Impact Performance of Flexible Guardrail Systems using LS-DYNA

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ABSTRACT

In Canada, different types of vehicle collisions are recorded every year, resulting in many injuries and fatalities (2,969 road users killed and 17,500 seriously injured during 1999, *Road Safety Vision 2001*). The severity of these collisions depends partly on the aggressiveness and incompatibility in vehicle-to-roadside hardware collisions. This paper evaluates, using LS-DYNA software, the vehicle impact performance of flexible barriers made of steel W-Beam guardrails supported over six different types of post configurations and material properties. These types include wood posts, steel I-shape posts, steel box-beam posts and steel Z-shape posts. The dynamic performance criteria considered in this paper include energy absorption for the guardrail, as well as the vehicle rails, were examined. Moreover, movements at the driver's side rocker panel along the bottom of the A-pillar and beneath the front door as well as along the bottom of the B-pillar, and at the brake pedal were measured. In addition, the acceleration at the driver's side rocker panel along the bottom of the B-pillar and beneath the front door was examined. Results show that The guardrail system with box-beam posts, sliding into a foundation tube that is driven into the ground with proper overlap, provided better safety performance than traditional wood and steel-I-beam posts. Results also showed that the danger of tire snagging was faced regardless of the type of the posts used. On contrast to the traditional concept of guardrail system design of absorbing impact energy and redirecting the vehicle on road, guardrail systems with Z-shape posts, connected to the guardrails along their flanges, showed quick post collapse and the vehicle continued moving off the road.

INTRODUCTION

In the recent years, a lot of obvious changes with the traffic safety and reliability of highways have happened along with the improvement of the road network and vehicle capabilities. However, the state-of-the-knowledge in designing traffic barriers dates back to 1970's. Traffic barrier design provided by the current *Canadian Highway Bridge Design Code of 2000* [1] is based upon the *AASHTO Guide Specifications for Bridge Railings* of 1989 [2] and the *AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers* of 1977 [3]. They include concrete barriers, Steel W-beam guardrail on wood or steel posts, steel box-beam on steel posts, cable guardrail with steel or wood posts and chain-link fence arresting barrier. A traffic barrier serves dual and often conflicting roles. It must be capable of redirecting and/or containing an errant vehicle without imposing intolerable conditions on the vehicle occupants. It should be able to do this for a range of vehicle sizes and weights, impact speed and impact angles. Compromises are necessary to achieve a balance between the structural and safety requirements. Crashworthiness focuses on the capability of a vehicle to protect its occupants in a collision. The evaluation of vehicle crashworthiness has involved numerous full-scale crash tests of the vehicle and highway hardware to verify the compliance with regulatory requirements. This test-guided product development process is very costly and time-consuming. As an alternative, computer simulation tools are increasingly being used for the upfront assessment of crashworthiness without going through multiple-cycles of prototype testing and iterative design changes. In impact design, yielding of steel, as well as large deformation, is desirable for economic and safety reasons. As the structure is stressed in the plastic region, it continues to absorb the impact by balancing kinetic energy of the crash against its strain energy. The dynamic performance criteria considered herein for traffic barrier include (i) structural adequacy, (ii) impact severity, and (iii) vehicle trajectory hazard. Few authors dealt with finite-element modeling for comparison with results from experimental testing on traditional guardrail systems [4] [5] [6]. A most recent report [7], published by the National Cooperative Highway Research Program in February 2003, presented a summary of the state-of-the-art on the use of various guardrail systems, defined strengths and weaknesses of the current systems, and proposed recommendations for changes to the strong-post W--beam guardrail system. The current paper summaries results from finite-element modeling done by the authors on the impact of pickup truck with steel W-beam guardrail system with six different post configurations and material properties. Their dynamic performance is then discussed.

FINITE-ELEMENT MODELING

In this study, the guardrail system type RWM02a was modeled using LS-DYNA software. It was composed of W-shaped, 12-gauge, galvanized steel rail attached to posts at closely spaced internals of 1905 mm. six different configurations and material properties of the rail posts were considered in this study. The first one was made of wood, with cross-section of 150×390 mm with the shorter side in the direction of the guardrail. A W150×14 steel section formed the second type of posts. The third and the fourth types of guardrail posts were made of two steel tubes. The upper part, which was made of 152.4×152.4×3.0 mm square steel box sections, slides into a foundation tube (177.8×177.8×4.8) that is driven into the ground. The minimum overlap length of the two tubes was 105 mm in the former and 260 mm in the latter. The fifth and sixth post types were made of Z-shape case1 and case2 sections with 1.52 and 3.50 mm thickness [7], respectively. In case 5, the guardrail was connected to the flange of the Z-shape section. While in case 6, the guardrail was connected to the post normal to the flange of the Z-shape cross-section. Figure 1 shows the layout and cross-section of box and Z posts. The cross sections for all posts except of the wood posts provide the same section modulus.

Wood posts were modeled using eight-node solid elements. While other types of steel posts were modeled using shell elements to capture the three-dimensional effects of the structure. For all post simulations, total spring coefficients, shown in Table 1, were considered in the directions parallel and perpendicular to the guardrail. Each spring coefficient was distributed equally over five nodal points in post cross-section. A finite-element model for a pickup truck [8] has been used to simulate a vehicle heading towards the guardrail with an angle of 25° at a speed of 100 km/h (http://www.ncac.gwu.edu/archives/model/, 2002). The major characteristics of the complete FE vehicle model can be identified elsewhere [8].

Table 1. Spring coefficients considered in this study

Section location from ground level	Spring coefficient parallel to guardrail, N/mm	Spring coefficient normal to guardrail, N/mm
	31,120	23,500
2	63,400	47,985
3	96,400	73,100
4	130,000	98,750
5	164,100	124,850
6	198,700	151,350
7	233,700	178,250
8	269,100	205,450
9	309,900	236,850

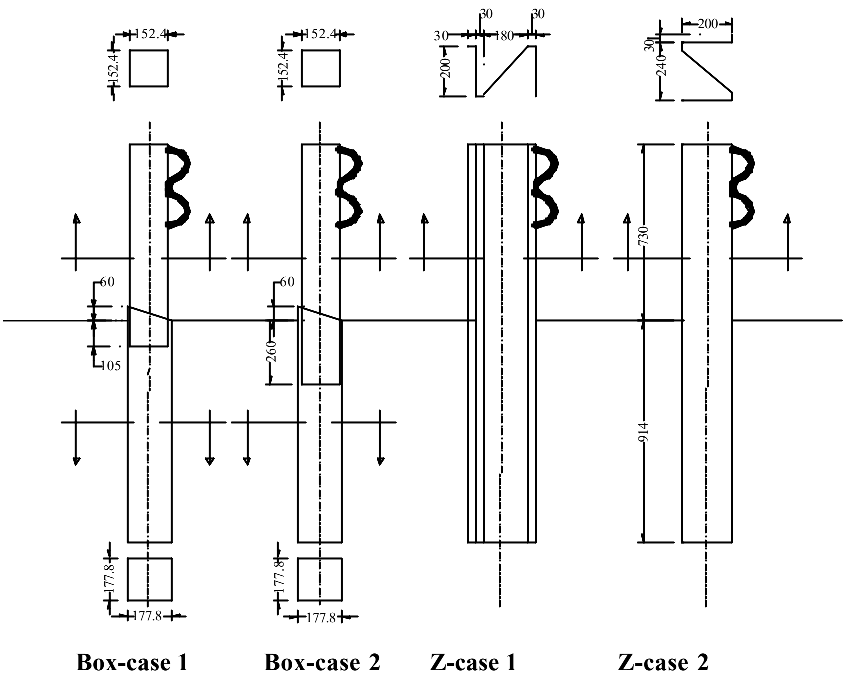
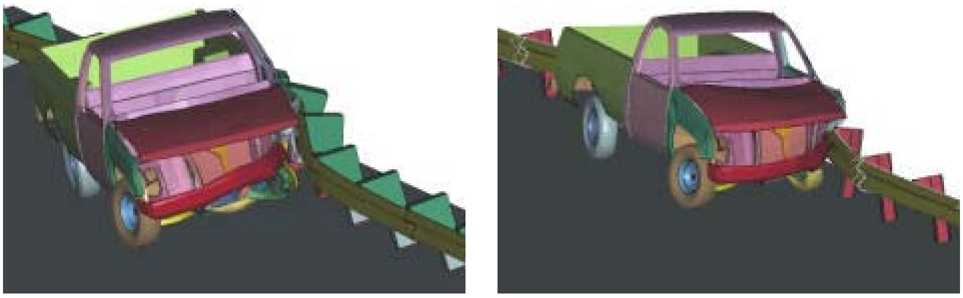


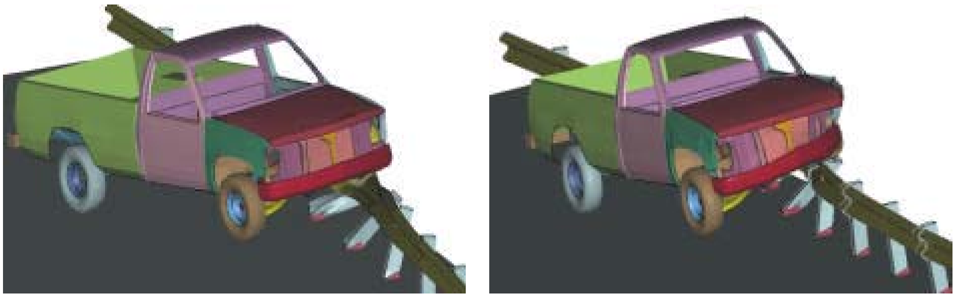
Figure 1 Layout of the box and Z-shape steel guardrail posts considered in this study

SUMMARY OF RESULTS

The finite-element simulation was performed for a maximum time of 60 ms using the nonlinear FE code LS-DYNA. The vehicle model was given initial velocity of 100 km/h to impact the guardrail system at an angle of 25° to the rail. Figure 2 shows deformations of both the vehicle and the guardrail for the six guardrail post configurations. It was observed that wood, steel I-shape and Z-shape case 2 posts were able to redirect the pickup truck in the road. However, in other post configurations, the guardrail could not keep the car inside the road as a result of quick collapse of the posts close to the impact location. However, It was observed that in all cases the danger of tire snagging was faced regardless the type of the posts used.

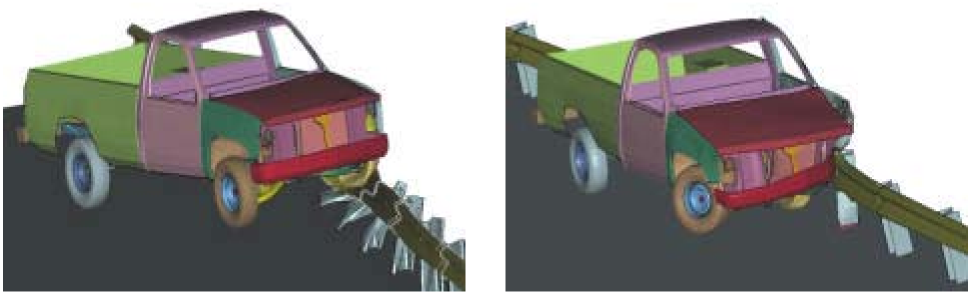


(a) Impact with wood posts (b) Impact with Steel I-beam post



(c) Impact with steel box post, case 1

(d) Impact with steel box post, case 2



(e) Impact with Z-shape post, case 1

(f) Impact with Z-shape post, case 2

Figure 2. Deformed shape of the guardrail system during vehicle impact

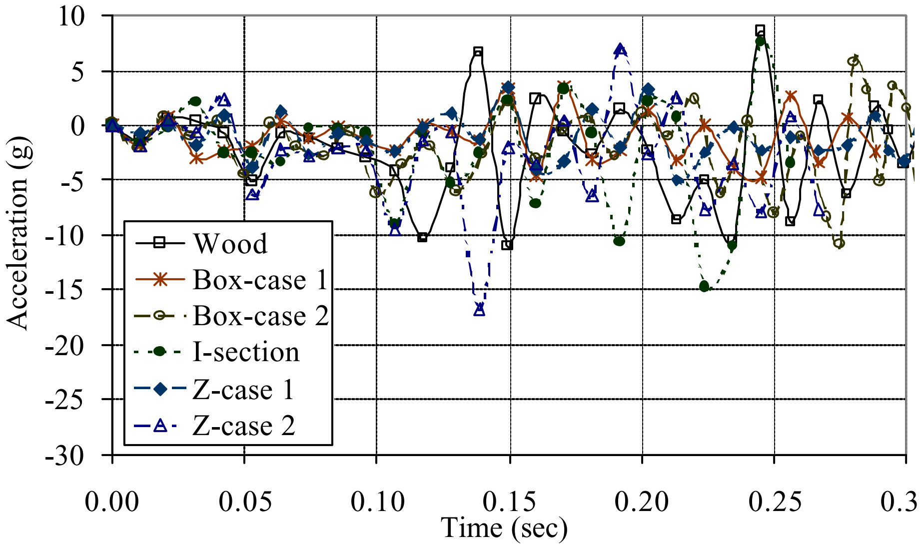


Figure 3. Acceleration-time history of B-Pillar for different post configurations

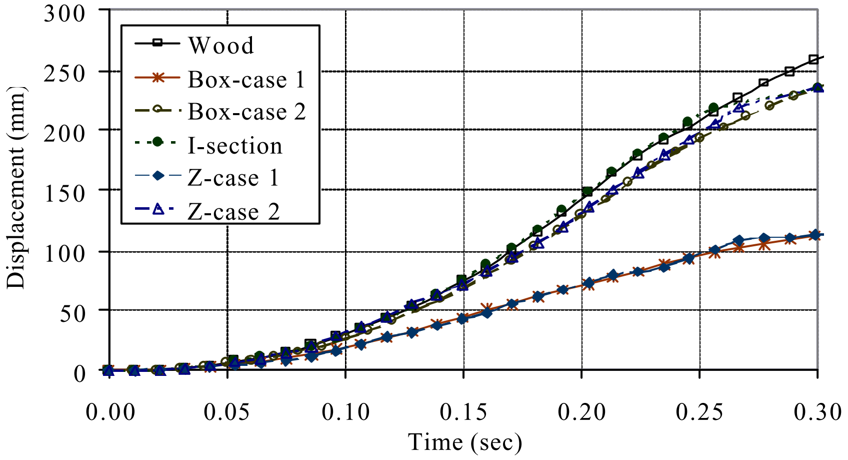


Figure 4. Movement-time history of A-Pillar for different post configurations

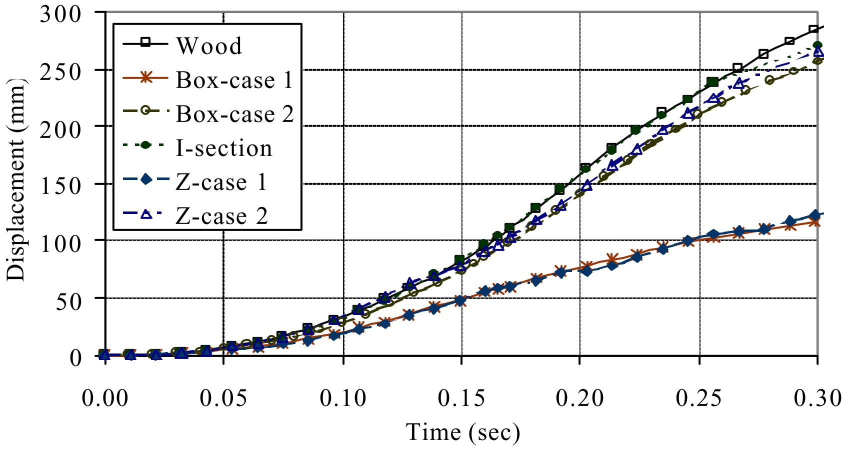


Figure 5. Movement -time history of B-Pillar for different post configurations

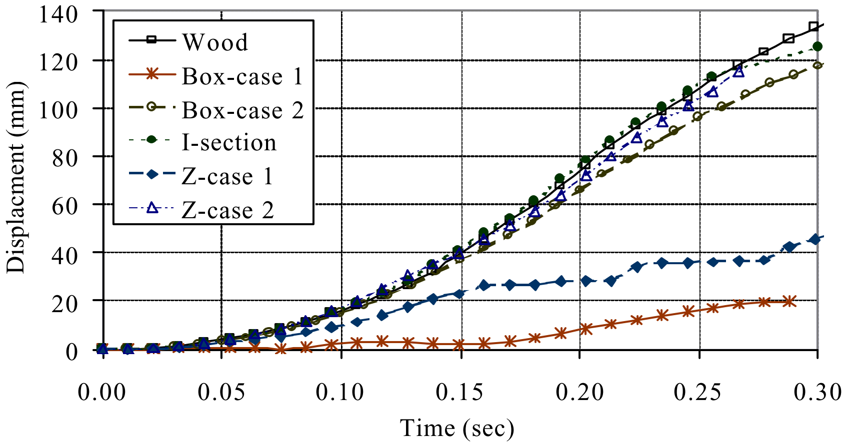


Figure 6. Movement-time history of brake pedal for different post configurations

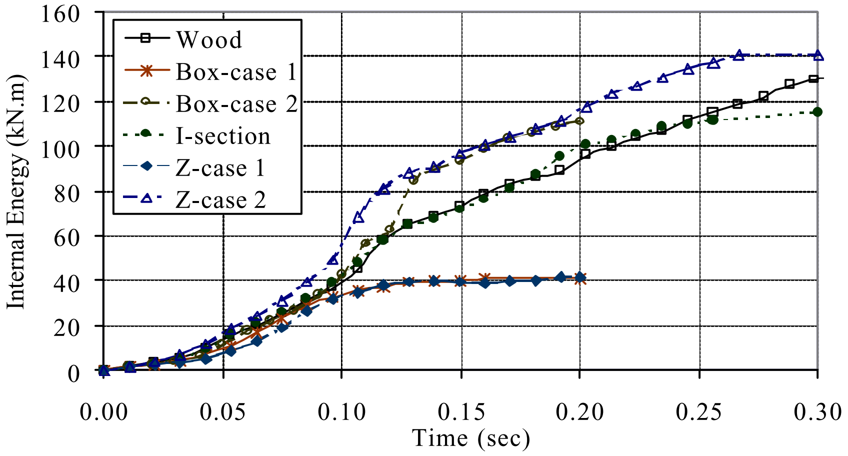


Figure 7. Internal absorbed energy of the guardrail for different post configurations

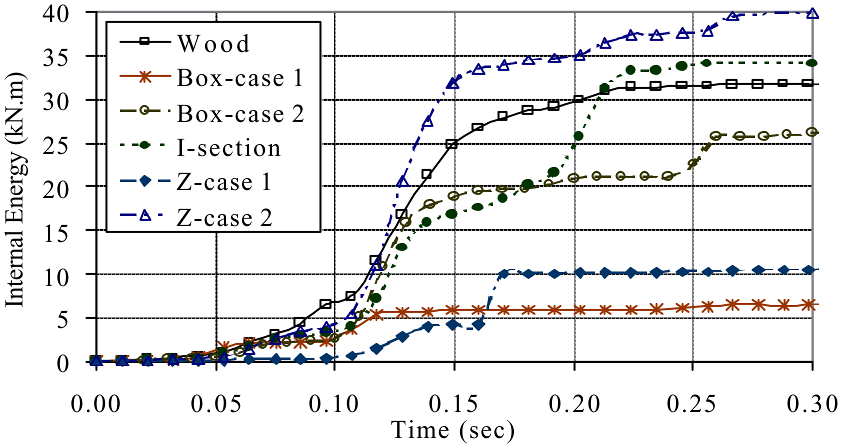


Figure 8. Internal absorbed energy of the vehicle main rail for different post configurations

Figure 3 shows the acceleration-time history at the driver's side rocker panel along the bottom of the B-pillar and beneath the front door for different guardrail post configurations for the first 30 ms. It can be observed that guardrail systems with Z-shape case 2 posts and steel I-beam posts exhibited larger accelerations that other systems with other post types. However, this is not an issue herein since the maximum observed accelerations is considered within the practical limits.

While figures 4, 5 and 6 show the movement-time history at the A-pillar, B-pillar and brake pedal for different post conditions, respectively. It can be observed that guardrail systems with both Box beam case 1 and Z-shape case 1 posts provided the least deformation in the vehicle as a result of excessive deformations induced on them from impact, followed by complete collapse. It should be noted that in case of Z-shape case 1 and box beam case 1 posts, the pickup truck continued moving outside the road. Guardrail systems with other post types exhibited almost similar deformation on the vehicle, with slight increase in case of wood posts.

Figures 7 and 8 show the internal absorbed energy of guardrail and the car main rail, respectively, for different post configurations. It can be observed that guardrail systems with Z-shape, case 1, and box-beam case 1 posts provided the least energy absorption for both the guardrail and the car main rail. This may be attributed to the fact that the quick collapse of the posts close to the impact locations allowed the car to continue moving with insignificant obstruction, thus producing less minor damage in the car itself. On the other hand, it was also observed that guardrail system with Z-shape case 2, wood and I-shape posts absorbed more energy than other types as results of large deformation. However, the absorbed energy of the car main rail in this impact case with Z-shape case 2 posts was higher than those produced in other guardrail system configurations. It should be noted that the absorbed energy by guardrail systems with wood posts was less than those produced by guardrail systems other than the collapsed ones. This would prove that the guardrail system with wood posts is the most feasible type for vehicle safety performance, followed by the guardrail system with Z-shape and I-beam posts. It is also interested to note that the performance of box-beam guardrail-posts system is improved by increasing the overlap between the box-beam post and the fundamental tube in the ground. However, the system was unable to redirect the vehicle on the road for the case considered herein.

CONCLUSIONS

This paper presents a summary for the finite-element modeling of different types of guardrail systems and their interaction with the soil during impact events using the nonlinear finite-element program LS-DYNA. The post-soil interaction was modeled using the subgrade reaction approach, which involved an array of nonlinear springs attached along the length of the post below grade. The post type was proved to be a fundamental component of a guardrail system. Based on the data generated from this simulation study, the following conclusions were drawn:

1- The guardrail system with wood posts provided better safety performance than other posts types.
2- The danger of tire snagging was faced regardless of the type of the posts used.
3- On contrast to the traditional concept of guardrail system design of absorbing impact energy and redirecting the vehicle on road, guardrail systems with Z-shape case 1 and box-beam case 1 posts showed quick collapse of the post and the vehicle continued moving off the road. These systems may be acceptable of the road shoulder is wide enough to accommodate further forward movement of the vehicle after impact.
4- Guardrail system with Z-shape case 2 posts did redirect the vehicle on the road. However it showed the highest internal energy absorbed by the vehicle.
5- Further study is recommended to examine the proper overlap length between the box-beam post and the embedded tube under the ground level to reach the most appropriate safety performance as suggested by *NCHRP Report 350.*

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REFERENCES

1. CANADIAN STANDARD ASSOCIATION. (2000) "Canadian Highway Bridge Design Code", CAN/CSA-S6,00, Toronto, Ontario, Canada.

2. AASHTO. (1989) "AASHTO Guide Specifications for Bridge Railings", American Association of State Highway Officials, Washington D.C., USA.

3. AASHTO. (1977) " AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers", American Association of State Highway Officials, Washington D.C., USA. .

4. GENTRY, T. R., BANK, L. C. (1998) "Finite-element Modeling and Model Verification of Steel W-beam Guardrails Subjected to Pendulum Impact Loading, Transportation Research Board, 1-20.

5. PLAXICO, C. A., PATZNER, G. S. AND RAY, M. H. (1998) "Response of Guardrail Posts under Parametric Variation of Wood and Soil Strength", Transportation Research Board, 1- 27.

6. MARTIN, O. S. AND WEKEZER, J. W. (1998) "Crash Impact Analysis of the G2 Guardrail: A Validation Study", Transportation Research Board, 1- 17.

7. NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM, (2003) "Development of an Improved Roadside Barrier System - Phase I", Research Results Digest No. 273, Transportation Research Board, pp. 1-23, February.

8. http://www.ncac.gwu.edu/archives/model/. (2002). FHWA/NHTSA National Crash Analysis Center George Washington University, U.S.A.