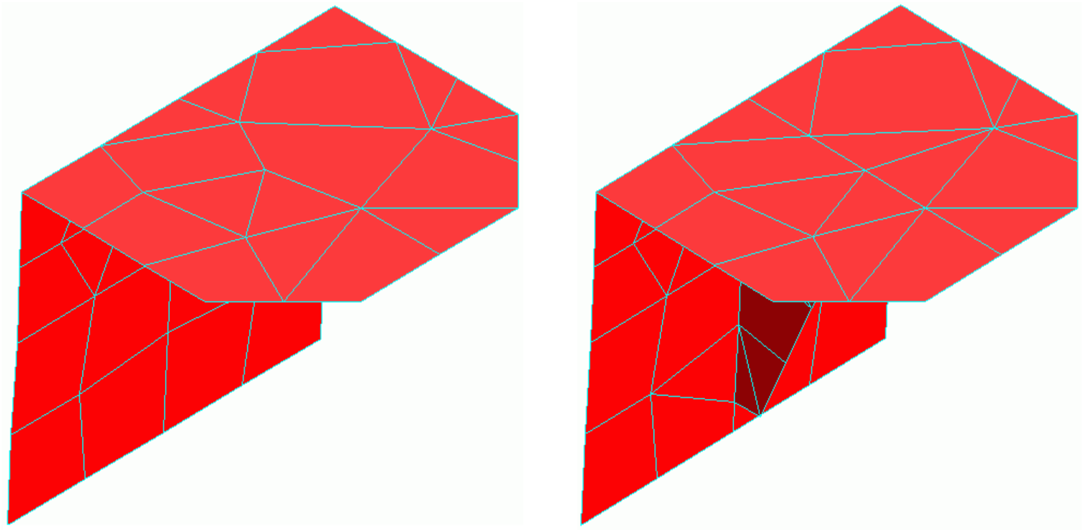

Fig.13 FEM models of the original and improved guide bracket

Simulation results with the basic setting of „parameters“ (maximum front wheel angle 15° during the avoidance manoeuvre, trolleybus driving speed 40 km/h, passenger mass 85 kg, distance from the doors 0.825 m and the passenger height 1.8 m.) served as input data for the FEM calculation of composite doors stress in COSMOS/M program and as the data for the experimental tests on their real prototype. On the basis of the simulations results the structure of the steel guide brackets of the mechanism for shutting the doors was improved (Fig.13).

The correctness of the computer simulation results was confirmed by means of tearing the guide bracket from the composite part of the doors. The test was carried out on the real prototype of doors in the Accredited Dynamic Testing Laboratory of ŠKODA RESEARCH Ltd.

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