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The Development of a Rail Passenger Coach Car Crush Zone

1. Introduction

There is currently an active program within the United States to improve the passive safety of train systems. In particular, the Volpe Center is supporting the Federal Railroad Administration's research that includes numerous analytical studies and laboratory tests. The Center is managing a series of full-scale passenger car collision tests. Three tests of conventional equipment have been completed, and two other tests are planned for the spring. After completion of these tests, the next phase will be to carry out full-scale collisions of passenger cars equipped with modern crashworthiness features, such as an integrated crash management system. Such systems, incorporating crush zones in vehicle ends, have been applied to passenger cars around the world, and have been shown to be highly effective in protecting car occupants from injury in a collision.

The objective of the work reported here is to develop a detailed final design of a crash energy management system that can be installed into an existing passenger coach car and subjected to a full-scale collision test. Elements in the program are to develop and evaluate strategies for the proposed system, prepare and analyze a preliminary design, fabricate and test critical components of the design, and finalize the design in the light of test and analysis results. The end product will be detailed drawings for a design ready to be fabricated and installed on the selected test vehicle.

2. Background

The requirements for the crash energy management system were developed in recognition of the vehicles and trains that have been designed throughout the world and on the prevailing philosophy of passive protection. Thus, the system includes three elements. These are: a pushback coupler and an interlocking anticlimber to ensure that the underframes of interacting vehicles transfer load through their primary load-bearing structure; and a zone at the end of the car designed to crush and absorb energy in a controlled manner without endangering the occupant volume. Table 1 lists some of the systems that were reviewed as part of the study and that have been designed with similar goals. Based in part on this review, a goal for the energy absorption of the coach car end was set at 2.5×10^6 ft-lbf (3.4 MJ) in 36 inches (0.9 m) of crush.

There are important lessons to be learned from each of these and other systems. For example, it has been found difficult to achieve a desired force-crush response by modifying an underframe only through cutouts or reinforcements. In general, the use of independent prismatic members, through careful selection of cross section, thickness, transverse reinforcements and cutouts, enables one to achieve the desired response for a variety of impact speeds and misaligned loads. It is also necessary to ensure that the material properties for crushable structure fall within a specific range; that is, they must have both minimum and maximum values. In addition, limiting most of the crush to the energy absorbing elements reduces the number of subcomponents that must be tested. In some cases, one can be successful using the primary energy absorbers to also carry required operational loads (active elements). However, the design process becomes more complex, generally requiring many iterations.

One of the challenges of our project is the need to incorporate the design crush zone into an existing and, likely, aged vehicle. In this case the load paths and approaches to connecting the crush zone to the vehicle are limited. These disadvantages are offset by the advantage of substantially reducing the cost of the program and providing a demonstration of the feasibility of incorporating these types of systems into conventional North American construction.

Table 1: Crush Zone Examples Reviewed as Part of the Program

System/ Vehicle	Crush Zone Design Energy Absorption (10^6 ft-lbf)	Primary Energy Absorption Approach	Absorption Material
Acela	4.5	Dedicated energy absorbers	301L, HSLA50
TGV Duplex	3	Underframe (slotted) beams	Carbon steel
XTER	2.8	Isolated underframe absorbers	Carbon steel
ICE3 Cab Car	2	Dedicated energy absorbers	Glass epoxy
NYT R142 (Bombardier Design)	1.0	Absorption elements that also carry operational loads	HSLA50
Canadian Via System	1.0	Box absorbers	Carbon steel
Mk1 Modifications	0.7	Cut-outs in underframe	Carbon steel
NJT Hudson-Bergen LRV	0.4	Dedicated energy absorbers	Extruded aluminum

3. Crush Zone Design

3.1 Concept

Figure 1 shows the overall concept for our crush zone, which we refer to as a sliding sill crush zone. The operating loads, both longitudinal and transverse are carried by a ‘center sill’ that consists of a sliding and a fixed component, connected by a series of bolts. Under severe collision conditions, and after the pushback coupler mechanism (see below) has been activated, the bolts shear and the sliding sill moves longitudinally into the fixed sill. This system also carries vertical and lateral loads during the crush process. Separate energy absorbers, which carry no load during normal operation, are crushed as the sliding sill moves inward toward the center of the car.

3.1 Pushback Coupler

The pushback coupler consists of a conventional U.S. coupler and draft gear. The buff (compression) lug is connected to the sliding sill element through eight bolts designed to shear at a load of about 450×10^3 lbf (2000 kN). A total of about 8 inches (200 mm) of pushback motion occurs during which a block of aluminum honeycomb is crushed. The energy absorbed by this pushback motion is approximately 0.3×10^6 ft-lbf (0.4 MJ). Figure 2 shows a drawing of the pushback coupler.

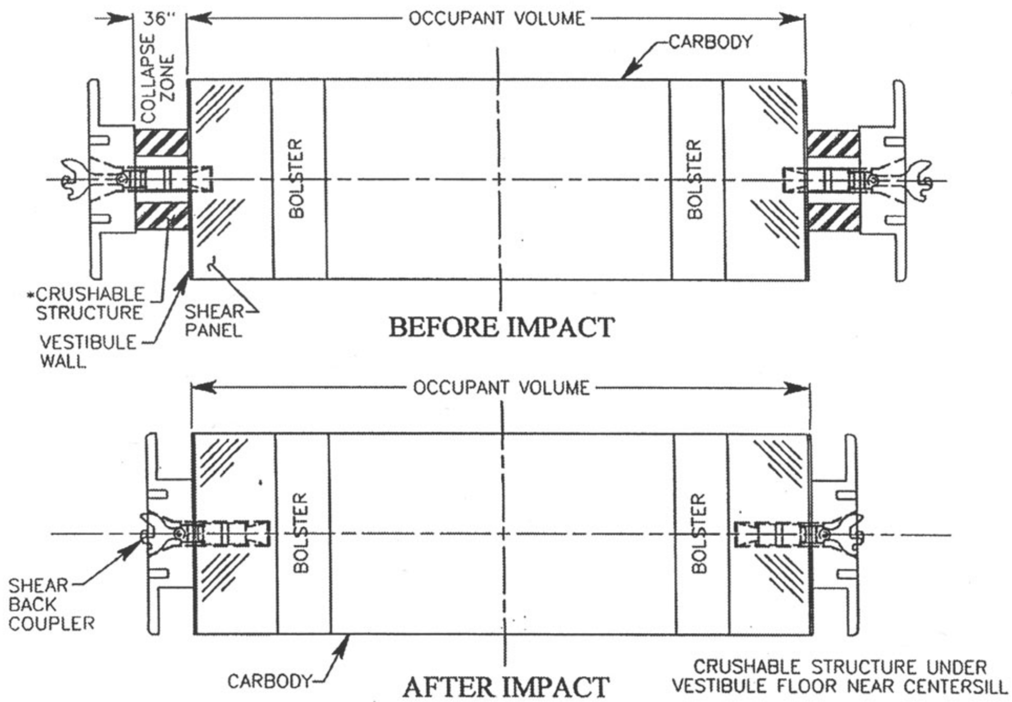

Figure 1: The Sliding Sill Crush Zone Concept

3.2 Interlocking Anticlimber

Our approach for ensuring that two interacting vehicles cannot climb with respect to each other is to use a ribbed anticlimber element mounted on the end of the underframe over the coupler. This is shown in Figure 2. No energy absorption is associated with the anticlimber element. The vertical strength of the ribs and their attachment to the car as well as the supporting structure is:

a) 100×10^3 lbf (445 kN) for crush values up to the design crush of 36 inches (0.9 m).
b) 200×10^3 lbf (890 kN) for a crush value of 36 inches (0.9 m).

We have conducted an extensive study on systems to prevent override as reported in [1].

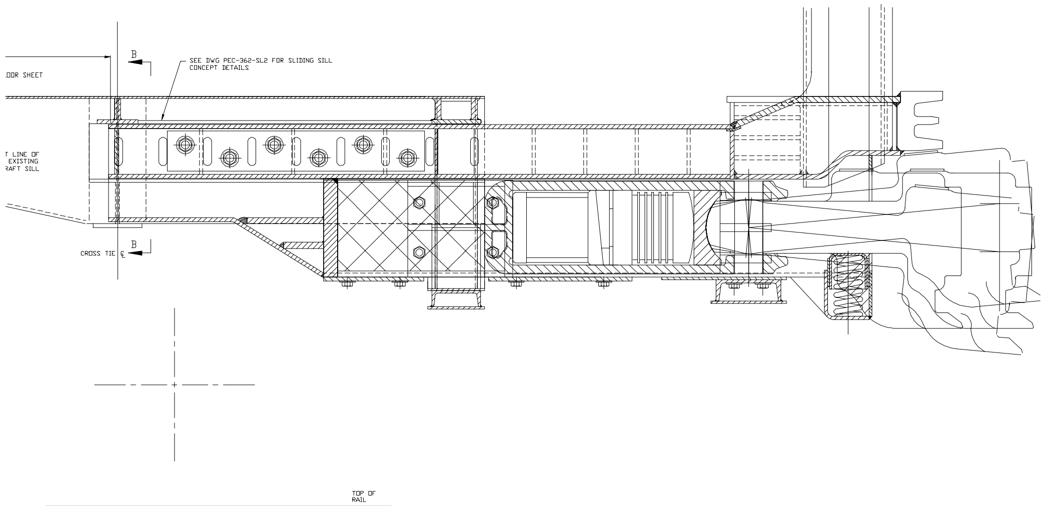

Figure 2. The Pushback Coupler Element (Side View)

3.3 Sliding Sill Crush Zone

3.3.1 Overview

The overall vehicle end crush zone is illustrated by the finite element model shown in Figure 3. As stated previously, the sliding sill-to-fixed sill connection is made with a series of 20 bolts, whose combined shear strength is approximately 800×10^3 lbf (3600 kN). Once these bolts are sheared, the sliding sill itself is free to move back into the vehicle. However, during this motion, crush occurs in two types of elements: the two primary energy absorbers and four longitudinal roof elements. The primary energy absorbers are described in a separate section below. Two of the roof elements are attached to the antitelescoping plate at the corner posts and the other two are attached to the collision posts which have been extended upwards to the roof. These longitudinal elements are stiffer inboard of the crush zone to promote folding of the roof within the crush zone. The energy absorbed by this roof crushing is about 0.2×10^6 ft-lbf (0.3 MJ).

3.3.2 Primary Energy Absorbers

Each of the two primary energy absorbers consists of two tubes of square cross section. Figure 4 illustrates one-half of one of the absorbers. The material of construction is currently A572-50 steel. The total length of the 0.25 inch (6.4 mm) thick elements is 40 inches (1.0 m). Lateral, internal diaphragms and cutouts are included to achieve the desired crush response for a variety of collision speeds. Figure 5 shows the calculated load-crush response for two collision speeds.

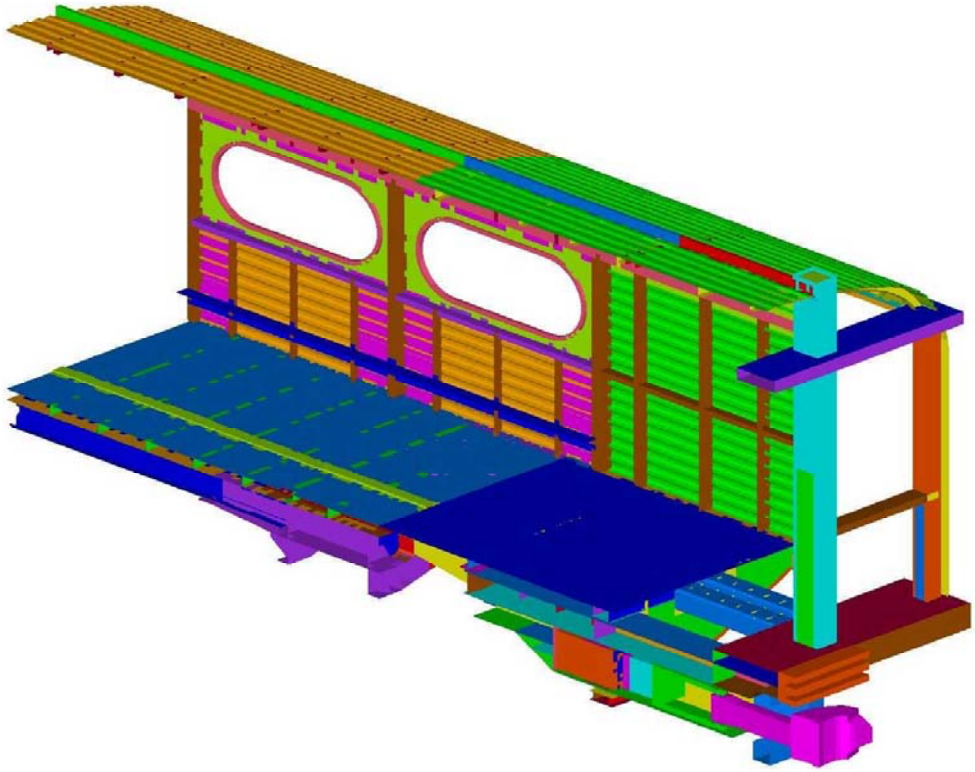

Figure 3. The Sliding Sill Coach Car Crush Zone Design (Half Finite Element Model)

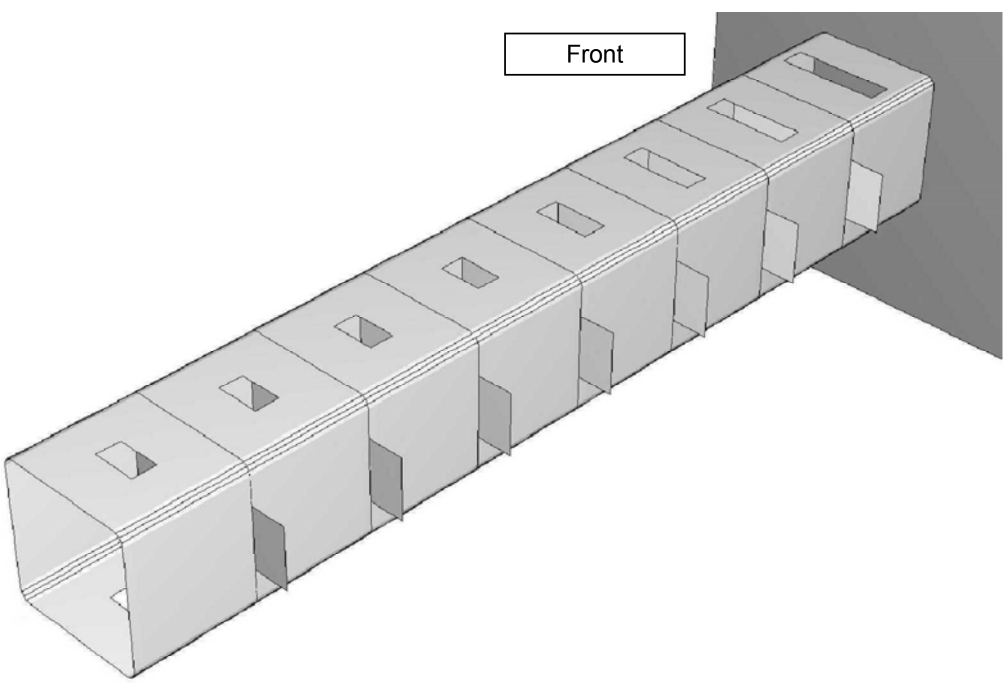

Figure 4. An Illustration of One-Half of One of the Primary Energy Absorbers

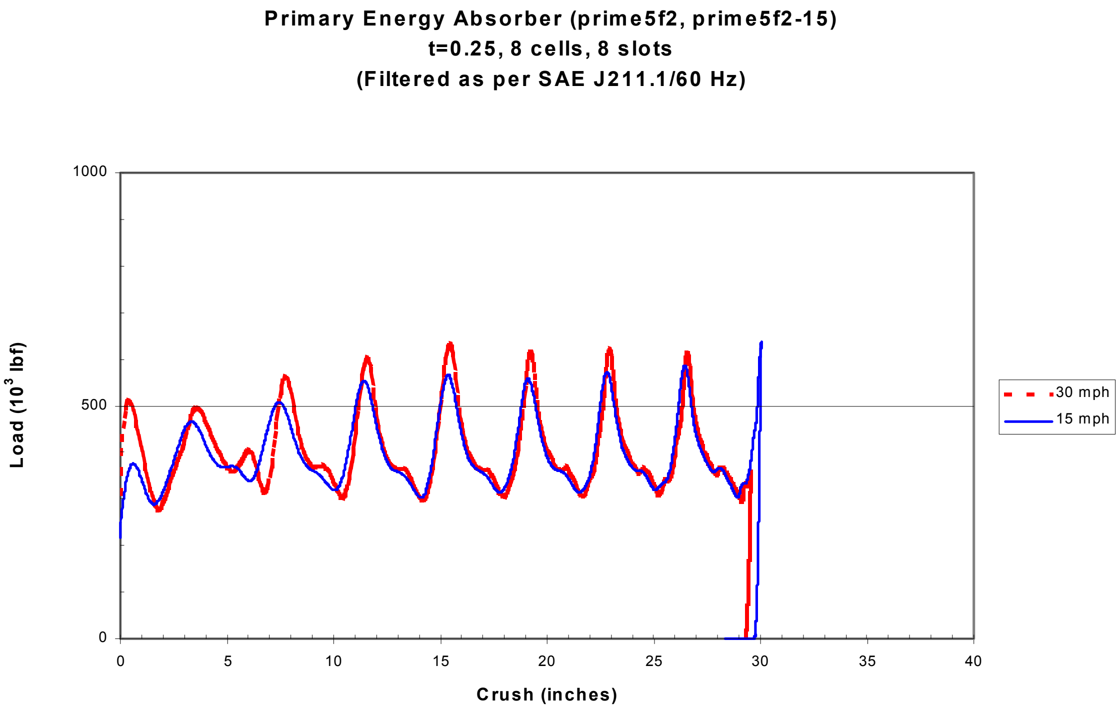

Figure 5. The Calculated Load-Crush Response for an Entire Primary Energy Absorber

3.3.3 Overall Crush Zone Response

Figure 6 shows a deformed mesh plot for the predicted crush of the coach car crush zone corresponding to about 25 inches (0.64 m) of crush. Note that even though there is some downward motion of the relatively rigid buffer beam, the primary energy absorbers and the sliding sill element are crushing as intended.

4. Component Testing

The program includes testing of three of the crush zone components. These include the pushback coupler, the primary energy absorber and the sliding sill-to-fixed sill connection. These test articles are currently being prepared for testing in the drop tower facility illustrated in Figure 7. The results of the testing will be utilized with additional finite element analysis to refine the design.

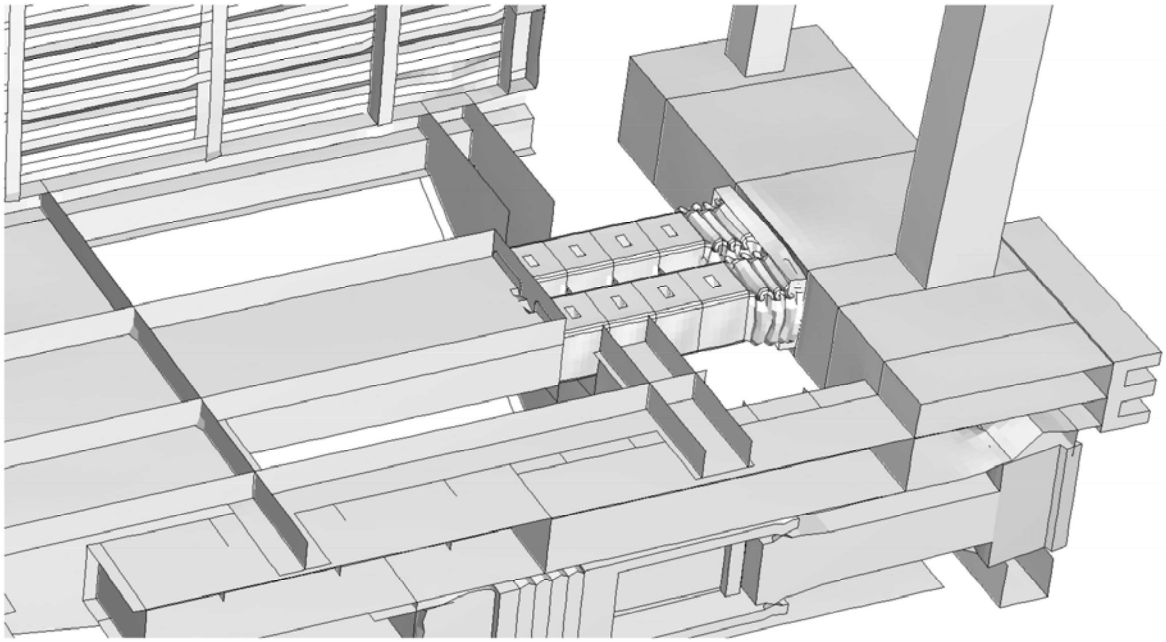

Figure 6. Finite Element Prediction of the Deformation of the Crush Zone

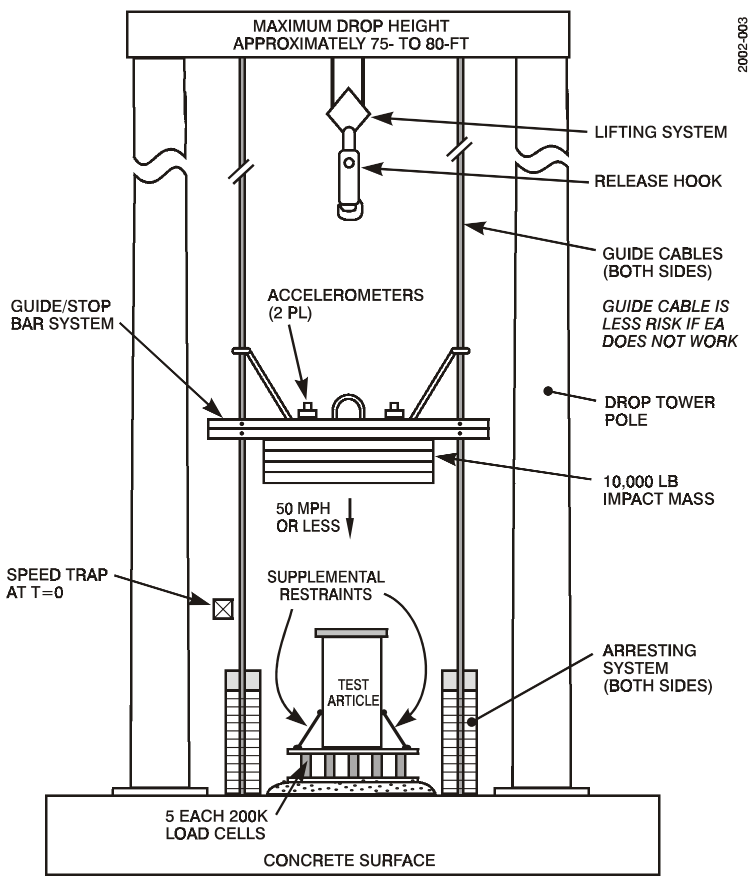

Figure 7. An Illustration of the Drop Tower Facility That will be Used to Impact the Test Articles

5. Summary

We have described the current status of a project to develop a detailed design of a crash energy management system for a rail vehicle passenger coach car. The initial design is complete and we await the results of component tests to refine the design. When completed, the system will be installed onto the end of an existing car for full-scale testing.

References

1. Mayville, R.A., Stringfellow, R.G., Johnson, K.N., and Landrum, S., Crashworthiness Design Modifications for Anti-Climbing Systems, Final Report to the Volpe National Transportation Systems Center, Ref. 71558 (February 2002)100 pages.

Acknowledgements

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