Numerical Simulations in Vehicle Restraint System Development

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1 Abstract

Since 2016 there has been a research project going on which is focused on development of new design of portable road barriers with integrated anti-noise walls. The key feature of the new barrier design is a material selection for anti-noise panels. New panels made of wood and cement-bonded wood-chip material called Velox significantly improve noise absorption properties of the barrier. However, the question is: what are their qualities from mechanical point of view? And will such barrier be able to withstand crash tests required by the highest containment level, H4b according to EN1317 standard? Numerical simulations are being utilized in this research at all levels in order to reduce costs and to predict how particular design modifications influence restraint capabilities of the barrier.

As a starting point there were crash test simulations with original barrier design performed and after achieving sufficient correlation between the simulations and the real crash tests, modified systems were designed and tested. Firstly, there were the new panels. From mechanical point of view, Velox is very complex material so an extensive investigation of its mechanical properties had to be performed. This investigation covered small scale tests (quasistatic and dynamic) and large scale dynamic tests as well. Based on the experiments there was an appropriate material model chosen and its parameters determined to faithfully describe behavior of the material. Since crash test simulations with the first Velox wall design identified several weaknesses, certain preventive measures had to be introduced. Besides design changes of the bottom part of the barrier, several kinds of Velox boards back face treatment were proposed in order to enhance resistance and keep overall integrity of the structure after crash load exposure. All these design changes are now being analyzed and further developed based on crash test simulations but also with regard to production processes and mobility of the barrier.

2 Introduction

Barriers for European Union traffic are categorized according to their containment level. In order to achieve certain containment level they must withstand a crash tests required by EN 1317 standard. Testing a barrier design which is aiming at the highest containment levels (H4b – barrier protecting against impact of 38-tonne articulated truck at 65 km/h) is naturally very costly and setting up a test site for such crash test requires a lot of time as well. For this reason numerical simulations have huge potential in the process of designing these barriers. Simulations are able to predict many crash test scenarios and based on them it is possible to avoid unsuccessful designs so using simulations in product development means considerable reduction of time and money expenses. Moreover analyzing results of simulations often inspires introduction of new improvements and preventive measures.

In this article there is a description of latest progress in the development of portable barrier with anti-noise wall. The aim of this development is to integrate cement-bonded woodchip material called Velox into the current design of the barrier. In the current design the panels of anti-noise wall are made of concrete. Main reason for integration of the new material is that Velox has very good noise absorption capabilities so using panels covered with Velox significantly improves overall noise absorbing performance of the wall.

Numerical simulations performed in LS-DYNA play a key role in this research and they are utilized at all levels. Setup of a FEM model of this complex event requires many measurements of material properties, vehicle behavior observations and many other experiments. Based on them FEM model parameters can be obtained in order to maximize its accuracy and reliability. On the other hand, there has to be noted that a perfect match between the numerical simulations and the experiments can never be 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.).

3 Barrier

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 an anti-noise wall.

Fig.1: Portable road barrier with integrated anti-noise wall

The basis of the barrier consists of concrete blocks (a single block is 4 m long and weighs up to 12 t depending on its width). 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 panels for the noise protection purposes. There are two basic types of panels:

a) Concrete anti-noise panels – made of two types of concrete
b) Velox anti-noise panels – made of wooden frame with Velox boards attached with screws

Width of the blocks and total height of the wall depends on particular barrier variant.

4 Crash test

European standard EN1317 prescribes crash tests which must be successfully passed in order to achieve certain containment level. Based on the containment level this barrier was aiming at, there was a focus on TB 81, TB 51 and TB 11 crash tests.

Crash test	Vehicle	Vehicle mass [kg]	Impact velocity [km/h]	Impact angle [°]
TB 11	Passenger car	900	100	20
TB 51	Bus	13 000	70	20
TB 81	Articulated truck	38 000	65	20

Table 1: Crash tests (EN1317)

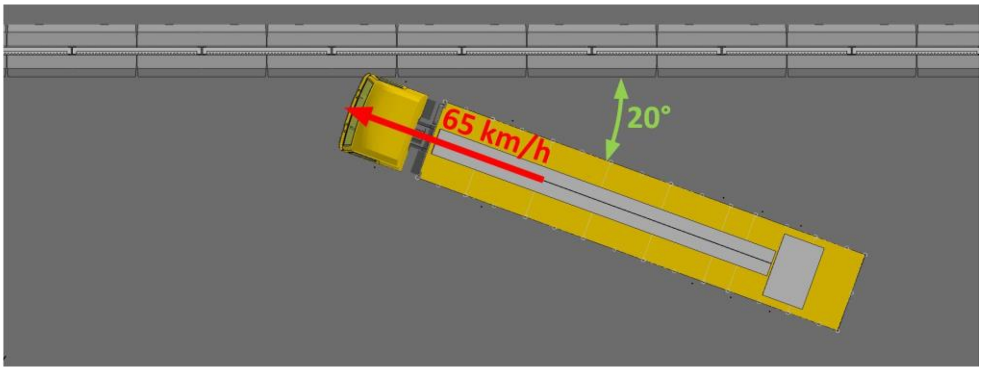


Fig.2: TB81 crash test scheme

5 Numerical model

5.1 FEM model of the barrier

FEM model of the barrier consists of more than 1000000 elements divided to 20 – 30 parts. There are solid elements used for concrete blocks and anti-noise wall panels, shell elements for steel pillars and beam elements for concrete reinforcement. The model covers an 80 m long stretch of the barrier (20 concrete blocks) and the ends are bonded in a manner which substitutes ongoing concrete blocks. Area of the impact is prepared in higher level of detail and its discretization is also finer.

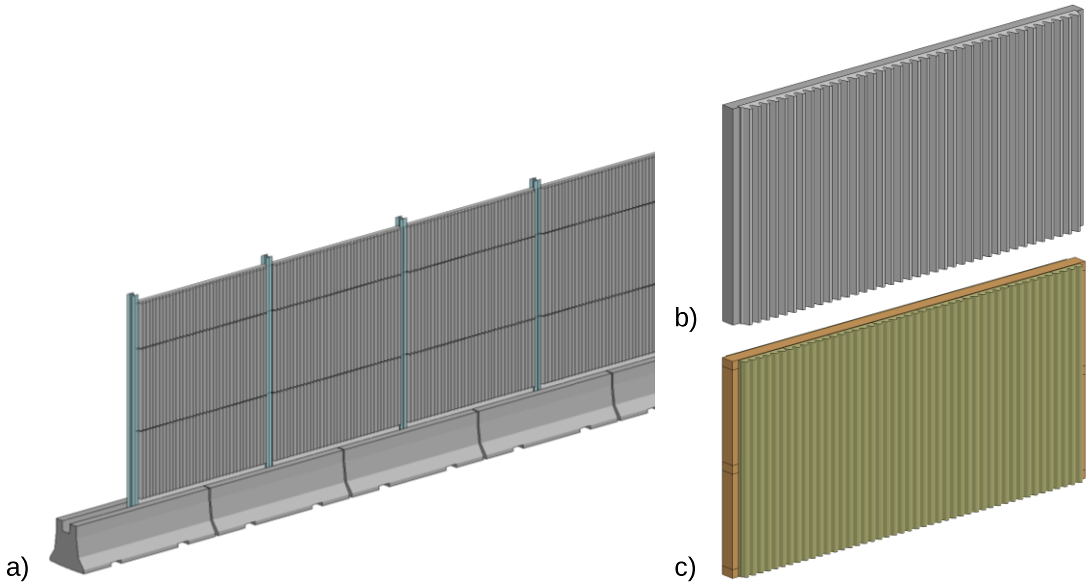


Fig.3: Barrier FEM model: a) whole barrier, b) concrete panel, c) Velox panel with wooden frame

5.2 FEM models of vehicles

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). Eventually major portion of the model had to be rebuilt and only a few parts from the original vehicle model 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. FEM models of a bus and a passenger car had to be made from scratch as no adequate models were available.

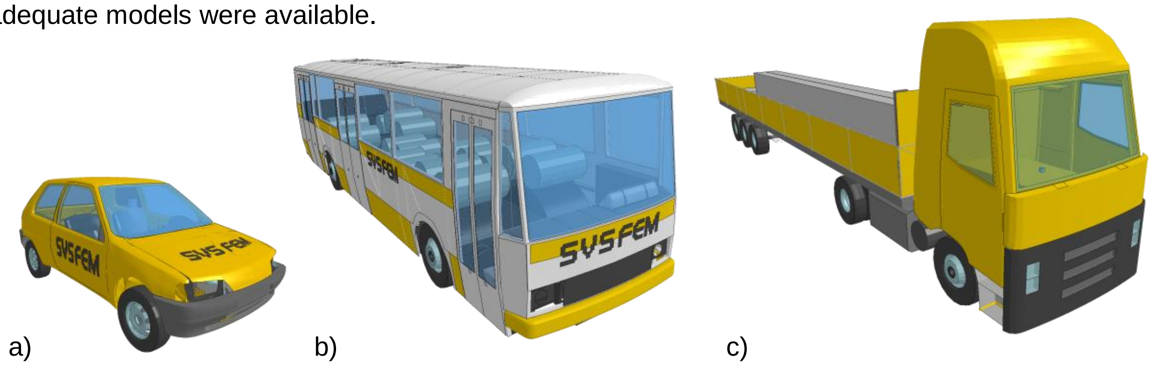


Fig.4: Vehicle FEM models: a) passenger car, b) bus, c) articulated truck

All created vehicle FEM models are being constantly further developed to provide as accurate and reliable results as possible. Along with the development the vehicle models are being assessed in various tests which are designed in accordance with CEN/TR 16303-1 Road restraint system (Technical report, Jan 2012):

a) Vehicle in idle
b) Linear track
c) Curb test
d) Full scale crash test

Aim of these tests is to point out unrealistic behavior and contribute to enhancement of the model and finally, to prove reliability and stability of the model.

Fig.5: Vehicle FEM model testing: Bus model curb test

6 Velox

Velox is a cement-bonded wood-chip material frequently used in civil engineering for noise absorbing purposes. For this reason it was chosen as a promising substitute for concrete at anti-noise wall. However, as a composite of wood and cement-based bonding matter this material represents very complex material from mechanical point of view. Therefore, description of its mechanical material properties and searching for appropriate material model and its parameters was very crucial part of this research.

Fig. 6: Velox material

The first step in this process was determination of its mechanical properties based on set of small scale tests. These tests covered: quasi static standard tests like tensile, compressive and bending strength tests as well as dynamic drop test and test with IZOD measurement device. Similarly to concrete materials, Velox exhibits very different behavior in tension and in compression. Eventually `*MAT_PLASTICITY_COMPRESSION_TENSION` accompanied by `*MAT_ADD_EROSION` was chosen as the most appropriate material model and its parameters were optimized in program OptiSLang in order to achieve the best correlation with all performed experiments. However, there was found that in dynamic tests the agreement between simulations and experiments was dependent on mesh size. This fact is caused by mesh size independent failure criteria. A combination of failure criteria of maximum principle strain and minimum pressure was chosen to ensure tension-compression dependent failure. For final fitting of the failure criteria, large scale tests were performed. Two kinds of dynamic large scale impact tests provided failure related experimental data and based on them the failure criteria of Velox material model were optimized in OptiSLang.

The first one of these impact tests includes two rigid bars parallel to each other (supporting a specimen) and another rigid bar with a weight of 89 kg (also parallel to the other bars) impacting the middle of the specimen (see fig. 8). The impacting bar with weight is guided as it falls so its movement is uniaxial with no rotations. Resistance of the specimen against the impact is measured as a force at the impacting bar. The second dynamic large scale impact test was a concrete ball impact test. During this experiment a concrete ball is dropped from given height, falls freely without any guidance and hits the specimen. The event of impact is recorded as a high speed video and amount of damage is observed.

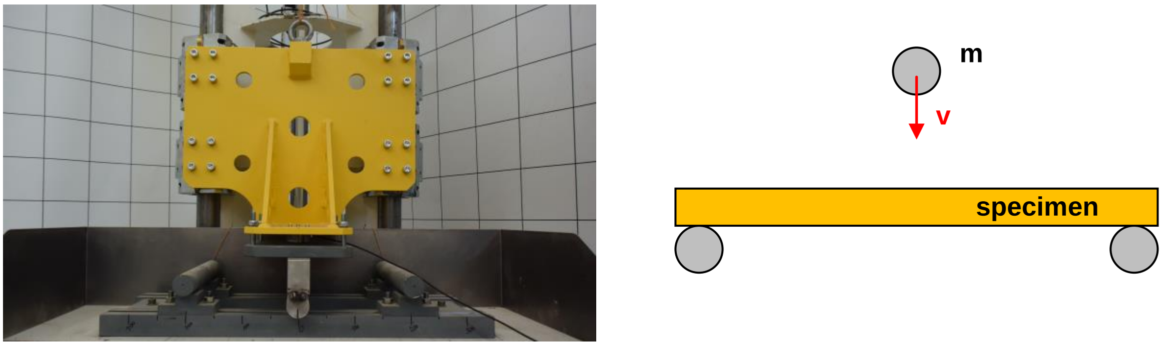


Fig.7: Bar impact test

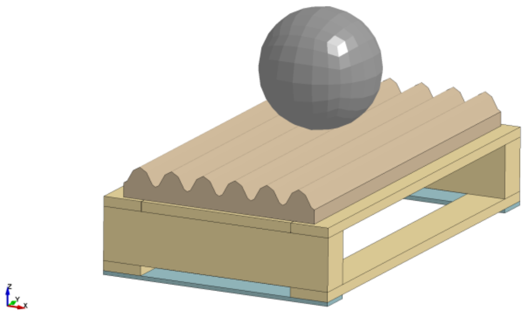
a)  b) 

Fig.8: Concrete ball impact test: a) experiment, b) simulation

7 Crash test simulations

7.1 Original barrier design

As far as full scale crash test simulations are concerned, simulations with original designs of the barrier (barrier with concrete anti-noise wall) were performed first. After sufficient agreement between the simulation and the real crash tests was achieved the research moved on to including various design changes.

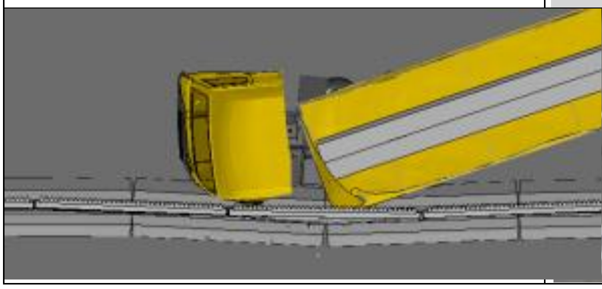
simulation	real crash test
	
	

Fig.9: TB81 crash test: simulation – experiment comparison

7.2 Barrier design with Velox panels

Simulation with panels consisting of wooden frames with Velox boards attached with screws revealed two problems. Firstly, it was a fatal failure of the pillar and secondly, it was an extensive fragmentation of Velox (see fig. 10). Since the compliance of the panels with wooden frame is significantly higher than the compliance of concrete panels, the penetration of right front corner of semitrailer was also significantly deeper. As a result, a pillar of the anti-noise wall was hit by the frame of semitrailer causing a fatal failure of the barrier. The simulations also revealed an unacceptable fragmentation of Velox panels after being hit by a vehicle. Even if the barrier as a whole withstands the vehicle impact, the fragmentation is still an important factor for final evaluation of crash test success. Therefore, to achieve success of the barrier it is necessary to avoid both of these problems.

With regard to production processes and mobility of the barrier, several preventive measures were suggested:

a) increasing stiffness of wooden frame
b) change of bottom concrete block dimensions
c) fabrics or polymer coating applied to the back face of Velox boards

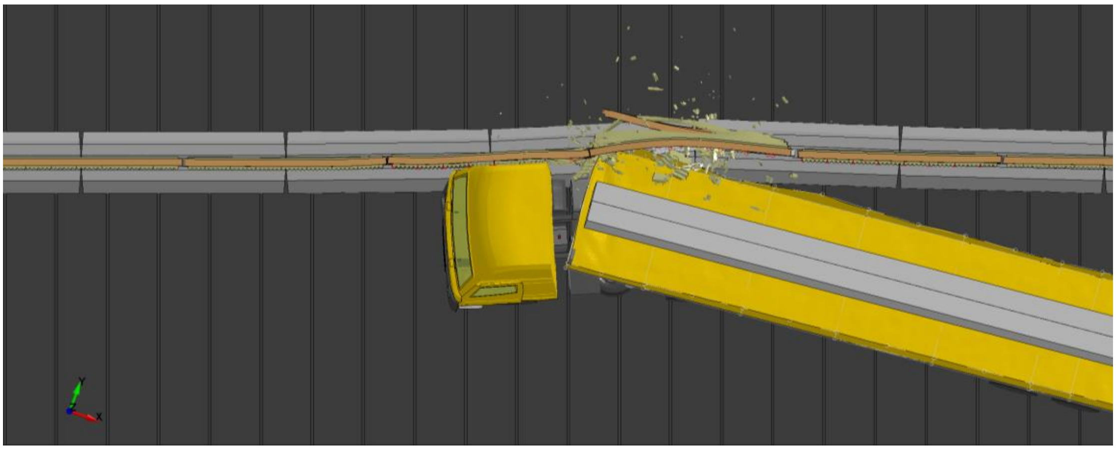


Fig.10: TB81 crash test: major failure of the barrier

Increasing stiffness of wooden frame was supposed to prevent semitrailer from penetrating barrier so deep that it hits the pillar. An extra wooden beam was added to increase the stiffness. However, simulation of the crash test showed that this preventive measure has very little effect on deflection of the panel and cannot prevent major failure of the barrier.

On the other hand, change of bottom concrete block dimensions turned out to be very promising. Increasing its height by 18% was enough to keep the corner of semitrailer from getting above the concrete blocks. Therefore, also penetration through the panels was prevented this way. The simulation revealed that the remaining issue - the fragmentation of Velox could be solved by increasing not only height but also width of the concrete blocks. However, combination of these two design changes causes significant increase of the mass, which is undesired for a mobile barrier.

Reduction of the amount of separated matter without unacceptable increase of mass could be also achieved by improving integrity of Velox boards. For this reason several kinds of fabrics and polymer coatings, which would be applied to the back face of the Velox boards, were proposed. Enhancement of impact resistance of Velox boards due to individual back face treatments was experimentally tested on bar impact test (see fig. 7).

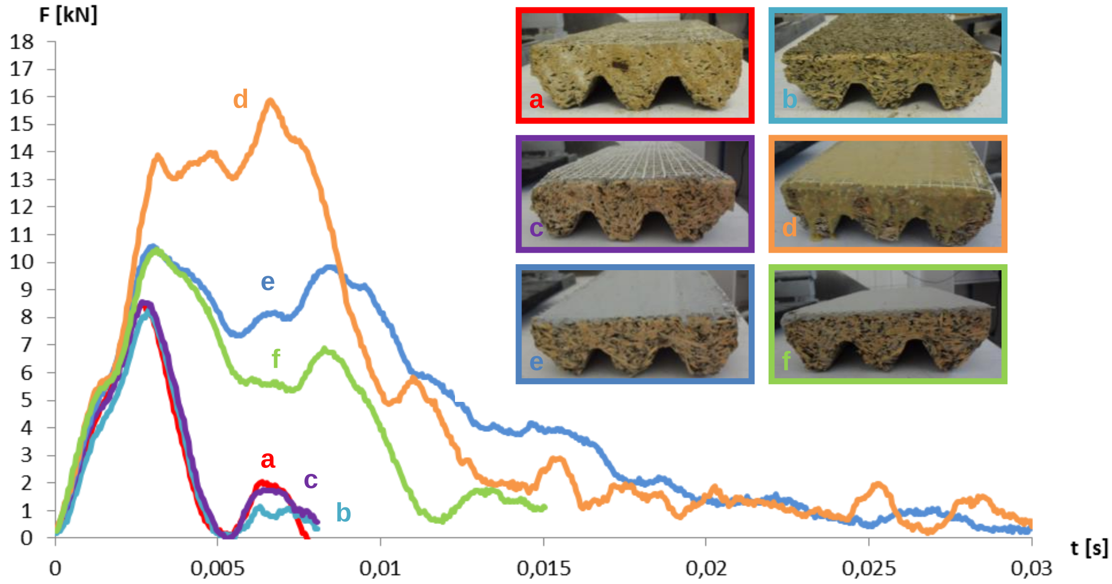


Fig.11: Impact resistance of proposed Velox back face treatments: a) Velox, b) Velox + epoxy glue, c) Velox + fiberglass mesh, d) Velox + fiberglass mesh + polyurethane resin, e) Velox + fiberglass mesh + polyurea, f) Velox + fiberglass mesh + common wall coating

Measured experimental data suggest that the best integrity of Velox panels could be achieved by applying fiberglass mesh with polyurethane resin to the back face of Velox. This treatment doubles maximum force that is necessary to break a specimen. The question is whether this enhancement is sufficient to prevent extensive fragmentation, which was observed in simulations of full scale crash test. In order to find out, it will be necessary to fit material behavior of this composition and to perform another crash test simulation.

8 Summary

This research focused on development of new design of portable barrier with anti-noise wall made of Velox receives benefits of numerical simulations at all levels. Besides simulations, another essential elements of the research are experimental measurements and observations which allow fitting of material models and behavior of vehicle FEM models. Due to comprehensive investigation of material properties of Velox (including static and dynamic, small scale and large scale tests) a reliable material model was developed. In the process of preparing full crash test simulation, three vehicle FEM models (TB81, TB51, TB11) were created and their behavior was tested. After achieving agreement between the simulations and the real crash tests with the current barrier design, the research proceeded to analyzing a barrier with Velox anti-noise panels. Simulation of TB81 crash test revealed two crucial weaknesses of the Velox version of the barrier. Firstly, it was a fatal failure of a pillar and secondly, it was an extensive fragmentation of Velox. As a countermeasure, several design changes were proposed and their effect was tested in the simulations. While reinforcing a Velox panel with an extra wooden beam turned out to be inefficient, increasing height and width of concrete blocks is a promising measure which can prevent both undesired effects. Also a back face treatment can be applied to the Velox boards as an anti-fragmentation measure. Experiments confirmed that Velox integrity could be significantly improved by a back face treatment but its effect in full crash test simulation is still a subject of future study. Subsequently, crash test simulations of categories TB51 and TB11 will be performed and analyzed as well.

9 Acknowledgments

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