

Rail Equipment Crashworthiness Research

Passenger Equipment Crashworthiness

The Federal Railroad Administration (FRA) has been working with the Volpe National Transportation System Center (Volpe Center) to conduct research into rail equipment crashworthiness. The approach in conducting this research has been to propose strategies for improved crashworthiness and to apply analytic tools and testing techniques for evaluating the effectiveness of those strategies. The information from this research has been used to develop the crashworthiness requirements for Amtrak's high-speed trainset, to develop the FRA's Passenger Equipment Safety Standards, and to draft revisions and additions to current FRA locomotive crashworthiness regulations and the Association of American Railroads (AAR) standards. This research was also applied to support the FRA in evaluating Amtrak's request to grandfather Talgo equipment for continued use in the Pacific Northwest. Information from the research is currently being used by the American Public Transportation Association (APTA) to develop further and refine industry standards and recommended practices for rail passenger equipment crashworthiness. And will support FRA efforts to make improvements to its passenger equipment safety standards as well.

The principal activities of the research include technical studies, the documentation and dissemination of the results of these studies, and the application of the study results to standards development. Through the APTA and the AAR, the railroads and suppliers are involved in planning and conducting these studies. The results are also presented to these organizations, and are documented in Government reports and in technical papers written for the American Society of Mechanical Engineers (ASME,) the Transportation Research Board (TRB,) and other technical organizations.

The overall objective of the rail equipment crashworthiness research is to develop design strategies with improved crashworthiness over existing designs. The rail equipment crashworthiness research strategy is as follows:

1. Define the occupant protection scenarios. For developing crashworthiness, the occupant protection scenarios are the conditions to be survived, if possible. These protection scenarios include the primary accident - a collision or derailment - and the secondary collision - the interaction of the occupant with the interior of the vehicle.
2. Develop information on the features of existing designs that influence crashworthiness. Information on the design details of the equipment - both for the carbody and for the interior arrangement - is developed for use in analytic models and in the fabrication of test articles. Information developed from accidents includes the damage to the carbodies, such as structural failure, and forensic evidence, such as blood, in the interior.
3. Develop options for alternative designs. In some instances, potentially effective changes in either the carbody structure or the interior arrangement can be directly inferred from accident consequences. In other instances, extensive analysis is required to determine potentially effective crashworthiness strategies.
4. Determine the effectiveness of equipment of existing design and alternative design. Post-accident results can show how effective the equipment was in preserving the survival space for the occupants and in maintaining the forces and decelerations imparted to the occupants to survivable levels. There are typically gaps and uncertainties in the information available from accidents; for example, the precise impact speed and initial conditions at impact are rarely, if ever, known in an accident. Analyses and tests are used to fill in the gaps of information available from accidents. Analytic models and tests, similar to those developed and conducted for conventional equipment, are used to evaluate the effectiveness of alternative designs.
5. Compare the crashworthiness of alternative designs with existing designs. For a given occupant protection scenario, comparisons are typically made either in terms of the maximum primary collision speed for which everyone would be expected to survive, or, to support a benefit/ cost analysis, in terms of fatalities and injuries as a function of collision speed.

Protection Scenarios

Passenger train accidents can occur under a wide range of circumstances, but those that can be mitigated by crashworthiness features of the train can be placed into three broad categories:

1. collisions with another train,
2. collisions with objects, such as a grade crossing collision, and
3. single train events, such as a derailment

Further classifications can be made within each of these categories. For example, significant differences may be expected for a locomotive-led train colliding with another locomotive-led train than for a locomotive-led train colliding with a cab car-led train. Track route alignment can also significantly influence the consequences of a collision; the consequences of a head-on collision on tangent track may be expected to be significantly different from an oblique collision at a switch. Similarly, the consequences of a grade crossing collision with a heavy highway truck are significantly different from a grade crossing collision with an automobile. For all accident types, the collision speed can also profoundly influence the consequences of the collision. Placing the accidents into categories allows calculation of the likelihood of occurrence for each collision category as well as the development of strategies for protecting the occupants in each collision category.

Of particular concern are collisions involving cab cars as one or both of the impacting cars. In comparison to locomotives, cab cars are exposed to more risk in collisions. The presence of passengers, the cab car being of lighter weight and weaker strength than the locomotive, and the cab operator being placed at the extreme end of the car, with essentially no structure ahead of him or her, render the car vulnerable. Cab cars are used in all commuter operations in the U.S., either in push-pull operation with a locomotive pushing or in multiple-unit operation, where most of the cars are self-powered.

Some accidents happen under such circumstances - for instance at such great speed -- that it is a practical impossibility to survive such collisions. Very high speed collisions require the use of buffer cars or other measures which may not be considered practical.

Field Study of Occupant Injury

The Volpe Center, in support of the FRA and with the cooperation of the National Transportation Safety Board (NTSB), is conducting a field study of occupant injury during train collisions. The objectives of this study are to determine:

1. the range of severity of the injuries that occur in train collisions and derailments,
2. the types of injuries that occur,
3. where these injuries occur on the train, and
4. the causal mechanisms for these injuries.

The results of this study will be used to focus the research efforts on occupant protection and to provide information for benefit/cost analyses of potential occupant protection measures. As part of the study, detailed observations are made of the train interior locations where injuries have occurred, and interviews are conducted with accident survivors and medical personnel treating the survivors. Observation of the train interior, with its associated forensic evidence, allows development of the causal mechanisms for casualties.

Six accidents have been investigated as part of this study:

- a passenger train derailment in Lake City, South Carolina on August 21, 2000,
- a passenger train collision with a freight train in Syracuse, New York on February 5, 2001,
- a passenger train derailment in Nodaway, Iowa on March 17, 2001,
- a passenger train derailment in Crescent City, Florida on April 18, 2002,
- a passenger train collision with a freight train in Placentia, California on April 23, 2002, and
- a passenger train derailment in Kensington, Maryland, July 29, 2002.
- Three more accidents will be investigated as part of this study.



Fullscale Testing of Passenger Equipment

Two series of tests have been planned: one based on a head-on collision scenario, in which a cab car-led train collides with a locomotive-led train, and the second based on a grade-crossing collision scenario, in which a cab car-led train collides with a tractor trailer carrying a coil of sheet steel. Conventional and alternative designs are to be tested in both series of test.

The conditions and the sequence of the tests are listed in Table 1. The overall objective of these tests is to demonstrate the effectiveness of improved-crashworthiness design equipment. The first series of four tests defines the crashworthiness of conventional-design equipment in the in-line and grade-crossing collision scenarios. The performance of improved-crashworthiness design equipment will be measured in the second series of four tests. This arrangement of the tests allows comparison of the conventional-design equipment performance with the performance of improved-crashworthiness design equipment. The in-line collision tests are intended to measure the crashworthiness of a single car, then the interactions of two such cars when coupled, and finally the behavior of complete trains, including the interactions of the colliding cars. As part of these tests, interior configurations with forward-facing unrestrained, forward-facing restrained, and rear-facing unrestrained test dummies are being used to measure potential occupant dynamics during a train collision. The grade-crossing collision tests are intended to measure the effectiveness of the car end structure in preventing intrusion during a grade-crossing collision.

Test Conditions	Conventional-Design Equipment	Improved-Crashworthiness Design Equipment
Single-Car Impact with Fixed Barrier	November 16, 1999	December 3, 2003
Two-Coupled-Car Impact with Fixed Barrier	April 4, 2000	February 26, 2004
Cab Car-Led Train Impact with Locomotive-Led Train	January 31, 2002	March 23, 2006
Single-Car Impact with Steel Coil	June 4, 2002	June 7, 2002

To date, the three in-line tests for existing-design equipment, the first two in-line tests for the improved-crashworthiness design, and both grade-crossing tests have been conducted. The train-to-train test of improved-crashworthiness design equipment, incorporating crushable end structures, is planned for 2005. As part of this test, four coach cars and one cab car are currently being modified to include crush zones at each end.

The results of the grade-crossing tests demonstrate that improved-design corner posts are effective. The conventional design did not withstand the impact of the heavy object and the coil eliminated the operator's

volume and nearly intruded into the passenger compartment. In contrast, the improved-crashworthiness design withstood the impact of the heavy object under similar collision conditions.



The results of the in-line tests of conventional equipment show that the crush is focused on the impacting cab car. Consequently, there is a substantial loss of occupant volume. The results of the two in-line tests of the improved-crashworthiness design equipment conducted to date show that crush does not have to be focused on the impacting car. By distributing crush, the occupant volume can be preserved. In the train-to-train test of conventional equipment, the cab car overrode the locomotive. In the train-to-train test of improved-design equipment, override is not expected to occur between the colliding cab car and locomotive.



While the principal objective of these tests is to determine effective strategies for improved structural crashworthiness and improved occupant protection, a secondary objective is to validate and improve the computer models that have been developed as part of the rail vehicle crashworthiness research. As part of the planning of these tests, detailed computer simulations are performed prior to the tests. The results of the simulations are used to determine the impact speed as well as other details of the test such as accelerometer size and location. After the test, the simulation results are compared with the test measurement and the analyses are refined as necessary. After the first test, the test measurements indicated that the simulation captured the underlying mechanics of the response of the car structure during the test, but that a number of refinements could be made to the simulation. After the most recent test, there was very close agreement between the pre-test simulation results and the test measurements that no refinements were made of the simulation.