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CRIPPLING TEST OF AN M1 PASSENGER RAILCAR

SUMMARY

Occupied volume integrity (OVI) refers to a passenger railcar's ability to preserve interior cabin space for passengers and crew during an accident. By preventing or minimizing structural deformation of, or intrusions into the rail vehicle's interior, passengers are better able to withstand, sustain and survive the immense forces resulting from an impact or other high magnitude event. The Federal Railroad Administration's (FRA) Office of Research and Development (R&D) is sponsoring research to investigate OVI. The results of a series of tests have been published in an FRA report [1]. This research forms the basis for establishing alternative OVI evaluation procedures. The alternative procedures permit an analysis to be validated with data from an elastic test. The validated analysis may then be used to extrapolate the behavior of the subject car under destructive load conditions, without companion destructive testing.

The previous tests used Budd Pioneer passenger cars that had been fitted with crash energy management (CEM) systems. The CEM systems on these cars altered the path of collision loads through the occupied volume of the vehicle. For the test, evaluation loads were placed along the collision load path. The results of this previous program indicate that an analysis that has been properly validated with elastic test data is capable of estimating the carbody's behavior under destructive loading conditions. The results of the destructive analysis were reasonably representative of the results of destructive tests that were performed on the carbodies.

Currently, an FRA-sponsored research program is underway to expand upon the results of the previous program. This research program will subject a CEM-equipped Budd M1 passenger railcar to a program of testing and analysis as if an OVI waiver were being sought according to established procedures [2].

The testing portion of this program includes an elastic test as well as a crippling test. The elastic test was performed at Transportation Technology Center (TTC) on March 13, 2013. A second test increased the load until the car reached its ultimate or crippling load. The second test was performed on July 17, 2013.

The outcomes of this program will include documentation of the results of the 800-kip test and analysis, as well as discussion of the data necessary to achieve model validation. The results will include the information expected in an actual application for a waiver.

BACKGROUND

The overall plan for the M1 testing program was previously summarized in a *Research Results Report* [3]. This program consists of an elastic test, a crippling test, and finite element analyses (FEA) of both test conditions. The test vehicle chosen for this program is a Budd M1 passenger railcar. The specific car has been modified to include floor-level and roof-level energy absorbing components as part of a CEM system.

The first test placed 800 kips on the floor-level energy-absorber supports. This test was intended to generate data for use in a program of model validation. This test resulted in some limited areas of permanent deformation in the side structures of the car. Following the 800-kip test, FEA was performed to evaluate the M1 car's crippling behavior. The second test performed in this series was a destructive crippling test in which the load was increased until the load-bearing capacity of the structure was fully exhausted.

OBJECTIVES

The principal objective of the crippling test was to increase the compressive load on the M1 car until the ultimate load capacity of the car was reached. The key outputs from this test were the force-versus-displacement behavior and the overall mode of deformation of the M1 car at crippling. The key measurements that were made included the applied loads, the reaction loads, the displacements of the underframe and the ends of the car, and the strains in key longitudinal members.

METHODS

The car was restrained within a frame at TTC, as seen in Figure 1. This frame enabled loads to be introduced into the two floor-level and two roof-level energy absorber support structures on the F-end of the car. Hydraulic actuators were used to apply the longitudinal forces. The car was restrained at the B-end through the four energy-absorber supports. Load cells were installed between the car and the test frame at each load or reaction location to measure the applied or reaction forces.

Figure 1. M1 in Test Frame

During the test, the longitudinal strains on key structural members were measured. These members consisted of the center sill, both side sills, belt rails, roof rails, and center of the roof itself. Additionally, displacement measurements were made at the load or reaction sites and at stations on the center sill and side sills along the length of the car. The measurement sites on the underframe of the car featured string potentiometers capable of measuring the vertical, lateral, and longitudinal displacements.

RESULTS

The post-test car is shown within the test frame in Figure 2. Damage to the roof can be seen on both ends of the car near the doors. Sidewall damage can also be observed on the F-end inboard of the door. The roof on the F-end of the car was the first area of the car observed to buckle. Buckling of the F-end roof initiated at a total applied load of approximately 700 kips.

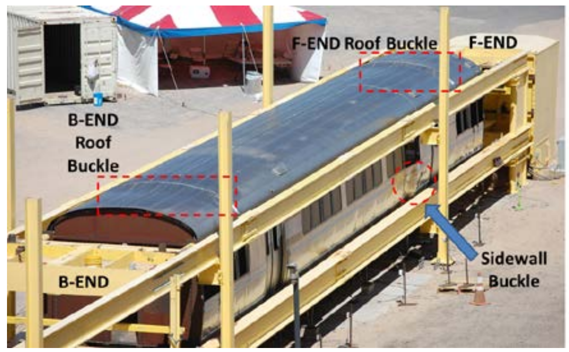

Figure 2. Post-test Photograph of M1

The underframe of the car, consisting of the center sill and two side sills, buckled in several areas during the test. The right side sill had several buckles in one region. This region was adjacent to the sidewall damage observable in Figure 2, as well as to a previously repaired buckle. This previous damage is believed to have occurred when this car was used in a dynamic impact test. A patch had been installed on the side sill and sidewall of the car in this area prior to the 800-kip test. The post-test damage to the right side sill is shown in Figure 3, with three different areas of side sill buckling indicated. The arrow on the left-most buckle was drawn on the side sill prior to the crippling test. This mark indicates that a small buckle already existed at this location prior to the crippling test. This existing buckle served as an initiation site for the larger buckle that occurred in this area during the test.

Figure 3. Right Side Sill Damage

The left side sill was found to have buckled in two different locations. Figure 4 shows the damage closer to the B-end of the car. The arrow in the B-end photograph was drawn on the side sill before the crippling test to indicate that a small buckle already existed at this location. From the figure below, it is apparent that this pre-existing buckle served as an initiation site for the side sill's buckle in this location. A second buckle, on the upper part of the side sill, is visible closer to the F-end of the car in this figure.

Left Side Sill, B-end

Figure 4. Buckle on B-end of Left Side Sill

The second buckled area on the left side sill occurred closer to the F-end of the car. This area of buckling is shown in Figure 5. From the strain gage data, it appears that the buckle on the B-end of the left side sill occurred earlier in the load sequence than the buckle on the F-end. The buckle on the F-end of the left side sill is located in the vicinity of the patch that was added to the left side sill to maintain symmetry with the right side sill's patch.

Figure 5. Buckle on F-end of Left Side Sill

The center sill of the car had several minor buckles and one large buckle. This large buckle is located at a cross-section of the car adjacent to the two side sill patches. Based on the strain gage results, the center sill buckles at approximately the same time as the buckle that occurs on the F-end of the left side sill. This buckling event occurs at the highest load recorded during the test, indicating that crippling of the car occurs because of buckling of the center sill and left side sill. The buckle on the center sill is shown in Figure 6. This figure shows the damaged center sill from the left and right sides.

Figure 6. Buckle on the Center Sill

The total load applied by the four F-end actuators was summed and plotted against the change in length of the underframe on the left, center, and right sides of the car. The change in length was obtained by subtracting the longitudinal displacement measured by the left, center, or right string potentiometer on the B-end of the car from the corresponding longitudinal displacement on the F-end. This manipulation ensures that any rigid body motion of the car associated with stretching of the test frame is removed from the data.

The resulting force-displacement characteristics are plotted in Figure 7. These characteristics indicate that the right side of the car has a slightly higher relative stiffness than the center or the left side. The global maximum load, or crippling load, is approximately 1.15 million pounds for this car. At that point, the center sill and the left side sill at the F-end of the car buckle. The car's overall structure has been compromised completely and the load for further displacement starts to drop.

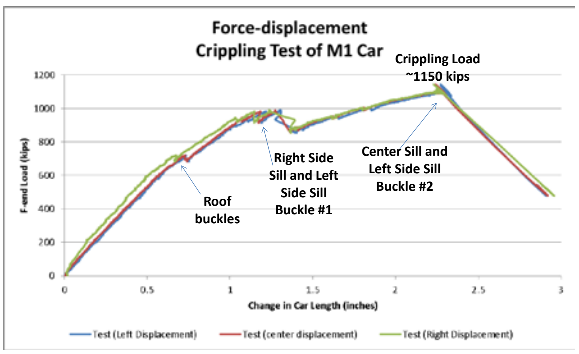

Figure 7. Force-displacement Characteristics

SUMMARY

A crippling test of a Budd M1 passenger railcar was successfully performed at TTC. This test loaded the car, which had been used in a previous dynamic impact testing program, to its crippling load of 1.15 million pounds. This value is comparable to that measured in previous similar tests of two Budd Pioneer passenger cars, which crippled at 1.15 and 1.2 million pounds [1]. The data collected during this test will help guide the development of alternative strategies for the evaluation of OVI in passenger rail equipment.

REFERENCES

[1] Carolan, M., Perlman, B., and Tyrell, D. "Alternative Occupied Volume Integrity (OVI) Tests and Analyses." U.S. Department of Transportation, DOT/FRA/ORD-13/46. October, 2013.

[2] Carolan, M., Jacobsen, K., Llana, P., Severson, K., Perlman, B., and Tyrell, D. (eds). "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, DOT/FRA/ORD-11/22. October, 2011.

[3] "Application of Alternative Criteria and Procedures to Passenger Railcars." (in publication).

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KEYWORDS

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