Numerical Simulations of Vehicle Restraint Systems

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Abstract

This paper provides an overview of the progress that has been achieved so far in the investigation of restraint abilities of portable road barriers with integrated anti-noise wall. The aim of this project is to develop finite element models that would be able to faithfully describe actual crash tests of several categories. Numerical simulations using these models could significantly reduce financial and time costs connected with the development process of these barriers. At the first step, the finite element models of the barrier with concrete anti-noise wall and two vehicles (TB81 - an articulated truck and TB51 – a bus) have been created and tested. Then a crash test simulation with the articulated truck model was performed and correlated with the experimental data from an actual crash test. The correlated aspects were: overall behavior of the vehicle and the barrier, maximum dynamic deflection of the top of the barrier and maximum permanent deflection of the bottom of the barrier. The simulation achieved fairly good agreement with the experimental data. The next step in this process will be a crash test simulation with the bus finite element model. Once the simulations of all required categories are able to faithfully describe the actual crash tests they will be used to predict restraint ability of another version of the barrier that is currently being developed. In this barrier there are panels made of cement-bonded wood-chip material called Velox used instead of concrete panels in the anti-noise wall. In order to be able to simulate new version of the barrier, material properties of Velox had to be determined and subsequently used to create a material model. This effort led to a material model that sufficiently matches experimental data obtained from a set of static and dynamic measurements. Dynamic material properties of Velox material will be further tested with Split Hopkinson Bar (SHB) method as the SHB testing device for large specimen (Φ 50 mm) is currently being developed in SVS FEM in cooperation with Research Institute for Building Materials, Brno. The last step before performing a full scale crash test simulation with Velox version of the barrier will be a punch test simulation of a whole Velox panel. Explicit solver of finite element program LS-DYNA® was chosen to obtain solutions of mentioned numerical problems.

Introduction

Any vehicle restraint system in EU has to comply with strict conditions defined in national standards for safety on roads. These standards require expensive crash tests (up to 100 000 €). In addition, to set up such a vehicle restraint system crash test site often requires several weeks of work. Numerical simulations serve as efficient tools in the development process of these vehicle restraint systems. The main advantage of the simulations is the fact that with their help it is possible to significantly lower financial and time costs of the development process. A numerical simulation of a crash test can reveal weaknesses of the system itself or weaknesses of the test conditions. This information enables designers of the vehicle restraint systems to fix these weaknesses even before the actual crash test is done. Furthermore, a numerical simulation which faithfully describes the actual crash test becomes very powerful tool for predicting responses of the system to various design or material changes.

The aim of this work is to improve quality of current numerical simulations in order to enhance their ability to faithfully describe several categories of road restraint crash tests. Analyses are focused on safety road barrier with integrated anti-noise wall. Results from numerical simulations and real experiments were correlated for variant with typical anti-noise concrete panels in the wall. Once the crash test simulations correspond to the experimental results they will be used to predict behavior of a new barrier variant. The new variant utilizes panels made of cement-bonded wood chips material (Velox) instead of concrete panels. This paper was created in order to report current progress in this investigation.

It has to be noted that there can never be a perfect match between the numerical simulations and the experiments achieved. Even though a lot of crash test conditions are prescribed by the standards there are still hundreds of uncertainties present in each individual crash test (actual age and condition of various parts of the vehicle, actual weather conditions, variance in speed, etc.). Explicit solver of finite element program LS-DYNA is a suitable tool to obtain solution of this numerical problem.

Road barrier with integrated anti-noise wall

The studied barrier represents a unique combination of desired barrier properties. The barrier is able to withstand enormous amount of energy while still being portable. There is no fixation to the ground needed. In addition, the upper part of the barrier serves as a noise wall.

Pic. 1: Safety road barrier with integrated noise wall

The basis of the barrier consists of concrete blocks (a single block is 3,98 m long and weighs 11,9 t). These blocks are linked together with a locking system so they form a typical road barrier chain. Each block also serves as a foundation for a steel column. These steel columns hold together concrete panels for the noise protection purposes.

Crash tests conditions

Whole simulation setup corresponds to the national and EU standard for safety on roads ČSN EN 1317-2. The barrier analyzed in this work had to prove its restrain ability at levels H2 (crash test TB 11 and TB 51) and H4b (crash test TB 11 and TB 81) according to the standard.
TB 11: a passenger car (900 kg), impact velocity 100 km/h, impact angle 20°
TB 51: a bus (13000 kg), impact velocity 70 km/h, impact angle 20°
TB 81: an articulated truck (38000 kg), impact velocity 65 km/h, impact angle 20°
There have been already TB 11, TB 51 and three TB 81 real crash tests performed. Individual TB 81 tests vary in barrier height and bottom block mass. During all these tests there were many quantities monitored and recorded. Several of these quantities were chosen for the purposes of experiment – simulation correlation:

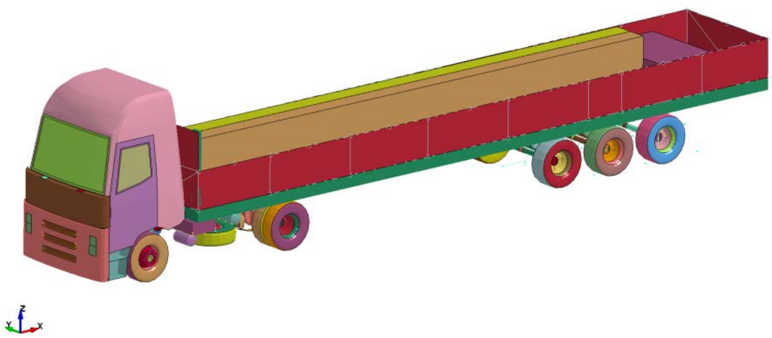
- maximum dynamic deflection of the top of the barrier
- maximum permanent deflection of the bottom concrete blocks
- overall behavior of the vehicle and the barrier

The overall behavior of the vehicle and the barrier during the impact was correlated with simulations due to the video records.

Numerical model

For the purposes of simulating above mentioned categories of crash tests it was necessary to create FEM models of vehicles corresponding to the standards.

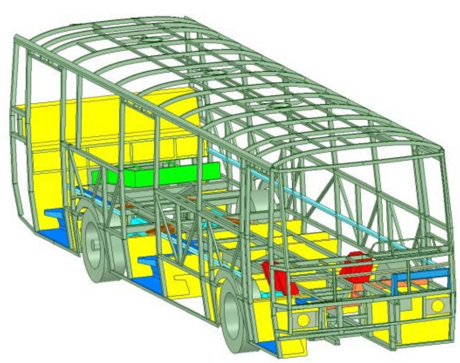
The truck model was originally based on freely available “38-ton Articulated Heavy Goods Vehicle” model (LAST Labs, Department of Aerospace Engineer, Politecnico di Milano). This truck model was used for the initial attempts but it did not match enough the behavior of the trucks used in the actual crash tests. Therefore major portion of the model had to be rebuilt and eventually only a few parts from the vehicle remained original. The tractor of the truck including suspension system was the main difference and had to be completely recreated based on Renault T truck.



Pic. 2: Articulated truck FEM model (TB 81)

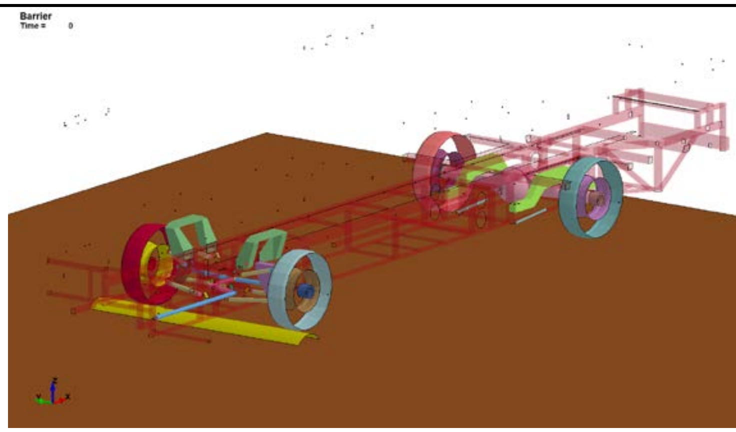
The bus used in the experiments done by national testing authority (Technical and Test Institute for Construction Prague) is usually bus model named Karosa type 700. When creating the bus FEM model it had to be started from scratch as no FEM model of this particular bus model was available. In order to do so the geometry of the bus parts had to be drawn first. While preparing CAD model there was a partially disassembled specimen of this bus model available as well as some partial technical drawings. The CAD model was created in ANSYS SpaceClaim system.

Pic. 3: TB 51 vehicle sample - Karosa 700



Pic. 4: TB 51 vehicle - CAD model

As suggested by CEN/TR 160303 standard there were also behavior of the model in several prescribed conditions checked. Among others, it was the ability of the bus to keep the straight direction and the behavior of the bus while going over a speed bump at various velocities. During this testing mainly the behavior of the suspension system was observed and further developed.



Pic. 5: TB 51 FEM model – suspension testing

The last step in the bus FEM model testing was a full scale crash test. The aim of this crash test was to check behavior of individual parts and their mutual connections. For this testing the vehicle with prescribed initial velocity of 80 km/h was placed in front of a rigid wall with 20° impact angle. The rigid wall in this test was a simplification during a bus model development. The optimized model of the bus will be used in numerical simulation of the crash test with real concrete or Velox anti-noise barrier system.

Pic. 6: Bus FEM model – crash test

Simulations of TB 81 crash test were performed in parallel. After several attempts with "38-ton Articulated Heavy Goods Vehicle" we decided to create a vehicle model which would match more the vehicles used for the actual crash tests (see pic. 2). Due to the truck model which corresponded to the vehicles used for the actual crash tests the simulations of the TB 81 crash tests were able to achieve fairly good agreement with experimental data.

Pic. 7: TB 81crash test: experiment – simulation comparison

The overall behavior of the restraint system in the simulation corresponded well with the experiment. The barrier as a whole remained in both cases almost intact. Only in the area of impact there was some damage observable. Several concrete blocks closest to the impact area were slightly moved while the rest of the barrier remained practically in their original positions.

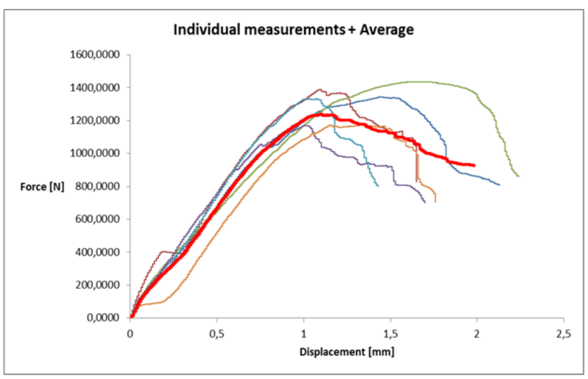
The computed maximum permanent deflection of the bottom concrete blocks correlated well with the data recorded at the actual crash test. The maximum permanent deflection in numerical simulation was found about 113 mm and the maximum permanent deflection at the real crash test was 127 mm. Another quantity that was compared was maximum dynamic deflection of the top of the barrier. There was, however, not such a good correlation achieved. The value of maximum dynamic deflection of the column tops closest to the impact were 118 and 151 mm at the actual crash test while it was only about 90 mm in the simulation. This difference suggests higher stiffness of the upper part of the barrier in the simulation than in reality.

Cement-bonded wood chips anti-noise panels – Velox

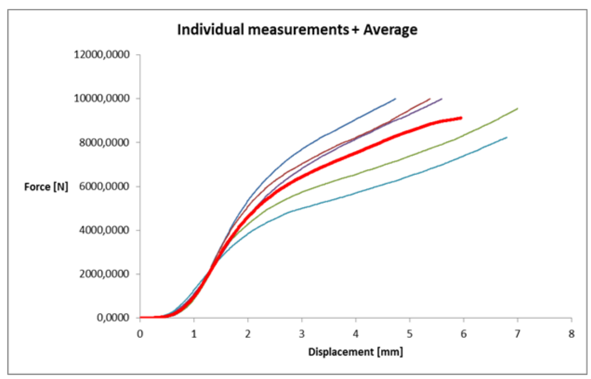
Besides the concrete panel version of the barrier, there is currently another version of the barrier in development process. This version employs panels which are made of cement-bonded wood-chip material, produced in Velox Werk GmbH company, instead of concrete panels.

Pic. 8: Velox material

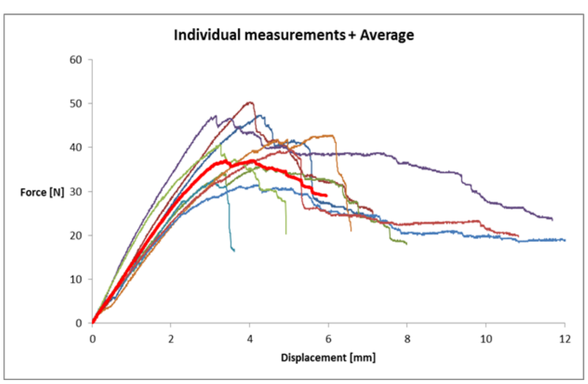
For the purposes of simulating crash tests of the Velox barrier version it was necessary to determine its mechanical properties and to create its material model first. Set of material properties measurements was performed: quasi static standard tests as tensile, compressive and bending strength test as well as dynamic drop test and test with IZOD measurement device. Based on the measurements the material Velox WSO 80 was chosen for detailed investigation.



Tensile test



Pressure test



Bending test

IZOD test:
Impact strength $a = 3,8\ kJ/m^2$
Residual kinetic energy $\Delta E_k = 4,75\ J$

Pic. 9: Velox WSO 80 experimental measurement results

Velox material model

The creation of Velox WSO 80 material model was done in 2 steps. In the first step the material was modeled as solid elements representing the cement “matrix” filled with large number of wooden beam elements. The second step was focused on applicability enhancement of this material model since the material model is meant to be used in a model of a vehicle restraint system.

In the first step the beam elements were modeled with standard material properties for spruce wood (bilinear material model). Then also the fact that in reality the wooden chips are bonded together with cement had to be reflected in the model. To model this connection the wooden beam elements were placed into solid elements and *CONSTRAINED_LAGRANGE_IN_SOLID condition was applied. To obtain as much as possible authentic distribution of the beam elements we also simulated the producing procedure of Velox boards. There was a rigid empty mold in the shape of small part of an actual Velox panel and the wooden elements were placed above this mold. During the simulation of producing process the wooden elements were let to fall into the rigid mold and they were subsequently pressed with a rigid surface. This configuration very closely reflected the structure of Velox material. The numerical models of specimens were afterwards prepared by modifications of the base sample.

Since the Velox material exhibited significant difference in tensile, bending and compressive loading a material model with different stiffness curves in tension and compression was used as an optimum solution - *MAT_PLASTICITY_COMPRESSION_TENSION.

Pic. 10: Numerical model of Velox material for basic tensile test

The set of measurements (quasi static standard tests as tensile, compressive and bending strength test and test with IZOD measurement device) was simulated and correlated with experimental results. During an optimization process (done in program optiSLang) we achieved satisfactory agreement with the experimental results.

In the second step of material modelling it was necessary to get rid of the beam elements because if they were used in the whole barrier, the model would consist of excessive number of elements which is beyond available computational capabilities. Therefore it was necessary to adjust the “matrix” material model in a way so the solid elements would be able to capture the behavior of Velox material even without the wooden beam elements. The created material model was able to sufficiently match experimental data in quasi static standard tests as tensile, compressive and bending strength test.

As a verification there was also dynamic drop test with Newton cradle principle performed for further material model check. During this testing a specimen is attached to a rod that hits another rod with prescribed velocity. At the moment of impact a specimen is deformed between the rods. The energy absorbed in a specimen can be simply evaluated by residual potential energy of a punch body. The residual velocities of both hitting rods from an experiment and simulation were compared resulting in maximum difference under 8% in velocity values.

The development of material model will continue with a punch test of a full-scale Velox panel which will serve as a final step in verification process of the Velox material model. Once the material model proves its reliability in this test it will be used to investigate behavior of the Velox barrier version in TB 81, TB 51 and TB 11 crash tests.

Conclusion

Numerical simulations utilizing LS-DYNA explicit solver were used to investigate crash tests of vehicles according EN 1317 against the road restraint system with integrated anti-noise wall. Numerical models of vehicles satisfying TB81 and TB51 level of the standard were built.

The simulations of TB 81 crash tests proved their reliability as the overall behavior of the vehicle and the restraint system and deflections of the barrier sufficiently corresponded with observations from real crash tests. Based on this agreement the simulations will be further used to predict behavior of cement-bonded wood-chip material (Velox) variant of anti-noise panels. This material was analyzed in set of static and dynamic experiments. The material model that sufficiently matched behavior in individual measurements was prepared. For further investigation a punch test simulation of a whole Velox panel will be performed and compared with experiment in order to prove reliability of the developed material model before computing full crash test simulations.

Acknowledgments

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