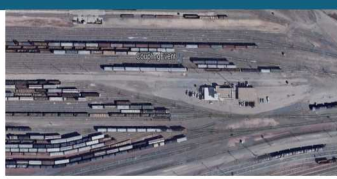
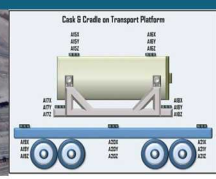
SAND2019-8494C

Shock Environments for the Nuclear Fuel Transportation System (Transportation Platform, Cask, Basket, and Surrogate Assemblies) during Rail Transport





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PATRAM, the International Symposium on the Packaging and Transportation of Radioactive Materials

August 4 – 9

New Orleans, LA, USA

PRESENTED BY

Catherine Wright

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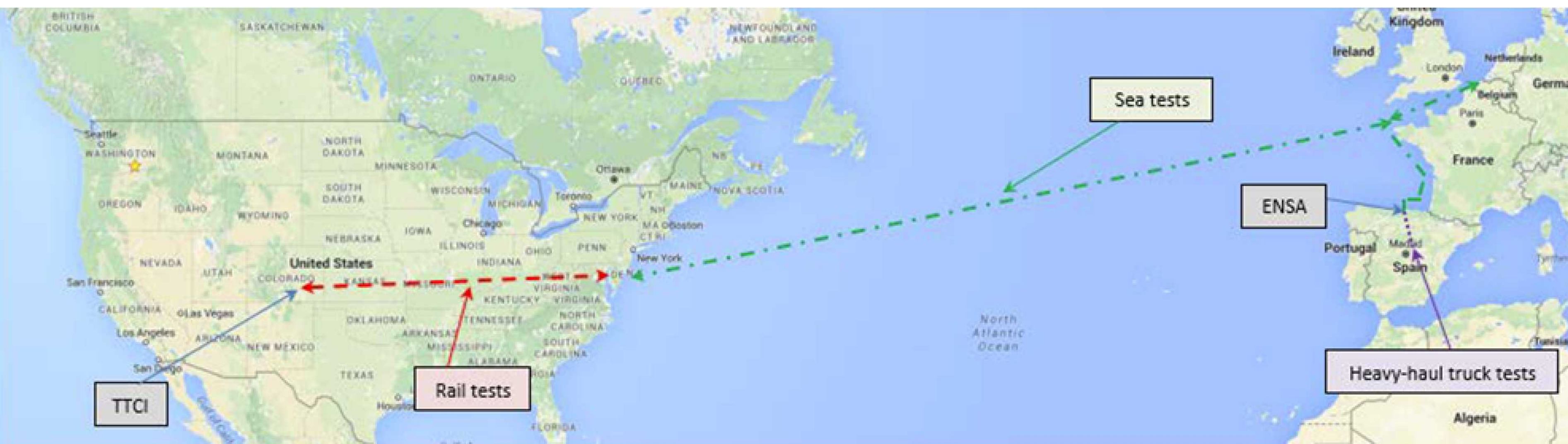
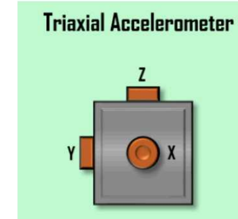
Transportation Test Route *(Transportation Triathlon)*

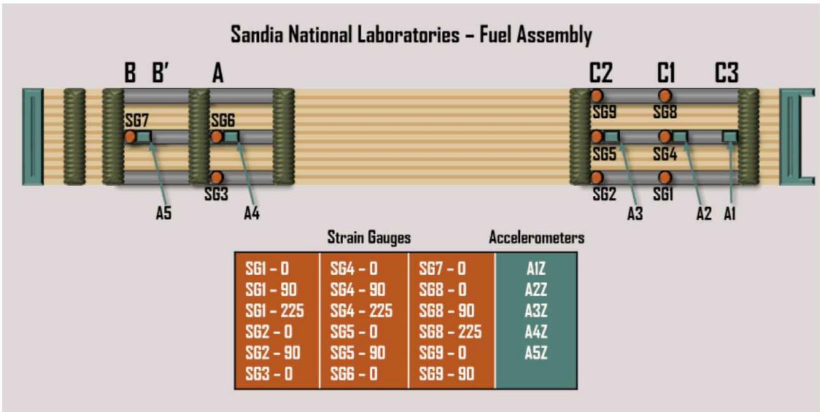
- 54 days of data collection
- 6 terabytes of data
- 4 modes of transportation
- 9,458 miles
- 7 countries
- 12 states



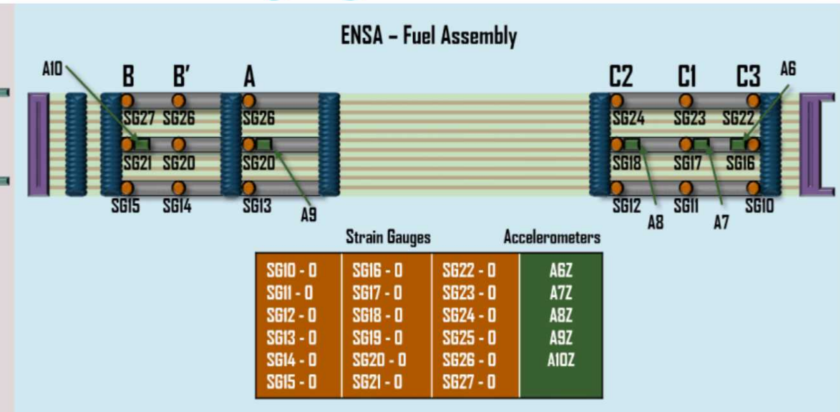
Transportation System Instrumentation



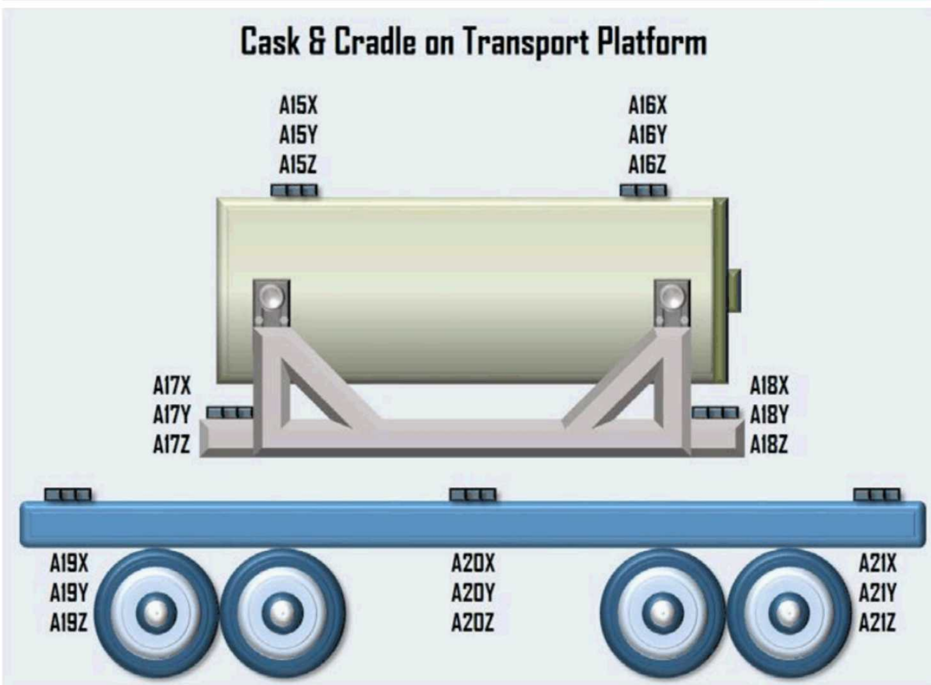
40 accelerometers and 37 strain gauges

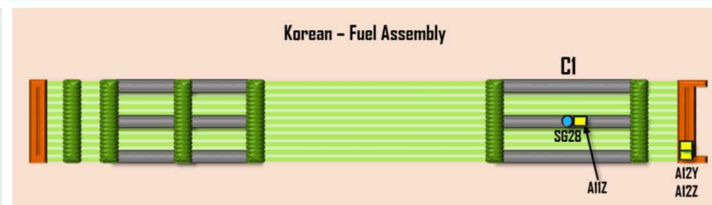


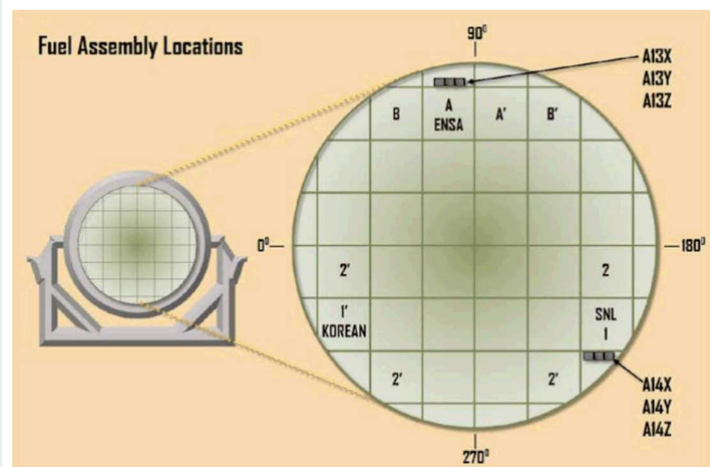
Strain Gauges			Accelerometers
SG1 - 0	SG4 - 0	SG7 - 0	A1Z
SG1 - 90	SG4 - 90	SG8 - 0	A2Z
SG1 - 225	SG4 - 225	SG8 - 90	A3Z
SG2 - 0	SG5 - 0	SG8 - 225	A4Z
SG2 - 90	SG5 - 90	SG9 - 0	A5Z
SG3 - 0	SG6 - 0	SG9 - 90	



Strain Gauges			Accelerometers
SG10 - 0	SG16 - 0	SG22 - 0	A6Z
SG11 - 0	SG17 - 0	SG23 - 0	A7Z
SG12 - 0	SG18 - 0	SG24 - 0	A8Z
SG13 - 0	SG19 - 0	SG25 - 0	A9Z
SG14 - 0	SG20 - 0	SG26 - 0	A10Z
SG15 - 0	SG21 - 0	SG27 - 0	







Rail 1 & Rail 2

12-axle Kasgro railcar

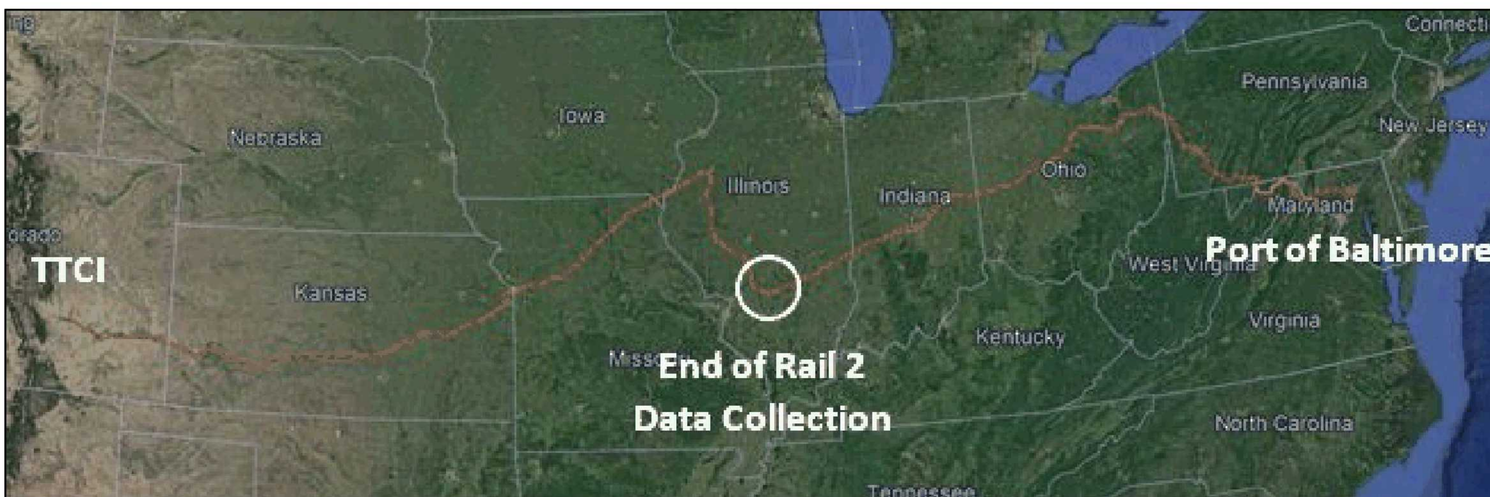
512 Hz data collection

<u>Rail 1</u>

- Dedicated rail transport
- 6 day trip
- 1,950-mile route from Port of Baltimore to TTCI in Pueblo, Colorado

<u>Rail 2</u>

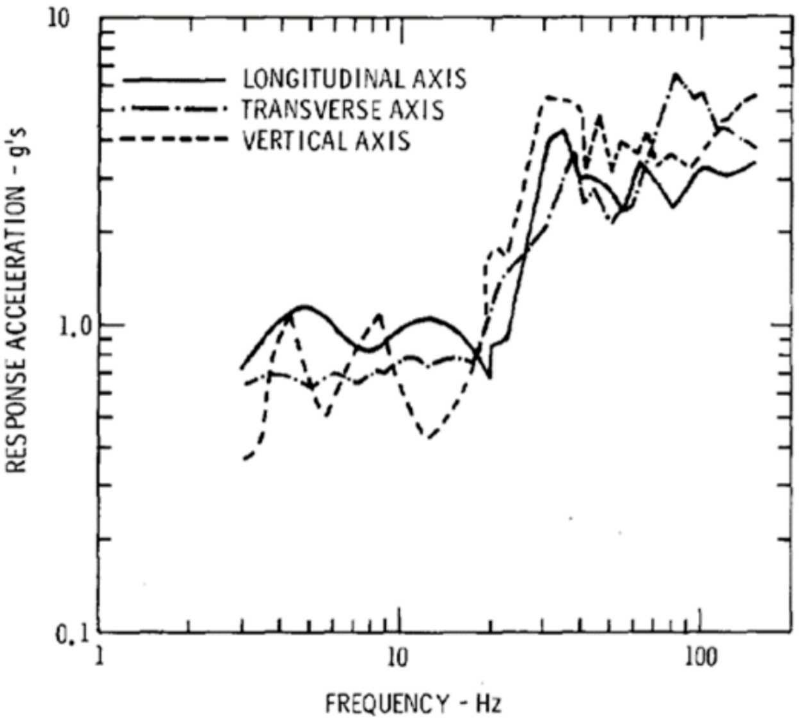
- General freight rail transport
- 18 days recorded
- Captured 1,125-mile route from TTCI to St. Louis, Illinois

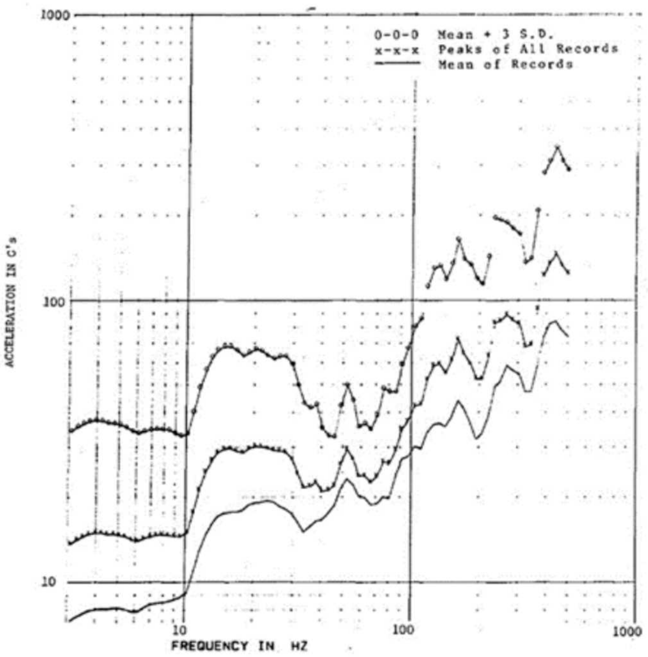


Previous Work

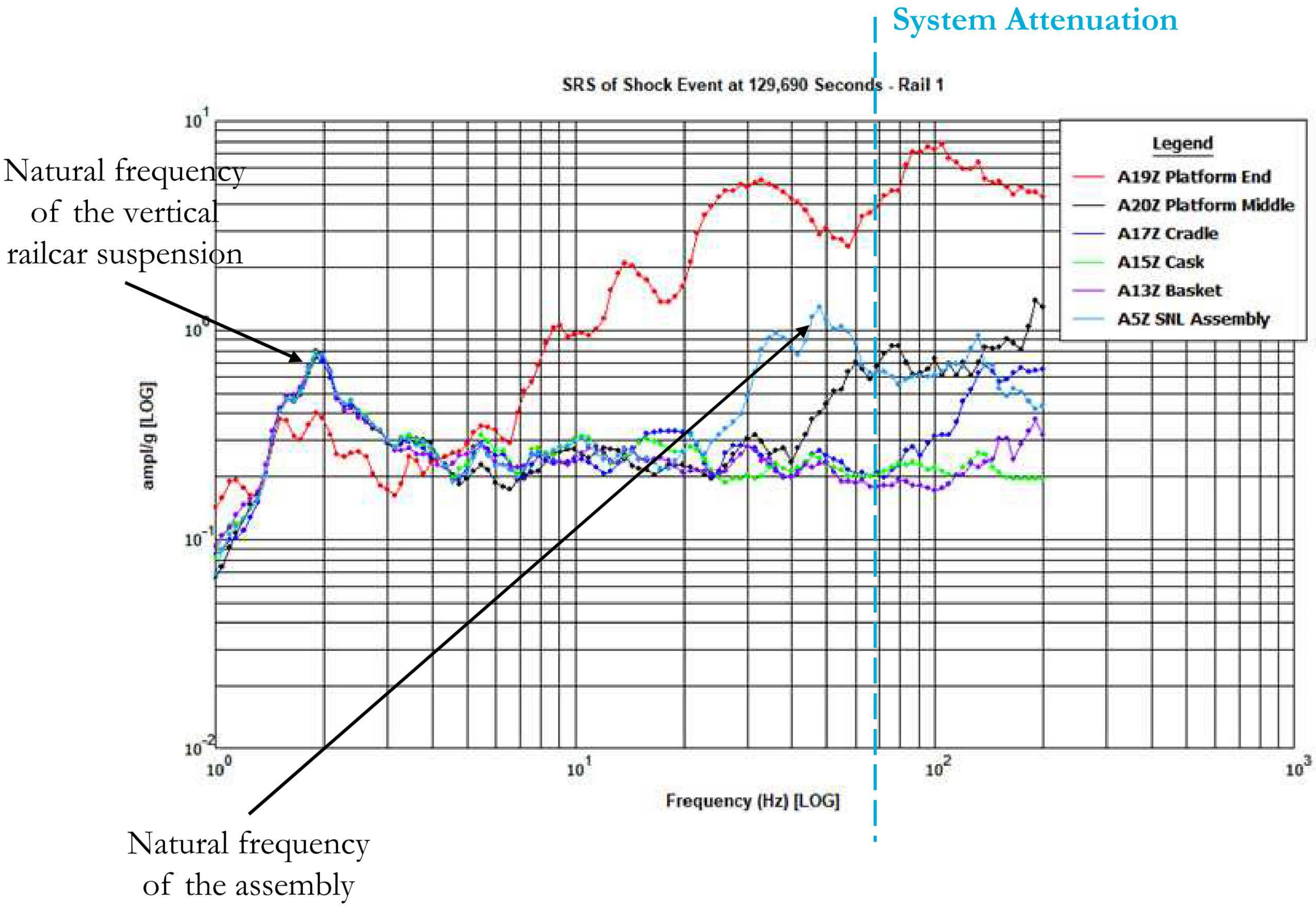
- NUREG 766510 and NUREG/CR-1277 (late 1970's)
- Left: SRS from 100-mile rail route containing rail joints, switches, and run-in/out track features (NUREG 766510).
- Right: SRS during a railcar coupling with a 70-ton cask at 8.0-11.2 mph (NUREG/CR-1277).

Only the railcar platform and cask exterior were instrumented

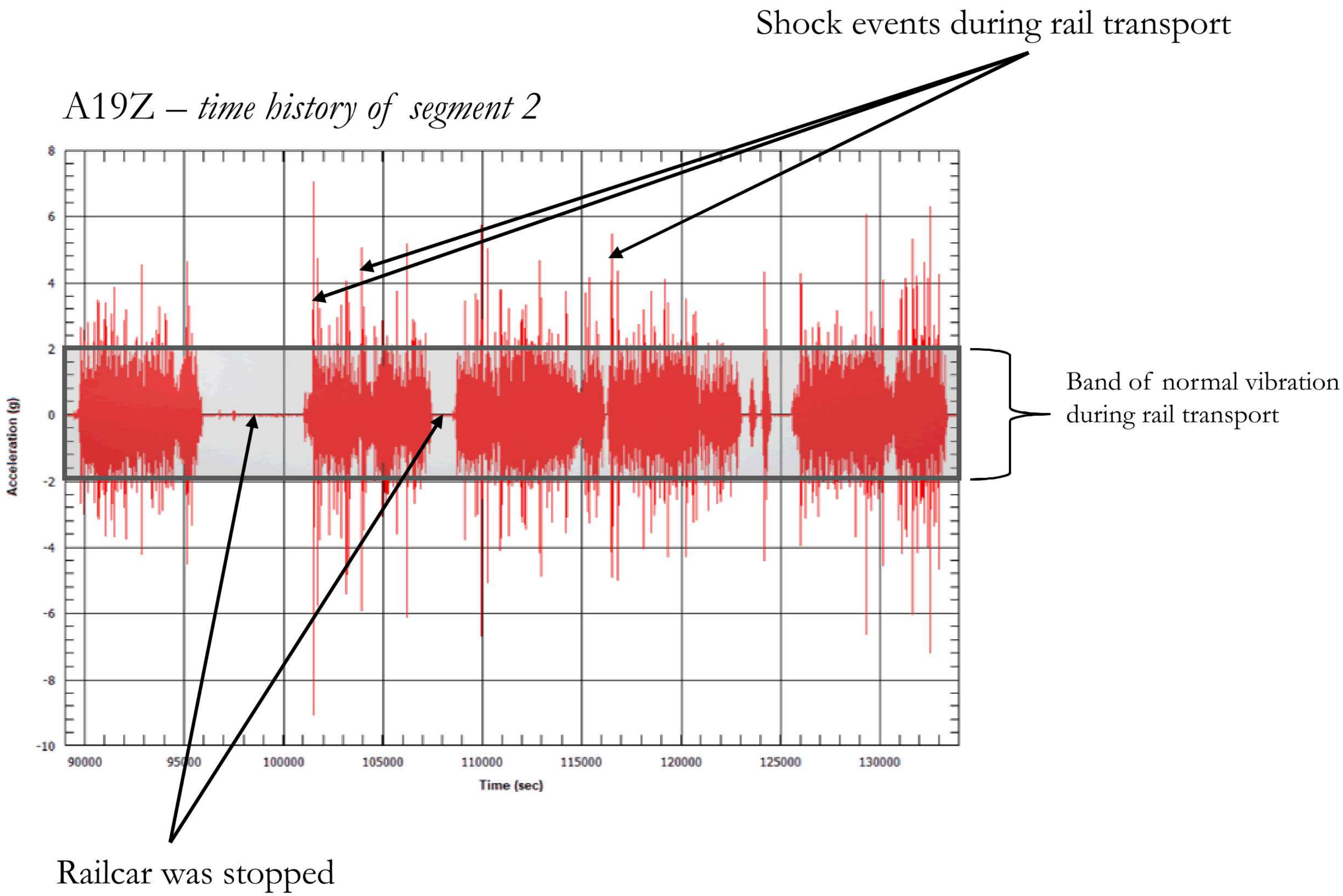




Acceleration response of the transportation system during a typical shock event.



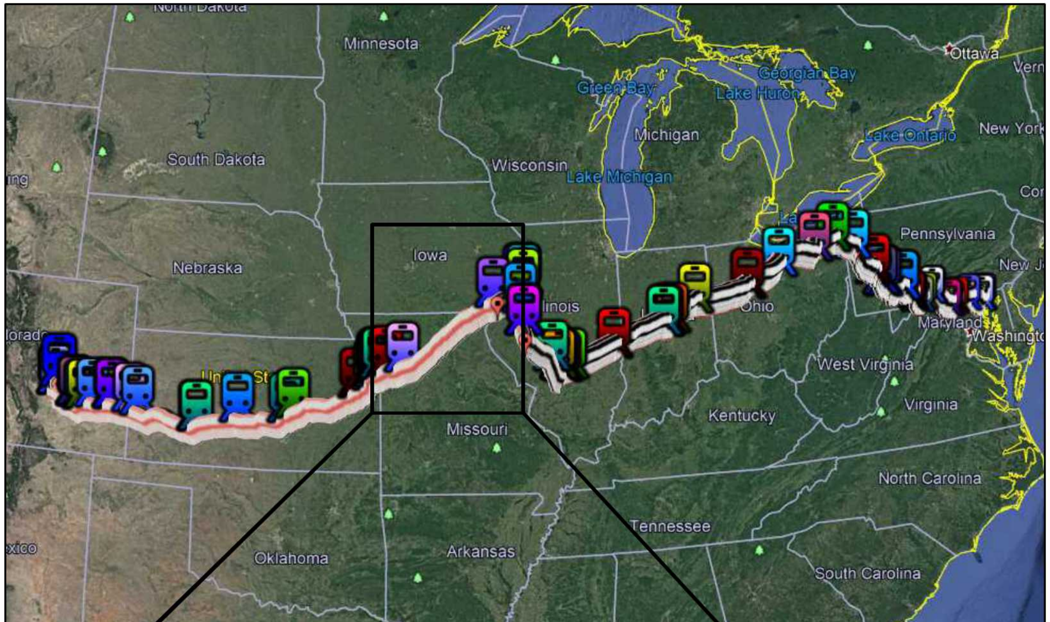
Shock Event Definition

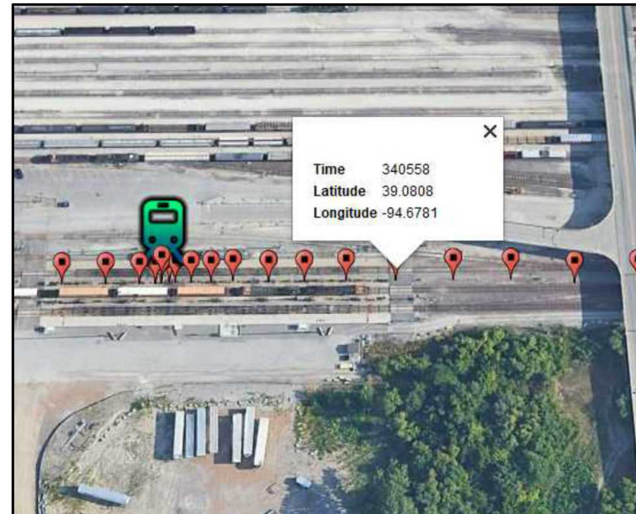


The events with platform acceleration equal to or exceeding +/- 2.0 g were classified as shock events.

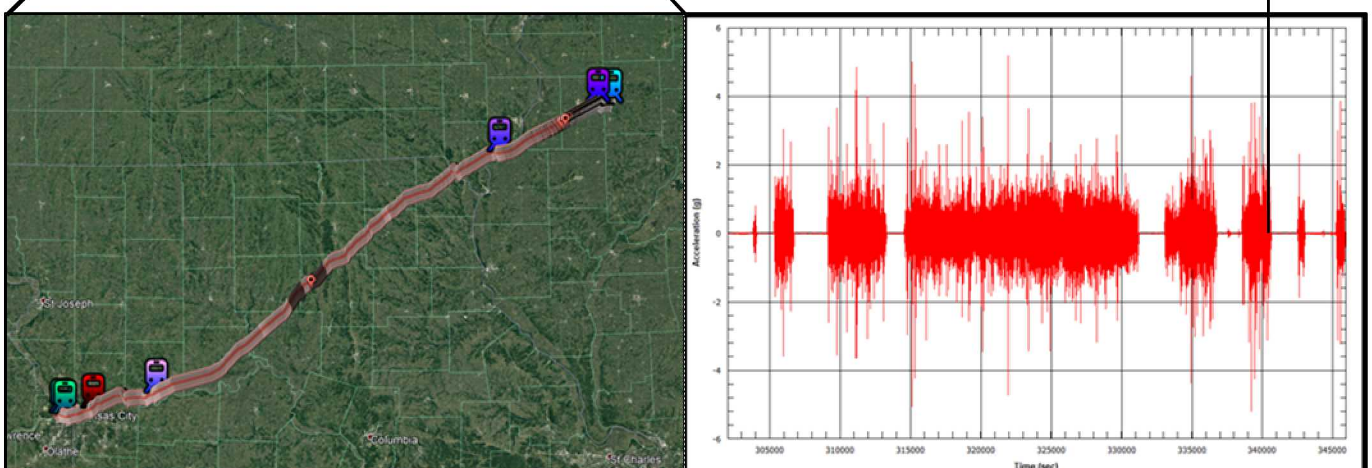
GPS data

Rail 1 GPS data. Train icons indicate places the train stopped.





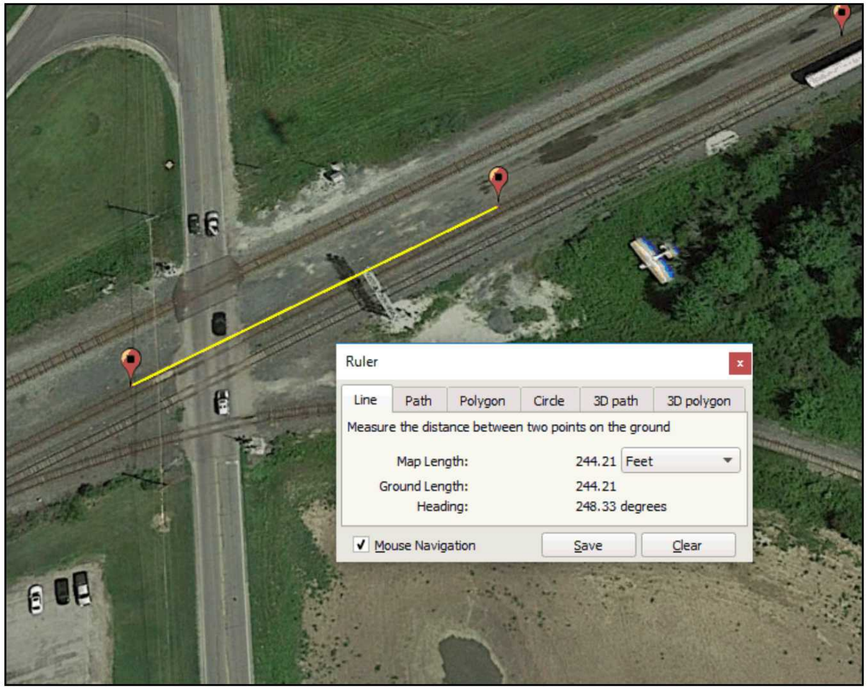
Example of mapping time history data to GPS location



Segment 7: GPS data and corresponding time history

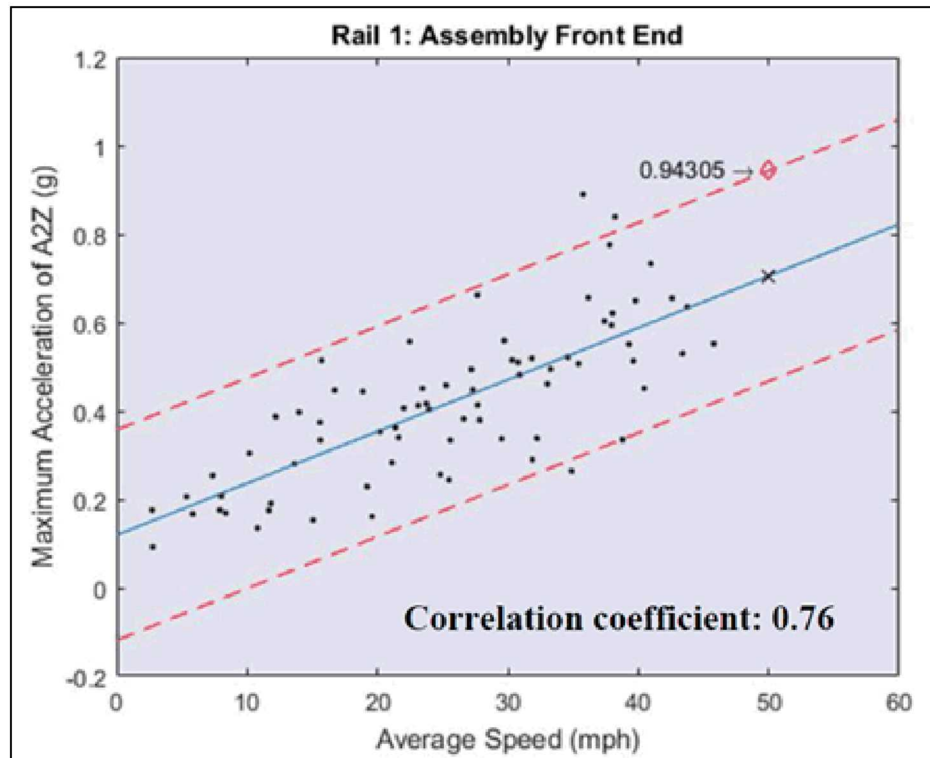
Images courtesy of Google Earth Pro

Speed Calculation and Predictive Interval



Google Earth Ruler tool was used for measuring the ground distance between two points 5 seconds apart.

In this example Rail 1 was traveling 33 mph when it crossed over a road.



Average speed of every block of motion vs. maximum acceleration to SNL assembly front end.

Predictive interval places maximum acceleration at 50 mph to be less than 1g with 95% confidence.

Classification of Event Cause

Events Caused by a Track Switch

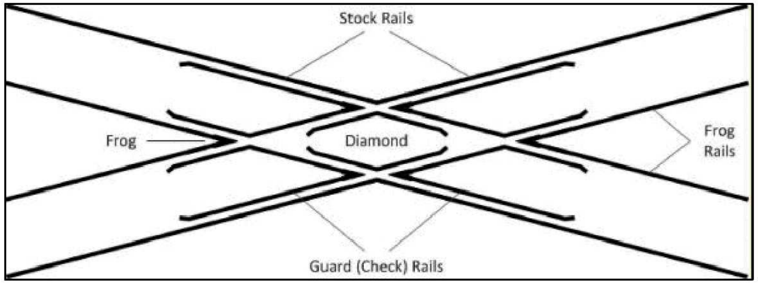
- Train passing a switch (main track or side track)
- Train passing a diamond crossing

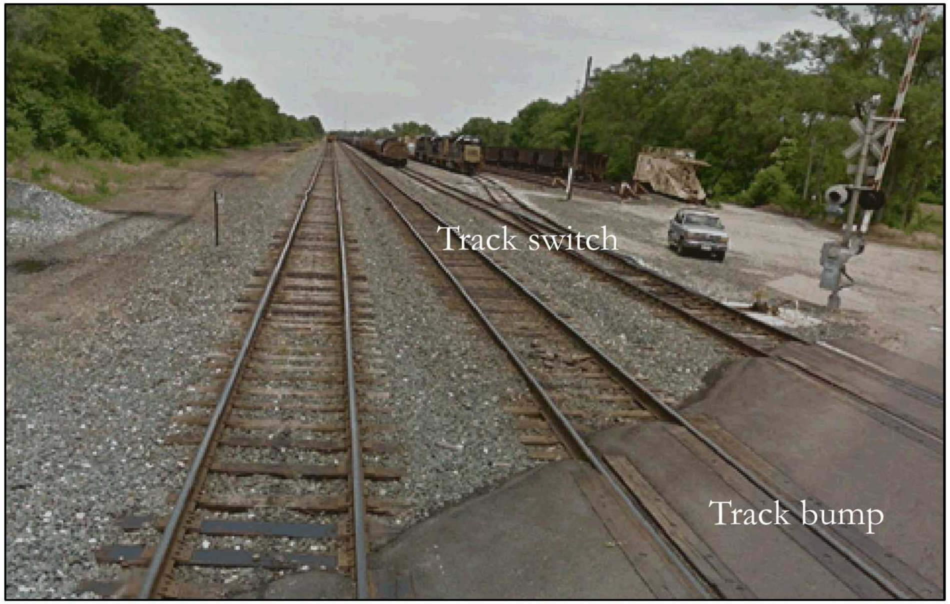
Events Caused by a Track Bump

- Train passing dips or humps in the rail
- Presence of an bridge abutment
- Presence of a road crossing
- Track imperfections

Events with No Visible Cause

- Peak in acceleration with no visible cause
- Rail appears straight, with no imperfections or switches
- Possibly degrading rail, soft subgrade, or poor image quality of GEP

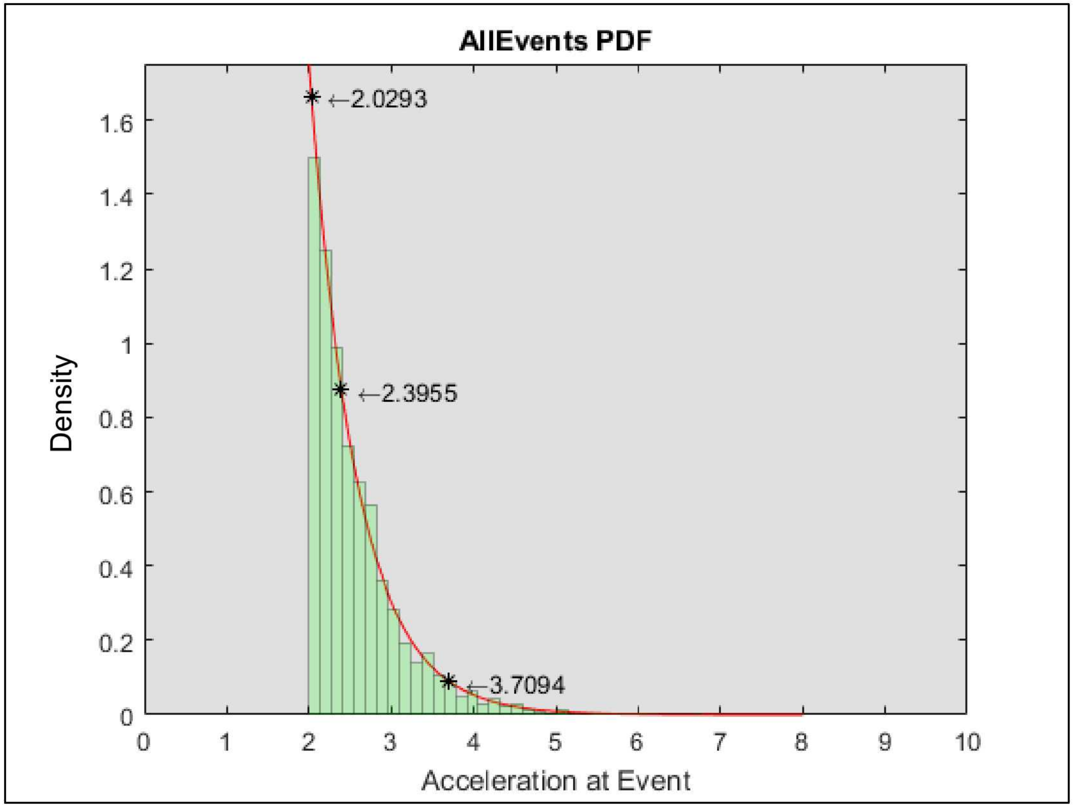




Images courtesy of Google Earth Pro

Platform Acceleration Histogram and PDF for Shock Events on Rail 1

	Occurrences over Rail 1 duration	*Maximum Transportation Platform Acceleration (g)*	*Average Frequency (mi/event)*
Event Switch	629	7.97	3.1
Event Bump	1,029	5.10	1.9
Event w/out Visible Cause	1,281	4.79	1.52
Total events	2,939	7.97	0.66



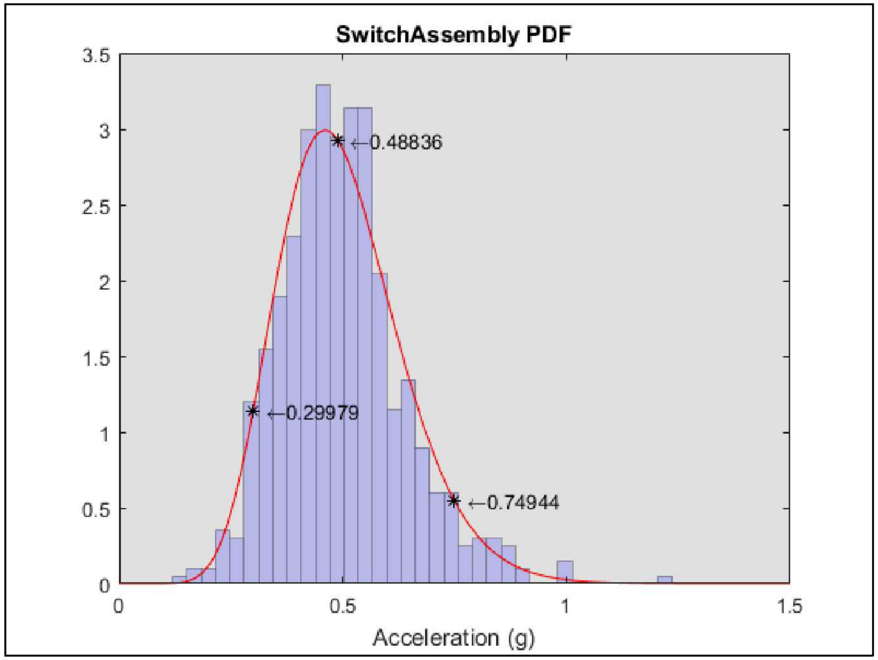
- Exponential Distribution
- PDF: $f(x;\ \lambda) = \begin{cases} \lambda e^{-\lambda(x-\theta)} & x \geq \theta \\ 0 & otherwise \end{cases}$
- $\theta = 2$ for shock events
- $\lambda = 0.57$ calculated using a maximum likelihood estimation (MLE).
- The probability of any event causing acceleration greater than 3.71 g to the rail platform is less than 5%.

SNL Assembly Acceleration Histograms and PDFs for Switch and Bump Events

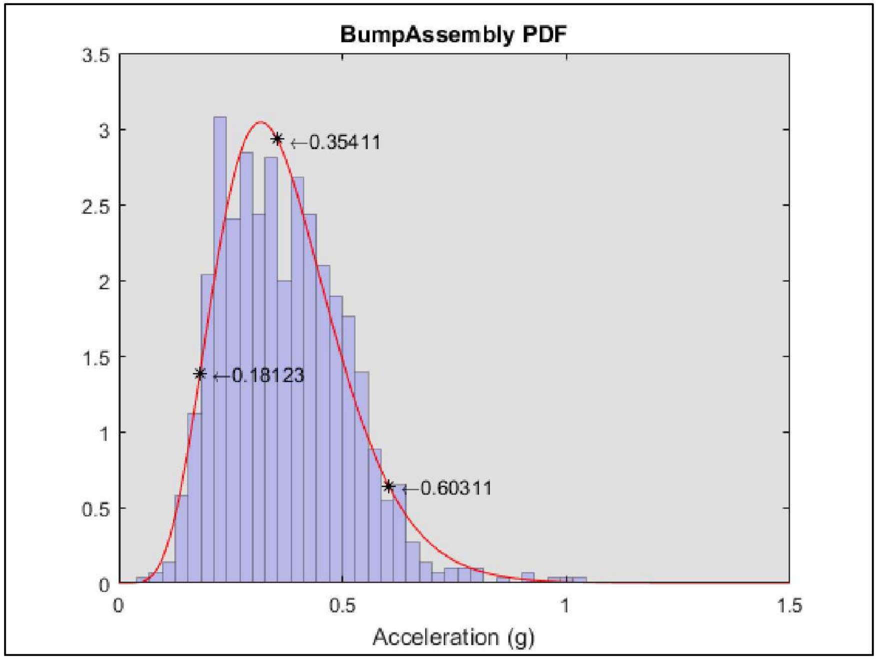
$$PDF(x;k,\theta) = \left(\frac{1}{\Gamma(k)\theta^k}\right)x^{k-1}e^{-\frac{x}{\theta}}$$

$$with\ x > 0\ and\ k,\theta > 0$$

Gamma distribution with parameters calculated using MLE



$k = 13.06 \quad \theta = 0.038$



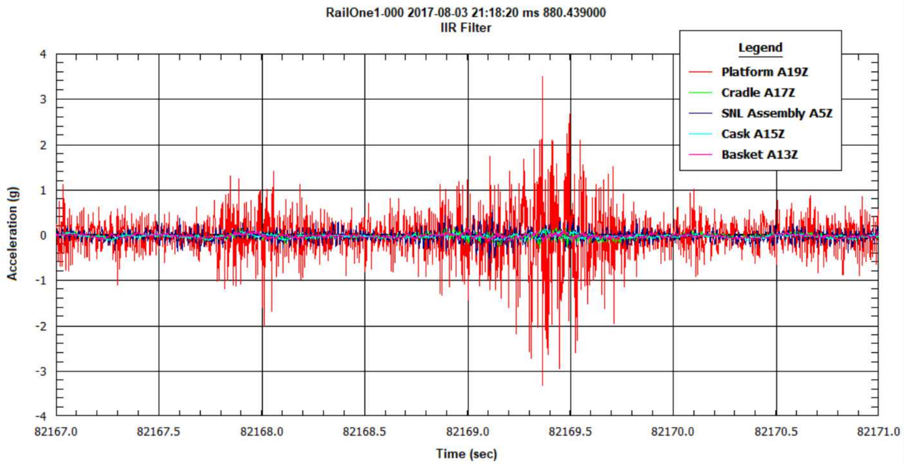
$k = 7.014 \quad \theta = 0.053$

The probability of a switch event with the SNL assembly acceleration greater than 0.75 g is less than 5%.

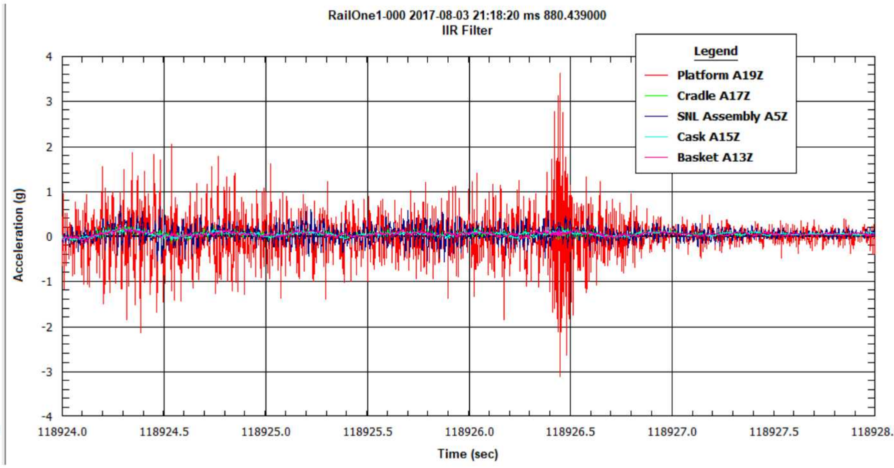
The probability of a bump event with the SNL assembly acceleration greater than 0.60 g is less than 5%.

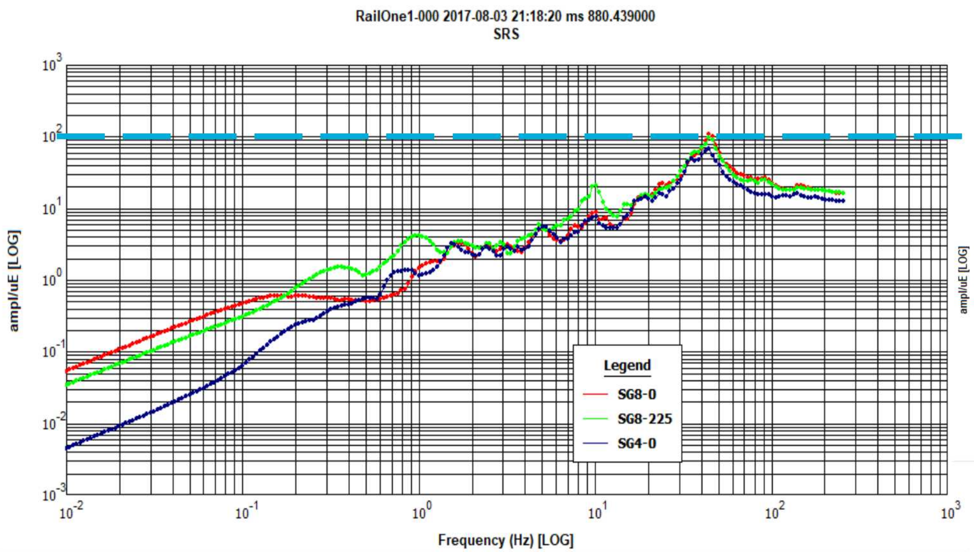
Comparison of Switch and Bump Events

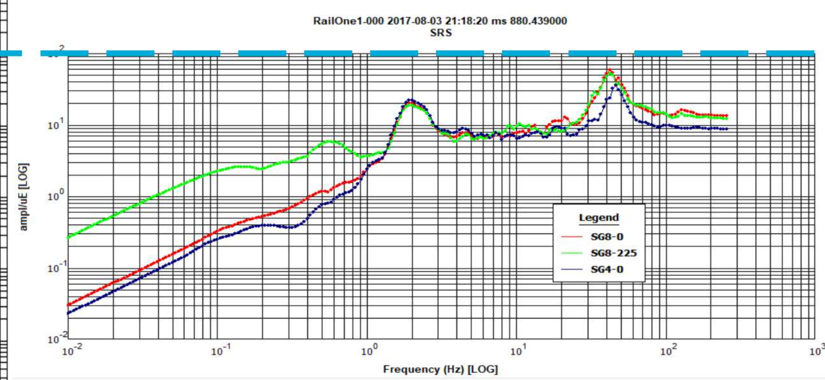
Switch Event



Bump Event





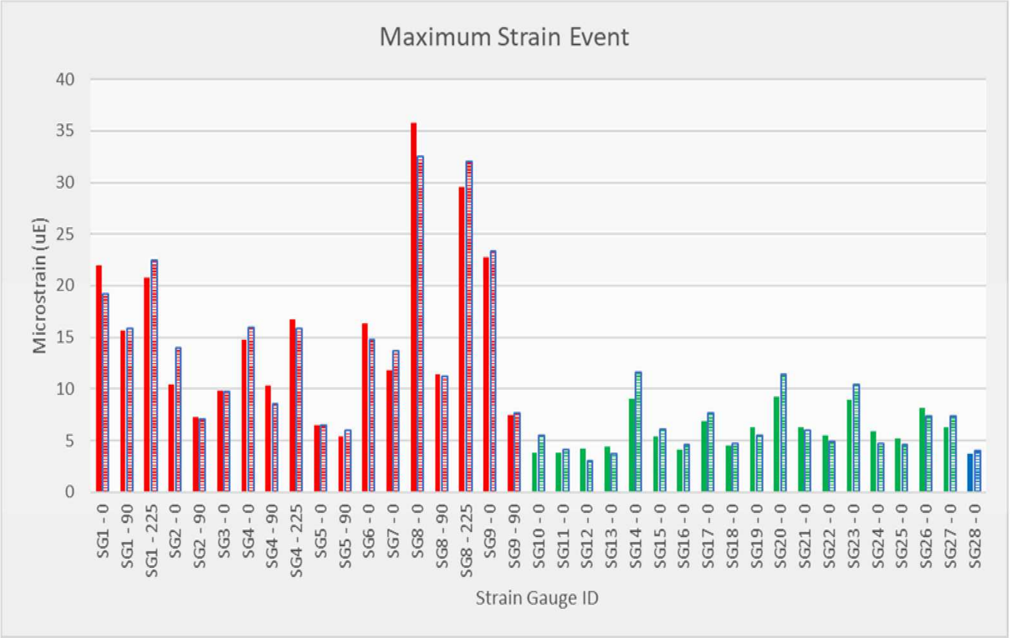


The switch events result in higher assembly accelerations than the bump events.

Maximum Acceleration and Maximum Strain Events

Maximum Acceleration Event

- Caused by a diamond crossing in Jacksonville, Illinois
- FRA Class 3 rail (max freight speed 40 mph)
- Rail 1 traveling 36 mph
- Peak acceleration: 8.68 g in A21Z
- Peak assembly acceleration: -0.65 g in A5Z
- Peak strain: -20.7 µE in SG8-225



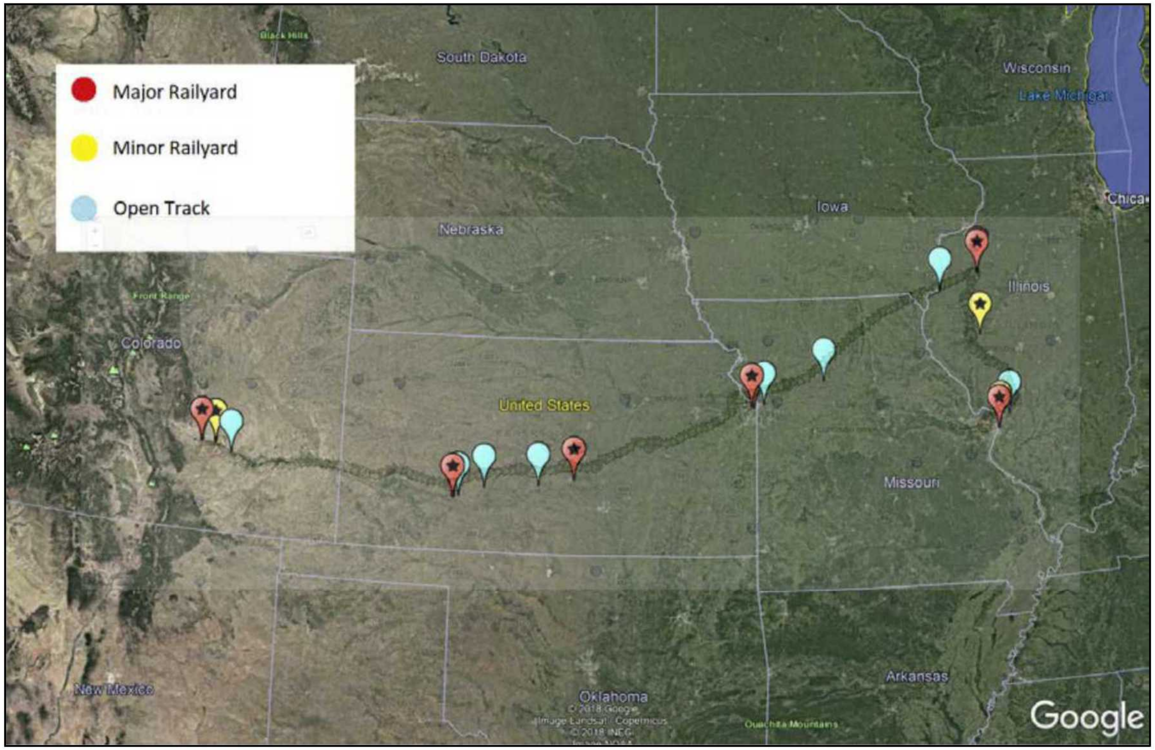
Solid bars indicate maximum, striped bars indicate absolute value minimum.

SNL assembly ENSA assembly KEPCO assembly

Maximum Strain Event

- Caused by a switch in Kendall, Kansas
- FRA Class 4 rail (max freight speed 60 mph)
- Rail 1 traveling 45 mph
- Peak acceleration: -3.78 g in A21Z
- Peak assembly acceleration: -0.63 g in A5Z
- Peak strain: 35.8 µE in SG8-0

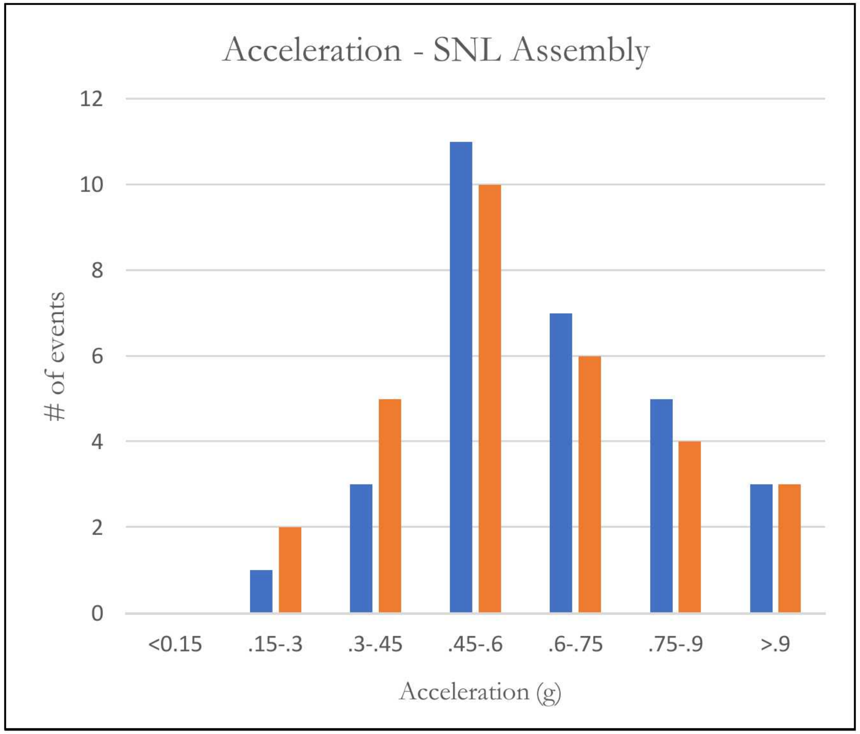
Locations of Coupling Events on Rail 2 Route

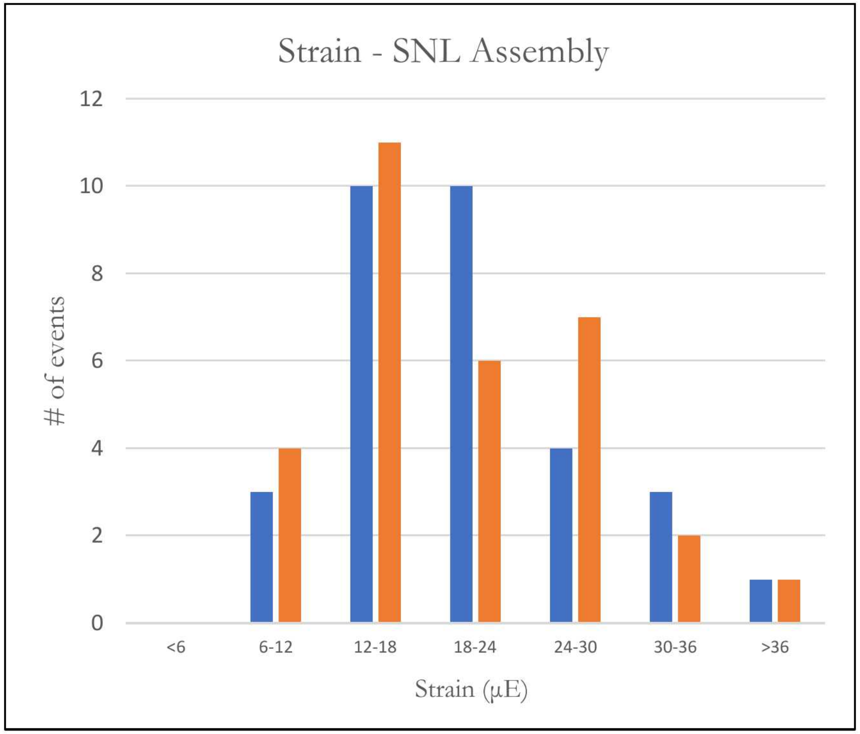


- Points indicate locations in which coupling events occurred.
- 30 events at railyards were identified along Rail 2
- 23 occurred at major railyards.

Example of a major railyard

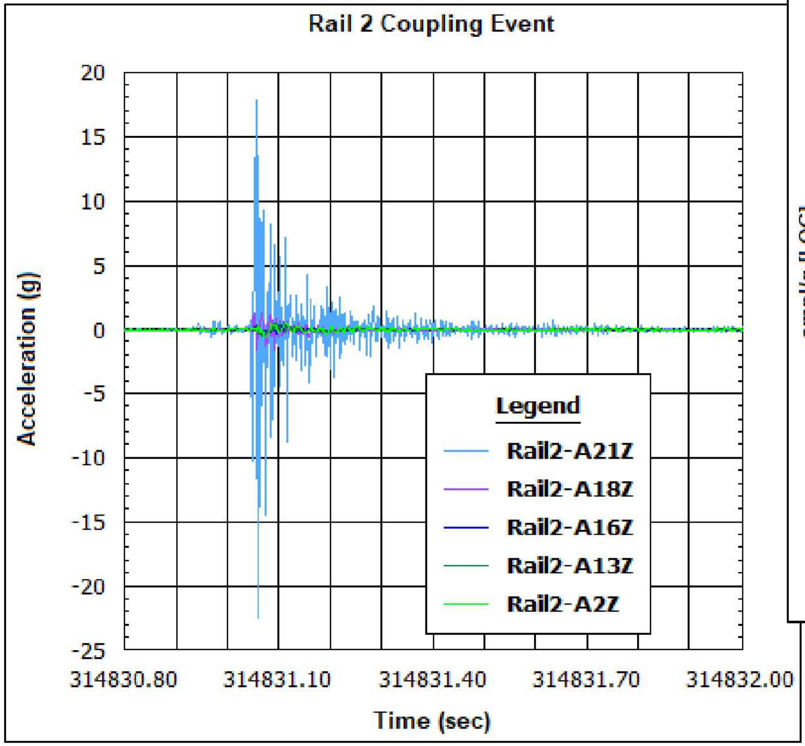
SNL Assembly Accelerations and Strains in Rail 2 Coupling



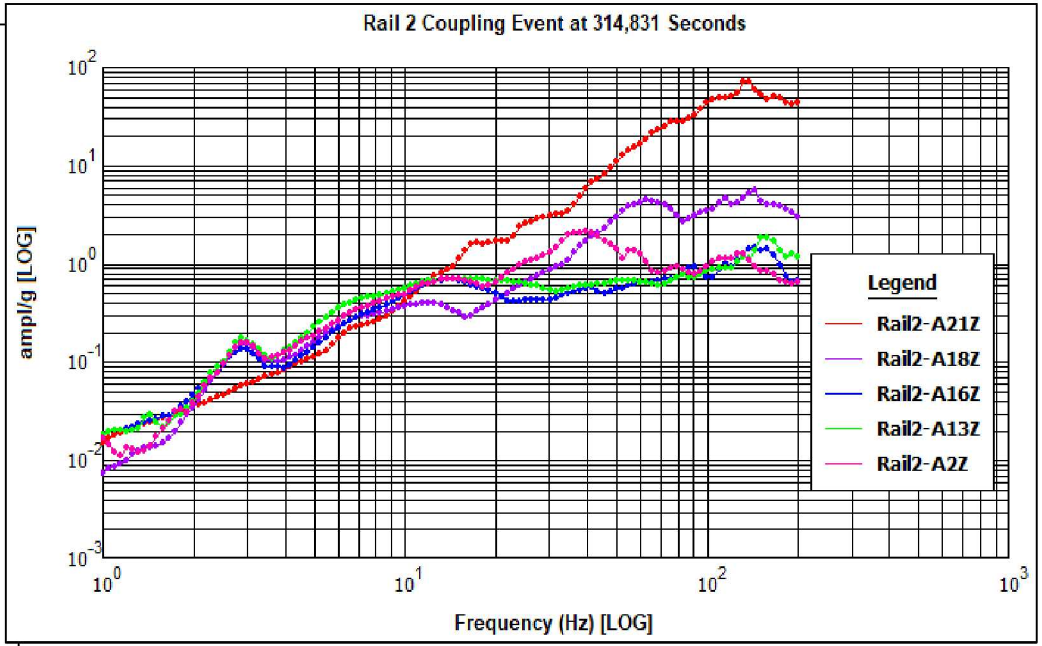


The maximum acceleration on the SNL assembly was 1.06 g and the maximum strain was 39 µE.

Coupling Event during Rail 2



Time history showing characteristic coupling response



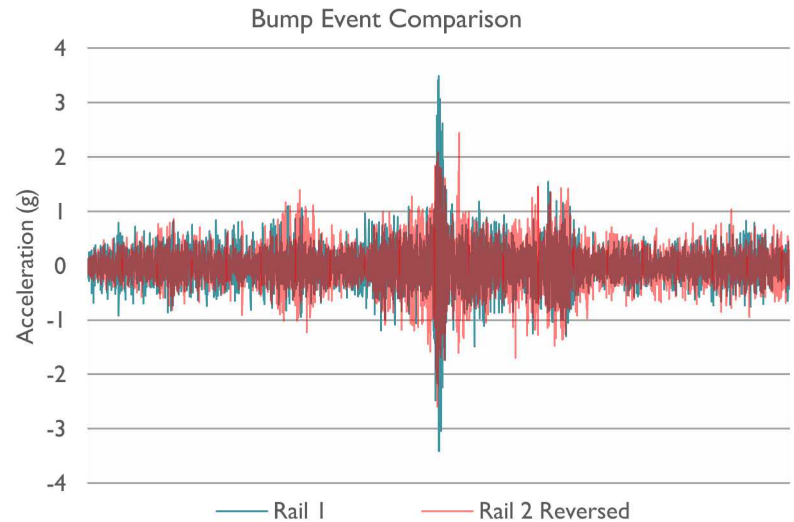
SRS of system response to coupling event at 314,831 seconds

The accelerations and strains during the coupling events are generally somewhat higher than during the switch and bump events.

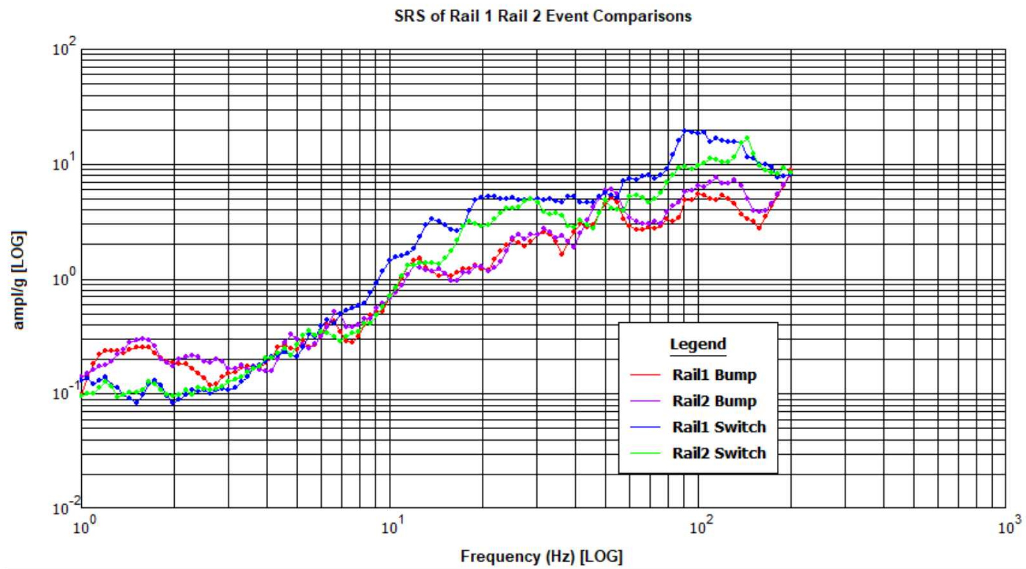
GPS location of coupling event at 314,831 seconds

Crossing Same Switch and Same Bump during Rail 1 and Rail 2 Transport

Rail 1 40.1 mph **Rail 2** 29.9 mph



Rail 1 44.3 mph **Rail 2** 44.6 mph



The accelerations are very similar and only slightly higher on Rail 1 due to the higher train speed.

Summary

- Rail tests demonstrate that different system elements behave differently to shock events.
- Higher accelerations and strains typically occur at assembly resonant frequency (40-45 Hz)

<u>Rail 1</u> (1,950-mile route) *Analysis of system response during normal rail transport*

- 2,939 shock events were identified and analyzed.
- Less than 5% probability that a switch event will cause SNL assembly acceleration greater than 0.75 g.
- Less than 5% probability that a bump event will cause SNL assembly acceleration greater than 0.6 g.
- Maximum SNL assembly acceleration was 1 g, and maximum SNL assembly strain was 35.8 µE.
- Acceleration increase linearly with train speed.
- Maximum acceleration on the SNL assembly is predicted to be less than or equal to 0.94 g at 50 mph.

<u>Rail 2</u> (1,125-mile route) *Analysis of system response during coupling events*

- 30 coupling events were identified at railyards.
- Accelerations and strains during coupling events are somewhat higher than switch and bump events.
- Maximum SNL assembly acceleration was 1.06 g and maximum SNL assembly strain was 39 µE.

The test results provided a compelling technical basis for the safe transport of spent fuel under normal conditions of transport.

During normal conditions of transport, including coupling, the accelerations on the assembly are expected to be below 1 g and the strain is expected to be below 40 µE. Consequently, the stress fuel rods experience is far below yield limits for cladding.


Questions?