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# LOCOMOTIVE CRASH ENERGY MANAGEMENT: TRAIN-TO-TRAIN IMPACT TEST

## SUMMARY

Research to develop new technologies for increasing the safety of passengers and crew in rail equipment is being directed by the Federal Railroad Administration's (FRA's) Office of Research, Development, and Technology. Two crash energy management (CEM) components, integrated into the end structure of a locomotive, have been developed: a push-back coupler (PBC) and a deformable anti-climber (DAC). These components work in unison to inhibit override in the event of a collision. The results of vehicle-to-vehicle override, where the strong underframe of one vehicle, typically a locomotive, impacts the weaker superstructure of the other vehicle, can be devastating and compromise the occupied space. The objective of this research program is to demonstrate the feasibility of these components in improving crashworthiness for equipped locomotives in a wide range of potential collisions, including collisions with conventional locomotives, conventional cab cars, and freight equipment.

This report describes the results of the program's latest impact test, conducted in August 2022: the train-to-train impact test. In this test, a CEM-equipped locomotive leading two passenger cars impacted a stationary, conventional locomotive leading two freight cars, shown in [Figure 1](#). The primary objective of the test was to demonstrate the effectiveness of the CEM system in managing the load path, absorbing impact energy, and inhibiting override and lateral buckling in a train-to-train collision scenario. The target impact speed was 21 mph. The actual speed of the test was 24.3 mph. The impact test resulted in the CEM system working exactly as designed, successfully absorbing energy and keeping the vehicles in-line, with no

derailment and no signs of override. The damage sustained during the collision was documented and the test results were evaluated and compared to model predictions.

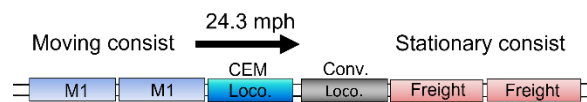


Figure 1. Train-to-Train Impact Test Schematic

## BACKGROUND

In recognition of the importance of override prevention in train-to-train collisions in which one of the vehicles is a locomotive [1], and in light of the success of CEM technologies in passenger trains [2], FRA seeks to evaluate the effectiveness of crashworthy components that are integrated into the end structure of a locomotive. These components are specifically designed to mitigate the effects of a collision and, in particular, to prevent override of one of the lead vehicles onto the other [3].

Therefore, FRA sponsored a research program to develop, fabricate, and test CEM components for retrofit onto the forward end of a locomotive: (1) a DAC and (2) a PBC. Researchers developed detailed designs for these components, and they then evaluated the performance of each design through large deformation dynamic finite element analysis (FEA). Two test articles were fabricated and individually dynamically tested by means of a rail car impact into a test wall to verify performance characteristics of the two components individually relative to specific requirements. The tests were successful in demonstrating the effectiveness of the two design concepts. Test results were consistent with finite element model predictions in terms of energy absorption



capacity, force-displacement behavior, and modes of deformation. In this research program, the two CEM components were integrated into the end structure of a locomotive to demonstrate through dynamic testing that such components work together to mitigate the effects of a collision and prevent override.

Each of the locomotive tests conducted as part of this research program were based on a head-on collision scenario in which a locomotive-led train collides with a stationary train. The first two series of tests were coupling tests that demonstrated the PBC performs as expected in service. The vehicle-to-vehicle tests demonstrated that the components work together as an integrated system to provide crashworthiness with a range of equipment, and the train-to-train test demonstrated the effectiveness of the crashworthy components within an entire consist.

## OBJECTIVES

The overall objective of the locomotive research program was to demonstrate the effectiveness and feasibility of the CEM system to improve crashworthiness for equipped locomotives in a wide range of potential collisions, including collisions with conventional locomotives, conventional cab cars, and freight equipment.

The primary objective of the train-to-train impact test was to demonstrate the effectiveness of the CEM system in managing the load path, absorbing impact energy, and inhibiting override and lateral buckling in a train-to-train collision scenario.

The team chose the target impact speed of 21 mph to fulfill the following test requirements:

1. Triggering and complete stroke of the PBC
2. Impact of the PBC with the sliding lug
3. Shear bolt failure and translation of the sliding lug
4. Absorption of at least 50 percent (i.e., 300 ft-kips) of the DAC energy absorption requirement (i.e., 600 ft-kips)

## METHODS

Researchers conducted the train-to-train test at the Transportation Technology Center (TTC) in Pueblo, Colorado, in August 2022. A CEM-equipped F40 locomotive leading two M1 passenger cars impacted a stationary conventional F40 locomotive backed by two hopper cars. The team retrofitted the CEM locomotive with the PBC and DAC. The impact interface is shown in [Figure 2](#).



**Figure 2 Pre-impact photo of conventional locomotive (left) and CEM locomotive (right)**

The entire CEM system is designed so the colliding vehicle ends engage while absorbing the energy of the collision. This minimizes lateral buckling and ramp formation due to uncontrolled crush, both of which promote override.

When an impact occurs at greater than typical coupling speeds, a specific sequence of events should occur. The deformation tube of the PBC begins to deform permanently at a trigger force of approximately 670 kips. It then pushes back at that load level, absorbing a substantial amount of energy. When the PBC stroke is exhausted, the back of the PBC head impacts the front of the sliding lug, causing a sudden increase in load to approximately 1,100 kips, activating the failure of the 12 shear bolts. This causes the sliding lug to push back into the 10-inch draft pocket. Prior to exhaustion of the PBC stroke, the DAC impacts the anti-climbing structure of the conventional locomotive. Once the shear bolts break, the load path transfers



completely from the PBC to the DAC, which then continues to crush in a controlled manner, absorbing additional collision energy.

Researchers instrumented the vehicles and CEM components to measure the longitudinal, vertical, and lateral accelerations of the equipment, the displacements of the couplers and other key end structures, and the extent of strain on the surface of key structural elements at specific locations. The team used high-speed and high-definition video cameras to document the impact test. The passenger cars housed occupant protection experiments, which are described in a companion Research Results [4].

### RESULTS

The target impact speed was 21 mph and the actual speed of the test was 24.3 mph. The CEM system successfully kept the vehicles engaged and in-line, with no derailment and no signs of override. The system worked exactly as designed, with controlled vehicle motion and controlled deformation. Post-test FEA results at the actual test speed compared very well with the test results, as shown in Figure 3 and Figure 4. Figure 3 shows the relative displacements of the locomotive underframes.

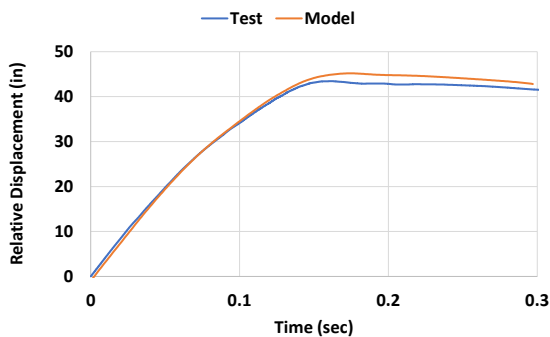


Figure 3. Post-test FEA vs impact test comparison of relative displacement vs. time curves

All of the test objectives were met. The PBC triggered properly and deformed its complete stroke of 21 inches, with an energy absorption of ~1080 ft-kips. The shear bolts failed and the sliding lug translated back its full 10 inches into the draft pocket. The DAC total energy absorption was ~600 ft-kips. The top tubes

crushed extensively to conform to the conventional locomotive underframe, and the bottom tubes deformed about 1 inch when impacted by the conventional locomotive end plate. There was no evidence of wheel lift in any of the vehicles.

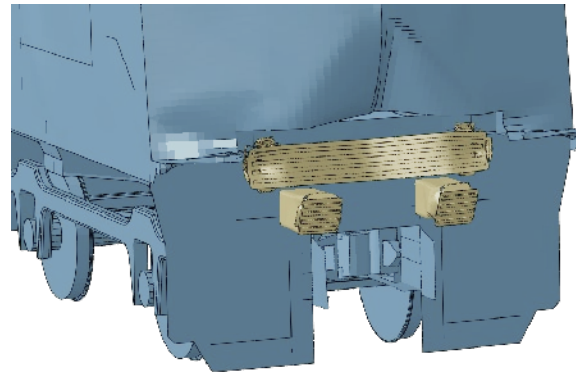


Figure 4 Post-test FEA results (top) vs post-test photo of the CEM locomotive

The two engaged consists traveled approximately 635 feet before impacting a single loaded “catch” car, pushing that car ~50 feet until all vehicles came to a complete stop. A hydraulic cylinder was required to pull the vehicles apart after completion of the test.

As predicted by pre-test FEA, there was some deformation in the CEM support structures and end structures. Similarly, there was some deformation to the front end of the conventional locomotive, also predicted by pre-test FEA. All significant plastic deformation occurred in the colliding locomotives; however, there was evidence of minor rippling of the M1 car side walls and side sill. The bottom plate of the forward draft gear of the forward M1 failed,



causing the draft gear, yoke, and rear end of the coupler to fall and rotate downwards.

## CONCLUSIONS

Researchers judged the train-to-train impact test a success. The CEM system kept the vehicles engaged and in-line, with no derailment and no signs of override. The CEM system worked exactly as designed, controlling vehicle motion and deformation. The outcome of the test was consistent with post-test modeling at the actual test speed. The CEM locomotive test program demonstrated that CEM on locomotives improves crashworthiness by inhibiting override and absorbing collision energy.

## FUTURE ACTION

Next steps in the CEM locomotive research program include comparing the train-to-train test results to the previous vehicle-to-vehicle results, as well as conducting an override study. The findings from this research will provide FRA information on locomotive crashworthiness alternative compliance.

## REFERENCES

- [1] Mayville, R., Stringfellow, R., Johnson, K., & Landrum, S. (February 2003). [Crashworthiness Design Modifications for Locomotive and Cab Car Anticlimbing Systems](#) (Report No. DOT/FRA/ORD-03/05). Federal Railroad Administration.
- [2] Tyrell, D, Jacobsen, K, Martinez, E, & Perlman, A.B. (November 2006). [Train-to-Train Impact Test of Crash Energy Management Passenger Rail Equipment: Structural Results](#). *Proceedings of the ASME 2006 International Mechanical Engineering Congress and Exposition. Rail Transportation*. Chicago, IL. ASME.
- [3] Llana, P. & Stringfellow, R. (March 2011). [Preliminary Development of Locomotive](#)

[Crashworthy Components](#) (Report No. JRC2011-56104). *Proceedings of the ASME/ASCE/IEEE 2011 Joint Rail Conference JRC2011*. Pueblo, CO. ASME.

- [4] Eshraghi, S. & Severson, K. (September 2022). [Train-to-Train Impact Test: Wheelchair Securement Experiments](#) (Report No. RR 22-27). Federal Railroad Administration.

## ACKNOWLEDGMENTS

Engineers at the Volpe National Transportation Systems Center planned and managed the locomotive crashworthiness research program, developed the test requirements, and analyzed the test results. Engineers at CAMX developed and analyzed the finite element models. Engineers and technicians at MxV (formerly TTCI) conducted the tests.

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## KEYWORDS

Crashworthiness, crash energy management, CEM, locomotive, train-to-train test, rail passenger safety

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