ACTA TECHNICA JAURINENSIS
Vol. 16, No. 3, pp. 107-115, 2023
10.14513/actatechjaur.00690

Research Article

Analysis of Truck Crashes with W-beam Guardrail

Tran Thanh Tung [1,*], Tso-Liang Teng [2]

[1] Faculty of Engineering Mechanics and Automation, VNU University of Engineering and Technology, 144 Xuan Thuy - Cau Giay District , Hanoi, Vietnam
[2] Department of Mechanical Engineering, Hsiuping University of Science and Technology, No.11, Gongye Rd., Dali Dist., Taichung City 412, Taiwan
*e-mail: tranthanhtung@vnu.edu.vn

Submitted: 16/03/2023 Accepted: 10/05/2023 Published online: 07/07/2023

Abstract: W-beam guardrail is an excellent method for enhancing traffic safety. The W-beam guardrail comprises of a W-shaped segment and specialized constructions known as support posts. Identifying the effect of the W-beam heights, post spacing, shaped supporting posts, and post-soil interaction may be crucial to improving the crashworthiness of W-beam guardrail. This study evaluated the W-beam guardrail using a finite element model in the event of a 10,000 kg truck collision. Simulations of crash tests were conducted to evaluate the crashworthiness of the W-beam guardrail in accordance with European standard EN1317. The results of this analysis can assist evaluate the design of W-guardrails and guide the future development of guardrail technologies.

Keywords: crashworthiness; W-beam guardrail; simulation; EN1317; LS-DYNA

I. INTRODUCTION

Off-road vehicle accidents occur when drivers lose control of their vehicles or veer to avoid the roadside hazard. As a result, the car could crash into other vehicles, pedestrians, or objects. These crashes could result in serious injuries or even death [1-8].

The W-beam guardrail is installed on the roadway to protect vehicles from roadside hazards and providing a high level of safety in and after the collision. Usually, the W-guardrail consists of a metal W-shaped segment and a supporting post, as shown in **Fig. 1**.

Figure 1. *W-beam guardrail [8]*

W-beam guardrails are an effective solution to reduce the risk of injury, save lives, and ensure road safety in the event of an accident. Previous research's indicate that the number of fatalities resulting from collisions with roadside guardrails was less than that resulting from collisions with other roadside hazards (trees, embankments, etc.) [9-11]. Thus, W-beam guardrails have proven an effective solution to reduce harm to cars and people when a collision occurs [12-14].

Usually, the W-beam guardrail must fulfil the European standard EN1317. The standards offer crash test details between multiple vehicle types with road safety W-beam guardrails. In addition, each W-beam guardrail must pass normalized crash tests according to established standards [15-16].

There were many studies which have been undertaken to investigate the capacity of W-beam guardrail based on European standard EN1317. Atahan et.al [17] shown a series of experimental impact test to determine the crashworthiness of the W-beam guardrail. In their study, Matthew Gutowski [18] proposed a new W-beam guardrail structure using the simulation method. Matej et al. [19] presented a steel-reinforced wooden W-beam guardrail design tested according to the EN1317 standard. Many researchers [20-23] provided an overview of the behavior of crashworthiness of roadside W-beam guardrail with different designs. Ferdous et al. [24] performed simulations with variable guardrail vehicle impact heights with W-beam guardrail. Lee et al. [25] evaluated the automotive crash performance of W-Beam steel post flexible rails in sloping ground supported with three types of cylinder shapes.

Normally, The W-beam guardrail structure was made to have certain dimensions, including the height from the ground surface and the distance between two posts [26–28]. In general, the installation of W-beam guardrails on European highways uses many shaped supports [29-30]. In addition, the W-guardrail guardrail is usually installed in a certain terrain where the poles will be embedded into the ground at a certain depth. W-beam guardrails can be installed on stable ground, asphalt, or concrete [11] [31-32]. Therefore, the influence of the soil on the posts an important factor in the safety performance of the W-beam guardrail, because the W-guardrail guardrail is often installed on different locations. As mentioned above, rail heights, post spacing, supporting posts, and post-soil were important factors affecting in safety performance of W-beam guardrails. Therefore, it was necessary to understand the influence of these parameters on safety performance. In the previous researches, Teng et al. [33-36] apply the finite element method to estimate the safety performance of W-beam guardrail, in which a 900 kg car crashes with W-beam guardrail (TB11-impact speed and impact angle were set 100 km/h and 200, respectively) in different rail height, post spacing, and post-soil interaction. The finite element approach was used to determine the safety performance of the W-beam guardrail constructed for varied structures: height and spacing of post, soil qualities, and shaped posts when impacted by a truck. The analytical results obtained here can help evaluate W-beam guardrail design and guide the future development of guardrail technologies.

II. W-beam guardrail and European standard EN 1317

1. W-beam guardrail

W-beam guardrail is the most commonly specified road safety barrier device in the world to protect vehicles and drivers from hazardous road places. **Fig. 2** depicts a typical W-beam guardrail, which consists of a W-shaped structure called a w-beam and specifically constructed posts. The W-beam guardrail absorbs a portion of the impact energy to lessen the risk to the driver and restrict vehicle deformation.

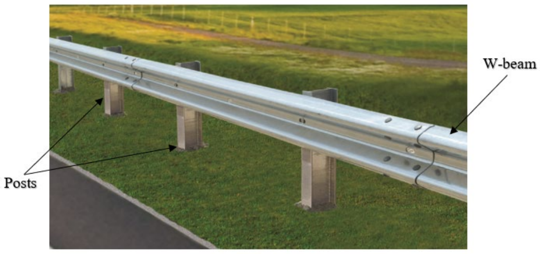


Figure 2. *Typical W-beam guardrail [8]*

2. European standard EN 1317

Typically, W-beam guardrails were constructed employing severity (ASI, THIV) and working width in accordance with European standard EN 1317-2 [15]. These standard tests depict conventional vehicle vs W-beam guardrail collision testing. The W-beam guardrail was built in accordance with the European standard EN 1317, taking into account three primary criteria for difference performance levels: containment level, impact severity, and working width.

Containment level: this represents the level of road safety barriers for various accident situations in terms of vehicle type, angle of impact, and impact speed. There were four containment levels from low to very high were specified.

Impact severity was characterized by the acceleration severity index (ASI) and the theoretical head impact velocity (THIV). To ensure safety, the following requirements must be met: ASI $\leq$ 1.0 (level A), 1<ASI$\leq$1.4 (level B), 1.4<ASI$\leq$1.9 (level C) and THIV$\leq$33 km/h.

Barrier deformation (Wm)) is regarded as the barrier's maximum lateral deformation with eight classes (W1–W8) were defined.

III. Simulation Models of Impact Test

In this study, simulations of TB42 type crash tests for heavier vehicles were performed to investigate the crashworthiness of different W-beam guardrail structures. This model consists of the truck (10,000 kg) with the W-beam guardrail according to the TB42 test (impact speed and impact angle were set 70 km/h and 15°), as shown in the **Fig. 3.**

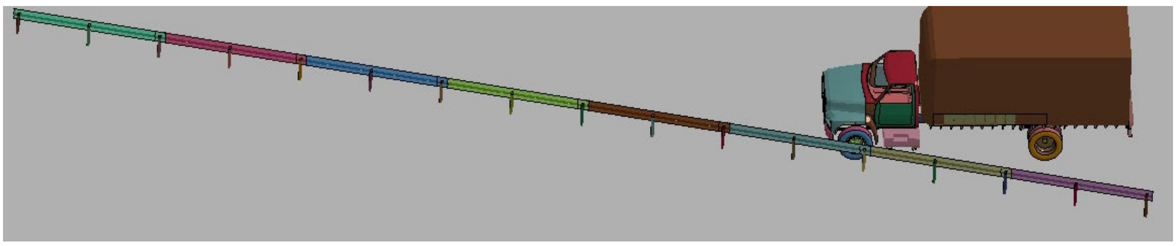


Figure 3. *Simulation model test*

The development and validation of a finite element model for W-beam guardrail according to European standard EN 1317 were proposed, details on the numerical model such as mesh parameters, soil modeled, boundary conditions, contact types, material model, etc. were explained in previous researches [33-36].

3. Impact testing model

Fig. 4 depicts the vehicle and W-beam guardrail models used in the impact test. The W-beam guardrails used in this study were ALKA AG04-2.0 guardrails [17]. The W-guardrail splice is 4,300 meters long. The C-post measures 1,600 mm in length and 950 mm in depth. The post dimensions are 125 mm x 62.5 mm x 25 mm. The truck selected from the NCAC database according to the European standard EN1317 [37].

Figure 4. *W-beam guardrail system and truck*

4. Boundary condition

W-beam guardrail continuation was represented by the addition of elastic springs at both ends of each node along the W-beam (**Fig. 5**). Post–soil interaction was represented using discrete spring elements attached to the posts. The stiffness of the nonlinear springs increased with depth and soil properties.

Roadway mode: was defined using RIGIDWALL_PLANAR card to simulate contact between the truck and the W-beam guardrail.

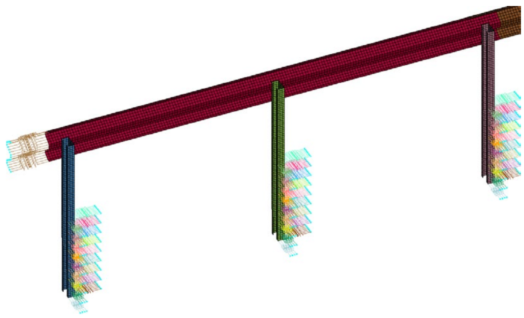


Figure 5. *Boundary condition*

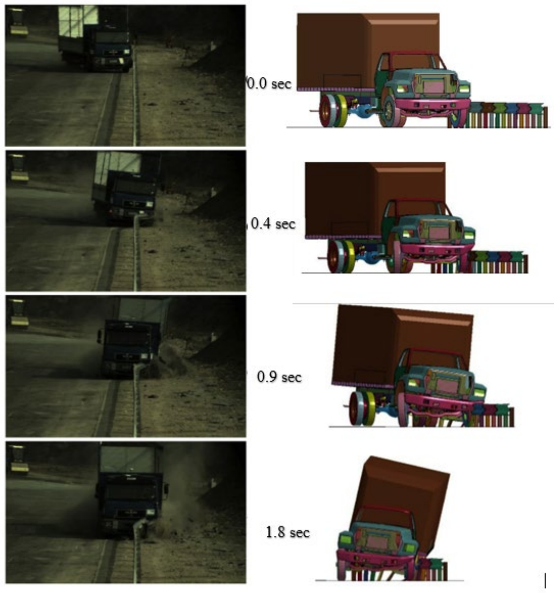
IV. Model validation

Fig. 6 depicts a time sequence comparison between simulation results and the test outcomes. Experimental test was conducted by Ali Atahan et.al [17]. The crash test and simulation vehicles were effectively diverted. In TB 51 test, the experimental and simulated working widths were 1300 mm and 1280 mm, respectively. In TB 11 test, the validation model was introduced in detail in a previous study [36]. **Table 1** depicts a ASI and THIV comparison between experimental and simulation test.

Table 1. *Comparison between experimental and simulation [36]*

Evaluation Criteria	Experimental Result	Simulation Result
THIV (km/h)	31	26.1
ASI	0.94	0.93

There was an acceptable relationship between the test and simulation outcomes. Consequently, the model was validated and served as a baseline.



Experimental [9] Simulation

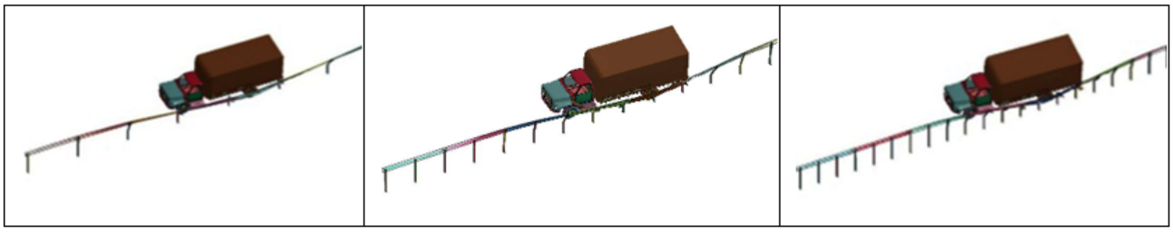
Figure 6. *Validation result on simulation*

V. Results and discussion

1. Effect of various post spacing and rail heights

The distances between the posts in the three models were 1333, 2000, and 4000 mm, respectively. All models had a W-beam guardrail height of 750 mm.

Fig. 7 shows the results of the TB42 impact test. These simulations illustrated that the W-beam guardrail prevented the vehicle from leaving the roadway.



a) ***b)*** ***c)***

Figure 7. *Sequential of TB42 test with 4000 mm (a) 2000 mm(b) and 1333 mm (b) posts spacing*

The ASI, THIV, and the working widths of the impact tests are summarized in **Table 2**. These data show that the working width Wm of the guardrail post decreases proportionally to the distance between the posts. W-beam guardrails with post spacing 1333, 2000 and 4000 mm have working widths of 850, 1280 and 1450 mm, respectively. These values meet the working width classes of W3, W4 and W5. The W-beam guardrail meets the EN1317 standard in all three test conditions. W-beam guardrail with a distance between posts of 4000 mm have the highest ASI results (1.32), and to meet impact severity B. Both W-beam guardrails with a distance of 2000 mm and 1300 mm corresponding to impact severity A because the structure have ASI lower than 1. Compared to the other two post spacing, the W-beam guardrail with a post spacing of 2,000 mm gives the best protection under these test conditions. again.

Table 2. *Simulation TB42 test results with difference distance between posts*

Post spacing (mm)	THIV (km/h)	ASI	W_m (mm)
4,000	26.6	1.32	1450
2,000	24.6	0.87	1280
1,333	23.5	0.71	850

In simulations, the posts heights from the ground level were installed as follows: 800-, 750-, 700- and 650-mm. **Fig. 8** and **Table 3** represent the simulation results.

In all three cases, the W-beam guardrail can redirect the vehicle back to the roadway, which indicates that the W-beam guardrail meets EN 1317. There is a slight variation in the THIV value. Only the case of barriers up to a bar height of 650 mm has a working width class of W3, and the remaining have a working width class of W4. A W-beam guardrail height of 650 mm has the highest ASI value is 1.25 and a W-beam guardrail height of 800 mm represents the lowest ASI value is 0.72. The impact severity of 750 and 800 mm post height of W-beam guardrail corresponds to class A. The other collision W-beam guardrails correspond to class B. Therefore, 750 and 800 mm high W-beam guardrails carry a higher level of protection. The W-beam guardrail with a height of 800 mm and a spacing of 2,000 mm between posts has the lowest ASI, hence this structure provides better protection compared to the other.

Table 3. *Simulation TB42 test results with difference height of post*

W-beam guardrail height (mm)	THIV	ASI	Wm (mm)
650	26.6	1.25	980
700	26.5	1.1	1250
750	24.6	0.87	1280
800	24.3	0.72	1100

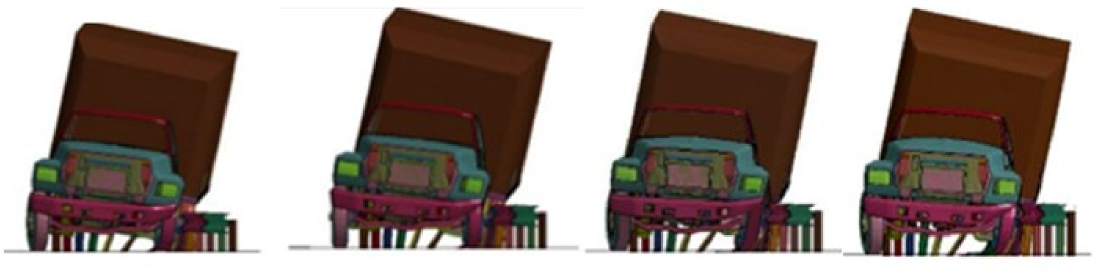


Figure 8. *Impact test results at different guardrail height*

2. Effect of soil properties

In this study, four various types of soil were used to simulate, various soil properties are described in the previous study [35-36].

Fig. 9-10 show the results of the road safety W-beam guardrail impact test. In all four conditions, the W-beam guardrail could prevent the vehicle from exiting the road and redirecting back into the lane.

In all four conditions, the W-beam guardrail meets the EN1317-2 standard for impact severity corresponding to class A. There is not much difference in ASI and THIV values, while there is a difference. very clear between working width values (**Table 4**). The results clearly confirm that soil properties do not affect the severity of impacts (ASI, THIV).

Table 4. *Simulation TB42 test results with various soil conditions*

Soil properties	THIV	ASI	Wm (mm)
Loose sand	24.6	0.87	1280
Medium sand	25.2	0.86	1350
Dense sand	26.8	0.86	1525
Very dense sand	25.7	0.88	1740

The results indicate that the W-beam guardrail's working width increases proportionally with the soil's abrasiveness. The results indicate that soil conditions have no effect on the impact severity (ASI, THIV) but do influence the deformation of the W-beam railing. The outcomes can be utilized as a guide for installing the W-beam guardrail system in different locations.

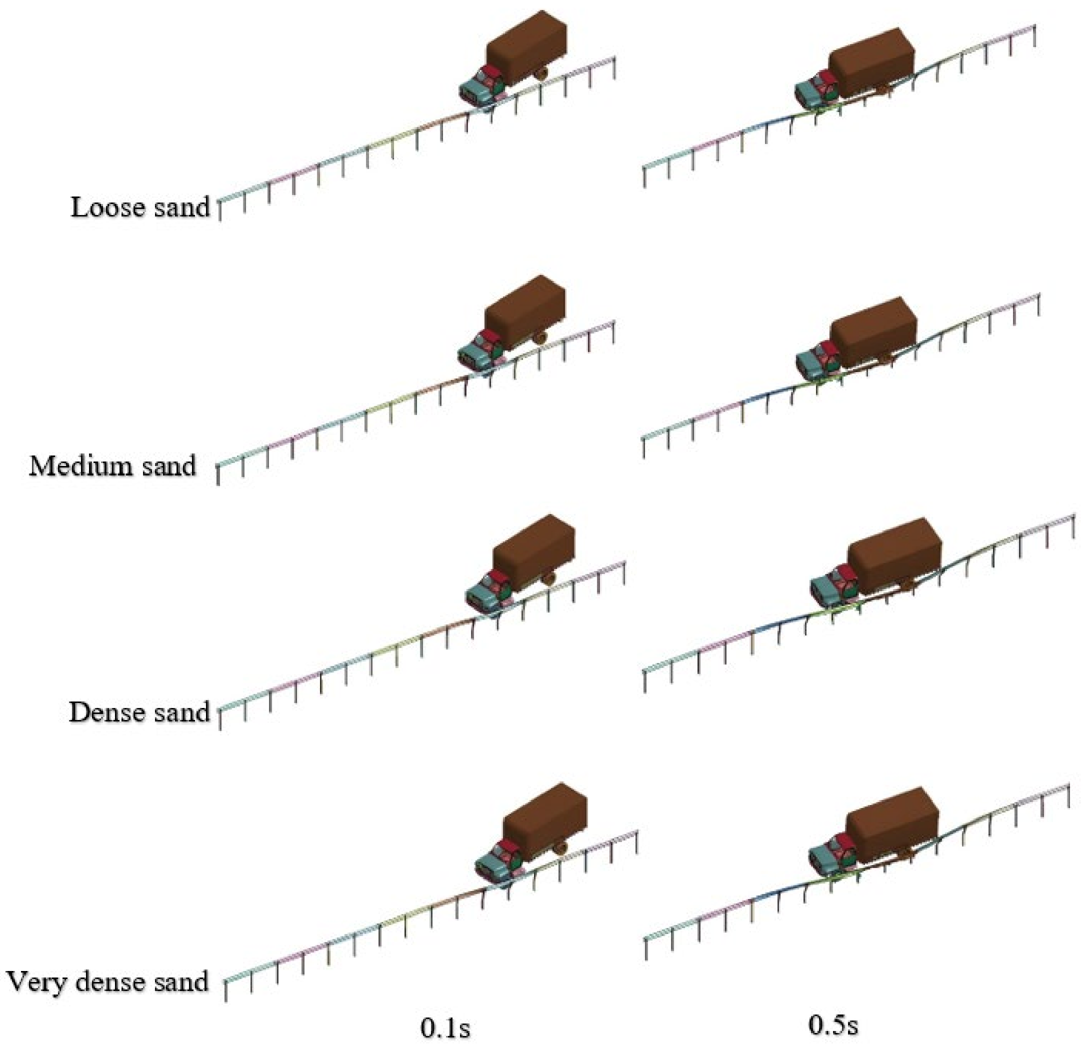


Figure 9. *Simulation TB42 test result with various soil properties*

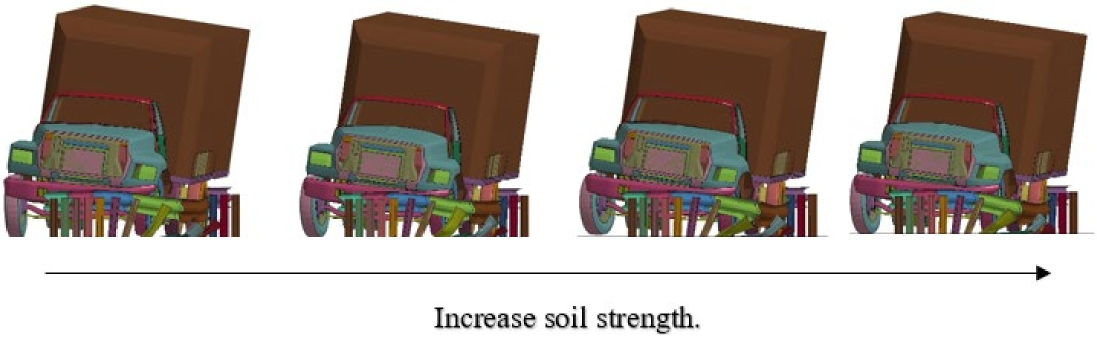


Figure 10. *W-beam guardrails with various soil conditions.*

3. Effect of different shaped post

The U-shaped, I-shaped, C-shaped, and Sigma-shaped post types have been analyzed and contrasted. The cross sections of the shaped posts are described in the previous research by Teng et.al [35].

Fig. 11-12 show simulation results when a truck impacts the guardrail at a speed of 70 km/h and a collision angle of 15 degrees. **Table 5** shows the severity of the impact (ASI and THIV) and the working width of the structures. All four cases, the guarail meets the EN1317-2 standard and has a W4 working width level. The W-beam I-beam guardrail provides a higher level of safety for vehicle drivers than in other cases. The I-shaped guardrail represents the biggest working width value is 1,340 mm and the W-shaped guardrail with C-shaped posts illustrates the lowest working width is 1,280mm.

Table 5. *Simulation test results with different shaped posts*

Soil properties	THIV	ASI	Wm (mm)
Loose sand	24.6	0.87	1280
Medium sand	25.2	0.86	1350
Dense sand	26.8	0.86	1525
Very dense sand	25.7	0.88	1740

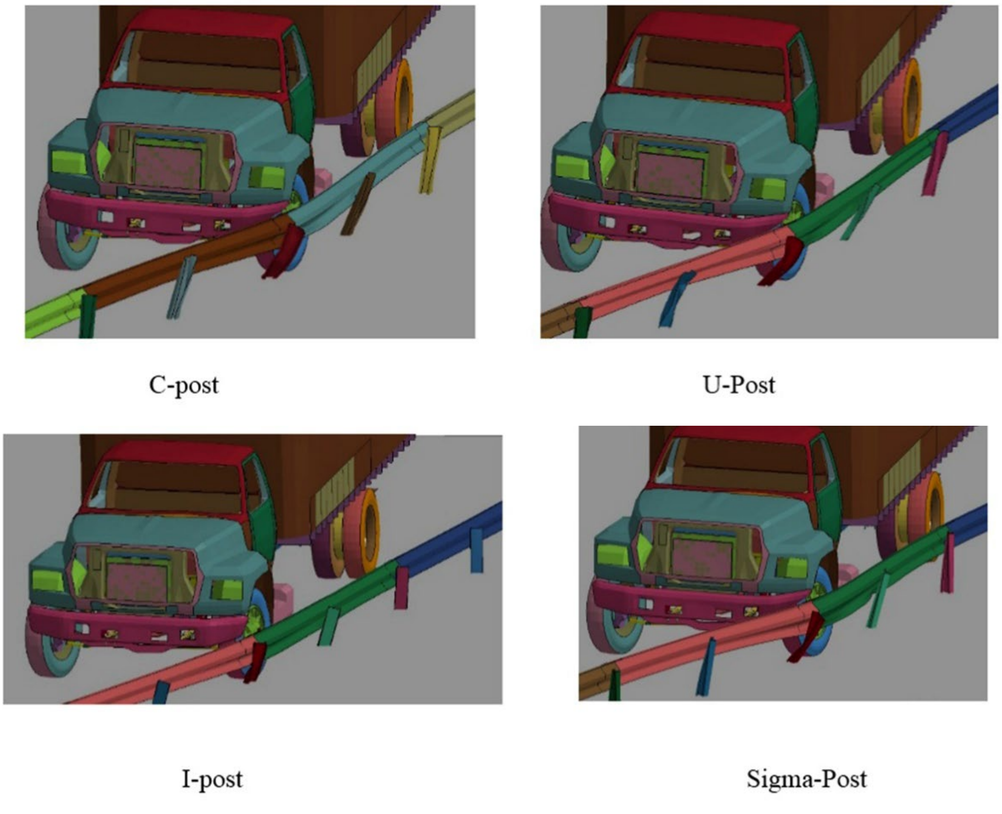


Figure 11. *Deformed of the W-beam guardrail system during TB42 impact test*

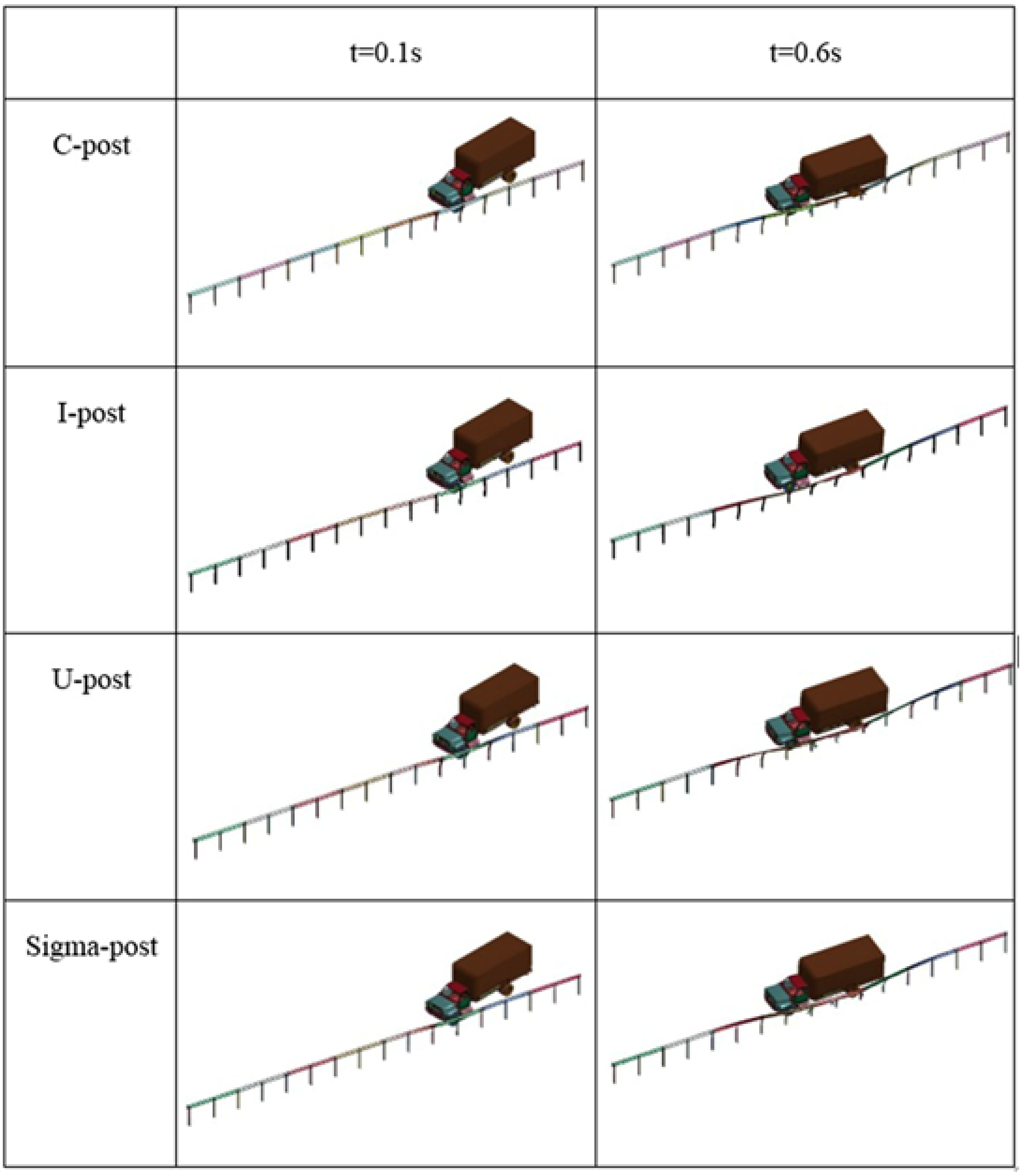


Figure 12. *Sequential figures from TB42 test with various shaped post*

VI. Conclusion

The study presents an investigation of the safety performance of the W-beam guardrail in various collisions according to the European standard EN1317 in collisions with a 10,000 kg truck. The study provides a very convenient way to increase the safety of W-guardrail guardrail. The main achievements, including contributions can be summarized as follows:

a) All W-beam guardrails with a 700 mm height and three-post spacing (4000, 2000 and 1333 mm) conform to the EN1317 standard. The working width of the W-beam guardrail decreases with the distance between the posts decreasing.
  – W-beam guardrail with span 1,333 and 2,000 mm corresponds to impact class A, and guardrail post W beam with span 4,000 mm has the highest ASI value and impact severity class B. Good level of protection The most in this case belongs to the W-beam guardrail with a distance between the posts of 1333 mm

b) For the four cases of height (650, 700, 750 and 800 mm) and the same post spacing of 2000 mm, the W-beam guardrail with a rail height of

800mm provides the highest level of protection.

c) Test simulations have been carried out demonstrating that different soil conditions do not affect the protection of the barrier according to the European standard EN1317. The results show that the properties of the soil do not affect the impact severity (ASI) but affect the working width. The working width of the W-beam guardrail increases in proportion to the stiffness of the soil.

d) For various shaped post
   – The best protection is in the W-beam guardrail with the cross-section of the I-shaped post. The worst protection is in the W-beam guardrail with the Sigma cross-section.

AUTHOR CONTRIBUTIONS

Tran Thanh Tung: Conceptualization, Finite element modelling, Writing,

Tso-Liang Teng: Review and editing.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] The Institution of Engineering and Technology: Glossary of Safety Terminology. No.00, 2017. https://www.theiet.org/impact-society/factfiles/engineering-safety-factfiles/glossary-of-safety-terminology/

[2] United States Department of Transportation, Insurance Institute of Highway Safety (IIHS). Collisions with fixed objects and animals, 2021. https://www.iihs.org/topics/fatality-statistics/detail/collisions-with-fixed-objects-and-animals

[3] Wang, J.; Lu, H.; Sun, Z.; Wang, T.; Wang, K. Investigating the Impact of Various Risk Factors on Victims of Traffic Accidents. Sustainability, 12 (9) (2020) 3934. https://doi.org/10.3390/su12093934

[4] Molan, A.M.; Rezapour, M.; Ksaibati, K. Investigating the relationship between crash severity, traffic barrier type, and vehicle type in crashes involving traffic barrier. Journal of Traffic and Transportation Engineering 7 (1) (2020) pp. 125–136. https://doi.org/10.1016/j.jtte.2019.03.004

[5] International Transport Forum. Road Safety annual report 2021. https://www.itf-oecd.org/road-safety-annual-report-2021 (accessed May 2023)

[6] Type of Crash https://injuryfacts.nsc.org/motor-vehicle/overview/type-of-crash/ (accessed May 2021)

[7] Federal Highway Administration. https://safety.fhwa.dot.gov/roadway_dept/ (accessed May 2021)

[8] Trinity Highway. https://trinityhighway.com/product/t-31-guardrail/ (accessed May 2021)

[9] The National Road Safety Strategy. National Road Safety Action Plan 2023-5. https://www.roadsafety.gov.au/action-plan/national-road-safety-action-plan-2023-25

[10] Albuquerque F.D.B., Awadalla DM. Roadside fixed-object collisions, barrier performance, and fatal injuries in single-vehicle, run-off-road crashes. Safety, 6 (2) (2020), p. 27. https://doi.org/10.3390/safety6020027

[11] Safe German Guardrail Technology. Heintzmann Basic W-beam guardrail. http://www.heintzmann.eu

[12] Qiao, W.; Huang, E.; Guo, H.; Liu, Y.; Ma, X. Barriers Involved in the Safety Management Systems: A Systematic Review of Literature. International Journal of Environmentral Research and Public Health, 19 (15) (2022) 9512. https://doi.org/10.3390/ijerph19159512

[13] W beam 4mm thickness base metal crash barrier guardrail, Shandong Huaan Traffic Facilities Co., Ltd. https://www.guardrailfactory.com/gb-guardrails/w-beam-4mm-base-metal-crash-barrier-guardrails.html

[14] Crash Barrier Systems Market Report 2022 – Market Forecast, Trends And Strategies, 2022. https://www.thebusinessresearchcompany.com/press-release/crash-barrier-systems-market-2022

[15] European Standard EN 1317–1, EN 1317–2:2010. Road restraint systems.

[16] AASHTO. Manual for Assessing Safety Hardware (MASH). Washington, DC: American Association of State Highway and Transportation Officials (AASHTO), 2009.

[17] Atahan AO, Yucel AO, Erdem MM. Crash testing and evaluation of a new generation L1 containment level guardrail. Engineering Failure Analysis 38 (2014) pp. 25-37. https://doi.org/10.1016/j.engfailanal.2014.01.003

[18] Matthew Gutowski, Emre Palta, Howie Fang. Design optimization of a new W-beam

guardrail for enhanced highway safety performance. Advances in Engineering Software, 112 (2017) pp. 154-164. https://doi.org/10.1016/j.advengsoft.2017.05.002
[19] Matej Borovinšek, Matej Vesenjak, Zoran Ren. Improving the crashworthiness of reinforced wooden road safety W-beam guardrail using simulations of pre-stressed bolt connections with failure. Engineering Failure Analysis 35 (2013) pp. 625-635. https://doi.org/10.1016/j.engfailanal.2013.06.006
[20] Mehrtash Soltani, Taher Baghaee Moghaddam, Mohamed Rehan Karim, N.H. Ramli Sulong. Analysis of developed transition road safety barrier systems. Accident Analysis and Prevention, 59 (2013) pp. 240-252. https://doi.org/10.1016/j.aap.2013.05.029
[21] Amirarsalan Mehrara Molan , Khaled Ksaibati. Impact of side traffic W-beam guardrail features on the severity of run-off-road crashes involving horizontal curves on non-interstate roads. International Journal of Transportation Science and Technology, 10 (3) (2021) pp. 245-253. https://doi.org/10.1016/j.ijtst.2020.07.006
[22] Plaxico CA, Guardrail MH and Hiranmayee K. Compariosn of the impact performance of the G4 (1S) and G4 (2S) guardrail systems under NCHRP report 350 Test 3-11 conditions
[23] M I Gheres and I L Scurtu. Crash testing and evaluation of W-beam guardrail using finite elements method. IOP Conference Series: Materials Science and Engineering, 1220 (2021) 012049. http://doi.org/10.1088/1757-899X/1220/1/012049
[24] Ferduos MR, Odeh AA, Bligh RP, et al. Performance limit analysis for common roadside and median W-beam guardrail using LS-DYNA. International Journal of Crashworthiness, 16 (6) (2011) pp. 691-706. https://doi.org/10.1080/13588265.2011.623023
[25] Lee DW, Ahn JS, and Woo KS. Vehicle impact analysis of flexible W-beam guardrail supported by different shaped posts in sloping ground. Advances in Mechanical Engineering, 6 (2014). https://doi.org/10.1155/2014/705629
[26] W-Beam Guardrail, Materials Handling Pty Ltd. https://www.materialshandling.com.au/products/w-beam-guardrail/
[27] Flexbeam Guardrail Crash W-beam guardrail https://www.ingalcivil.com.au/products/road-safety-barriers/guardrail/flexbeam
[28] W-Beam Guardrail Effectively Makes the Highway Safer https://www.highway-guardrail.com/highway/w-beam-guardrail.html
[29] Safe Direction. Protecting Life& Property. W-beam guardrail semi-rigid protection. Product manual. Ref: PM 003/01. http://www.safedirection.com.au
[30] NZ Transport Agency. Specification and guidelines for road safety hardware and devices. NZTA M23A: 2022. https://www.nzta.govt.nz/assets/resources/road-safety-barrier-systems/docs/m23-road-safety-barrier-systems.pdf
[31] Voestalpine. Vehicle restraint system. http://www.voestalpine.com/strassensicherheit/en/products
[32] Fracasso hellas- Quality in Safety. http://www.fracassohellas.gr
[33] Tso-Liang Teng, Cho-Chung Liang, Thanh-Tung Tran, Effect of various W-beam guardrail post spacings and rail heights on safety performance, Advances in Mechanical Engineering, 7 (11) (2015) p. 16. https://doi.org/10.1177/1687814015615544
[34] Tso-Liang Teng, Cho-Chung Liang, Ching-Yu Hsu, Chien-Jong Shih, Thanh-Tung Tran, Impact Performance of W-beam Guardrail Supported by Different Shaped Posts, International Journal of Mechanical Engineering and Applications, 4 (2) (2016) pp. 59-64. https://doi.org/10.11648/j.ijmea.20160402.14
[35] Tso-Liang Teng, Cho-Chung Liang, Ching-Yu Hsu, Chien-Jong Shih, Thanh-Tung Tran. Effect of Soil Properties on Safety Performance of W-beam Guardrail. Proceedings of the 2016 International Conference on Advanced Materials Science and Environmental Engineering. https://doi.org/10.2991/amsee-16.2016.10
[36] Teng T-L, Liang C-C, Tran T-T. Development and validation of a finite element model for road safety W-beam guardrail impact tests. Simulation, 92 (6) (2016) pp. 565-578. https://doi.org/10.1177/0037549716644507
[37] NHTSA Crash Simulation Vehicle Models https://www.nhtsa.gov/crash-simulation-vehicle-models