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DECELERATION AND DEFORMATION DURING DYNAMIC LOAD OF MODEL LONGITUDINALS - REAL CONDITIONS AND SIMULATION

Summary. The manner and degree of taking over impact energy by the passive safety elements of the vehicle body is the basis for providing conditions for the survival of people using the means of transport (driver and passengers). The elements specially designed for this purpose in the self-supporting body are longitudinals. Their energy-absorbing properties are designed by using a specific shape, by using appropriate connections of their components and by choosing the right material. Determining the degree to which the vehicle (body) ensures safety during collision requires testing. The most complex and expensive tests are the ones carried out on a complete real object (whole vehicle). The solution worth considering is a bench test of individual body elements designed as energy-consuming (for example, longitudinals). In addition, it is also possible to carry out computer simulations in this area. The purpose of this article was to present and compare the results of dynamic studies on model energy-consuming real objects

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and compare the results obtained this way with the results of computer simulation in the same range. The scope of work was adopted on this basis: passive safety, model energy-absorbing elements of steel self-supporting vehicle body, dynamic tests, computer simulations. For the purpose of this study, a model of vehicle passive safety elements (model longitudinals) was designed for which dynamic tests were carried out on a specially designed test stand (speed of the hammer was up to 9.7 m/s, impact energy was up to 23.6 kJ). This test stand enabled registration of the deceleration during impact and deformation of the tested object. Next, computer simulations were carried out for geometrically and material-identical models. On the basis of the conducted tests, it was found that it is worth considering the replacement of collision tests of the whole vehicle by tests of its individual components. These tests can also be supported by computer simulations.

Keywords: longitudinal, passive safety, impact energy, dynamic load, simulation

1. INTRODUCTION

According to the currently valid concept of a safety bodywork, the vehicle has zones that are supposed to be deformed during a crash. The degree and way of deformation depend on the energy of the vehicle at the moment of impact (the actual mass of the vehicle and the velocity of impact are very important). All of the elements in the deformation zones during their deformation absorb the impact energy. For example, both the bumper and the external fender deformed during the collision absorbed some of the vehicle energy. The difference is in their energy-consuming abilities [1÷3].

In crash control zones energy-consuming elements are intentionally placed. They are designed in such a way that during the collision, they are deformed and absorb as much of the vehicle's energy as possible. The vehicle components included in the crash control zones can be divided basically into two groups. The first group includes elements that have been deliberately designed and used to absorb impact energy (for example, crash box). The second group includes elements that in addition to their basic task have been designed in a way that ensures their energy-consuming properties (for example, longitudinals). The basic elements included in the crash control zones include, among others: bumpers and sub-bumper beams, crash boxes, a front partition, longitudinals and the bonnet (Figure 1).

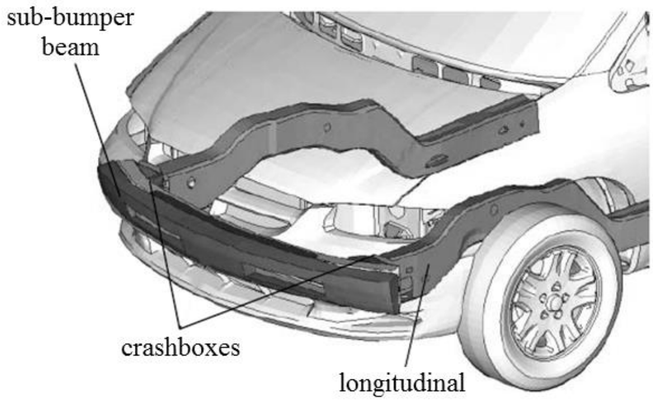

Fig. 1. Elements of the crash control zone [4]

2. LONGITUDINALS

Longitudinals are the basic elements in the construction of a self-supporting vehicle body. They combine several functions. The most important of them are undoubtedly the functions of the load-bearing element for the engine or the whole drive unit, as well as the suspension of the front vehicle. Due to the fact that the stringers now appear in almost every car body, and because of their shape and characteristic location in the vehicle, they were entrusted with an additional task - absorbing the collision energy during a car crash. As research shows, mainly longitudinals take over the impact energy. For this reason, their role in the aspect of passive safety of car body and whole vehicle safety is very important (Figure 2).

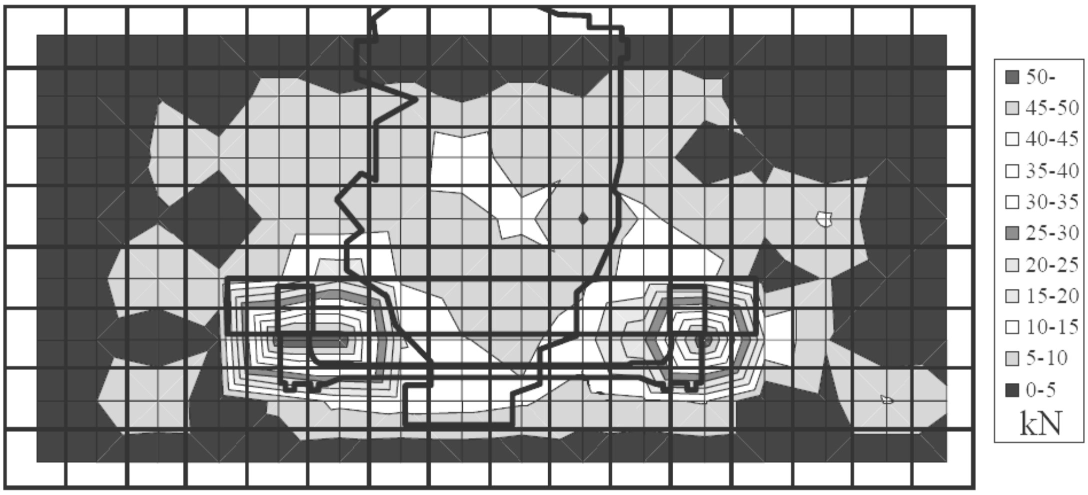

Fig. 2. The results of measurements of the impact force of a passenger car in a rigid barrier at a speed of about 50 km/h [5]

Longitudinals in the self-supporting body can be treated as a remnant from times when frame constructions prevailed.

However, the geometrical shapes of the modern longitudinals as members of the self-supporting body do not resemble unfinished longitudinals from frame structures made as one element. The longitudinal of the currently produced passenger cars generally has a closed cross-section. It is composed of at least two extrudates. In addition, a series of additional elements may be included in the longitudinal member (Figure 3).

During the design of the geometrical shapes of the longitudinal, the constructor may in a sense, programme the manner and course of its deformation during the collision (Figure 4). This, of course, has an effect on the value of deformation of the body and the value of deceleration as it affects the users of the vehicle. In order to give the longitudinal a shape that ensures the optimal manner and course of deformation, a series of ribs or holes were formed as geometric notches. It is in these places that the deformation of the longitudinal will be initiated during the impact.

An important issue regarding the longitudinals in a self-supporting car body is the way in which they are combined with the whole car body integrity. The method of transferring forces from the longitudinal to the rest of the car body depends on the solution of this construction node. In principle, it is possible to distinguish longitudinals passing into the floor pane and longitudinals extending to the thresholds.

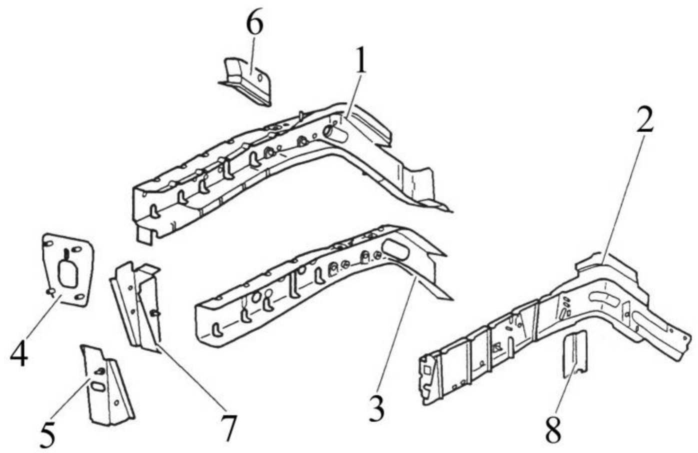

Fig. 3. Citroen C8 left front member: 1. longitudinal member, 2. side member, 3. side member reinforcement, 4. bracket, 5. end of the longitudinal member, 6. longitudinal strut, 7. side member, 8. reinforcement stringer closing [6]

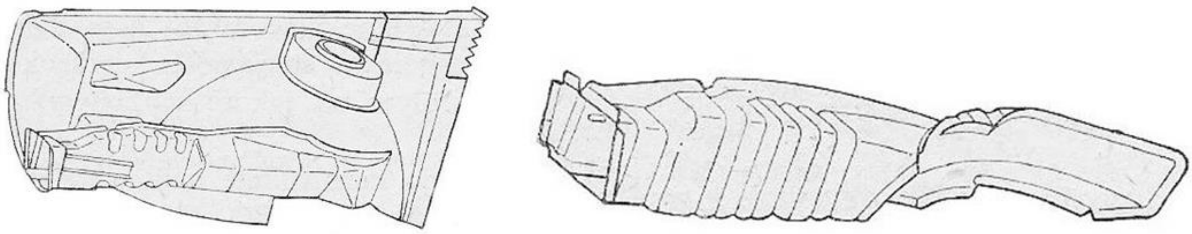

Fig. 4. Longitudinal with a given deformation solution [7]

3. INVESTIGATION AND RESULTS

Two types of investigations were carried out. These are; dynamical test and computer simulation.

Dynamical test was done using a special test stand [8÷12]. Main characteristics of the test stand for the dynamic test are shown in Table 1. Test stand is shown in Figure 5.

Tab. 1.

Characteristics of the test stand for the dynamic test

Ram mass	to 500 kg
Impact velocity	to 9.7 m/s (to 35 km/h)
Free fall height	to 4.8 m
Impact energy	to 23.6 kJ

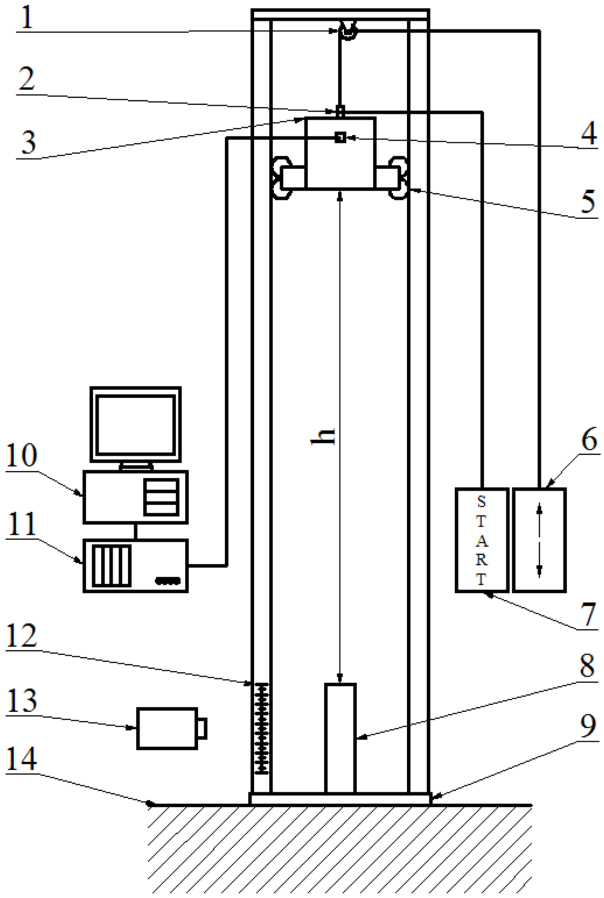

Fig. 5. Schematic diagram of the test stand for dynamic testing of model car body elements, h – height of free fall of the ram, 1. hoist, 2. trigger, 3. ram, 4. deceleration sensor, 5. guide rollers, 6. hoist panel, 7. trigger device, 8. model longitudinal, 9. base of the test stand, 10. computer, 11. device for data acquisition, 12. graduation, 13. camera, 14. foundations.

Model longitudinals were done for dynamic investigation. It consists of a few steps. In the beginning, investigations of the real form of longitudinals were done. Examples of its results are portrayed in Figure 6.

Next model of longitudinals was designed. In this step, some main model features were set (shape – Figure 7, material – Table 2, joint characteristics – Tables 3 and 4). The material used was typical steel of increased strength. The model longitudinal was 0.5 meter long and their cross-section was close to the pair of Ω profile. Incisions were made in the corners as deformation initiation elements. Additionally, through holes and edge cuts were made in the walls of the model longitudinal.

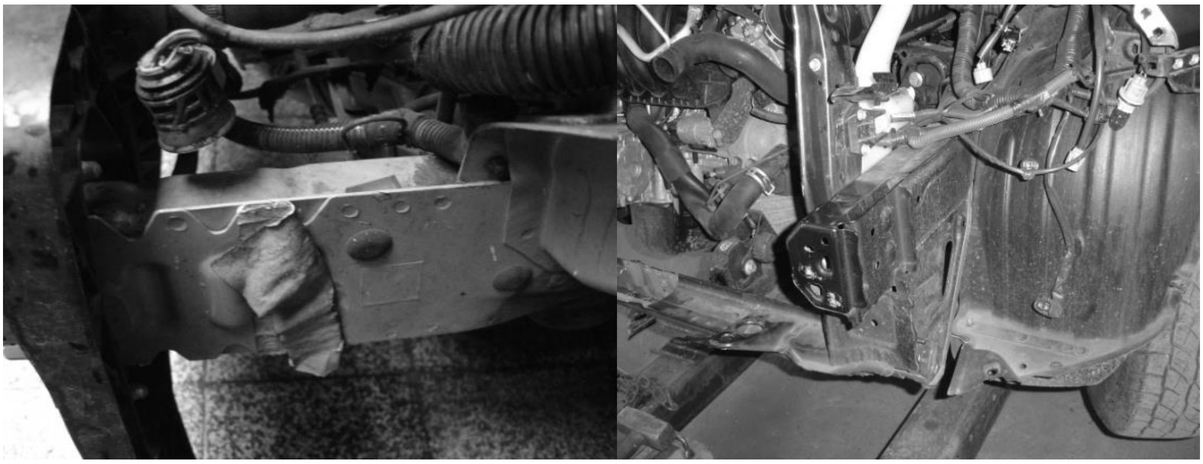

Fig. 6. Example of observed real longitudinals of a car body

In general, spot welding was used to connect the parts of the model longitudinal. In order to obtain the gradation of stiffness of the model longitudinal, marginal welds at the end of it were made. The parameters of point resistance welding are shown in Table 2, while welding parameters in gas shields are shown in Tables 3 and 4.

Tab. 2.

The chemical composition of the steel from which the model longitudinal were made

Steel grade	Chemical composition, %				
S355J2G3	C	Mn	Si	P max	S max
	0.2	1.45	0.51	0.035	0.035

Tab. 3.

Parameters of point resistance welding

Diameter of electrodes, mm	Current, kA	The force of electrode pressure, kN	Welding time, s
8.6	18.8	3	0.45

Tab. 4.

Metal Active Gas (MAG) welding parameters

Shielding gas	Gas flow rate, dm^3/min	The diameter of the electrode wire, mm	Current, A	Voltage, V	Wire feeding speed, m/min
82% Ar + 18% CO_2	16	1.2	150	25	11

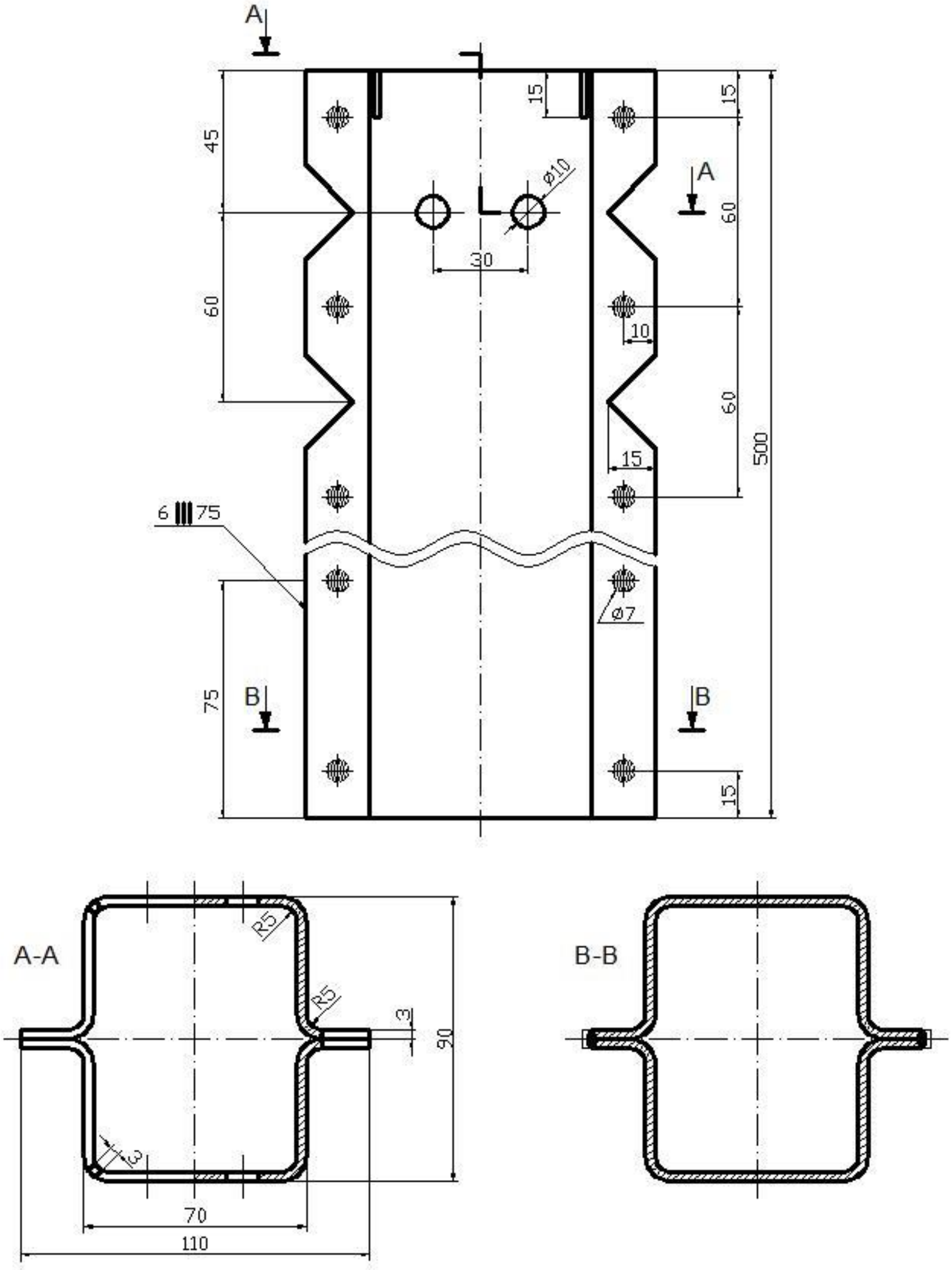

Fig. 7. Model longitudinal

The advantages of the designed test stand for dynamic test is that the velocity of impact can be smoothly adjusted and free fall mass can be gradually changed. In addition, it is possible to study model energy-absorbing elements of the car body as well as elements of the real self-supporting car body.

According to the main assumption regarding the method of testing, during the impact process, the deceleration of free fall mass and the deformation of the tested element are recorded as a function of time. Deceleration was measured by a single axis deceleration sensor. Deformation was measured by a speed camera.

In Figure 8-11 examples of results obtained during dynamical tests are shown. These figures illustrate the first phase of the impact (compression). There are:

- value of deceleration of RAM in depends on time during impact.
- value of velocity of RAM in depends on time during impact.
- value of model longitudinal deformation in depends on time during impact.

The duration of the impact process (first phase of the impact) was about 0.038 s. The maximum value of the deceleration during impact was about 480 m/s2. The maximum value of the deceleration was observed at the beginning of the impact process. It is a characteristic feature of the time course of the deceleration during impact. This is due to the fact that at the beginning of the impact the test piece (model longitudinal) exhibited the highest stiffness. The time course of the deceleration had a specific shape (characteristic changes in the parameter value). This was due to the predetermined deformation of the model longitudinal during the collision.

The changes in the speed of the RAM are similar to linear. Slightly higher intensity of velocity decreasing can be observed only at the beginning of the impact. As already mentioned, it is caused by the stiffness of the tested element (model longitudinal) at the beginning of the impact (initiation of deformation).

The change in the value of model longitudinal deformation in depends on time during impact can be described as square function. At the beginning of the impact process, the increases in the deformation value are clearly greater than at the end of the process. This is due to the fact that at the beginning of the impact, the RAM had great velocity and therefore great kinetic energy. The maximum deformation value of the tested component (model longitudinal) is approximately 88 mm.

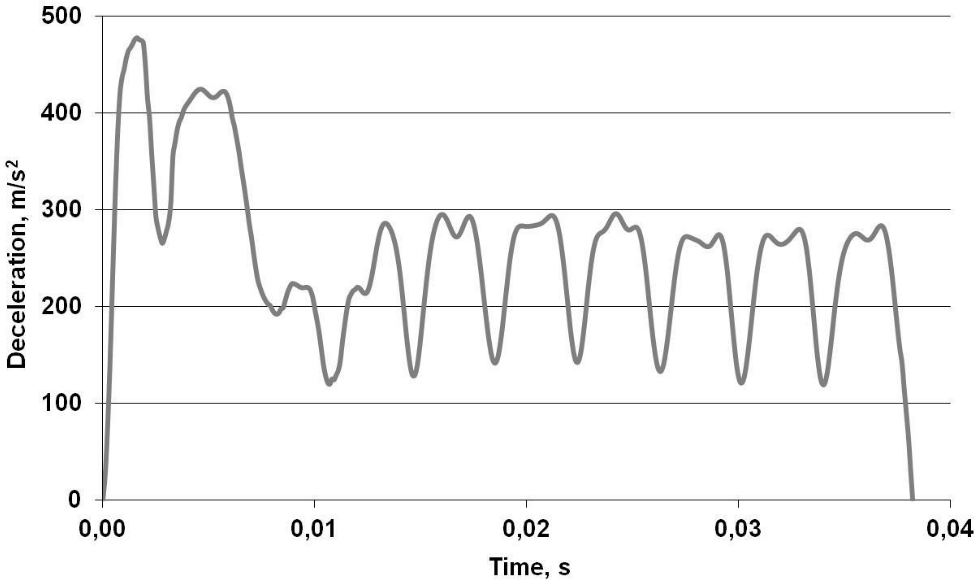

Fig. 8. Value of deceleration of RAM in depends on time during impact (Example)

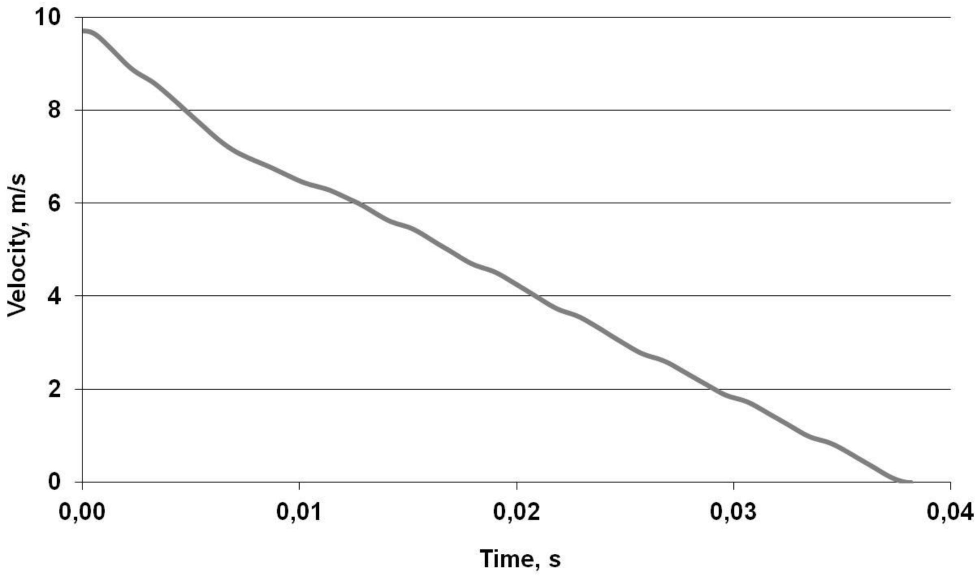

Fig. 9. Value of velocity of RAM in depends on time during impact (Example)

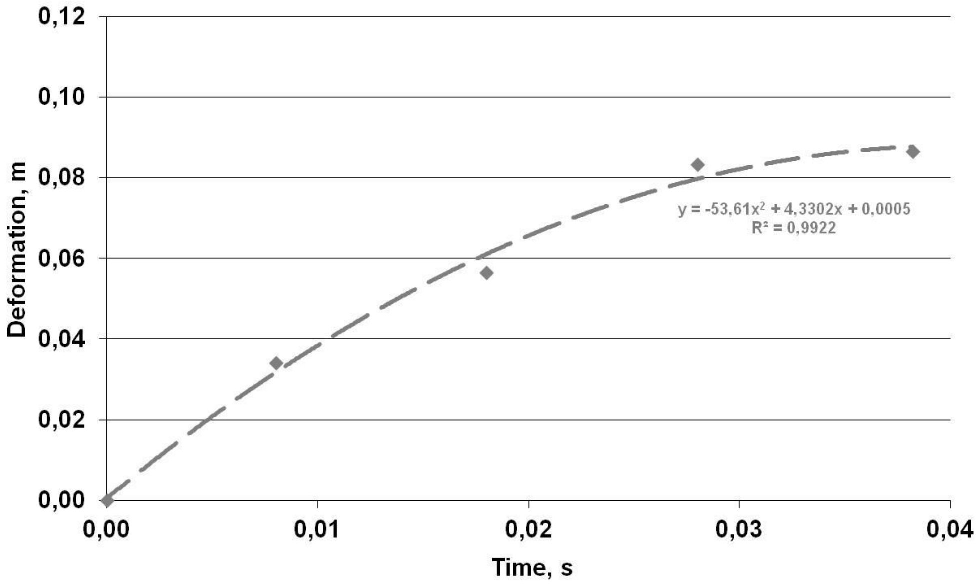

Fig. 10. Value of model longitudinal deformation in depends on time during impact (Example)

Next part of the test was a computer simulation. It was done using the Autodesk Simulation Mechanical 2017. Simulations reproduce identical experimental conditions as in real samples on model objects (model longitudinals). Examples of the results obtained during computer simulations are presented in Figures 11 and 12.

It should be noted that the results obtained during computer simulation are similar in value to the results of tests on the real model longitudinal (Figures 11 and 13).

Fig. 11. Examples of model longitudinal after tests

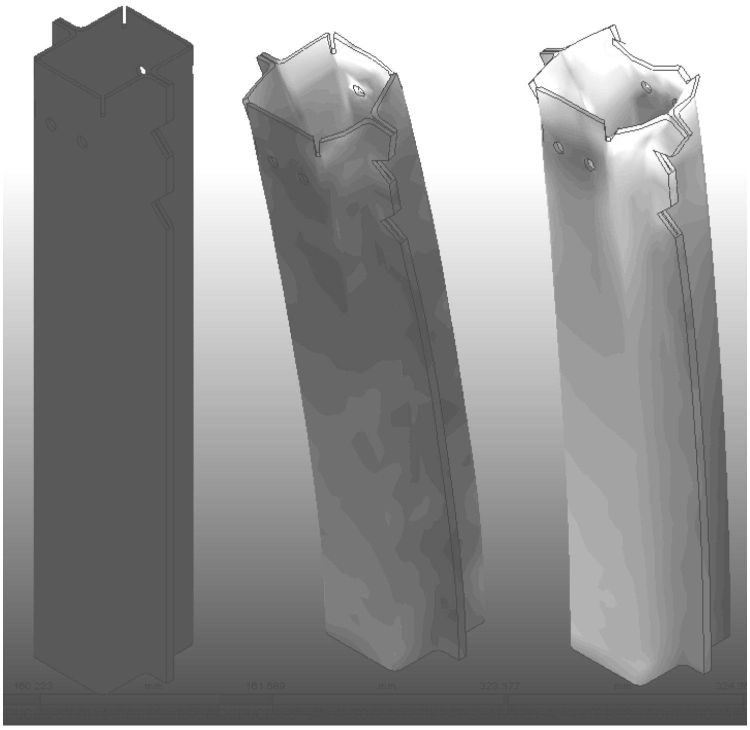

Fig. 12. Examples of computer simulation results

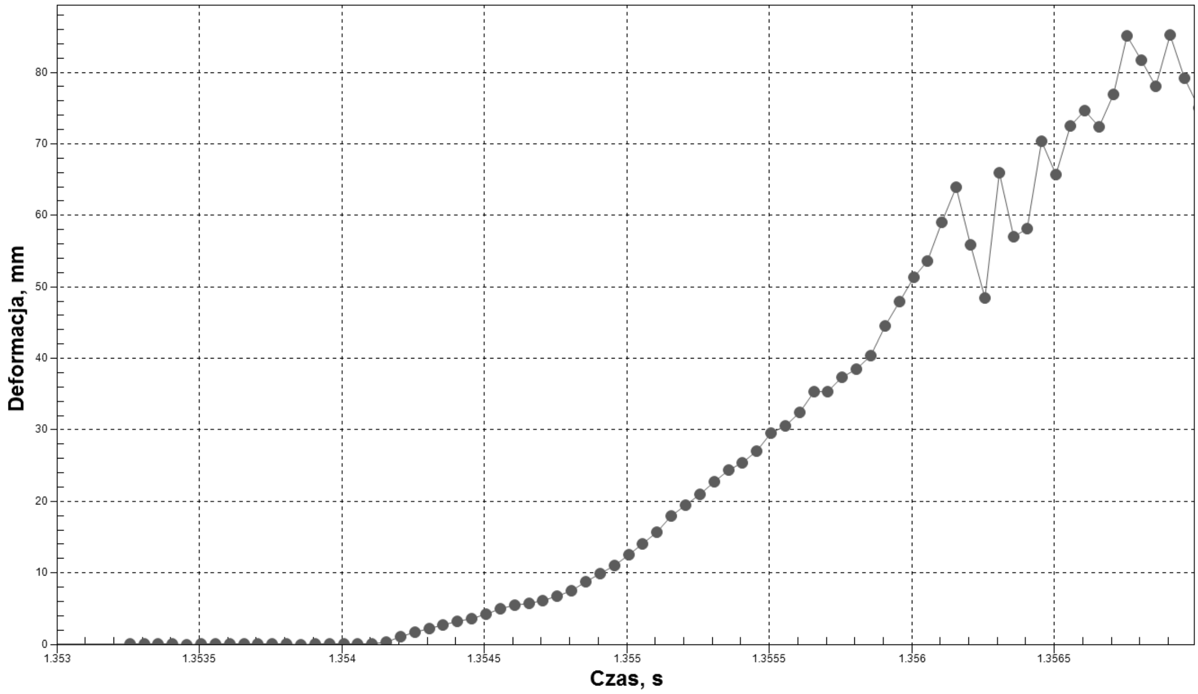

Fig. 13. Value of model longitudinal deformation in depends on time during impact (Example of computer simulation)

4. SUMMARY

The aim of this paper was to present and compare the results of dynamic studies on model energy-consuming real objects and compare the results obtained this way with the results of computer simulation within the same range.

For investigation simplified test stand was designed and constructed (experimental research stand). Moreover, a computer simulation was done for similar conditions.

On the basis of this investigation, it is possible to conclude that:

- passive safety of the car body is a very important subject.
- longitudinal is the component which absorbed a lot of impact energy.
- it is possible to carry out crash tests on individual components of the car body (instead of the whole car).
- the time course of the impact deceleration has a characteristic shape (high values at the beginning of the process and subsequent variations of the parameter value).
- it is possible to carry out a computer simulation of the impact process, and the results obtained there are comparable to those on real objects (values of parameters).

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