NTSB Rail Safety Forum:
Transportation of Crude Oil and Ethanol by Rail

Volpe Center Support in FRA Hazardous Materials Tank Car Safety Research Program

David Y. Jeong
Volpe National Transportation Systems Center
U.S. Department of Transportation

April 22, 2014

Volpe Center Support to FRA Research Programs

- Vehicle Systems
- Track Systems
- Vehicle-Track Interaction
- Human Factors
- Highway Railroad Grade Crossing Safety

NTSB Accident Investigation Support

Tank Car Integrity

Crashworthiness

Bridgeport, CT
May 17, 2013

Rail Integrity

Columbus, OH
July 11, 2013

Train-Track Dynamics

Bronx, NY
July 18, 2013

Timeline of FRA/Volpe Hazmat Tank Car Research

1980

1980: Switchyard Impact Tests

1986-87: Investigation of Stub Sill Tank Car Failures

1992: Chlorine Tank Car Puncture Resistance

1993: Stress Analysis of Stub Sill Tank Cars

1997: Residual Stresses Near Weld Ends

2001: Engineering Analyses for Tank Car Head Puncture

2004: Research Addressing NTSB Recommendations from Minot, ND Derailment

2007-2008: Next-Generation Rail Tank Car (NGRTC) Project

2008-2011: Research on Shell Protection

2007- present: Full-scale Testing and Analysis of Tank Car Shell Impacts

2014

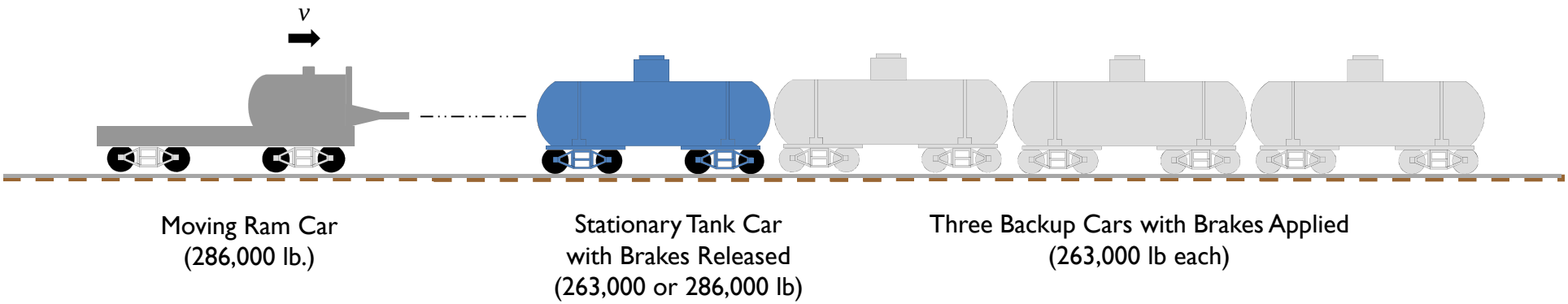
Head impact testing conducted by Government and Industry in 1970s and '80s

Toxic by Inhalation Hazard (TIH) Tank Cars

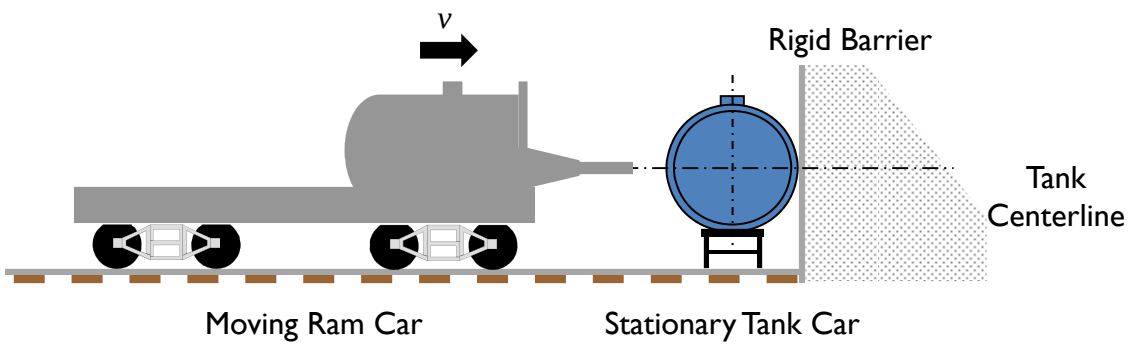
Crude Oil and Ethanol

Generalized Head and Shell Impact Scenarios

Head – Code of Federal Regulations (CFR) § 179.16



Shell – Ongoing Research



Development of Generalized Shell Impact Scenario

- Based on Results from
  - Train Derailment Dynamics Research
  - Accident Data and Forensic Evidence
- Idealized Impact Condition
  - Repeatable
  - Analyzable
  - Results in Failure Mode(s) Similar to Accidents
  - Represents Essential Accident Characteristics
  - Safe/Controlled
- Provides Means of Comparing Alternative Designs
- Provides Means for Qualifying Designs
- Approach Parallels Automotive 30-mph Barrier Test

Macdona, Texas on June 28, 2004

Automobile Side Impact Test

Full-scale Tank Car Shell Impact Tests

April 11, 2007

DOT105
10.0 mph
3

July 11, 2007

★ DOT105
15.1 mph
1

This Presentation

December 18, 2013

★ DOT111
14.0 mph
2

Previous Presentation

2007 2011 2014 2015

April 26, 2007

DOT105
14.0 mph
3

May 18, 2011

DOT105
17.8 mph
2

February 26, 2014

DOT112
14.7 mph
2

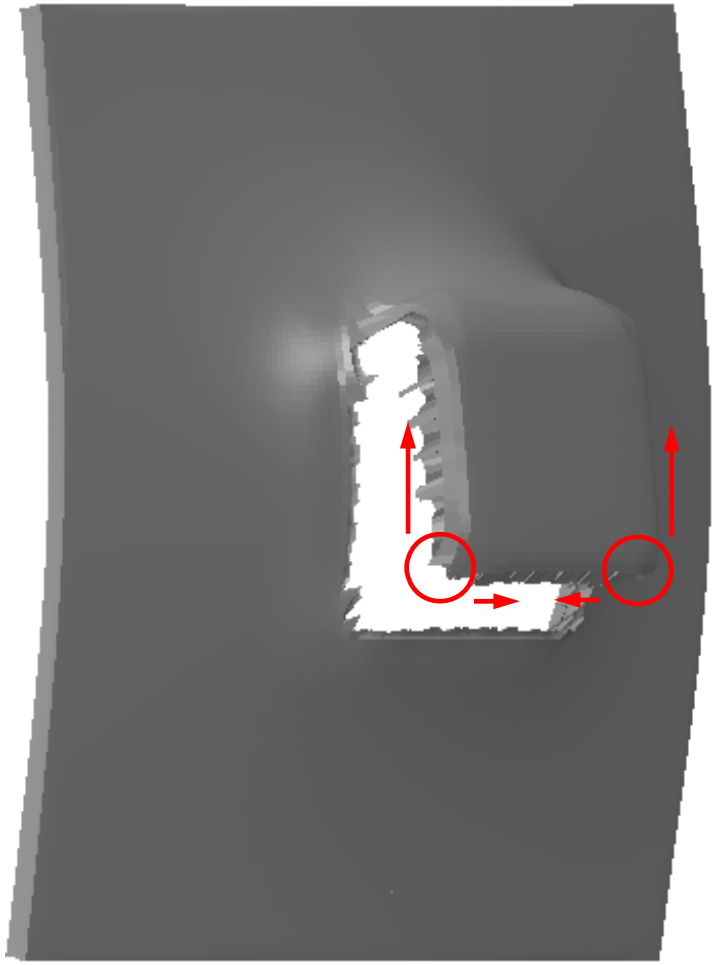
★ Tank Punctured

Indenter Sizes (W × H)

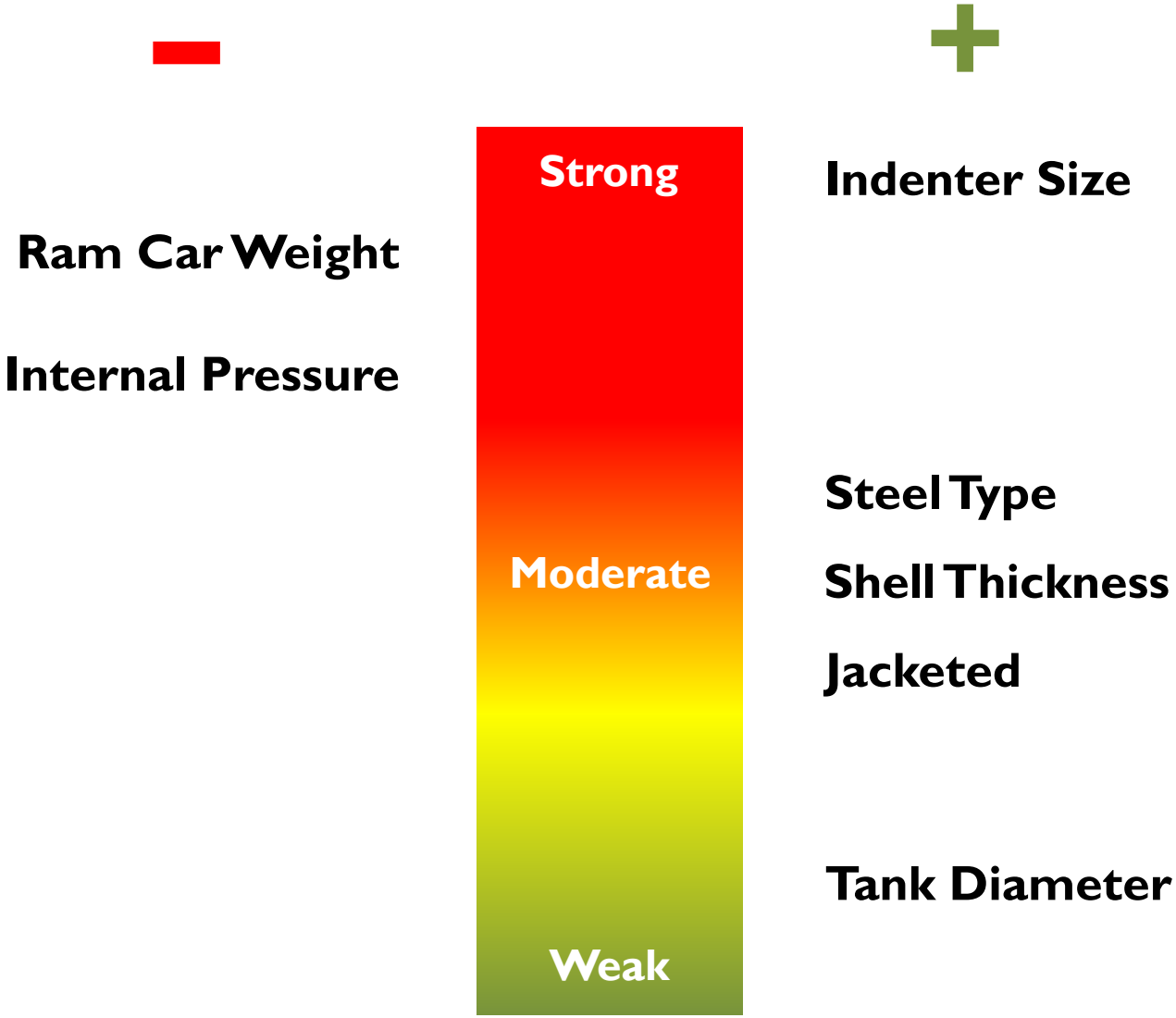
1 6" × 6"
2 12" × 12"
3 17" × 23"

Video of Puncture Test and Analysis

Predicted Damage to Tank Shell



Relative Effect of Various Factors on Puncture Speed



Video of Full-scale Test with Protective Panel

Summary

- The Volpe Center provides technical support to all of the agencies within the US Department of Transportation.
- The Volpe Center has provided technical support to the Federal Railroad Administration since the late 1970s.
- Support to the FRA Tank Car Safety Research entails both long-term research and as-needed assistance.

Thank you

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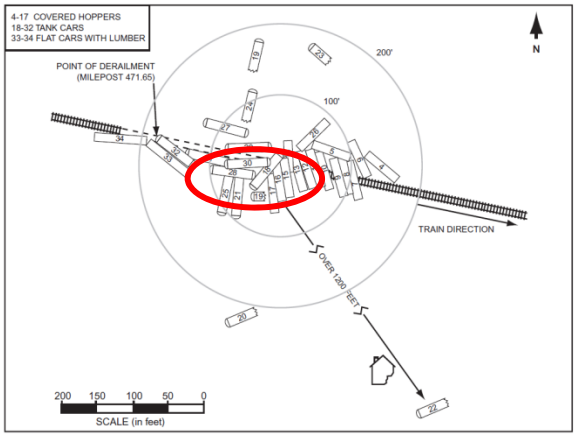
http://www.volpe.dot.gov/infrastructure-systems-engineering/structures-and-dynamics/tank-car-structural-integrity

Backup Slides

Derailment Pile-Ups



Minot, North Dakota on January 18, 2002

Oneida, New York on March 12, 2007

Macdona, Texas on June 28, 2004

Lac-Mégantic, Quebec on July 5, 2013

Semi-empirical Method for Head Puncture

- Based on extensive head testing conducted in 1970s and '80s
  - RSI-AAR
  - FRA

- Forces and deformations based on Hertz contact

- Failure based on transverse shear stress criterion

Correlations with Test Data and Engineering Analyses

- Semi-empirical method gives reasonable but conservative estimates for head puncture speed.

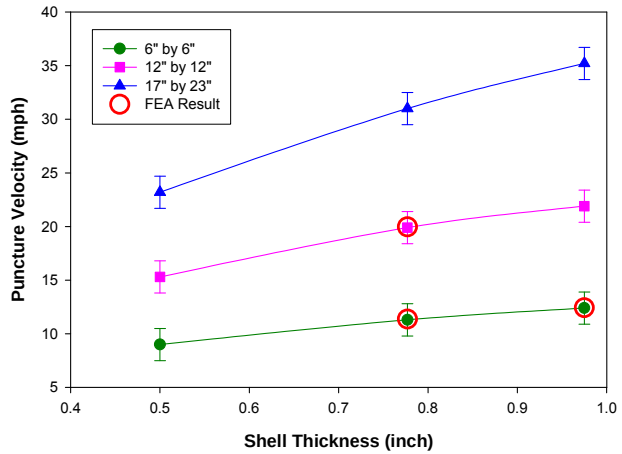
- Conservative means
  - Lower-bound estimate
  - Actual or true puncture speed is most likely to be somewhat higher than estimate

http://www.fra.dot.gov/eLib/details/L04134

http://www.fra.dot.gov/eLib/details/L04135

Semi-analytical Method for Shell Puncture

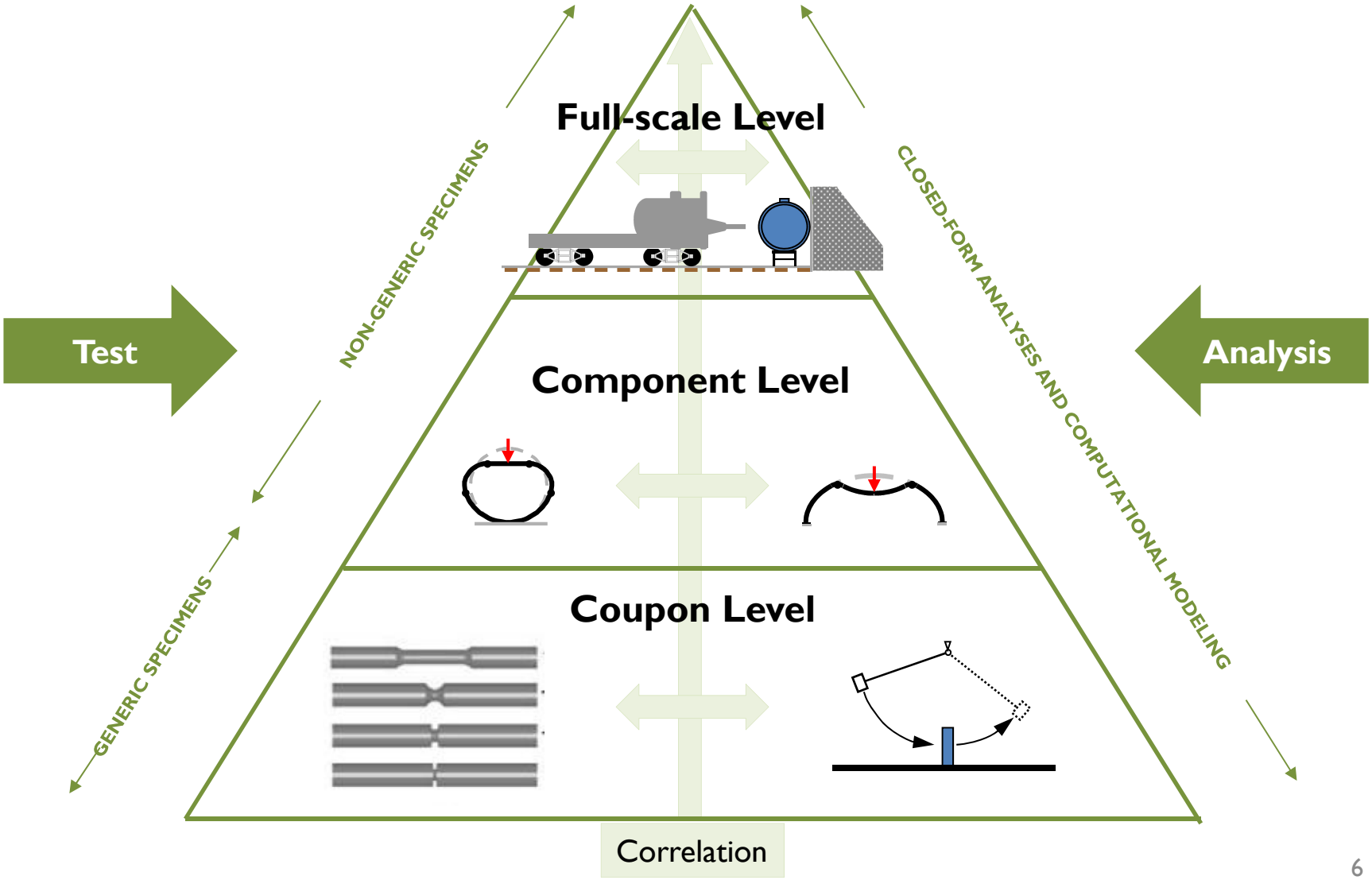
- Based on results from finite element analyses
- Validated with limited full-scale testing



http://ntlsearch.bts.gov/tris/record/ntl/37910.html

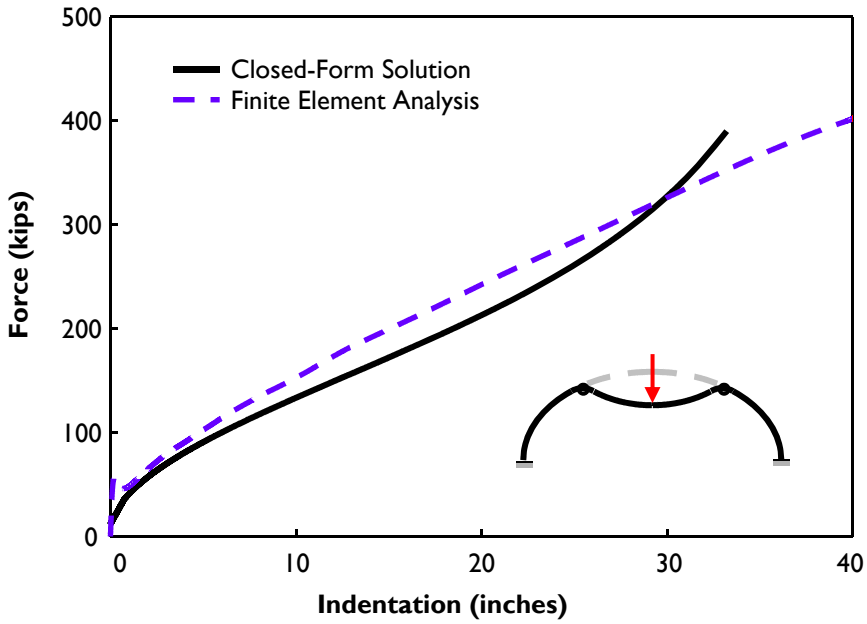
http://ntlsearch.bts.gov/tris/record/ntl/47391.html

Building Block Approach



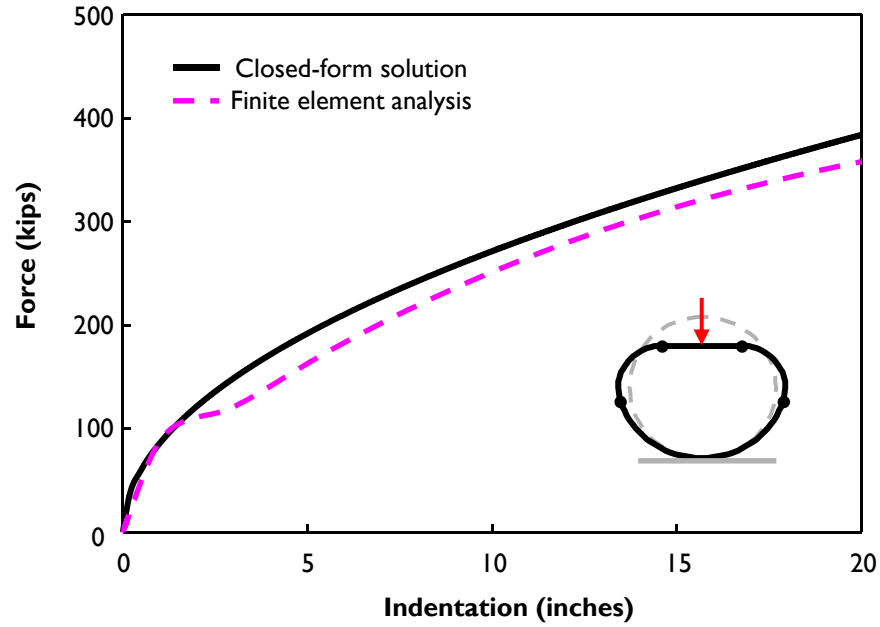
Verification for Head and Shell Deformations

Head



SOURCE: D.Y. Jeong et al., "Engineering Analyses for Railroad Tank Car Head Puncture Resistance," IMECE2006-13212, November 2006.

Shell

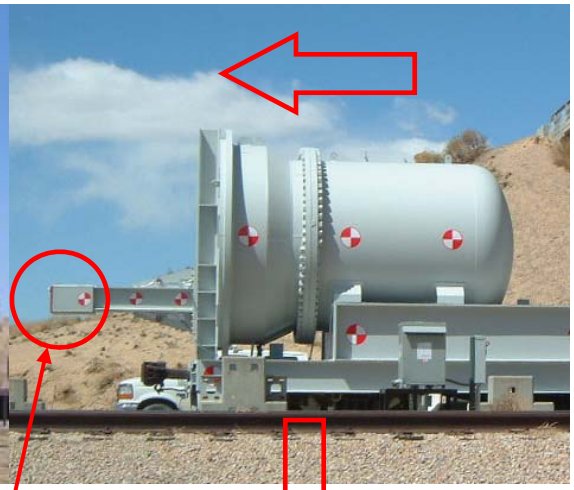


SOURCE: Y.H. Tang et al., "Analyses of Full-Scale Tank Car Shell Impact Tests," RTDF2007-46010, September 2007.

Significant Factors in Shell Impact Test

Tank Car Specification

Impact Speed



Indenter Size

Ram Car Weight

Comparison of Indenter Faces

Indenter (W x H)	**Comments**
6” x 6” (½-inch radii) 	• Similar to coupler shank with broken head
12” x 12” (1-inch radii) 	• Similar to standard coupler
17” x 23” (1-inch radii) 	• Smaller than draft sill • Larger than standard coupler • Similar to shelf coupler on car rolled onto side

Major Railroad Accidents Involving HAZMAT Release Composite Summaries for 1969 to 1978

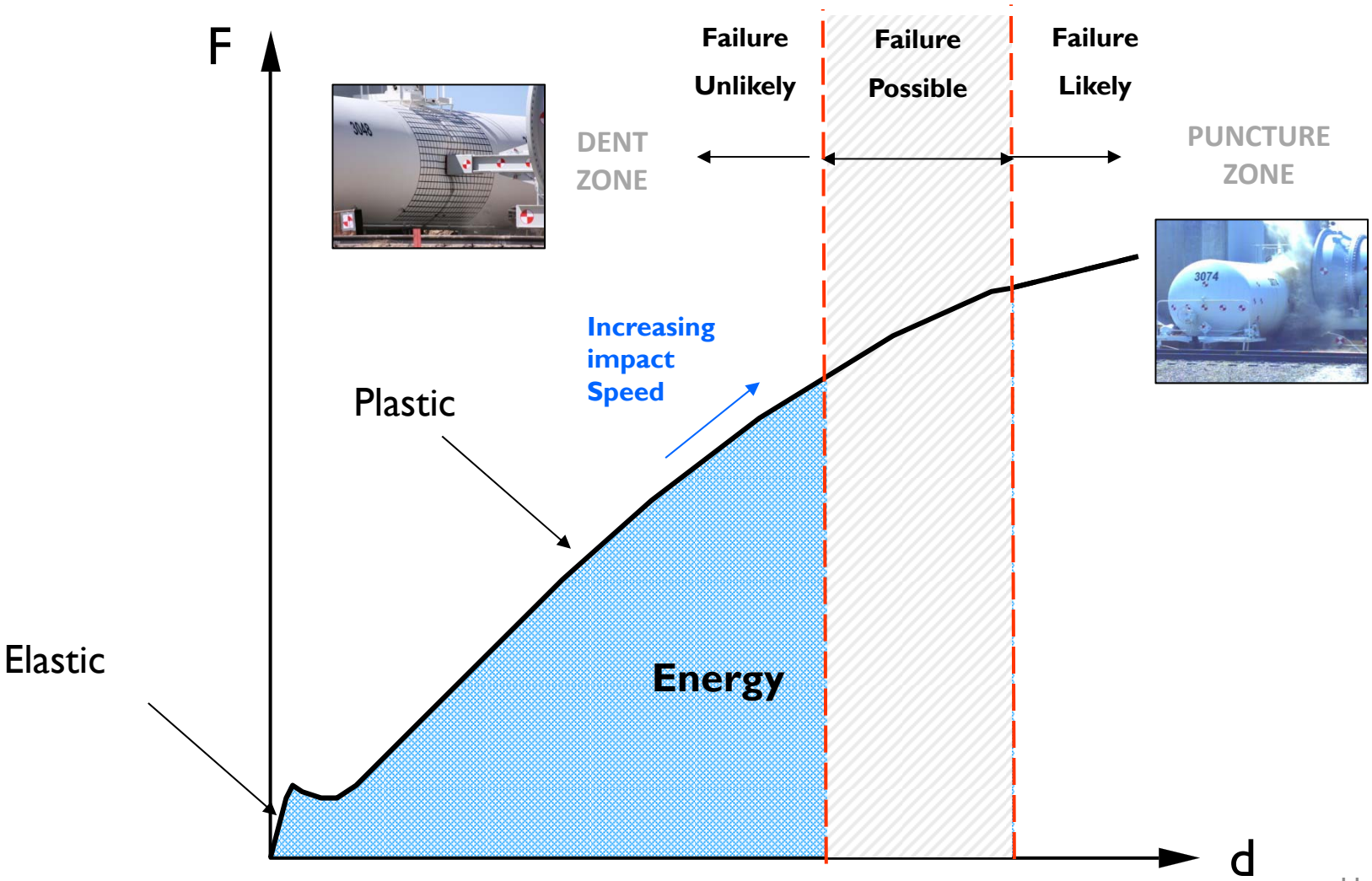
- Total of 75 accidents in this time period

- 22 accidents in which probable impacting object was reported
  - 13 couplers
  - 5 drawbars
  - 2 rails
  - 1 wheel
  - 1 end sill

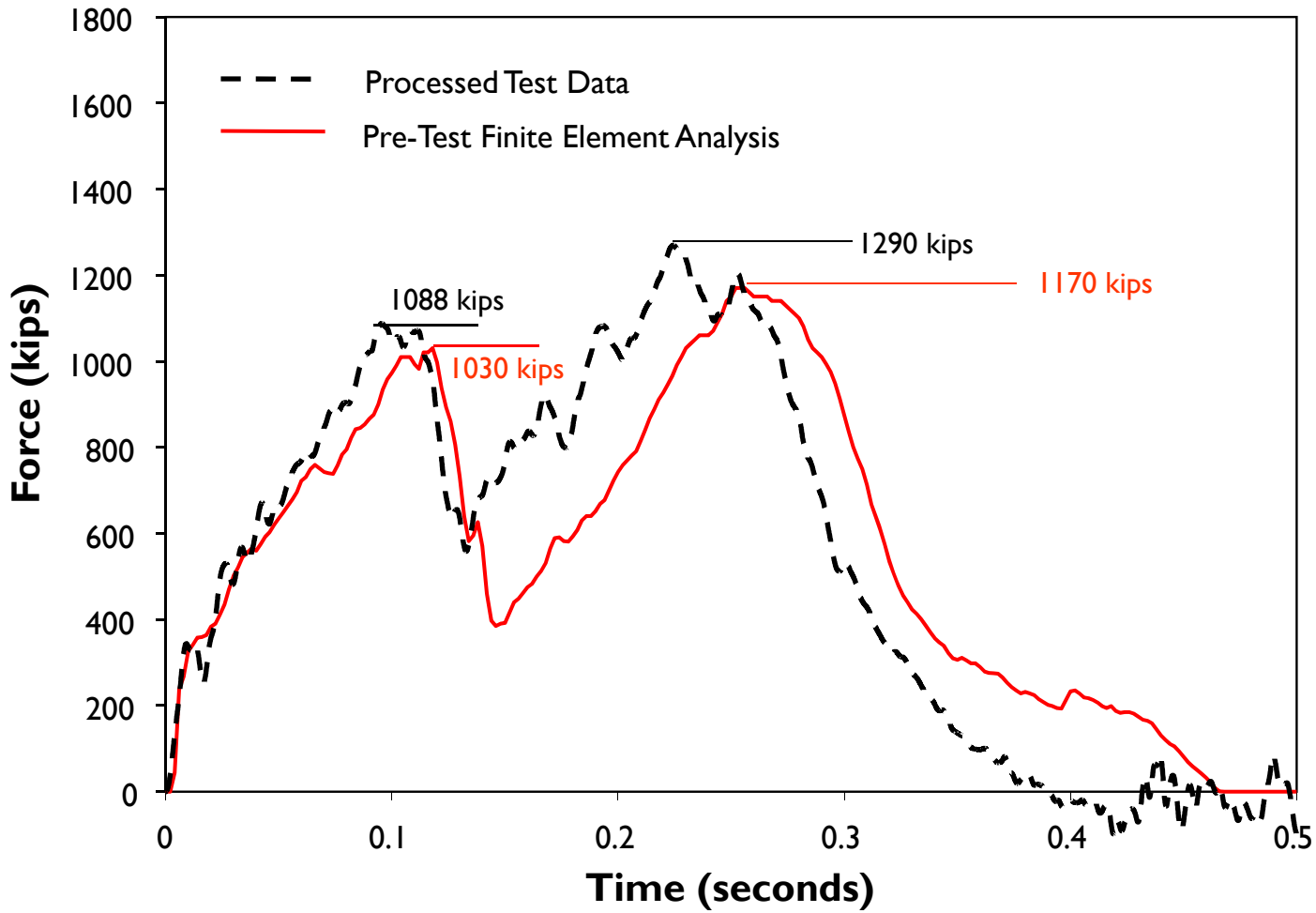
- Probable cause of these accidents
  - 16 Derailments
  - 6 Collisions

Generic Force-Indentation Characteristic

For a given tank car specification and indenter size

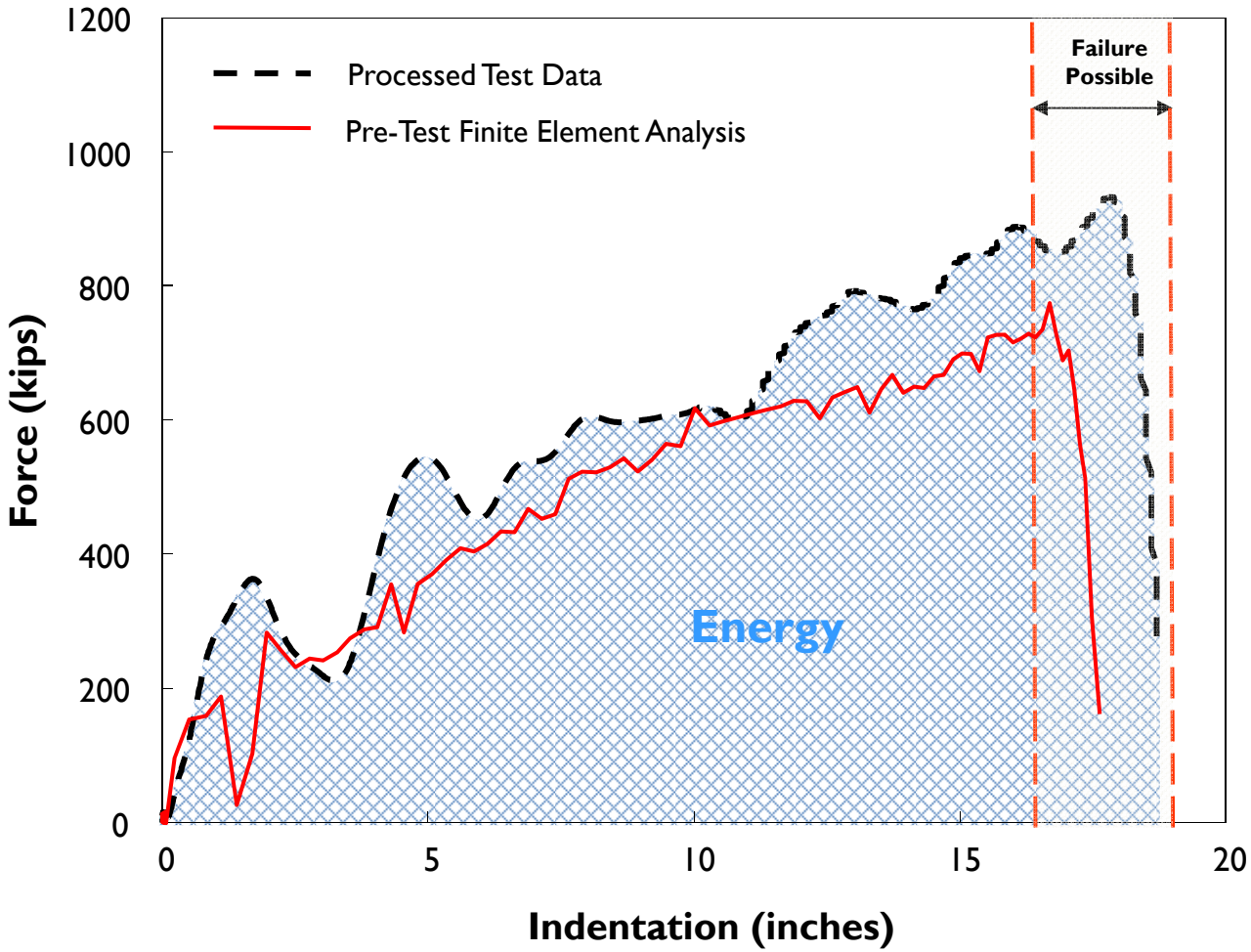


Force-Time Histories in Full-Scale Shell Impact Test 1 (14 mph, 17" x 23" Indenter)

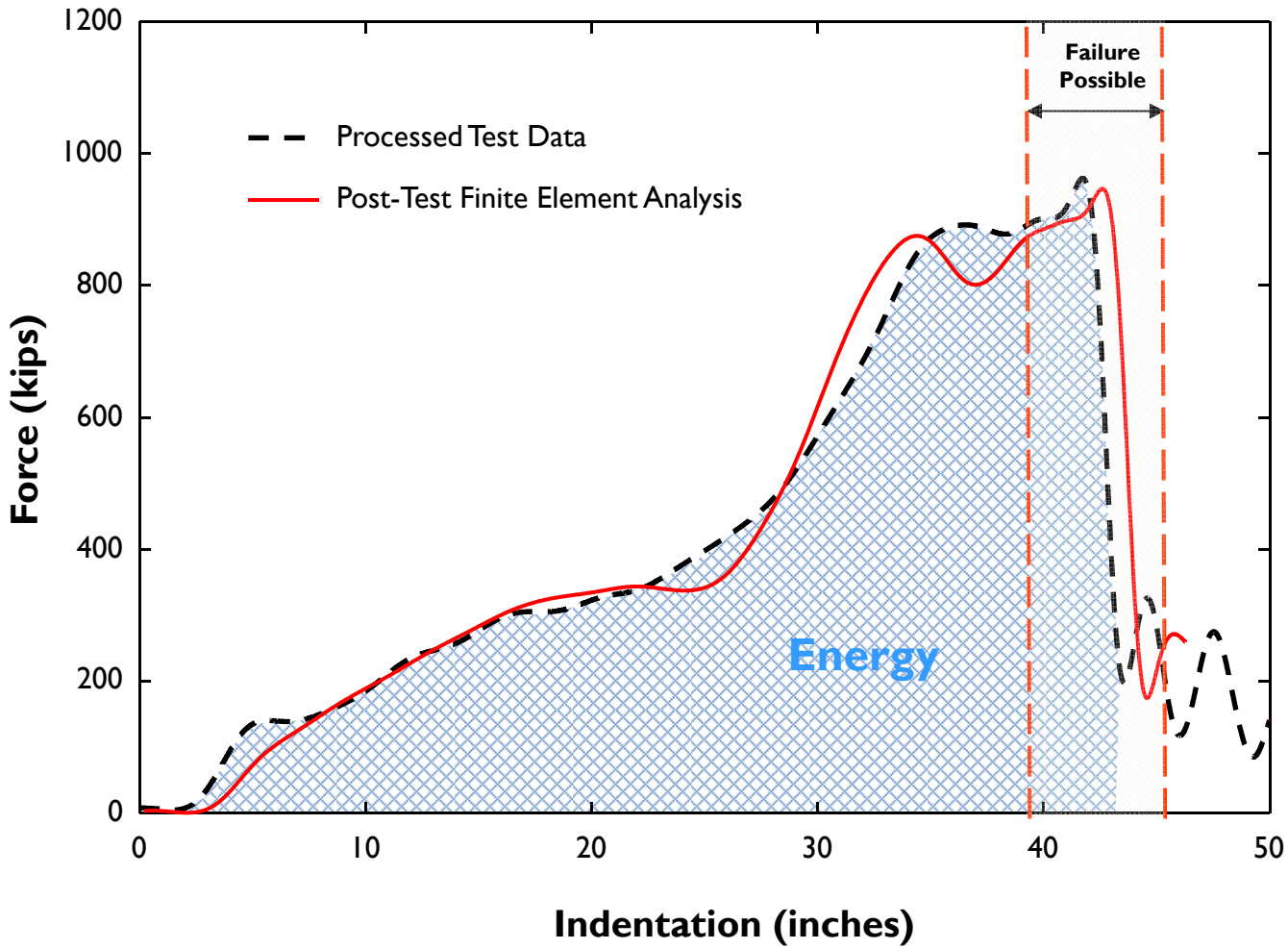


SOURCE: Y.H. Tang et al., "Analyses of Full-Scale Tank Car Shell Impact Tests," RTDF2007-46010, September 2007.

Force-Indentation in Full-Scale Shell Impact Test 2 (15 mph, 6” x 6” Indenter)



Comparison Between DOT111 Test and FEA (14 mph, 12” x 12” Indenter)

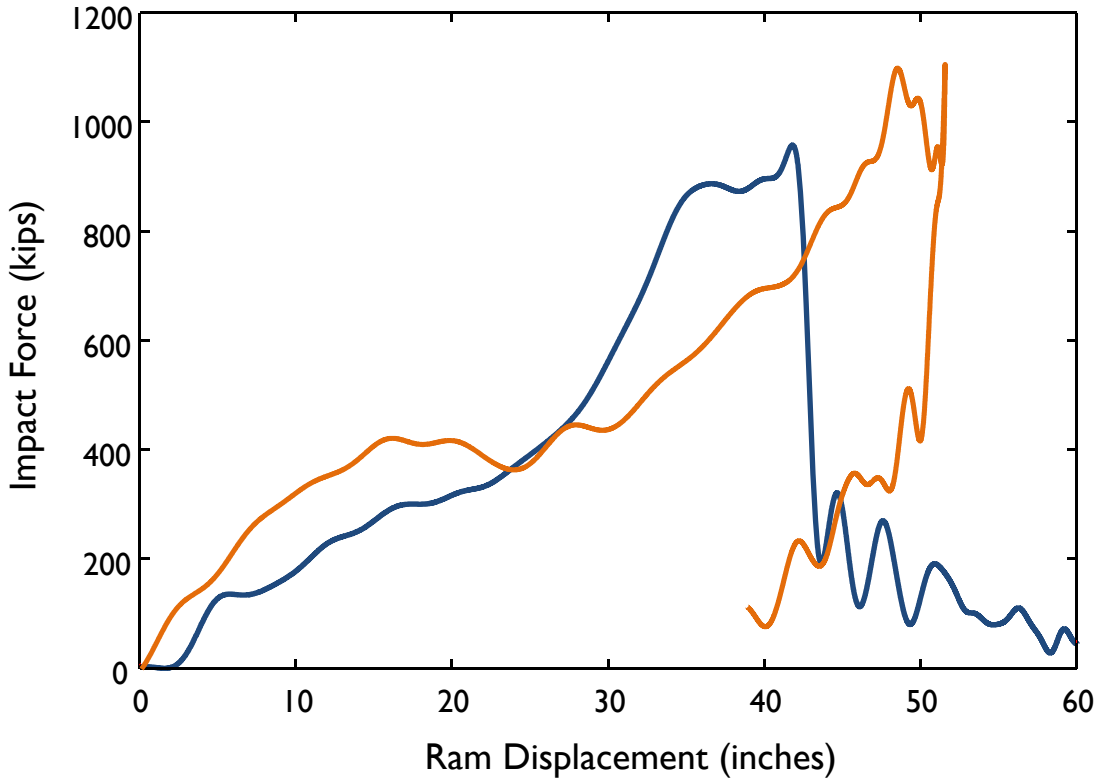


DOT111 and 112 Cars in Full-scale Tests

DOT111A100W1	**DOT112J340W**
General purpose	LPG service
Built in 1974	Built in 2001
$^{7}/_{16}$" shell thickness	0.618" shell thickness
$^{7}/_{16}$" head thickness	$^{11}/_{16}$" head thickness
ASTM 515 Grade 70	TC128 Grade B, Normalized
Sloping bottom rings; 106 to 110¼" diameter	117⅞" diameter
4" insulation	½ " insulation

Comparison of Full-scale Tank Car Shell Impact Test Results

	Car Type	Test Impact Speed (mph)	Kinetic Energy (M ft-lb)	Estimated Puncture Speed (mph)	Outcome
	DOT111	14.0	1.95	12	PUNCTURE
	DOT112	14.7	2.14	16	Tank Integrity Maintained

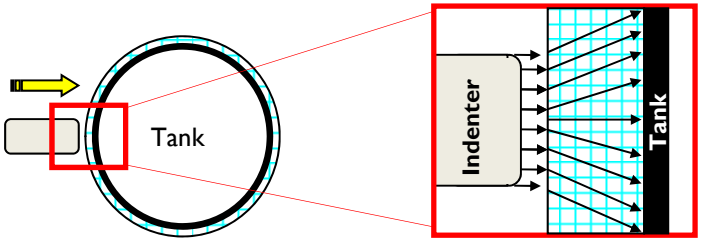


Applications of Force-Indentation Characteristic

- Automotive Crashworthiness (to Analyze Wall Test)
- General Aviation and Transport Aircraft (to Analyze Failed Takeoff/Landing)
- Building Protection Barriers
- Passenger Rail Equipment Crashworthiness
- Locomotive Crashworthiness

Strategies for Improved Puncture Performance

- Blunting the Impact



- Managing Collision Energy

- Providing Support Structure for Load-Blunting and Energy-Managing Features

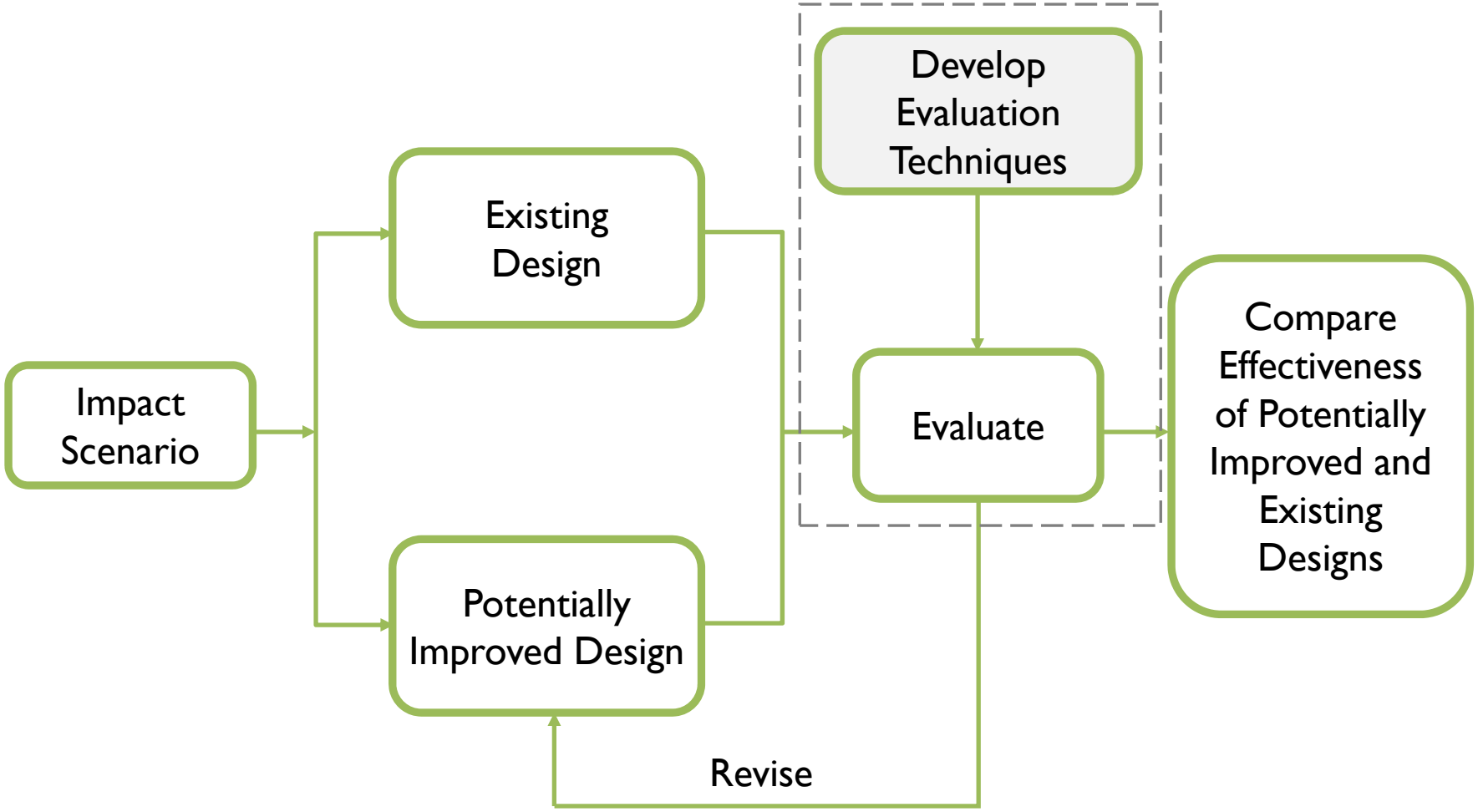
Weak Support Structure Collapses

Approximate Initial Shape

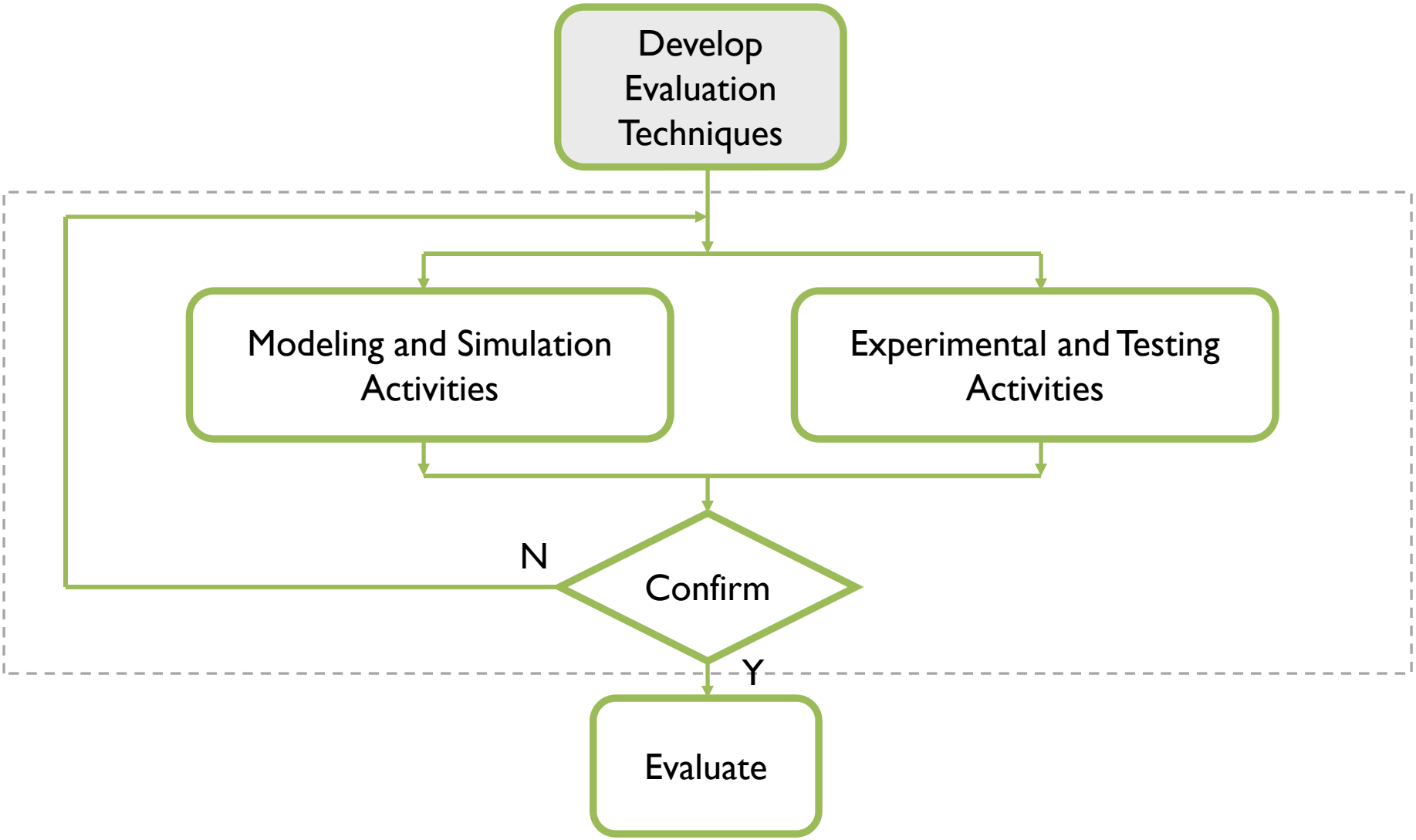
Strong Support Structure Upholds

Approximate Initial Shape

Framework for Improved Designs

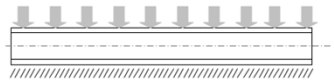


Developing Evaluation Techniques



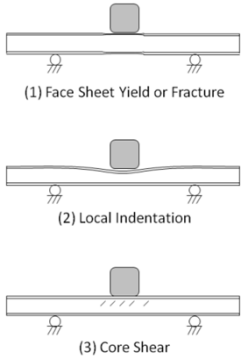
Development of Protective Panel

Quasi-static Crush Tests



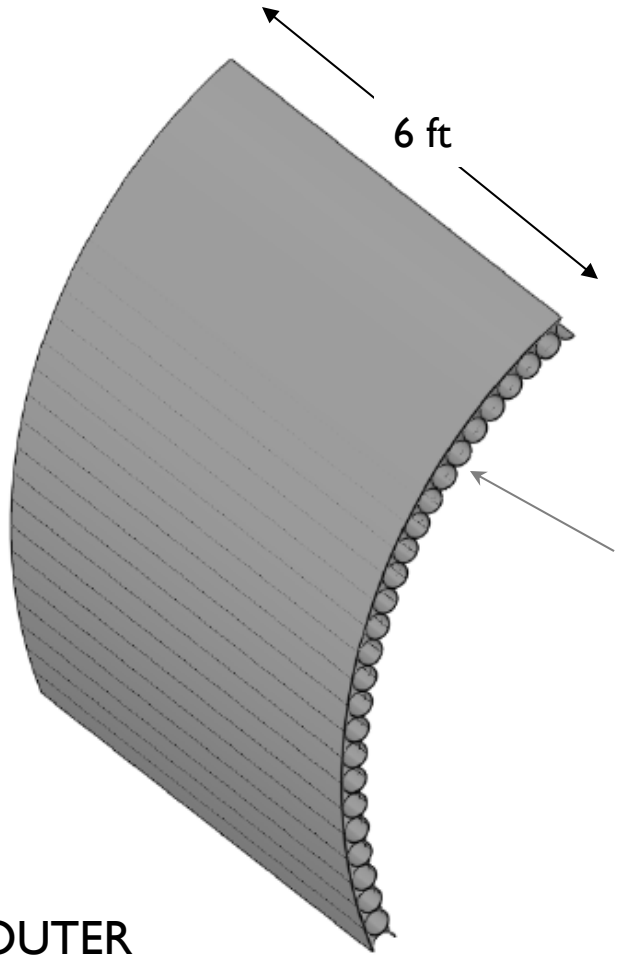
5" Pipe Core	
3" Pipe Core	
2" Pipe Core	
X-Core	
Diamond Core	

Quasi-static Three-point Bend Tests

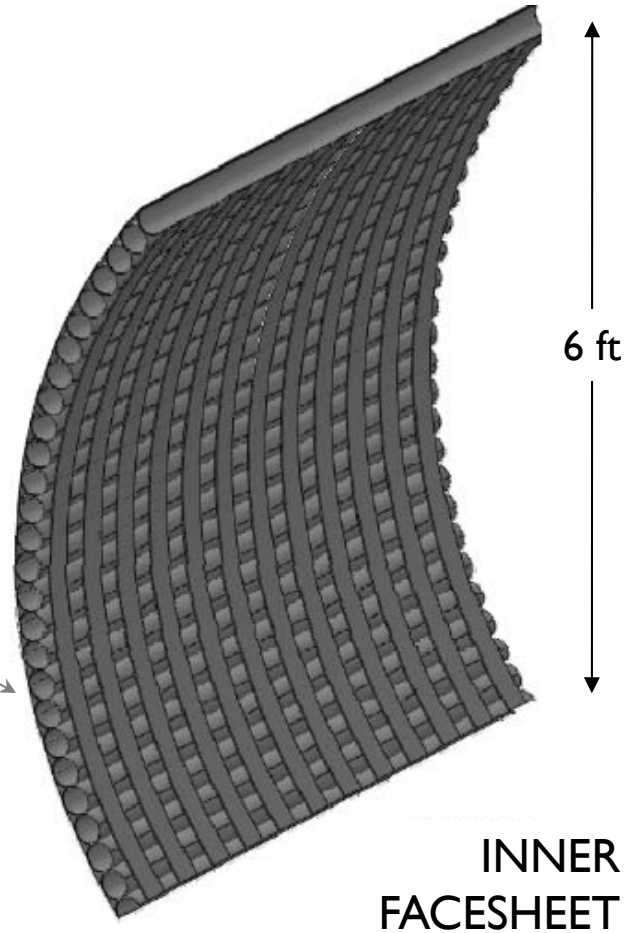


SOURCE: M.E. Carolan et al., "Application of Welded Steel Sandwich Panels for Tank Car Shell Impact Protection," Final Report, DOT/FRA/ORD-13/19, April 2013

Schematic of Protective Panel



3" OD pipes
0.086" thickness

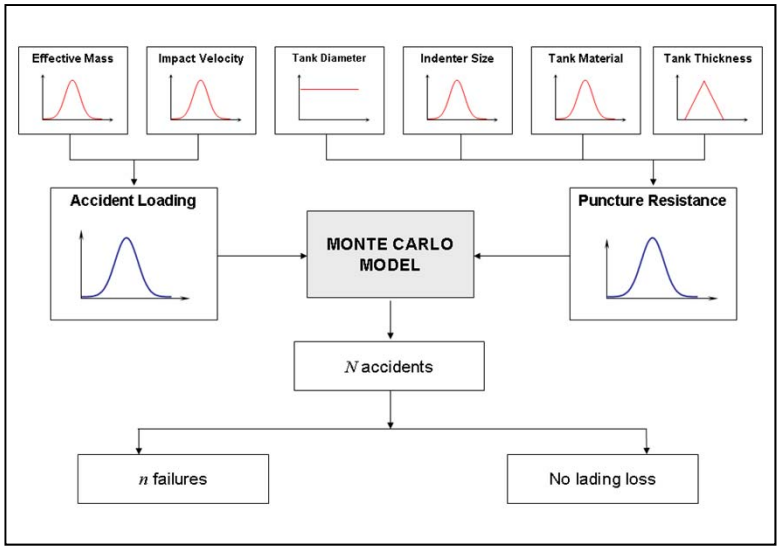


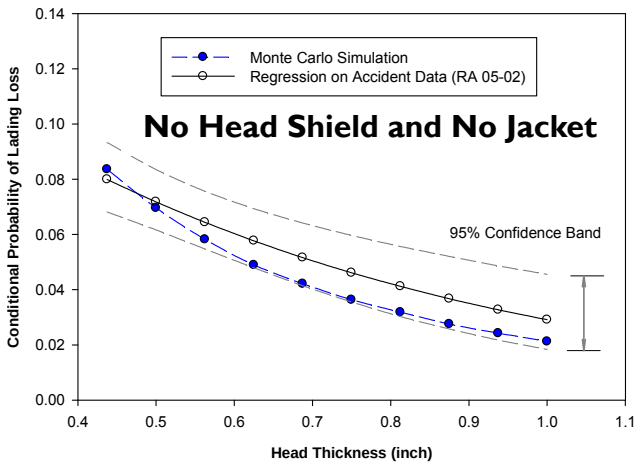
OUTER
FACESHEET
0.12" thickness

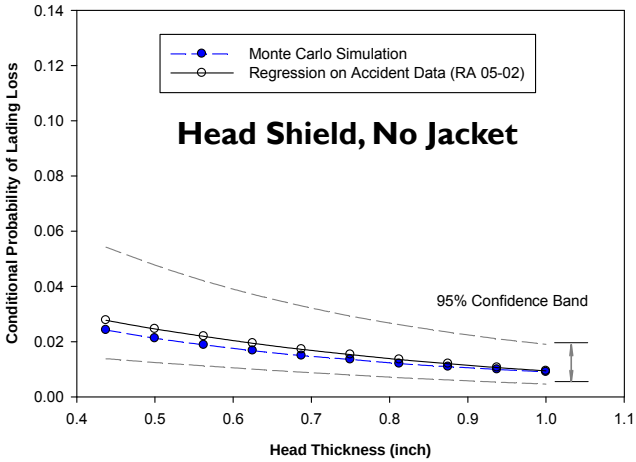
INNER
FACESHEET
0.12" thickness
Strips 3" wide, 3" spacing

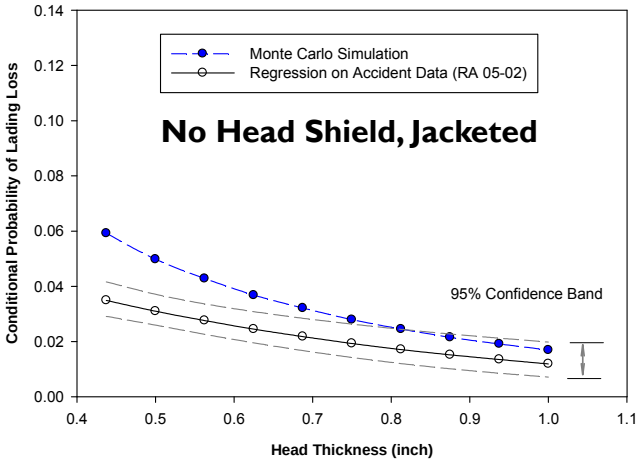
Material	AISI 1010
Weight	803 lb (21 psf)

Correlating Engineering Analyses and Conditional Probability of Release







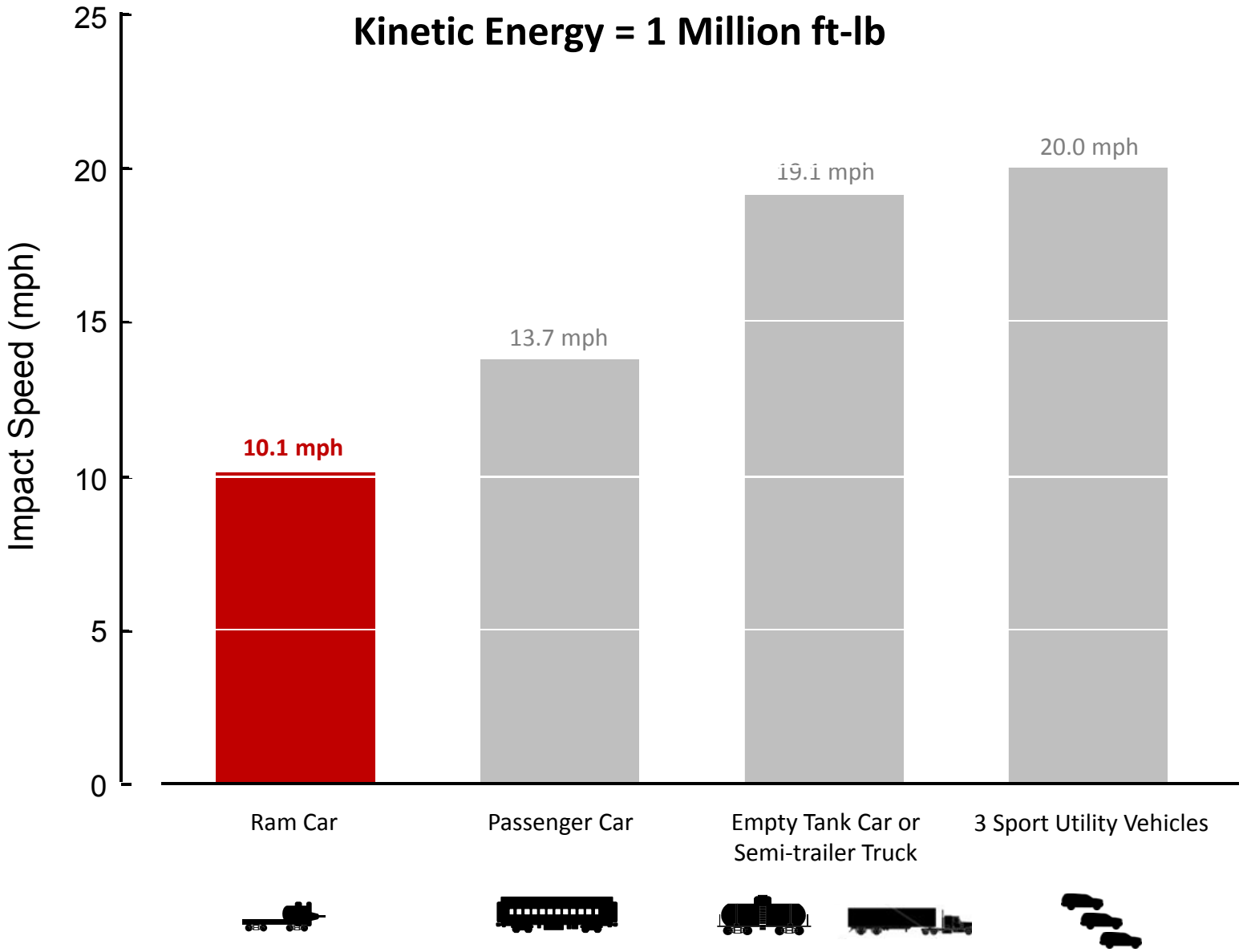


SOURCE: D.Y. Jeong, "Probabilistic Approach to Conditional Probability of Release of Hazardous Materials from Railroad Tank Cars During Accidents," IMECE2009-10872, November 2009.

Estimated Shell Puncture Speeds for Selected Cars

This slide has been removed from the presentation
at the request of the Dr. David Jeong (May 1, 2014)

Impact Scenarios with Equivalent Kinetic Energy



Estimated Shell Puncture Speeds for Other Cars

This slide has been removed from the presentation
at the request of the Dr. David Jeong (May 1, 2014)