OFFICE OF RESEARCH & DEVELOPMENT

2012 R&D REVIEW

Engineering Task Force and Occupant Volume Integrity

JEFF GORDON
Program Manager
Office of Research and Development
Office of Railroad Policy and Development

MICHAEL CAROLAN
Mechanical Engineer
The Volpe Center

U.S. Department of Transportation
Federal Railroad Administration

Program Area & Risk Matrix

Engineering Task Forms & Occupant Volume Integrity

Program Areas / Risk Factors	Trespass	Grade Crossing	Derailment	Train Collision	All Other Safety Hazards
Railroad Systems Issues					
Human Factors					
Track & Structures					
Track & Train Interaction					
Facilities & Equipment					
Rolling Stock & Components				X	
Hazardous Materials					
Train Occupant Protection				X	
Train Control & Communications					
Grade Crossings & Trespass					

U.S. Department of Transportation
Federal Railroad Administration
OFFICE OF RESEARCH & DEVELOPMENT
2012 R&D REVIEW

Acknowledgements & Stakeholders

Acknowledgements

- The tests conducted in this program were performed by Transportation Technology Center, Inc. (TTCI) in Pueblo, CO.

- The Budd Pioneer cars used in this program were donated by SEPTA.

Stakeholders

- The Engineering Task Force (ETF) included members from:
  - Passenger railroad operators
  - Passenger rail rolling stock manufacturers
  - Engineering consultants
  - Rail labor

Crashworthiness Concepts

- **Buff Strength** – The ability of a passenger car to support a load along its line-of-draft without undergoing permanent deformation

- **OVI** – Occupant Volume Integrity – The load-bearing capacity of a railcar above which intrusion into the spaces designated for the passengers and crew occurs.

- **CEM** – Crash Energy Management – A design strategy where designated areas ("crush zones") are engineered to deform and absorb energy during a collision

Introduction to Project

- Currently, passenger rail equipment must demonstrate its ability to maintain space for occupants by resisting an 800,000 pound compressive load along its line-of-draft without experiencing permanent deformation
- FRA, supported by Volpe, has been examining alternative methods of evaluating occupant volume integrity (OVI) for non-conventionally designed passenger railcars since 2006
  - This research supported the Railroad Safety Advisory Committee (RSAC) Engineering Task Force (ETF) in its development of alternative OVI evaluation criteria and procedures in 2010
- A series of compression tests and finite element (FE) analyses has been performed to evaluate the OVI of passenger railcars following the ETF's guidelines

Introduction to ETF

- RSAC established the ETF in 2009 with a mission to:

  …[P]roduce a set of technical evaluation criteria and procedures for passenger rail equipment built to alternative designs. The technical evaluation criteria and procedures would provide a means of establishing whether an alternative design would result in performance at least equal to the structural design standards set forth in the Passenger Equipment Safety Standards (49 CFR Part 238).

- The ETF's criteria and procedures are meant to be applied to an alternatively-designed passenger trainset when a waiver of the existing regulations is sought

- The ETF's Report was uploaded to FRA's website in 2010.
  - This report includes recommended criteria and procedures for evaluating the OVI of alternatively-designed passenger rail equipment

Motivations for Project

- The OVI Criteria and Procedures adopted by the ETF differ from the conventionally-applied buff strength requirement

- Recommended OVI Criteria
  - Option A: 800,000 pounds without permanent deformation
  - Option B: 1,000,000 pounds with limited permanent deformation
  - Option C: 1,200,000 pounds without crippling

- Recommended OVI Procedures
  - Test car structure with elastic load.
  - Validate FE model with elastic test results.
  - Use now-validated FE model to simulate carbody response to higher load along its collision load path.

U.S. Department of Transportation
Federal Railroad Administration
OFFICE OF RESEARCH & DEVELOPMENT
2012 R&D REVIEW

Engineering Task Force and Occupant Volume Integrity

Timeline

2006 | 2007 | 2008 | 2009 | 2010 | 2011

2006
Discussion of examination of collision load path through passenger equipment begins

2007
Simplified FE models developed to examine passenger car loading
-

2008
Technical paper describing examination of occupant volume strength published

2009
ETF established, meetings held

OVI testing strategy developed and presented

2010
ETF meetings and teleconferences held

Preliminary 800k test conducted

Draft ETF report made available on FRA's website

2011
800k test and two crippling tests performed

Final ETF report published

TRL 9
TRL 8
TRL 7
TRL 6
TRL 5
TRL 4
TRL 3
TRL 2
TRL 1

Technology readiness level

ETF *Criteria and Procedures* final report published by FRA.

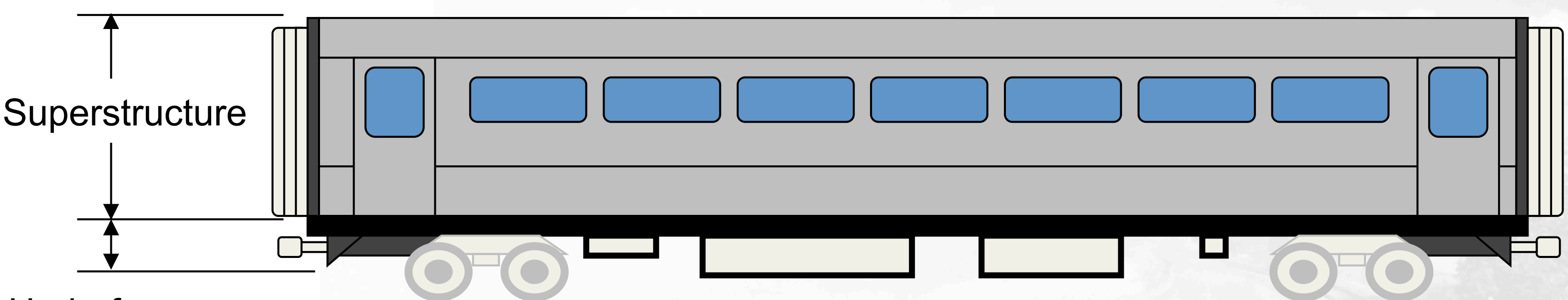
Criteria and Procedures are able to be applied in seeking a waiver of the applicable regulations.

Tests have confirmed the applicability of the ETF's OVI *Criteria and Procedures* .

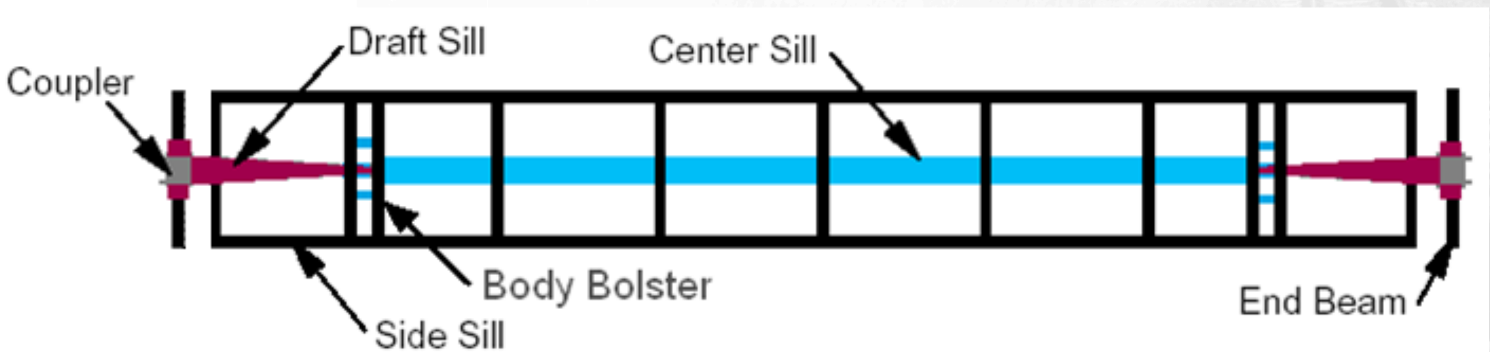
Conventional U.S. Railcar Design

Conventionally-designed single-level railcar features structurally significant underframe to carry service loads

- Generally, superstructure is designed to carry much less load



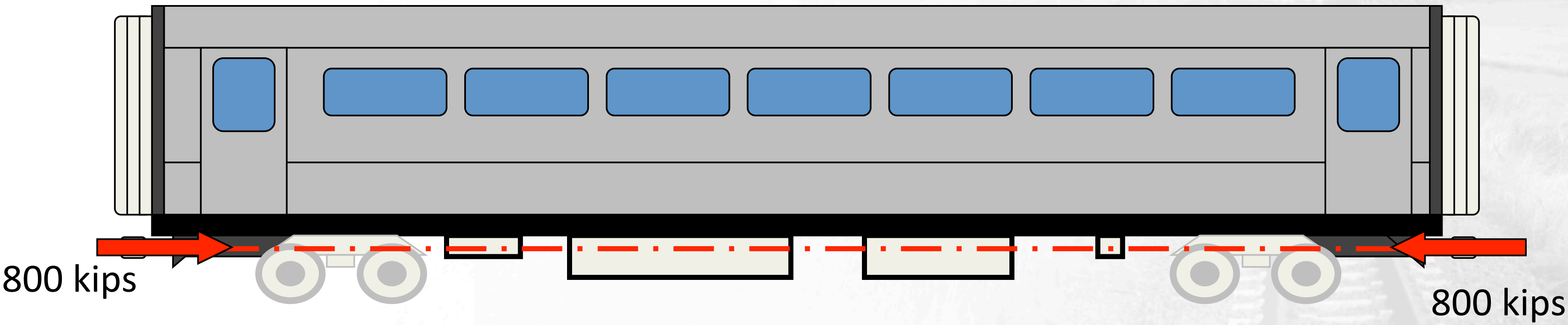
Side View



Underframe View

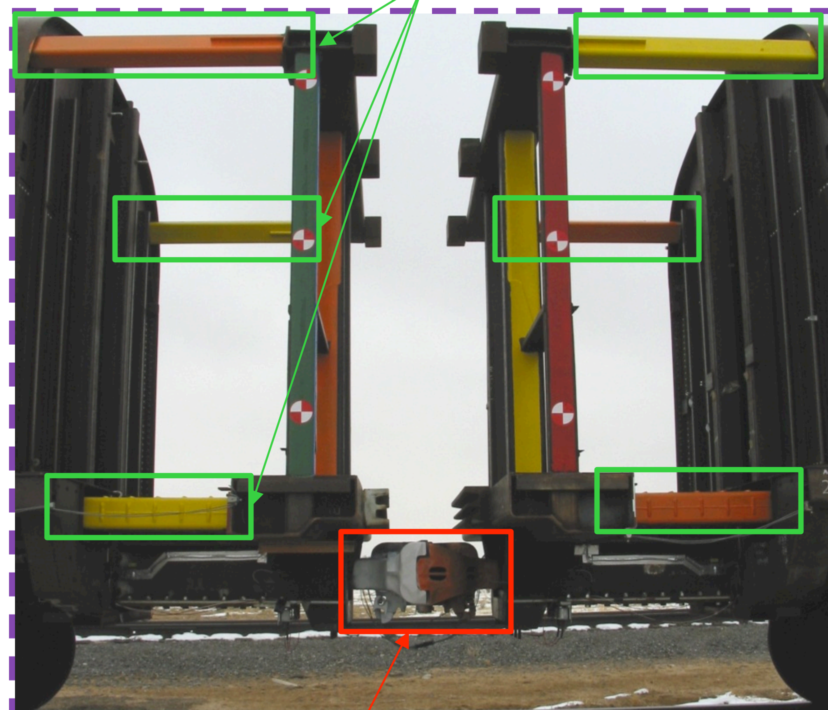
Conventional U.S. Load Requirement

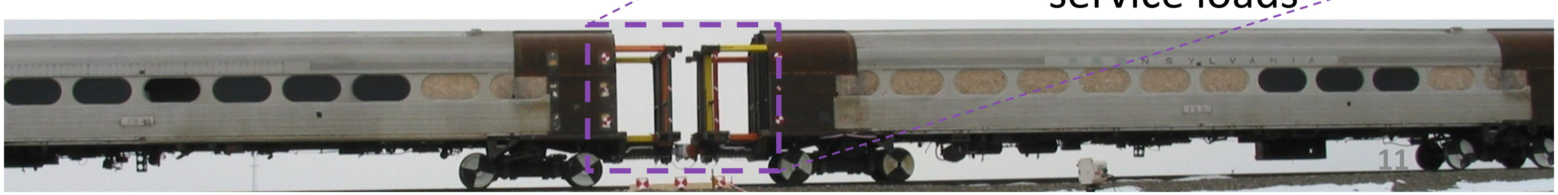
- Carbody must resist 800,000 pounds applied statically on the line-of-draft without permanent deformation
  - This value is required both by regulation (49 CFR 238) and industry standards (APTA SS-C&S-034)
- This imaginary line runs from the coupler at one end of the car to the coupler at the other end



Alternative Railcar Design: Crash Energy Management (CEM)

- CEM railcars feature areas designed to crush and absorb collision energy
- In CEM equipment, normal service loads travel through the car along a conventional load path but collision loads travel along a different path
- Sufficient Occupant Volume Integrity (OVI) is critical to ensuring proper operation of the energy-absorbing components





History of Occupant Volume Integrity (OVI) Requirements

1900 — 2000

1906

Pennsylvania RR develops early steel cars designed to 400,000 pound buff strength

1945

AAR Standard S-034 includes 800,000 pounds applied on the center line of draft for passenger cars

1999

FRA rule and APTA standard require all passenger equipment to "resist a minimum static end load of 800,000 pounds applied on the line of draft…"

2006

Metrolink orders fleet of 800,000-pound compliant commuter rail cars with CEM features

2010

RSAC Engineering Task Force adopts alternative means of evaluating OVI

Tests and Analyses: Process

FRA conducted a series of tests and FE analyses to study railcars' behavior when loaded up to the crippling load

Three tests were performed:

1. Conventional 800,000 pound line-of-draft test (Car 244)
    - Test results used for FE model validation
2. "Shakedown" crippling test (Car 248)
    - Test verified newly-installed test frame and hydraulic control system performance
3. Fully-instrumented crippling test (Car 244)
    - Test verified the ability of FE model to capture crippling behavior of passenger railcar

Companion FE analysis simulated the elastic and crippling tests

ETF Process and Research Program

ETF Methodology

Quasi-static test of elastic load with no permanent deformation → Quasi-static FE analysis of elastic load → Quasi-static FE Analysis to Option A, Option B, or Option C

FRA Research Program

Quasi-static test of 800,000 pounds with no permanent deformation → Quasi-static FE analysis of 800,000 pounds → Quasi-static FE Analysis up to crippling → Quasi-static test to crippling

Analysis

Test

Benefits and Disadvantages of ETF Methodology

Benefits

- ETF options accommodate a wide variety of railcar designs while ensuring acceptable OVI
- ETF recommendations embrace latest crashworthiness technology
- ETF recommendations based on FRA research results and world-wide practice
- Applicability of ETF recommendations confirmed by recently-completed tests

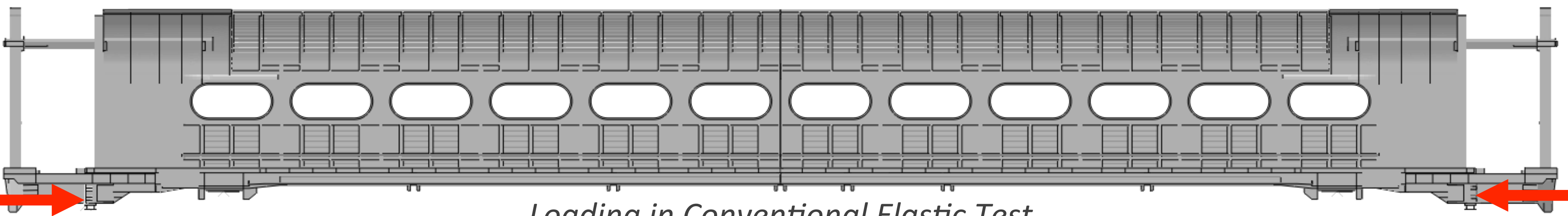
Disadvantages

- Successful FE analysis requires careful construction of a detailed model
- FE model used to describe OVI must be carefully validated with elastic test data to ground the model in reality
- Lack of experience in applying the methodology may lead to the need to provide clarification as experience is gained

Tests in this Project

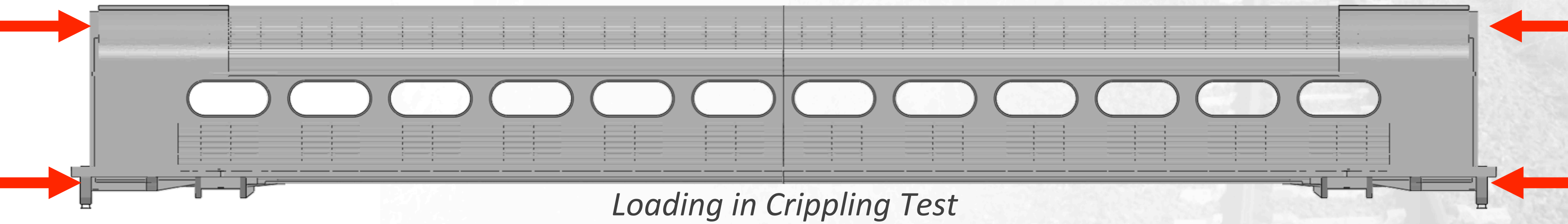
Two types of test were performed in this program

- Conventional elastic test placing 800,000 pounds along line-of-draft



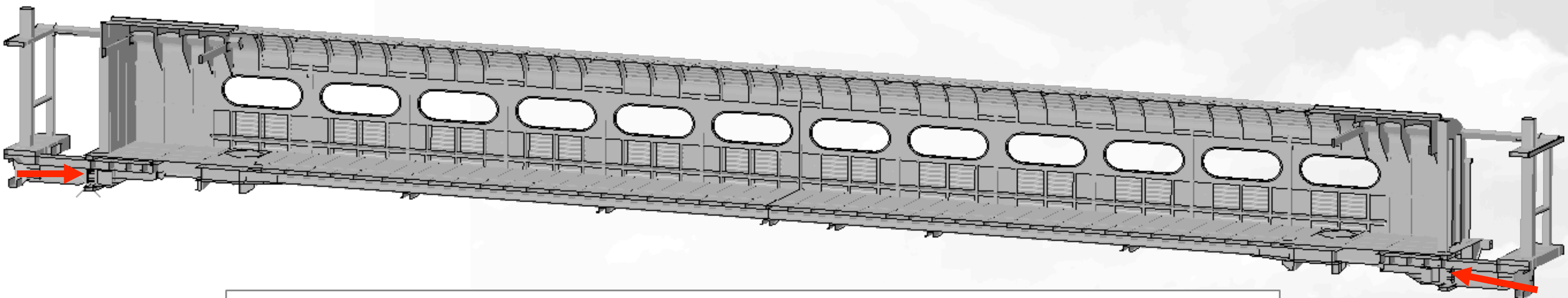
Loading in Conventional Elastic Test

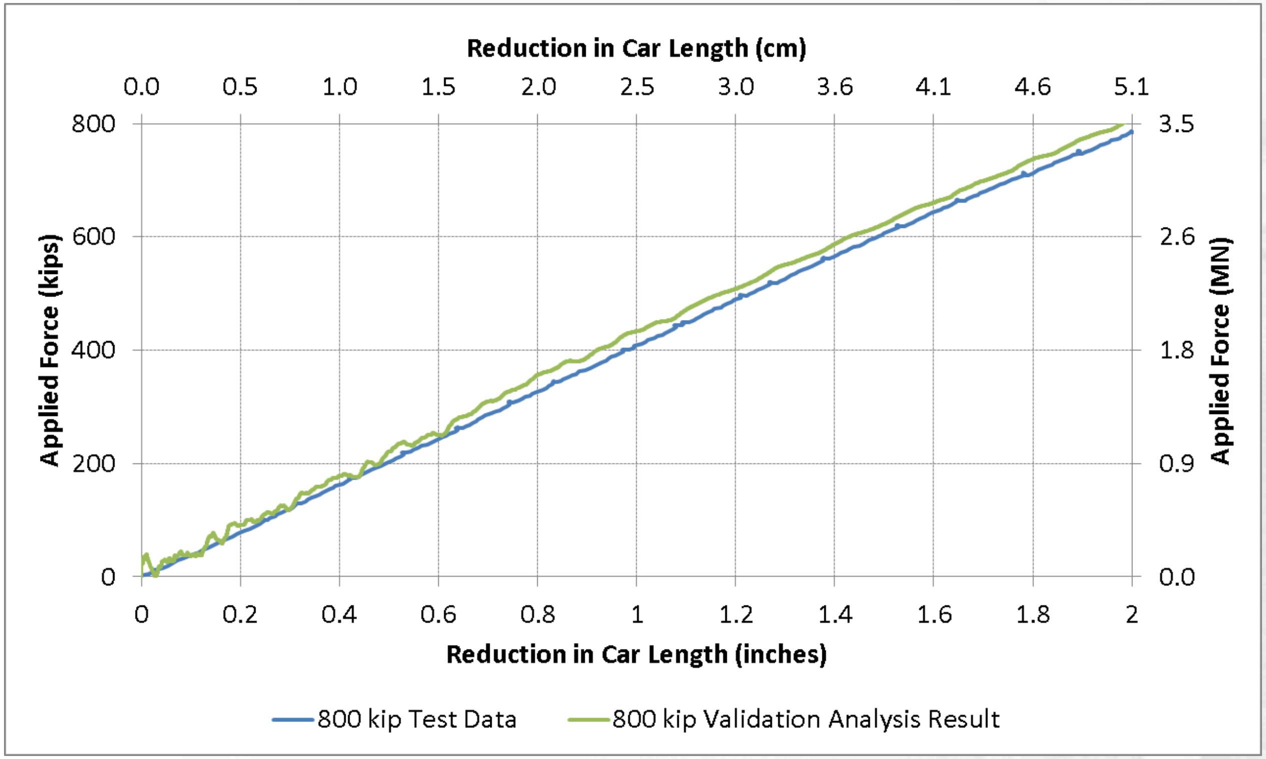
- Crippling test distributing load over the collision load path of the particular car being tested



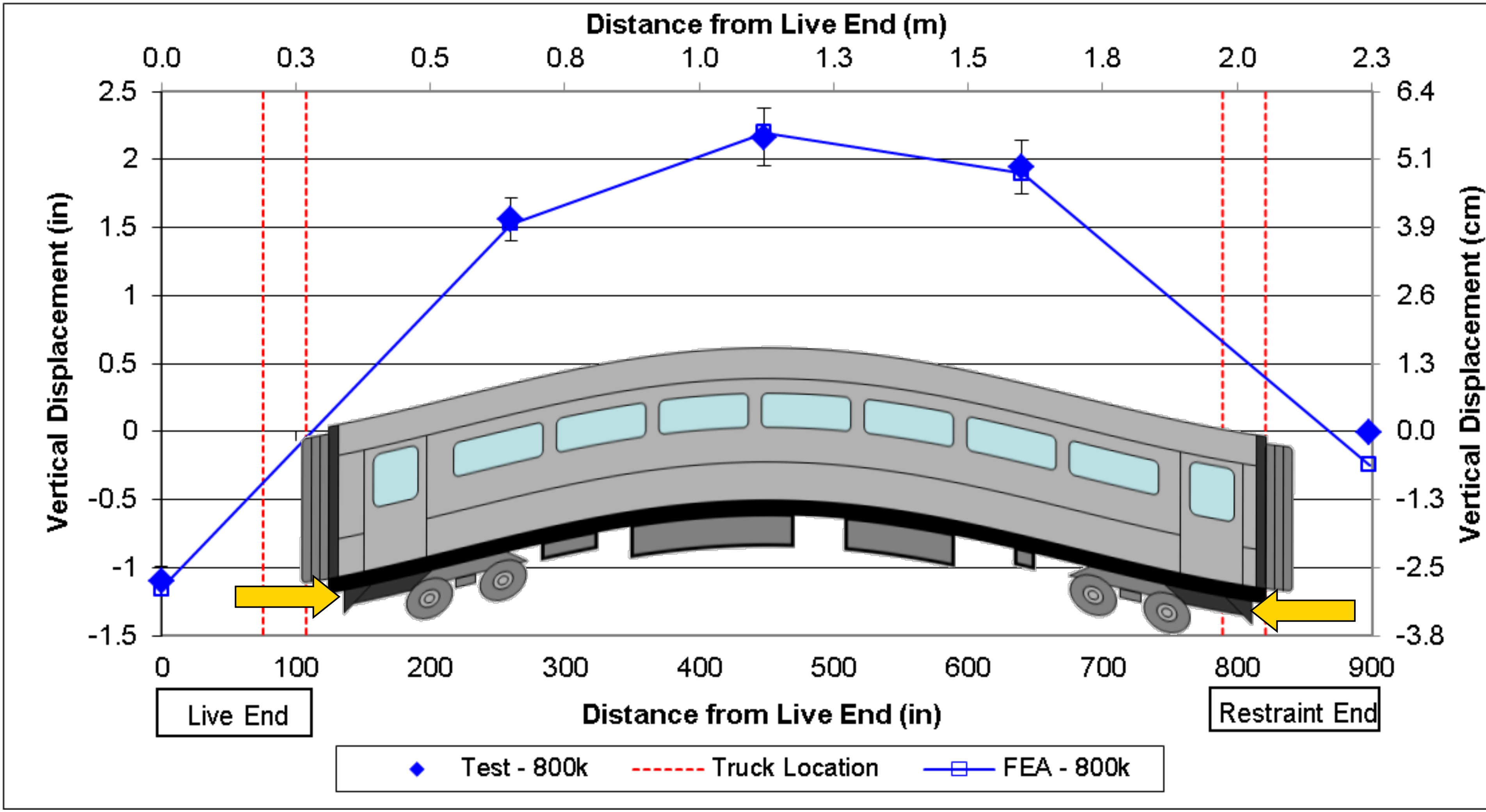
Loading in Crippling Test

Example Results:
800,000 pound Elastic Test and Analysis Car Shortening





Results:
800,000 pound Elastic Test and Analysis Vertical Deformation



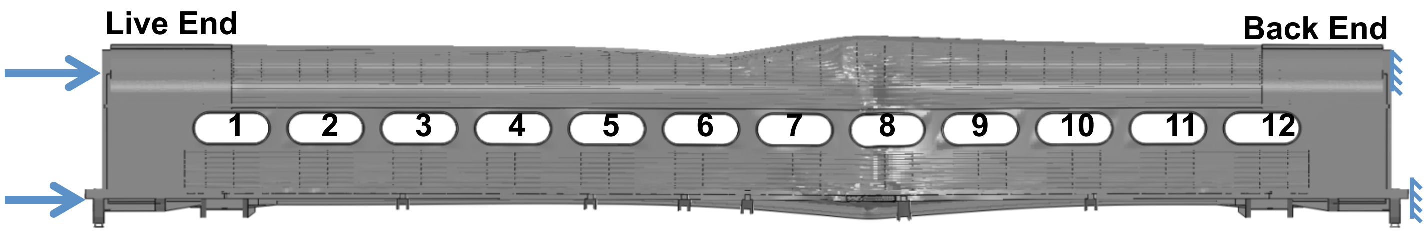
Error Bars Indicate +/- 10% of Test Measurements.

Results:

Crippling Tests and Analysis Deformed Shape

The total load applied to each car was increased until the crippling load was reached

FE model

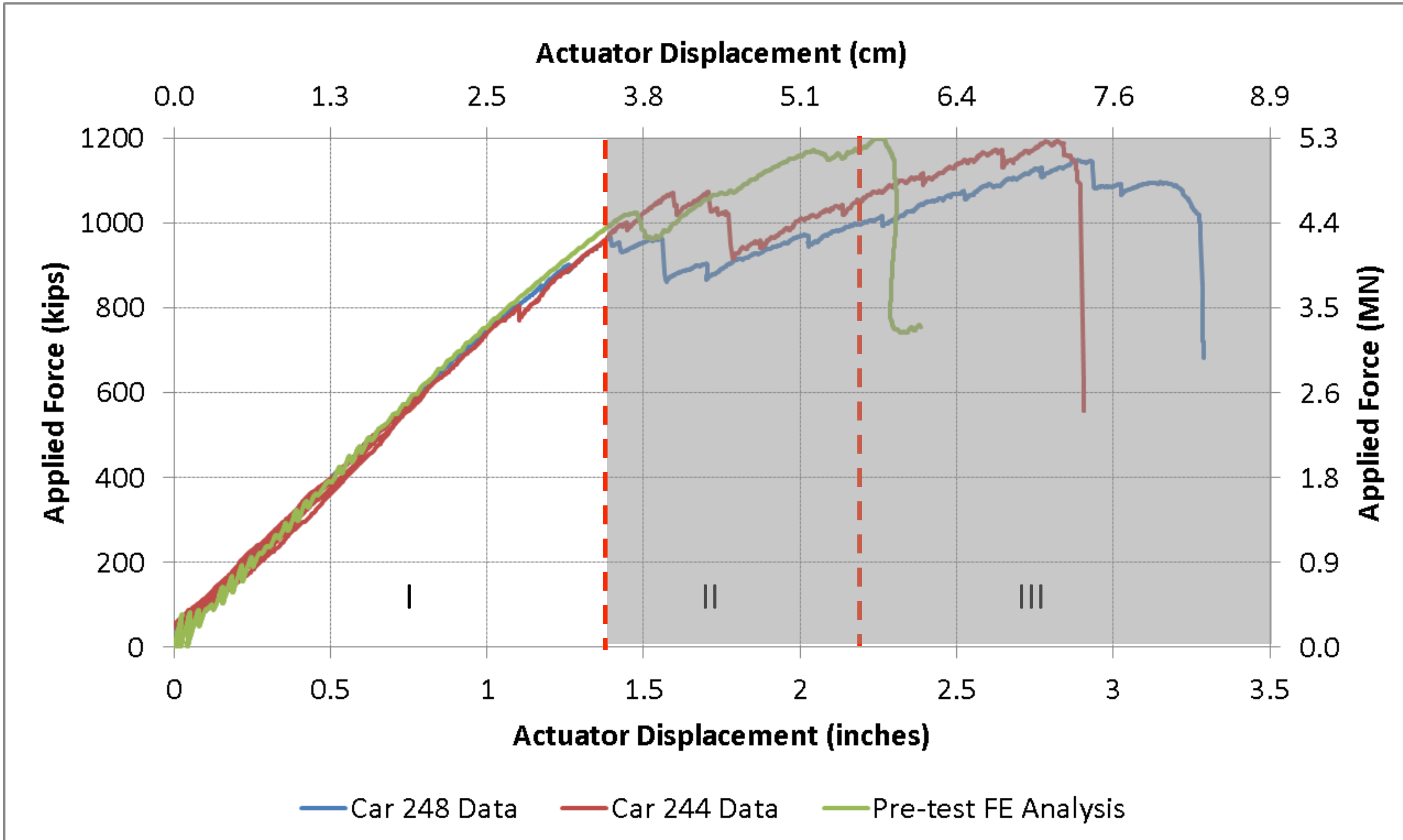


"Shakedown" Test
Car 248

Fully-instrumented Test
Car 244

Results:

Crippling Tests and Analysis Applied Load vs. Actuator Displacement



*FE Analysis was adjusted to include test frame extension

Lessons Learned

- **Elastic test and analysis**: A high-fidelity model is capable of describing the elastic behavior of the test car

- **Crippling tests:** Three distinct regions observed on force-displacement curves
  I. Elastic behavior
  II. Stable inelastic behavior
  III. Crippling

- **Crippling analysis:** The FE model capable of describing the global force-displacement behavior of the car in each of the three regions