FRA Locomotive Crashworthiness Research Program Overview

Presentation to NGEC

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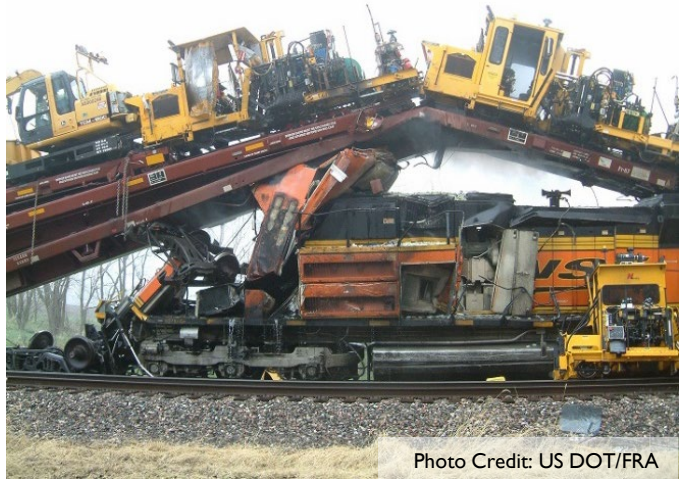
Motivation: Locomotive Override

- Locomotives are susceptible to override in train-to-train collisions
- Conventional anti-climbing structures:
  - Can deform on impact and lose their vertical load-carrying capacity due to fracture as they crush longitudinally
  - Can lead to ramp formation, increasing likelihood of override

Cayce, SC, February 4, 2018: 50 mph

Georgetown, KY, on Mar 18, 2018: 32 mph



Red Oak, IA, April 17, 2011: 23 mph

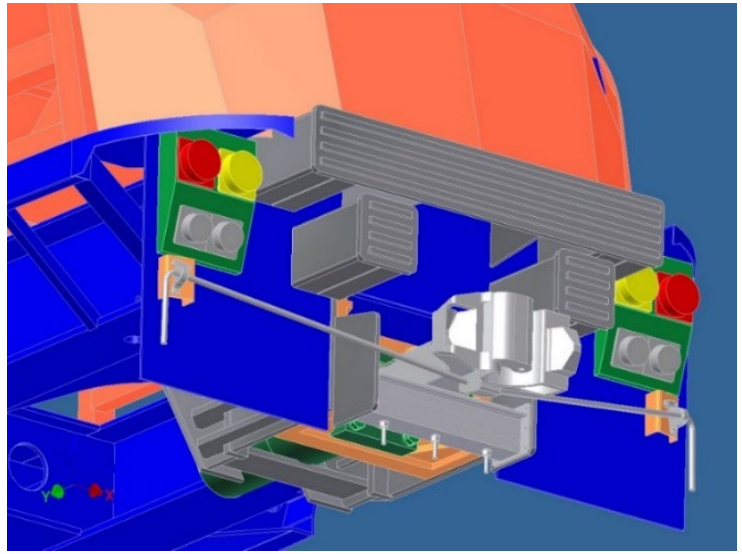
Chicago, IL, Nov 30, 2007: 33 mph

Objective & Research Approach

Objective: Develop and demonstrate the effectiveness of the locomotive Crash Energy Management (CEM) system

- CEM improves existing locomotive crashworthiness
- CEM features can be retrofit onto existing locomotives
- Simulations & test results form basis for performance-based requirements

CEM system retrofit design

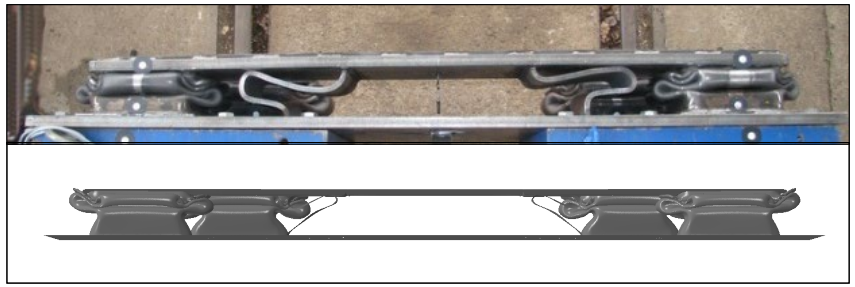


CEM system retrofit
onto existing locomotive

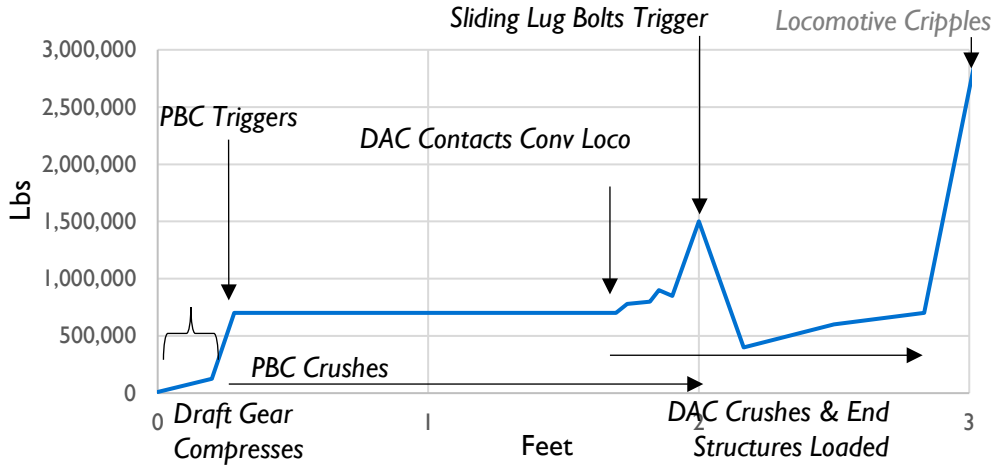
Pushback Coupler (PBC)
Test Article After Impact

Deformation Tube

Deformable Anticlimber (DAC)
Test Article After Impact, 14.9 inches of crush



Top View



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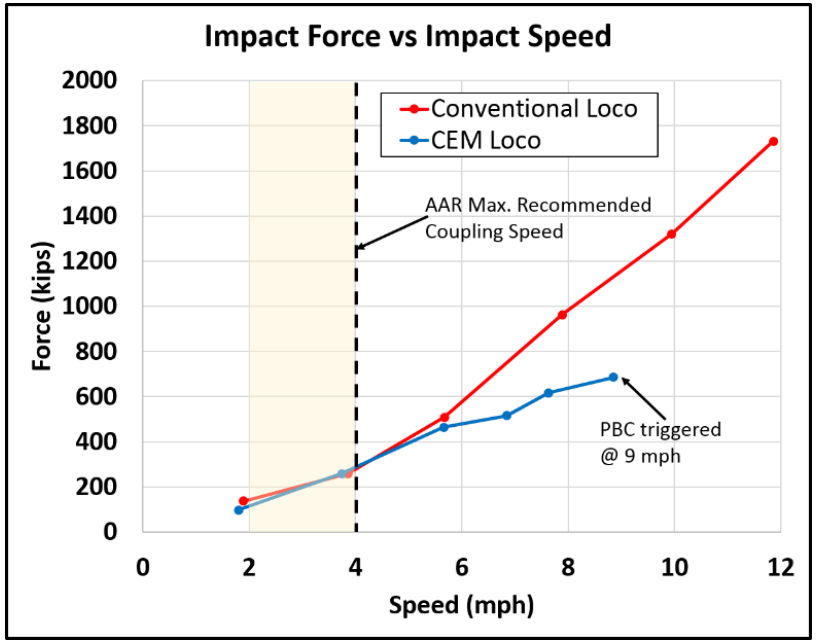
CEM Locomotive Test Program

Tests	Test Objectives
Conventional & CEM Coupling Tests Nov 2015 & Oct 2017	• Demonstrate performance of PBC under range of coupling speeds • Results: PBC activation at 9 mph, cab car damage begins at 6 mph
Vehicle-To-Vehicle Tests Jan 2019 & Nov 2021	• Demonstrate performance of PBC and DAC working as a CEM system in two different impact scenarios (conventional locomotive & passenger car) • Results: CEM system worked as designed, kept vehicles in-line with no derailment & no signs of override
Train-To-Train Test Aug 2022	• Demonstrate effectiveness of CEM system in a consist: managing load path between colliding equipment, and inhibiting override and lateral buckling • Results: CEM system worked as designed, kept vehicles in-line with no derailment & no signs of override

Coupling Tests Comparison



* All tests validated computer models for CEM performance & vehicle performance

Train-to-Train Test Results

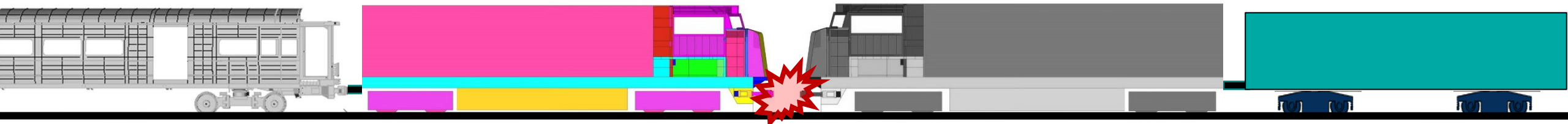
- Scenario: CEM locomotive leading two M1 cab cars, impacted conventional locomotive leading two hopper cars.
- Demonstrated proof of concept: effectiveness of the CEM integrated system within a consist
- Demonstrated CEM retrofit reparability, serviceability, and robustness

CEM Retrofit F40 + 2 M1 cars w/occup. prot. exp.

V_{actual} = 24.3 mph

Conventional F40 locomotive + 2 hopper cars

V = 0 mph



232 + 80 + 78 = 390 kips

255 + 60 + 59 = 375 kips

Both couplers closed at impact

Test Video: Test speed = 24.3 mph (target = 21 mph)

Test Results: PBC & DAC Performance

Before impact

DAC

PBC Deformation Tube

After impact

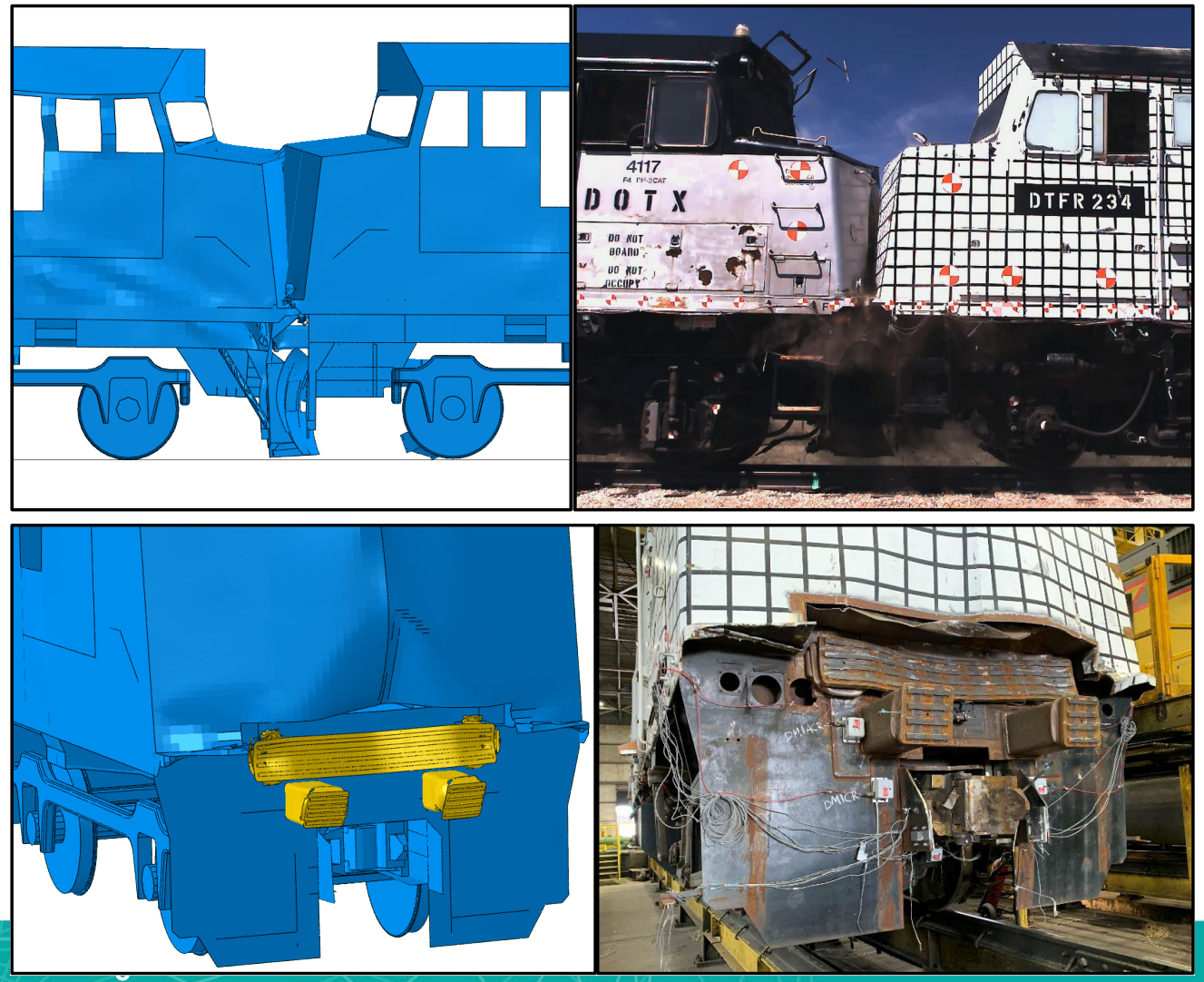
After locomotives pulled apart

DAC

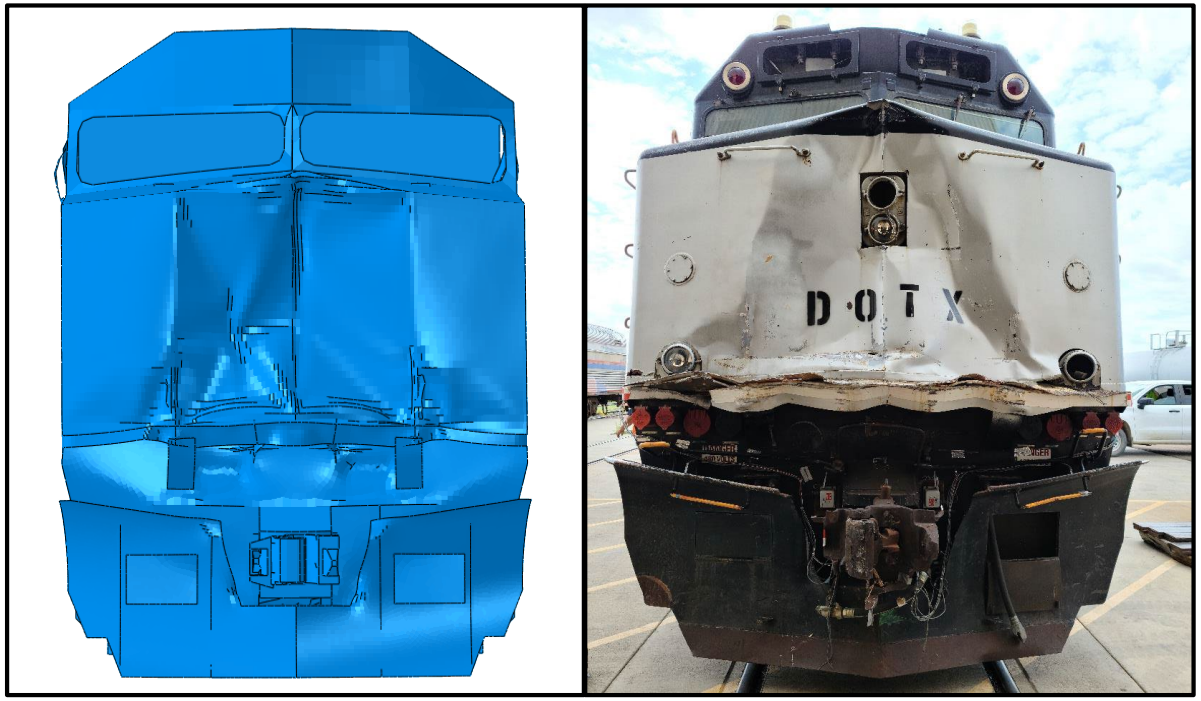
PBC Deformation Tube

Post-Test FEA vs Test Results: Deformation

Model predictions of deformation in very good agreement with test results.



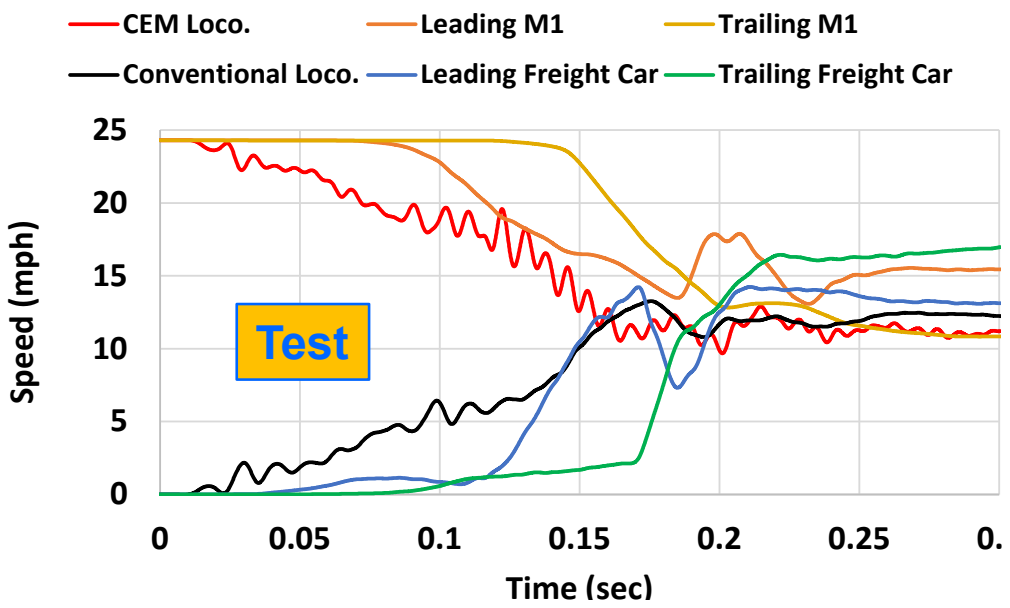
Conventional Locomotive

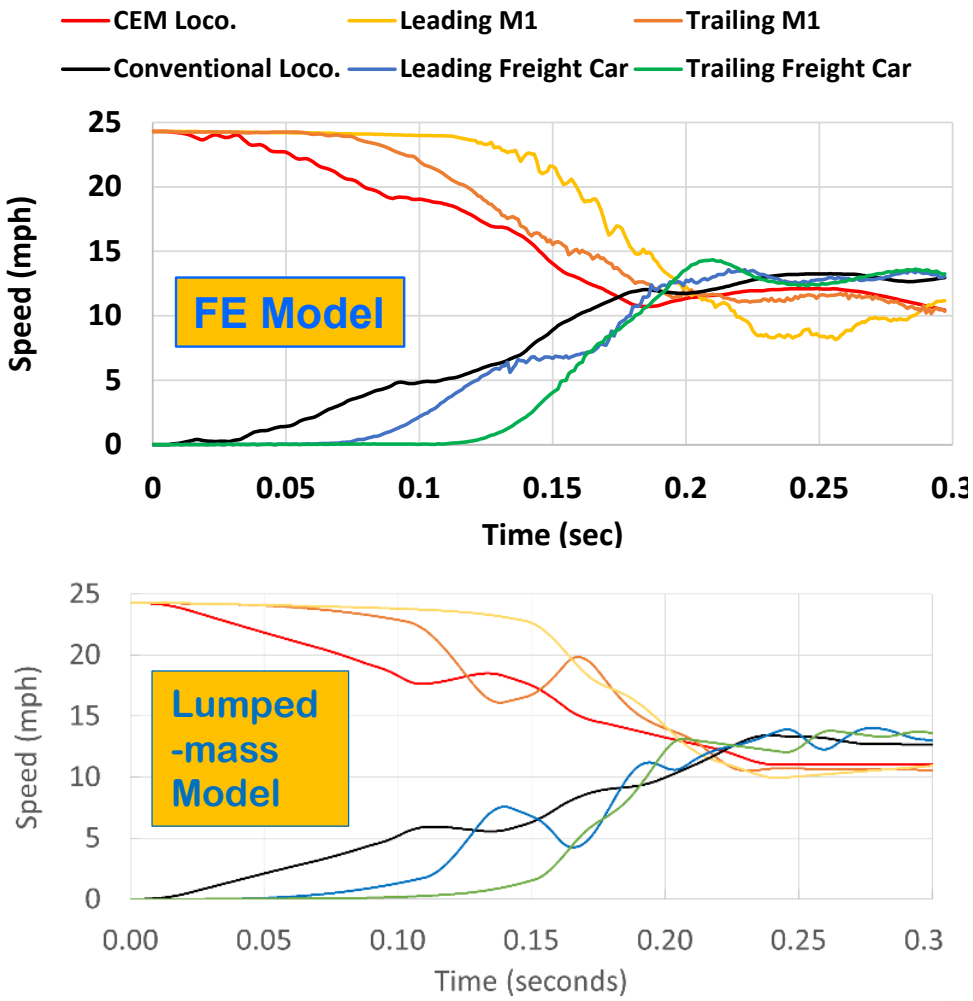


CEM Locomotive

Post-Test Models vs Test Results: Gross Motions

Model predictions of gross motions in very good agreement with test results.





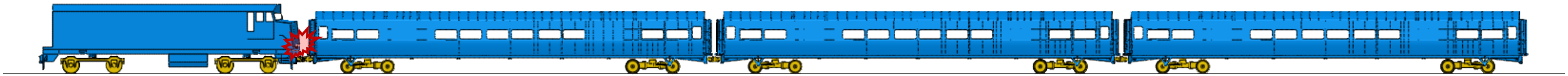
Override Study

- Override study conducted as part of locomotive crashworthiness research program
- Objectives:
  - Demonstrate whether the CEM locomotive reduces propensity for override
  - Determine the extent to which various factors affect propensity for override
- Parametric finite element analyses performed to assess effects on propensity for override:
  - Locomotive type: Conventional locomotive & CEM locomotive
  - Impact speed: 25 mph, 30 mph, 35 mph
  - Consist make-up: short consists & long consists
  - Vertical offsets: in-line, +2 in., -2 in.
- Criteria evaluated:
  - Deformation modes
  - Vertical motion of underframes with respect to one another
  - Total crush of lead vehicles
  - Loss of occupant volume

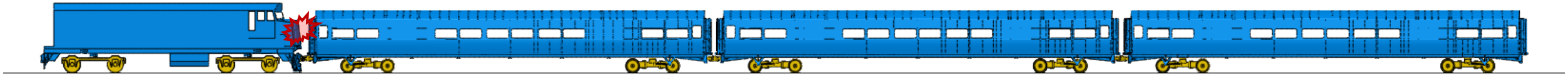
Override Study: FE Models

FE models for four baseline consists were implemented: 2 short consists & 2 long consists

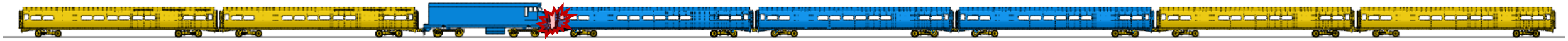
CEM locomotive impacting a standing cab car with two trailing cab/passenger cars:



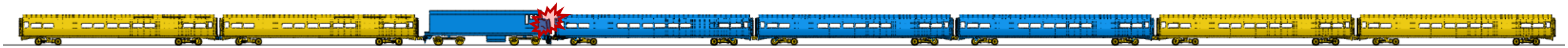
Conventional locomotive impacting a standing cab car with two trailing cab/passenger cars:



CEM locomotive with two trailing cab/passenger cars impacting a standing cab car with two trailing cab/passenger cars



Conventional locomotive with two trailing cab/passenger cars Impacting standing cab car with two trailing cab/passenger cars



Note: vehicle bodies in yellow are modeled as rigid.

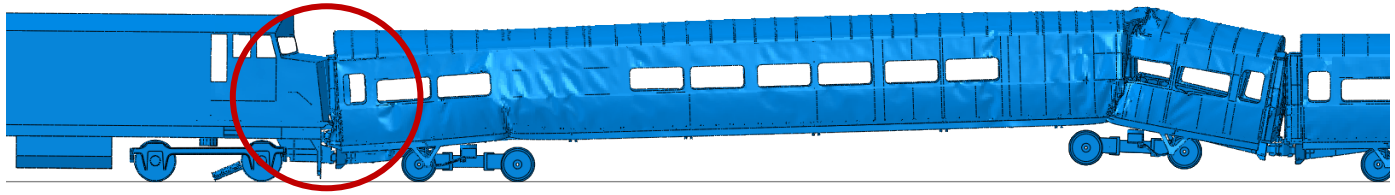
Override Study Results

The results indicate that the CEM components are effective at inhibiting the deformation modes associated with the onset of override.

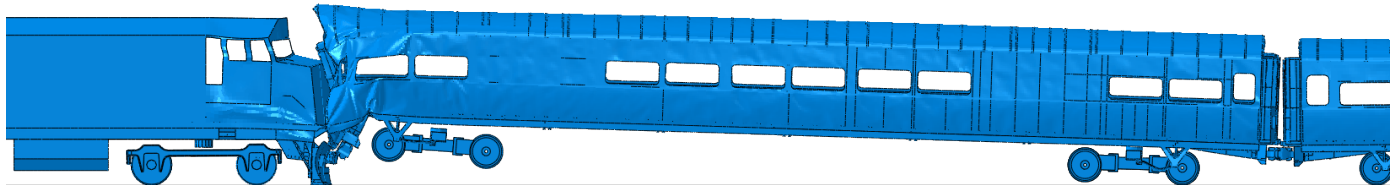
Conclusions:

- CEM features effectively lock vehicle ends together and inhibit deformation modes that lead to override
- In stark contrast, conventional locomotive results show deformation modes consistent with impending override and, are similar to results of the 2002 conventional train-to-train test

CEM Locomotive/Long Consist



Conventional Locomotive/Long Consist

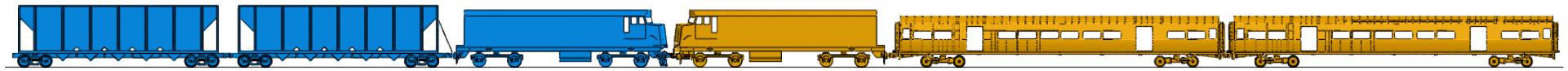


Of note:

- While the CEM locomotive appears to be effective at inhibiting override, other modes of failure, such as crippling of the cab car, are possible and become more likely as the collision speed increases
- At higher impact speeds, additional means of absorbing collision energy, such as CEM features in the passenger cars, would provide substantial additional benefit.

Benefits & Impact of CEM in Locomotives

- Mitigating the propensity for locomotive override reduces fatalities and serious injuries in rail accidents
- CEM design concept can be retrofit onto existing locomotives, is reparable, serviceable, and compatible with a range of equipment
- Simulation and test program results form the basis for performance-based requirements
- Eleven ASME papers and ten FRA Reports based on this research so far



CEM Locomotive Test Program Goals

- ✓ CEM on locomotives improves crashworthiness by minimizing override and absorbing collision energy
- ✓ CEM on both locomotives and passenger cars improves crashworthiness further

- ➢ Provide FRA Guidance on Locomotive Crashworthiness Alternative Compliance

Current Status & Next Steps

- Train-to-Train Test ASME Technical Paper (May 2024)
- Locomotive Override Recent Accidents Technical Paper & Presentation
- Override Study Paper & Presentation
- Additional Override Analyses

Acknowledgements

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  - Program Managers: Melissa Shurland, John Manutes, Kevin Miles, Tarek Omar
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