A STAND FOR THE MODELLING OF CRASH TESTS OF SOME PARTS CRITICAL TO THE PASSIVE SAFETY OF A VEHICLE

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Summary

Results of investigations of modelled crash tests have been presented. The results were obtained with the use of a measuring stand that was designed and built at the Department of Vehicles and Fundamentals of Machine Design of the Technical University of Lodz for the simulation of vehicle collisions together with the accompanying phenomena. The stand included a scale vehicle model made of steel profiles with adjustable crumple zone size and variable pre-crash mass, a model acceleration track with a precise vehicle start positioning system where the model was brought to its starting position with the use of a tractor provided with a stepping motor, a non-deformable obstacle, as well as time and deceleration measuring systems. The basic design requirements adopted and the stand calibration procedures have been presented. The research possibilities related to the investigation of modelled crash tests have been described and illustrated with measurement examples. The stand makes it possible to carry out model tests both on the controlled crumple zone and, after inverting the reaction system, on energy-absorbing traffic barriers. Apart from being used by University staff for their own research work, the stand has constituted for several years a cognitively attractive facility willingly used by students during their laboratory classes in subjects related to vehicle construction and passive safety problems.

Keywords: crash test, passive safety.

1. Introduction

The road accident is a traffic event in result of which a road traffic participant has been injured or killed and/or material losses have been incurred. In this consideration, it is important that a vehicle should be appropriately designed so that the highest possible degree of safety of road traffic participants is obtained.

The safety of motor vehicle design is directly connected with appropriate deformability of the front, rear, and side parts of the vehicle. The proper design of the vehicle body

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must ensure adequate absorption of the energy of impact thanks to the application of appropriately located controlled crumple zones. Simultaneously, the vehicle cabin should be sufficiently rigid to provide adequate survival space for the occupants. The controlled crumple zone is formed by appropriately shaped and situated bodywork components made from energy-absorbing materials, whose role is to be deformed and thus to absorb a part of the energy of impact during a collision. During crash tests where a vehicle hits on a flat rigid obstacle with a speed of 64 km/h, the crumple zone of the present-day passenger cars extends over up to 0.7 m. For these data being taken into account, the maximum deceleration and the deformation time may be specified as 23 g and 80 ms, respectively.

1. Basic design requirements

The work was undertaken because of relatively difficult acquisition of empirical information about the phenomena accompanying vehicle collisions. Computer simulation and engineer's software make it possible to obtain preliminary results describing the vehicle behaviour during a collision; however, these results must be verified experimentally.

Therefore, a decision was made to build a simulation test stand that would offer adequate model similitude in terms of both space and time, based on similitude theory principles.

The starting-point assumptions were made as follows:
- The crash test would be carried out on a scale model, which would represent a real passenger car as accurately as possible;
- The model would be a device intended for repeated use, with replaceable crumple zone;
- The model mass and dimensions and the test conditions should be interrelated in accordance with similitude theory principles;
- The range of the decelerations occurring at the collision of the model with the obstacle should correspond to the values observed at actual crash tests;
- The deceleration of the centre of mass would be measured during the collision;
- In the future, the test stand would be combined with another facility, where the operation of airbags would be represented;
- In consideration of the test stand construction costs and the model dimensions, a gravitational drive system would be made in the form of a sloped acceleration track.

Taking into account the possibility of building the test stand inside the laboratory hall available, a decision was made to adopt a scaling representation factor of 10.

2. Test stand

To carry out crash tests of selected parts that are important for the passive safety of a motor vehicle, a test stand has been designed and built. The stand consists of the following major components:
- Model acceleration track;

- Obstacle;
- Model of a passenger car;
- Measuring apparatus;
- Drive system to bring the model to its starting position.

The model acceleration track, on which the model is to run down freely before the test, has been so shaped that the desired vehicle motion parameters would be achieved before the vehicle hits on the obstacle. A schematic diagram and dimensions of the track have been presented in Fig. 1. An important part of the track is the model guiding system specially designed and made, thanks to which the vehicle can maintain the desired direction of its motion when running down the track. A photograph of the track has been shown in Fig. 2.

Another major part of the test stand is the obstacle, on which the vehicle model hits during the experiments. It is an immovable element, made of steel plate 30 mm thick and fixed to the building structure. Thanks to this, the obstacle may be considered non-deformable during the crash test.

The main part of the test stand is the vehicle model. The model body is a frame structure, made of steel sections. The model has an energy-absorbing zone adjustable within the range from 40 to 80 mm, situated at the front. The part constituting the energy-absorbing zone can be completely removed from the model, thanks to which the range of possible model applications can be considerably widened. The model mass is 8.4 kg (with

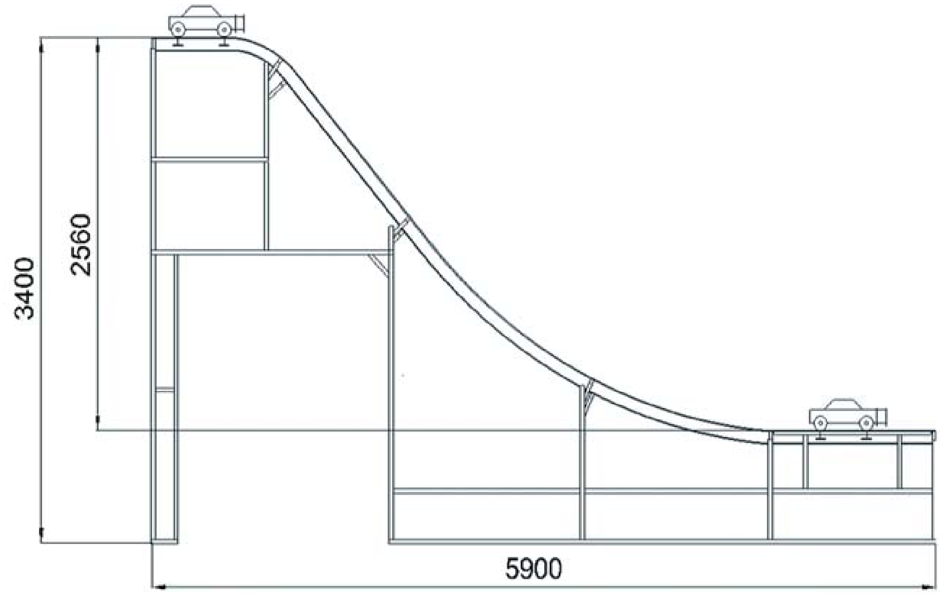


Fig. 1. Schematic diagram and of the model acceleration track

Fig. 2.Model acceleration track

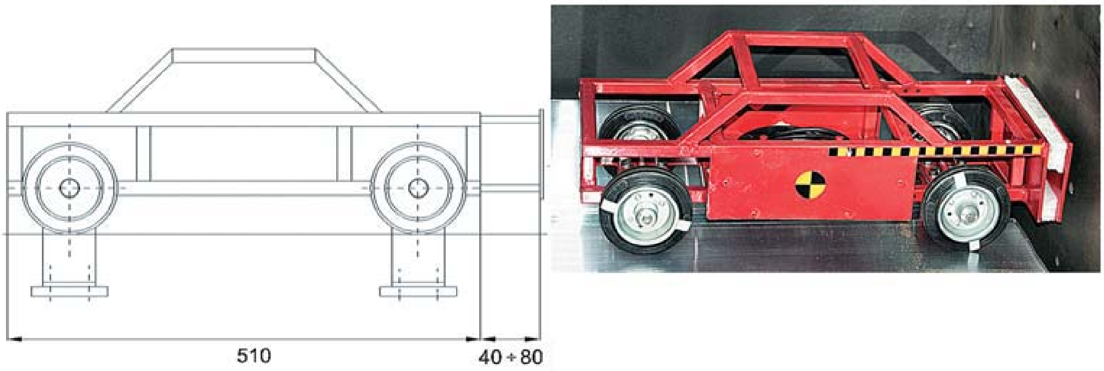


Fig. 3. Dimensional diagram and photograph of the model

a possibility of being increased) and the overall length of the model is 510 mm (see Fig. 3).

For individual crash tests, elements of different stiffness, to be crumpled during the tests, are installed between the front plate and the body frame of the model.

The vehicle model has been provided with guiding parts interacting with the track guides and thus causing the vehicle to maintain the desired direction of its motion during the test.

A deceleration gauge specially made for this purpose has been placed at the centre of mass of the model. As the measuring element, an integrated micromechanical accelerometer ADXL 250 manufactured by Analog Devices has been used. This module includes two measuring units with their operating axes situated perpendicularly to each other. In the

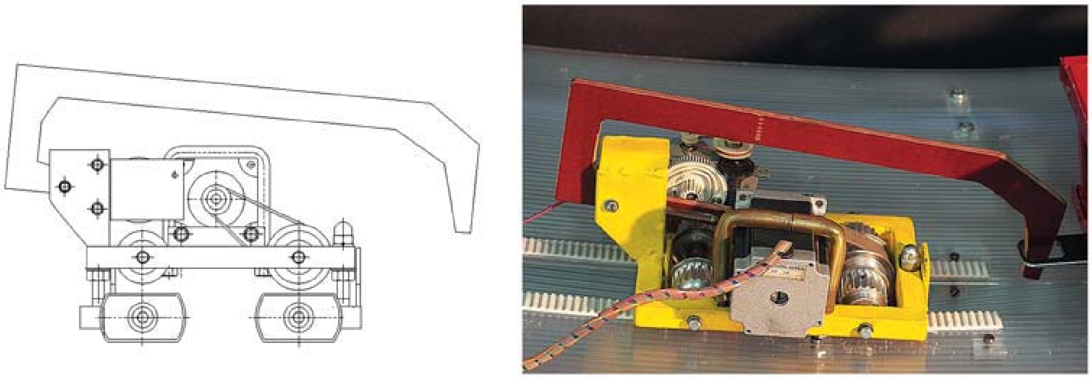


Fig. 4. Design diagram and photograph of the tractor

deceleration gauge made for the purposes of this work, both the measuring units have been used; the measuring ranges for the horizontal and vertical axes have been set at ±50 g and ±25 g, respectively. The gauge design makes it possible to transpose the measuring axes and thus to change the sensitivity of the gauge.

The impact speed of the model is measured at the final horizontal section of the track, with a system of two photoelectric cells situated 1 m away from each other being used for this purpose. At a measurement resolution of 1 ms, the actual repeatability of measurement results is better than 0.5%. The signal generated by the photocell situated closer to the impact point is simultaneously used to trigger the recording process. The sampling period adopted as 0.02 ms has been found sufficient at the present stage of operation of the test stand but it is very likely that tests will also be carried out at higher sampling frequency.

The model is brought to its starting position by an autonomous tractor moving on the track (Fig. 4). The tractor driving system with a stepping motor and an electric mechanism used to release the vehicle model ensure the vehicle positioning to be easy, precise, and perfectly repeatable.

The measurement results are supplemented with video records made at speeds from 470 to 1 000 fps, which facilitate the analysis of the phenomena that take place during the impact. To make records with such speeds, advanced digital cameras manufactured by Casio and Fuji are used, which produce records of adequate quality if appropriate illumination is provided.

3. Measurement results

When the test stand was put into operation, a number of trials were carried out on it in order to find out the range of the obtainable test results. The actual repeatability of test conditions, suitability of various materials used to make the crumple zone, and durability of the model were assessed.

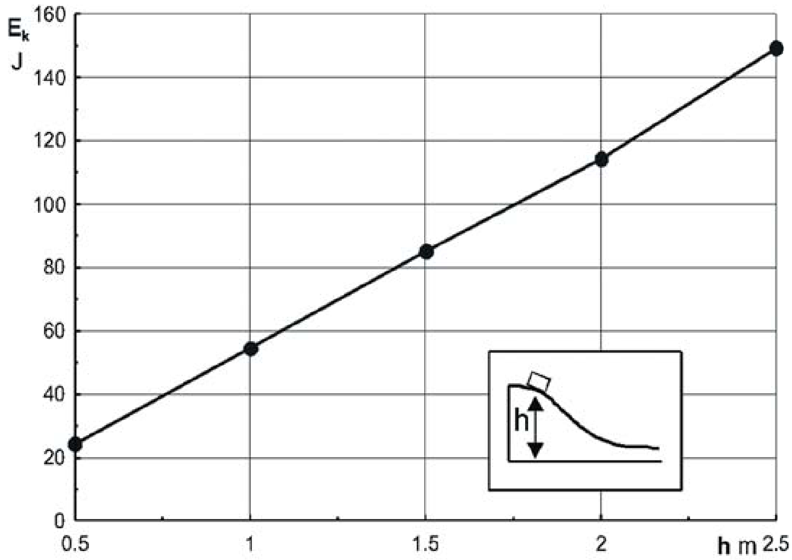


Fig. 5. Dependence of the kinetic energy of impact on the height of the starting position of the model

An example of calibration of the test stand is the curve shown in the graph, representing the dependence of the kinetic energy of impact on the height of the starting position of the model. These trials were carried out for various values of the model mass, thanks to the possibility of installing additional weights on the model. The results of these trials have been presented in Fig. 5.

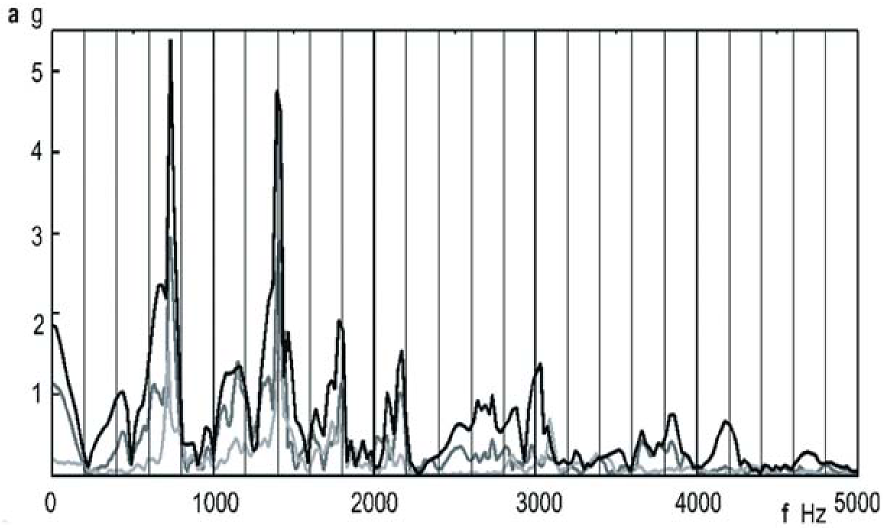


Fig. 6. Examples of spectral distribution curves of the accelerometer signals recorded

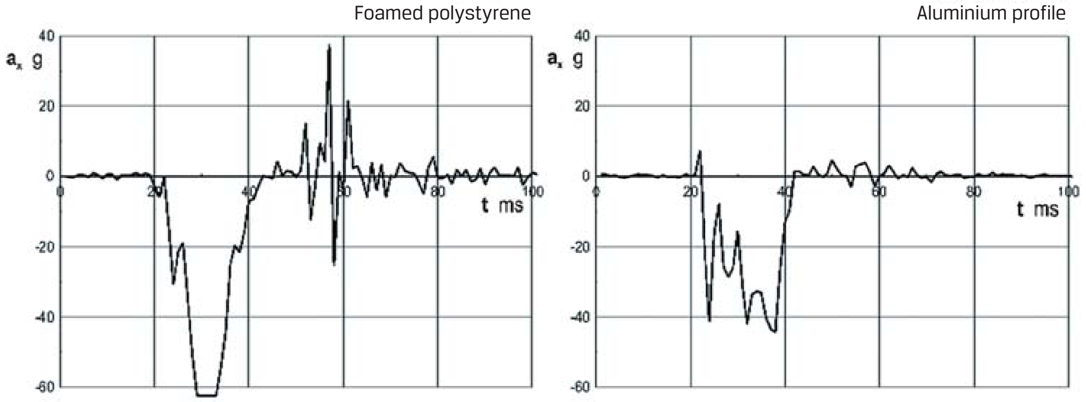


Fig. 7. Deceleration vs. time curves recorded at crash tests with a non-deformable obstacle

Multiple trials showed very good repeatability of the final model speed, with the deviation not exceeding 1%.

The trials carried out with different model masses revealed the influence of the resistance component depending on vertical forces, which was consistent with the phenomena related to the rolling resistance of a real vehicle.

The test results obtained were analysed with the use of digital filtering (based on the fast Fourier transform – FFT) in order to separate the signal components caused by vibrations of the material undergoing destruction in the crumple zone and vibrations of the structural model parts from the main signal related to the movement of the centre of mass of the model. Fig. 6 shows spectral distribution curves of three examples of the signals recorded, which make it possible to determine the required parameters of the FFT low-pass filter.

The example presented above reveals the presence of a signal component related to the natural vibration of the model structure, the frequency of which significantly exceeds that of the expected useful signal.

Examples of time histories of the decelerations that were recorded at the model crash tests carried out with various materials of the crumple zone have been presented in Fig. 7.

The effects of the application of homogenous crumple zones of different stiffness values can be seen in Fig. 8. The graph shows a comparison between crash test results obtained for three different crumple zone stiffness values. The stiffness values were diversified at these tests by installing different numbers of identical deformable elements made of an aluminium profile and arranged in parallel in the crumple zone.

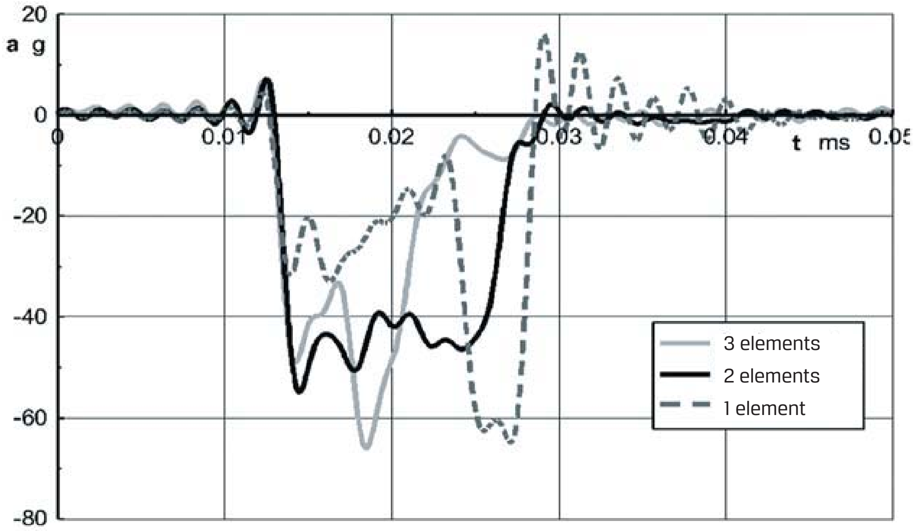


Fig. 8. **Comparison between results of 3 crash tests: a crumple zone of homogenous structure with different stiffness values**

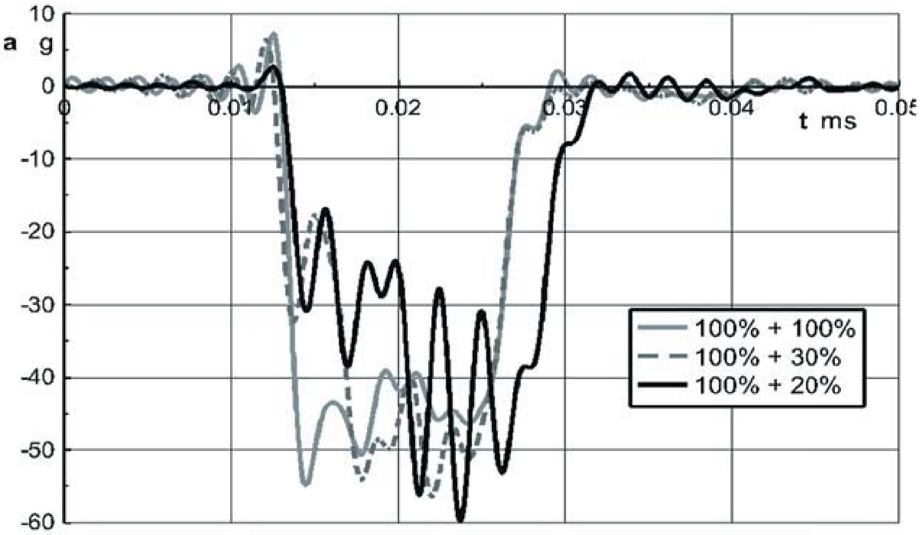


Fig. 9. **Comparison between results of 3 crash tests: a two-element crumple zone; one version with homogenous structure (of constant stiffness) and two versions with variable stiffness (100% = full length of the longest deformable element)**

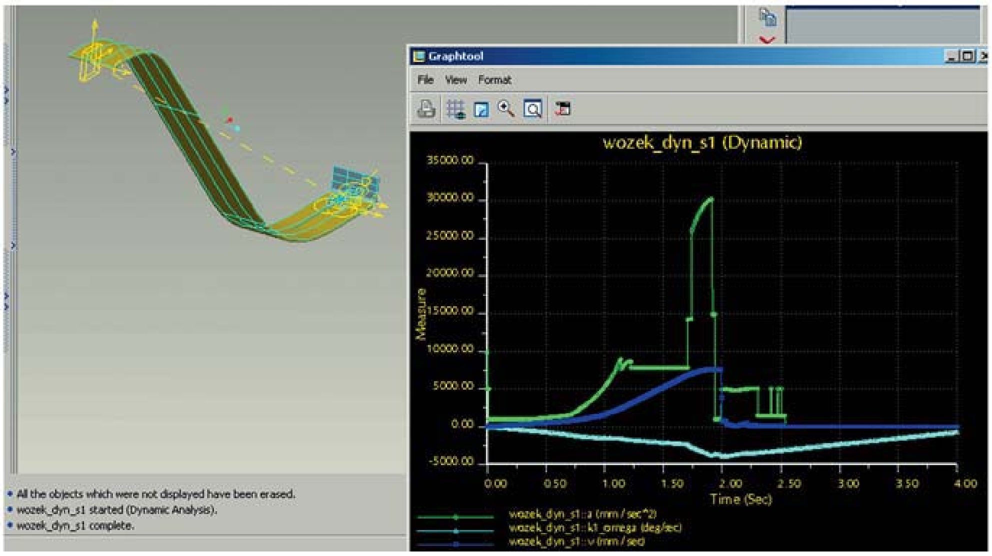
Tests were also carried out with the load displacement phenomenon being simulated, which included the situation of free load movement and the situation where the load was fixed to the vehicle with constraints of limited strength.

Such tests may be developed to a certain extent by adding a driver model (a "dummy") with a separate accelerometer installed in it.

Fig. 10. Example of the crumple zone, made within a student's project

The design of the plate installed at the track end makes it possible to introduce flexible obstacles in the future, which would model the impact conditions as required in the standard crash tests carried out throughout the world.

With the vehicle model design kept unchanged, the test stand may be used for model testing of energy-absorbing traffic barriers. High repeatability of the test results obtained,



- All the objects which were not displayed have been erased.
- wozek_dyn_s1 started (Dynamic Analysis).
- wozek_dyn_s1 complete.

Fig. 11. An attempt to model the test stand in the Pro/Mechanism – Pro/ENGINEER computer program

as regards both the initial impact speed and the deceleration recorded, makes it possible to observe the effects of even minor modifications, e.g. changes in the materials used.

The measuring system of the test stand is just to be developed by the introduction of an optical displacement sensor fixed on the track. This will enable the instantaneous vehicle model position to be recorded during the impact, separately from the fast frame-by-frame video recording.

The test results obtained from the stand have also become a basis for attempting to represent the phenomena observed on the stand in the Pro/Mechanism – Pro/ENGINEER computer program (author: J. Ormezowski, D. Eng., Department of Vehicles and Fundamentals of Machine Design of the Technical University of Lodz).

4. Conclusions

The device presented here makes it possible to carry out crash test analyses; the deceleration vs. time curves obtained from the crash tests modelled on this device coincide with those having been known e.g. from UTAC or ADAC publications as obtained from crash tests carried out on real vehicles.

Even in the present form, the test stand under consideration may produce important didactic effects in the process of education of engineering personnel because it motivates and enables the students to acquire knowledge of the topics related to the curricula followed within various subjects of study. Further development of the test stand may be reasonably expected to provide possibilities of carrying out a wider variety of tests that would successfully model different aspects of road collisions.

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