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Spent Fuel and Waste Science and Technology

Preliminary Results of the Multi-Mode Transportation Test Rail Data Analysis

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Sandia National Laboratories

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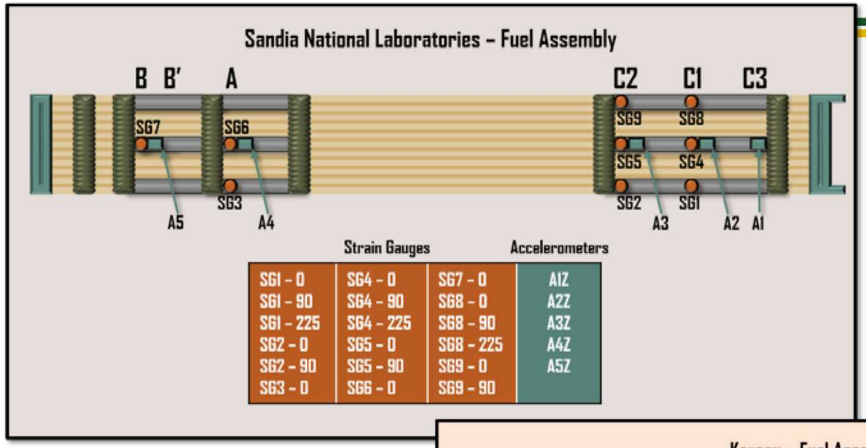
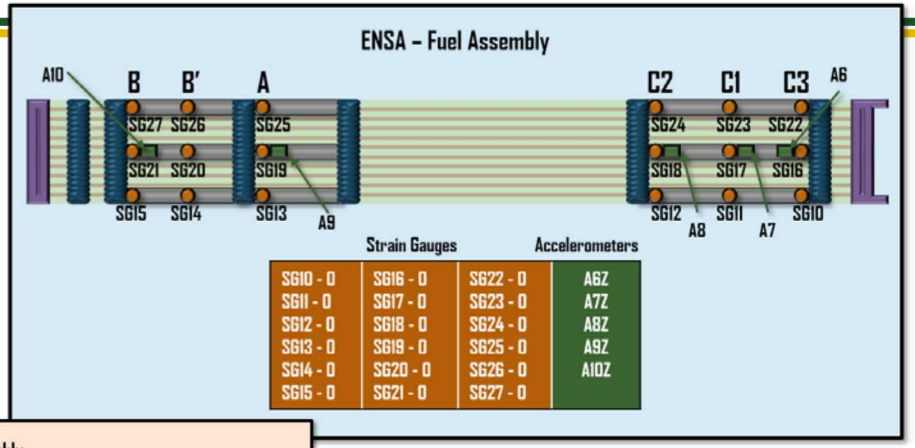
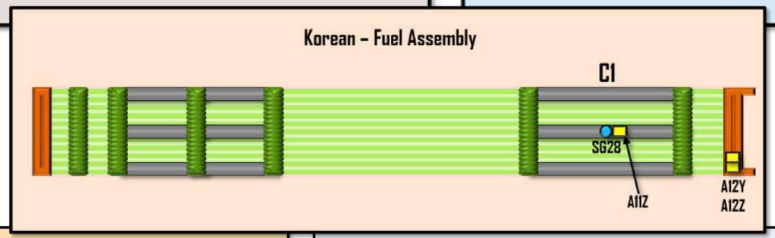
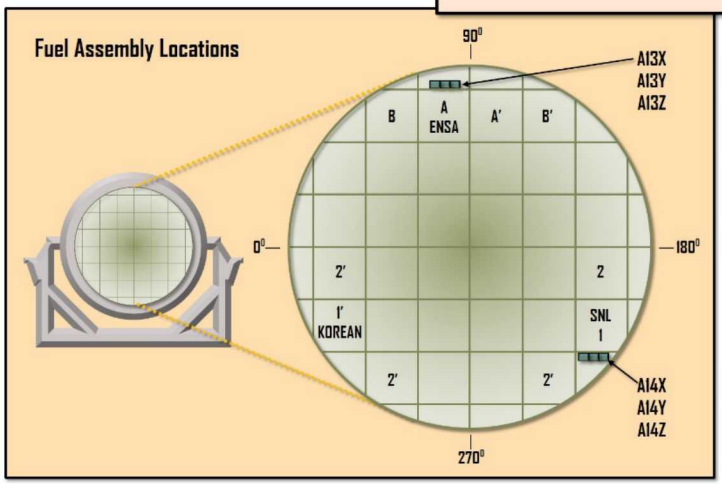
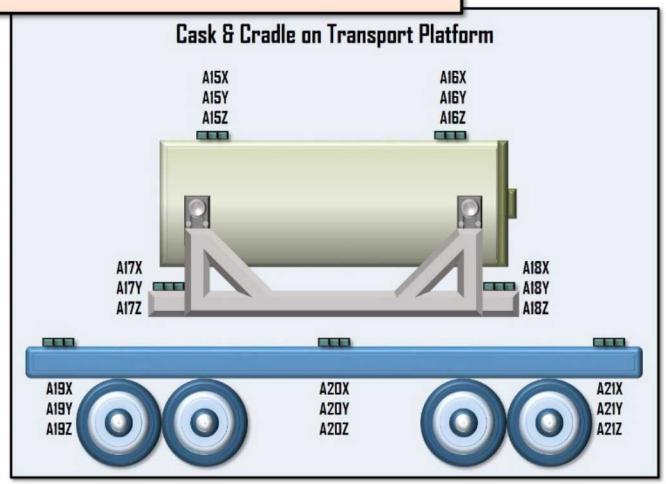
Transportation System Instrumentation











Assemblies & Cask System Instrumented with 40 Accelerometers & 37 Strain Gauges

Data Collection Frequency
TTCI: 10,240 Hz
Rail: 512 Hz

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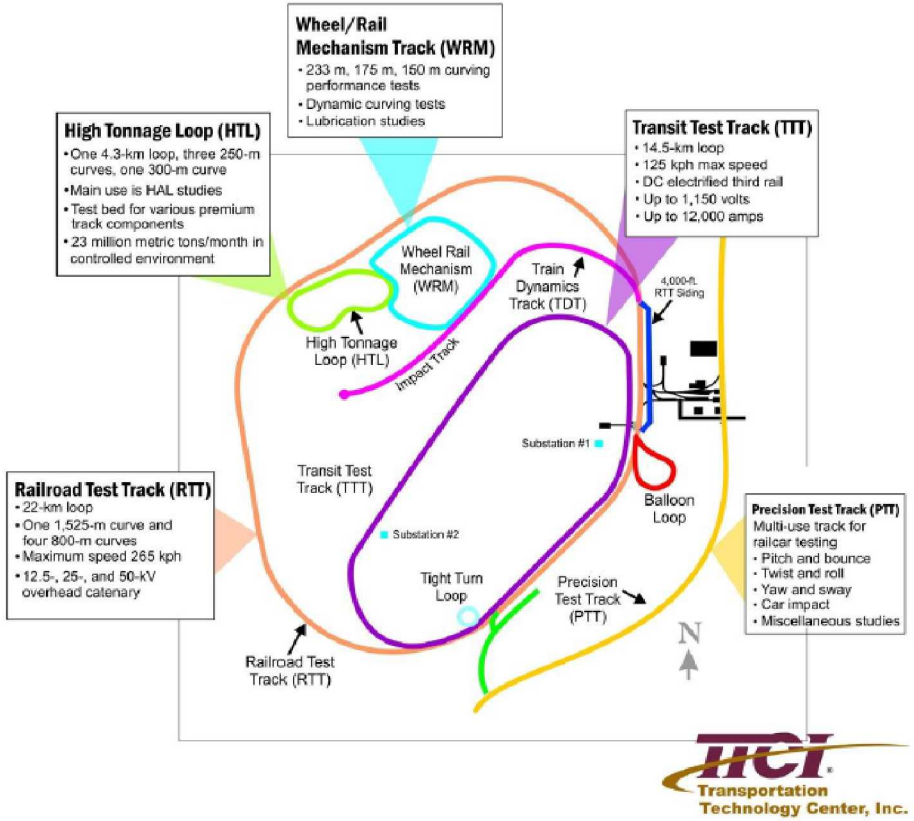
TTCI Tests Setup

Why TTCI

- *Short duration tests with known conditions*
- *Design parameters somewhat beyond expected on the commercial railroads*
  - ✓ *Track design*
  - ✓ *Speeds*
  - ✓ *Coupling impact velocities*

TTCI Rail Track Map



Kasgro 12-Axle Car with Cask at TTCI

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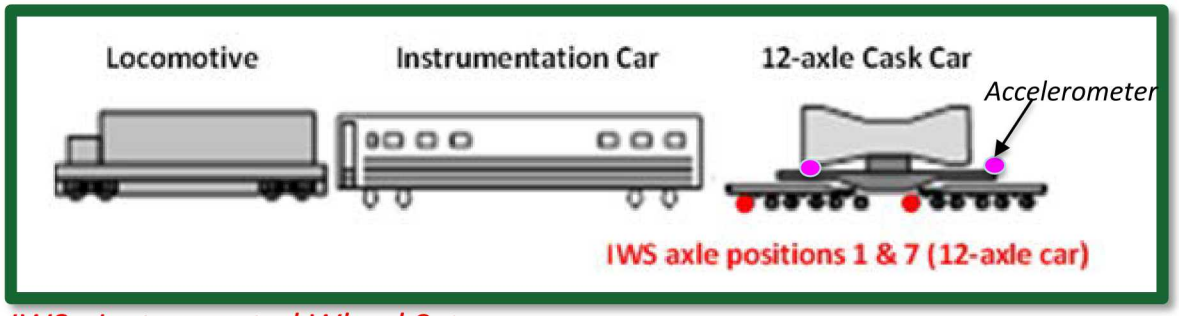
Series of Tests Conducted at TTCI

- **TWIST & ROLL TESTS** (18 TESTS) **LATERAL INPUTS**
  - ✓ *Determines car's ability to negotiate oscillatory cross-level perturbations.*
- **PITCH & BOUNCE TESTS** (9 TESTS) - **VERTICAL INPUTS**
  - ✓ *Determines car's ability to negotiate parallel vertical rail perturbations.*
- **DYNAMIC CURVING TESTS** (25 TESTS) **LATERAL INPUTS**
  - ✓ *Determines car's ability to negotiate curving over jointed track with combination of lateral misalignment at outer rail joints and cross-level due to low joints on staggered rails.*
- **TESTS AT U.S. ARMY PUEBLO CHEMICAL DEPOT** (17 TESTS) **VERTICAL INPUTS**
  - ✓ *Determines performance over FRA Class-2 railroad track and tests through No. 8 turnout and No. 8 crossovers.*
- **SINGLE BUMP TESTS** (12 TESTS) **VERTICAL INPUTS**
  - ✓ *Determines performance at grade crossings.*
- **CROSSING DIAMOND TESTS** (6 TESTS) **VERTICAL INPUTS**
  - ✓ *Determines vehicle's behavior when crossing diamonds (or "frogs'), a leading cause of derailments.*
- **HUNTING ON RAILROAD TEST TRACK & TRANSIT TEST TRACK** (30 TESTS) **LATERAL INPUTS**
  - ✓ *Determines stability at 30, 40, 50-75 mph at 5 mph increments.*
- **COUPLING IMPACT TESTS** (10 TESTS) **LONGITUDINAL INPUTS**
  - ✓ *Determines longitudinal inputs from coupling at higher than normal speeds.*

Data Collected by TTCI



IWS - Instrumented Wheel Set

Purpose: *to compare railcar performance against AAR requirements*

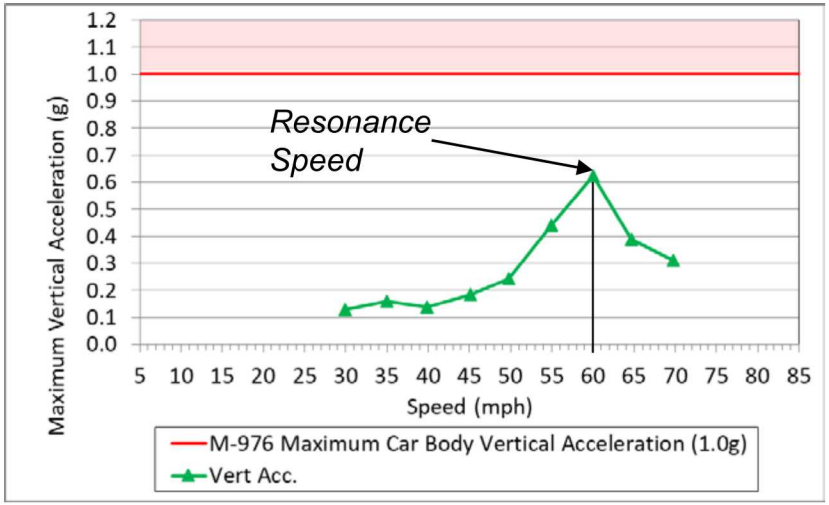
Data Collection Frequency

- *Tests with IWS: 1,200Hz*
- *Tests without IWS (hunting): 600Hz*
- *Coupling impact tests: 500Hz*

Data Filtering

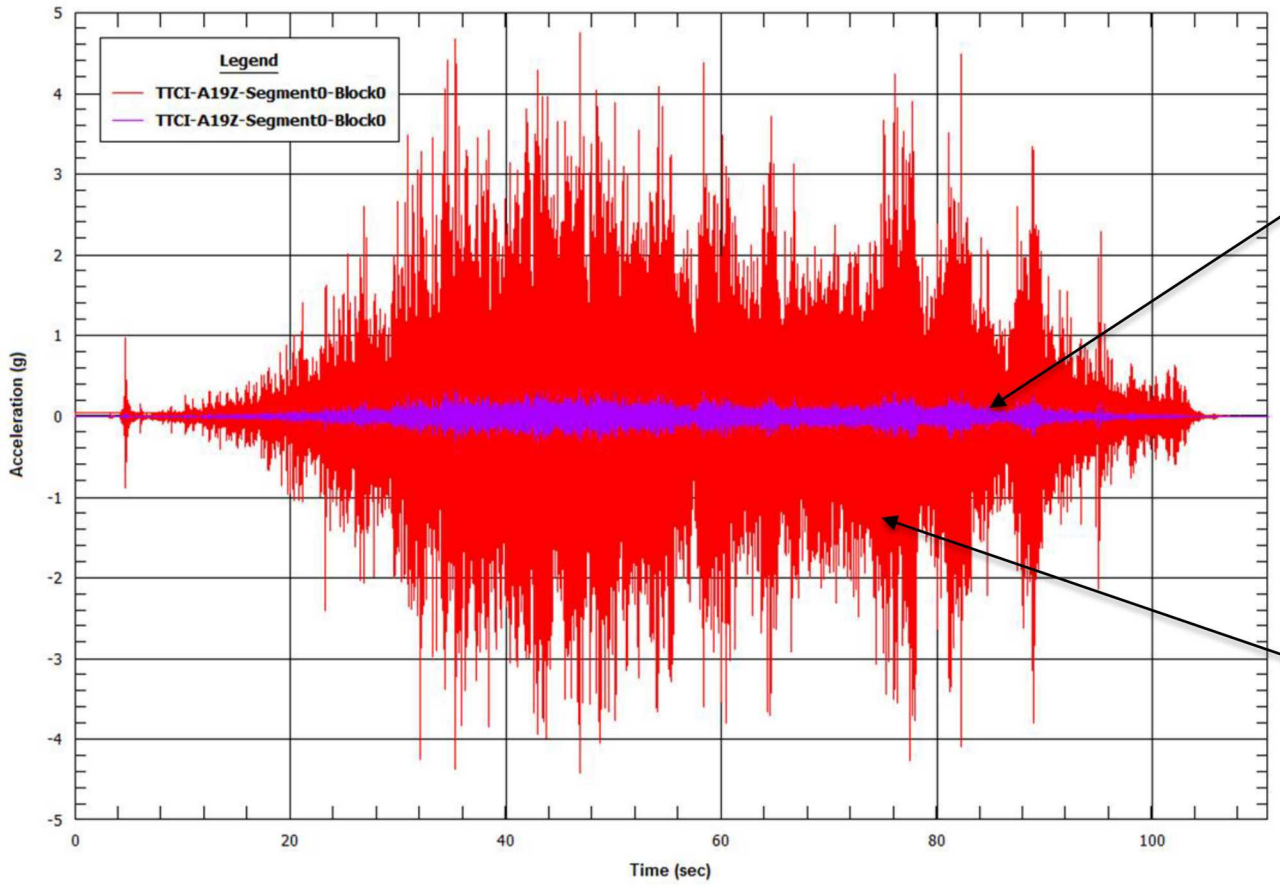
- *Acceleration data: 30Hz*
- *IWS data: 15Hz*

Maximum Carbody Acceleration in Pitch&Bounce Test



Test Data With & Without Filtering

Acceleration Time History



Transportation Tests Data Filtered with 15 Hz

Unfiltered Data

- *Transportation test analyzes unfiltered data.*
- *The filtered data are shown for comparison purpose only.*
- *The filtered data are similar to the TTCI data.*

Summary of TTCI Data Analysis

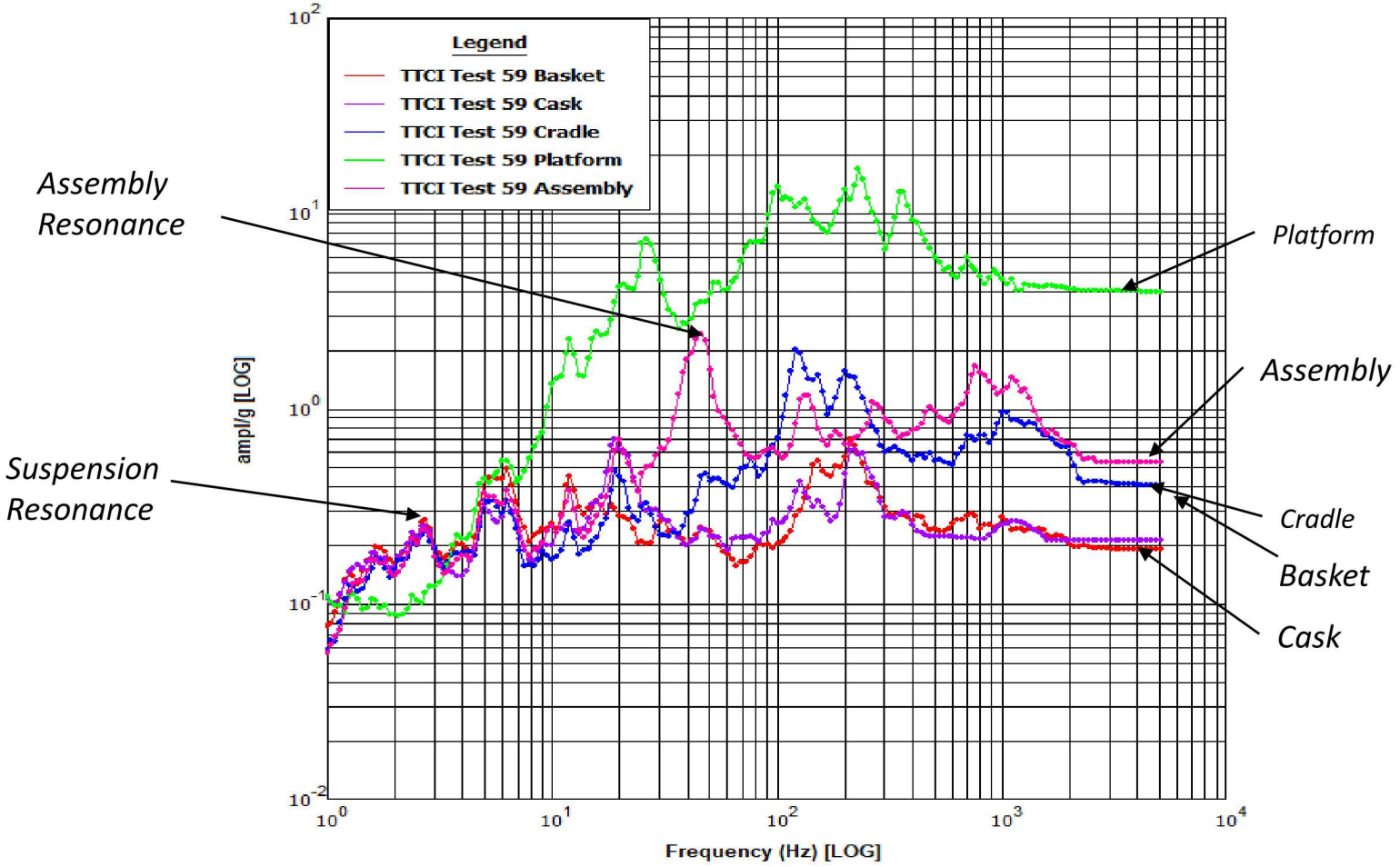
MAJOR GOAL: *understand the responses of the transportation system to the different types of the transient inputs – different test conditions and speeds in all* ***125 test cases*** *to the system elements.*

This is important for ***model validation*** *and for* ***the analysis of the rail data*** *on the route to and from Baltimore.*

ANALYSIS OUTPUTS

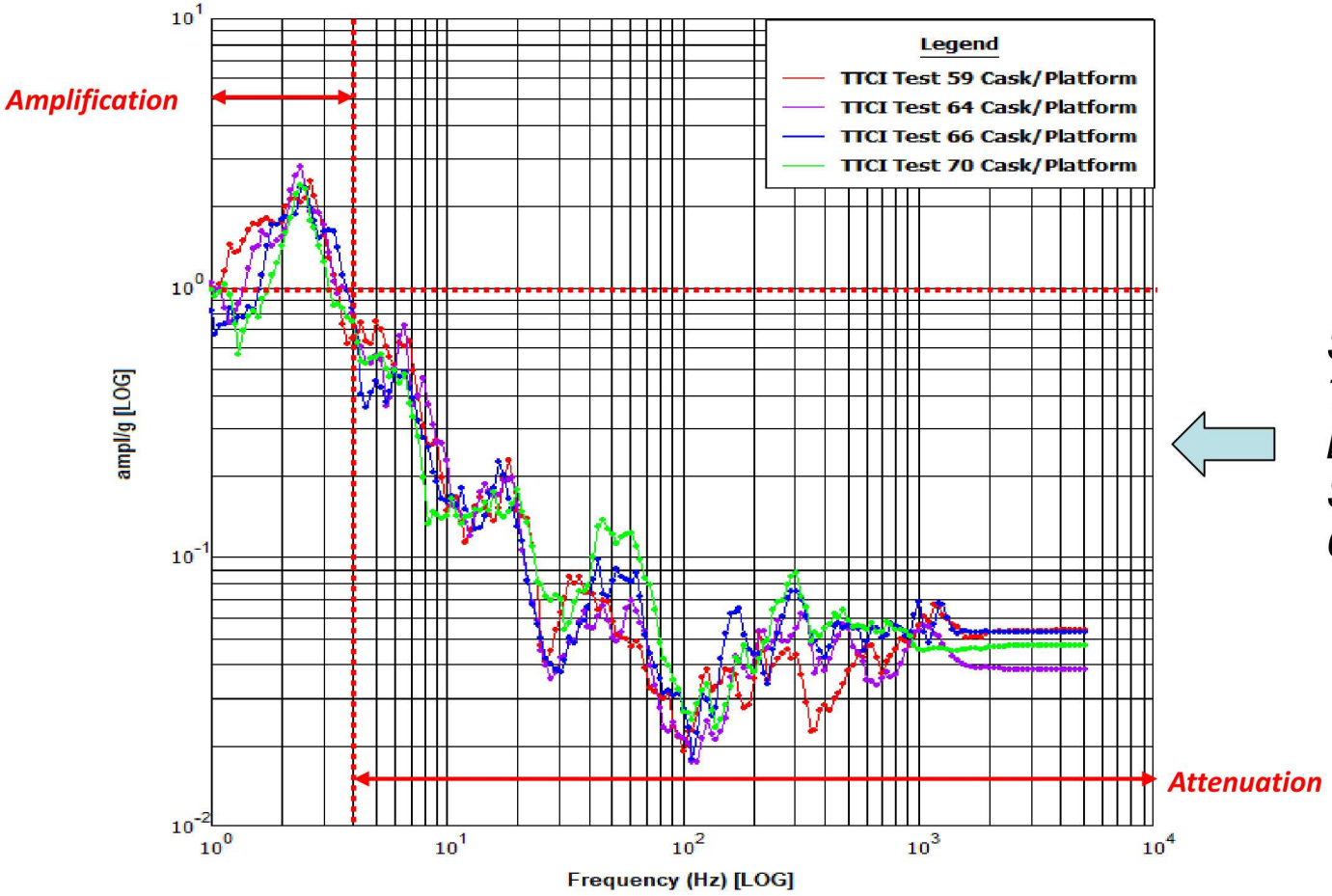
- *Min and max accelerations/strain for each of 40 accelerometers/37 strain gages for each test case.*
  - ✓ *The min/max values are derived from the analysis of the* ***unfiltered time histories*** *corrected for bias. Butterworth's band filter (0.1Hz-1,000Hz) was in a few cases on the data significant drifts.*
- *Acceleration and strain Shock Response Spectra (SRS) for different transportation system elements for each test case.*
  - ✓ *The SRS predicts the maximum amplitude at which various single-degree-of-freedom systems would respond to the transient inputs.*
- *Attenuation and amplification from the transportation platform to the assembly and cask as a function of frequency for each test case.*

Representative Transportation System SRS



- *The elements of the transportation system respond differently to the shocks.*
- *Correlation coefficient between the assembly and cradle acceleration is ~ 0.25*

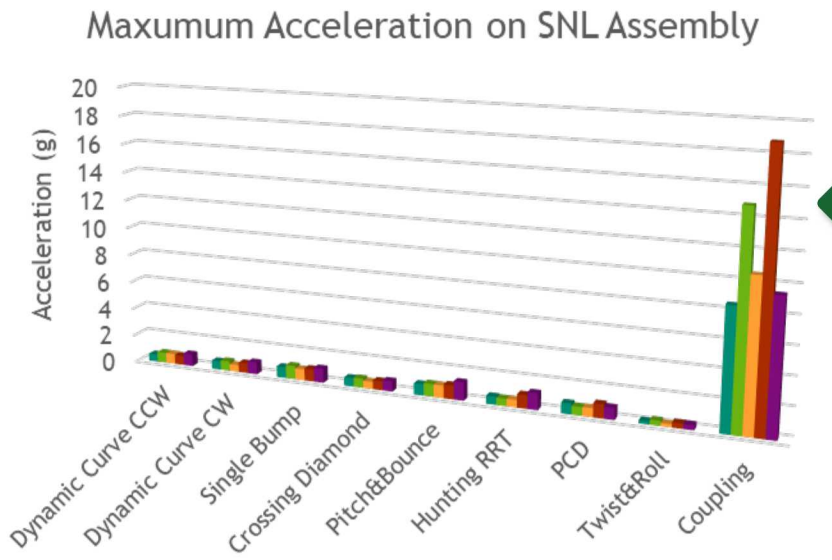
Representative Transportation System Attenuation & Amplification



Single Bump Tests at 4 Different Speeds: 40; 55; 60; and 75 mph

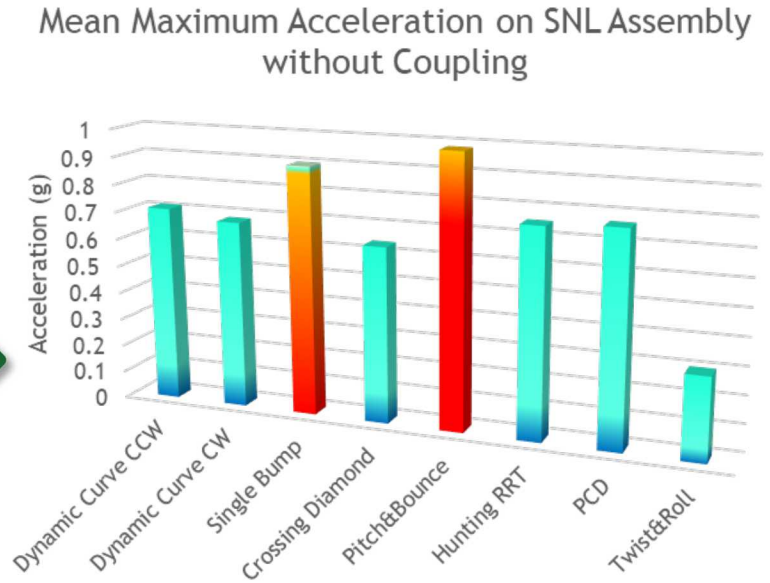
- *There is noticeable attenuation from the transportation platform to the cask and assembly, except the low frequencies (below 4Hz).*

SNL Assembly Accelerations in Different TTCI Tests

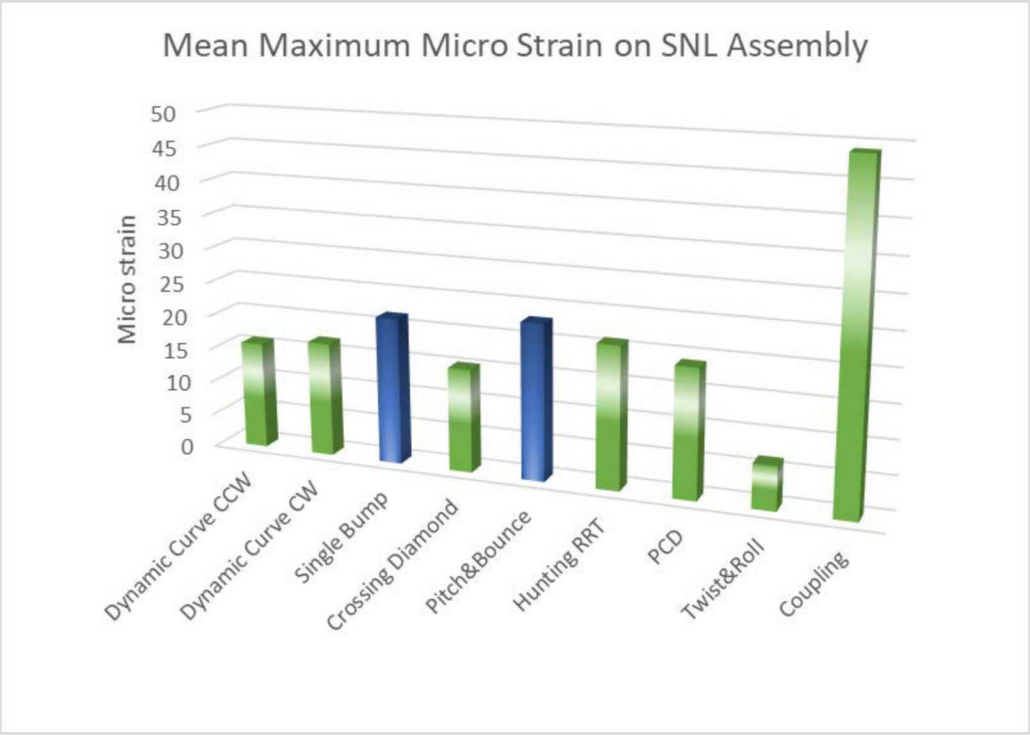


Shock from rail coupling is significantly more severe than the other types of shock events.

Single Bump and Pinch and Bounce tests have largest accelerations compared to the other tests, except coupling impact.



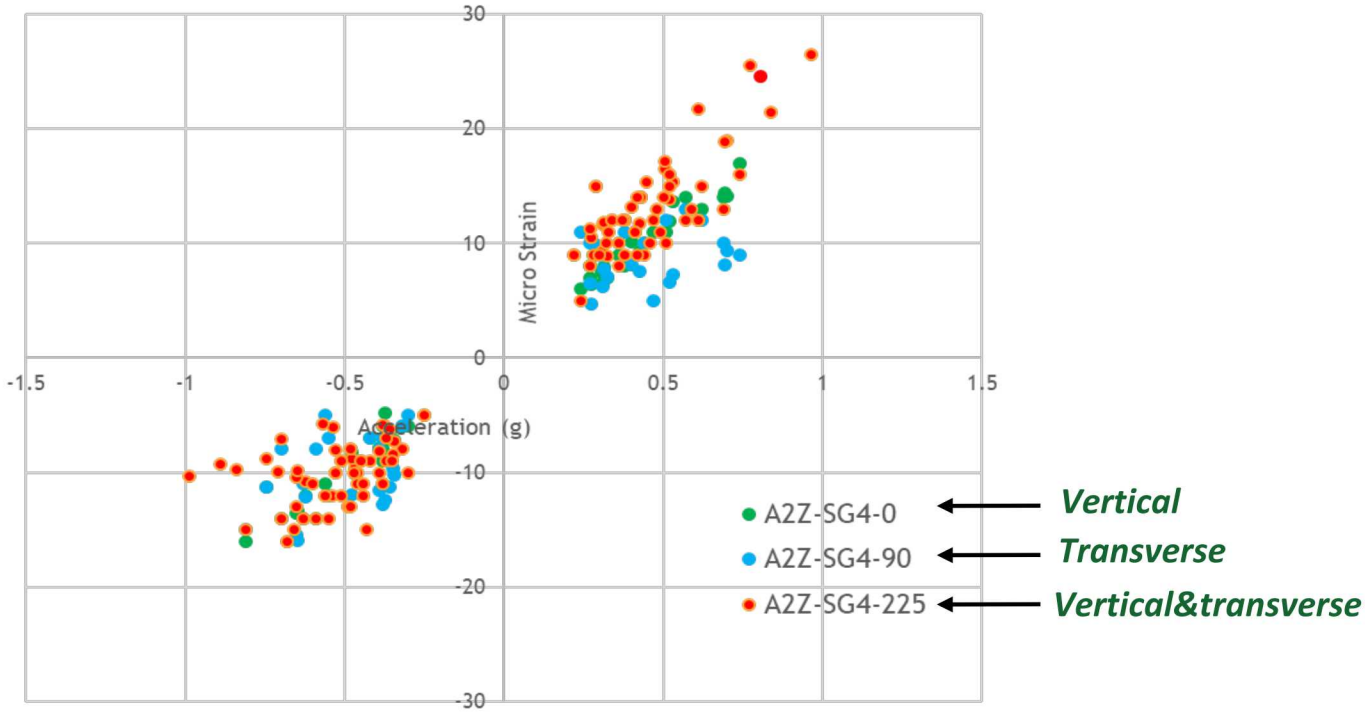
SNL Assembly Strains in Different Tests



- *Coupling impact results in significantly higher strains compared to the other tests.*
- *Single Bump and Pinch and Bounce have largest strains compared to the other tests, except coupling impact.*

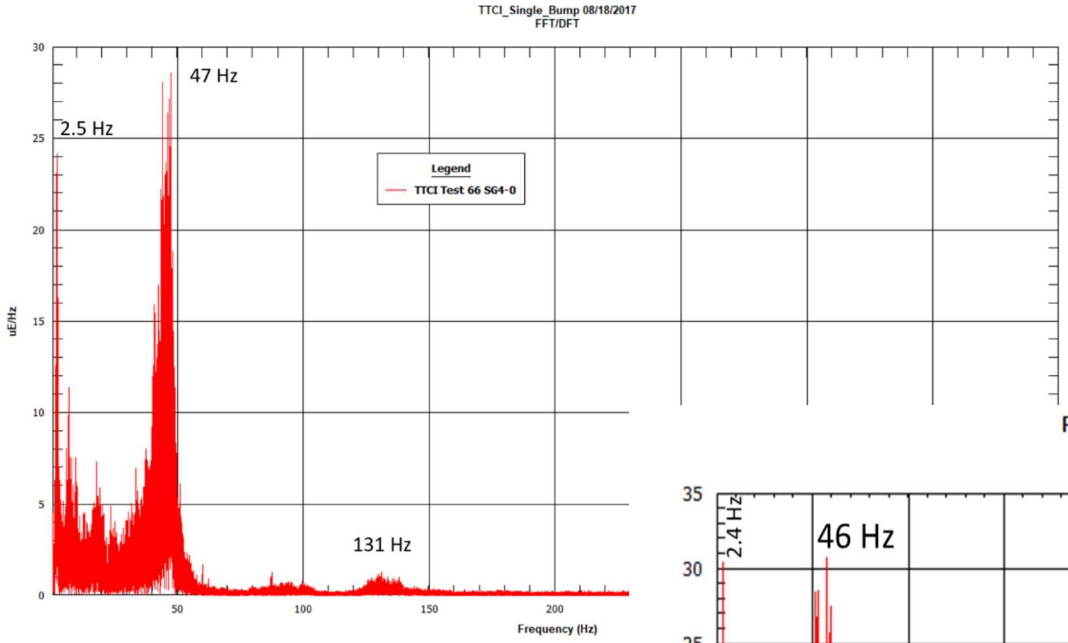
Acceleration-Strain on the SNL Assembly Front

Mo Pellets Rod, All Tests Except Coupling Impact



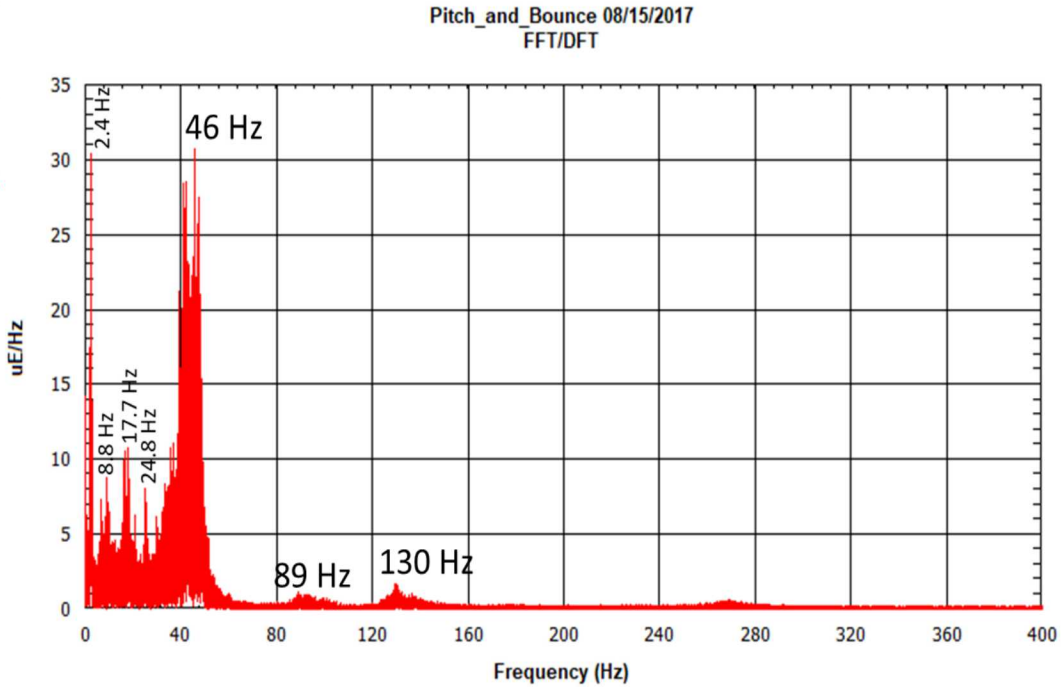
- *There is a clear acceleration-strain correlation.*
- *In all the tests, except coupling impact, the acceleration on the rod is from -1g to 1g and the strain is from 25 to -18 micro strain.*

Strain FFT for SG4-0



Single Bump:
Peaks: 2.5 and 47Hz

Pitch and Bounce
Peaks: 2.5 and 46 Hz



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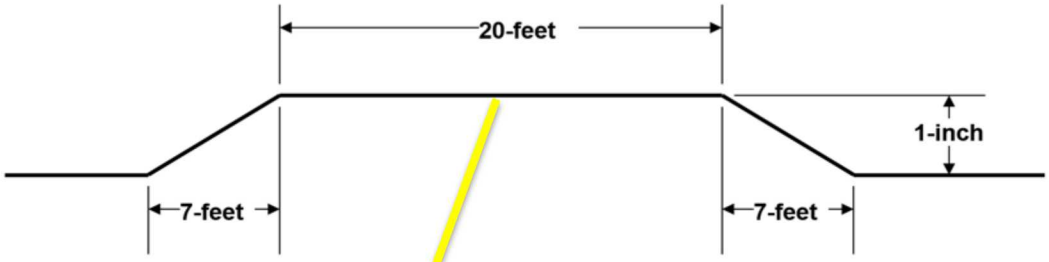
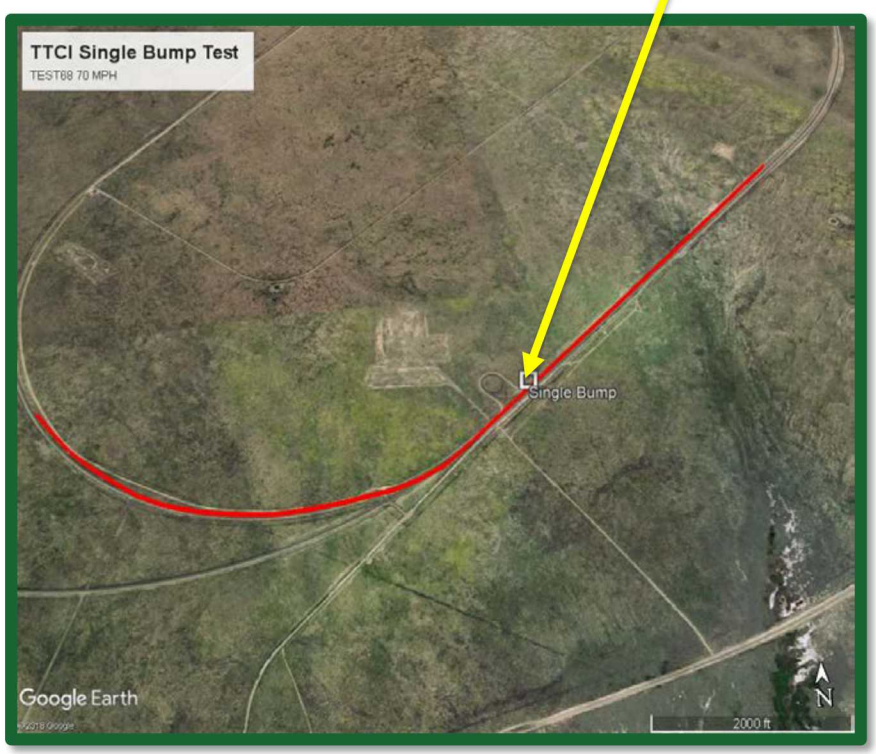
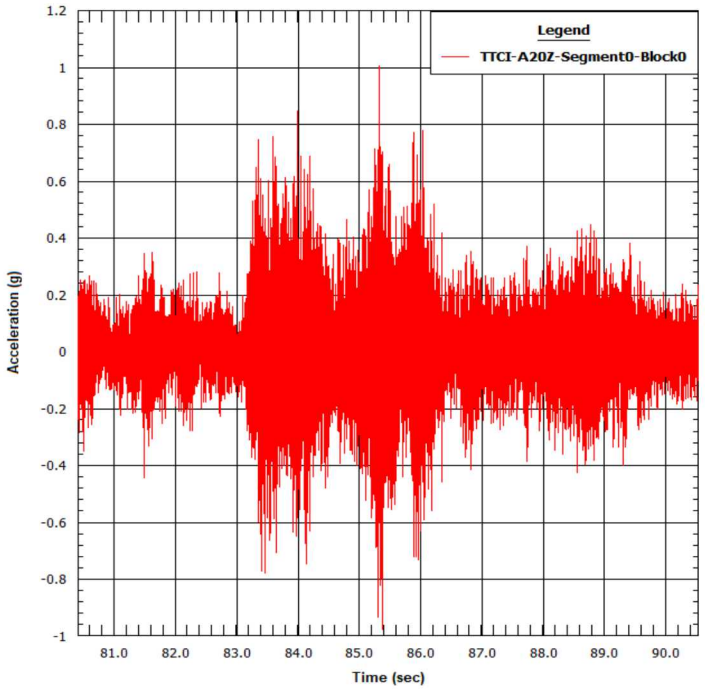
Single Bump (12 Tests)

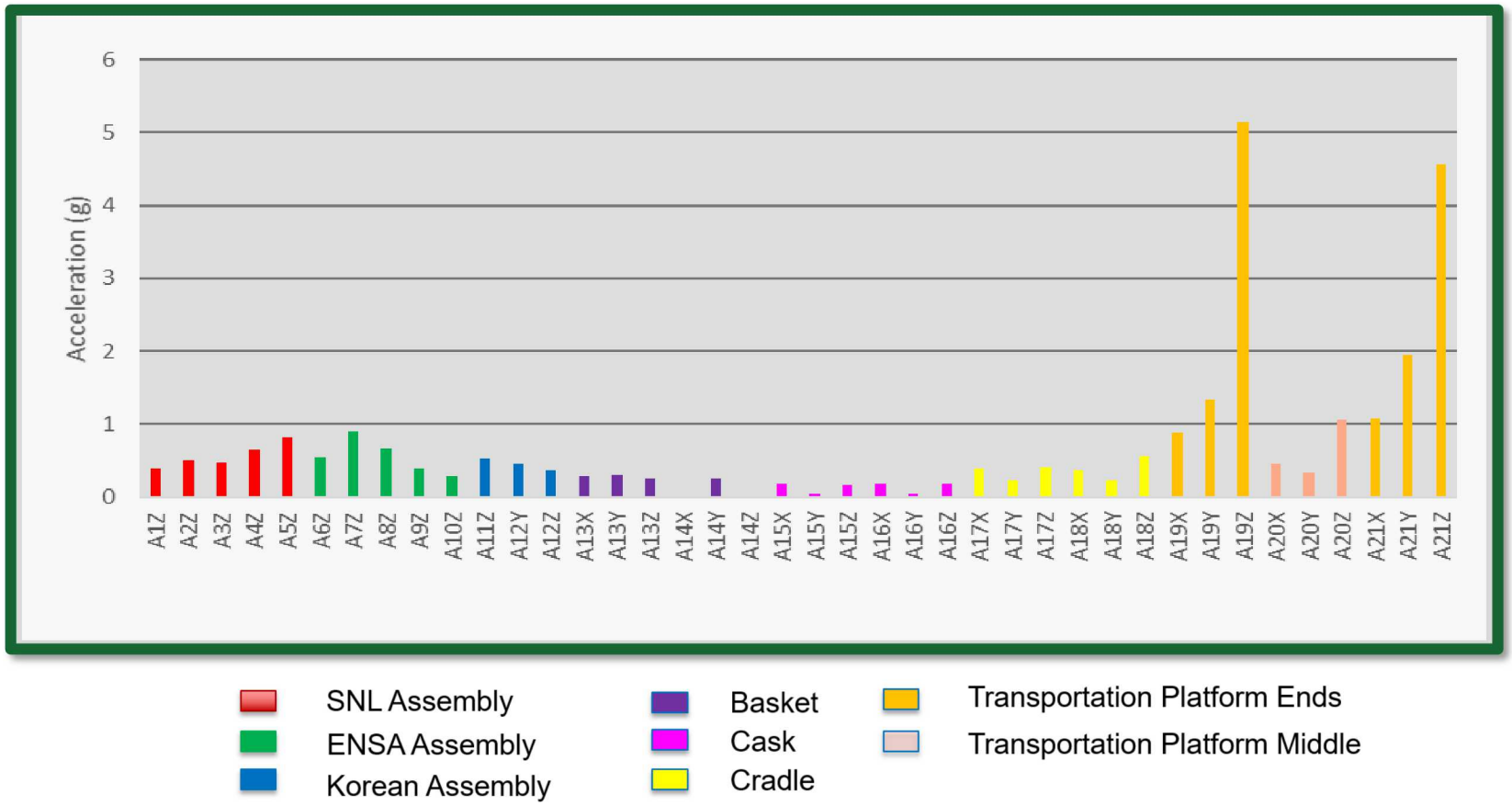






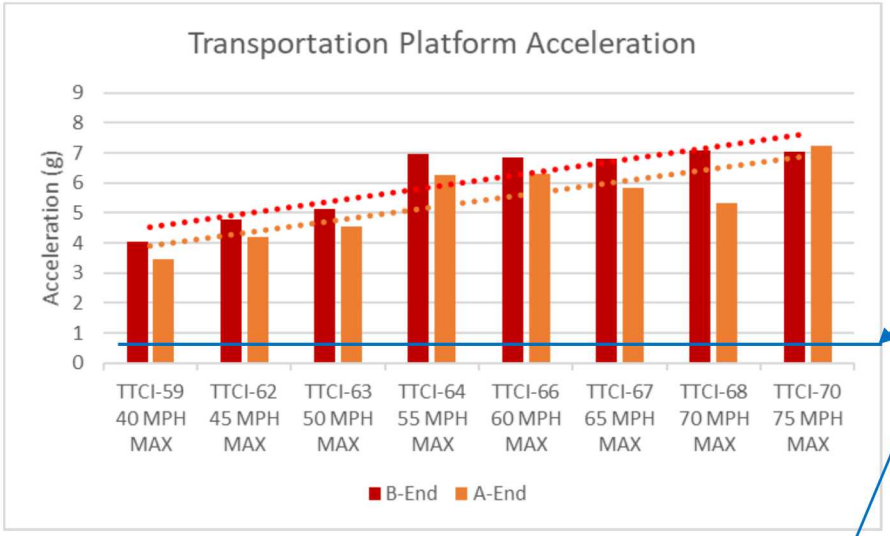
Example of Acceleration Time History

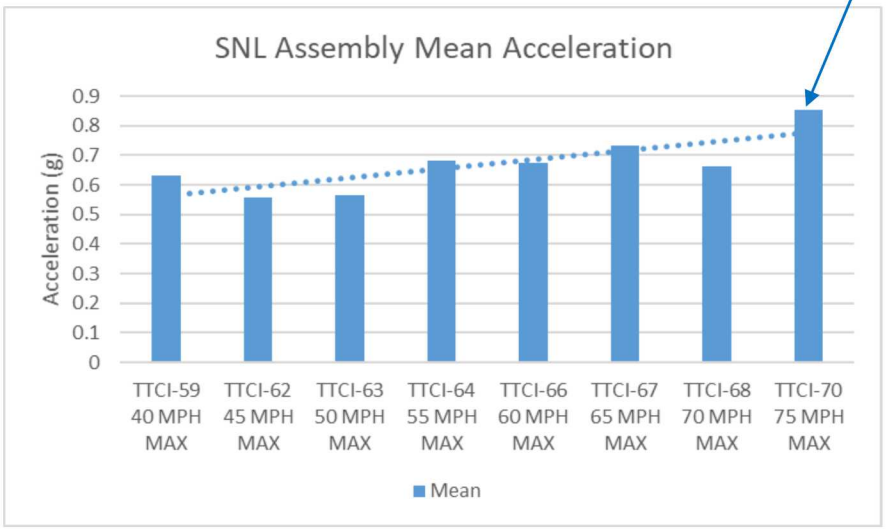
Maximum Accelerations in Single Bump Test



- *All 3 surrogate assemblies and the cradle have similar accelerations.*
- *The accelerations are the lowest on the cask and highest on the transportation platform.*
- *The vertical acceleration on the platform are significantly higher than the lateral and transverse.*
- *The vertical, lateral, and transverse accelerations are comparable for the cask and cradle.*

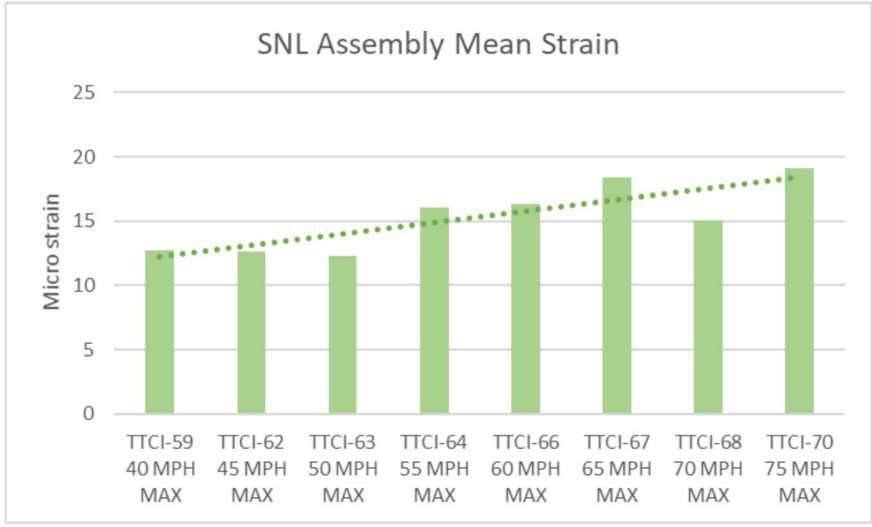
Single Bump Test Results for Differerent Speeds





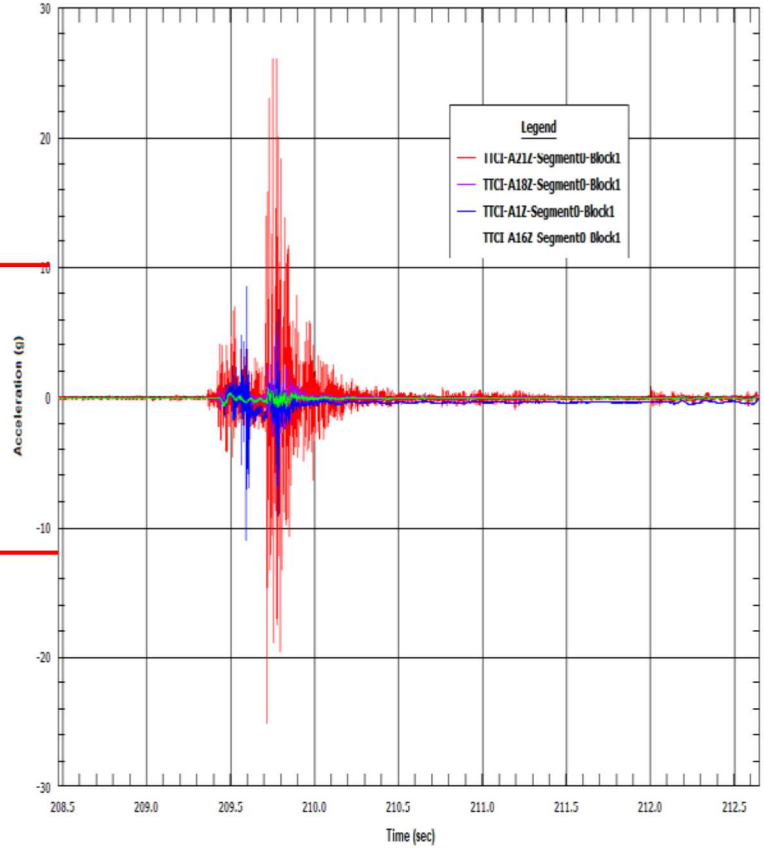
- *Accelerations and strains increase with speed*

Max Acceleration on Assembly

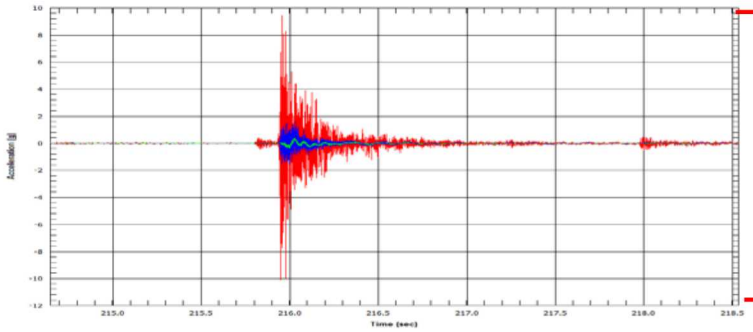


Coupling Impact Acceleration Time History Comparison

Impact at 8.0 mph



Impact at 4.1 mph

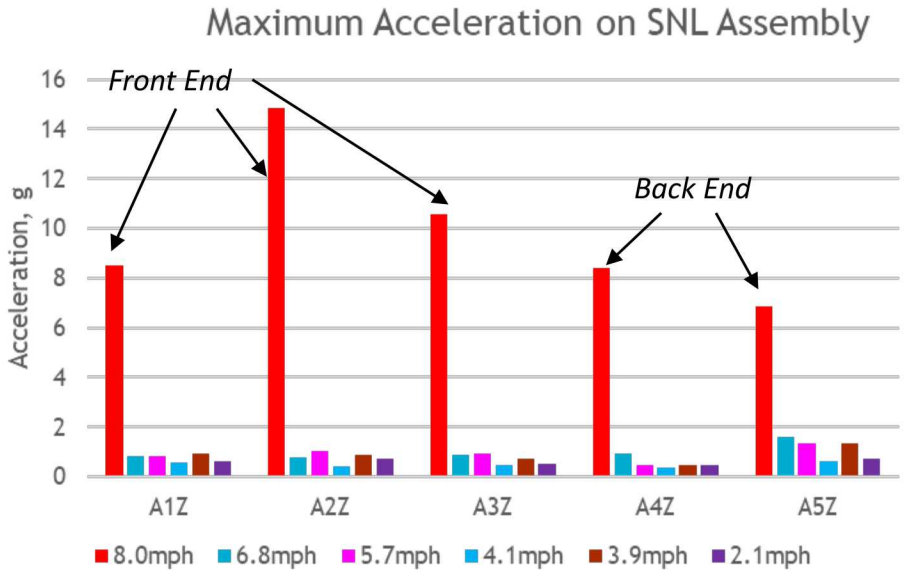


Transportation Platform max/min acceleration 9.5g/-10.1 g

- Transportation Platform (A21Z)
- SNL Assembly (A1Z)
- Cask (A16Z)

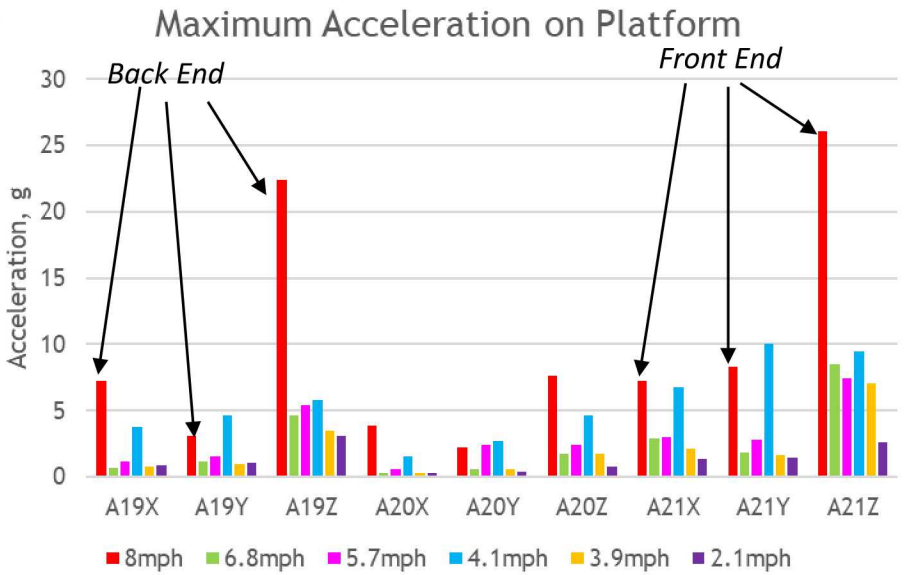
Transportation Platform max/min acceleration 26.1g/-25.1 g

Comparison Between B-End Coupling Impact Tests

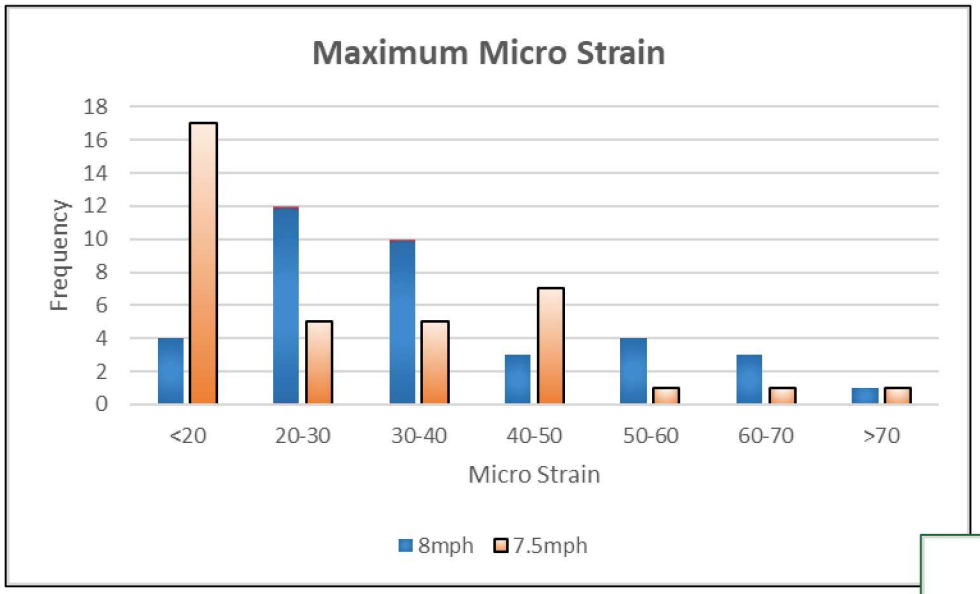


- *The coupling at 8mph has significantly larger acceleration that coupling at 2.1-6.8mph*

- *The accelerations are higher at the front end while coupling is on the back end (B-end).*

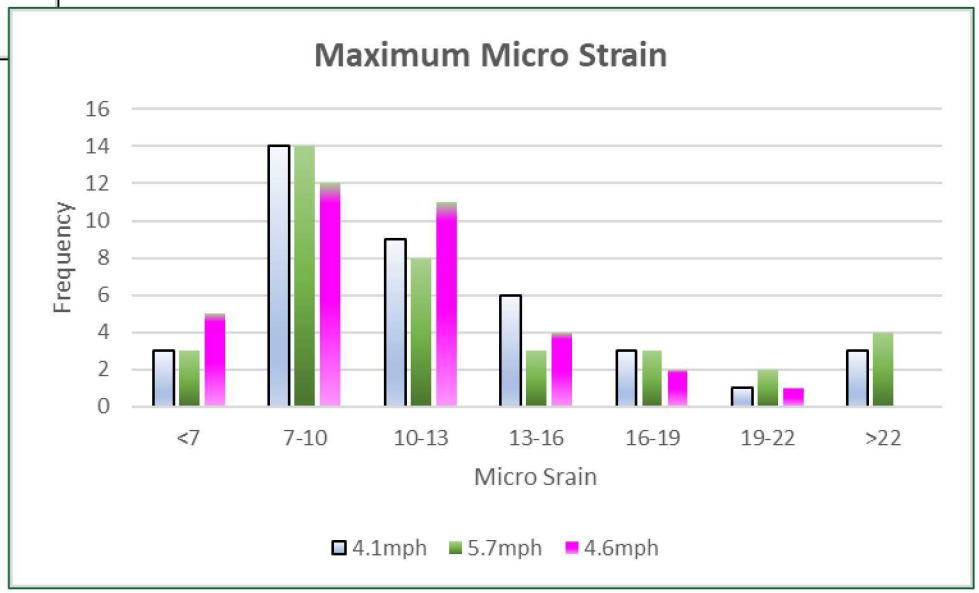


Comparison Between Micro Strains in Different Coupling Impact Tests

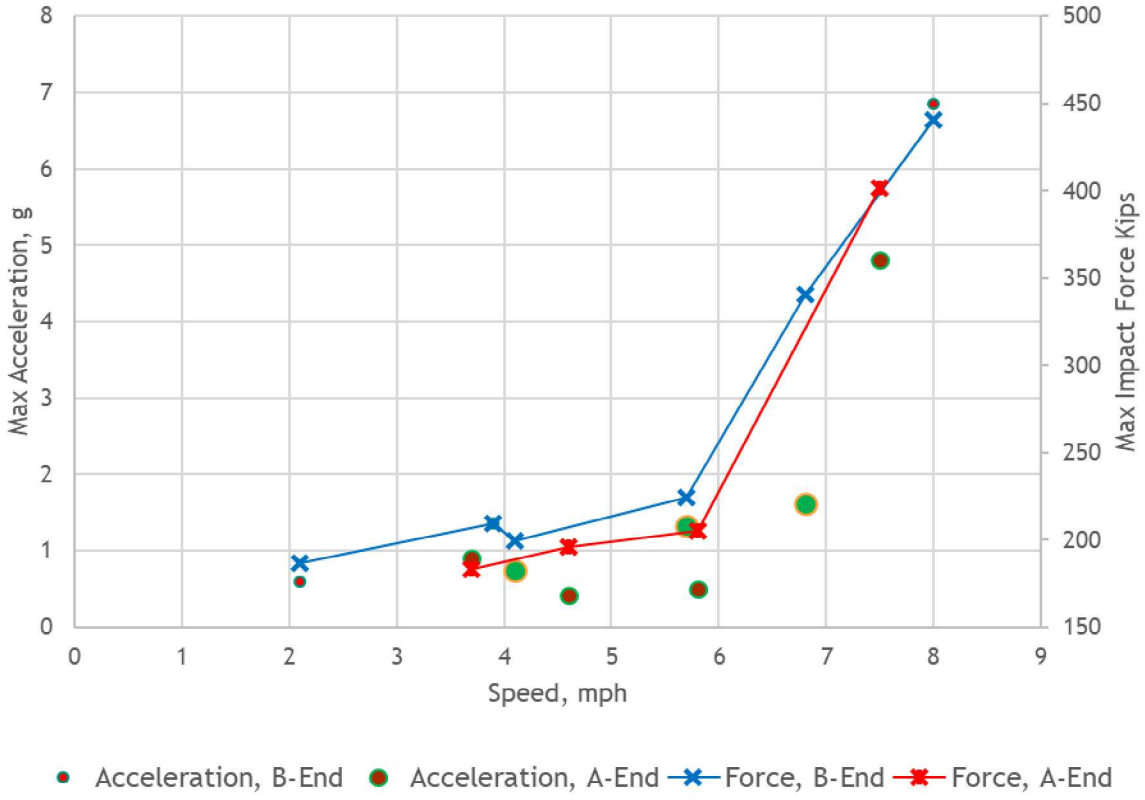


Only one strain gage displayed strain amplitude > 70 micro strain. The maximum measured strain was -99.0 micro strain in 7.5mph test.

60% of strain gages in 4.1-5.7mph tests were in the range from 7 to 13 micro strain.



Accelerations and Impact Forces in Coupling Impact Tests

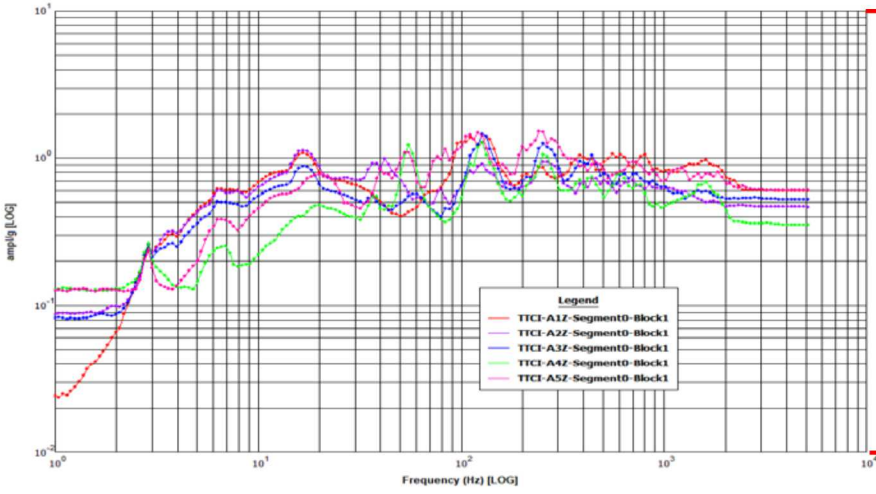


	Speed at Impact, mph					
B-End	2.1	3.9	4.1	5.7	6.8	8
A-End	3.7	4.6	5.8	7.5		

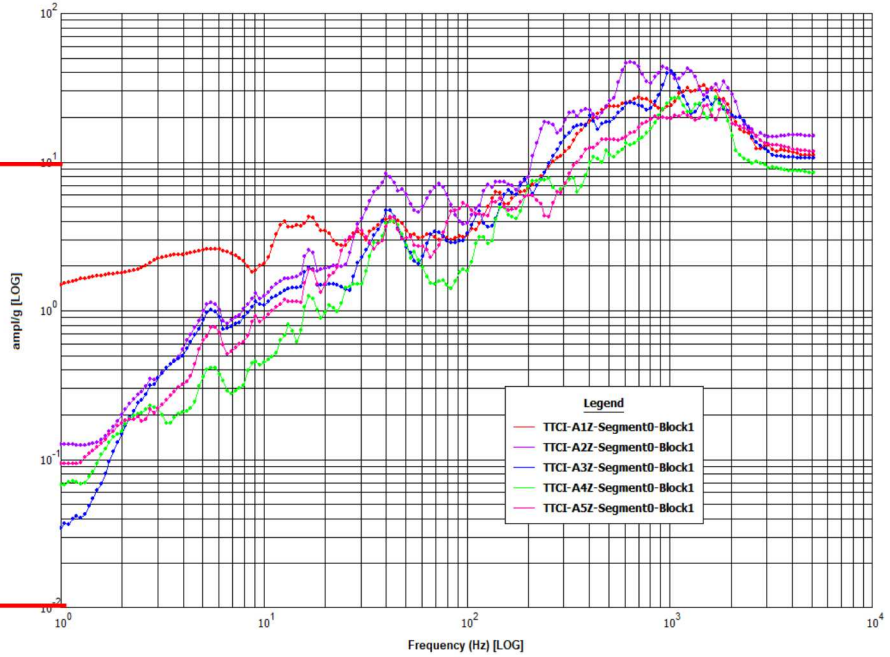
The measured maximum accelerations follow the same trend as the measured maximum impact force.

SNL Assembly SRS Comparison in Coupling Impact Tests

Impact at 4.1 mph



Impact at 8.0 mph

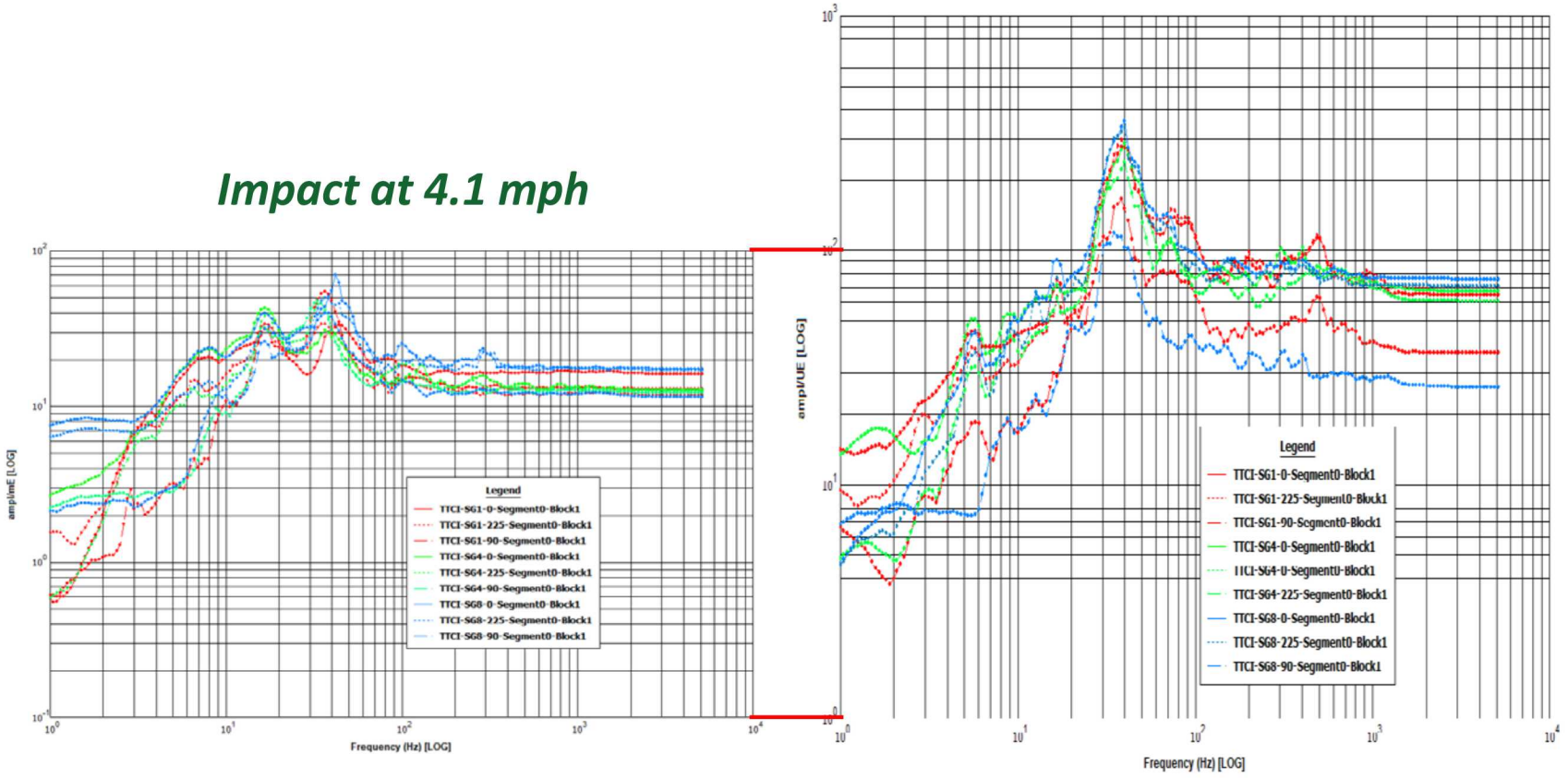


Coupling at 8mph results in significant high frequency assembly response.

Strain SRS on SNL Assembly Front in Coupling Impact Tests

Impact at 8.0 mph

Impact at 4.1 mph



Strain response is significantly higher in coupling at 8mph, but the maximum occurs at the assembly resonance frequency ~45Hz.

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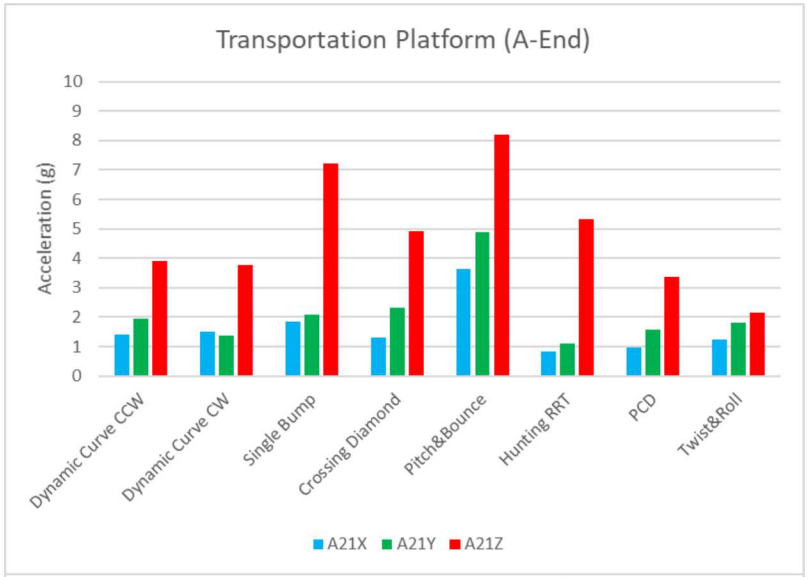
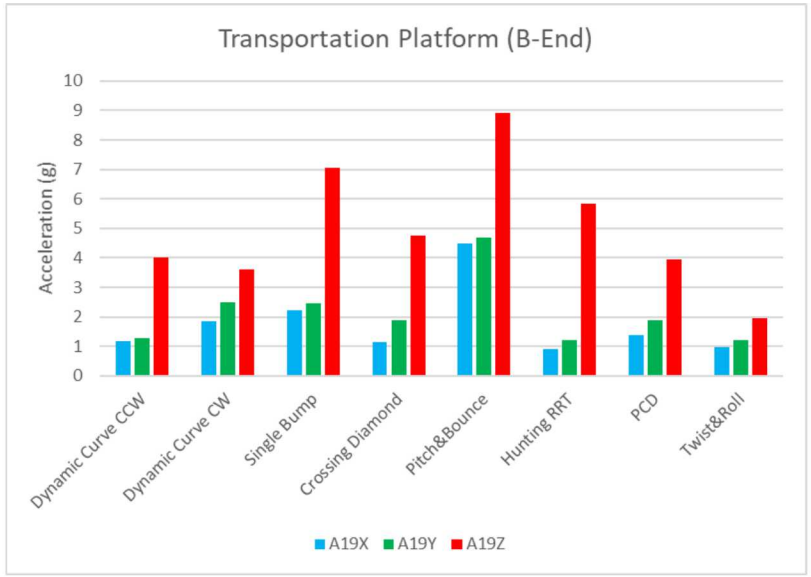
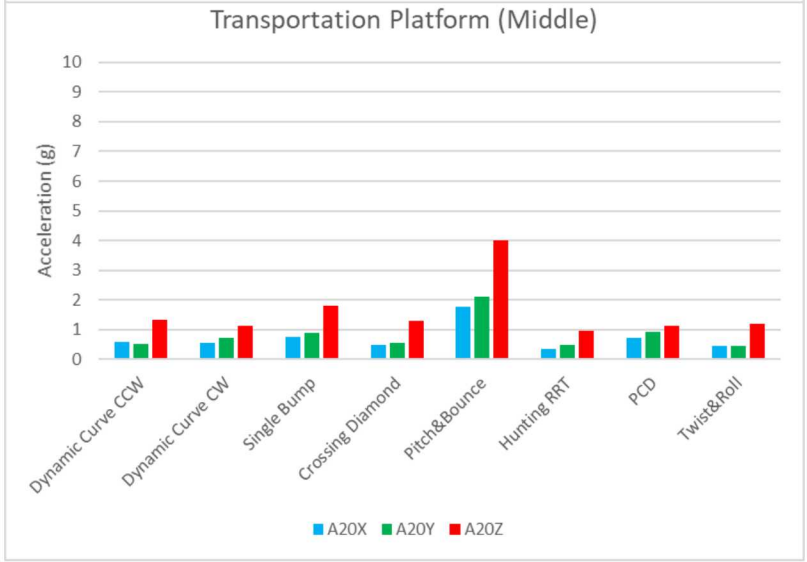
Lateral (X), Transverse (Y), and Vertical (Z) Accelerations on the Platform







Z acceleration on the platform is higher than X and Y in all tests except coupling.

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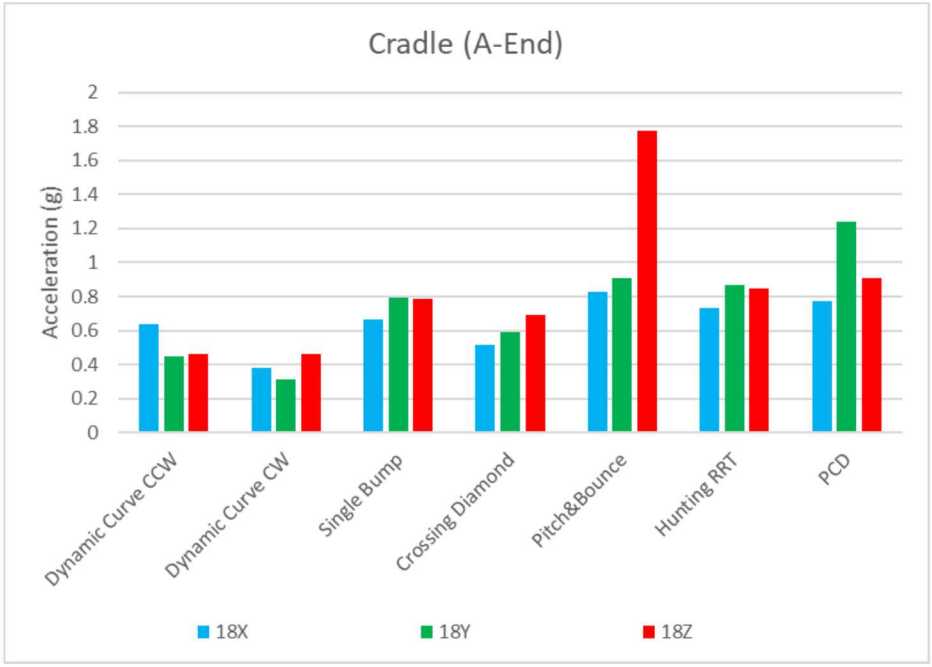
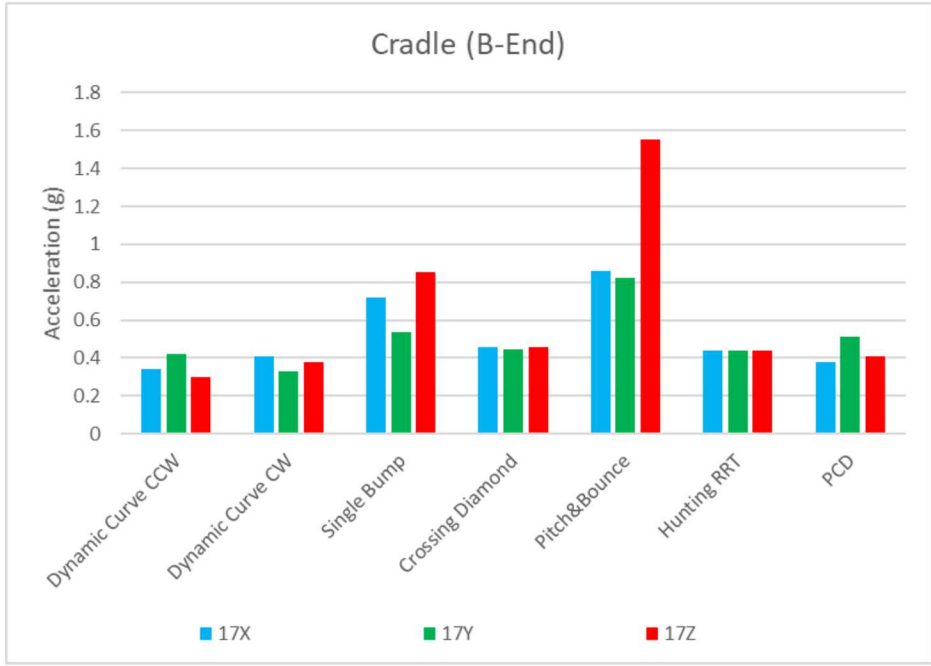
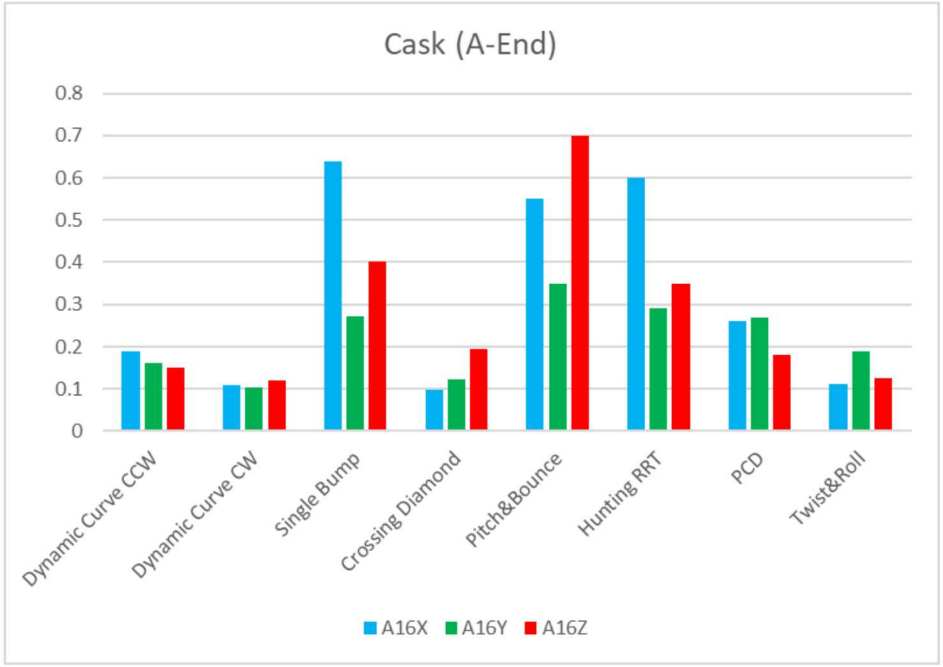
Lateral (X), Transverse (Y), and Vertical (Z) Accelerations on the Cradle



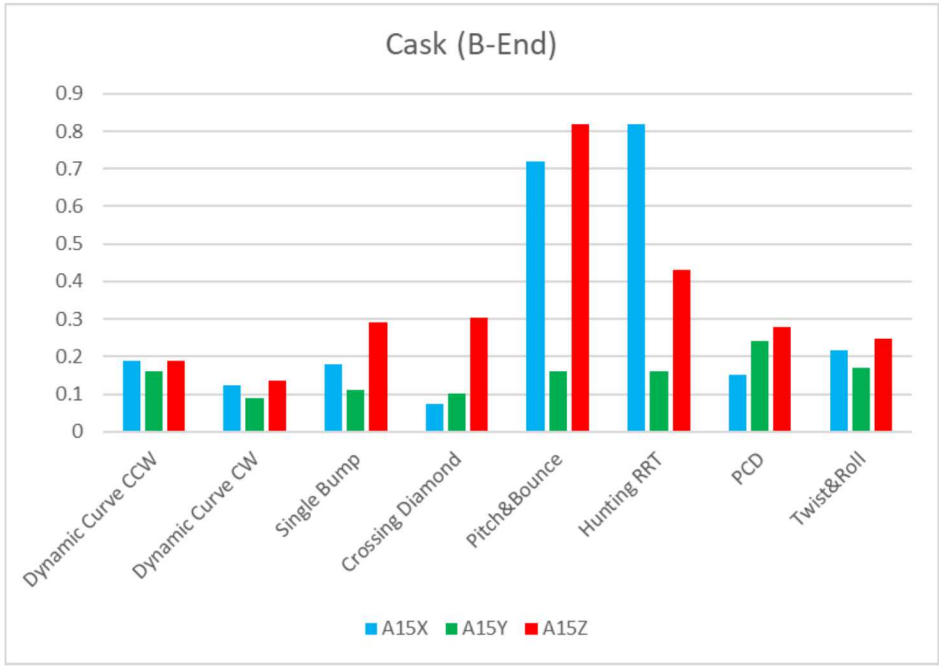
*X and/or Y acceleration on the cradle are higher than Z in **Dynamic Curve**, **Hunting**, and **PCD** tests.*



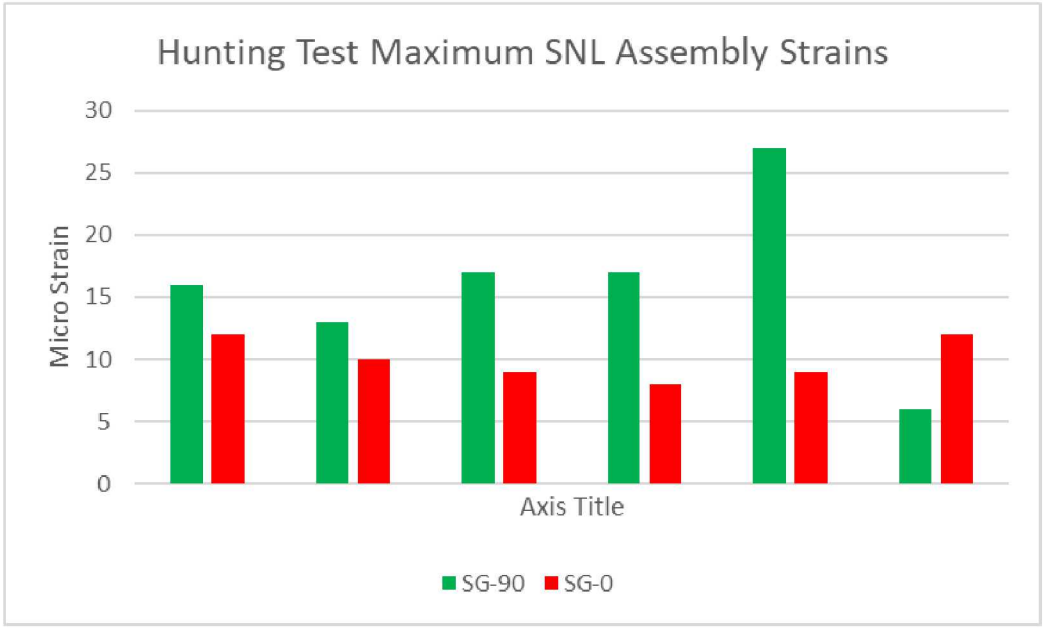
Lateral (X), Transverse (Y), and Vertical (Z) Accelerations on the Cask



*X and/or Y acceleration on the cradle are higher than Z in **Dynamic Curve**, **Hunting**, **PCD, Single Bump, and Twist and Roll** tests.*

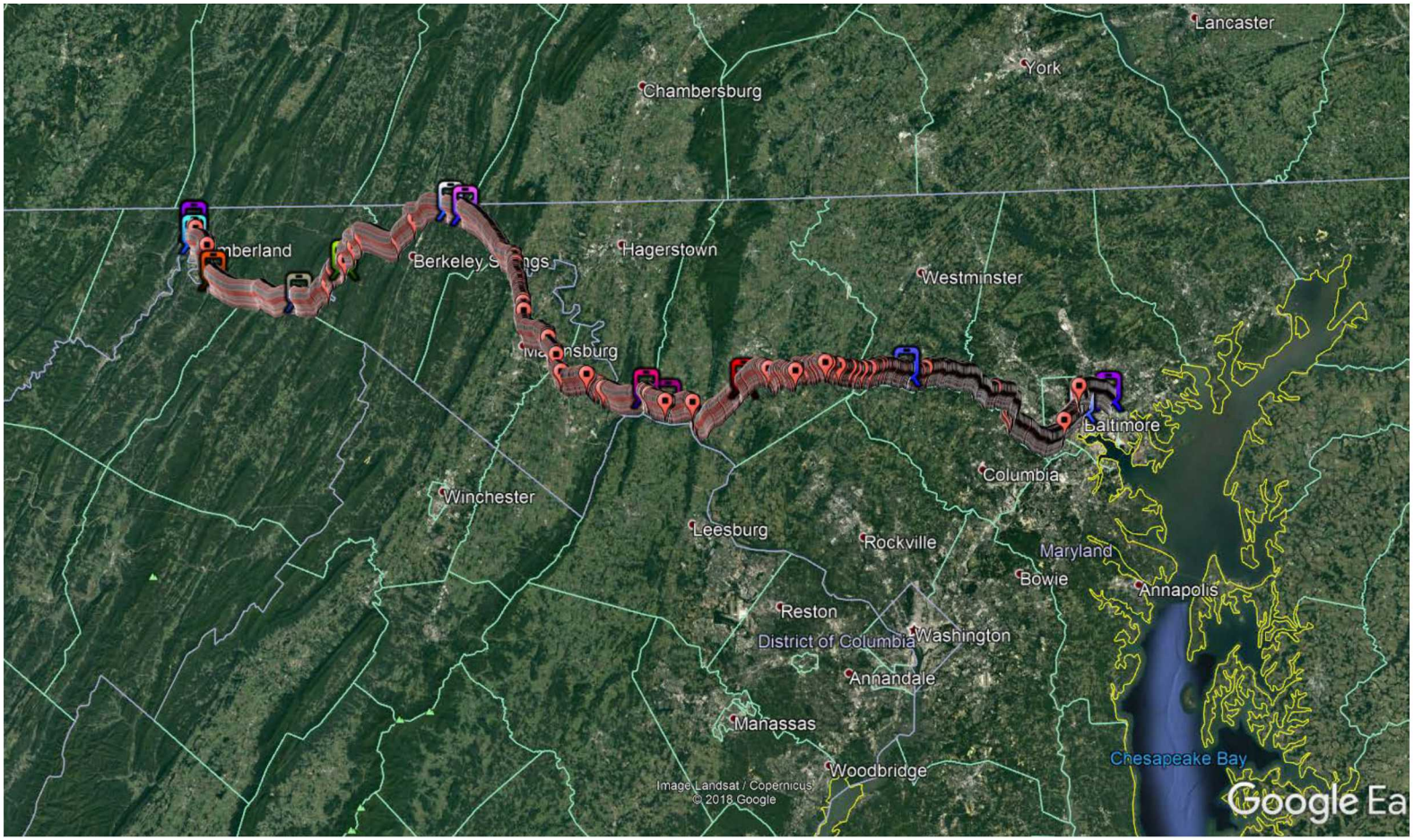


Lateral versus Vertical Strain in Hunting Test



- *The higher lateral than vertical accelerations on the cradle and cask in **Hunting** tests result in higher lateral strains on the SNL assembly.*

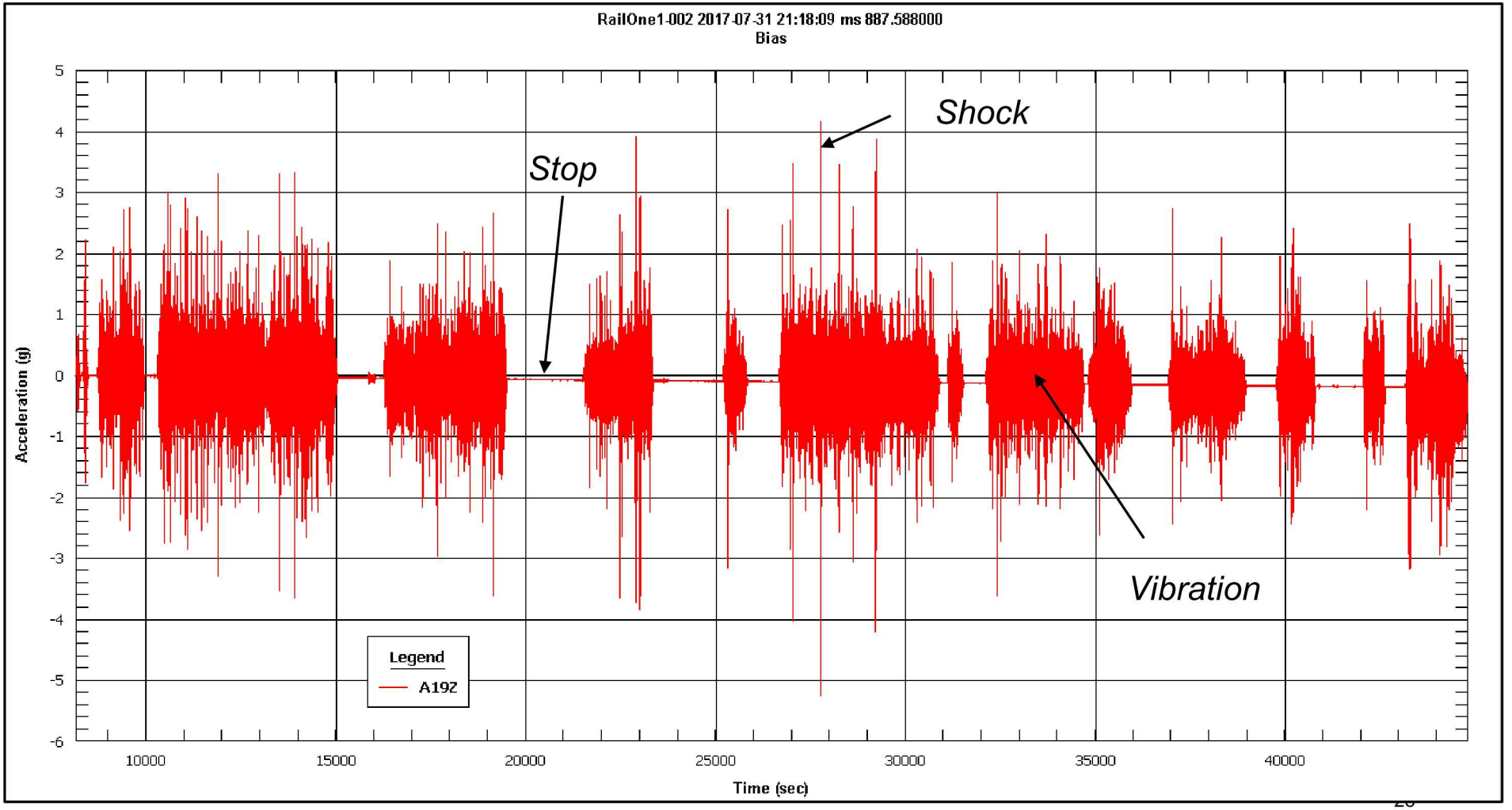
Data Analysis Examples for Rail1, Segment 0, Route



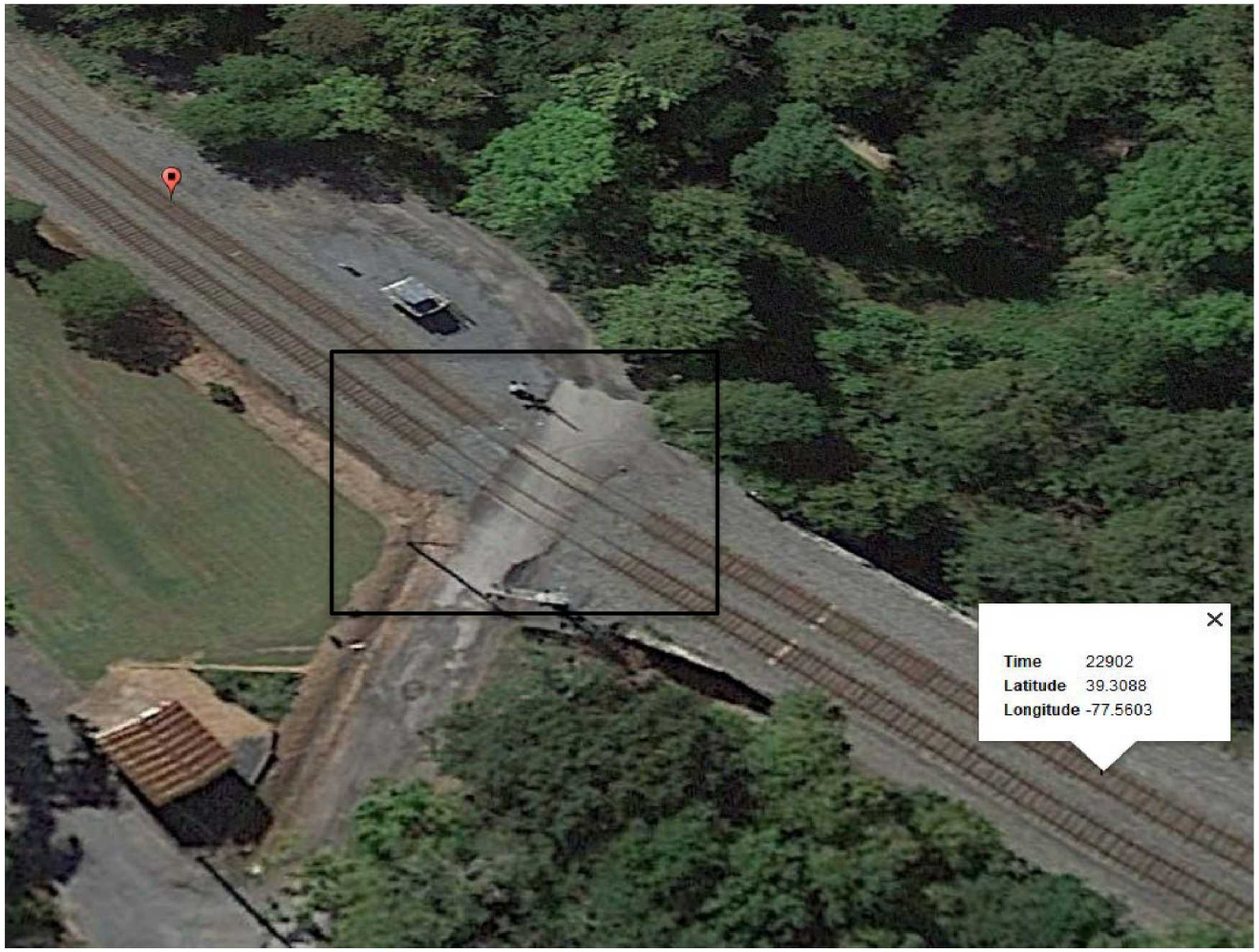
Train icons shows the stops

- *Distance: 162 mi*
- *Travel time: 6.6 hrs*
- *Average speed: 24.8 mph*

Platform (A19Z) Time History



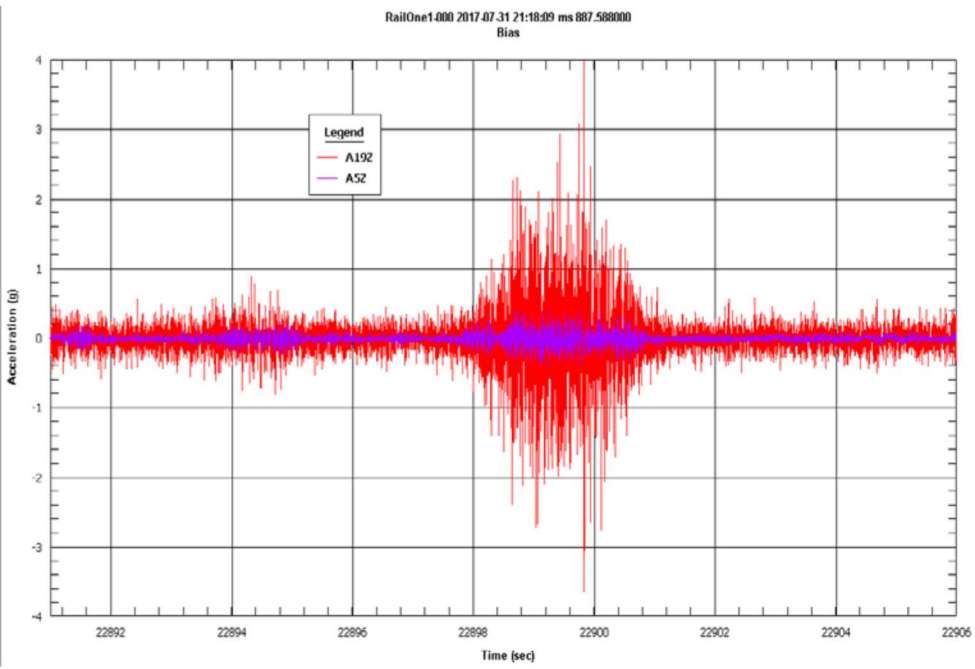
Bump Event on Road Crossing



- *Event time: 22,900 sec*
- *Train speed: 39.8 mph*
- *Max acceleration: 3.98 g (A19Z)*

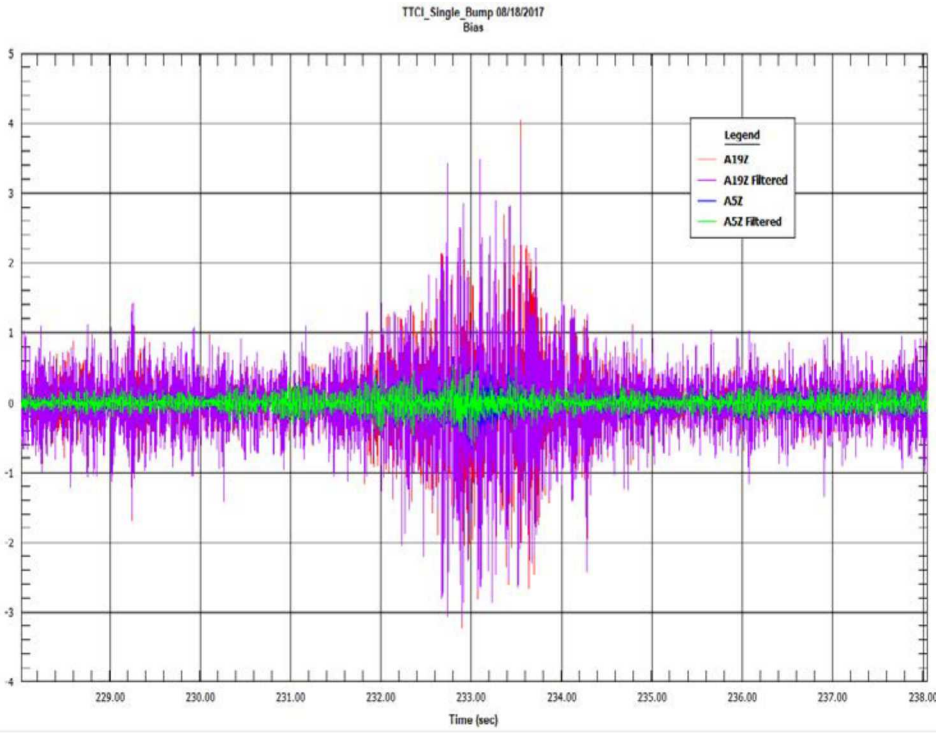
Bump Event Compared to TTCI Single Bump Test

Rail 1 Bump Event at 22,900 sec



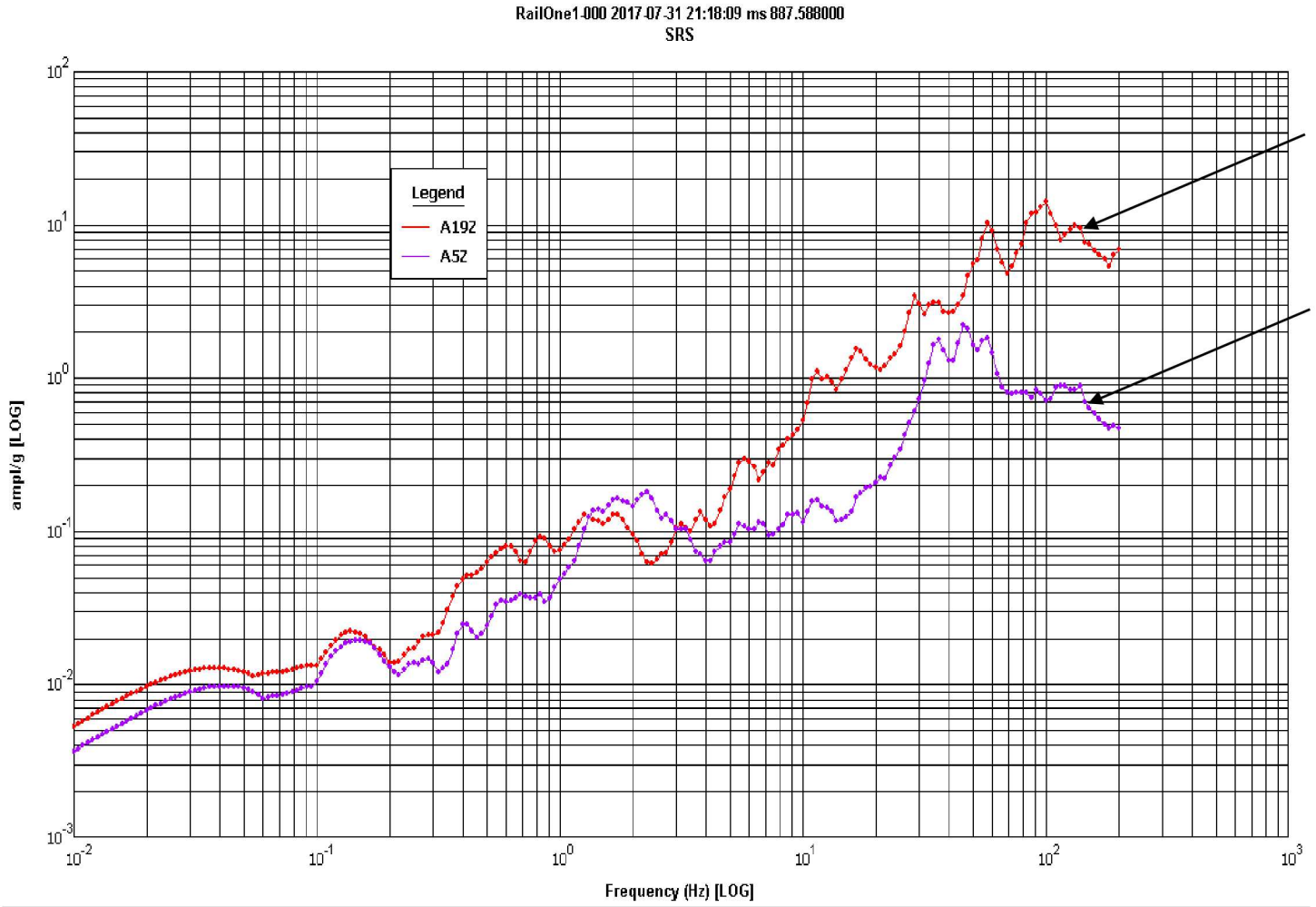
- Max platform acceleration (A19Z): 3.98 g
- Max assembly acceleration (A5Z): 0.42 g

TTCI Test 59 filtered to 200 Hz

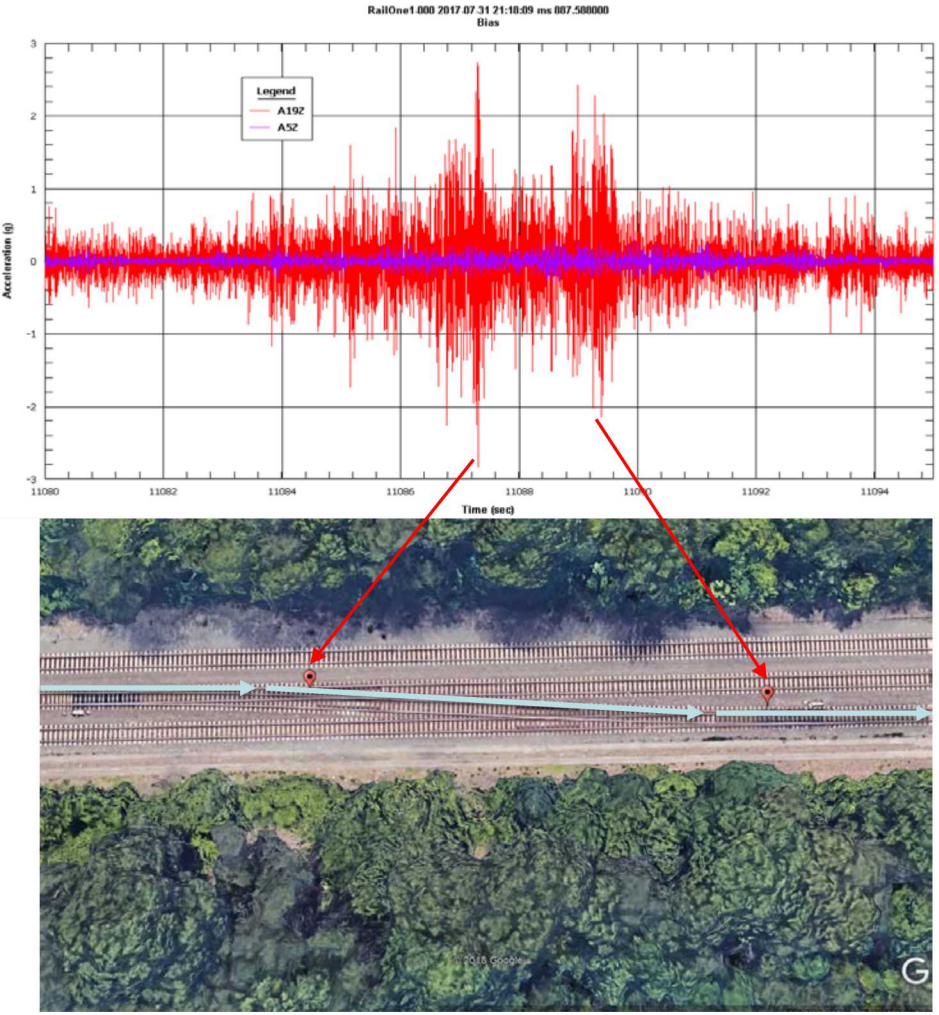


- Max platform acceleration (A19Z): 4.05 g
- Max filtered platform acceleration (A19Z): 3.71 g
- Max assembly acceleration (A5Z): 0.65 g
- Max filtered assembly acceleration (A5Z): 0.56 g

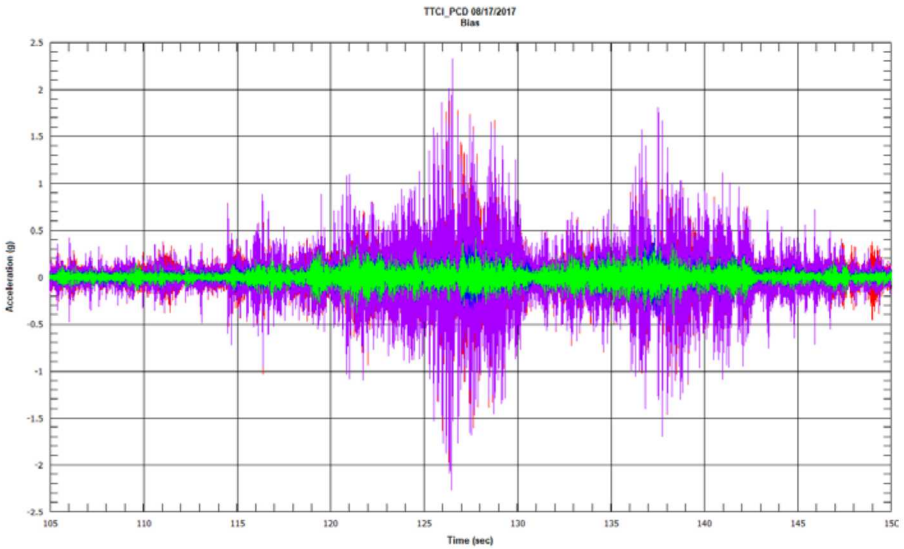
Bump Event SRS



Track Switch Event Compared to TTCI PCD Test



TTCI PCD Test 53, Track Switch and Rejoin



Track Switch Event on Rail 1

- *Event at 11,087 sec with peak acceleration of 2.73 g (A19Z)*
- *Event at 11,089 sec with peak acceleration of 2.43 g (A19Z)*
- *Train speed 25.6 mph*

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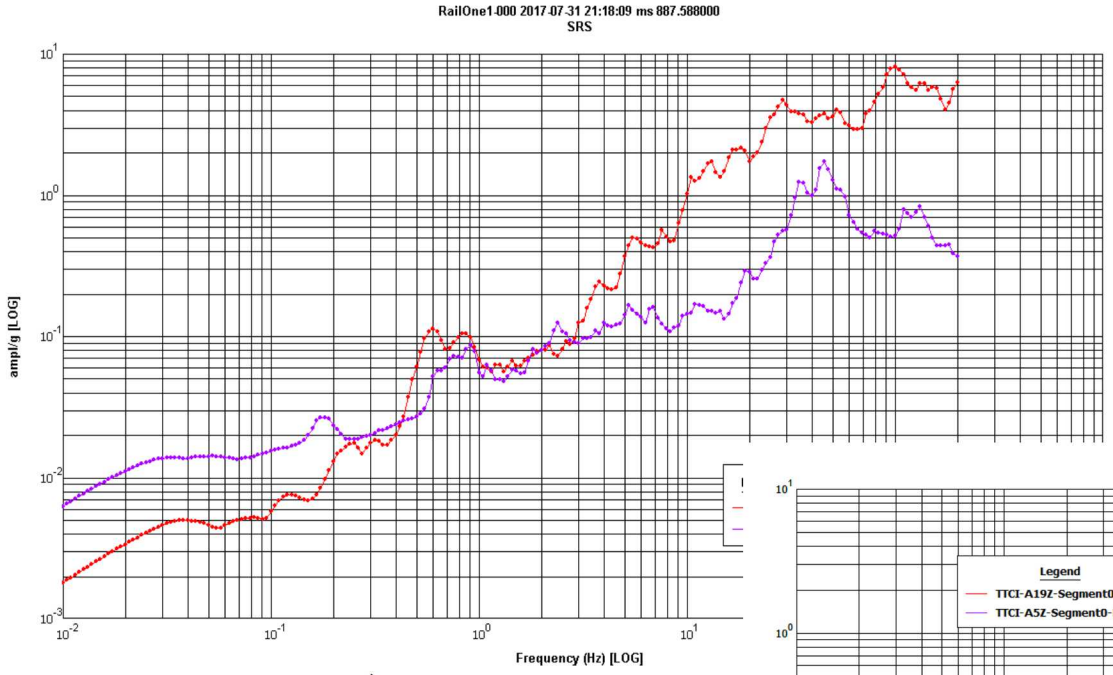
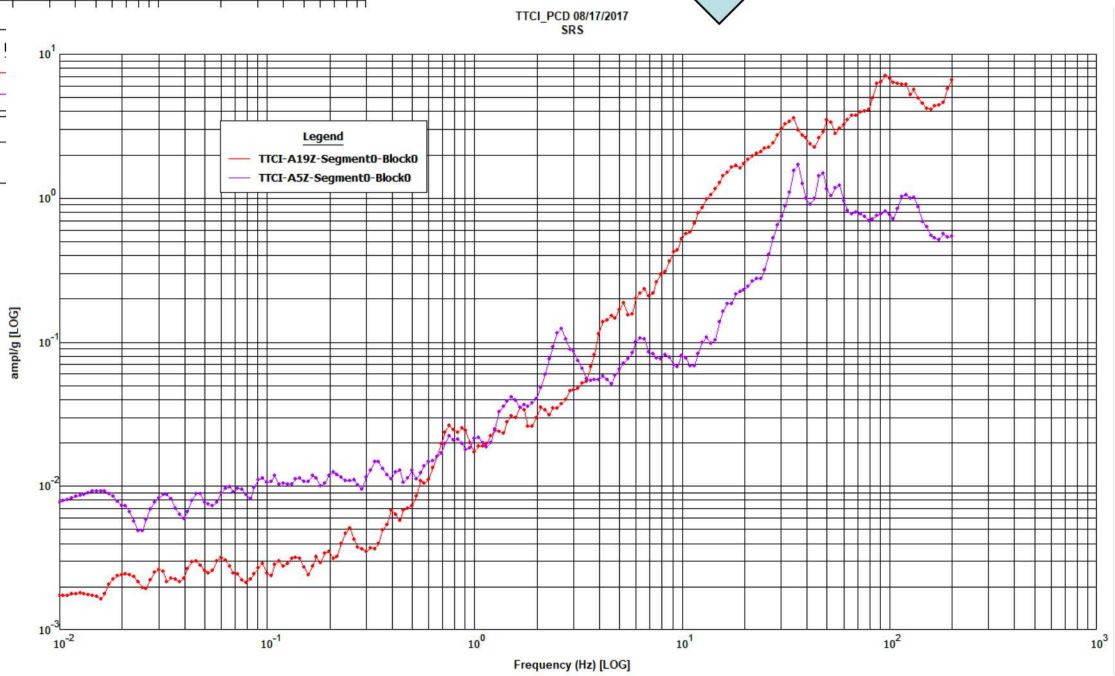
Track Switch Event and TTCI PCD Test SRS

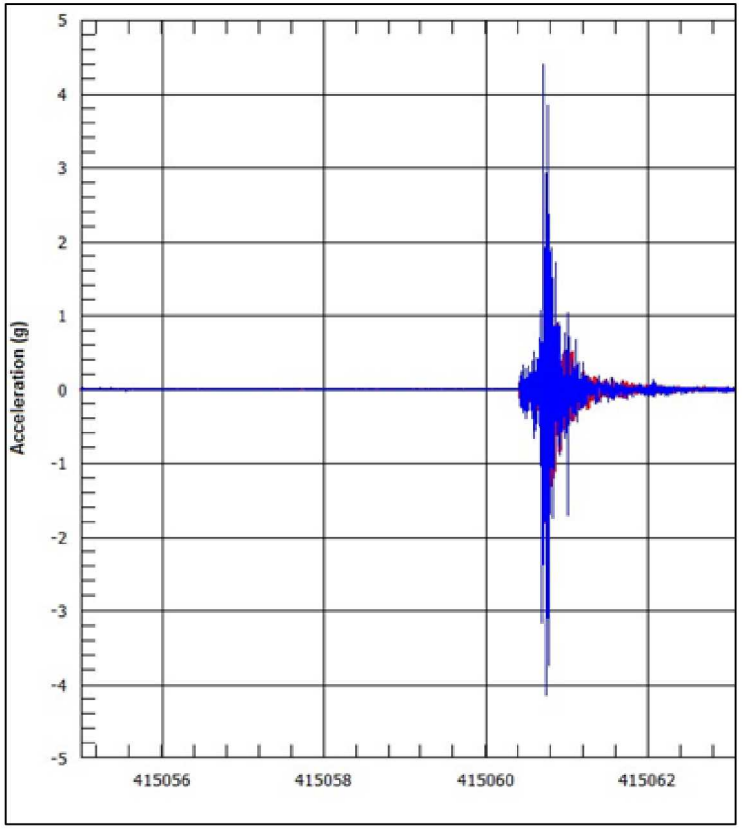


Rail 1 Track Switch Event

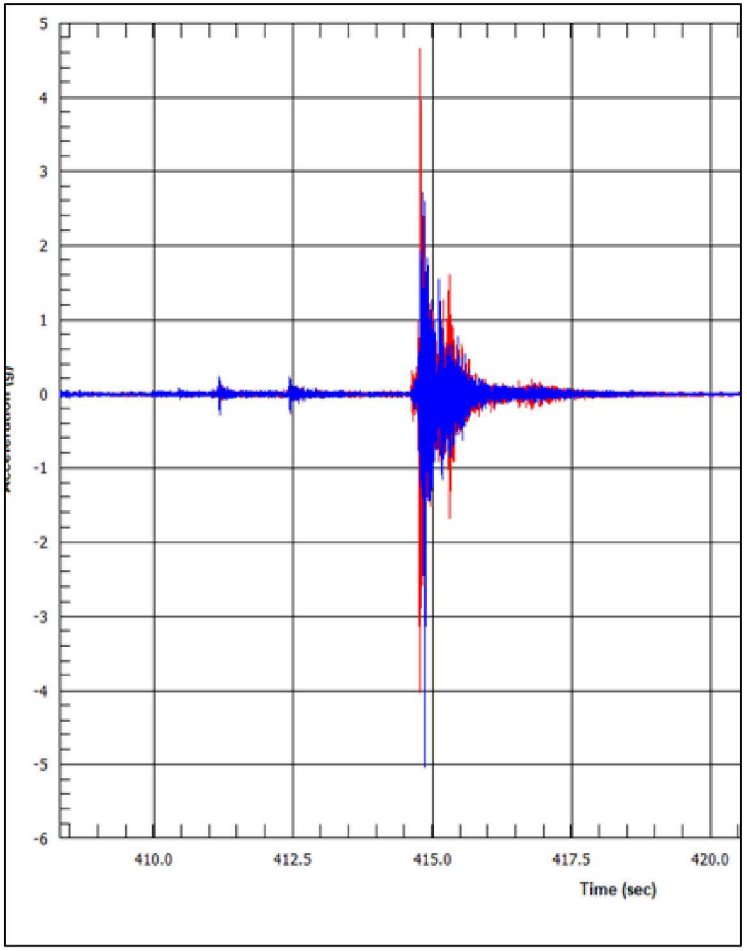
TTCI PCD Test 53



Accelerations in Coupling Event Compared to TTCI Coupling Impact Test

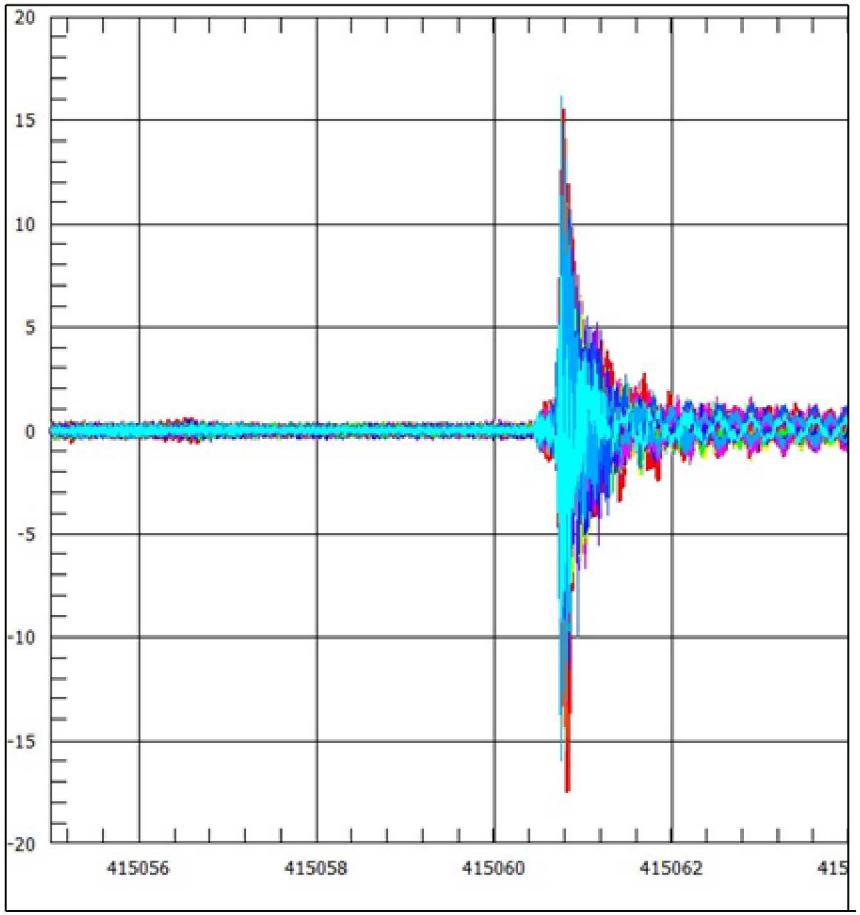


Rail 1 Coupling Event

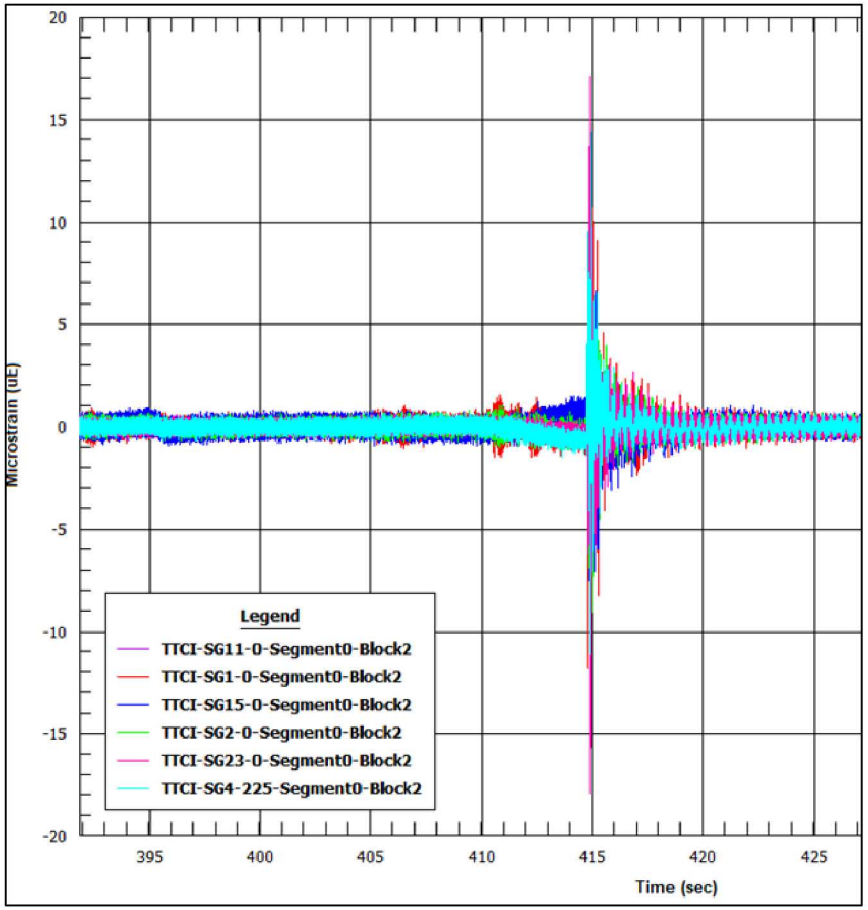


A-End Coupling at TTCI, 4.6mph

Strains in Coupling Event Compared to TTCI Coupling Impact Test



Rail 1 Coupling Event



A-End Coupling at TTCI at 4.6mph

- *The coupling shock events with similar acceleration signals have similar strain signals.*

Summary

- **Preliminary analysis of TTCI test data demonstrated:**
  - ✓ *Elements of the transportation system respond differently to the shocks.*
  - ✓ *There is noticeable attenuation from the transportation platform to the cask and assembly, except the low frequencies (below 4Hz).*
  - ✓ *Shocks from the coupling impacts greater than 6mph are significantly more severe than all the other shocks and may result in amplification in the system at higher frequencies.*
  - ✓ *The highest accelerations and strains (except coupling impact) were observed in Single Bump and Pitch and Bounce Tests.*
  - ✓ *Dynamic Curve, Hunting, PCD, Single Bump, and Twist and Roll tests have larger lateral than vertical accelerations on the cask. This results in higher lateral strains on the assembly.*
  - ✓ *Accelerations and strains show good correlation in all tests except coupling impact.*
  - ✓ *Maximum strain in all 125 tests at TTCI was 99 micro strain (coupling at 7.5 mph).*
- **Preliminary analysis of Rail 1 data demonstrated:**
  - ✓ *The rail events such as road crossing, switching tracks, and coupling are very similar to the corresponding TTCI tests with regard to time histories and SRSs.*