SAND2018-2610PE

MULTI-MODAL TRANSPORTATION TEST & ANALYSIS OF RESULTS TO DATE

PRESENTED BY

Elena Kalinina, *Sandia National Laboratories*

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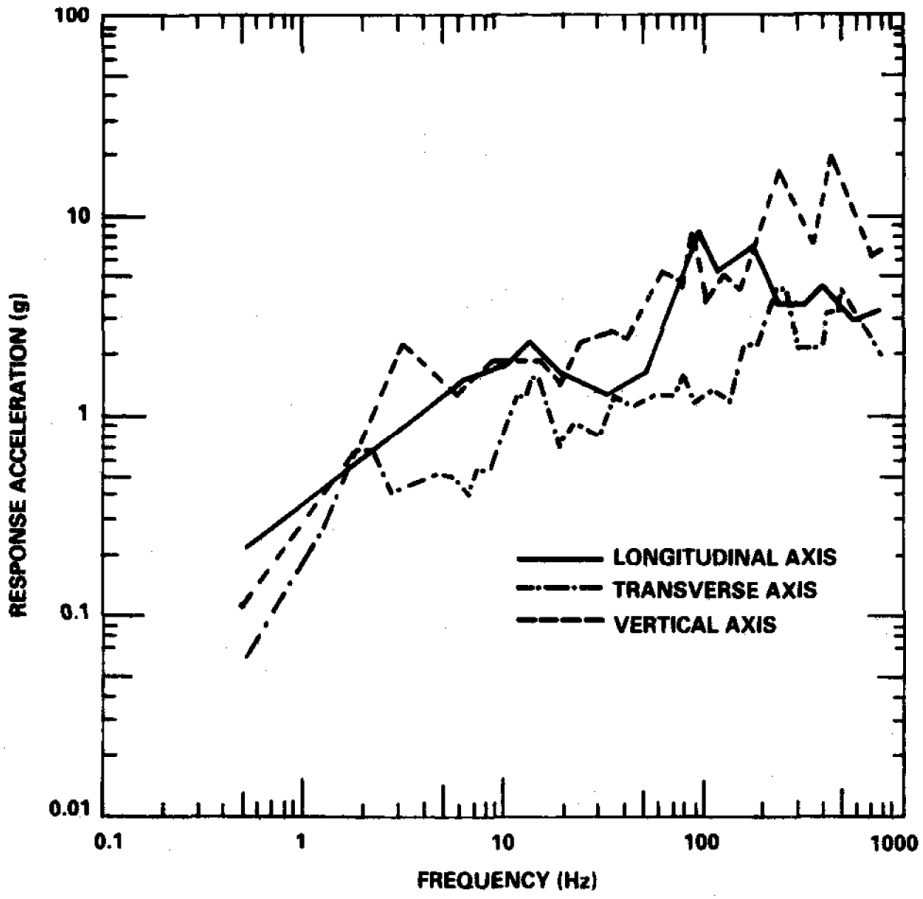
WHY WE NEED THIS TEST



Our Current Data

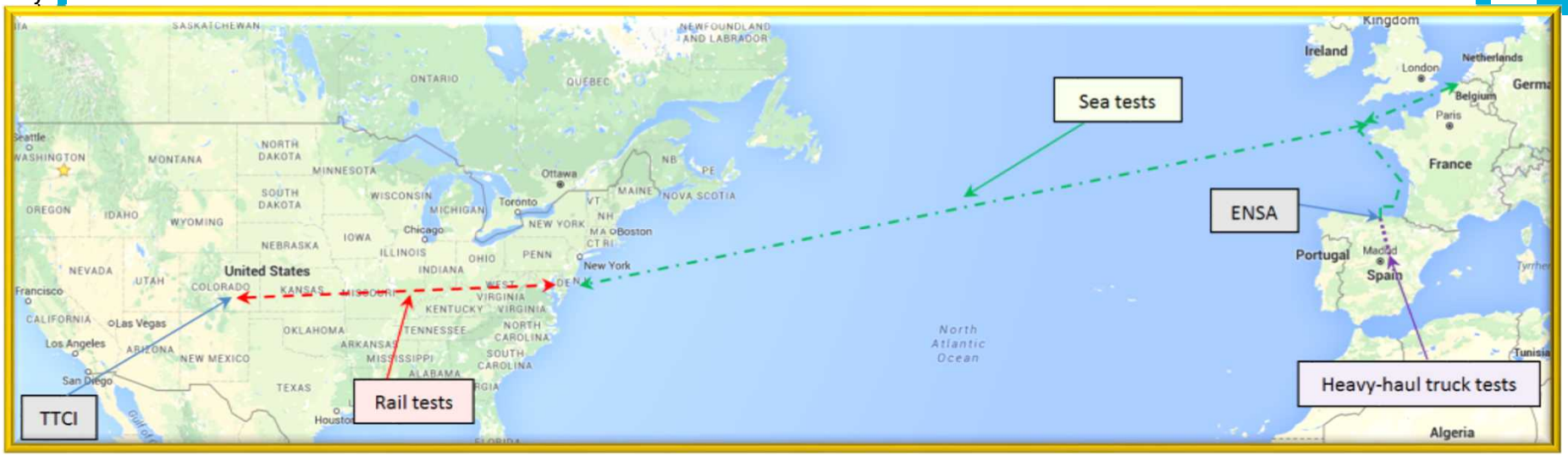
NUREG 766510 (SAND76-0427), 1978, *"The Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks".*

10CFR71.71 requires an assessment of "Vibration - Vibration normally incident to transport" imposed on transport packages and contents during "normal conditions of transport".

ENSA/DOE Multi-Modal Transportation Test with ENSA ENUN 32P Cask

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

CASK TEST ROUTE



Cask handling tests at ENSA, Santander/Spain (JUN 2017, 1 day)

Heavy-haul truck tests in northern Spain (JUN 2017, 2 days, 245 miles)

Ocean transport from Spain to Belgium (JUN 2017, 4 days, 939 miles)

Ocean transport from Belgium to Baltimore (JUL 2017, 14 days, 4222 miles,)

Rail shipment from Baltimore to Pueblo (AUG 2017, 6 days, 2000 miles)

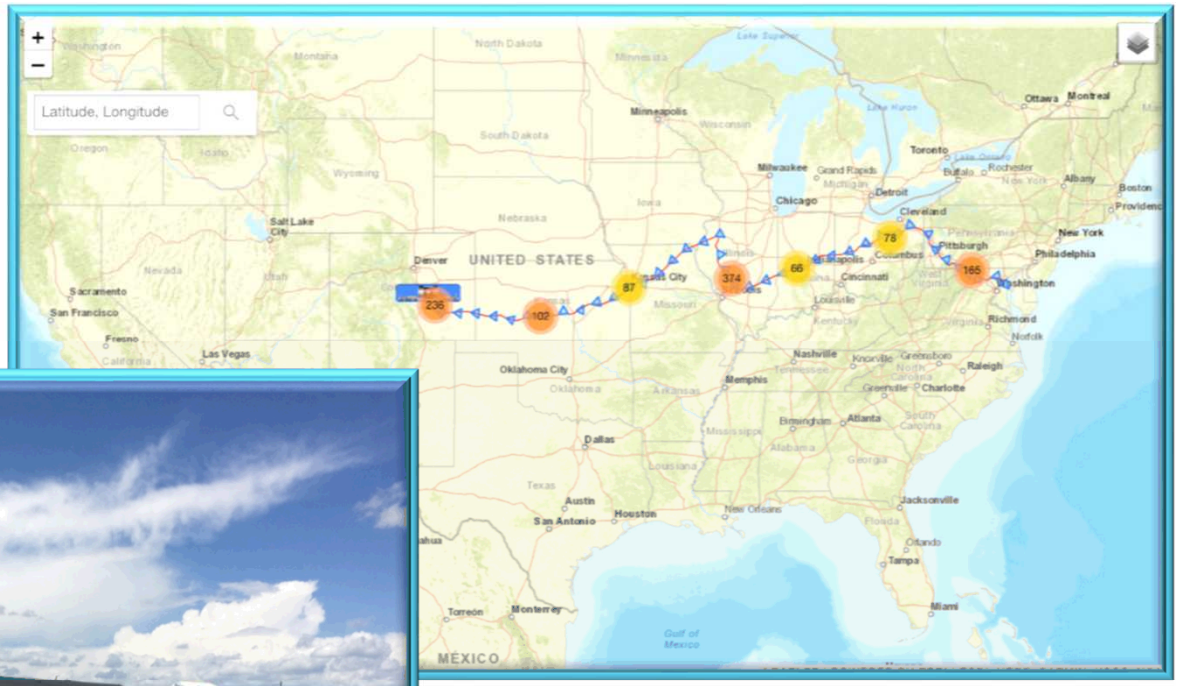
Tests at Transportation Technology Center, Inc., Pueblo (AUG 2017, 9 test days; 125 types of tests; 125 tests)

Rail shipment from Pueblo to Baltimore (OCT 2017, 43 travel days, 18 test days, 1125 test miles)

Ocean transport from Baltimore to Spain (DEC 2017, no data collected)

CASK TRANSPORTED BY RAIL TO TTCI FOR SERIES OF RAIL TESTS

8 Types of Tests

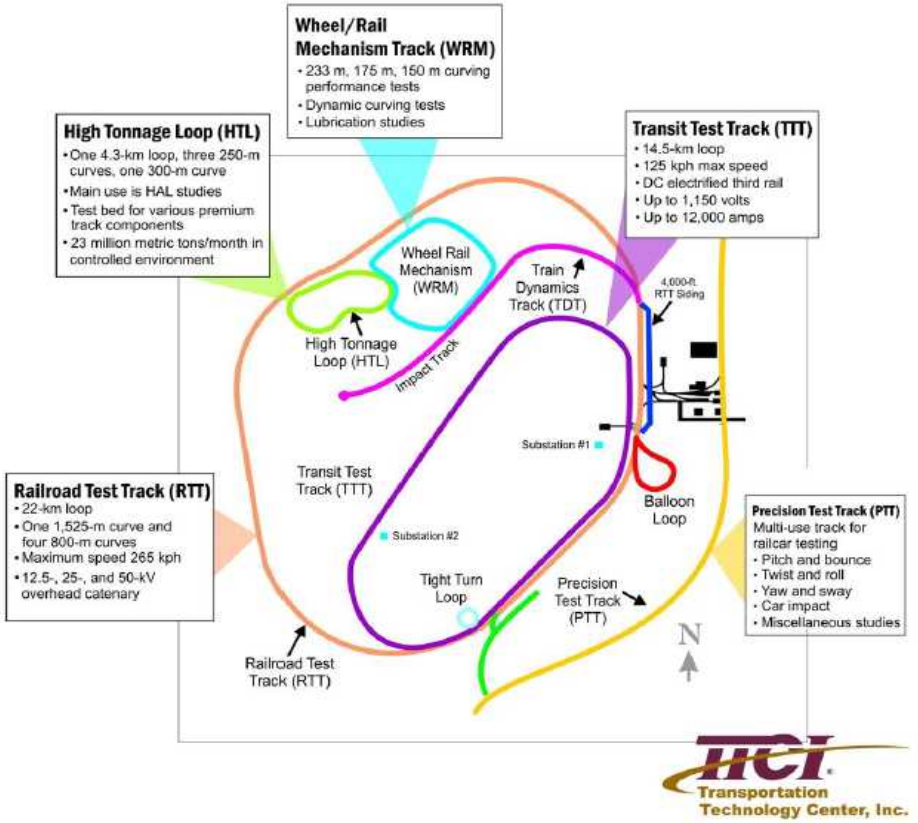


125 Separate Test Cases

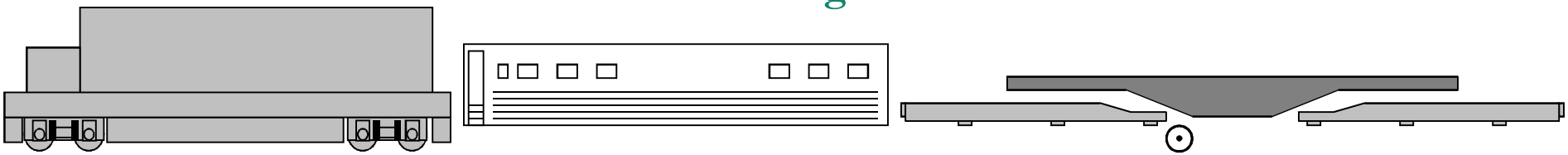
TEST SETUP

Kasgro 12-Axle Car with Cask at TTCI

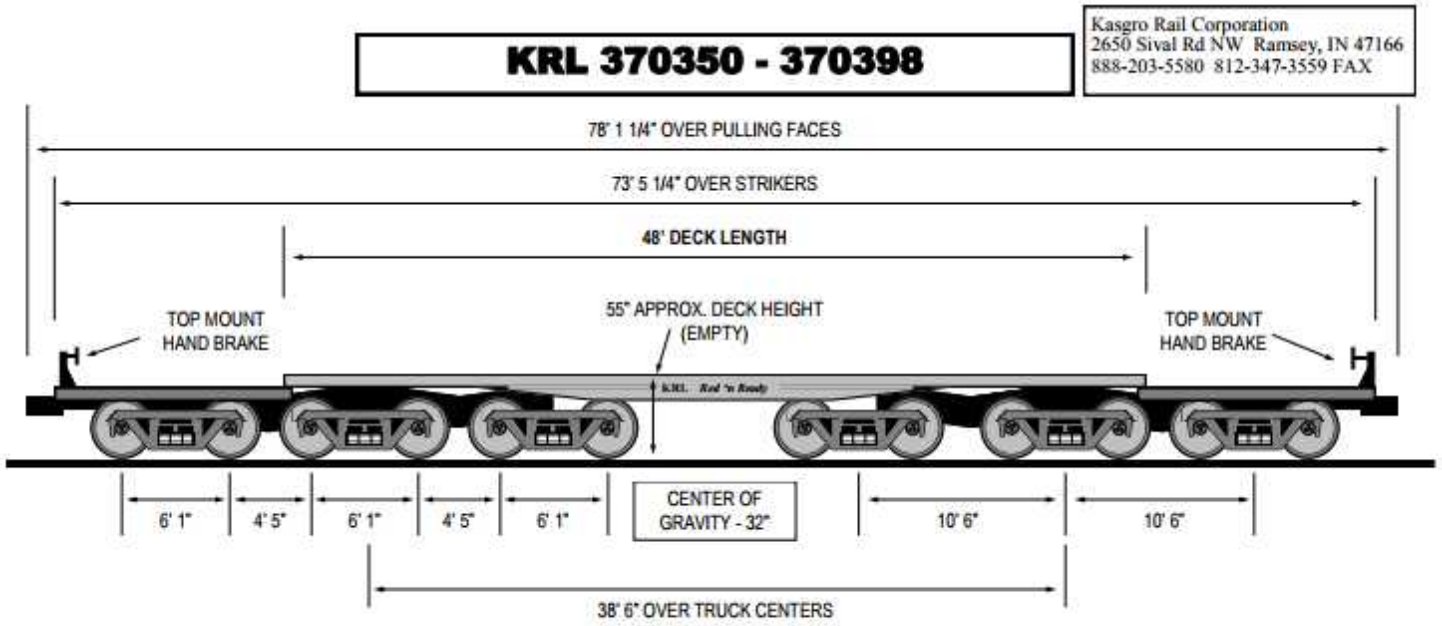
TTCI Rail Track Map



Consist Configuration



KASGRO KRL 370350 SCETCH

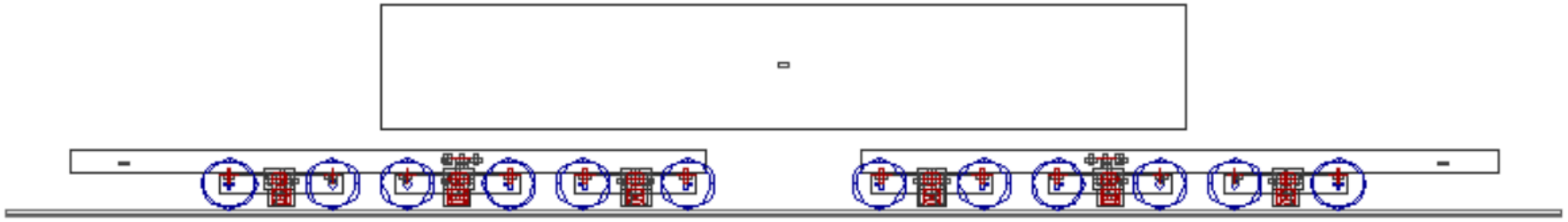


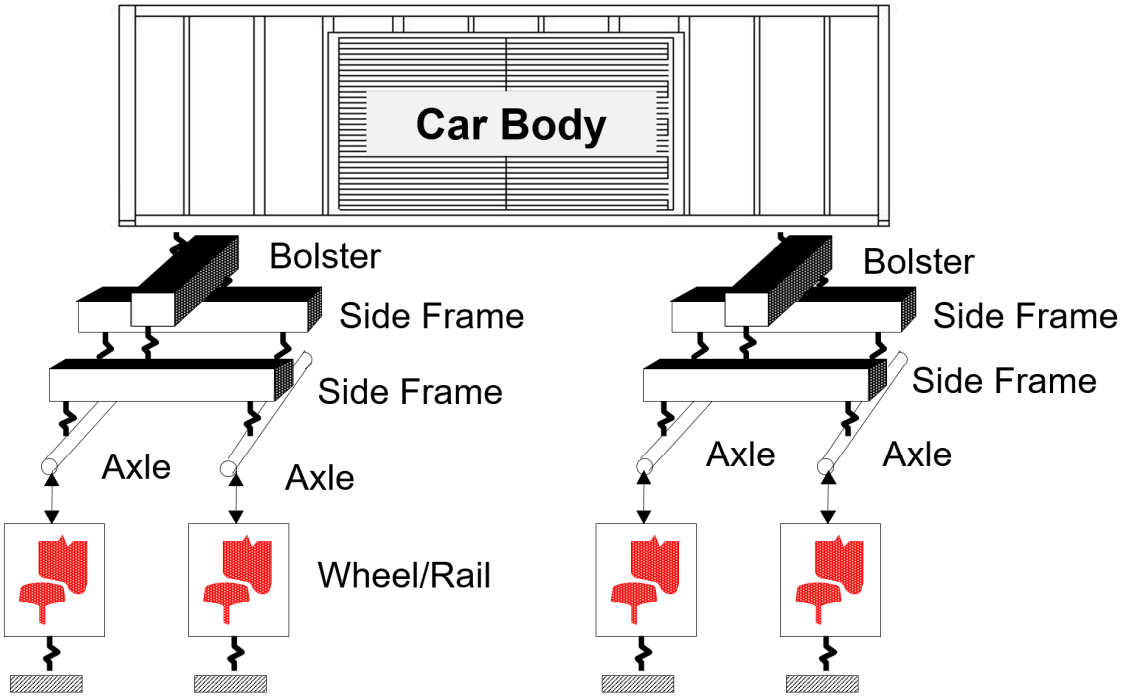
LENGTH OF LADING (ft)	LOAD LIMITS (lbs)	CAR NUMBERS	LOAD LIMITS (lbs)	LIGHT WEIGHTS (lbs)	MAXIMUM GROSS (lbs)	SPRING TRAVEL (in)	DECK LENGTH (ft-in)	DECK HEIGHT (ft-in)	JOURNAL SIZE BEARING TYPE
4' & OVER	744,000 MAX LOAD	370350-370398	744,000	201,000	945,000	4 1/4"	48' 0"	4' 7" EMPTY	7 X 12 ROLLER
						WHEEL DIAMETER (in)	DECK WIDTH (ft-in)	DRAFT GEAR	
						38"	10- 8"	15" EOC	

KRL 370350 - 370398
370 Ton - 48' Straight Deck Flat Car
Drawing No. A19626 Rev. C

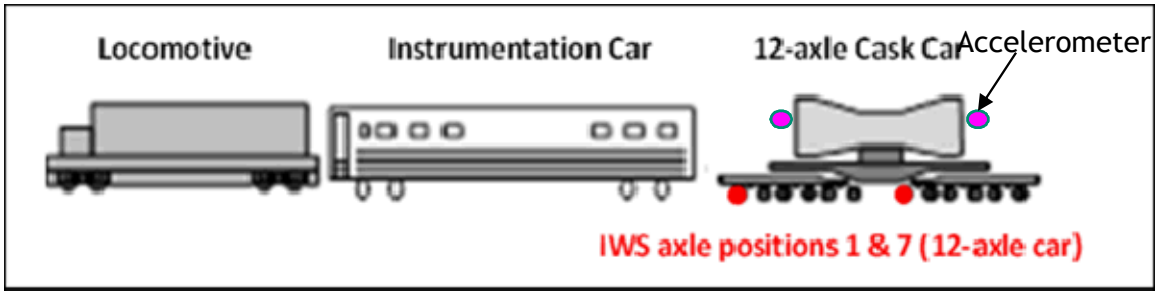
http://www.kasgro.com/car_sketch_revisions/SPEC%20A19626,%20Rev.%20C.pdf

NUCARS VEHICLE DYNAMICS MODEL



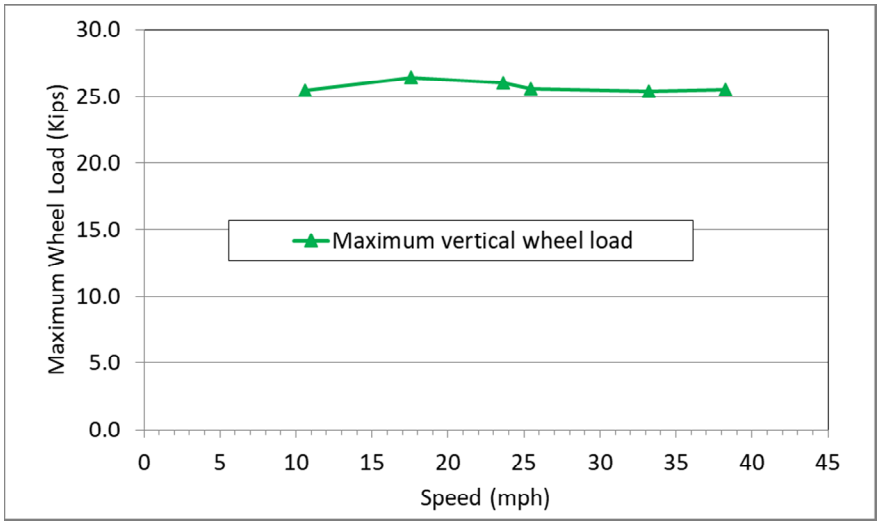


DATA COLLECTED BY TTCI



Instrumented Wheel Set

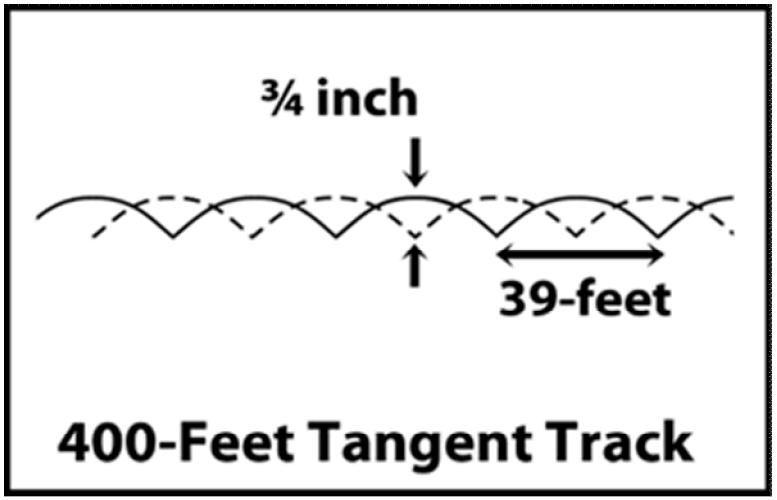
Maximum Wheel Load (Crossing Diamond)



8-11 strain gage bridges per wheel; signals are converted into wheel-rail forces

TWIST AND ROLL (18 TESTS)

Car's ability to negotiate oscillatory cross-level perturbations



Staggered Joints on a 39-foot Wavelength

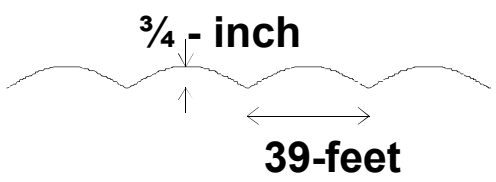
- 39-feet was the typical rail length
- "Rock off Derailments" were once a problem
- Continuously welded rail has reduced, but not eliminated this kind of behavior.

PITCH AND BOUNCE (9 TESTS)

Car's ability to negotiate parallel vertical rail perturbations

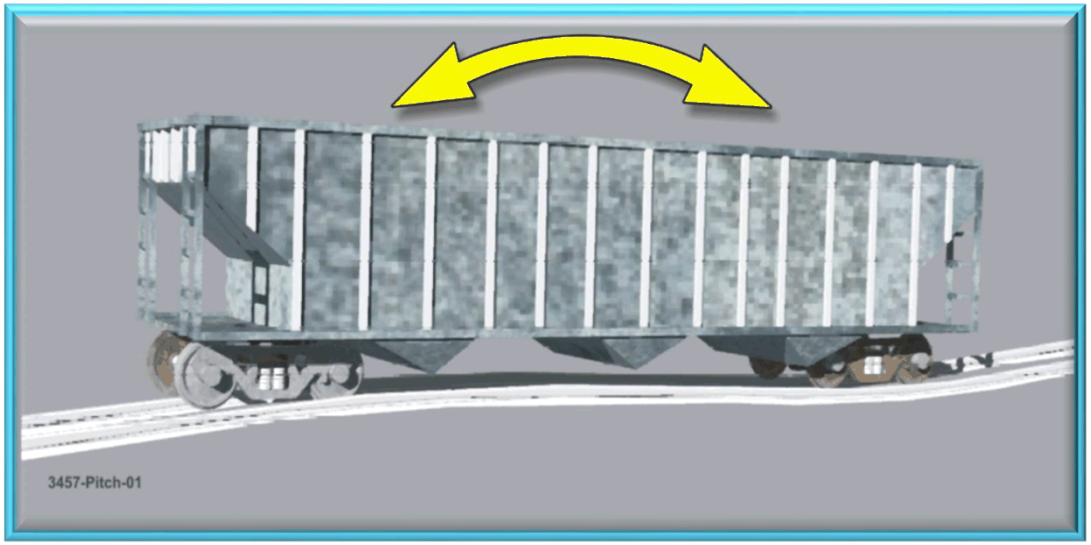
PITCH AND BOUNCE
Parallel Jointed Track

PTT Track

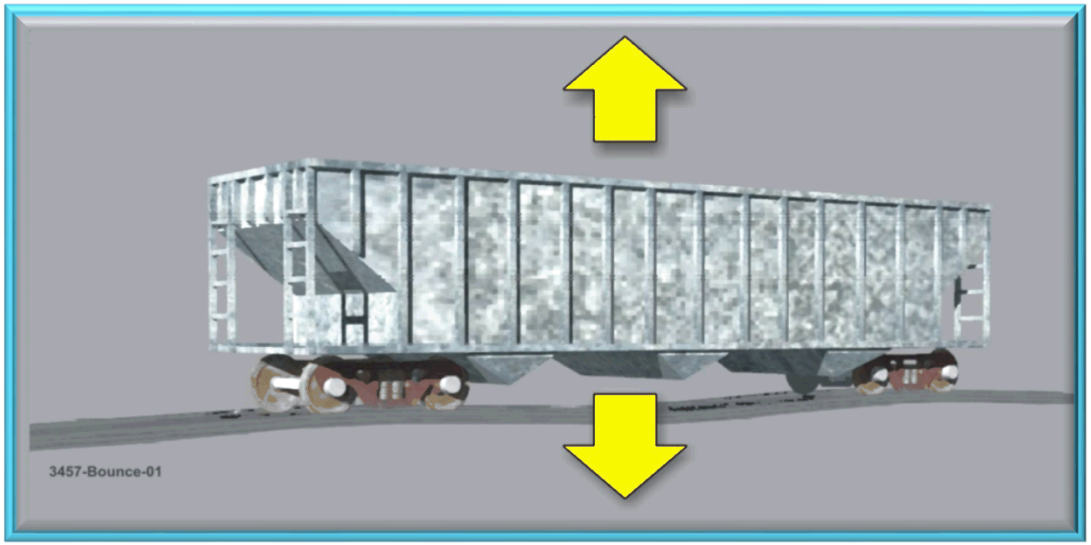


400 feet Tangent Track

- 39-foot wavelength
- Parallel Joints



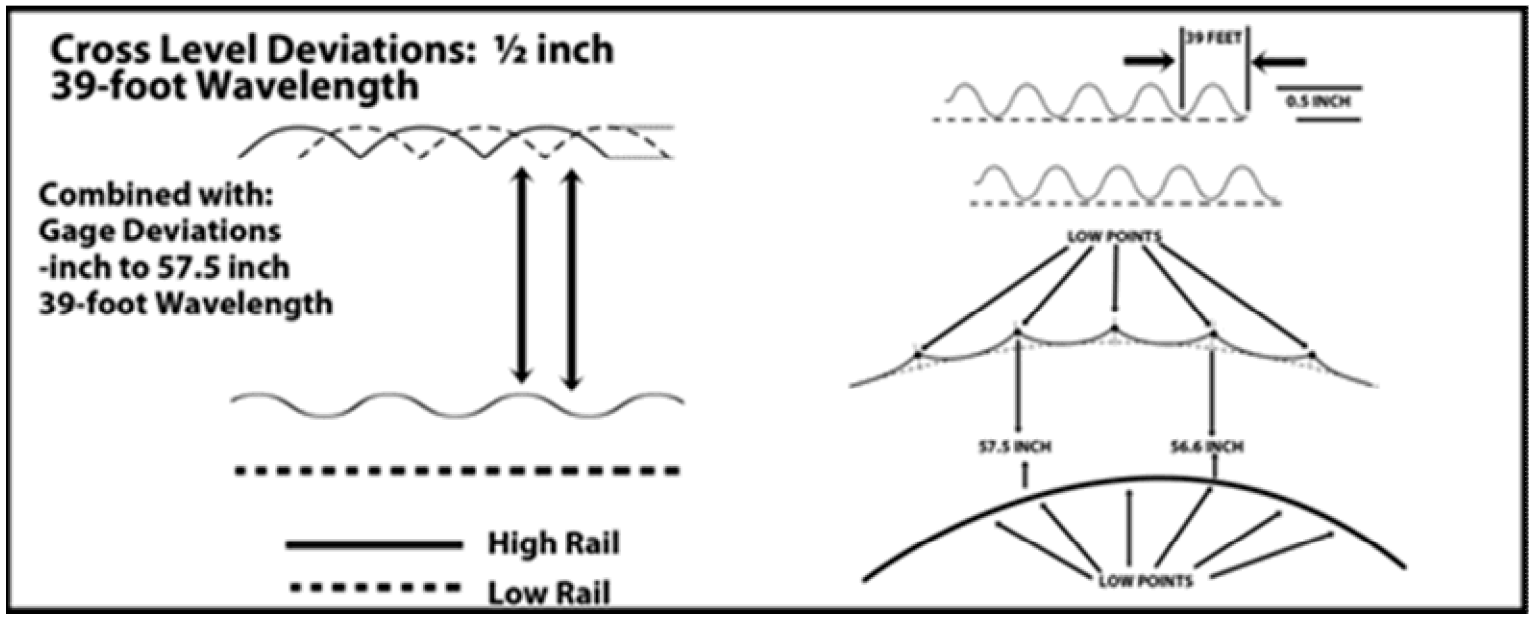
Pitch



DYNAMIC CURVING (25 TESTS)

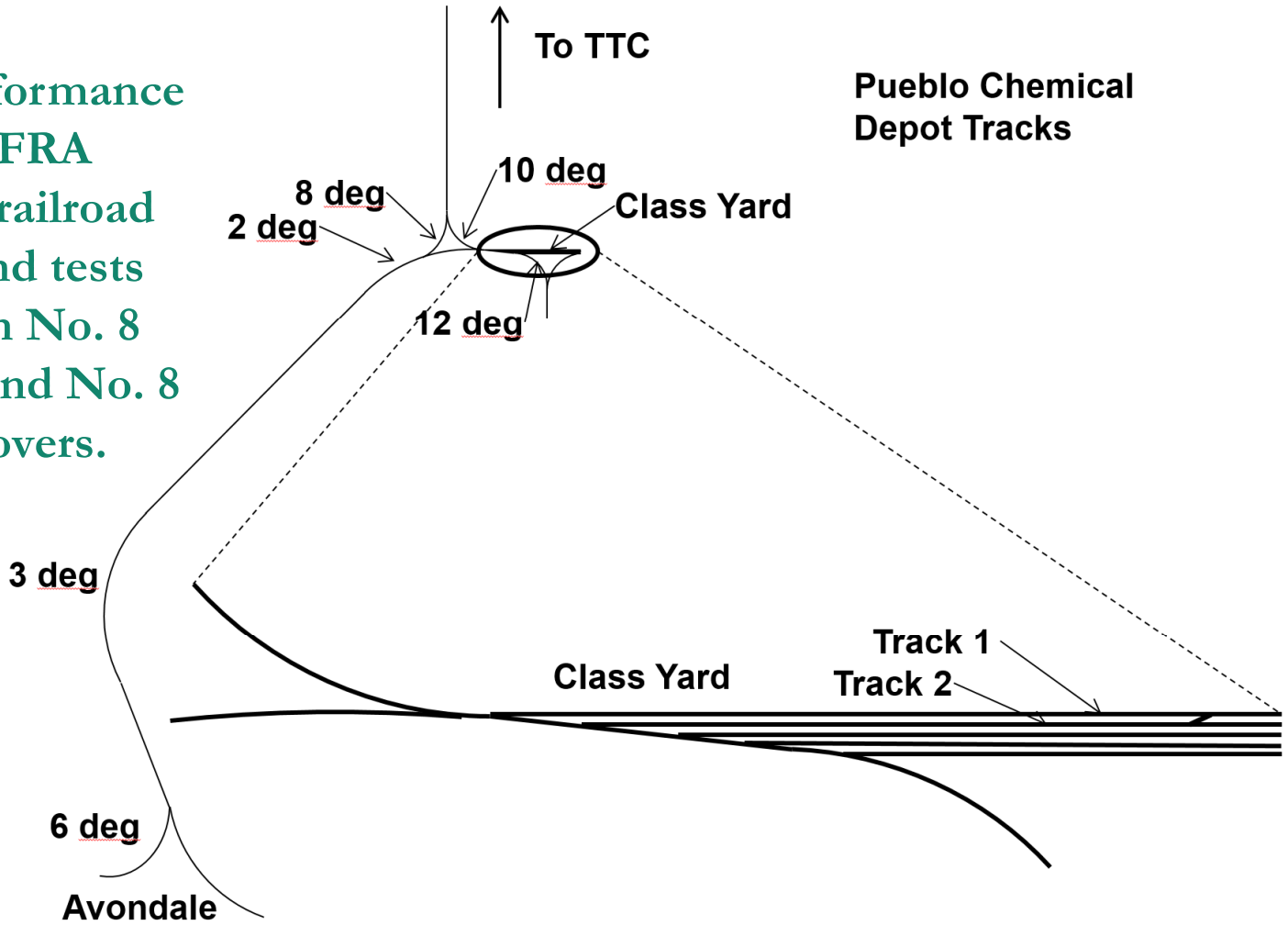
Car's ability to negotiate curving over jointed track with combination of lateral misalignment at outer rail joints and cross-level due to low joints on staggered rails.

- 39-foot wavelength
- Crosslevel deviations
- Gage deviations that create a "down and out" perturbation
- 10-degree curve with 4-inch superelevation



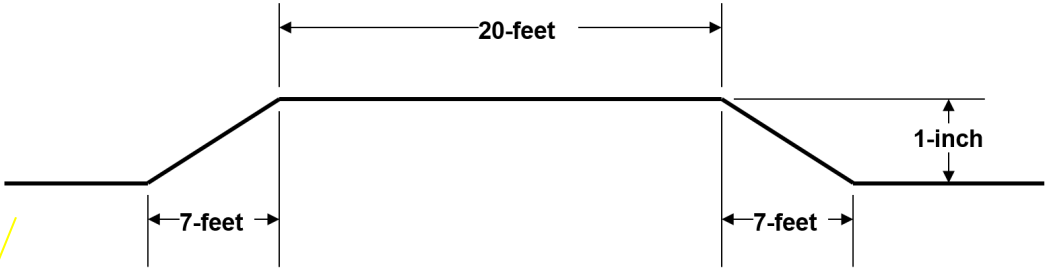
PUEBLO CHEMICAL DEPOT (17 TESTS)

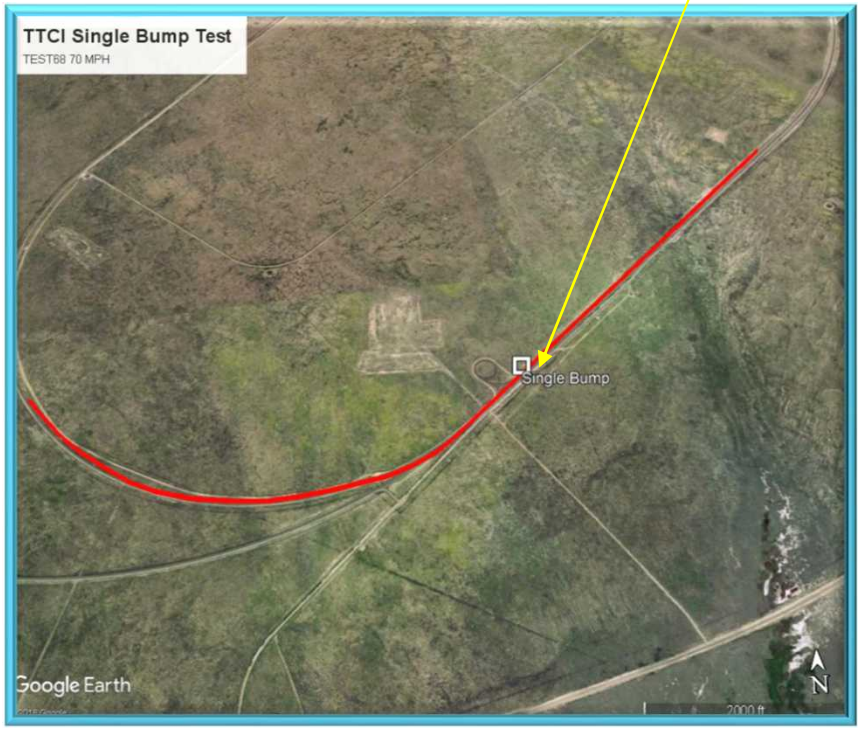
Car's performance over FRA Class-2 railroad track and tests through No. 8 turnout and No. 8 crossovers.



SINGLE BUMP (12 TESTS)

Car's performance at grade crossings



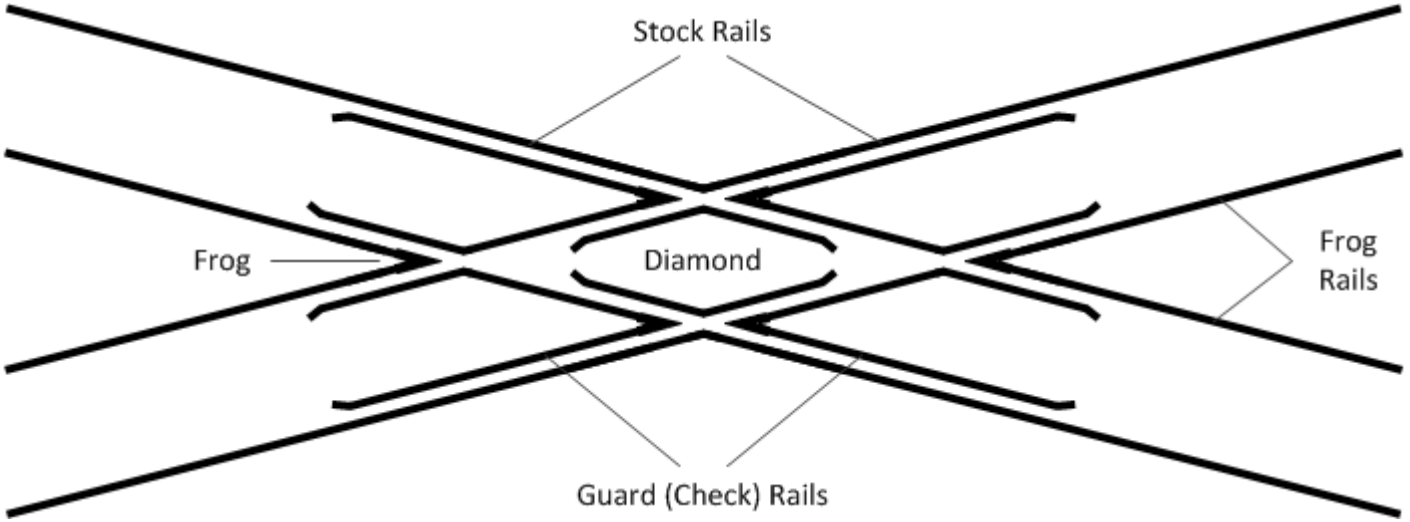


CONDUCTING SINGLE BUMP TEST

CROSSING DIAMOND (6 TESTS)

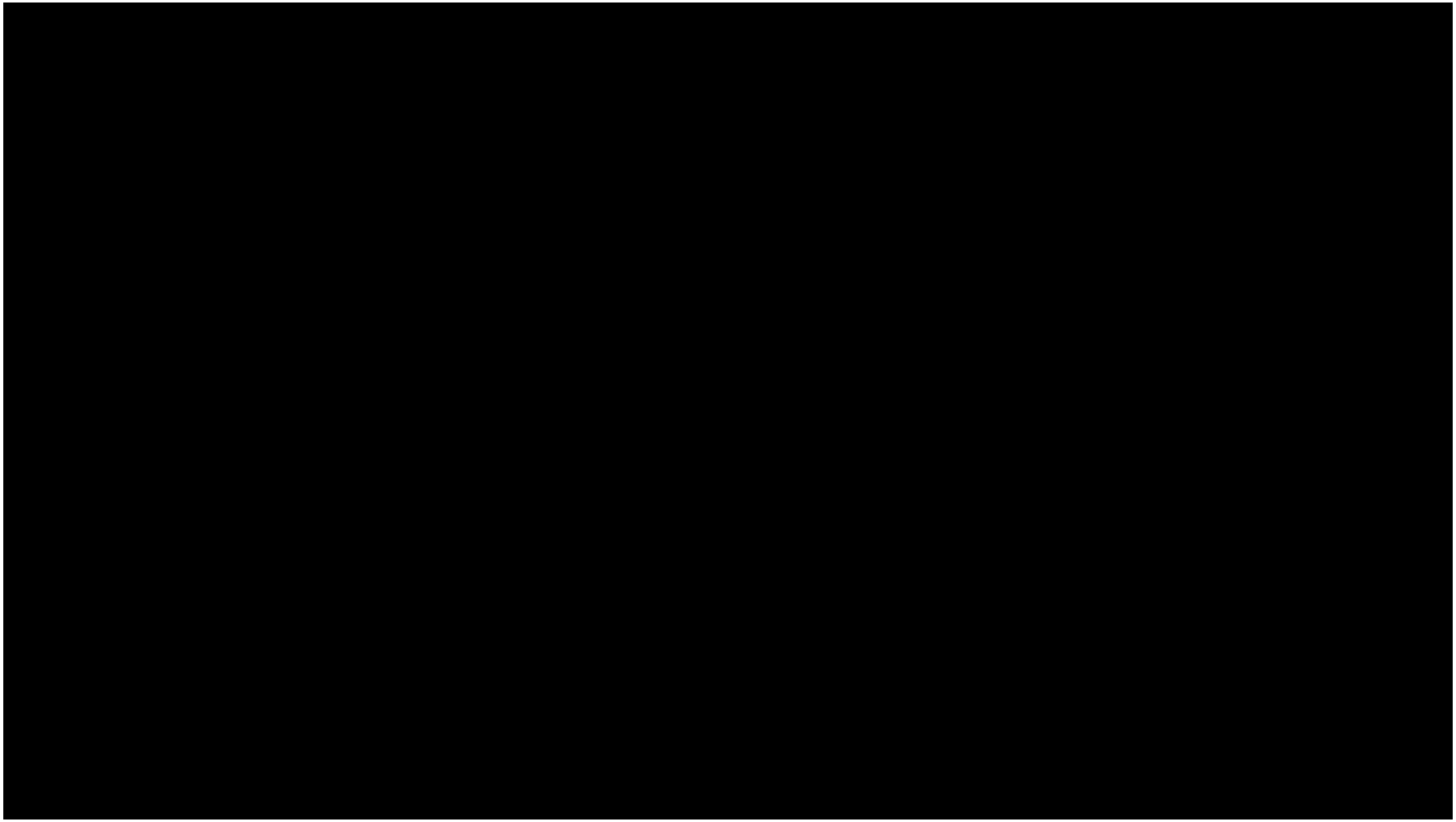
Car's behavior when crossing diamonds (or "frogs"), a leading cause of derailments.

Vertical impacts resulting from the wheels traversing gaps in the rails where tracks intersect.



The crossing diamond was simulated by cutting gaps in the rails matching the dimensions of those that would be present on an actual crossing diamond.

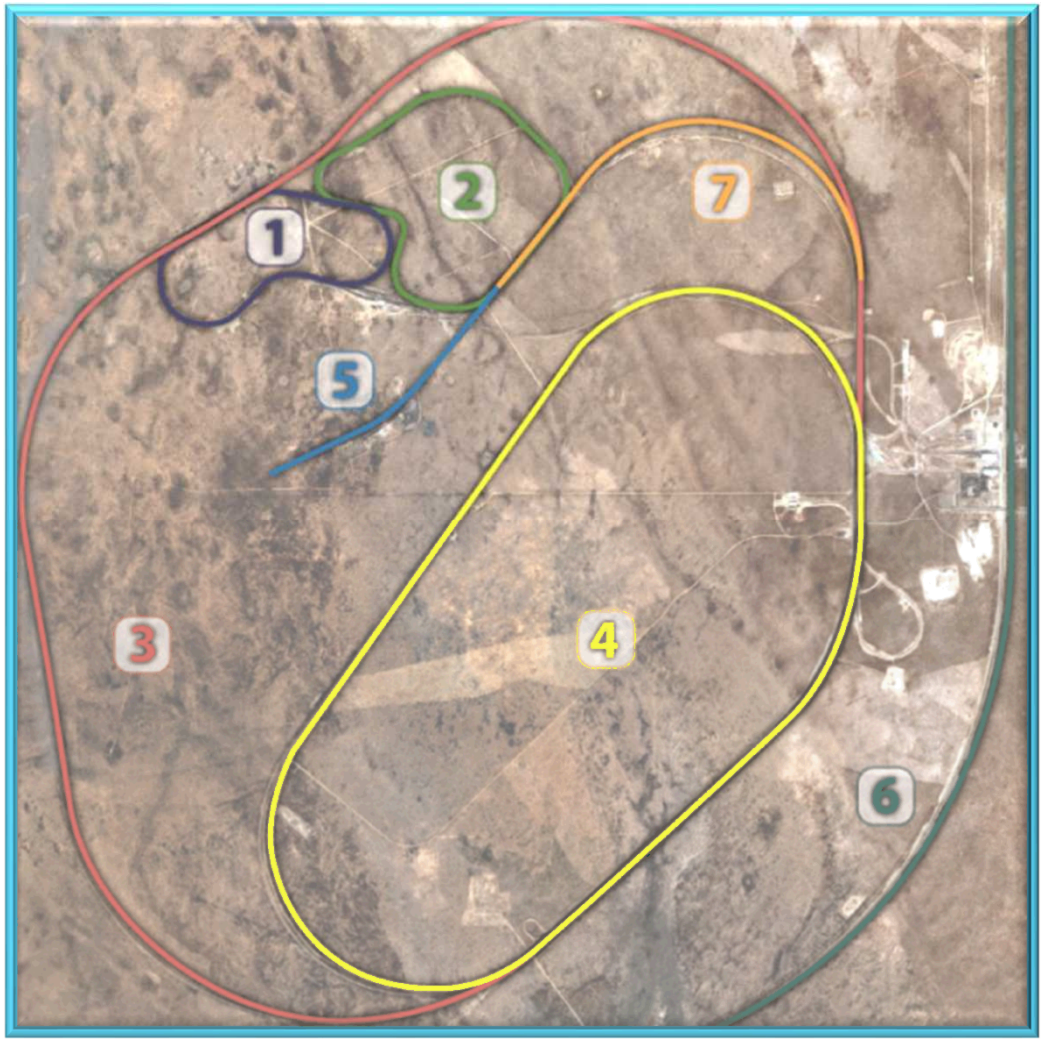
CONDUCTING CROSSING DIAMOND TEST



HUNTING HIGH SPEED STABILITY (30 TESTS)

Car's stability at 30, 40, 50-75 mph at 5 mph increments

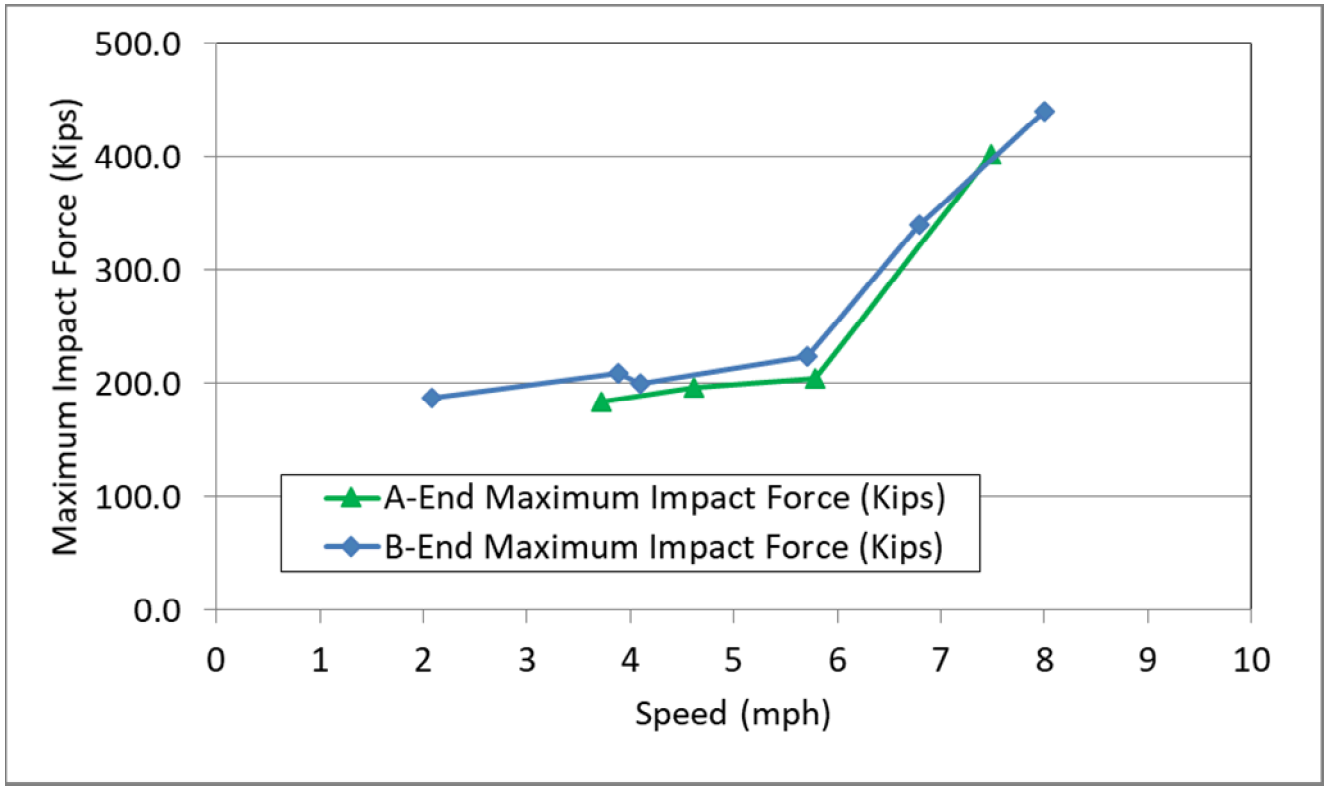
- Transit Test Track (TTT), Number 4
- Railroad Test Track (RTT), Number 3



COUPLING IMPACTS (10 TESTS)

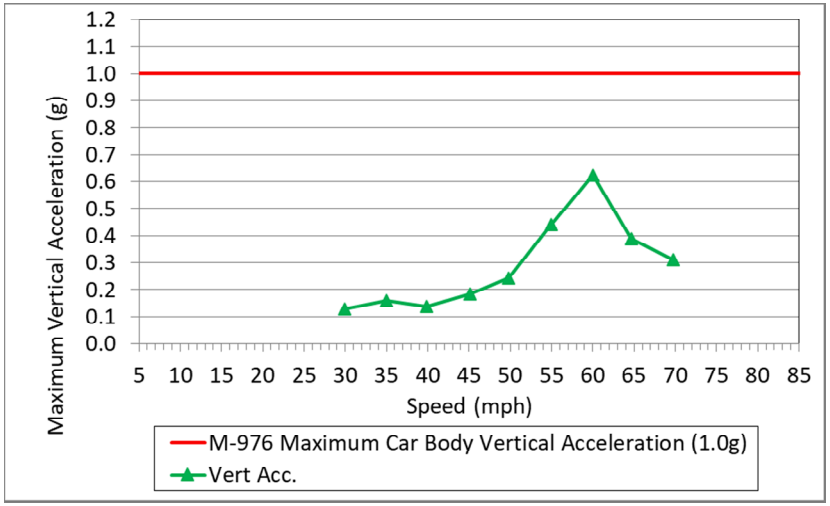
Evaluate longitudinal inputs from coupling at higher than normal speeds

Maximum Longitudinal Coupler Loads

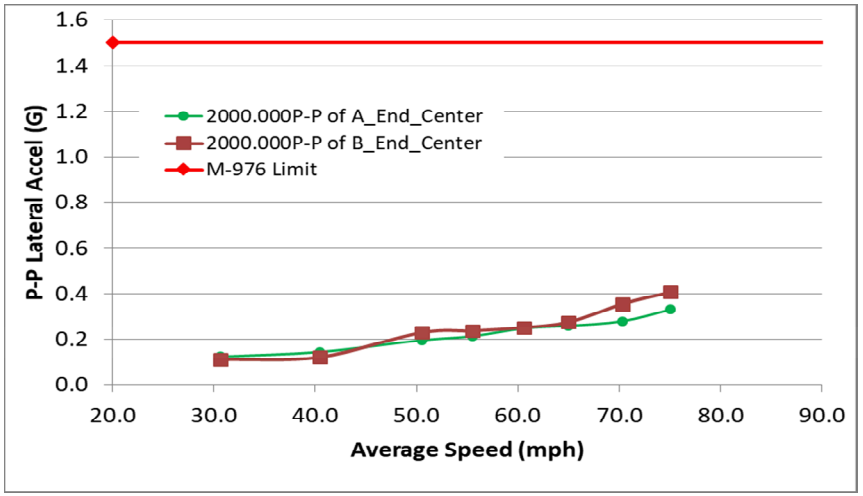


TTCI DATA SUPPORT THE AAR REQUIREMENTS

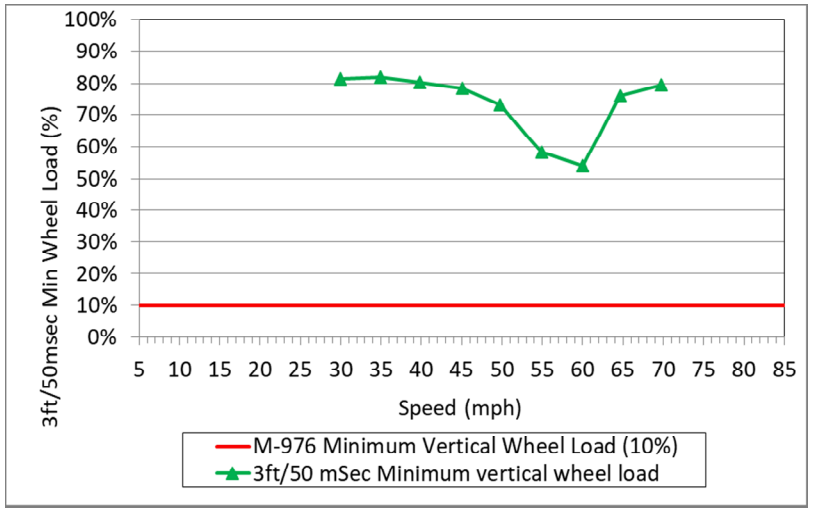
Maximum Carbody Acceleration



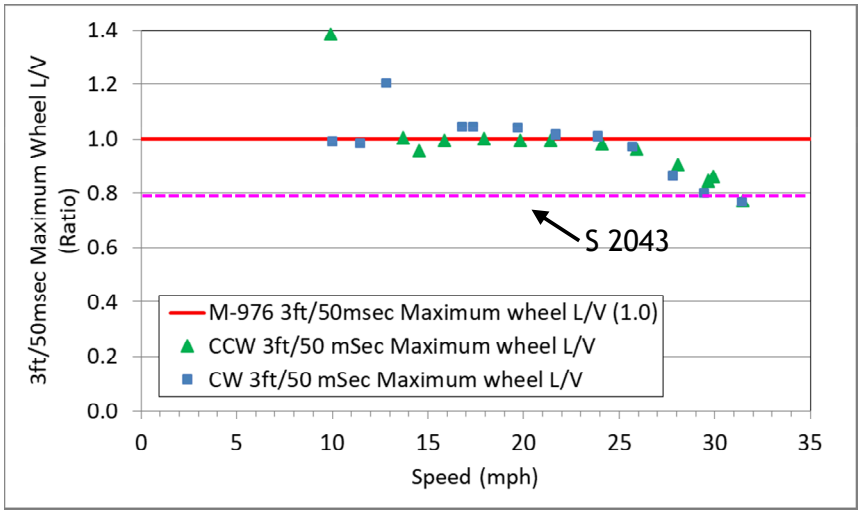
Peak to Peak Lateral Acceleration



Minimum Vertical Wheel Load

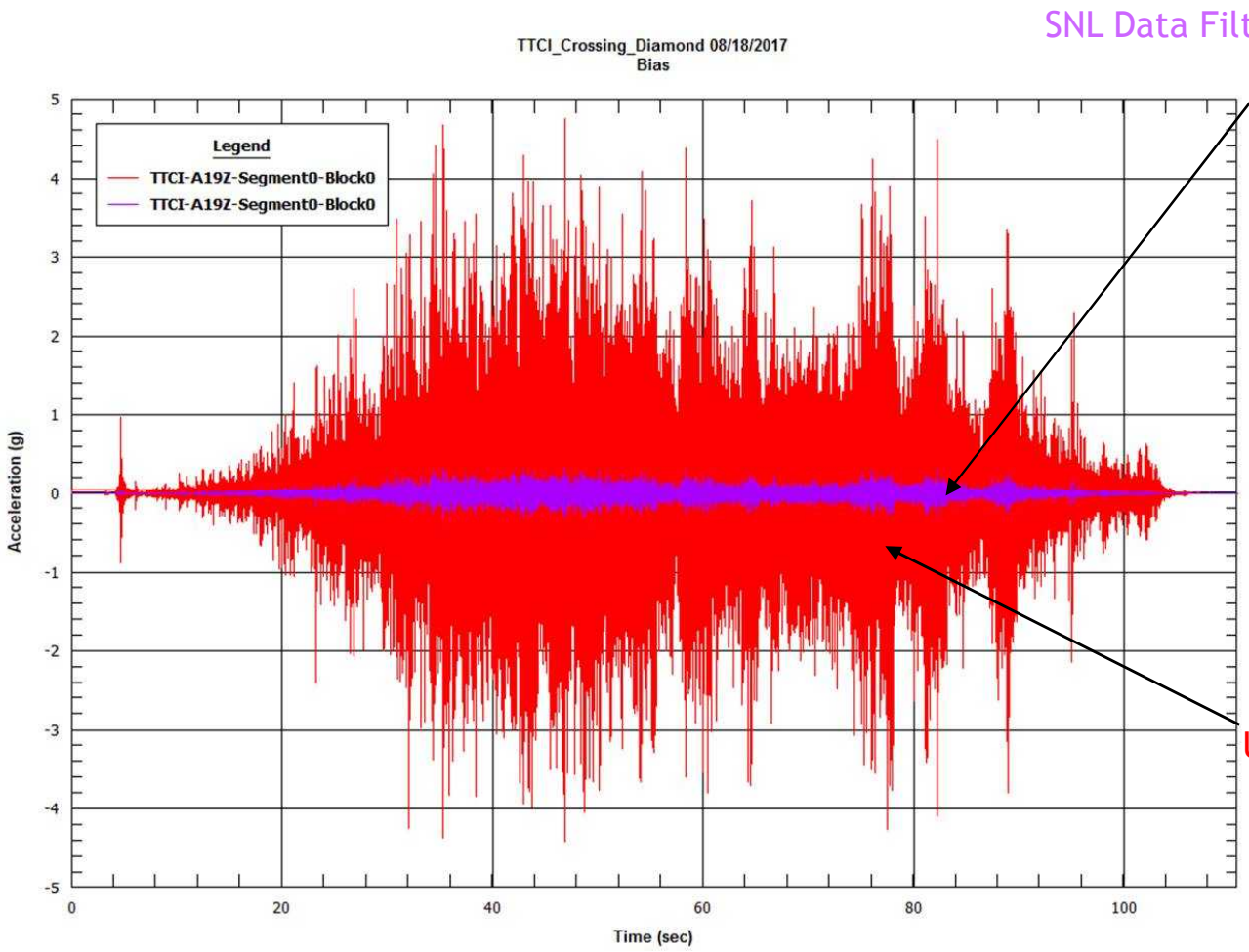


Maximum Wheel Lateral to Vertical Ratio



SNL VERSUS TTCI DATA

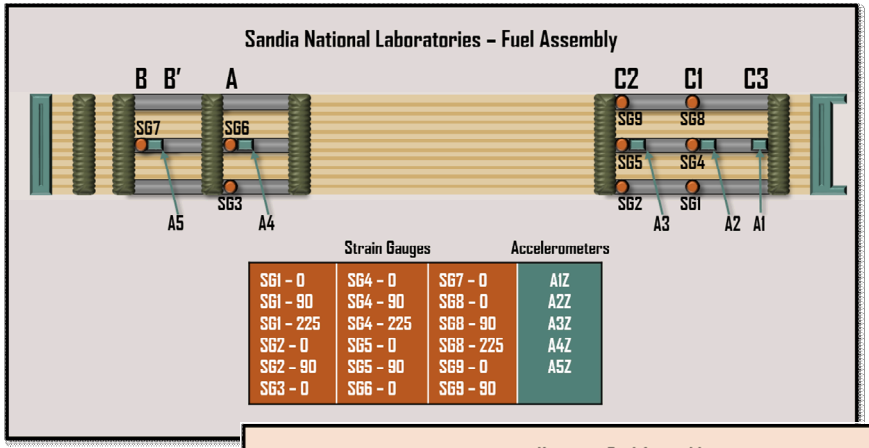
Acceleration Time History Comparison

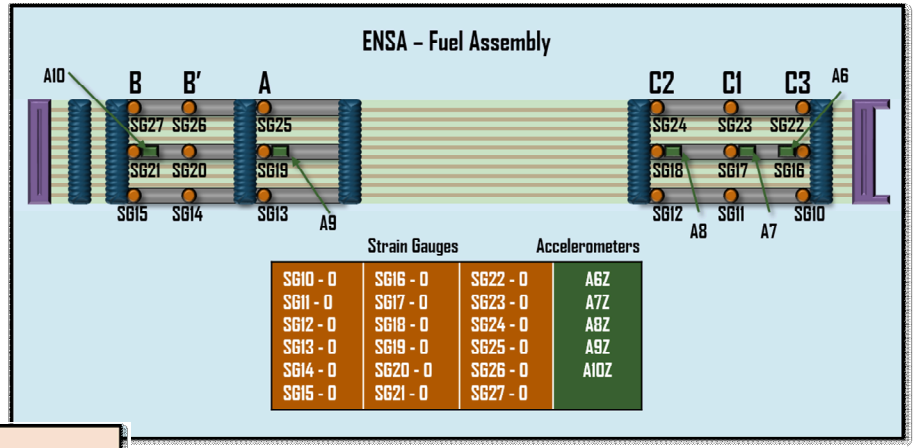


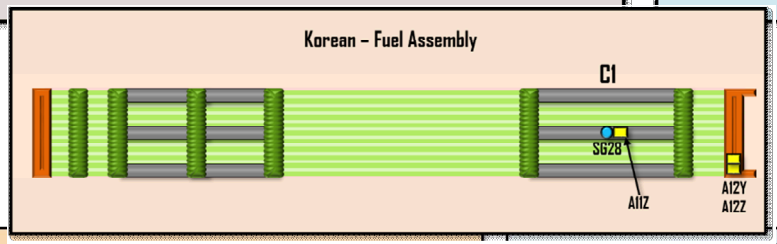
SNL Data Filtered with 15 Hz

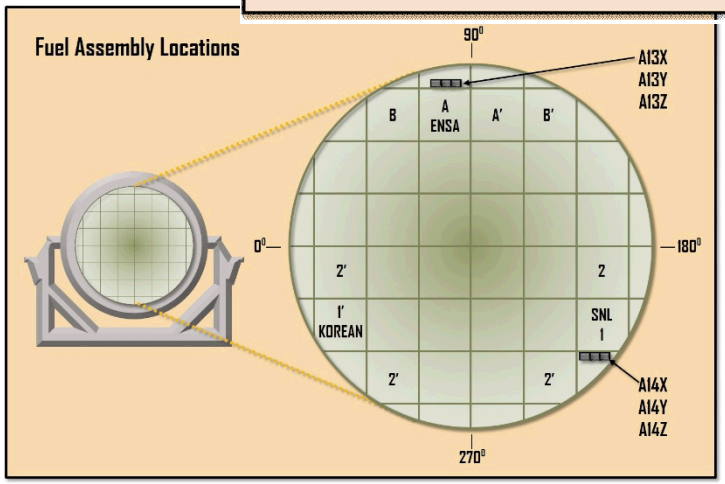
Unfiltered SNL Data

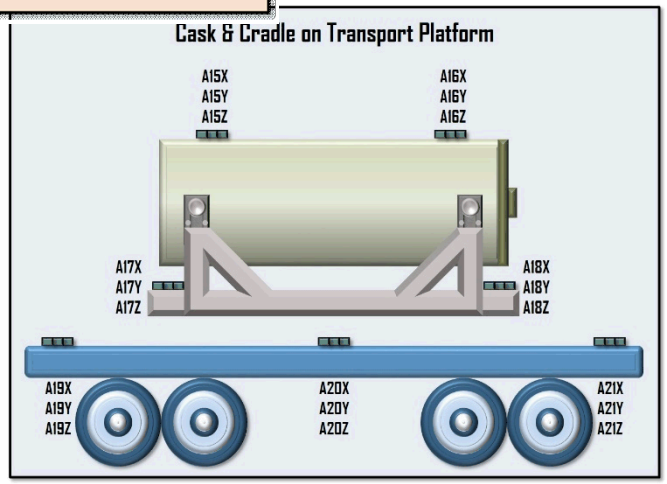
TRANSPORTATION SYSTEM INSTRUMENTATION











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

ANALYSIS METHOD

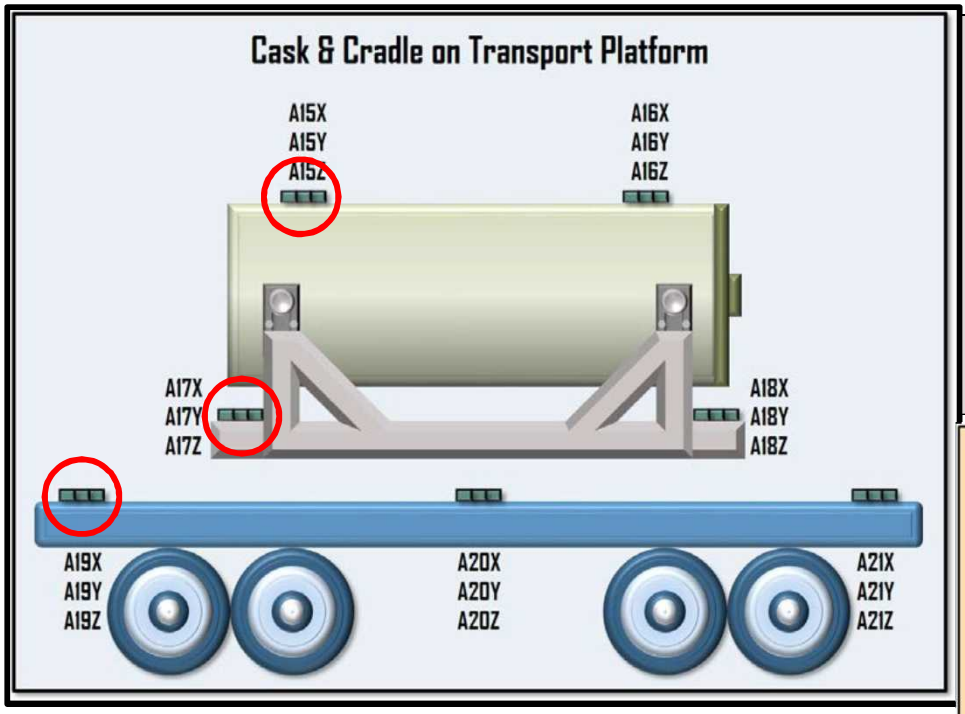
- Analyze time history *(corrected for bias)* of each sensor
- Define all shock events
- Calculate min and max acceleration and strain for each shock event
- Perform multiple comparisons of time histories and SRSs to define relationships between different systems *(transportation platform, cradle, basket, cask, assemblies)*
- Frequency analysis: FFT and PSD
- Attenuation and amplification in the system
- Develop conclusions regarding system behavior

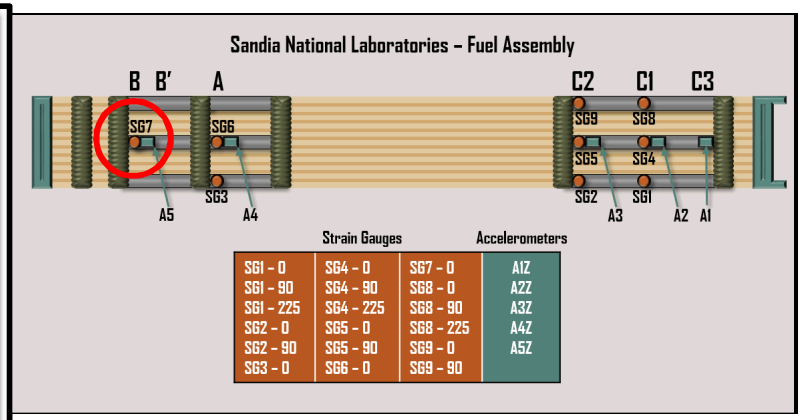
SNL Software Package K2

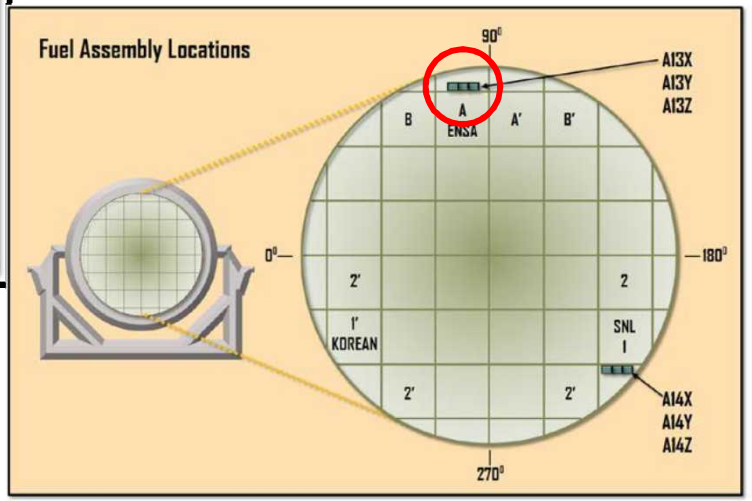
- Processing of very large data arrays
- Infinite Impulse Response (IIR) filters
- Finite Impulse Response (FIR) filters
- Fast Fourier Transforms (**FFTs**),
- Integration, Differentiation, Force, Displacement
- Power Spectral Density (**PSD**)
- Shock Response Spectrum (**SRS**)
- Convolution

BACK END OF THE TRANSPORTATION SYSTEM

Components Compared – A5Z, A13Z, A15Z, A17Z, A19Z

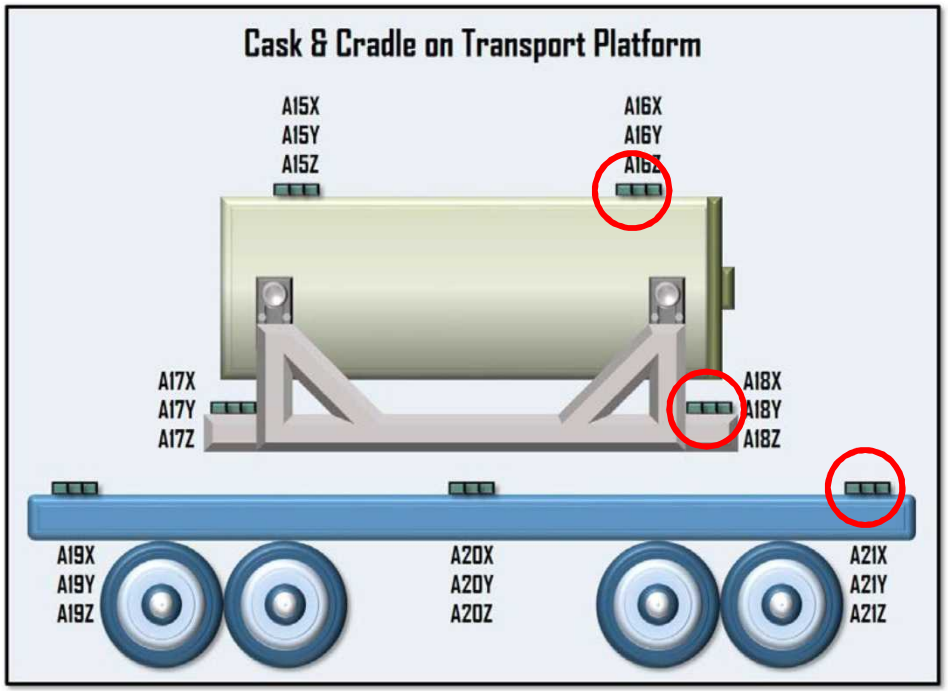


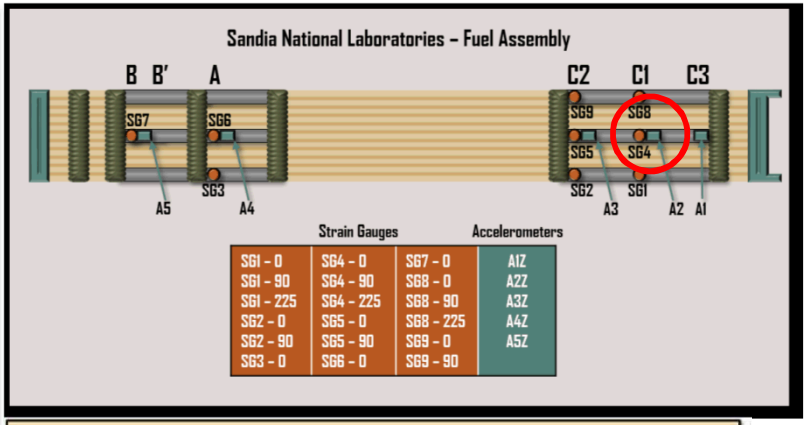


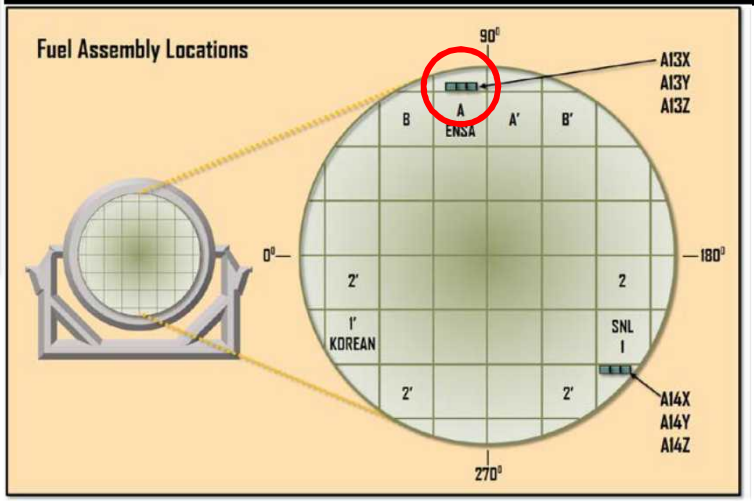


FRONT END OF THE TRANSPORTATION SYSTEM

Components Compared – A21Z, A18Z, A16Z, A13Z, A2Z

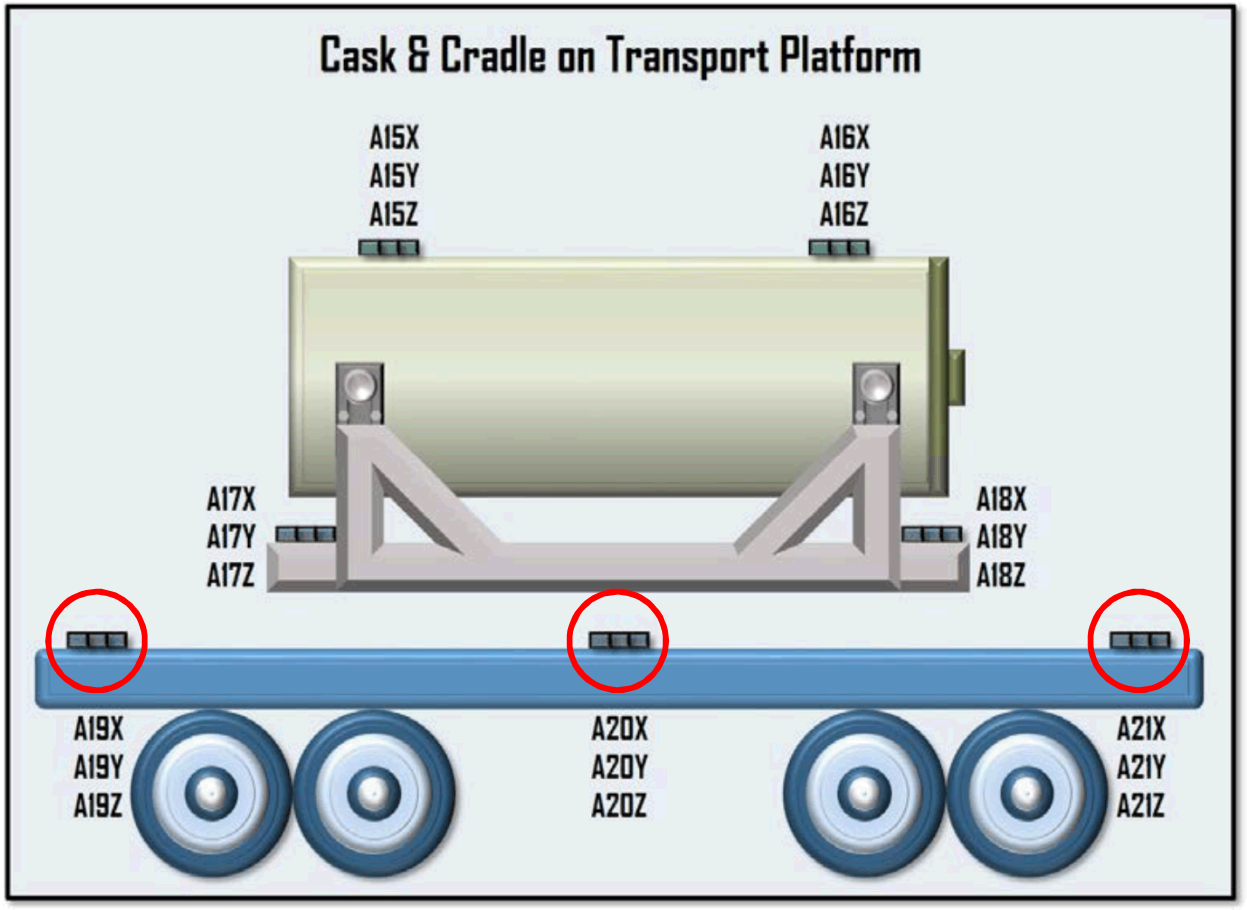






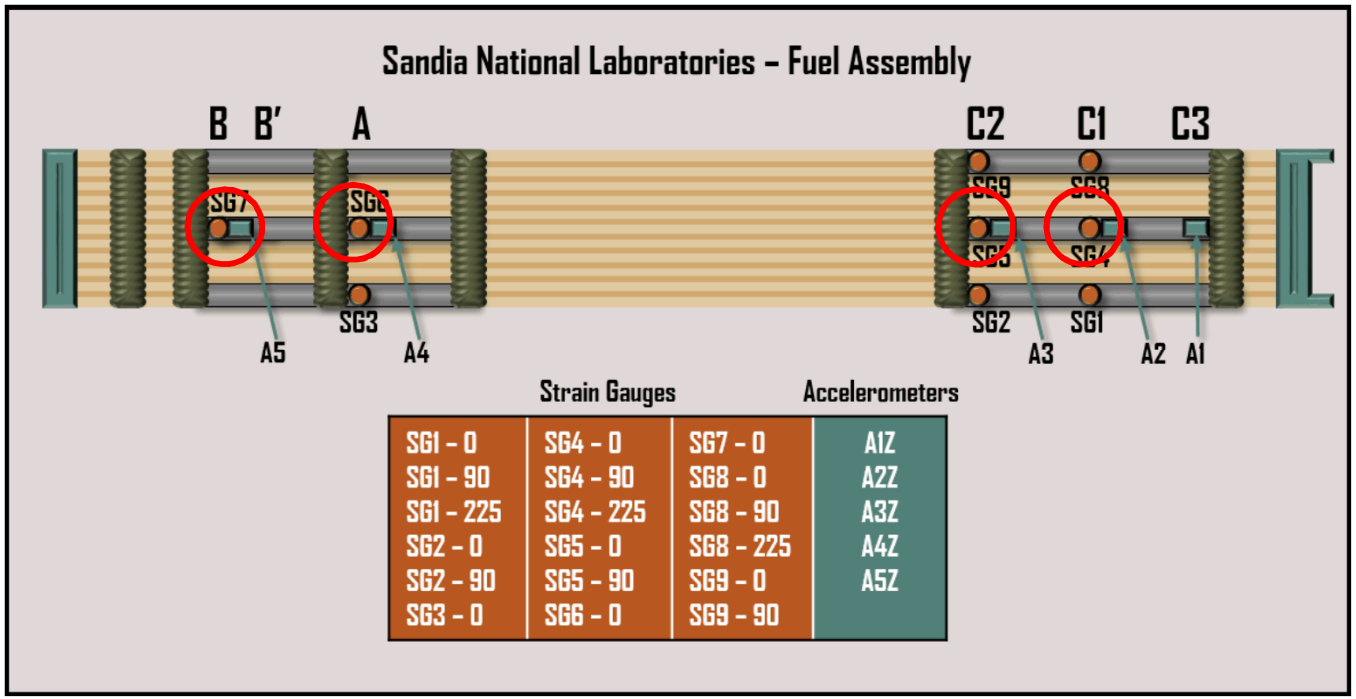
TRANSPORTATION PLATFORM

Components Compared – A19Z, A20Z, A21Z



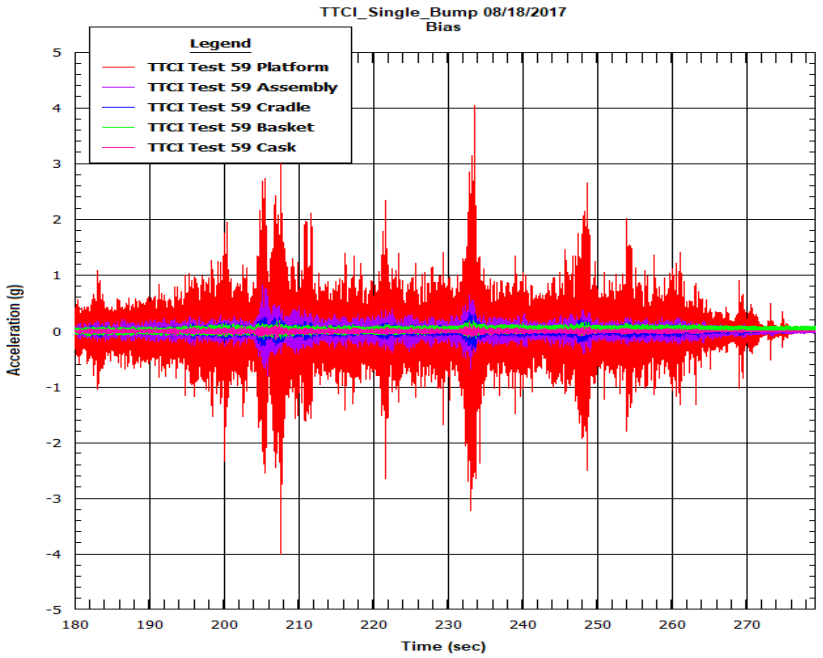
SNL ASSEMBLY

Components Compared – SG 4-0, SG 5-0, SG 6-0, SG 7-0

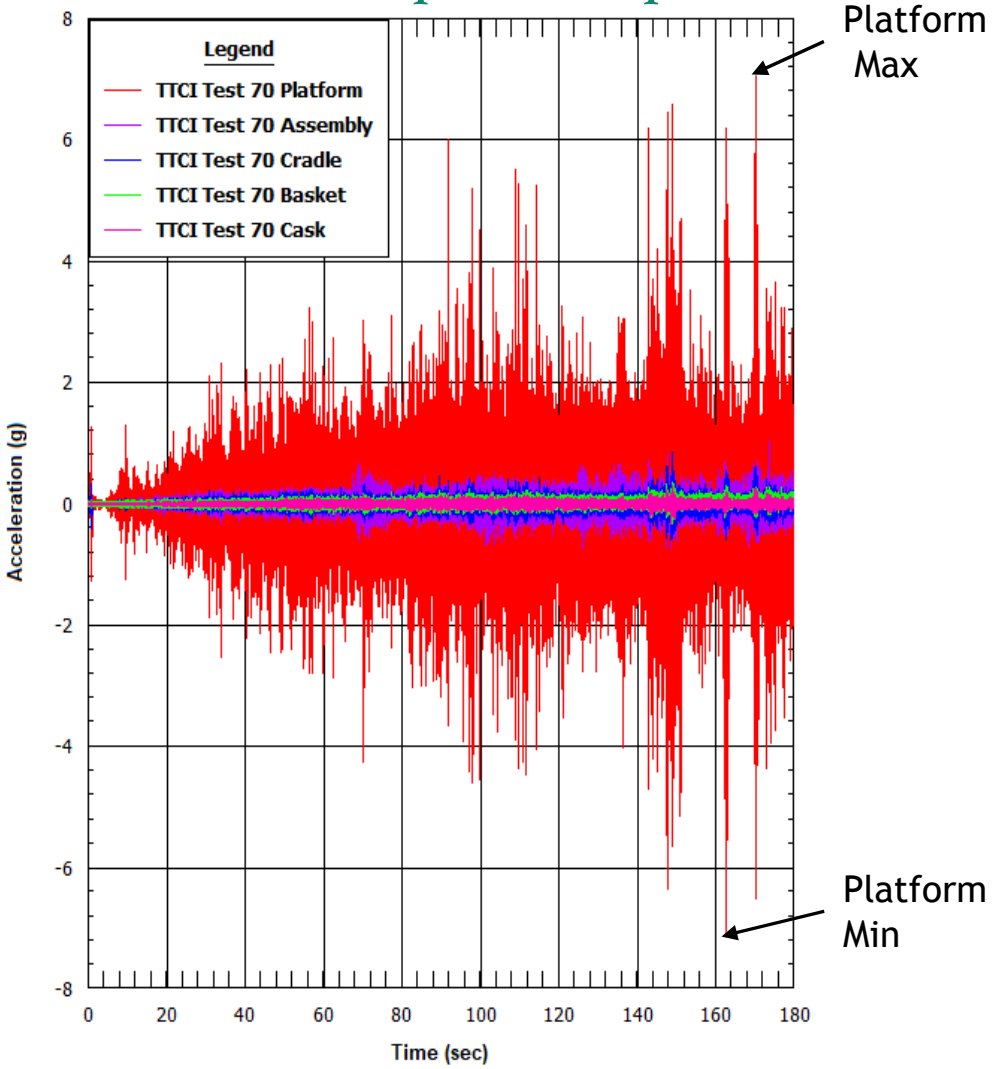


SINGLE BUMP BIASED TIME HISTORIES

Test 59: Speed 40 mph

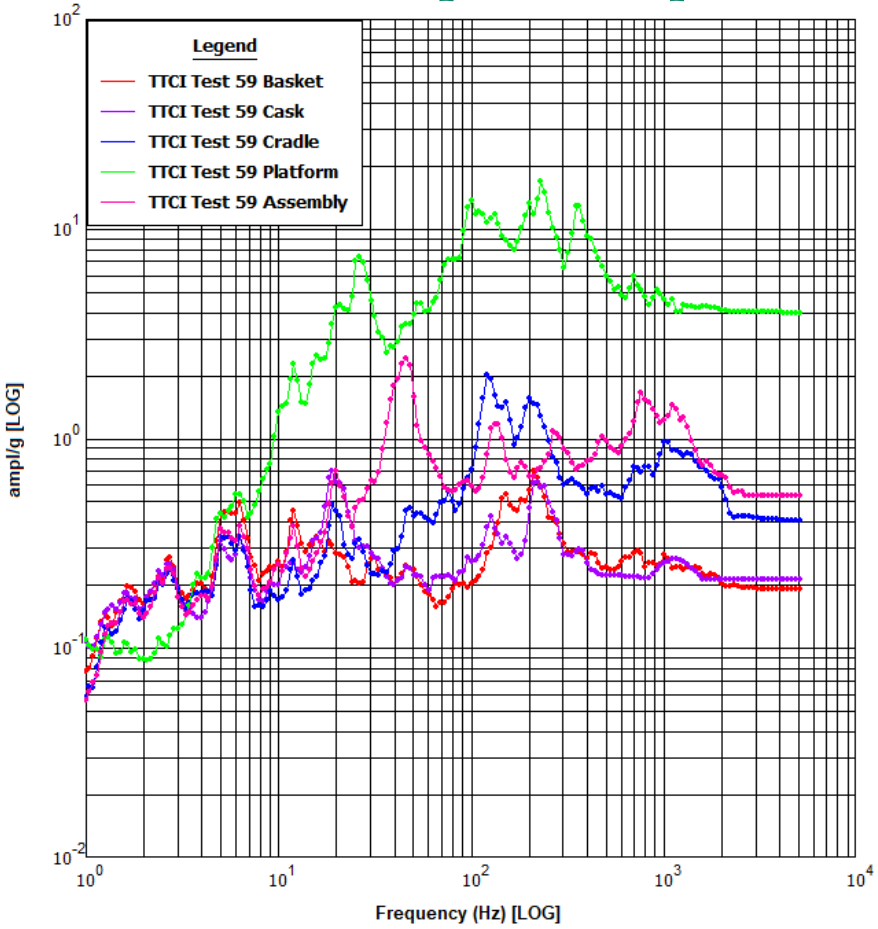


Test 70: Speed 75 mph

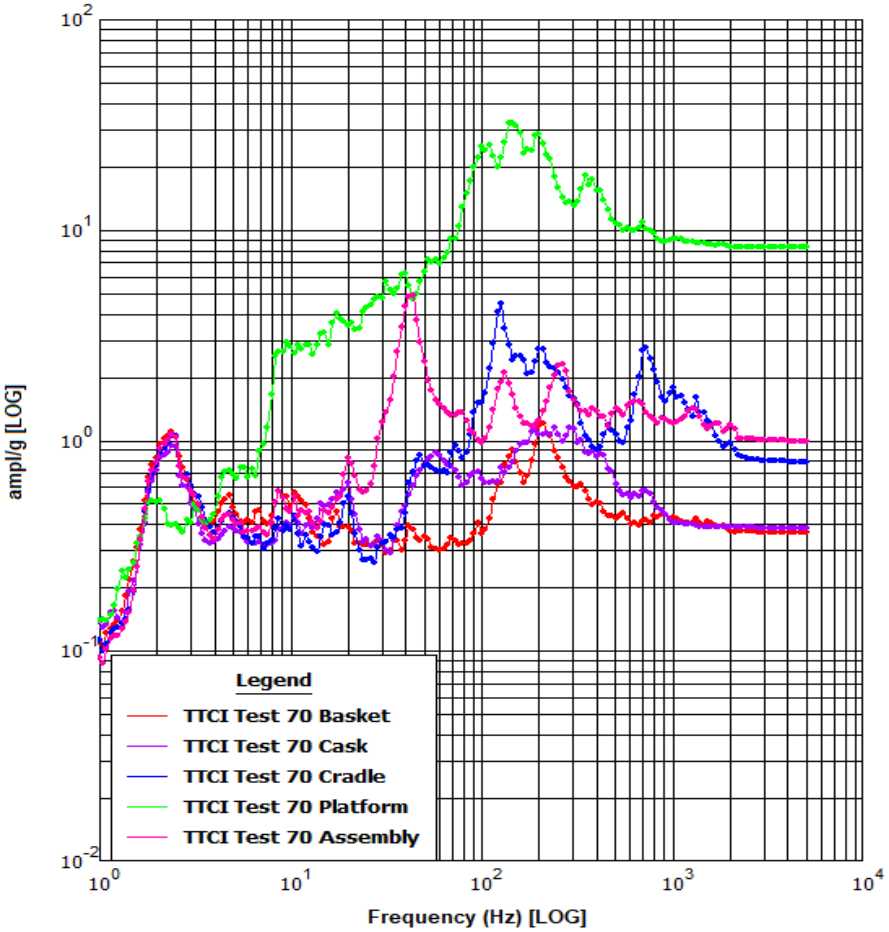


VERTICAL ACCELERATIONS IN THE SYSTEM

Test 59: Speed 40 mph

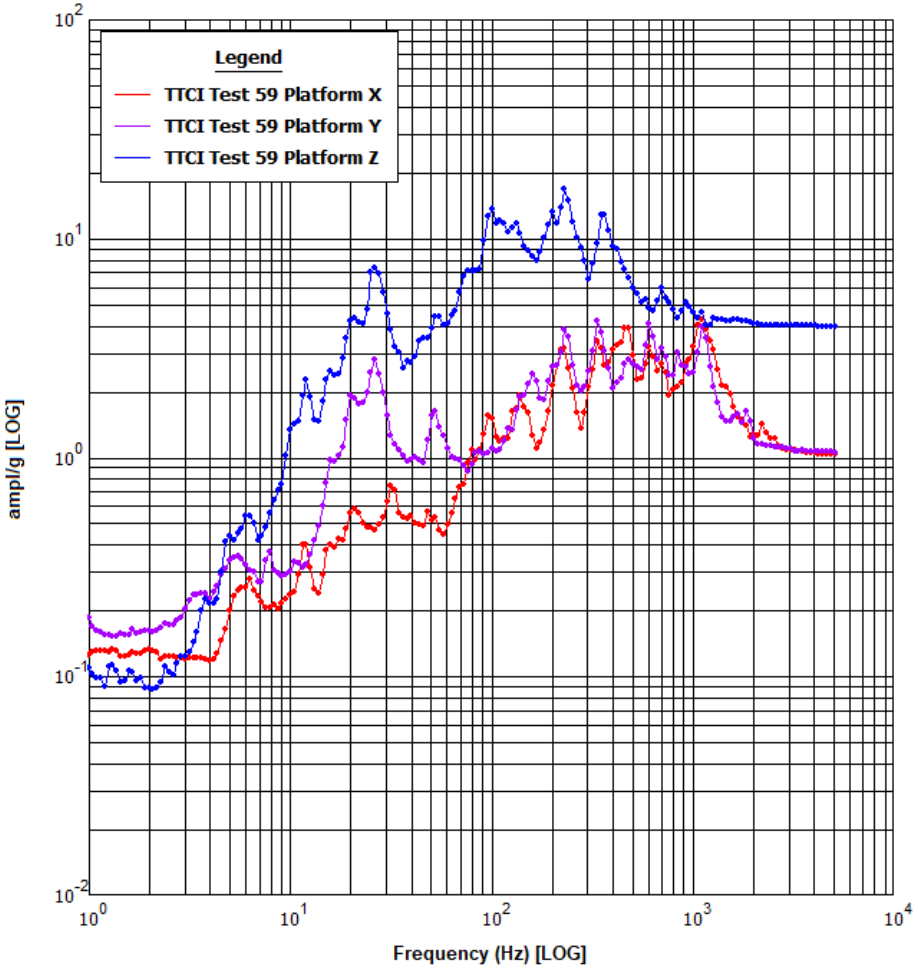


Test 70: Speed 75 mph

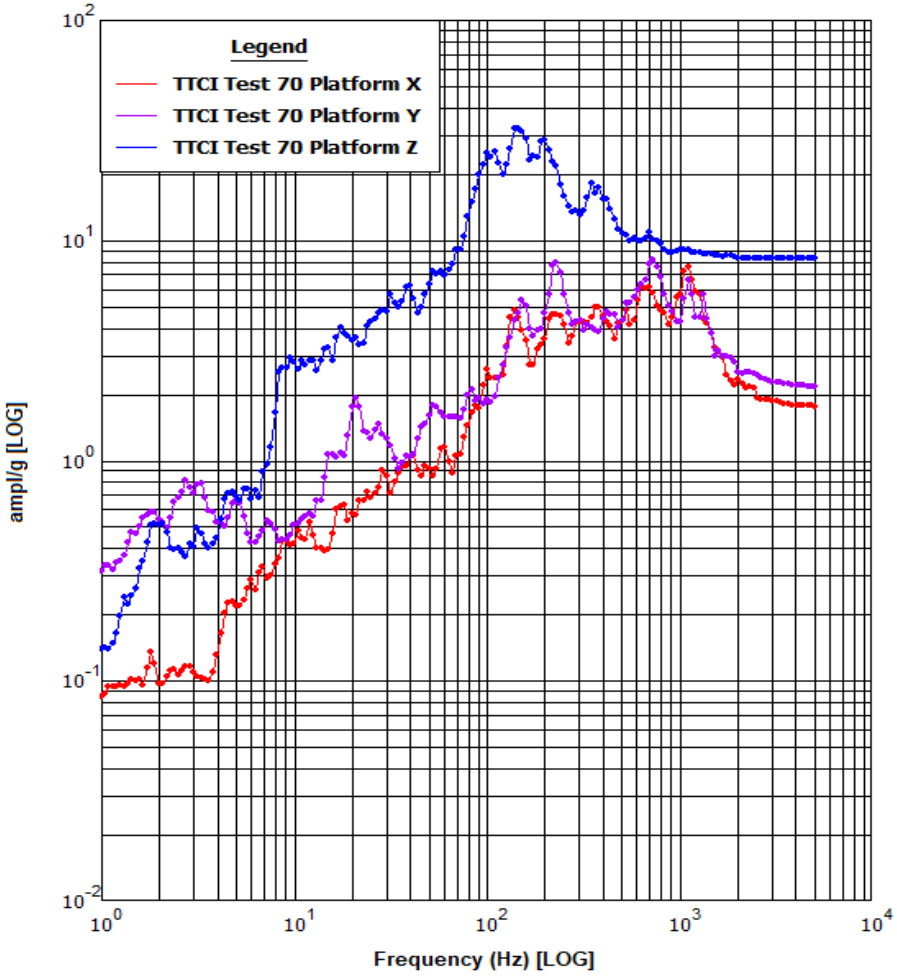


PLATFORM X, Y, Z ACCELERATIONS

Test 59: Speed 40 mph

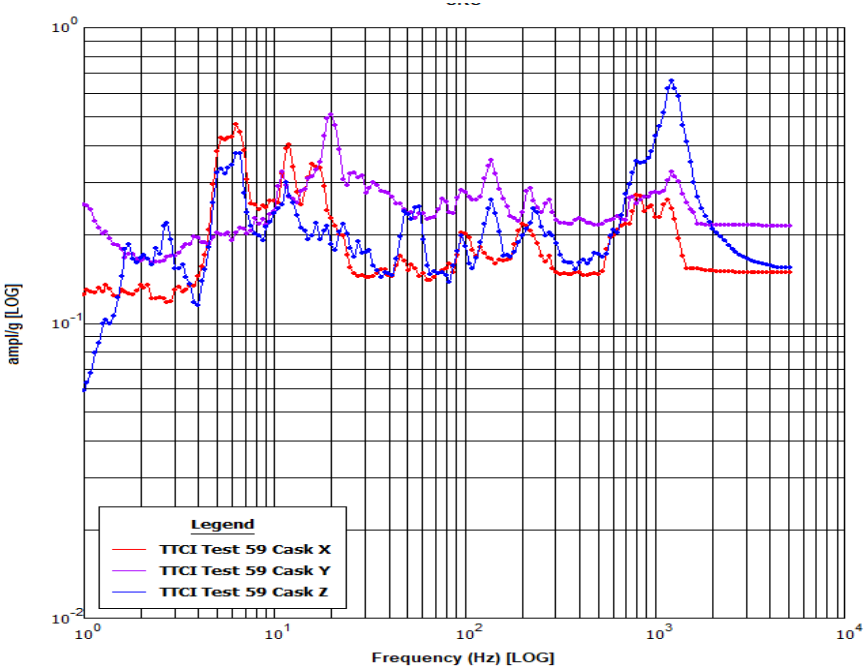


Test 70: Speed 75 mph

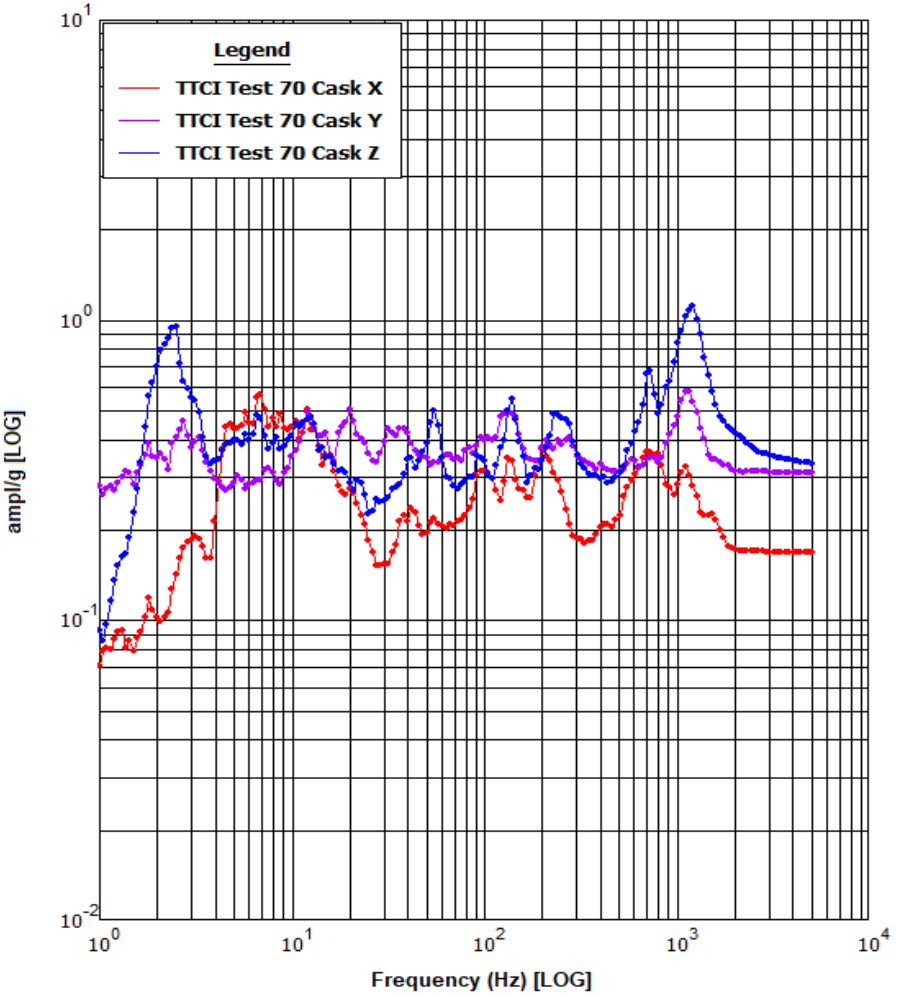


CASK X, Y, Z ACCELERATIONS

Test 59: Speed 40 mph

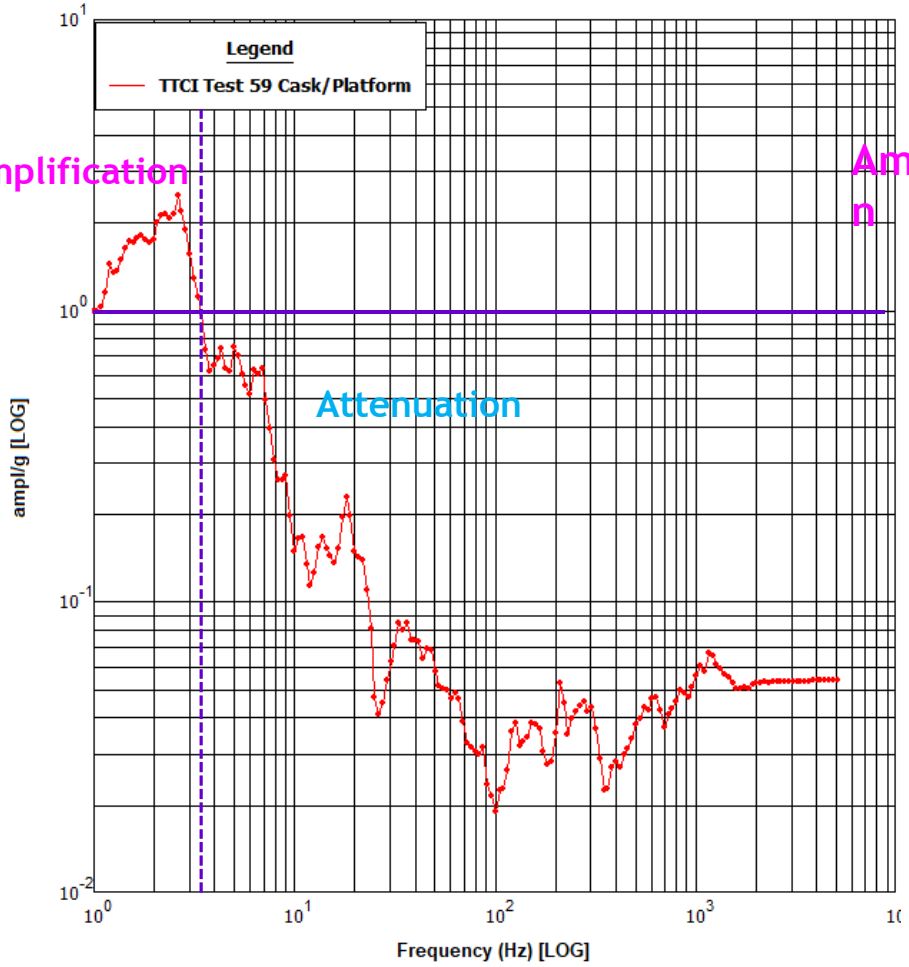


Test 70: Speed 75 mph

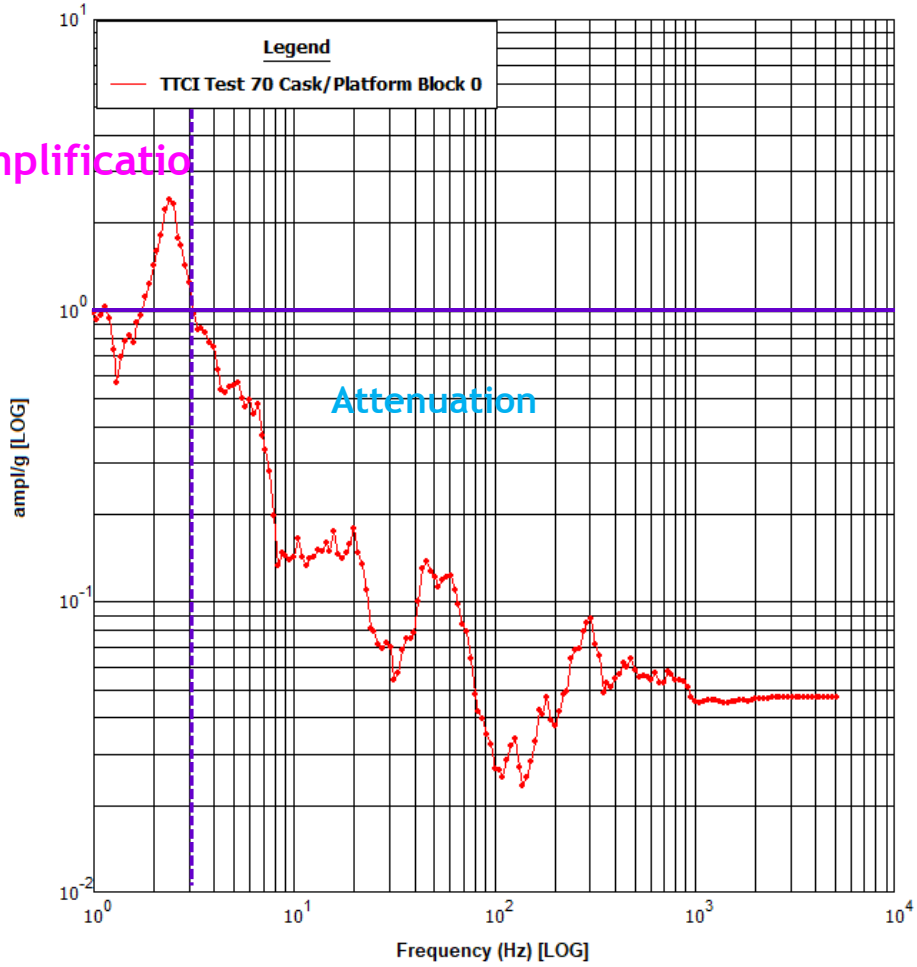


PLATFORM SRS/CASK SRS

Test 59: Speed 40 mph



Test 70: Speed 75 mph

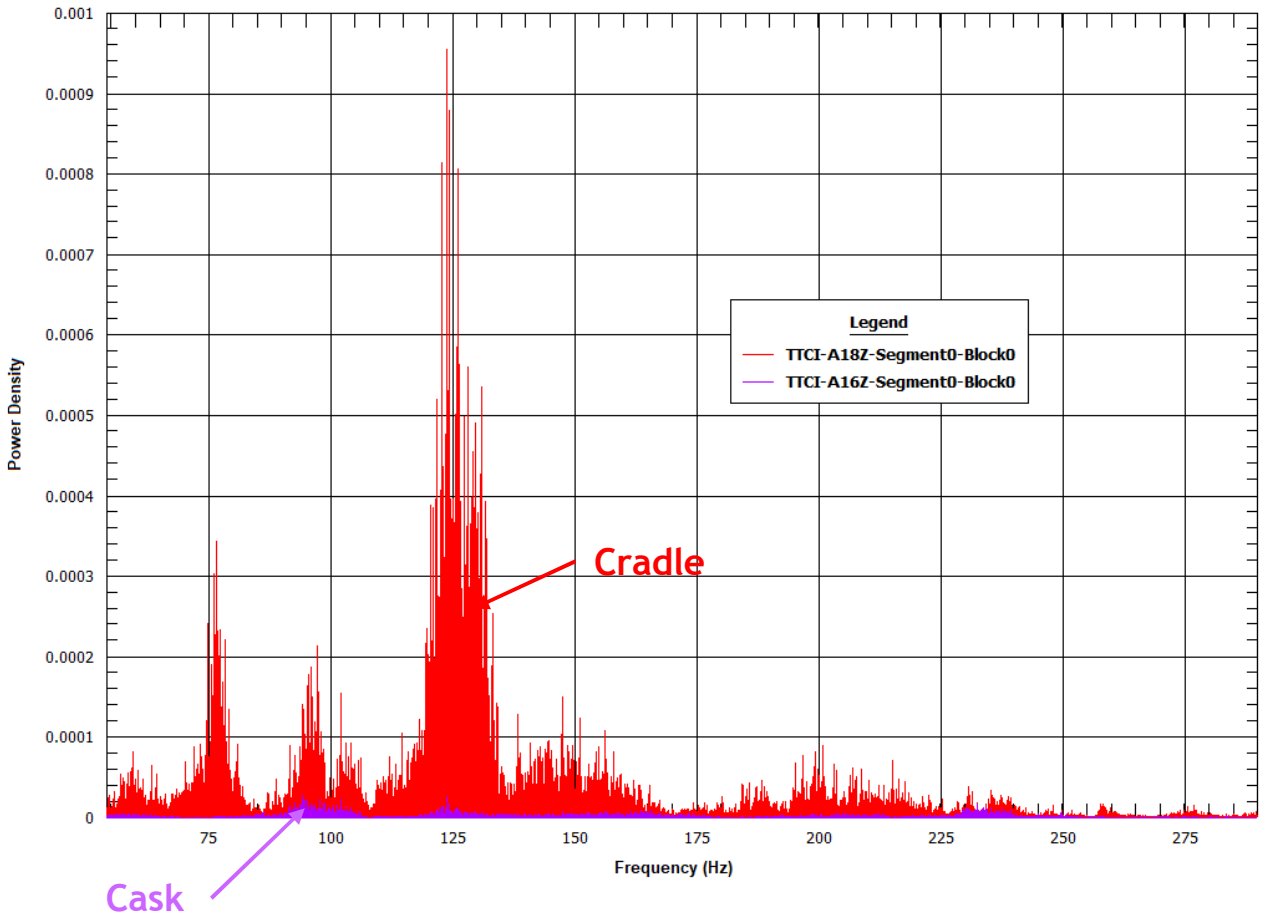


ACCELERATION CORRELATION MATRIX

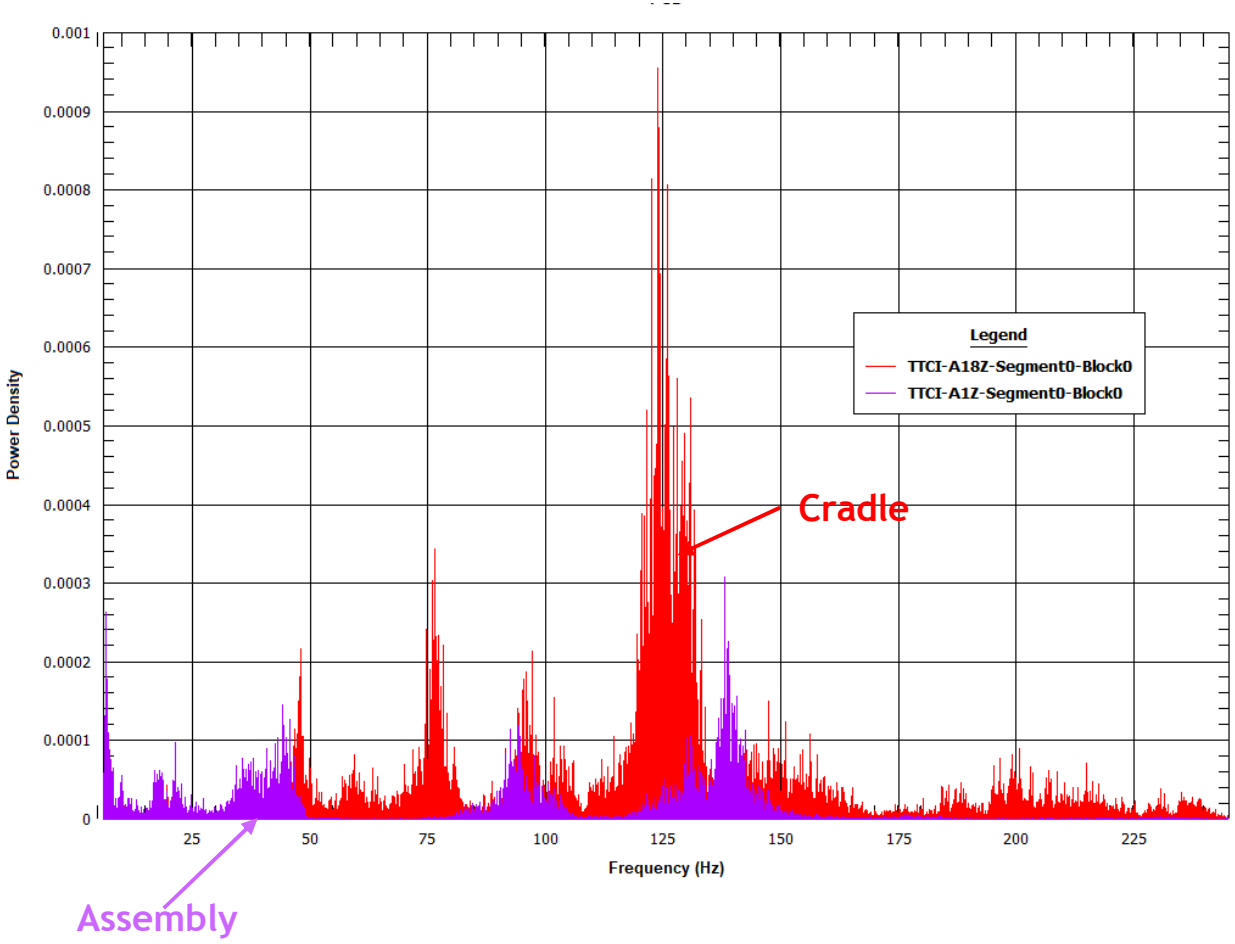
	A1Z	A2Z	A3Z	A4Z	A5Z
A1Z	1.00	0.57	0.29	0.16	-0.10
A2Z	0.57	1.00	0.41	0.15	-0.20
A3Z	0.29	0.41	1.00	-0.04	-0.06
A4Z	0.16	0.15	-0.04	1.00	0.10
A5Z	-0.10	-0.20	-0.06	0.10	1.00
A6Z	0.29	0.40	0.27	0.07	-0.05
A7Z	0.26	0.46	0.28	0.10	-0.14
A8Z	0.40	0.49	0.36	0.10	-0.17
A9Z	-0.00	-0.01	0.00	0.02	-0.20
A10Z	0.00	0.05	0.05	0.07	-0.21
A11Z	0.15	0.10	0.12	-0.02	-0.09
A12Y	-0.03	0.01	-0.03	-0.02	0.10
A12Z	-0.31	-0.11	-0.07	0.05	0.13
A13X	-0.40	-0.15	-0.22	0.04	0.06
A13Y	-0.08	-0.02	-0.00	0.04	-0.06
A13Z	0.49	0.19	0.29	0.02	-0.02
A14X	-0.09	-0.04	-0.06	-0.00	-0.00
A14Y	0.06	0.06	0.04	0.05	0.05
A14Z	0.00	-0.02	-0.00	-0.01	-0.00
A15X	-0.47	-0.19	-0.26	0.07	0.11
A15Y	0.04	0.01	0.06	0.06	0.05
A15Z	-0.24	-0.11	-0.12	0.12	0.18
A16X	-0.45	-0.17	-0.25	0.06	0.08
A16Y	-0.01	0.01	0.02	0.02	-0.00
A16Z	0.43	0.15	0.26	0.04	0.02
A17X	0.09	0.05	0.07	-0.02	-0.02
A17Y	0.00	-0.03	-0.03	-0.02	0.00
A17Z	-0.13	-0.09	-0.05	0.06	0.09
A18X	0.11	0.06	0.07	0.03	-0.03
A18Y	0.02	-0.04	0.01	-0.03	-0.01
A18Z	0.26	0.23	0.24	0.03	-0.01
A19X	0.06	0.03	0.04	-0.02	-0.03
A19Y	0.03	0.04	0.04	0.03	0.01
A19Z	-0.03	-0.01	0.01	-0.02	-0.03
A20X	0.08	0.02	0.02	-0.04	-0.03
A20Y	0.02	-0.01	0.00	-0.01	0.02
A20Z	0.08	0.09	0.07	0.05	-0.00
A21X	-0.08	-0.07	-0.08	0.01	0.02
A21Y	-0.03	-0.02	-0.03	-0.01	0.01
A21Z	-0.04	-0.06	-0.07	-0.01	0.00

Correlation between front end of the cradle and front end of SNL assembly

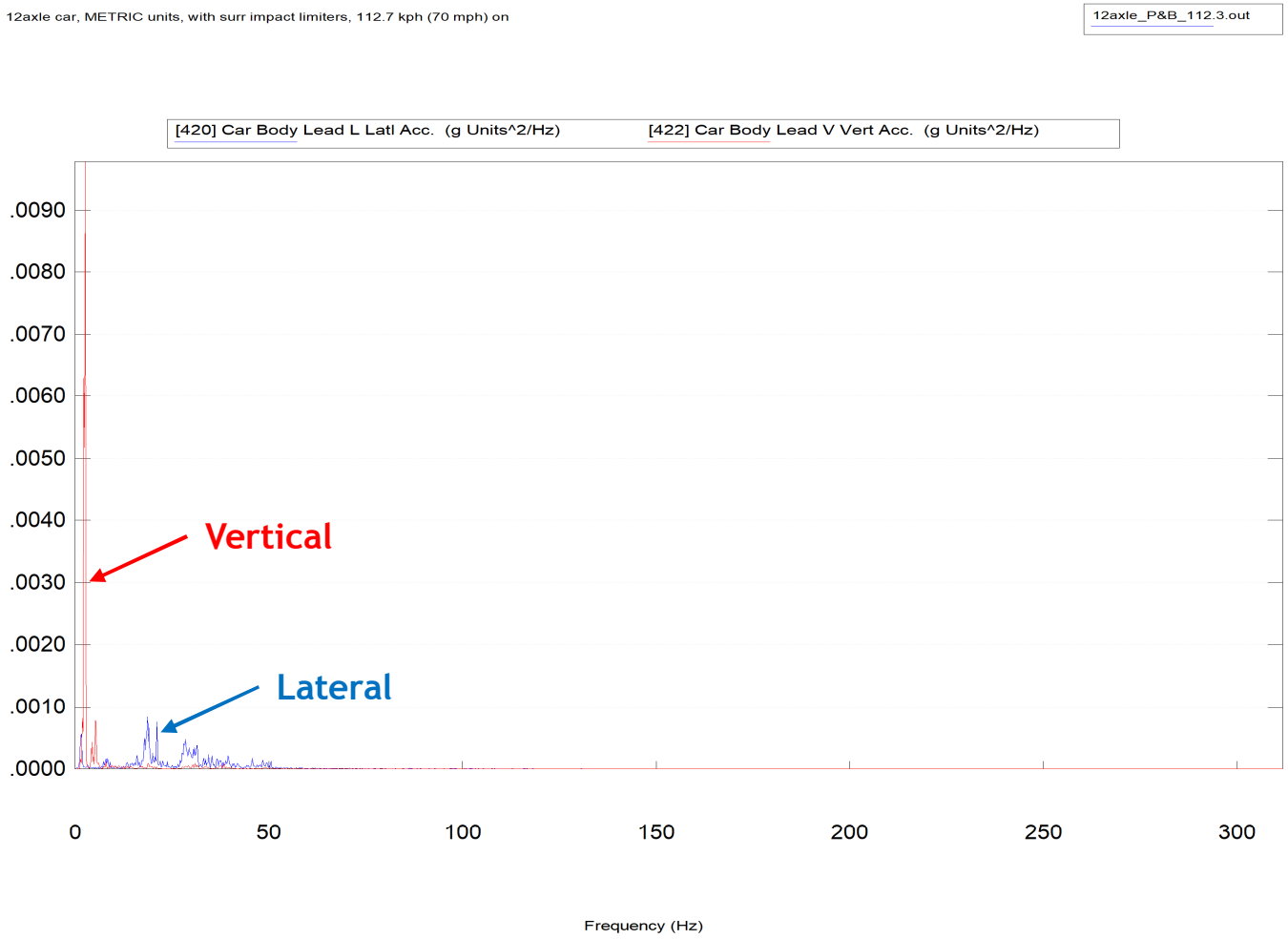
CRADLE AND CASK PDS



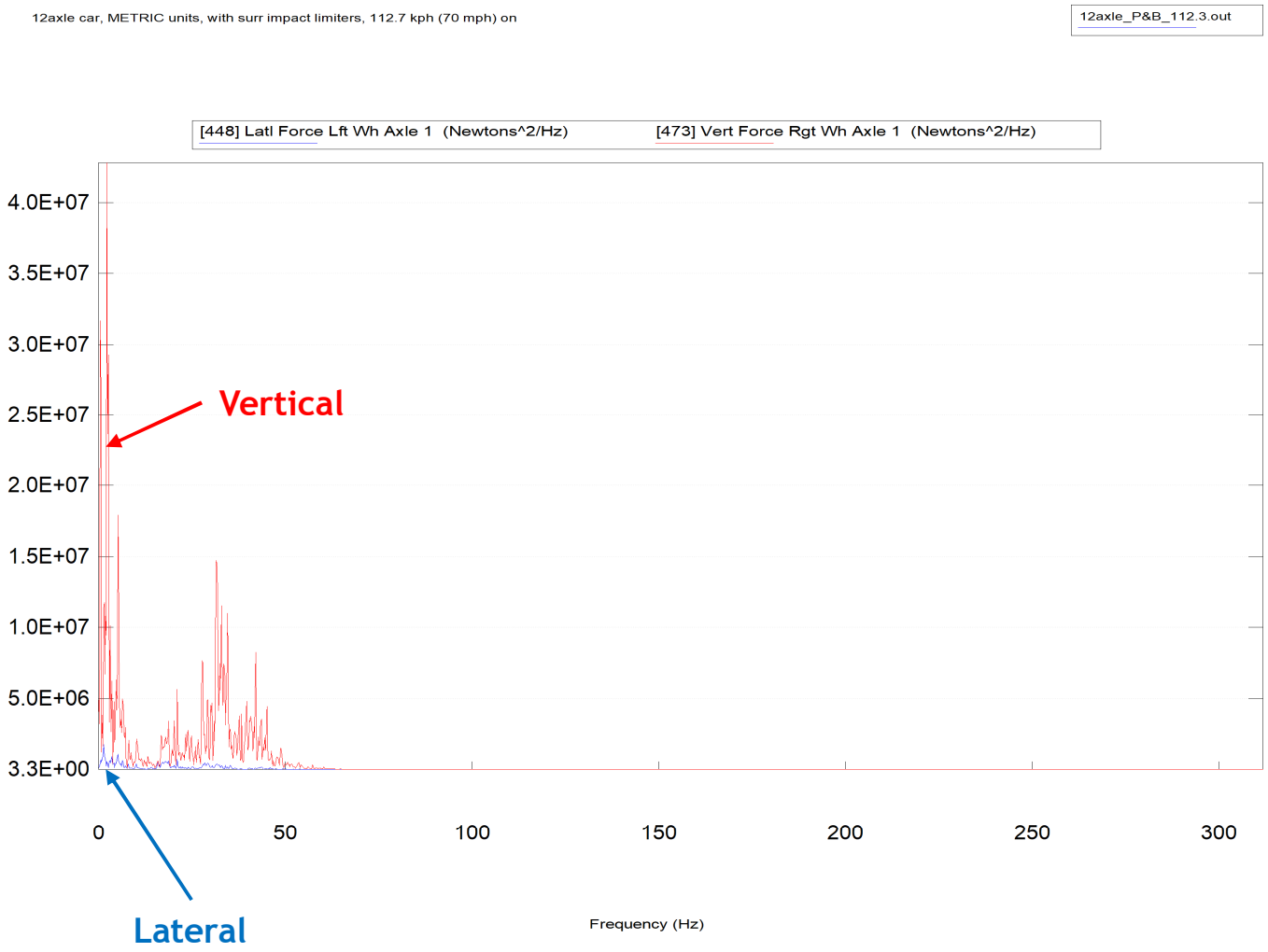
CRADLE AND SNL ASSEMBLY PDS



PLATFORM ACCELERATION PDS FROM NUCARS MODEL

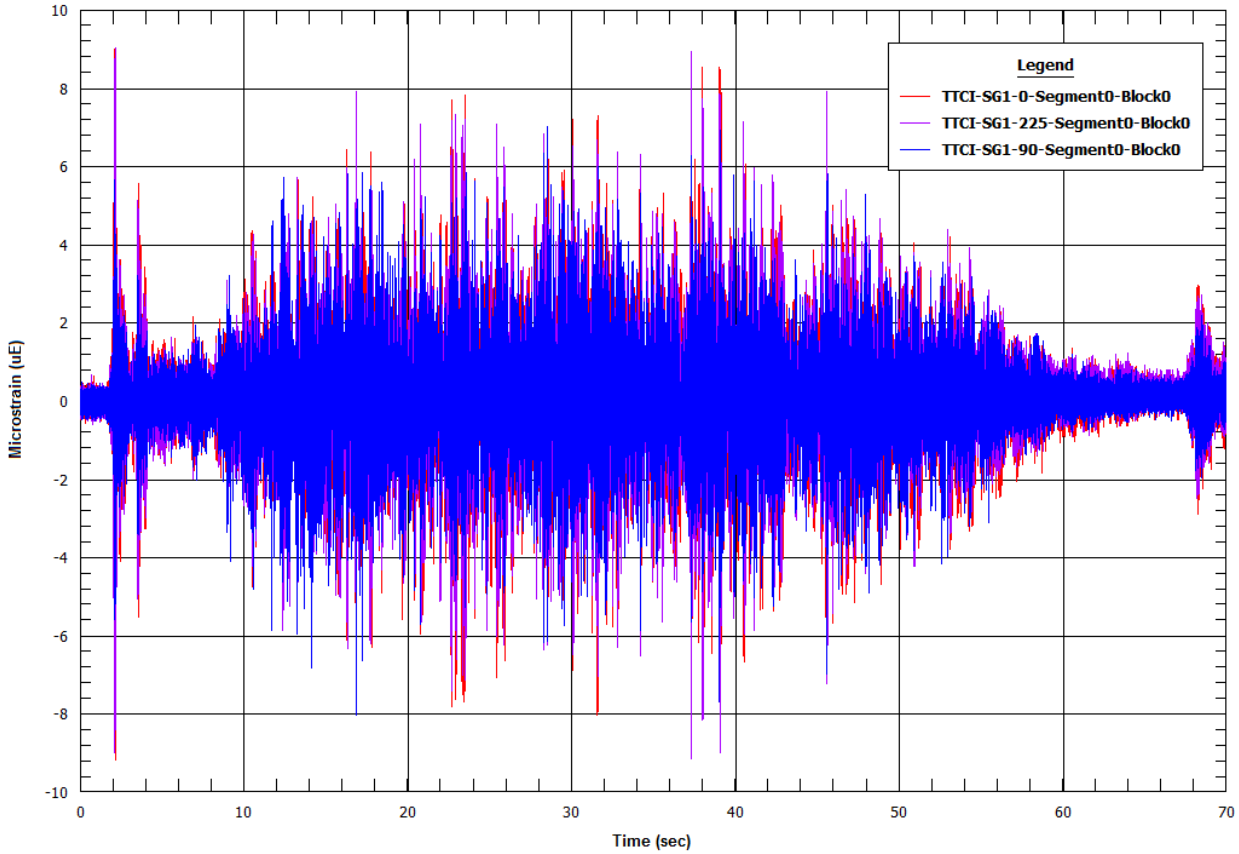


WHEEL FORCE PDS FROM NUCARS MODEL



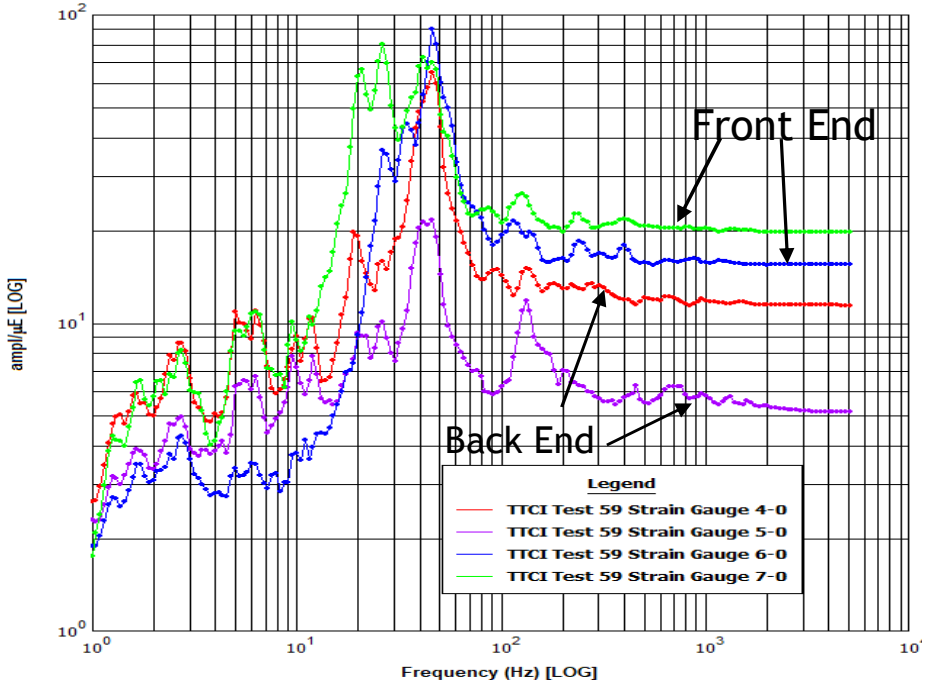
STRAINS AT 0, 90, AND 225 DEGREES

SG1-0; SG1-90, and SG1-225

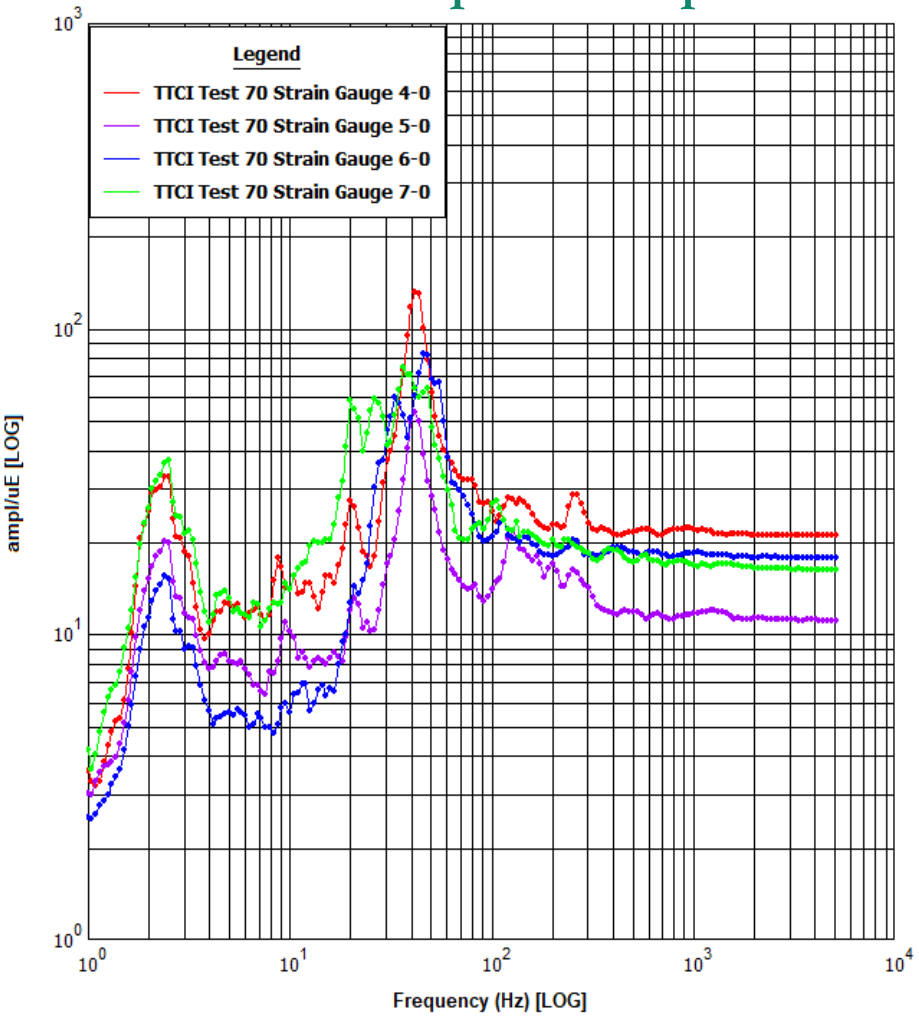


SNL ASSEMBLY STRAIN

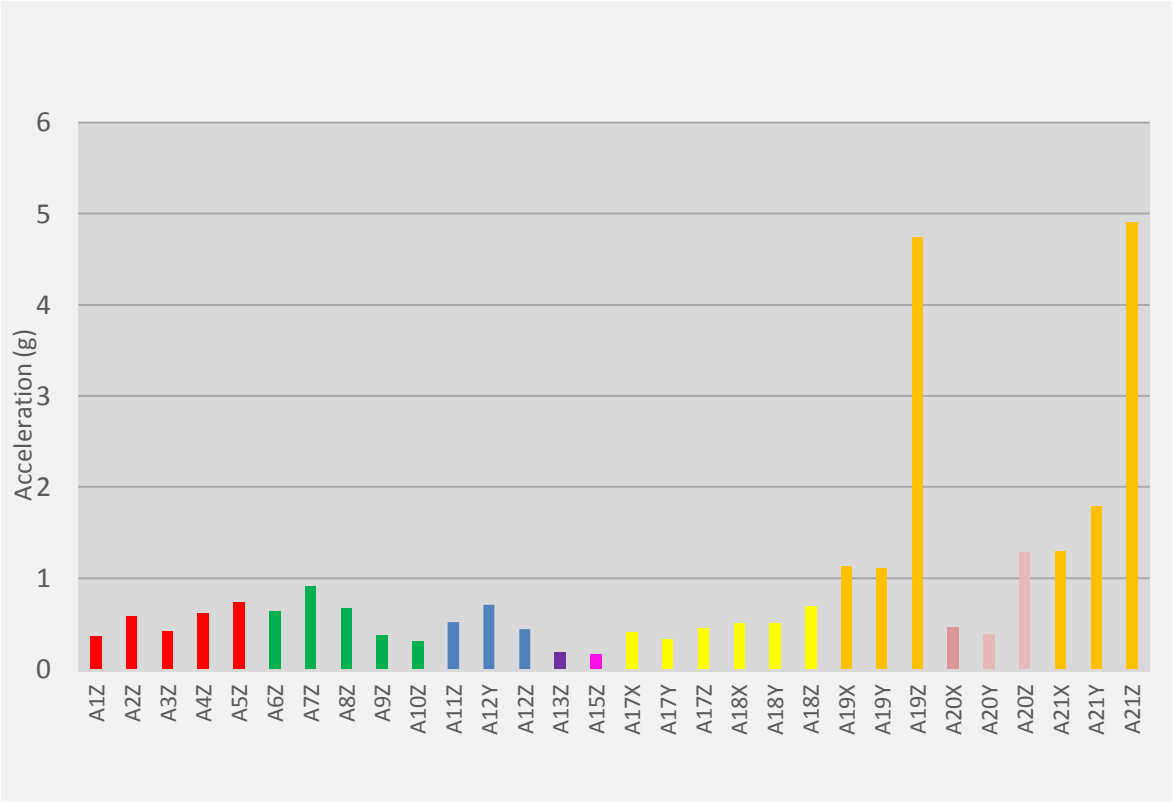
Test 59: Speed 40 mph



Test 70: Speed 75 mph

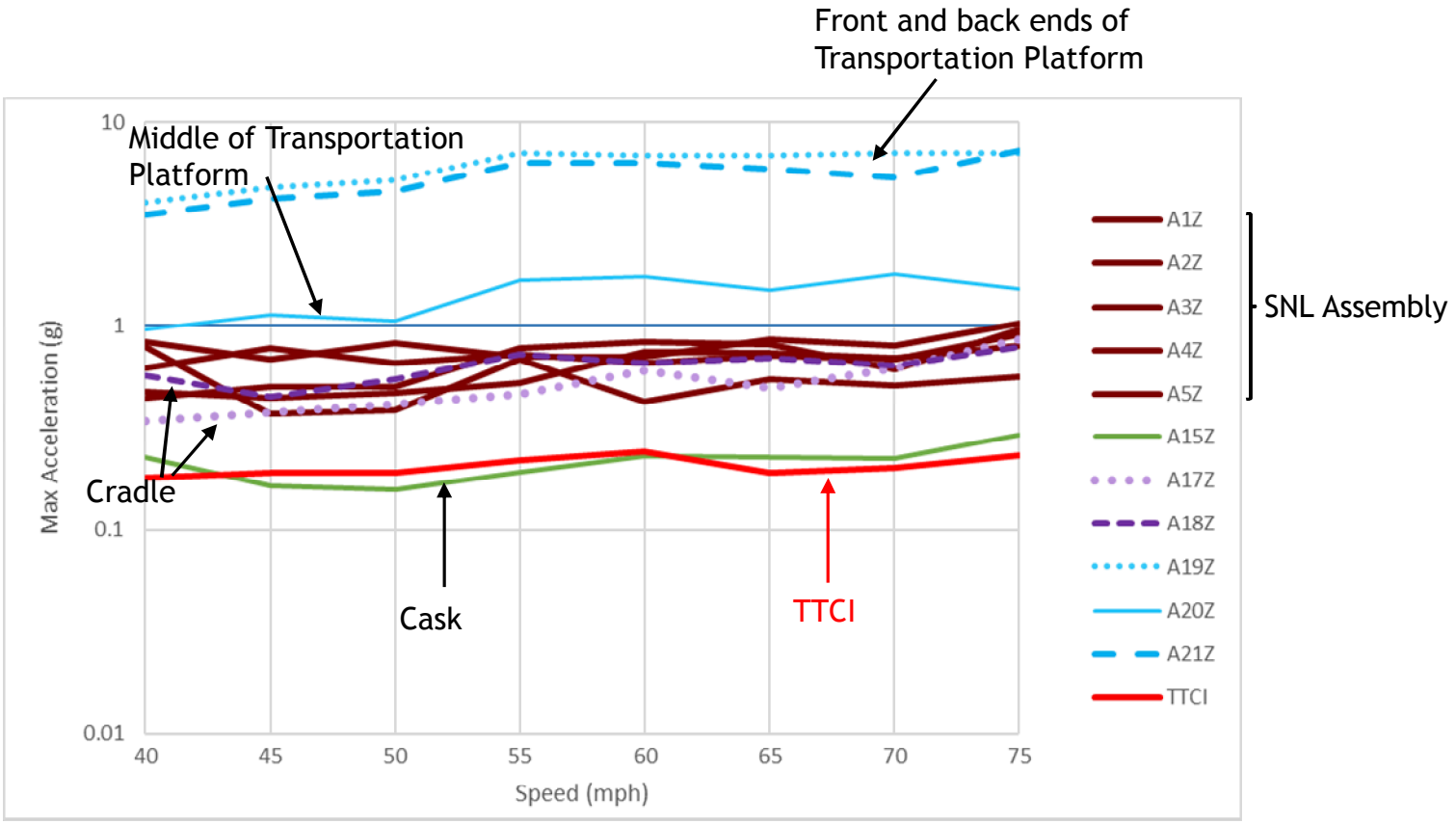


MAXIMUM ACCELERATIONS

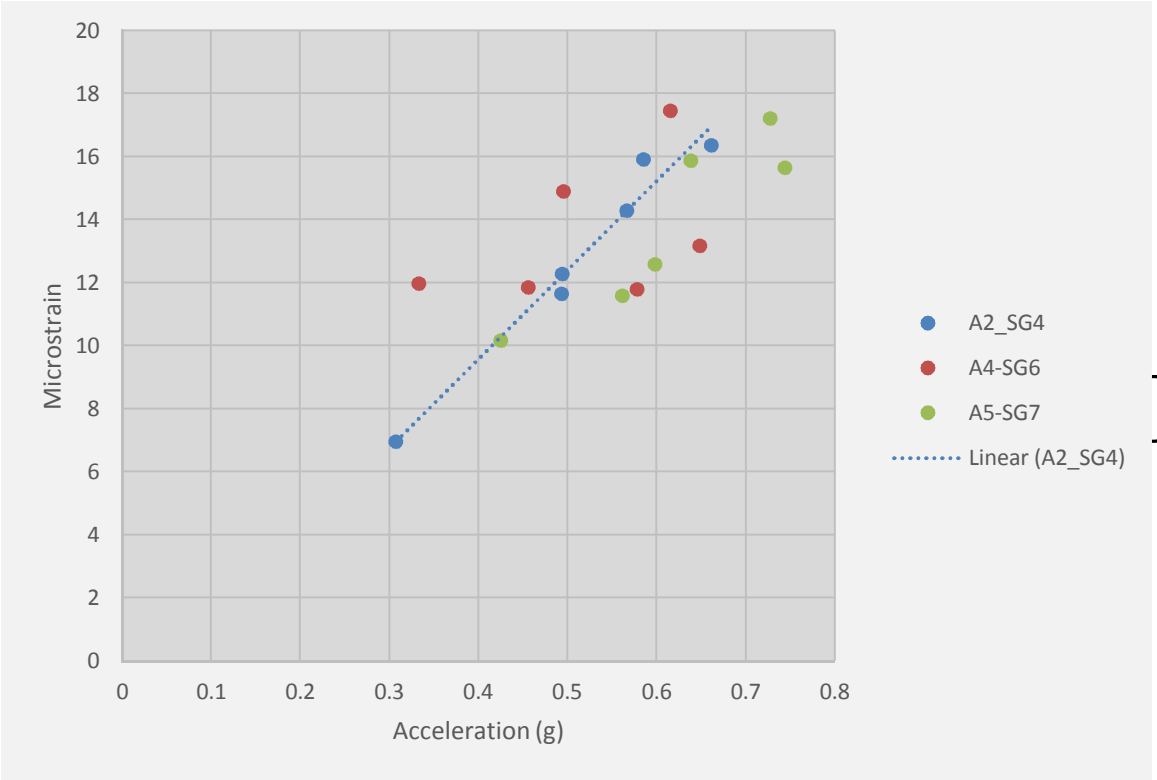


SNL Assembly
ENSA Assembly
Korean Assembly
Basket
Cask
Cradle
Transportation Platform Ends
Transportation Platform Middle

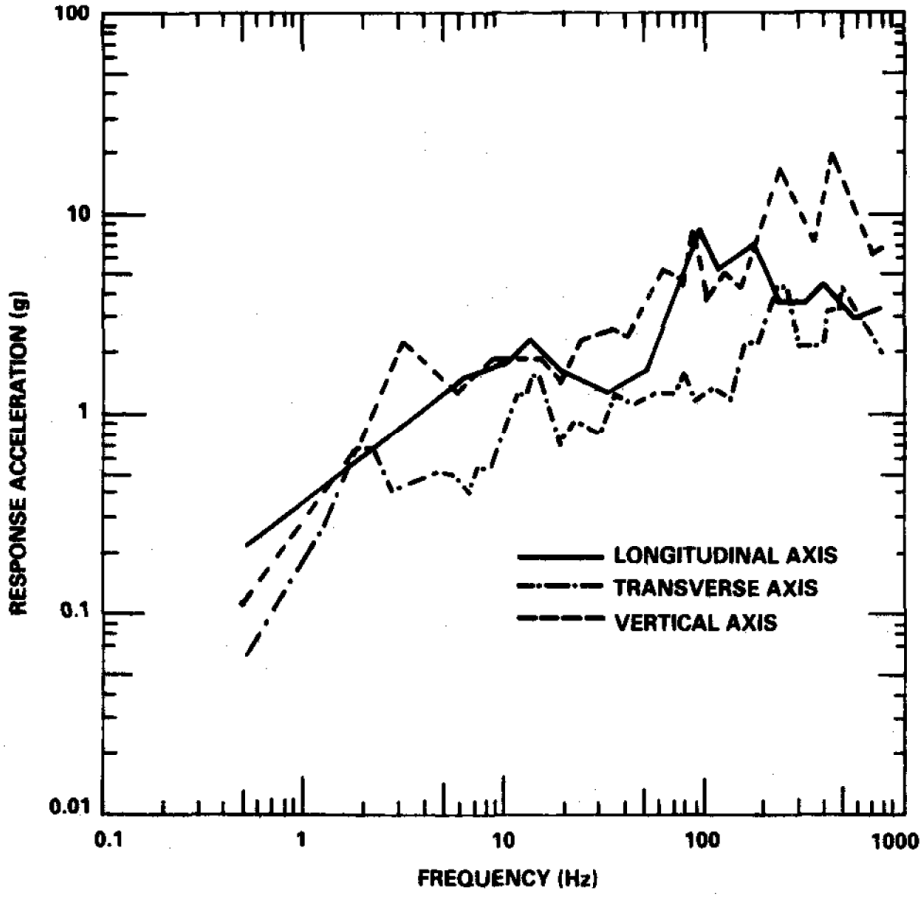
MAXIMUM VERTICAL ACCELERATIONS FOR DIFFERENT SPEEDS

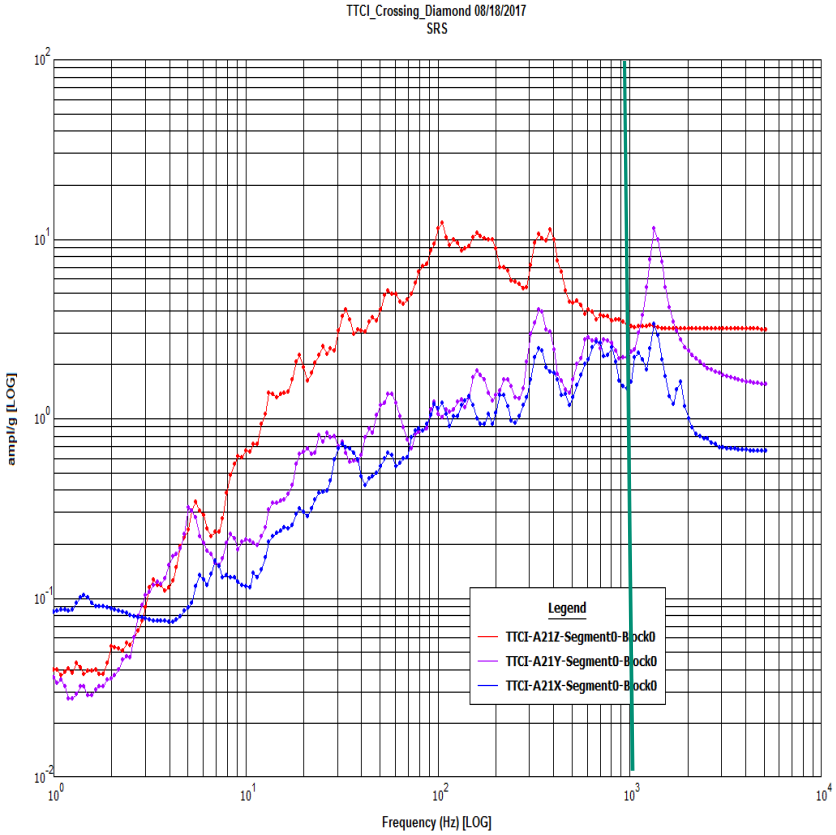


ACCELERATION-STRAIN FOR THE MO ROD, SNL ASSEMBLY

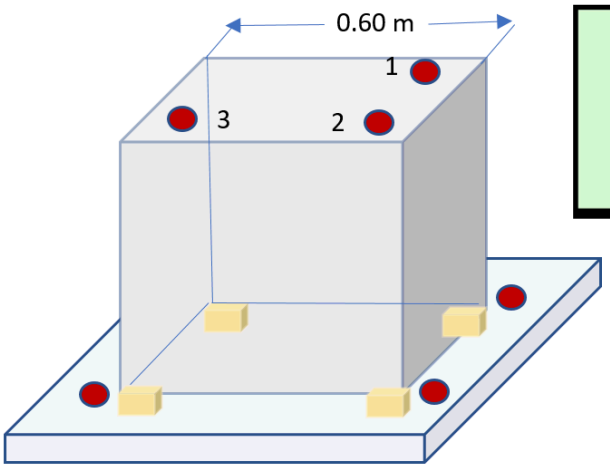


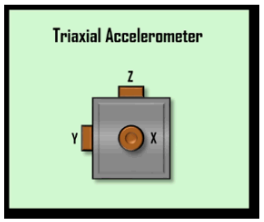
NUREG VERSUS NEW DATA





SHAKER TABLE EXPERIMENT





- 2 tests with block on shaker table
- 2 tests with block on 4 rubber legs
- 2 tests with block on 4 plywood legs

Rubber or plywood leg, 5.16 cmx5.16 cm, 1.27 cm thick

Triaxial Accelerometer

Steel Block

- Weight: 3,800 lb (1,723.65 kg)
- Dimensions: 0.60mx0.60mx0.60m

Legs

- Size: 5.16 cm x 5.16 cm, thickness 1.27 cm
- Material: rubber and plywood

Frequency

- 2 g frequency sweep 1-100 Hz

Leg Size Calculated From

- Transportation system weight: 149,000 kg (loaded cask, impact limiters, cradle and instrumentation box)
- Leg area in transportation test: 48cm x 48cm

Approach

- Maintain same volume of compressed rubber/plywood in experiment as in transportation test