



HAL
open science

Development of a W-Beam Guardrail Crashing Model by Considering the Deformations of Components

Gengjian Qian, Michel Massenzio, Mohamed Ichchou

► **To cite this version:**

Gengjian Qian, Michel Massenzio, Mohamed Ichchou. Development of a W-Beam Guardrail Crashing Model by Considering the Deformations of Components. 5th International Conference on Mechatronics and Control Engineering, Dec 2016, Venise, Italy. pp.42-46, 10.1145/3036932.3036939 . hal-04250001

HAL Id: hal-04250001

<https://hal.science/hal-04250001v1>

Submitted on 24 Oct 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Development of a W-Beam Guardrail Crashing Model by considering the Deformations of Components

Gengjian Qian

UCBL1,IFSTTAR,LBMC,UMR_T9406
GMP-IUT Lyon1, 17 Rue de France
69627, Villeurbanne, France
+33 7 81 81 57 19
qgjian000@gmail.com

Michel Massenzio

UCBL1,IFSTTAR,LBMC,UMR_T9406
GMP-IUT Lyon1, 17 Rue de France
69627, Villeurbanne, France
+33 6 32 63 64 44
michel.massenzio@univ-lyon1.fr

Mohamed Ichchou

École Centrale Lyon,LTDS,UMR5513
36, Avenue Guy de Collongue
69134, Ecully, France
+33 4 72 18 62 30
mohamed.ichchou@ec-lyon.fr

ABSTRACT

The subject of this investigation is to develop an accurate low calculation cost Finite Element (FE) model of vehicle impacting roadside safety structures. A W-Beam Guardrail of containment level N2 has been tested under TB32 test conditions by following European Norm EN1317 [1]. Full numerical simulations of such crashing models are usually of high calculation costs, the major issues for model simplification used and presented in this paper including: Continuation reduction of guardrail ends; Soil surrogate modelling; Bolted joints simplification; Meshing and Elements definition. By simplifying the small deformation components and detailed modelling of the parts which are exposed to impact loads, the crash test of the guardrail are simulated efficiently and accurately.

CCS Concepts

- General and reference → General conference proceedings
- Computing methodologies → Model verification and validation
- Applied computing → Computer aided design

Keywords

Guardrail; Structural Dynamics; Crash tests; Finite Element Simulation; LS-DYNA

1. INTRODUCTION

Roadside guardrails are specially designed to restrain an errant vehicle by dissipating or absorbing the impact energy and redirecting the vehicles to reduce impact severity. Crash test is commonly associated to the development of new device. The real installation conditions of guardrail and guardrail impact situations are innumerable. Standards such as EN1317 [1] for Europe and NCHRP [2] for the United States define the containment level of guardrails and the relative standardized test conditions and criteria. But crash test provides a view of the performances of the device of only one set of parameters, one cannot know how robust the design is because the repetition of crash test is economically infeasible and the system uncertainties (such as uncertainty of material mechanical properties, tolerance of manufacture, etc.) cannot be controlled in experimental tests. Numerical simulations utilizing nonlinear FE analysis tools (such as program LS-DYNA [3]) allow the evaluation of the robustness of a device taking into account all variations of uncertain factors

and realize the optimization of the structure. Model parameter studies such as sensitivity analysis [4] and robust optimization require large number of model runs, the main objective of this study is to create a low calculation cost FE model that can accurately simulate guardrail crashing test. The modelling of the roadside guardrail as well as of the vehicle demands for great accuracy and high skills. By dividing the complex structure into simple subsystems, multibody-system modelling has been used for guardrail simplifications [5]. A. Tabiei and J. Wu [6] summarized the three major issues for guardrail modelling including: bolt connections, soil-post dynamic interaction and effect of guardrail ends. Bolted joints were simulated by modelling the slotted holes and pre-loaded bolt & nut in [7-9] for detailed analysis, while spotweld or discrete elements were used for joints connection simplification in [5, 6,10]; soil solid material for roadside safety equipment simulation has been developed [11] and solid elements were used to simulate soil in guardrail crashing test model [8, 9], spring elements were used for soil modelling in [12, 13]; Continuations of the guardrail were modelled with spring elements to reduce the guardrail length in [6, 12, 13].

2. Guardrail crashing simulation

2.1 Guardrail performances criteria

The guardrail shall contain the vehicle without complete breakage of any of the principal longitudinal elements of the system. The vehicle shall not pass over/under the guardrail or roll over during impact. Quantitative performance criteria of the device include [1]:

Impact Severity Criteria

- Acceleration Severity Index (*ASI*) --- the maximum acceleration weighted in the three directions at the mass center of the vehicle;
- Theoretical Head Impact Velocity (*THIV*) --- The occupant is considered to be a freely moving object (head) that, as the vehicle changes its speed during contact with the safety feature, continues moving until it strikes an inner surface of the vehicle with the velocity *THIV*.

Deformation Criteria

- Working width (*W*) --- the distance maximum between the traffic face of the non-deformed guardrail and the lateral position of any part of the system during impact;

- Dynamic deflexion (D)--- maximum lateral dynamic displacement of the side facing the traffic of guardrail (see Fig.1).

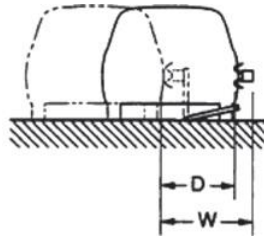


Figure 1 Guardrail deformation measure

2.2 Guardrail modeling& simplification

A W-Beam steel guardrail of containment level N2 (Fig.2) was tested under TB32 test conditions [14]. The tested device is composed with the W form beam Rail, Spacer, C form support Post. Both Post-Spacer and Spacer-Rail are connected with one single bolt and two Rails are connected with 8 bolts. A BMW 520i vehicle of 1431 kg was used in the test. The guided vehicle struck the device at a controlled, stabilized speed of 113.6kph, at an angle of 20°.

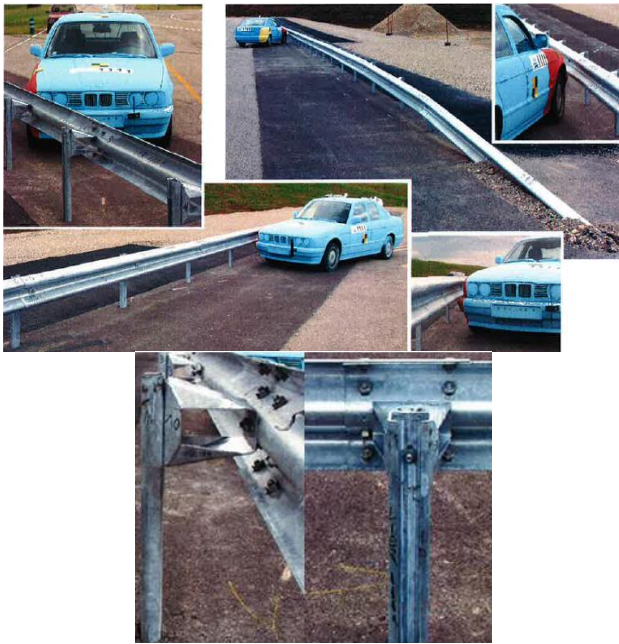


Figure 2 W-beam guardrail tested in [14]

Although a tested roadside guardrail may hundreds of meters in length and the vehicle used may contain thousands of components, only the parts which are exposed directly to impact loads are of remarkable deformations and should be modelled in detail. Considering components deformation magnitude, the crashing test was modelled and simplified as follows:

1) Meshing and Elements definition: Reduced vehicle model composed of shell elements was used for crashing simulation and guardrail components were modelled with coarse mesh. To ensure the accuracy of simulation, the mesh of guardrail and vehicle parts which exposed to impact loading and of large deformations were refined and defined by full – integration shell elements, while the Belytschko-Tsay shell were used for other shell parts. The meshes

of vehicle and guardrail components are illustrated in Fig.3 and Fig.4.

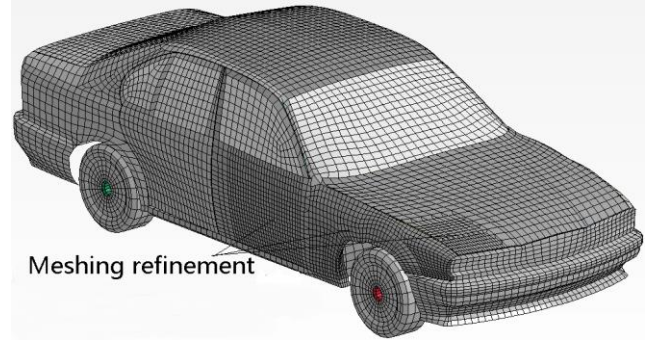


Figure 3 FE model of vehicle

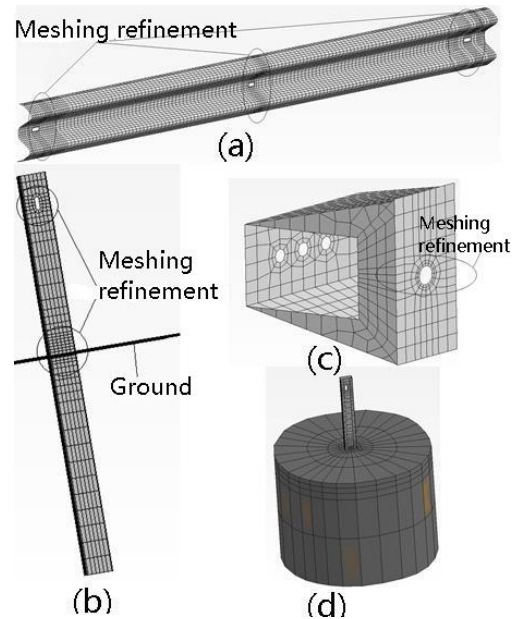


Figure 4 Guardrail components meshing: (a) w-rail; (b) support post; (c) spacer; (d) post fixed to soil foundation

2) Continuation reduction of guardrail ends: The length of the guardrail tested shall be sufficient to demonstrate the full performance characteristic of any longer installation. The tested device contains 21 Rails and is 84m in length with two ends fixed to the ground. In fact, only the 7 Rails in the middle of the device were deformed after crashing test according to report [14], and the rails at two ends serve to apply boundary constraints. In the numerical crashing simulation, 9 rails (7 rails with large deformations and the connected two rails) and the related posts, spacers were modelled. Continuations of the guardrail at ends are modelled with springs (see Fig.5 (a)). Different from [6, 12] who define springs with linear elastic properties by supposing its stiffness proportional to young Modulus, section area and inversely proportional to length of the replaced parts. The omitted guardrail parts were modelled to characterize mechanical properties of the spring elements (see Fig.5 (b)(c)): One end of the omitted guardrail was fixed and the other end was loaded with a time dependent force, the relations between loaded force and the displacement at the loaded end were measured, which defines spring stiffness in the crashing test guardrail model. 33 spring elements were used at each ends to define boundary constraints of guardrail and spring stiffness is illustrated in Fig.6.

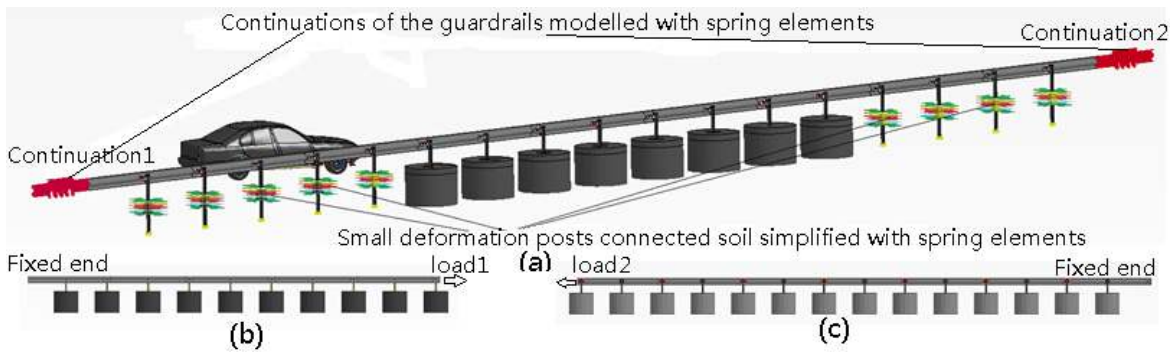


Figure 5 Numerical guardrail crash model: (a) simplified crash model; (b) Continuation 1 spring elements characterization; (c) Continuation 2 spring elements characterization

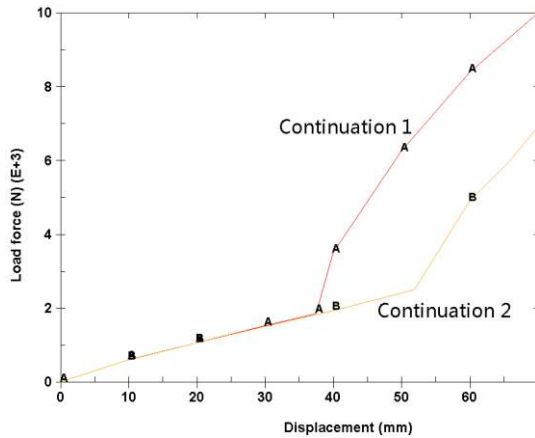


Figure 6 Spring characterization at two ends of guardrail

3) Soil surrogate modelling: Posts in the middle parts of guardrail were of large deformation and their connected soil were modelled with solid elements of cylinder shape to simulate the interactions of Post and Ground in detail (see Fig.4 (d)). The other soil parts were simplified by spring elements (see Fig.5 (a)). With elasto-viscoplastic characteristic varying with depth, appropriate material properties of spring elements were determined from performed parametric simulations. Comparing to previous studies who simulate the soil with only solid elements or spring elements [8,9,12,13], the combination of the two forms modeling of soil ensure simulation accuracy and decrease calculation cost.

4) Bolted joints simplification: rails, spacers and posts were connected with bolts, and connection failures are illustrated in Fig.7. After the crashing test, Rail-Rail bolts connections remained solid and the slippage between two rails was negligible, bolts Rail-Rail connections were simplified with high-strength spring elements in the numerical model; Both Post-Spacer and Spacer-Rail were connected with single bolt-nut, and the connection failure was the bolt pull-out from spacer slotted hole of the Post - Spacer connection (see Fig.7). To simulate the real connection conditions of Post-Spacer and Spacer-Rail, slotted holes were modelled (see Fig.4); bolts-nuts were modelled with rigid shell elements and connected with spring elements for Post-Spacer and Spacer-Rail connections in numerical model. The bolts connection failure in numerical simulation is illustrated in Fig.8. Rail-Rail connections were simplified; Components displacement freedoms (rail, spacer rotations, slip of slotted hole between the post and spacer and the horizontal slip of the slotted hole between the guardrail and the spacer) were respected and the

connection failure of bolt pull-out from the hole has been well modelled. The modelling of bolts connections are shown in Fig.9.



Figure 7 Bolts pull out failure of post - spacer connection [14]

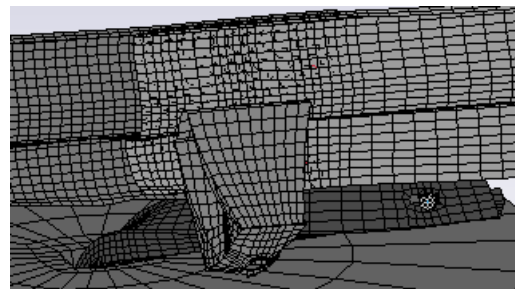


Figure 8 Bolts pull out failure simulation

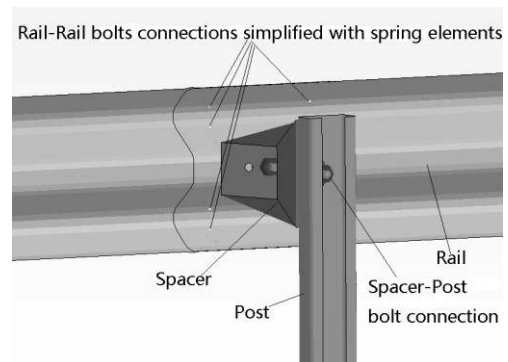


Figure 9 Guardrail modelling: rail, spacer, post and bolts

2.3 Model validation

Vehicle and VRS experimental crash test and simulation procedure is illustrated in Fig.10, with the crash begins at $t=0s$.

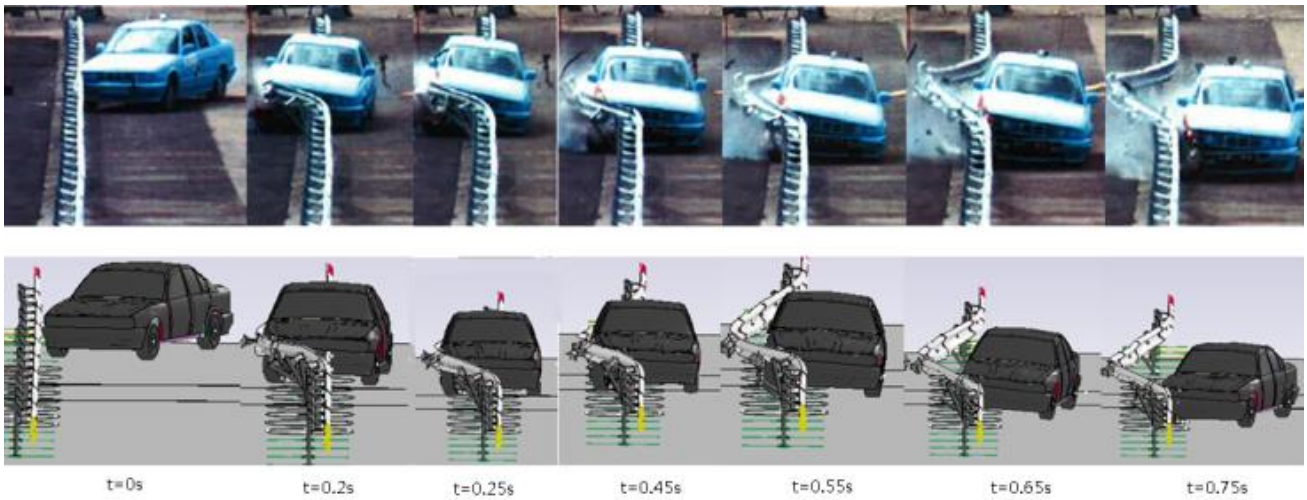


Figure 10 Guardrail crash test [14] & simulation

Vehicle was redirected by the barrier and the vehicle was parallel to the barrier at impact time $t=0.25s$, with about three-quarters of the vehicle invade into the barrier; The barrier restrains the vehicle on the road and about half the vehicle body invaded into the barrier at $t=0.45s$; The numerical model has simulated precisely the major procedure of crashing test, but from $t=0.55s$, the differences between experimental test and simulation analysis were more and more obvious. These differences were caused mainly by the defects of the vehicle model. Vehicle FE model was more rigid than the tested vehicle: After the impactation, the right front wheel was detached from the vehicle body and the tire was broken; while in the numerical simulation, the right front wheel rest connected to the vehicle body and no damage was detected to the tire (see Fig.11). Right front wheel of the vehicle was in direct contact with the guardrail support post at $t=0.55s$ (see Fig.12), and the defects of the vehicle in rigidity affect guardrail deformations and vehicle trajectory after $t=0.55s$. However, the criteria of main interest - *ASI*, *THIV*, *W* and *D* - were measured before $t=0.55s$ and they were very good matched to the measured values in the experimental test (see Table 1).



Figure 11 Vehicle after crash tests [14] and numerical model

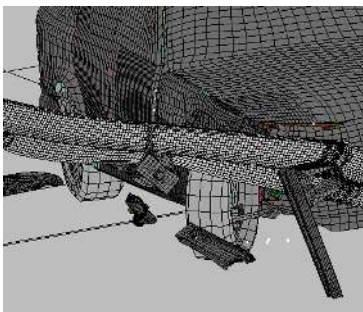


Figure 12 Right front wheel contact with post at $t=0.55s$

Table 1. Comparison of test results and simulation results

	<i>ASI</i>	<i>THIV</i> [km/h]	<i>W</i> [m]	<i>D</i> [m]
Test	0.8	24	1.5	1.2
Simulation	0.8	22	1.5	1.2

Energy distributions during crash simulation are illustrated in Fig.13. Thanks to the roadside guardrail, about 66% of total energy was absorbed by vehicle & guardrail deformation (curve C). By redirecting and restraining the vehicle on the road, more than 20% of vehicle kinetic energy remained after the crashing process (curve B). 12% of total energy was dissipated in sliding contact (curve D). Spring elements were used to simplify the crashing model, low value of spring & damper energy (curve E) demonstrates the rationality of our simplification. Model parts with remarkable deformations were simulated with full – integration elements and hourglass energy (curve G) added to small deformation parts is negligible comparing to internal energy.

Almost all the kinetic energy will be converted into vehicle internal energy in a short time when vehicle collides with rigid fixed objects (trees or rocks on the roadside for example). The roadside guardrail has well dissipated kinetic energy and extended the collision time, which largely reduced the impact severity.

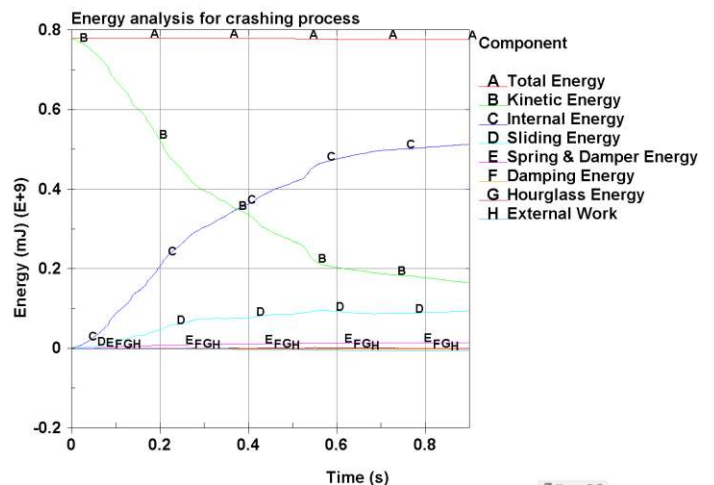


Figure 13 Energy distributions during crash analysis

3. Conclusions

Considering the deformation magnitudes of components in crash experiment, the numerical guardrail crash test model was simplified in these major issues:

- Reduced model with mesh refinement for parts of remarkable deformation;
- Boundary constraint applications for guardrail continuations at two ends with spring elements;
- Soil detailed modelling with solid elements for parts of evident deformation and its replacement with spring elements for others soil parts.
- Bolted joints simplification for Rail-Rail connections and detailed modelling for Post-Spacer and Spacer-Rail bolt connections considering magnitude of deformations and components degree of freedom.

Different from full modelling for guardrail crash test which may need days of simulation time, the simplified model simulate guardrail crash in 7 hours with a regular PC; Validated by experimental test, the simplified model is of good accuracy; More efforts are needed for vehicle wheel and tire modelling to predict vehicle trajectory during crashing test, but these defects have little influence on guardrail performance evaluations.

4. ACKNOWLEDGMENTS

This work is financed by the ‘China Scholarship Council’ under Certificate No. 201304490005, part of PhD thesis research at ‘Univ Lyon, Université Claude Bernard Lyon 1, IFSTTAR, LBMC UMR_T9406, F69622, Lyon, France’. Experimental crash test of roadside guardrail was carried out by TRANSPOLIS. Prof. D. Brizard from LBMC and Dr. C. Goubel, ex-researcher of TRANSPOLIS proposed useful suggestions for the research.

5. REFERENCES

[1] *EN 1317: Road restraint systems—Part 1: terminology and general criteria for test methods; road restraint systems—Part 2: performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets*. European standard, AFNOR, September 2010 ISSN 0335-3931.

[2] Ross, H., Sicking, D., and Zimmer, R. 1993. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. NCHRP Report 350. Transportation Research Board, Washington D.C.

[3] LSTC. Ls-Dyna. < <http://www.lstc.com/products/ls-dyna> >

[4] Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, G., Gatelli, D., Salsana, M., Tarantola, S. 2008. *Global sensitivity analysis The primer*. John Wiley and Sons Ltd, Cheichester, England.

[5] Neuenhaus, D.F., Gebler, U.J. and Feldmann, M. 2013. Using multibody-system modelling to make accurate predictions of vehicle impacts on road restraint systems. *Int. J. Nonlinear Mech.* 53 (2013) 24–31. DOI= <http://dx.doi.org/10.1016/j.ijnonlinmec.2012.10.011>

[6] Tabiei, A. and Wu, J. 2000. Roadmap for crashworthiness finite element simulation of roadside safety structures. *Finite Elem. Anal. Des.* 34 (2000) 145-157. DOI= [http://dx.doi.org/10.1016/S0168-874X\(99\)00035-9](http://dx.doi.org/10.1016/S0168-874X(99)00035-9)

[7] Reid, J.D. and Hiser, N.R. 2005. Detailed modeling of bolted joints with slippage, *Finite Elem. Anal. Des.* 41 (2005) 547–562. DOI= <http://dx.doi.org/10.1016/j.finel.2004.10.001>

[8] FHWA/NHTSA. 2007. *Development of a Finite Element Model for W-Beam Guardrails*, Technical Report. NCAC 2007-T-004.

[9] Marzougui, D., Mahadevaiah, U. and Opiela, K.S. 2010. *Development of a Modified MGS Design for Test Level 2 Impact Conditions Using Crash Simulation*, Technical Report. NCAC 2010-W-005.

[10] Department of Aerospace engineering Politecnico di Milano. *WP5 - Computational Mechanics Modelling of bolt connections for the ESP-N2 barrier*. Technical Report. ROBUST-05-016c-Rev.0.

[11] Federal Highway Administration. 2004. Manual for LS-DYNA Soil Material Model 147. Technical Report. FHWA-HRT-04-095.

[12] Borovinssek, M., Vesenjsek, M., Ulbin, M. and Ren, Z. 2007. Simulation of crash tests for high containment levels of road safety barriers. *Eng. Fail. Anal.* 14 (2007) 1711–1718. DOI= <http://dx.doi.org/10.1016/j.engfailanal.2006.11.068>

[13] Ren, Z. and Vesenjsek, M. 2005. Computational and experimental crash analysis of the road safety barrier, *Eng. Fail. Anal.* 12 (2005) 963–973. DOI= <http://dx.doi.org/10.1016/j.engfailanal.2004.12.033>

[14] *GS2 hard shoulder W-beam guardrail TB32 experimental test*. Technical Report. LIER-TRANSPOLIS (2007).