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# OCCUPANT VOLUME INTEGRITY EVALUATION IN PASSENGER RAIL CARS

## SUMMARY

This research, which is intended to enable the growth of high-speed and intercity passenger rail transportation, was sponsored by the Federal Railroad Administration (FRA) Office of Research and Development, as part of the train Occupant Protection research program.

Occupant volume integrity (OVI) describes a rail car's ability to maintain sufficient space for passengers and crew survivability during a collision. Alternatives to the traditional 800,000-pound buff strength requirement have been developed to assess the OVI of passenger rail cars in support of a request for a waiver of the existing regulation. A passenger car design compliant with the traditional requirement has been analyzed and tested against the alternative requirements. The results of the analysis and tests show that these alternatives are as effective as the traditional requirement in ensuring OVI of rail passenger equipment.

For the past 5 years, FRA's Passenger Equipment Safety Program has been conducting research on alternatives for ensuring OVI. In 2010, the Engineering Task Force (ETF) of the Railroad Safety Advisory Committee (RSAC) used the results of this ongoing research to develop alternative criteria and procedures for ensuring OVI [1]. These criteria and procedures allow greater flexibility in evaluating various passenger equipment designs while maintaining an equivalent level of OVI in comparison to equipment evaluated using the conventional methodology. The new methodology establishes three evaluation load levels and corresponding pass–fail criteria for each.

A series of compression tests on crash energy management (CEM)-equipped passenger cars has been performed as part of FRA's research program. These tests have been performed in conjunction with finite element (FE) analyses to evaluate the efficacy of using an alternative analysis to extrapolate data from testing to ensure OVI.

A conventional 800,000-pound buff strength test was performed on a CEM-equipped passenger car. The results of this test were used both to verify the car's structural integrity as well as to aid in validating an FE model. The ETF's alternative criteria and procedures were also applied to passenger cars of similar design. Per the ETF's procedures, the now-validated FE model was used to simulate loading of the passenger car along the load path taken by collision forces (collision load path) up to its ultimate, or crippling load. Finally, two CEM-equipped passenger cars were tested to determine their crippling loads. The crippling tests are not required under the ETF's procedures but were performed as an examination of the ability of the FE model to capture the crippling behavior of a passenger rail car.

The results from the tests and analyses agree with one another. The tested cars and the FE model each crippled at a load of approximately 1.2 million pounds. The research now provides a well-developed technical basis for use of alternative methods of evaluating OVI in rail passenger equipment.

## BACKGROUND

The ETF adopted alternative criteria for demonstrating that a vehicle's OVI is equivalent to that of a rail car that complies with the regulation at 49 CFR 238.203. These criteria include a dynamic collision scenario and a quasi-static analysis. The details of both the dynamic and the quasi-static analyses may be found in the ETF's report [1]. Three sets of loading conditions and pass–fail criteria were adopted for performing the quasi-static evaluation. A vehicle can meet any of the three options to demonstrate equivalent safety. For each of the three options, the load is introduced to the passenger car along its collision load path. The ETF's three load magnitudes and pass–fail criteria are summarized in Table 1.

**Table 1. OVI Load and Pass–Fail Criteria**

| | Load Magnitude (pounds) | Pass–Fail Criterion |
|---|---|---|
| **Option A** | 800,000 | No permanent deformation |
| **Option B** | 1 million | Limited permanent deformation |
| **Option C** | 1.2 million | Without crippling |

Before an analysis model can be used to evaluate any of the three options, the model must be validated with test data. An elastic test of the passenger car, loaded to at least 337,000 pounds along its service load path (e.g., line of draft), can be used to validate the model. The loading used for validation must represent that required by a recognized national or international standard. The results of the model must compare closely with the results of the test, in accordance with tolerances agreed upon by the ETF [1]. Once the model is validated, it can be used to predict the response of the car under a higher load, during which the car may deform permanently.

## METHOD

This research was undertaken to determine what analysis and test protocols are necessary to ensure a high level of confidence in the model predictions of the carbody response to high loads. The proposed procedures allow a combination of testing of the carbody with a relatively low elastic load and analysis of the carbody when the load is significantly higher. In essence, the analysis is used to extrapolate beyond the test results. The carbody remains elastic for the test (deformation of the carbody is not permanent). For two of the options (B and C), the analysis is expected to show that the carbody response is plastic and the carbody experiences permanent deformation.

The car design chosen for this research is the Budd Pioneer. This design is a single-level passenger car that complies with the existing 800,000-pound requirement. The cars chosen for this research have been retrofitted with CEM elements. These CEM elements shift the collision load path through the car away from the line of draft. The CEM-equipped ends of the car were removed in the crippling FE model and tests to permit loading along the collision load path. Figure 1 shows Pioneer 244 prior to removal of its end structures.

**Figure 1. Pioneer Car 244**

Two loading conditions were analyzed and tested. The first condition was the traditional 800,000-pound load applied along the line of draft. The second was a crippling load applied to the energy absorber supports, located at the floor and roof levels at the ends of the car.

### Analysis

The FE model used in this program was originally created for the first full-scale FRA passenger rail car impact test and has been further refined for the OVI tests. In the previous impact tests, the deformations were focused at the ends of the car, whereas in the OVI tests, the largest deformation was expected near the middle of the car. Because only the end structures of the earlier models used for impact analysis were characterized in detail, it was necessary to create a detailed representation of the structures in the center of the car for the OVI analyses. The modified FE model was used to analyze both the 800,000-pound elastic test and the crippling tests.

### Tests

A total of three tests were run in this series. All of the tests were performed at the Transportation Technology Center (TTC) in Pueblo, CO.

The first test in this series placed an 800,000-pound load on car 244 to verify that the car's structure was sound after it had been repeatedly subjected to impact tests and repairs. This test was also used to validate the FE model.

The second test in this series was a limited–instrumentation "pretest" of a second Pioneer car, 248. This pretest served as a shakedown test for the newly modified test fixture and hydraulic loading system. Limited instrumentation was installed on the test frame to measure the load and displacement of each hydraulic actuator on the live end of the car and the load at each restraint point. The car was loaded quasi-statically until the crippling load was reached.

The third test performed in this series was a fully instrumented crippling test of car 244. The instrumentation included the same load and displacement measurements used in the test of car 248 as well as strain gages on structural members and displacement transducers on the car's underframe. Car 244 was loaded quasi-statically until crippling was reached.

## RESULTS

The overall load–displacement characteristics from the two crippling tests and the FE analysis are plotted in Figure 2. The analysis and test results compare favorably at 800,000 pounds and the crippling load.

In the two tests and the simulation, the roof structure buckled at a total load of approximately 1 million pounds. The floor structure continued to bear load until crippling was reached. Car 248 had a measured crippling load of 1.15 million pounds, and car 244 crippled at 1.19 million pounds. The FE analysis calculated that a load of 1.19 million pounds would cripple cars of this design.

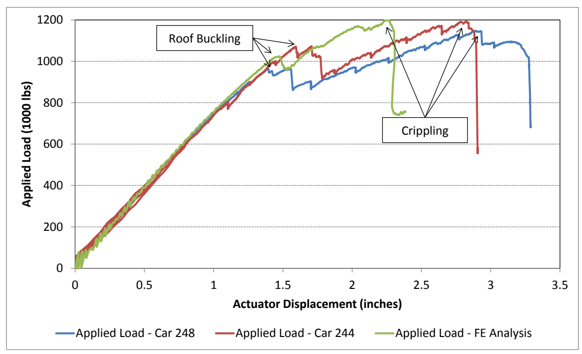


Figure 2. Predicted and Measured Force–Displacement Characteristics

Different modes of deformation were observed in both tests, and the mode of deformation in the FE model replicated well the observations from one of the tests. Figure 3 shows the FE analysis prediction for the deformation of the car. Figures 4 and 5 show the posttest deformations of cars 248 and 244, respectively.


Figure 3. Predicted Carbody Deformation

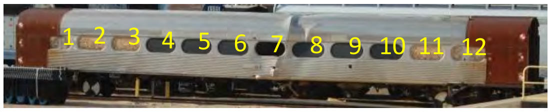


**Figure 4. Deformation of Car 248**


**Figure 5. Deformation of Car 244**

As shown in Figure 3, these variations in the deformation do not have much influence on the crippling load. The permanent deformation can be focused at several locations, but the crippling load is essentially the same regardless of the location of crippling along the length of the rail car.

## CONCLUSIONS

The results of the tests and analysis show that alternative OVI requirements are as effective as the traditional crashworthiness requirement in ensuring the OVI of rail passenger equipment. Alternative evaluation criteria and procedures, as adopted by the ETF, permit evaluation of varied designs while maintaining an equivalent level of protection to the current requirements. A series of full-scale tests was performed in parallel with detailed computer simulations to examine the efficacy of the proposed criteria and procedures. The testing and analysis program has successfully established a technical basis for the proposed alternative OVI requirements and methodology.

## REFERENCES

[1] Carolan, M., Jacobsen, K., Llana, P., Severson, K., Perlman, B., & Tyrell, D. (Eds.). (2011 Oct.). *Technical criteria and procedures for evaluating the crashworthiness and occupant protection performance of alternatively designed passenger rail equipment for use in tier I service* (U.S. Department of Transportation Report No. DOT-FRA-ORD-11/22). Washington, DC: Federal Railroad Administration, Office of Railroad Policy and Development.

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## KEYWORDS

Occupant volume integrity, OVI, crippling, buff strength, alternative criteria