Development of an Energy Absorbing End Terminal for Open Box Beam Guardrail

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Abstract

An energy absorbing end terminal was developed for use with the European box beam guardrail system. The European box beam rail sections have an open architecture that is different from what is used in North America. The overall design effort utilized finite element simulation, individual component testing using the bogie and pendulum, and performance validation by full scale vehicle crash testing. The design process involved addressing several individual component performance issues. Of these were the design of an extruder head, splice connections for attaching adjacent rail segments, the post to rail attachment connection and anchorage of the rail. The research approach and results are presented in this paper.

Background

Roadside guardrails are used to prevent errant vehicles from impacting roadside hazards, which in turn reduces the number of injuries and fatalities sustained by the motoring public. A variety of guardrail designs are used on roadways worldwide. While the W-beam guardrail system is the most common, the box beam guardrail system is used in a number of countries including the USA, UK, Finland and Switzerland.

The box beam guardrail system acts as a weak post strong beam system and has a relatively higher mounting height and ground clearance. While performance characteristics vary, weak post systems are generally more flexible and have higher overall deflections than strong post systems. The increased flexibility imparts reduced lateral accelerations on impacting vehicles, which in turn reduces the occupant injury probability and improves vehicle stability.

The exposed ends of a guardrail, if not properly treated, can pose a hazard for the motoring public. Ends of the box beam segments have been historically treated by turning them down and anchoring them to the ground. While this prevents the spearing type impact with the beam end, it can induce climbing, vaulting and rollover under certain impact conditions.

The objective of this research was to develop an energy absorbing end terminal for use with the box beam guardrail system with an open box beam rail section. Since this type of guardrail is mostly used in countries requiring compliance with the European Standard EN1317, the end terminal was designed to meet the criterions specified therein. There are some variations of open box beam cross-sections being currently used. Most open section box beams have rectangular cross-sections. However, the top and bottom sides of the UK box beam guardrail section are slightly angled as shown in FIGURE 1. Design efforts presented in this research have initially focused on the UK box beam guardrail cross-section.

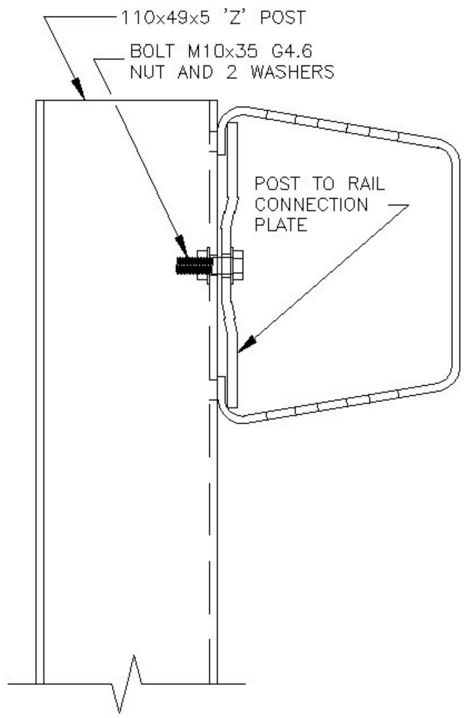


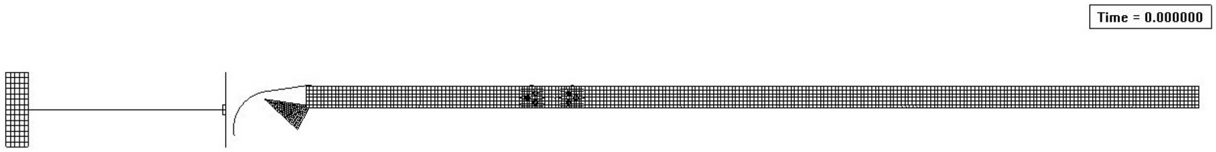
FIGURE 1 UK open box beam cross-section

Design Approach

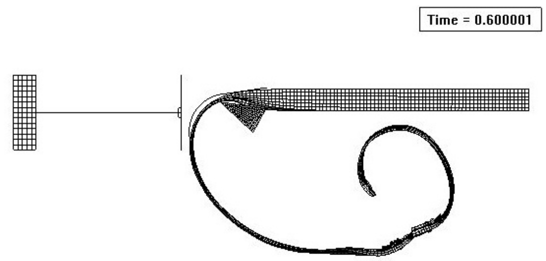
The overall design effort was lead by finite element simulations in conjunction with component level bogie and pendulum testing prior to final design verification through full scale vehicle crash testing. The design process involved addressing several issues. Of these were the design of an extruder head, splice connections for adjacent rail segments, post to rail attachment connection and the rail anchorage. Details of the design process for each of these issues are presented next.

Extruder Head

To absorb the energy of the errant vehicle an extruder head was designed such that when impacted head on, it moves downstream while extruding the open section box beam guardrail through it. Once inside the extruder head, the box beam is first bent open into a shape that approximates a shallow channel and is then deflected out of the path of the vehicle. This process dissipates the energy of the impact vehicle and brings the vehicle to a safe controlled stop. Simplified finite element models such as the one shown in FIGURE 2a were initially used to investigate several design parameters involved in rail extrusion. Simulations were conducted using the LS-DYNA finite element analysis package. These initial simulations consisted of the extruder head modeled as a throat and a deflector plate with rigid material representation. A surrogate vehicle impactor model was used to save computational time. This impactor consisted of a rigid block representing the mass of the vehicle, a spring element with stiffness value approximately comparable to a vehicle's front end crushing and a rigid plate that was attached to the extruder head. The surrogate vehicle impactor and the extruder head were constrained to translate in the direction of impact only. The rail was modeled with piecewise linear plasticity material model (MAT24 in LS-DYNA) and was constrained at the downstream end of the rail segment. The initial velocity was applied to the impactor block which caused the extruder head to move forward, thus feeding the rail through it (see FIGURE 2b).



(a)



(b)

FIGURE 2 Simplified finite element models (a) undeformed state (b) deformed state.

The effects of design parameters such as the extruder head inlet and outlet dimensions, deflector plate bend radius, taper of the extruder throat, etc. on the occupant risk numbers (THIV, PHD and ASI) and vehicle stopping distances were evaluated using these models. By varying the configuration of the extruder head, the net extrusion force could be varied. High extrusion forces resulted in higher THIV and PHD values that failed to meet the EN1317 criteria. On the other hand low extrusion forces resulted in longer stopping distances which require unnecessarily long end terminals.

Of the simulated configurations, the final head configuration selected consisted of a 254 mm radius deflector plate. The inlet and the outlet of the extruder throat were 130 mm and 55 mm, respectively. The length of the throat was selected to be 306 mm. This configuration showed reasonable margin in the occupant risk values from their failure thresholds and at the same time resulted in reasonable stopping distance.

Using basic extruder configurations selected above, remaining details were added to the extruder head design. One of the design objectives was to attain enough robustness so that the extruder head remains fairly reusable with few repairs after most impacts. At the same time it was desired to optimize the weight of the head by removing any extra material being used in the design. Detailed finite element models of the extruder head were develop and impacted by full scale vehicle models (see FIGURE 3). These simulations were used to identify areas of high stresses in the device and to improve and optimize the design in terms of its robustness and weight.

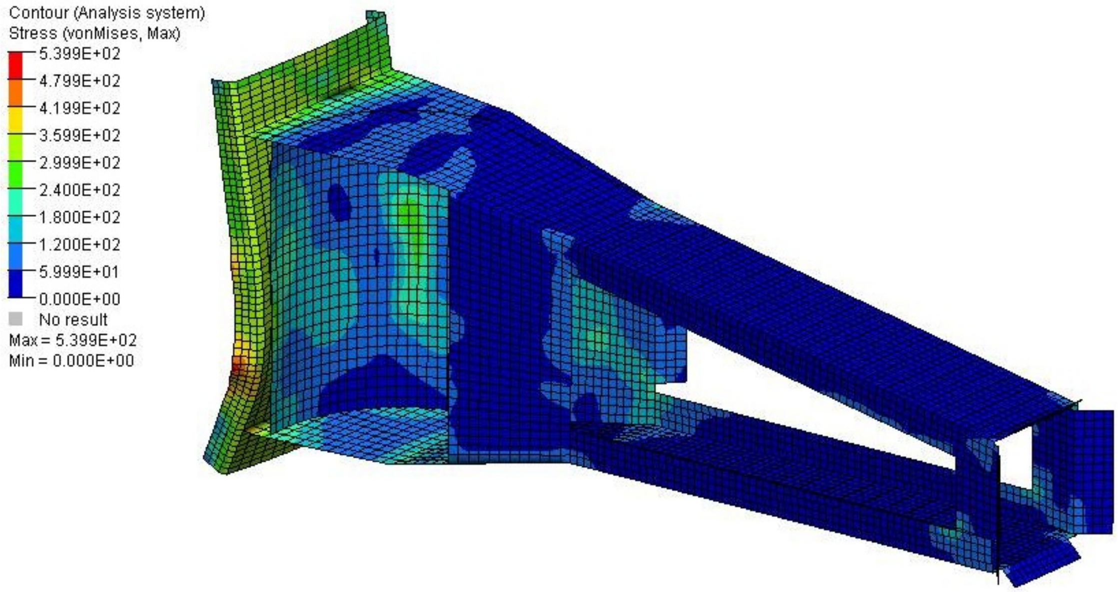
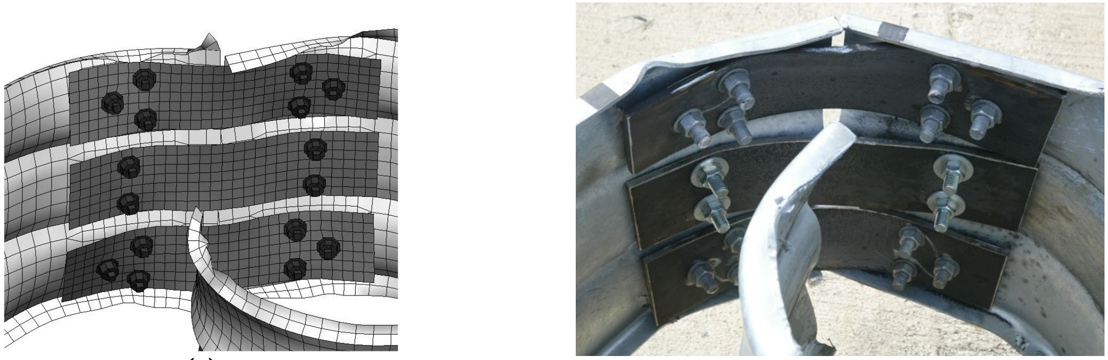


FIGURE 3 Stress contours in the extruder head after impact by a 2000 kg vehicle.

Splice Connection

The splice connection in the original UK box beam guardrail system consists of two shallow channels that trace the angled top and bottom profile of the UK box beam cross-section. These shallow channels (known as the 'fish plates') are bolted to the top and bottom faces on the inside of the adjacent guardrail segments to establish a connection. On being extruded through the extruder head, the shallow channels provide additional bending strength that causes the rail to choke in the extruder head. Moreover, the legs of the shallow channels provide a snagging hazard within the extruder head that can cause the rail to choke. Due to these factors, the original splice connection was modified.



(a) (b)

FIGURE 4 Evaluation of the modified splice connection (a) simulation result (b) bogie test result.

The modified design consisted of three flat plates bolted on the inside surfaces (top, bottom and side) of the adjacent rail segments. The plates matched the tensile and bending capacities of the UK box beam guardrail. Finite element simulation was used to evaluate the extrusion of the modified splice connection followed by a component level bogie test (see FIGURE 4). The modified splice successfully extruded through the extruder head in the simulation and the test.

Post to Rail Attachment

In the standard UK box beam guardrail system, the rail is attached to the posts using a bent clamp plate connection shown in FIGURE 5. This 6 mm thick plate is slightly depressed in the center and clamps the legs of the rail on the open side of the rail section to a “z” profile steel post. A bolt passing through the middle of the clamp plate attaches it to the post.

FIGURE 5 Post to rail attachment using clamp plate connection.

During the process of rail extrusion, the rail to post connection needed to disengage so as to prevent any abrupt stoppages. A bogie test was conducted to evaluate the performance of the clamp plate connection during rail extrusion. It was found that the connection disengaged without offering any significant resistance to the forward movement of the extruder terminal. While moving forward, the guide chute attached to the extruder head impacts the “z” post and tries to lay it down. This causes the post to pull on the bent clamp plate at its center through the connecting bolt. The plate therefore bends and releases the outer legs of the rail section, which was previously clamped in the interface between the clamp plate and the “z” post. The rail is thus released. Because of its acceptable performance, the standard clamp plate connection was used in the designed end terminal.

Rail Anchorage

A releasable cable anchor system was used to provide anchorage at the upstream and downstream ends of the terminal system. The cable anchor system was designed to provide anchorage to accommodate redirection impacts along the length of the terminal and to release when engaged by a vehicle in a head-on impact with the end of the terminal.

Initially the upstream anchor was designed using pendulum testing setup shown in FIGURE 6. The rail segment was punched with rectangular slots on the bottom side of the rail for attachment of a cable anchor bracket. Lugs on the cable anchor bracket engaged the slots on the underside of the rail, and a cable connected the anchor bracket and the base of the cable release post underneath the extruder head. The pendulum pulled on the rail at the second post, thus transmitting forces into the cable anchorage. The anchorage sustained sufficient force levels to warrant its use in the final terminal design.

(a) **(b)**

FIGURE 6 Pendulum test setup for applying loads on the cable anchor.

Crash Testing

As mentioned previously, the European Standard EN1317:2002 Part 4 was used to conduct the full scale crash tests. The standard requires four crash tests to be performed for terminal devices with the highest performance class of P4. All of these required tests were performed and were successful. The test agency that conducted these tests was MIRA Ltd. The test article setup for these tests was the same. Presented below are the details of the test article setup, followed by details of the individual crash tests.

Test Article

The energy absorbing end terminal for open box beam guardrail had an overall length of 15 m. The terminal was attached to a 14.39 m length of standard U.K. open box beam guardrail. The height from the ground surface to the center of the open box beam rail was 610 mm.

The end terminal region consisted of three 4796 mm long open box beam rail segments. The rail segments were connected to one another using a modified splice connection consisting of three 450 mm × 114 mm × 10 mm flat steel plates that bolted on the inside surfaces (top, bottom, and side) of adjacent rail segments.

The end terminal system incorporated a total of 7 posts to support the open box beam rail sections. Posts 1 and 6 were W150×13 Cable Release Posts (CRP). The inclined plates at the groundline of the CRP served as releasable anchorage points for a cable anchor system. Posts 2 and 7 were W150×13 Steel Yielding Terminal Posts (SYTP). The orientation and size of the groundline holes in the SYTP permits these posts to retain most of their strong axis strength to assist with vehicle redirection while significantly reducing their weak axis strength for end-on impacts.

The CRP (posts 1 and 6) and SYTP (posts 2 and 7) were welded to 254-mm × 203-mm × 22-mm thick steel base plates. The base plates were bolted to a 762-mm wide × 14.76-m long × 610-mm deep concrete foundation pad was that was cast along the length of the terminal section using four 19-mm diameter × 406-mm long anchor bolts.

Posts 3, 4 and 5 were standard, 5 mm thick, “Z” profile posts of material specification BSEN 10 025 grade S355 commonly used in the open box beam guardrail system. These posts were inserted 470 mm into 120-mm × 60-mm × 3-mm thick steel tube sockets cast into the concrete foundation pad. The total length of the test installation was 200m (see FIGURE 7).

FIGURE 7 Test article installation.

Crash Test D0030 (EN1317 Test Code TT 1.3.110)

This test evaluates the performance of the extruder terminal under impact from a 1500 kg vehicle with a velocity of 110 km/h and 0 degree impact angle.

A 1522 kg, Rover 75, 4-door impacted the extruder head with initial speed of 114.7 km/h at a 0 degree angle to the traffic face with the centerline of the test vehicle aligned with the centerline of the terminal system. The vehicle was contained by the barrier system and stayed on the barrier center line throughout the impact. It came to stop approximately 10 m downstream of the impact point (see FIGURE 8a). None of the major terminal parts detached or left the permanent lateral displacement zone as specified by the EN1317 criteria. No part of the terminal caused deformation or penetration to the passenger compartment of the test vehicle.

All occupant risk values were within acceptable limits. The theoretical head impact velocity (THIV) was 32 km/h. The post-impact head deceleration (PHD) was 9 g and the acceleration severity index (ASI) was 1.0. FIGURE 9a shows the sequential images from the test. The test was determined successful for having met all specified criteria. For more information the reader may consult reference (*1*).

Crash Test D0031 (EN1317 Test Code TT 2.1.100)

The objective of this test is to evaluate the performance of the extruder terminal under impact from a 900 kg (± 40 kg) vehicle with a velocity of 100 km/h and 0 degree angle to the traffic face. The vehicle impacted the end of the terminal with a ¼ vehicle offset toward the traffic side.

The test vehicle was an 907 kg Suzuki Swift, 3-door saloon. It impacted the terminal end at 105.0 km/h at angle of 0° to the traffic face. The centerline of the vehicle was offset 395 mm from the centerline of the terminal. On impact the rail started extruding from the extruder head. The vehicle rotated counterclockwise during impact and eventually lost contact with the terminal (see FIGURE 8b). None of the major terminal parts detached or left the permanent lateral displacement zone. No part of the terminal caused deformation or penetration to the passenger compartment of the test vehicle. The vehicle was successfully contained.

All occupant risk values were within acceptable limits. The THIV value was 38.08 km/h. The PHD was 13.64 g and the ASI was 1.3. FIGURE 9b shows the sequential images from the test. The test was determined successful for having met all specified criteria. For more information the reader may consult reference (*2*).

Crash Test D0032 (EN1317 Test Code TT 4.3.110)

The objective of this test is to evaluate the performance of the extruder terminal under impact from a 1500 kg vehicle with a velocity of 110 km/h and 15 degree impact angle at the 2/3rd length of the terminal.

A 1517 kg, Rover 75, 4-door impacted the traffic side of the end terminal with initial speed of 114.4 km/h at a 16 degree angle to the traffic face with impact at 2/3rd point of the terminal length. The vehicle was successfully contained and redirected by the barrier system. None of the major terminal parts detached or left the permanent lateral displacement zone (see FIGURE 8c). No part of the terminal caused deformation or penetration to the passenger compartment of the test vehicle.

All occupant risk values were within acceptable limits. The THIV value was 18.61 km/h. The PHD was 9.81 g and the ASI was 0.7. FIGURE 9c shows the sequential images from the test. The test was determined successful for having met all specified criteria. For more information the reader may consult reference (*3*).

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

FIGURE 8 After test images of the extruder terminal.

Crash Test D0033 (EN1317 Test Code TT 5.1.100)

The objective of this test is to evaluate the performance of the extruder terminal under impact from a 900 kg (± 40 kg) vehicle with a velocity of 100 km/h and 165 degree impact angle at the ½ length of the terminal. The impact is on the traffic side of the terminal.

The test vehicle was a 927 kg Suzuki Swift, 3-door saloon. It impacted the terminal end at 104.6 km/h at angle of 164.1° to the traffic face. The impact occurred at the point of ½ terminal length. The vehicle was successfully contained and redirected by the barrier system. The vehicle rotated counterclockwise during before coming to a stop. None of the major terminal parts detached or left the permanent lateral displacement zone. No parts of the terminal caused deformation or penetration to the passenger compartment of the test vehicle.

All occupant risk values were within acceptable limits. The THIV value was 20.0 km/h. The PHD was 18 g and the ASI was 1.0. FIGURE 9d shows the sequential images from the test. The test was determined successful for having met all specified criteria. For more information the reader may consult reference (*4*).

(a)

(b)

(c)

(d)

FIGURE 9 Sequential images from crash testing

Conclusions

An energy absorbing end terminal was developed for use with the European box beam guardrail system. LS-DYNA was used to optimize the terminal head design and minimize the number of full-scale crash tests required for the development effort.

References

1. Krik A. *Vehicle Impact into an Extruder Terminal*. Report 05-1008937, MIRA Ltd., Warwickshire, England, 2005.
2. Gorton M. *Vehicle Impact into an Extruder Terminal*. Report 05-1008938, MIRA Ltd., Warwickshire, England, 2005.
3. Gorton M. *Vehicle Impact into an Extruder Terminal*. Report 05-1008949, MIRA Ltd., Warwickshire, England, 2005.
4. Gorton M. *Vehicle Impact into an Extruder Terminal*. Report 05-1008950, MIRA Ltd., Warwickshire, England, 2005.