U.S. Department
Of Transportation

Federal Railroad Administration

Research Results

RR06-15
September 2006

Deformability and Energy Absorption for Optimized End Frame Designs for Passenger Rail Cars

SUMMARY

At the request of the American Public Transportation Association (APTA), the Office of Research and Development of the Federal Railroad Administration (FRA) sponsored a research initiative to clarify the definition of acceptable large deformations for end frame structural members. This request was prompted by discussions between two operating authorities currently evaluating a newly designed cab car for compliance with the requirements stipulated in the APTA-C&S-S034-99 standard for the design of passenger rail rolling stock and a car manufacturer directed to test the new cab car design. Within the then accepted standard was language requiring the end frame members of a car to maintain connection strength even when experiencing "*severe deformations*." The operating authorities and the car manufacturer could not agree on whether or not the quasi-static large deformation tests demonstrated the compliance of the design.

This research study addressed the issue raised by comparing the Bombardier's M7 cab car design with the FRA sponsored state-of-the-art (SOA) end frame design [1]. The SOA design deformed gracefully for large crush distances without experiencing failure at attachment points during the full-scale grade crossing test conducted on June 7, 2002, at the Transportation Technology Center. Models of both the M7 and the SOA end frames were subjected to quasi-static and dynamic loading conditions. Figure 1 shows a comparison of the deformations from the quasi-static testing of the M7 end frame with models where excellent agreement was demonstrated. The results presented served as the technical basis for developing revised language for incorporation into the APTA-C&S-S034 industry standard adopted in 2005 for deformability and energy absorption of end frame members, as well as proposed language for a dynamic performance standard for possible rule text promulgation.

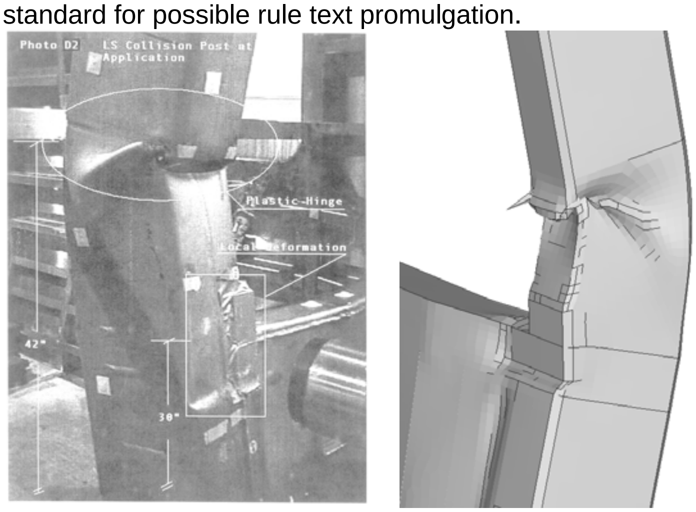

Figure 1. Comparison of Quasi-Statically Tested and Predicted Deformations on M7 Cab Car End Frame

BACKGROUND

During an offset impact, the cab car end frame is the only structure between the operator and the intruding object. It is vitally important that the end frame behave in a ductile manner, absorbing some of the collision energy while maintaining sufficient space for the operator to survive the collision.

FRA and the passenger rail industry have addressed this concern by the promulgation of Federal regulations of strength requirements and the issuance of an industry standard incorporating not only enhanced strength requirements but also a deformation requirement in 1999.

APTA requested that FRA demonstrate the improvements through full scale testing. Under the sponsorship of FRA, the Volpe Center developed a set of grade crossing dynamic tests to compare the performance of a design representative of those in operation in the early 1990's and what was then called a SOA end frame design, which incorporated both the enhanced strength requirements, as well as the ability to gracefully deform for large crush distances without experiencing failure at connections. That is, experience severe deformations while still preserving occupied space.

At the same time, after issuance of the APTA standard for the construction of rolling stock, several operating authorities in the process of purchasing cars added the enhanced strength and deformation requirements to their specifications. As a result of this, Bombardier designed the M7 cab cars. Included in the specification was the need to demonstrate compliance through testing. So a set of qualifying quasi-static tests was conducted. Questions arose in terms of clearly defining what the outcome of a successful test is and whether or not the quasi-static tests provide equivalent safety to the dynamic tests sponsored by the government.

This study presents results obtained from quasi-static testing on the M7 collision and corner posts and dynamic full-scale testing on the SOA corner post. In addition, large deformation analyses in the post-buckling regime of cab car end frame designs were conducted for strength-based requirements, as well as newly proposed performance-based requirements. Two designs were studied in detail: an FRA-sponsored prototype SOA, designed to optimize severe deformation capability and retrofitted onto a Budd Pioneer passenger cab car, and the Bombardier M7 cab car design currently in use by Long Island Railroad and Metro North Railroad. Both designs complied with all applicable Federal regulations and APTA standards promulgated in 1999. Figure 2 shows a schematic of the time line of the issue raised.

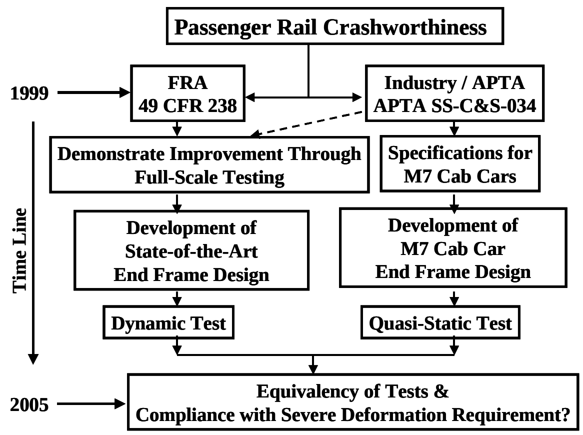

Figure 2. Time Line of Severe Deformation Issue

QUASI-STATIC TESTING AND ANALYSIS OF M7 COLLISION POST

The objectives of this study were to develop and then summarize the available technical information needed to make recommendations for standard development. Specifically, the study would investigate the large deformation behavior of the two cab car end frame designs developed to be compliant with the enhanced strength and deformation requirements outlined in the APTA standard. Secondly, the study was to determine whether there is equivalency in demonstrating compliance through either quasi-static or dynamic testing. This information was to be produced for discussions between FRA and the passenger rail industry through the forum of Passenger Safety – Crashworthiness Task Force of the Railroad Safety Advisory Committee (RSAC).

Figure 3 shows the two types of test setups. The quasi-static test of the M7 cab car was conducted on a mock-up test article. The figure shows the setup for a collision post loading condition. The full-scale dynamic test is for a corner post loading condition. The end frame impacts a steel coil in an offset manner. The coil is situated above the end/buffer beam of the end frame centered on the corner post. The key metrics of these types of tests are determination of the modes of deformation and failure that the structure experiences, as well as the force crush characteristics. The information measured in either type of test was used to ascertain the fidelity of the nonlinear large deformation finite element models developed.

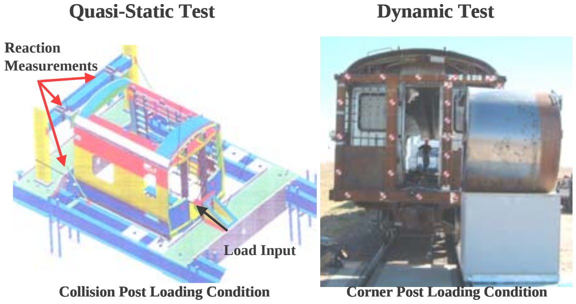

Figure 3. Quasi-Static and Dynamic Test Setups

Figure 4 shows the two models developed to analyze both the M7 and the SOA end frame designs. Both car types were analyzed for approximately the first 20 feet of the car out to the rear of the body bolster. 125,000 reduced integration 4-node shell elements were used to construct the models with the average coarse element size of 2 inches and the average fine element size of 0.5 inches. The models were fully fixed at the rear.

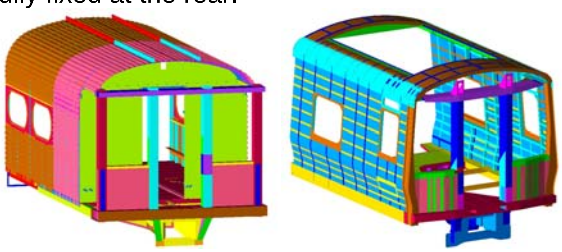

Figure 4. Nonlinear Large Deformation Finite Element Models of End Frame Designs

Figure 1 showed the excellent agreement obtained from the comparison of the quasi-static testing and analysis results for both modes of deformation and locations where material failure is expected to occur. Figure 5 shows the excellent agreement of the force-crush characteristics between the dynamic corner post-test of the SOA end frame design with the pre-test predictions.

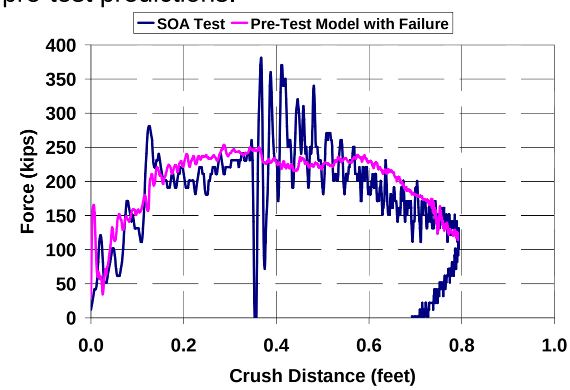

Figure 5. Correlation of SOA Dynamic Corner Post Pre-Test Model Predictions and Observations

Having established the fidelity of the models, a number of dynamic and quasi-static simulations were conducted on both designs for large deformation loading of the corner and collision posts. Figure 6 shows a comparison between the observed quasi-static deformation mode and that predicted for the dynamic coil loading condition on the M7 end frame. The modes of deformation are very similar at the same extent of longitudinal displacement. The locations where material failure is occurring are also the same. The predicted force-crush characteristics also show reasonable agreement within the repeatability of the tests.

Quasi-Static Test
Dynamic Analysis

Figure 6. Comparison of Quasi-Statically Tested and Dynamically Predicted Modes of Deformation and Failure for the M7 Cab Car End Frame

CONCLUSIONS

Both the SOA and M7 end frames were designed to be compliant with the APTA enhanced strength and deformation requirements. Both designs show improved crashworthiness protection compared to conventional pre-1999 designs. Graceful crush can be objectively measured using large deformation quasi-static and dynamic testing. This information has been presented to the Passenger Safety RSAC Crashworthiness Task Force, and discussions continue about development of enhanced standards that incorporate language associated with the severe deformation of the vertical end frame members. The quasi-static language developed for maximum allowable intrusion and minimum energy absorption have been adopted into the revised APTA-C&S-S034-05 industry standard for the design of passenger railroad rolling stock. Further dynamic testing is planned.

ACKNOWLEDGMENTS

This research was sponsored by the FRA Office of Research and Development and was conducted at the Volpe Center by the Equipment Safety Research Program. David Tyrell, Senior Engineer, leads the passenger rail equipment crashworthiness research at the Volpe Center. Eloy Martinez, Senior Engineer, Volpe Center, led the analysis effort described in this paper.

REFERENCES

Martinez, E., Tyrell, D., Zolock, J. Brassard, J., "Review of Severe Deformation Recommended Practice Through Analyses–Comparison of Two Cab Car End Frame Designs," American Society of Mechanical Engineers, Paper No. IMECE2005-70043, March 2005.

CONTACTS

Eloy Martinez
Federal Railroad Administration
Office of Research and Development
1120 Vermont Avenue NW - Mail Stop 20
Washington, DC 20590
Tel: (202) 493-6354
Fax: (202) 493-6333
Email: eloy.martinez@dot.gov

KEYWORDS: *End frame, severe deformation, crashworthiness, deformability, energy absorption*

Notice and Disclaimer: This document is disseminated under the sponsorship of the United States Department of Transportation in the interest of information exchange. Any opinions, findings and conclusions, or recommendations expressed in this material do not necessarily reflect the views or policies of the United States Government, nor does mention of trade names, commercial products, or organizations imply endorsement by the United States Government. The United States Government assumes no liability for the content or use of the material contained in this document.