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Impact Performance of W-beam Guardrail Supported by Different Shaped Posts

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Abstract: This study applied the finite element code LS-DYNA for evaluating the crashworthiness of W-beam guardrail. Four crash test simulations were conducted for evaluating the safety performance of the W-beam guardrail with four different post configuration according to the European standard EN1317. The results showed that the best performance was demonstrated by the sigma-shaped posts and the I-shaped posts absorbed the lowest amount of impact energy. The optimal result was registered by the barrier with sigma-shaped posts, which demonstrated a lower ASI value and higher energy crash absorption than the other models did.

Keywords: Roadside Safety, Energy Absorption, Crashworthiness, LS-DYNA, EN1317

1. Introduction

The W-beam guardrail is the most widely used road safety barrier worldwide. They are used for protecting vehicle occupants on dangerous areas of roadways. In the case of vehicle impact, the W-beam guardrail have the capability to reduce the kinetic energy of the impact, thus reducing damage to the vehicle and increasing the safety. A road safety barrier must meet minimum standards of construction and materials design. Conventionally, road safety barrier systems used on European highways must fulfil the European standard EN 1317 [1]. The European standard EN 1317 provides criteria for determining the levels of vehicle containment, appropriately redirecting errant vehicles to the road, and providing guidance for pedestrians and other road users. The current paper applied the finite element code LS-DYNA for evaluating the safety performance of W-beam guardrail with four different post configuration according to the European standard EN 1317 using finite element code LS-DYNA. Their crashworthiness is then discussed.

2. W-beam Guardrail System

The W-beam guardrails are roadside structures that are installed on certain sections of the road to improve highway safety by preventing a vehicle from leaving the road and colliding with roadside hazards. The W-beam guardrail is a semi-rigid barrier that is designed for moderate flexibility during a vehicle impact. Conventionally, W-beam guardrails comprise a rail element (called a W-beam) and supporting posts (Figure 1).

- W-shaped segments: which are longitudinally connected by bolts. They are deformable but are sufficiently strong to prevent rupturing in any situation
- Post: Carries the distance spacer and assures that the guardrail is positioned at a certain distance from the road. The posts are always oriented with the closed profile facing the traffic flow.

When a vehicle imact, the crash energy is absorbed by the barrier's deformation. The flexural resistance of the rail and the bending resistance of the posts help the barrier form a redirection ribbon, guiding the vehicle away from the nearby hazard. This may reduce damage from the impact and increase safety [2].

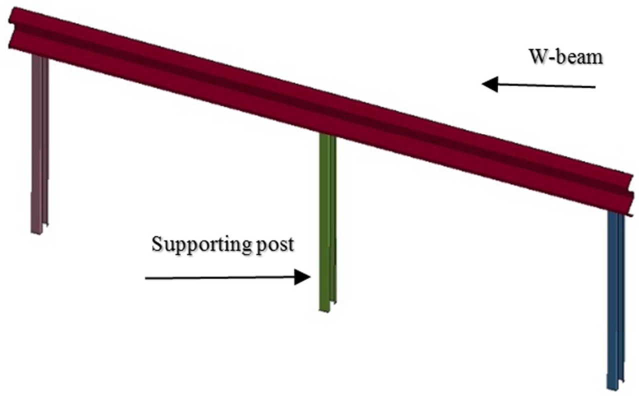


Figure 1. *W-beam guardrail.*

3. European Standard EN1317

The European standard EN 1317 was approved by the European Committee for Standardization in March 1998 and was revised on April 29, 2010 [1]. This standard represent common crash testing between vehicles and road safety barrier. The standard prescribes criteria that road safety barriers must fulfill to reduce the severity of accidents related to roadside barriers.

Table 1. *Vehicle impact test descriptions.*

Test	Impact speed (km/h)	Impact angle (^{0})	Total mass(kg)	Type of vehicle
TB 11	100	20	900	Car
TB 21	80	8	1300	Car
TB 22	80	15	1300	Car
TB 31	80	20	1500	Car
TB 32	110	20	1500	Car
TB 41	70	8	10 000	Rigid HGV
TB 42	70	15	10 000	Rigid HGV
TB 51	70	20	13 000	Bus
TB 61	80	20	16 000	Rigid HGV
TB 71	65	20	30 000	Rigid HGV
TB 81	65	20	38 000	Articulated HGV

(HGV: Heavy Goods Vehicle)

Table 1 presents impact tests between various vehicles and barriers. On the basis of the aforementioned standards, road safety barriers must be tested under various conditions (e.g., angle impact and vehicle velocity) by using different vehicles (e.g., passenger cars, buses, and trucks).

Safety barriers were designed according to the European standard EN 1317 by evaluating three main criteria for various performance levels.

- Containment level: This represents the level of containment of safety barriers for various types of impacting vehicles at various speeds and impact angles. Four containment levels (low, normal, high, and very high) were defined.
- Impact severity: During the impact phase between the vehicle and roadside barrier, two indices were proposed for assessing the injury criteria of the occupants: the acceleration severity index (ASI) and the theoretical head impact velocity (THIV). The ASI is used for characterizing the impact intensity, which is considered the most critical indicator of the impact rate on vehicle occupants. The THIV describes the theoretical speed at which an occupant's head collides with an obstacle during an impact.

To ensure safety, these indicators must not exceed the determined limits (Table 2).

Barrier deformation is expressed according to the working width (W_m), which is the maximum lateral distance between any part of the barrier on the undeformed traffic side and the maximum dynamic position of that part of the barrier. The deformation of road safety barriers can be categorized into eight classes (W1–W8), as shown in Table 3

Table 2. *Impact severity levels.*

Impact severity level	Index values	
A	ASI ≤ 1.0	THIV ≤ 33km/h
B	ASI ≤ 1,4	
C	ASI ≤ 1,9	

Table 3. *Levels of working width.*

Working width classes	Working width W_m (m)
W1	≤ 0.6
W2	≤ 0.8
W3	≤ 1.0
W4	≤ 1.3
W5	≤ 1.7
W6	≤ 2.1
W7	≤ 2.5
W8	≤ 3.5

4. Finite Element Model of Road Safety Barrier Impact Test

4.1. Road Safety Barrier Model

The current system comprised W-shaped guardrails and C-posts as shown in Figure 2.

Figure 2. *W-beam guardrail model.*

The length of the W-beam guardrail segments was 4,300 m. The C-post was 1,600 mm in length and was embedded 950 mm in the soil. The dimensions of the post were 125 mm × 62.5 mm × 25 mm. The distance between each post was 2 m.

The height of the barrier was 750 mm from the ground [3].

Three new type posts include: U-shaped, I-shaped and Sigma-shaped has been investigated and compared with the existing system. All models were identical, except for the shaped posts. The cross section of the shaped posts are depicted in Figure 3.

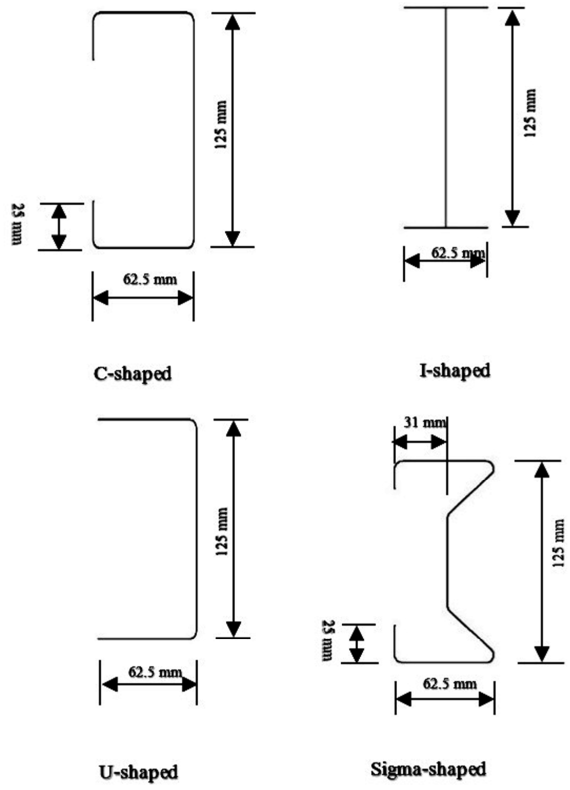


Figure 3. *Cross sections of the posts.*

The finite element model of road safety barrier impact test that takes from previous study [4]. All the parts of the safety barrier were modeled with fully integrated shell elements with five integration point through the shell thickness to prevent hourglass mode [5, 6]. The bolt connection between the W-shaped segments and the posts were modeled using a spot-weld element.

The keyword CONSTRAINT-SPOTWELD was used to simulate bolts that connected the barrier components.

The AUTOMATIC_SINGLE_SURFACE card with a soft constraint option assigned as type 1 was used to define a contact between the components of the barrier. The W-beam guardrail component materials, such as the posts and W-beam, were represented using MAT024 (a piecewise linear plasticity material model) in LS-DYNA. Table 4 presents the properties of the material for the road safety barrier model

Table 4. *Material parameter for modeling safety barrier.*

Material Properties	
Density	7850 kg/m^3
Yield stress	275 MPa
Young's modulus	200000MPa
Failure strain	0.2
Possion's ratio	0.3

4.2. Vehicle Model

The vehicle chosen according to European standard EN 1317 was a Geo Metro car (version GM-R3) from the NCAC database [7] was used in this simulation. The vehicle model was developed and improved in Politecnico di Milano, Italy and is publicly accessible on the NCAC Web page. This car was useful in simulating the impact of a passenger car (900 kg) on the road safety barrier according to the TB11 test regulation for EN 1317-2. The car model contained 227 parts, 25,037 shell elements, and 28,656 nodes (Figure 4)

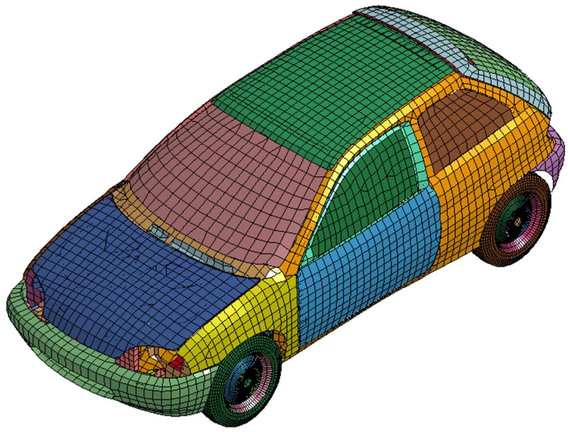


Figure 4. *Finite element model.*

4.3. Boundary Condition

The continuation of guardrail: The elastic springs were added at both ends of each node along the depth of the W-beam to represent boundary conditions, as shown in Figure 5. The springs are attached to the W-beam guardrail at one end and constrained translationally along the x, y, and z axes on the other end. This helped us to assume a long barrier.

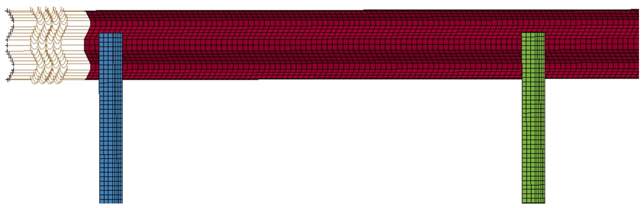


Figure 5. *The continuation of guardrail represent by elastic springs.*

The stiffness of the springs is calculated from the following equation:

$$K = \frac{EA}{L}$$

where

A: Cross-sectional area of the W-beam.

E: Young's modulus of steel.

L: Length of the unmodeled barrier.

The post–soil interaction was modeled using nonlinear spring elements fixed along the longitudinal and lateral directions on the two adjacent sides of the posts. On one side, these springs attached all the nodes of the cross-section and on the other side, the node was constrained in all six directions. Nine-layer springs with a spacing of 100 mm was used presented post-soil interaction, as shown in Figure 6.

The stiffness of the nonlinear springs increased with depth and was determined according to the method proposed by Habibagahi and Langer [8] and Plaxico et al [9, 10].

Roadway mode: The roadway was defined by a rigid wall card (RIGIDWALL_PLANAR) to simulate contact between the car and the ground.

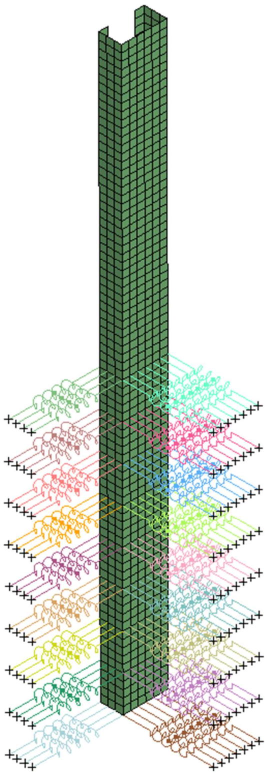


Figure 6. *Nonlinear springs represented post-soil interaction.*

4.4. Impact Test Simulation

Figure 7 depicts the initial condition of the road safety barrier simulation and experimental test. The impact test model comprised the vehicle and safety barrier. The vehicle speed was set to 100 km/h with an impact angle of 20° according to the TB11 test regulation [1]. An AUTOMATIC_SURFACE_TO_SURFACE card with soft constraint type 1 was used as a contact between the vehicle and the barrier. The static coefficient of friction was set to 0.15, dynamic coefficient of friction was set to 0.09, and exponential decay coefficient was set to 0.266e-3 [11].

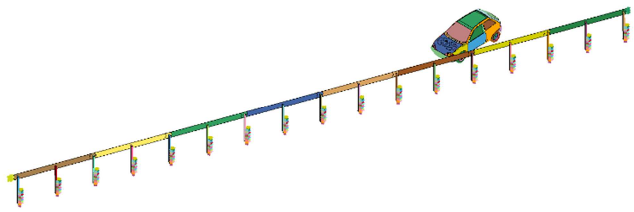
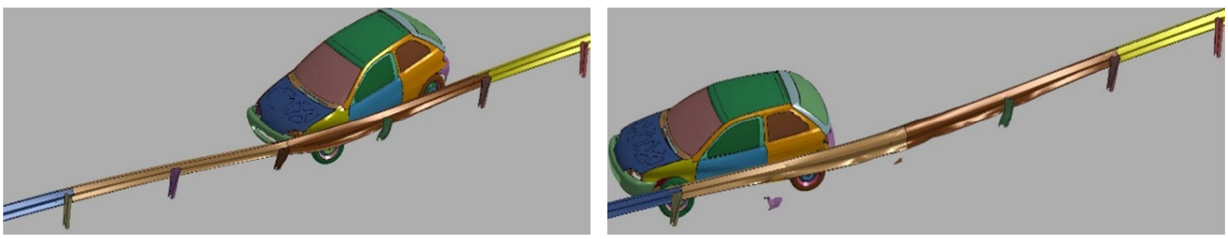


Figure 7. *Boundary condition.*

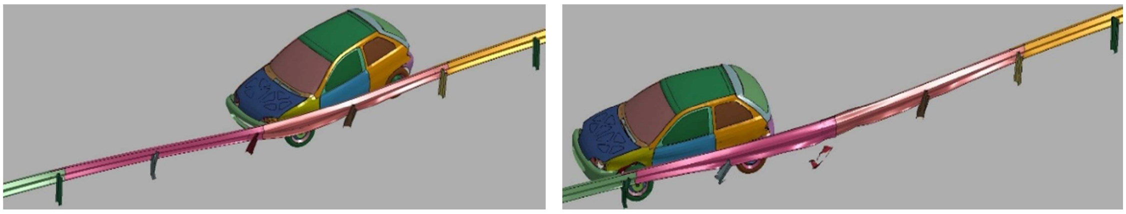
5. Analysis of Computational Results

During the result analysis and performance evaluation of the barrier, emphasis was placed on the potential of the barrier to contain and redirect the vehicle, with the acceptable impact severity and working width set according to EN 1317-2. The output data were filtered using a 180-Hz SAE filter and then processed using the Test Risk Assessment Program software developed by the Texas Transportation Institute [12]. Figure 8-12 show the simulation results of the safety barrier finite element models. Those figures show the vehicle trajectory and the deformation of guardrail when the 100 kg small car impacts the safety barrier with a speed of 100 km/h and an angle of 100 degrees. In all four cases, the barriers are strong enough to prevent vehicle from leaving the road and redirected the car back on road. Table 5 show the impact severity (ASI and THIV) and working width of the models. In all four test cases, the barriers meet the EN1317-2 requirement and registered working widths class W3. The barrier with I–shaped posts showed the highest ASI value (i.e., 1.08), and the barrier with sigma-shaped posts demonstrated the lowest ASI value (i.e., 0.91). Therefore the barrier with sigma-shaped posts provide a greater safety level for vehicle occupant compared with barrier installed with other posts. The barrier with sigma-shaped showed the highest working width (i.e. 925 mm), and the barrier with C-shaped posts showed the lowest working width (i.e. 805mm). Figure 13 illustrates the ASI values obtained over time for the three barriers with various post spacing. The impact severity levels of barrier with I-shaped posts corresponded to class B, whereas those of the remaining barriers corresponded to class A. Figure 14 illustrates the energy absorbed obtained over time for the four barriers with various shaped posts.



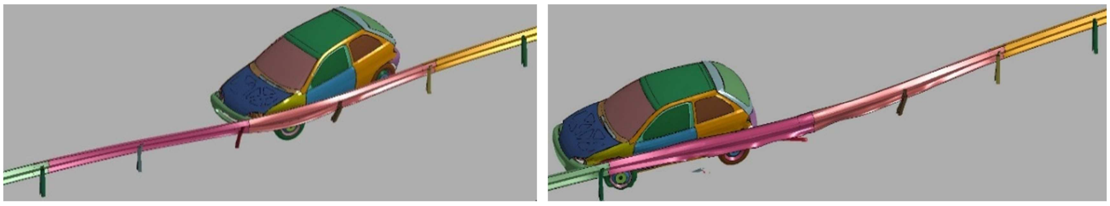
t=0.1s t=0.3s

Figure 8. *Sequential figures from barrier with C-post.*



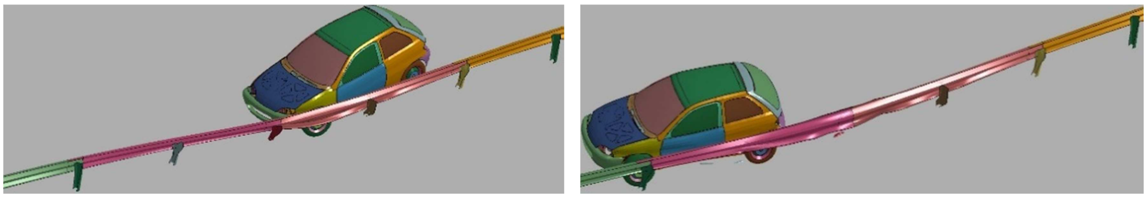
t=0.1s t=0.3s

Figure 9. *Sequential figures from barrier with I-post.*



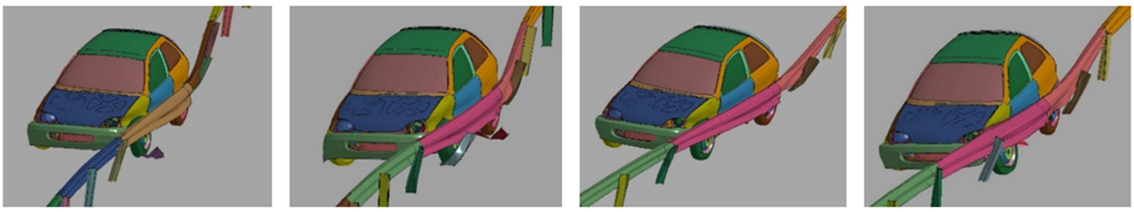
t=0.1s t=0.3s

Figure 10. *Sequential figures from barrier with U –post.*



t=0.1s t=0.3s

Figure 11. *Sequential figures from barrier with Sigma –post.*



C-post I -post U-post Sigma -post

Figure 12. *Deformed of the barrier system during impact.*

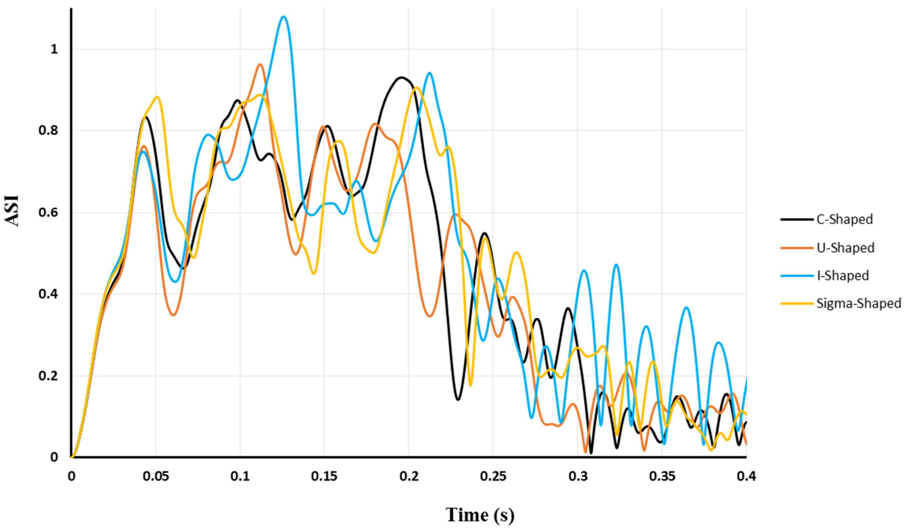


Figure 13. *Acceleration severity index value over time with various shaped post.*

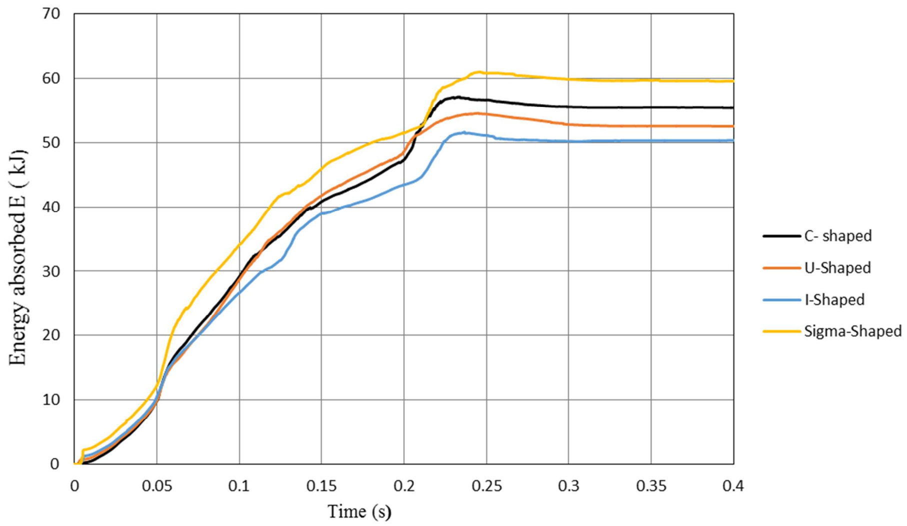


Figure 14. *Absorbed crash energy of four models.*

Table 5. *Simulation results with various shaped posts.*

Supporting posts	ASI	THIV (km/h)	Working width (mm)
C-shaped	0.93	26.1	805
I-shaped	1.08	25.6	916
U-shaped	0.96	24.8	820
Sigma-shaped	0.91	26.8	925

The results showed that the best performance was demonstrated by the sigma-shaped posts and the I-shaped posts absorbed the lowest amount of impact energy. The optimal result was registered by the barrier with sigma-shaped posts, which demonstrated a lower ASI value and higher energy crash absorption than the other models did.

6. Conclusion

This study presents a summary for the finite-element modelling of four different types of posts used in the W-beam guardrail system and their crashworthiness using LS-DYNA. Computational simulations have proved that in all four different shaped posts, the barriers are strong enough to prevent vehicle from leaving the road and the barrier met the EN 1317 standard. The best performance was demonstrated by the sigma-shaped posts and the I-shaped posts absorbed the lowest amount of impact energy. The optimal result was registered by the barrier with sigma-shaped posts, which demonstrated a lower ASI value and higher energy crash absorption than the other models did.

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