

# Computational simulations of road safety barriers using LS-DYNA

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## Abstract:

One of the major tasks in road transportation is to assure an adequate safety level for road users. To maintain and improve road safety, it is often necessary to install certain devices on the road that are intended to restrain vehicles and pedestrians from entering dangerous areas. The road safety barriers, designed according to the European standard EN 1317, provide certain levels of vehicle containment, properly redirect errant vehicles back on the road and provide guidance for pedestrians and other road users. This paper describes computational modelling of the safety barrier design and its behaviour under H1 (car and truck) vehicle impact conditions according to the EN 1317. The impact severity and the stiffness of the safety barrier have been evaluated with the explicit dynamic nonlinear analysis of full-scale computational models using the LS-DYNA code. Additionally, full-scale crash tests were performed and the measured experimental data were compared with the computational results. From the result comparison a very good agreement can be observed, which validates and justifies the use of computational simulations for further development of road safety barriers.

## Keywords:

Road safety barrier, Computational simulations, LS-DYNA, Full-scale crash tests

## 1 Introduction

The road safety barriers, designed according to the European EN 1317 standard, provide certain levels of vehicle containment, properly redirect errant vehicles back on the road and provide guidance for pedestrians and other road users. To provide appropriate safety level for vehicle passengers the safety barriers should be designed to absorb as much kinetic energy of impacting vehicle as possible through their deformation and at the same time maintain their integrity. Practical observations of installed systems indicate that currently used safety barrier designs on public roads are inappropriate, since vehicles often overrun the restraint system or the level of vehicle decelerations is unacceptable. By adopting the European transportation legislation, it is necessary to re-evaluate the safety barriers and propose certain design changes. This requirement prompted a new research into ways how to redesign the road safety barrier in order to achieve more crash energy absorption during vehicle impact. Additionally, the research resulted in development of necessary vehicle models to cover all the containment levels according to the EN 1317. Computational simulations of the full scale safety barrier model with the car and truck impacts were carried out with the explicit finite element code LS-DYNA. The road safety barrier was also tested in full-scale crashes according to the EN 1317. The crash test results and the computational results were then compared. According to that verification and validation of the computational model were performed.

## 2 Roadside safety and road safety barriers

Roadside safety addresses an area outside of the roadway and is an important component of the total roadway design. From a safety perspective, the ideal highway has roadsides and median areas that are flat and unobstructed by hazards. Elements such as side slopes, fixed objects and water are potential hazards which a vehicle might encounter when it leaves the roadway. These hazards present varying degree of danger to vehicle and its occupants. Unfortunately, geography and economics do not always allow ideal highway conditions [1].

Road design in the future will increasingly focus on the safety of all users. Upgrading existing roads to higher safety standards, coupled with greater driver's awareness, will lead to significant savings in road trauma and crash costs. Road maintenance such as resurfacing to improve skid resistance will continue to be a priority [2].

To achieve the goal of making roads safer one has to consider three key areas:

- safer people: to encourage safe behaviour by ensuring that the drivers adhere to the speed limits, that they do not drive, if impaired by alcohol or fatigue, that all vehicle occupants are using seatbelts and that young drivers have adequate knowledge and supervision;
- safer vehicles: continuing improvements in vehicle safety with introduction of advanced active and passive safety devices continues to be a priority in automotive industry. Current developments in vehicle engineering ensure that all systems within a vehicle are combined to provide optimum safety levels;
- safer roads: to lower the speed limits, to build and maintain better and safer roads, to improve safety barriers, to build traffic priority systems to ensure quicker responses by emergency services. Current improvements in road building legislation ensure that all new roads are built to the most stringent safety standards.

The road safety barriers installed on European highways have to fulfil the EN 1317 standard in terms of the impacting vehicle containment level, the level of expected vehicle occupant decelerations during impact and the consequent barrier system deformation [3]. The standard prescribes criteria which the safety barrier has to fulfil under specific impact conditions.

There are many different parameters that have to be taken into account when a vehicle collides with the safety barrier: vehicle velocity ( $v$ ), vehicle mass ( $m$ ), impact angle ( $\alpha$ ), type and behaviour of a vehicle and road conditions.

The safety barriers have to sustain impact of different vehicle types (from passenger cars to trucks) under different impact conditions regarding the vehicle velocity, impact angle and road conditions. In case of a lower-weight vehicle (car) impact, the restraint system should possess the ability to deform, so that the kinetic energy of an impact is absorbed mostly by the barrier and vehicle deformation. This significantly reduces deceleration levels experienced by vehicle occupants and increases their safety. However, in a case of higher-weight vehicle (truck, bus) impact, the system should contain and redirect the vehicle back on the road without complete failure of the main longitudinal elements of the system. Thus, the safety barrier design is a compromise between its deformability (stiffness) and strength.

The road safety barriers have to fulfil the following criteria according to EN 1317-2:

- containment level - represents the level of containment for different types of vehicles (Table 1). The standard defines four major classes of containment levels (low, normal, higher and very high containment), which are further subdivided (T1 ... H4b);

Table 1: Different types of tests according to EN 1317

Test	Vehicle type	Vehicle mass [t]	Impact angle [°]	Impact velocity [km/h]
TB 11	Car	0.9	20	100
TB 31	Car	1.5	20	80
TB 32	Car	1.5	20	110
TB 42	Truck	10.0	15	70
TB 51	Bus	13.0	20	70
TB 61	Heavy goods vehicle	16.0	20	80

- impact severity - a measure of impact consequences for the vehicle occupants. Three measures are used: the acceleration severity index (ASI), the theoretical head impact velocity (THIV) and the post-impact head deceleration (PHD);
- deformation of the barrier – a working width of the barrier (Figure 1), which is a distance between the side of the guardrail facing the traffic before the impact and the maximum lateral position of any major part of the system during the impact. There are eight classes of deformation of the road safety barrier (W1 ... W8).

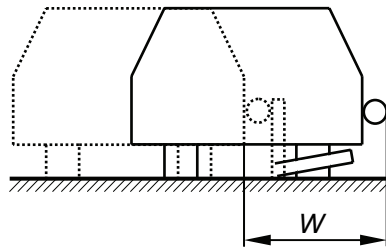


Figure 1: Working width ( $W$ ) of the road safety barrier

Average vehicle impact severity is usually measured with the maximum acceleration severity index (ASI). ASI is a measure of vehicle accelerations during impact, which is evaluated over a moving interval of 50 ms and normalised with allowable accelerations in all three longitudinal vehicle axes. If maximum ASI value exceeds 1.0 or 1.4 in some cases, then it is considered that the impact consequences for the passengers are dangerous or even lethal.

### 3 Description of used computational models

The computational model for safety barrier crash test simulations consists of the barrier and vehicle models. The barrier parts are modelled in compliance with their design using necessary simplifications. The vehicle models are purposely developed or can be retrieved from publicly accessible vehicle libraries, like the National Crash Analysis Center [4].

#### 3.1 The vehicle models

The initial finite element (FE) vehicle models for tests TB11, TB32 and TB42 (Figure 2) originate from the public library of the National Crash Analysis Centre. Later the vehicle models were subjected to certain changes to fulfil the EN 1317 standard regulations. On the impact side of the vehicles the density of the finite element mesh was increased to improve the contact behaviour between the vehicle and the barrier. A rigid shell element was added at the vehicle gravity centre to act as an accelerometer and to record the kinematic quantities in the vehicle local coordinate system. The vehicle wheels were modified to enable their rotational movement, which is very important during vehicle impact, since the vehicle wheel is in direct contact with the barrier. The wheel tire was modelled using LS-DYNA airbag model with internal pressure [5]. To fulfil the weight regulations of the EN 1317 the mass of the vehicles was also adapted to the required values.

The vehicle models for tests TB51 and TB61 (Figure 2) were developed purposely. The chassis of both models is based on slightly reinforced chassis of the TB42 model. The TB51 vehicle is a 8 ton bus, which is 12.0 m long, 3.0 m high and 2.6 m wide. Additional mass of 5 tons is added to simulate the passengers in the vehicle. Two wheels are attached to the front axis while four are mounted on the rear axis. The FE model is made of approximately 44000 linear Belytschko-Tsay shell elements with reduced integration scheme [6].

The TB61 vehicle model is a 16 ton heavy goods vehicle. The model is built using the data of the Liaz 110052 truck actually used in testing, which is 8.5 m long, 2.9 m high and 2.4 m wide. The configuration and the number of wheels and axis is the same as for the TB51 model. The model of this vehicle consists of approximately 32000 linear elements with reduced integration scheme. 1000 of those are solid elements, 500 are beam elements and the rest are the Belytschko-Tsay shell elements.

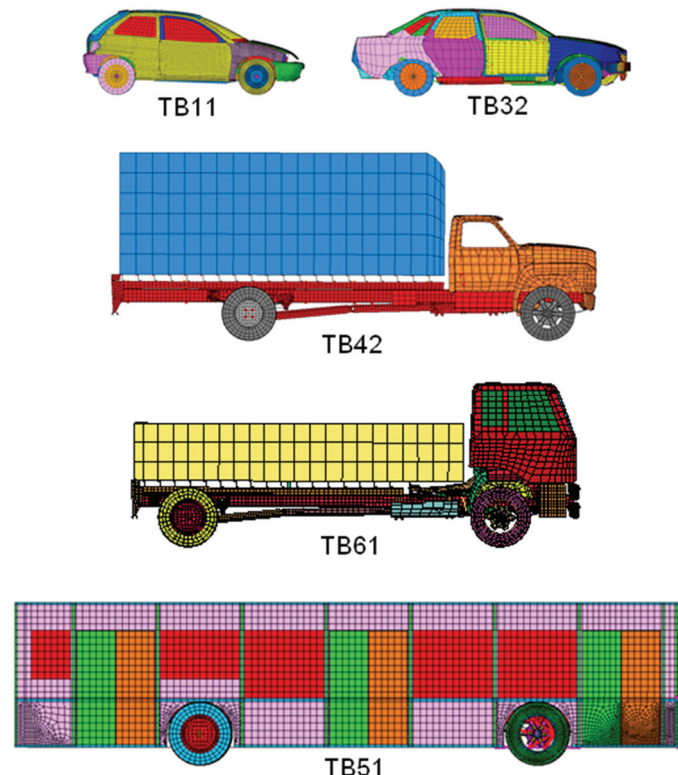


Figure 2: The vehicle models used in computational simulations

### 3.2 The safety barrier models

The main safety barrier parts, guardrail, posts, distant spacers and wheel guidance profile (Figure 3) are modelled in detail, while the bolt connections are represented with special beam elements. The required length of the modelled safety barrier depends on the type of the test. The barrier length for the TB11 test is 24 m while the barrier length for the TB42 test is 38 m. The vehicle impact point position is set to 8 m by the TB11 test and to 12 m by the TB42 test measured from the start of the barrier.

Full – integration shell elements with 5 integration points through thickness were used to model barrier parts which are exposed to impact loading to prevent hourglassing [6], while the Belytschko-Tsay shell finite elements with 3 integration points through thickness were used for other parts of the safety barriers to reduce the computational time. Bolt connections were modelled using linear Hughes-Liu beam finite elements or spot-weld constraints with failure criteria based on filtered forces.

Material properties of different sheet metal thicknesses were obtained experimentally and were modelled with the isotropic piecewise linear plasticity model [7, 8]. Material failure was introduced by defining the ultimate effective plastic deformation. Due to high dynamic loadings, the material models employ kinematic hardening and Cowper – Symonds strain rate dependency [6, 7, 9].

Beam element parameters for bolt connections are obtained by combination of experimental measurements and numerical simulation. The same bolt connection is first experimentally tested with a simple tensile test and afterwards parametrically simulated on the computer. The experimental and

computational results are matched so that the deformation of the whole bolt connection and the surrounding material is correctly represented by beam material parameters [10].

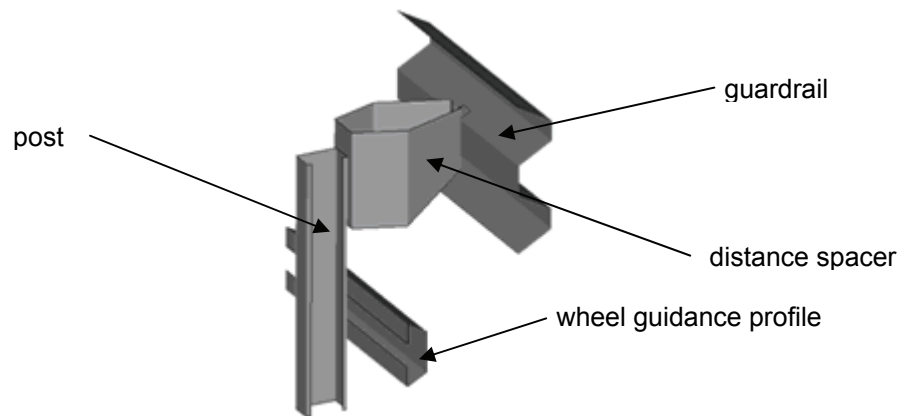


Figure 3: Main barrier parts

### 3.3 Boundary conditions and contact description

The initial conditions for the impact vehicle are prescribed by the EN 1317 norm in form of the initial vehicle velocity and its impact angle (Table 1).

Continuations of the guardrail and wheel guidance profile were modelled with spring elements (position 1 on Figure 4) with linear elastic properties and appropriate stiffness. The soil influence is simulated by using the spring elements (position 2 on Figure 4) with elastic-viscoplastic characteristic varying with depth. Appropriate material properties were determined from performed measurements and previous parametric simulations [7, 8, 10]. The number of used spring elements and their cross-sections are adapted to the length of the rammed post profile.

It is necessary to define four different contact regions: contact between the safety barrier parts, between the vehicle parts, between the impact part of the vehicle and the barrier and between the vehicle wheels and the ground. The static and dynamic friction coefficients are set in respect to the materials in contact.

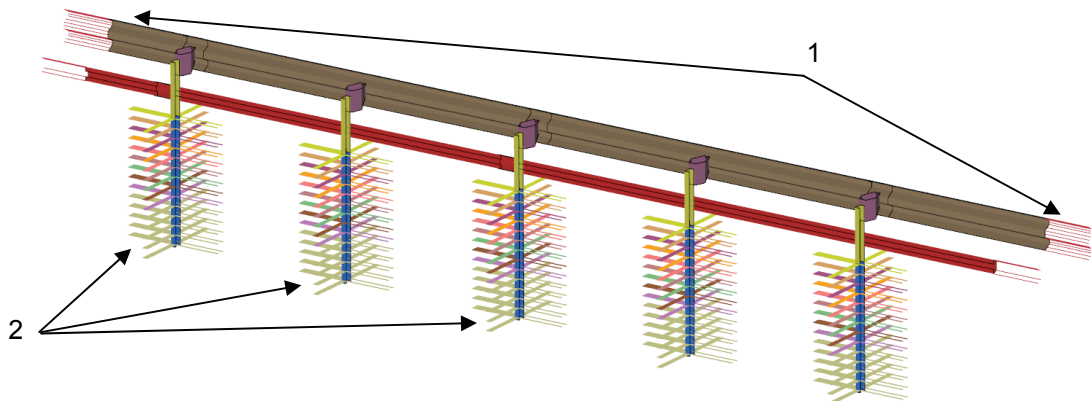


Figure 4: Boundary conditions of the road safety barrier model

### 3.4 Dynamic analysis parameters

The analyses of crash simulations were performed by using the MPP LS-DYNA Version 971 running on a PC cluster with Pentium IV 3.2 GHz processors. Each simulation employed eight cluster nodes since this configuration proved to be the most efficient [11]. The simulations are performed until the vehicle separates from the safety barrier and leaves the prescribed exit box.

#### 4 Comparison between the simulation and the large scale crash test

The impact severity parameters, which represent the effects of the impact on the vehicle passengers, were evaluated with the TB11 test while the strength and the maximum deformation (working width) of the safety barrier for the containment level H1 were determined with the TB42 test. Both simulation and experiment showed that all severity parameters evaluated from the TB11 test are below the prescribed limit values and that at the same time the safety barrier is strong enough to retain and redirect the truck (TB42 test) back on the roadway.

Figure 5 shows the deformation of the H1 safety barrier during the TB11 large scale test and experiment. The computational and experimental result comparison at four time sequences during the impact shows a very good agreement of barrier deformation and car behaviour.

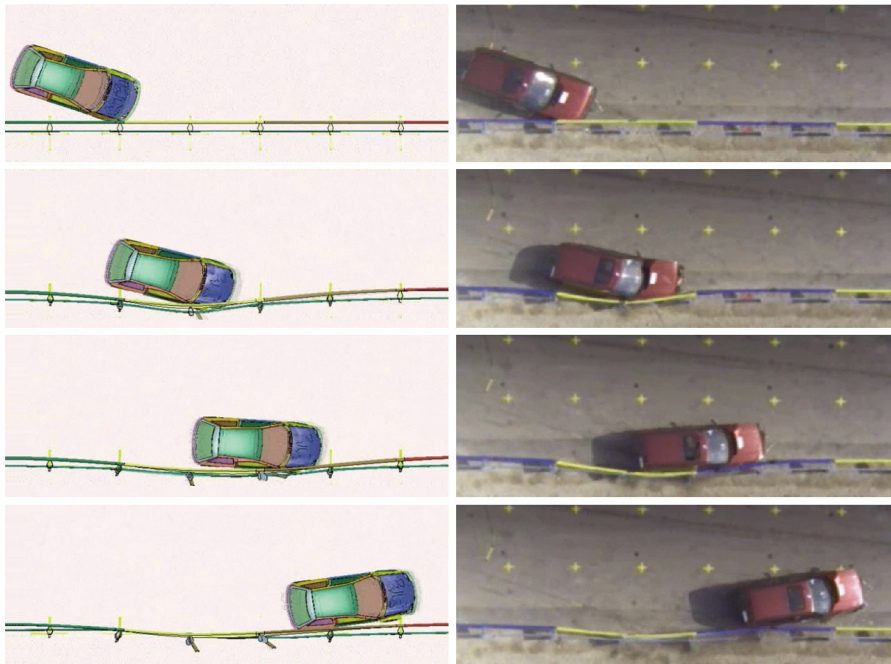


Figure 5: The barrier deformation during TB11 test (left – simulation; right – experiment)

All three impact severity parameters are calculated from accelerations measured in local coordinate system of the car. The most representative parameter is dimensionless parameter ASI – acceleration severity index, since it is calculated from all three normalized accelerations. The time dependency of the ASI parameter for the TB11 test is presented in Figure 6.

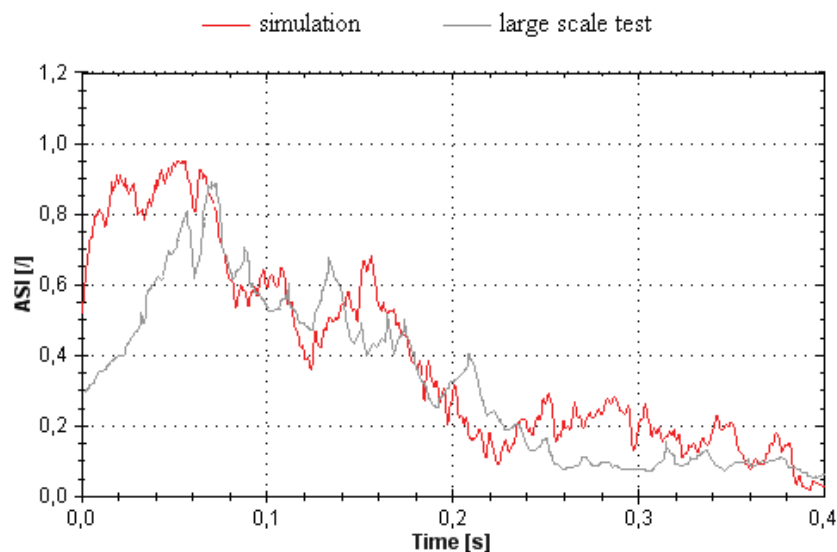


Figure 6: Time dependency of the ASI parameter



Differences are larger at the beginning of the car impact where the simulation predicts higher ASI values. This could indicate that the predicted stiffness of the ground or the impact side of the car was too high during initial simulation stages. The maximum ASI value calculated from the simulation and experiment equals  $ASI_{max,s} = 0.96$  and  $ASI_{max,e} = 0.85$ , respectively. The absolute and relative difference equal  $\Delta a = 0.11$  and  $\Delta r = 7.72\%$ , respectively. Despite the greater sensitivity of accelerations to not fully constrained experimental parameters [10], the results of the simulation and of the experiment differ inside acceptable  $\pm 10\%$  margin.

The barrier deformation and vehicle behaviour during the TB42 test is shown in Figure 7. The maximum deformation was observed at time  $t = 0.9$  s. The vehicle separated from the barrier at time  $t = 1.4$  s. Computationally estimated working width of the chosen barrier equals  $W_s = 1.71$  m. Experimental measurements during the full scale crash test returned the working width of  $W_e = 1.82$  m. The absolute and relative differences are only  $\Delta a = 0.11$  m and  $\Delta r = 6.0\%$ , respectively. Both working widths place the safety barrier in the W6 working width class ( $1.7 \text{ m} < W < 2.1 \text{ m}$ ).



Figure 7: The barrier deformation during TB42 test (top – experiment; bottom – simulation)

## 5 Conclusions

Computational nonlinear explicit dynamic analyses were employed for evaluation of the road safety barrier behaviour under H1 test vehicle impact conditions. The design of the tested safety barrier assures controllable deformation and high crash energy absorption which in turn decreases the decelerations of an impact vehicle and consequently increases the safety of vehicle passengers. Computational simulation predictions have been compared with the results of the full-scale crash test. Comparison of computational and experimental results proved the correctness of the computational model, which can be easily applied for prediction and evaluation of other road safety barriers in order to reduce the required number of expensive full-scale crash tests.

## 6 References

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