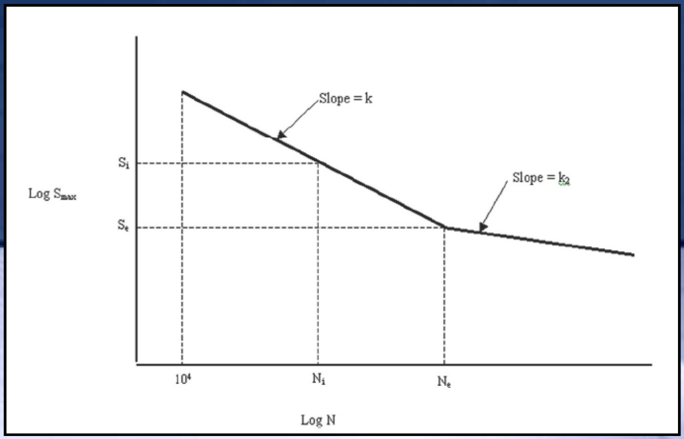
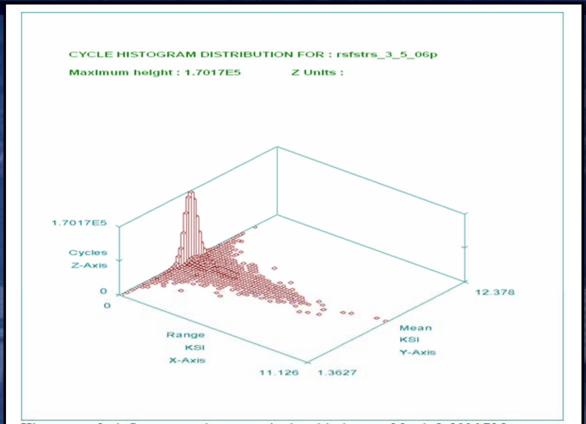
AAR/ARCI Freight Car Fatigue Task Force II



Update by

David Cackovic, AAR/TTCI



Histogram of rainflow counted stress cycles in critical area – March 5, 2006 PM

Acknowledgements

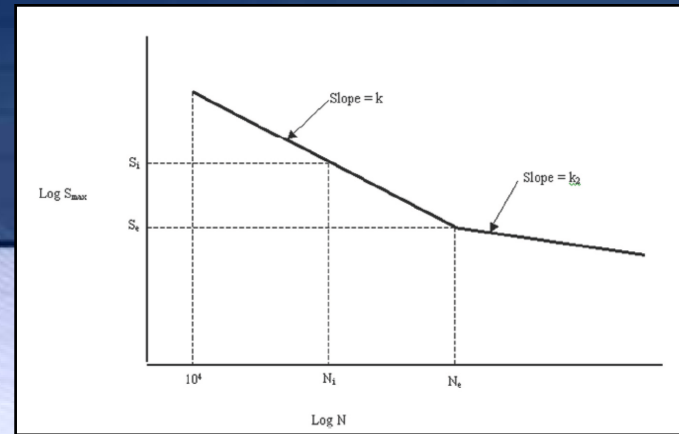
-- MARTS

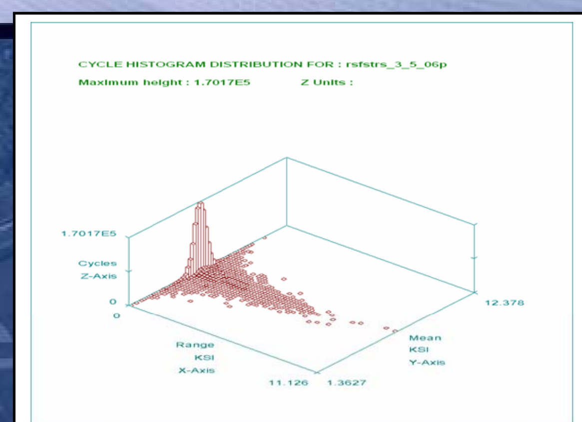
-- AAR/ARCI Fatigue Task Force

-- Kevin Koch, TTCI

-- Roger Sims, SPE

-- John Coulborn, Trinity





Histogram of rainflow counted stress cycles in critical area – March 5, 2006 PM

Today's Presentation:

- **Why Updating is Needed**
- How we are updating the Fatigue Guidelines and Prioritizing Car Types
- Test Program Execution and Results

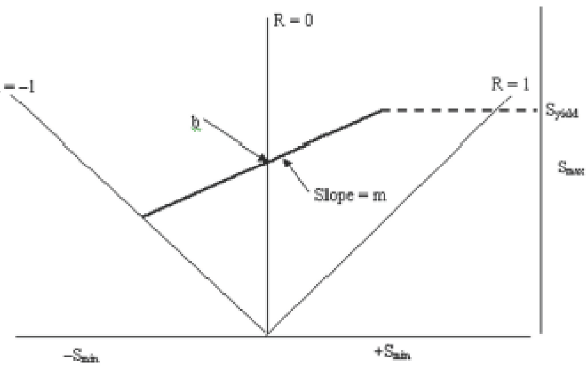


Fig. 7.2 Idealized modified Goodman diagram

Equation of MGD curve:

$$S_{max} = mS_{min} + b \qquad \text{Equation 9}$$

$$S_{min} = \frac{S_{max} - b}{m} \qquad \text{Equation 10}$$

By definition, $R = \frac{S_{min}}{S_{max}} = \frac{\frac{S_{max} - b}{m}}{S_{max}}$, but $S_{max} = S_e$ at fatigue limit. Therefore,

$$R = \frac{\frac{S_e - b}{m}}{S_e} \qquad \text{Equation 11}$$

or

$$S_e = \frac{b}{1 - mR} \qquad \text{Equation 12}$$

where

b = stress range at change of slope at $R = 0$
m = slope of the Goodman curve

Why Updating is Needed

Current Guidelines Based on:

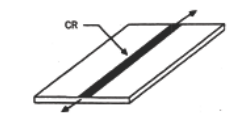
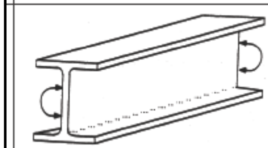
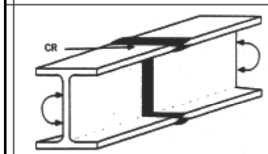
- Old Environment
  - Different roadbed today
    - Continuous welded rail
    - Concrete ties
    - Better ballast systems
  - Longer, heavier trains today
  - Higher tractive effort and high adhesion locomotives
  - Vibration was not addressed

Why Updating is Needed

Current Guidelines Based on:

- 1970's and Older Car designs
- Cars used for tests all out of production
- 263K GRL and lighter vs. today's 286K GRL
- Today's tare weights are often lower
- Materials today are higher strength
- Today use of aluminum is common

Table 7.63 Fatigue properties of members and details—steels
(If no value is shown, variable does not apply for this detail.)
Page 3 of 15

Member Details	Nom. Yield Stress (ksi)	Y Intercept of MGD (ksi) 2×10^6 (b)	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 2×10^6 cycles (S_e)
	36			0.15	19
	50			0.10	25
	100			(0.15)	31
	36	24	(0.9)	0.15	
	50	26	(0.9)	0.16	
	100	28	0.9	0.16	
	36			0.14	15
	50			0.23	15
	100			0.23	15

( ) = estimated value

Why Updating is Needed

- **Fatigue is the number one structural problem**

- Draft systems on steel gondolas
- Side sills of well cars
- Top chords of coal cars
- Container supports of well cars
- Center sills of spine cars
- Shear plate on stub sill cars
- Center beams
- And more

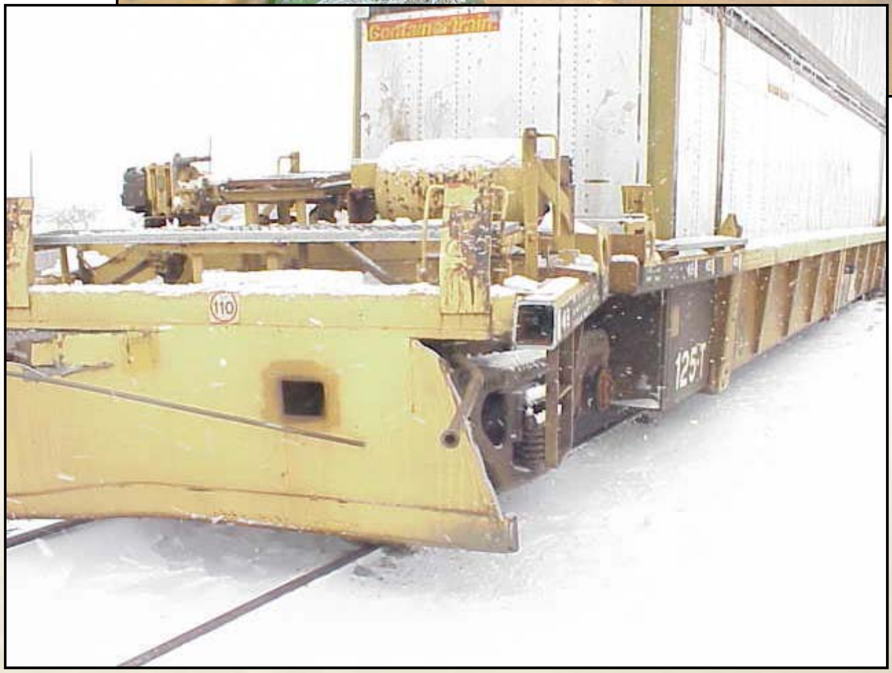
Why Updating is Needed

Fatigue failures are a safety issue

- Pull aparts
- Collapsed cars
- Lost loads
- Improper or poor quality repairs

Stress state issues

- AAR Standard S-286 requires fatigue analysis
- Defective wheels damage the car as well as the rail



Why Updating is Needed

A Little More Background:

The original Fatigue Task Force began work in the mid-70's as an ARCI endeavor.

Later the ARCI joined forces with the AAR and the work progressed under the Track Train Dynamics program.

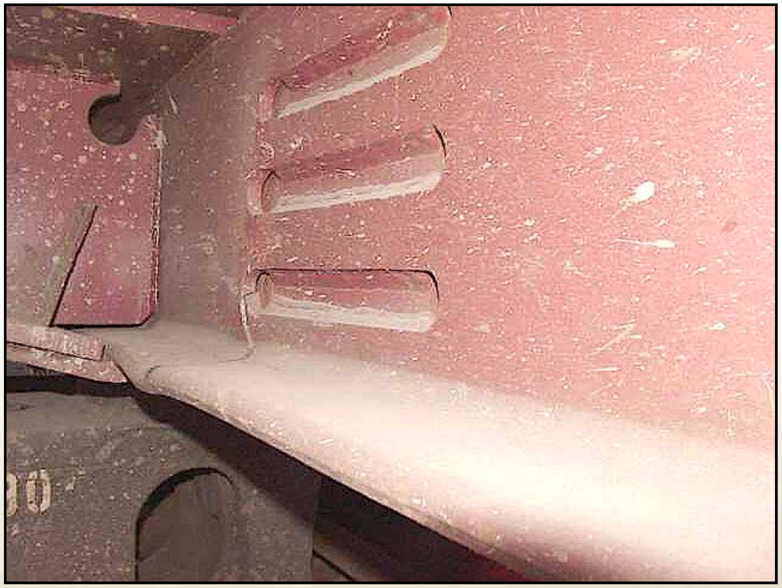
Road testing began in 1984.

Why Updating is Needed

The pathway to lighter, better cars requires accurate fatigue analysis

Without new tools development stops or we go down the wrong pathway

The industry has chosen the right pathway for improving the fatigue analysis tools by …………….



Reforming the FCFTF

Freight Car Fatigue Task Force II reformed September 29, 2004

- John Coulborn – Trinity Rail Group – Co-Chairman
- Shaun Richmond – Trinity Rail Group – Co-Chairman
- Members included: UP, CSX, BNSF, NS, FCA, Gunderson, NSC, Union Tank Car, Sims Engineering, FRA, Sharma and Associates, TTX, Columbus Steel Castings, and ASF-Keystone

- David Cackovic and Kevin Koch – AAR/TTCI

<u>Work Together</u>: Jointly work to update the specification requirements and to gather the new fatigue load environment data.

Approach Taken / This Task Force's Goals

<u>Today's Presentation:</u>

- Why Updating is Needed
- **Updating the Fatigue Guidelines and Prioritizing Car Types**
- Test Program Execution and Results

7.1.2 Analysis Requirements

7.1.2.1 Mileage Criteria for Analysis

The following minimum mileage criteria are to be used to determine the acceptability of fatigue life estimates (unless the purchaser has defined alternative criteria—only higher mileage criteria are allowed for equipment in North American interchange service):

Unit train and high utilization cars	3,000,000 miles
General interchange	1,000,000 miles

Revised AAR Specification M-1001 Chapter VII

Fatigue Analysis Calculation Method

- Method by original 1970's Task Force retained
- Updated Empty-Load Ratios
- Retained Miner's Rule, the most commonly used cumulative damage theory to calculate fatigue damage
- Added Section 7.7: Guidelines for FEA
- Retained original joint configurations
- Identified new joint configurations to add later
- Retained original REPOS until updates are done

For this example,

$$\beta_{EMP} = 354.661 \times \frac{0.93}{1.93} = 170.899 \text{ empty cycles/mile}$$

$$\text{Life}_{LD} = \frac{N_T}{\beta_{LD}} = \frac{85{,}183{,}706{,}000}{170.899} = 498{,}445{,}000 \text{ miles}$$

7.2.4.1.3.5 Calculate total life (loaded and empty):

$$\text{Total life} = \frac{1}{\frac{1}{\text{Life}_{LD}} + \frac{1}{\text{Life}_{EMP}}}$$

$$\text{Total life} = \frac{1}{\frac{1}{2{,}206{,}000} + \frac{1}{498{,}445{,}000}} = 2{,}197{,}000 \text{ miles}$$

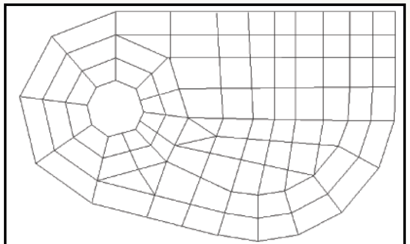


Fig. 7.12 Mesh should follow contour of part

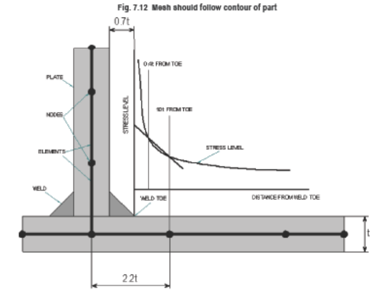
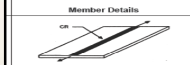
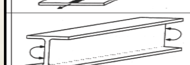
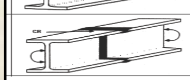


Fig. 7.13 Joint geometry and weld stress concentrations

Table 7.63 Fatigue properties of members and details—steels
(If no value is shown, variable does not apply for this detail.)
Page 3 of 15

Member Details	Nom. Yield Stress (ksi)	Y Intercept of MGD (ksi) 2 × 10⁶ (b)	MGD Slope (m)	S-N Slope (k)	Stress Range (ksi) at 2 × 10⁶ cycles (Se)
	36			0.15	19
	50			0.10	25
	100			(0.15)	31
	36	24	(0.9)	0.15	
	50	26	(0.9)	0.16	
	100	28	0.9	0.16	
	36			0.14	15
	50			0.23	15
	100			0.23	15

( ) = estimated value

Revised Chapter VII

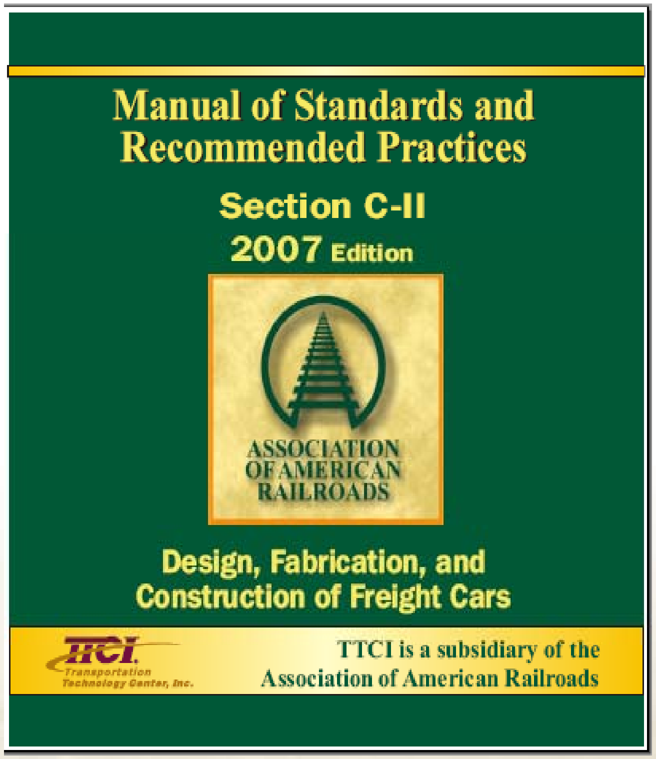
Over-the-road testing

- Established authority of EEC over tests
- Updated test methods and parameters
- Updated the format for data reduction
- Established the initial list of car types to be tested
- Established the initial priority of the tests
  - Coal, Tank and Intermodal first
  - Others to follow
  - Specific cars selected for testing are approved by the AAR Equipment Engineering Committee and the Task Force. Cars will be obtained for testing through donation agreements.

Update Fatigue Guidelines

Revised Chapter VII Implemented

- MSRP Section C, Volume 2 was Released May 7, 2007 by the AAR and the Equipment Engineering Committee via AAR Circular Letter C-10493.
- Includes Chapter VII.



Today’s Presentation:

- Why Updating is Needed
- Updating the Fatigue Guidelines and Prioritizing Car Types
- **Test Program Execution and Results**

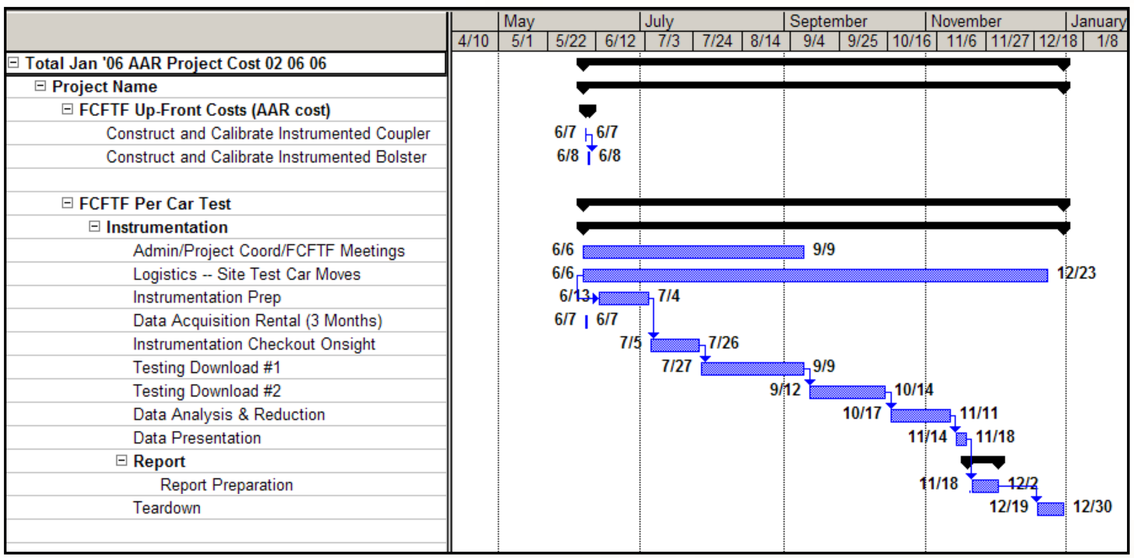
Test Program

Fatigue Test Requirements for Updating Freight Car REPOS (Road Environment Percent Occurrence Spectra)

- In the late 70’s and 80’s the basic test methodology was developed and implemented. The resulting output was test data required for railcar fatigue analysis and the specification “Chapter 7 - Fatigue Design of New Freight Cars.”
- Load spectra for the following cars were published:
  - High side 263K GRL coal gondola in unit train service
  - 263K GRL open top hopper
  - 263K GRL stub sill tank car
  - 70-Ton boxcar
  - 5-unit articulated TOFC spine car for 65K trailers

Test Program

- These tests are funded by the AAR Strategic Research Program and the RSI/ARCI Car Builders.
- This cooperative testing is tentatively planned for future years, until the need for current design spectra has been met.



- **As a side note, the FRA has joined the AAR and RSI/ARCI Car Builders in funding "sister" tests to obtain data for tank cars.**

Test Program

Test Car Selection and Loading

- Only loaded testing is to be conducted. Experience has shown that empty car operation has a minimal effect on fatigue life, so only the Tank Cars were tested in the empty configuration.

- Coal, Tank and Intermodal first.

Test Program

Test Route Selection

- The test route for each car type will be determined by the Task Force and approved by the Equipment Engineering Committee. Routes selected will be the most appropriate service and train makeup for the car type.

Train Makeup

- The test conductor will work to ensure that the car is located in the middle third of the train consists, as much as is reasonably possible.

Test Program

- **Data Acquisition System -- Unattended**
  - A relatively small, self contained system
  - 16 channels of data, 256 digital samples per second, and low-pass filtered at 30 Hz
  - Data storage size sufficient to need only two down loads in 10,000 miles.
- **Calibration of Transducers**
- **System Check-out in Controlled Environment**

Test Program

Chapter VII Updating and Data Formatting

- **Upon review and approval by the Freight Car Fatigue Task Force and the EEC, the new load spectra data will be added to Section 7.3 (“Environment Load Spectra”) of Chapter VII, either as an augmentation of existing data or as a replacement of existing data.**

7.3.2.52 Standard Bolster Center Plate Load—Empty Intermodal Car

Test Date	Dec. 1986–Feb. 1987
Test Mode	Intermodal Service
Max MPH	65
Average MPH	34.4
Recorded Mileage	4,548
Total Number of Cycles	973,599
Average Cycles/Mile	214.1
Track Class	Various

Table 7.55 Empty ARC-5 Car—intermodal standard bolster center plate load

Maximum Load	Minimum Load	Percent Occurrence	Maximum Load	Minimum Load	Percent Occurrence
10	5	0.002876	40	15	0.040879
15	0	0.000308	40	20	0.037079
15	5	0.041393	40	25	0.017975
15	10	4.838234	40	30	0.001438
20	0	0.001541	40	35	0.005444
20	5	0.107642	45	0	0.001335
20	10	2.896778	45	5	0.010271

Aluminum Coal Hopper CTRN 602704

5 Unit Intermodal Well Car DTTX751062

Test Program – Coal Car

FCFTF coal car testing became part of AAR Strategic Research Initiative 14D “In Service Load Monitoring” Program

- Monitor the stress state in railroad service
- Build database for 286K GRL coal service

Test Program – Coal Car

SRI 14D Instrumentation

- 2 Force measuring wheels
- 2 Axles to measure strain
- Accelerations on body both ends
  - One brake valve
- Brake beam strains
- Top chord strains

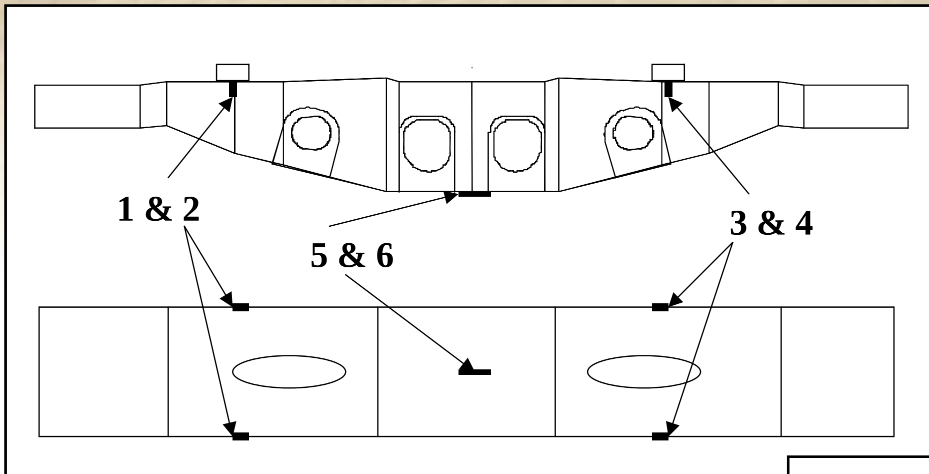
FCFTF Instrumentation

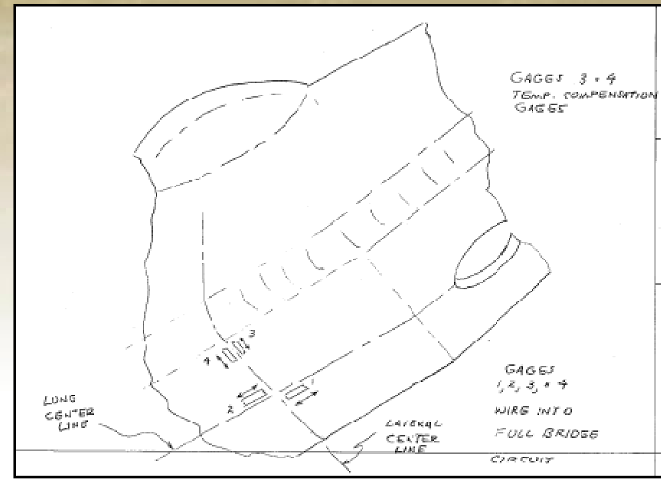
- Bolster strains and forces
- Side bearing loads
- Coupler Force
- Side frame loads
- Top chord strains

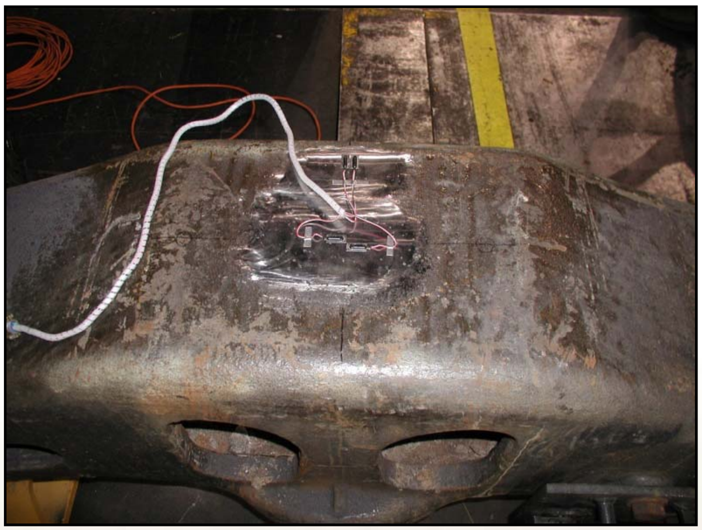
Test Program – Coal Car

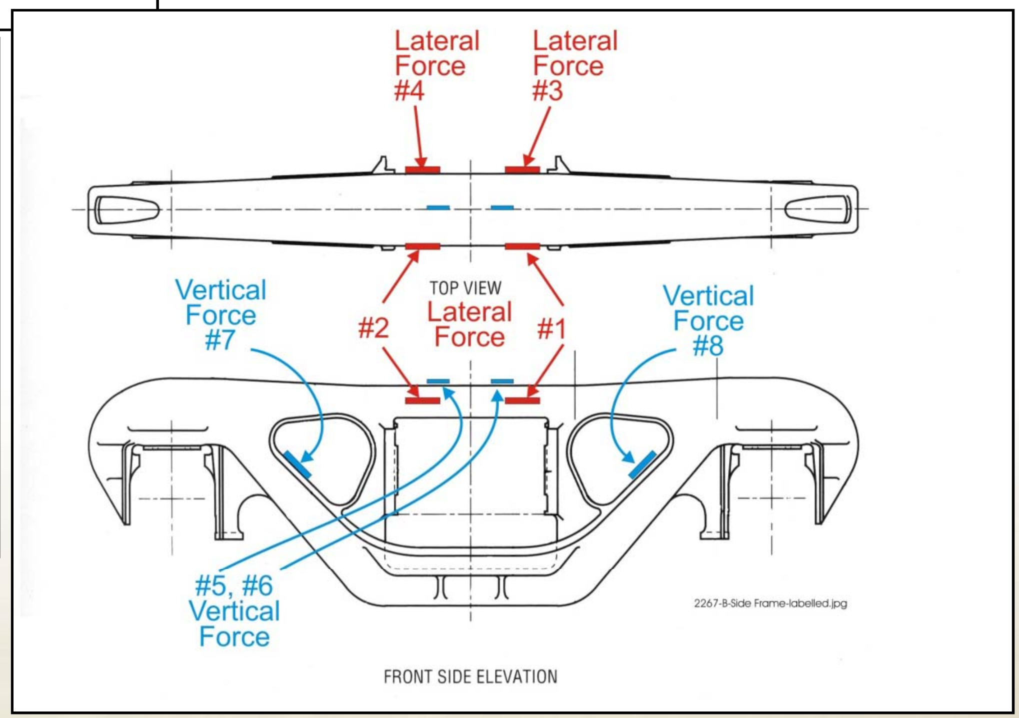
MEASUREMENT	Transducer Type, Comment	Data Type, Analysis
MEASURMENT		
Center Plate Vertical Load	Strain Gage, calibrated in load frame	Time History, Rainflow Cycle Counting Post Test Processing
Side Bearing Load Bridge		
Longitudinal Coupler Load	Instrumented Coupler	
SYSTEM MEASUREMENTS		
Power	System	Time History
GPS Train Speed	GPS	Time History
GPS Train Location	GPS	Time History
CAR BODY STRUCTURAL MEASUREMENTS		
Car Body Strain Locations (Key locations, twist, etc.)	Strain gage, locations based on car type (history, analysis)	Time History, Rainflow Post Processing
BOLSTER AND SIDEFRAME LOAD SPECTRA		
Bolster Load	Strain Gage, calibrated in load frame	Time History, Rainflow Post Processing
SF Vertical Load		
SF Lateral Load		

Test Program – Coal Car





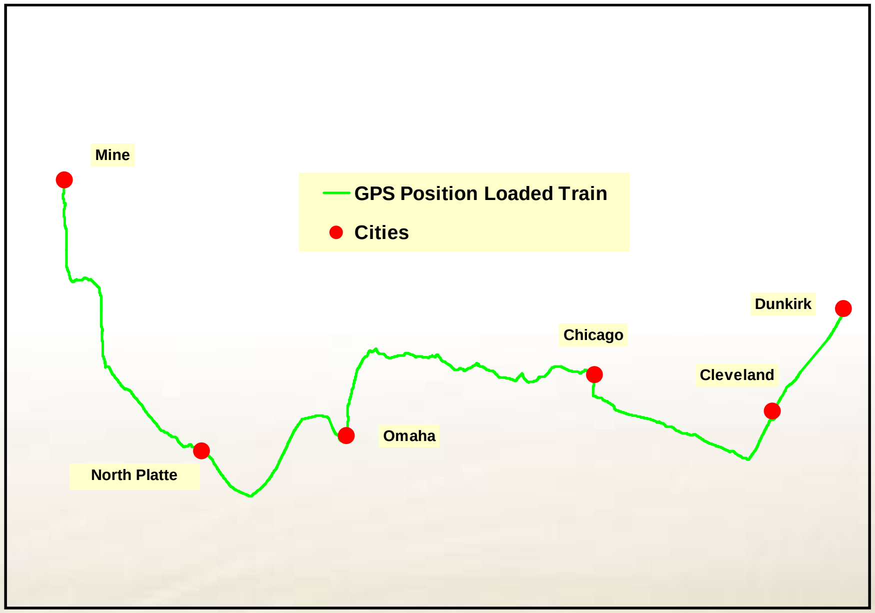




Test Program – Coal Car

Phase I Tests, with instrumentation coach, conducted in 2006

- Western and Eastern RR
- 3,200 miles of loaded car data
  - Wyoming to NY on UP / CSX
  - Wyoming to Georgia on BNSF / NS
- Aluminum coal cars in front of coal train



Phase II Tests, unattended

- Most measurements obtained 4,900 loaded miles of data, some measurements obtained 5,200 miles.

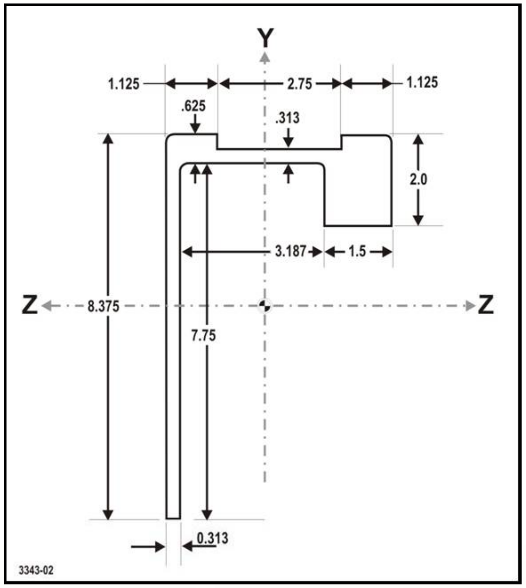
Test Program – Coal Car

- **Top chord strains**
  - **Approached buckling limit in body bounce motions**
  - **Bending strains not as significant**
  - **Highest stress at speeds above 45 mph**
  - **Will evaluate coupler force link to high strains**

Test Program – Coal Car

Large top chord stresses were recorded

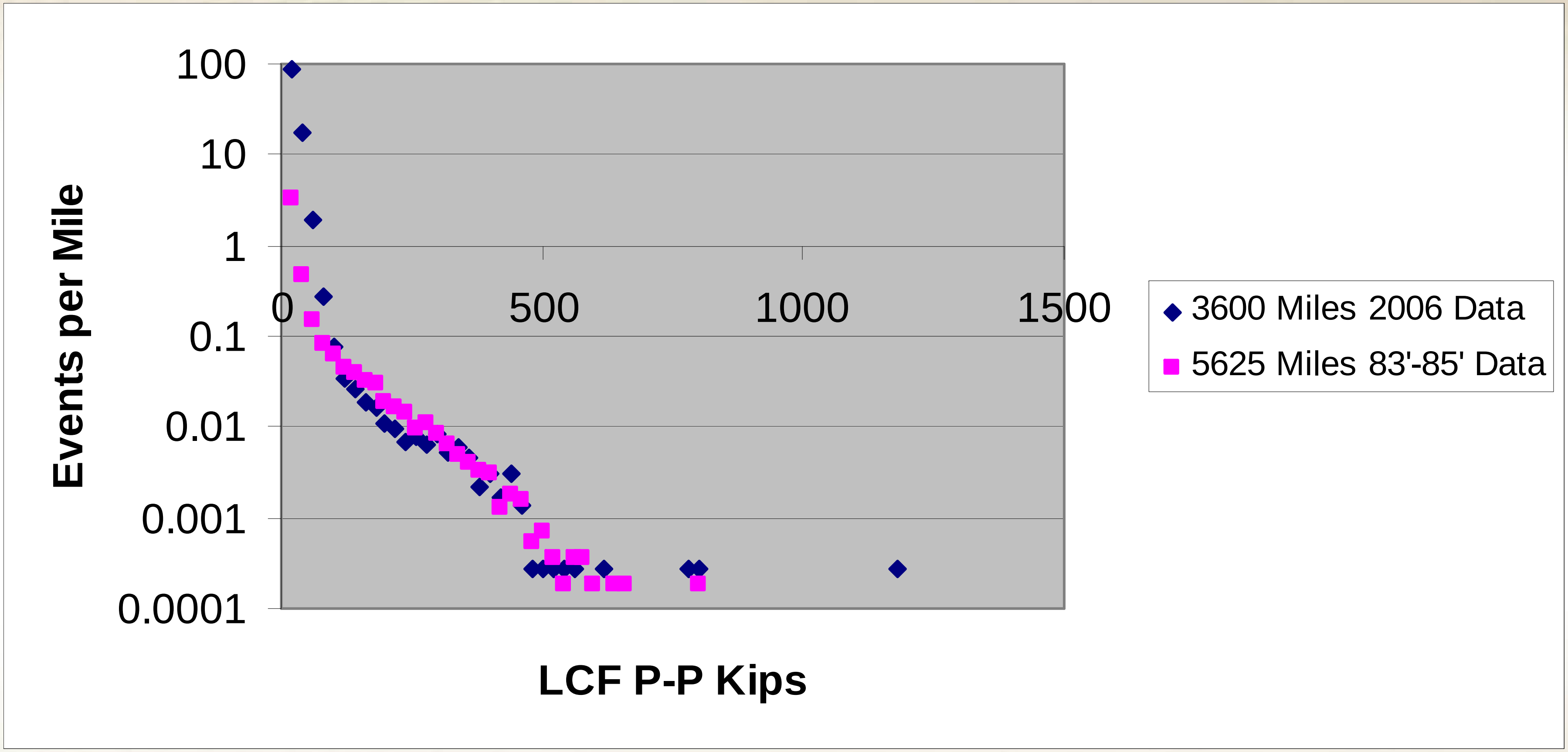
Top Chord



Location on Route	Test Speed (mph)	Compressive Axial Stress	Bending Stress	Vertical Wheel Force
Clinton Sub., MP 148.13, Right Switch	51.8	20,820	2,320	76,710
Columbus Sub., MP 86.49, Bridge	49.5	18,210	2,190	73,460
Columbus Sub., MP 88.23, Culvert	50.0	17,520	2,030	68,230
South Morrill Sub., MP 62.89, Road Crossing	50.0	16,270	1,680	56,560
Clinton Sub, MP 159.31 - culvert	43.1	15,960	2,150	65,450
Calculated Critical Compressive Stress for Buckling – 22,300 psi.				

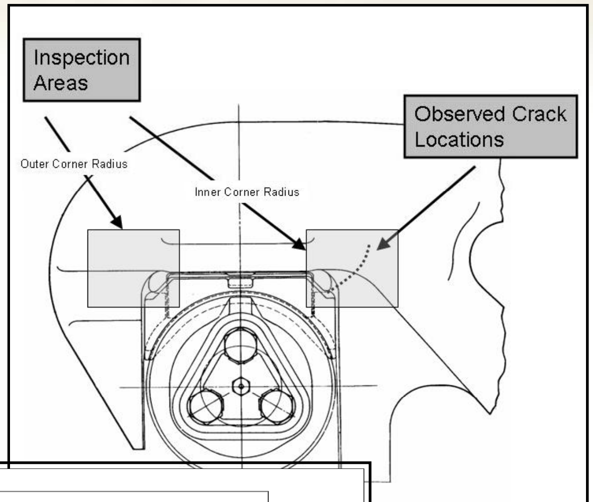
Maximum compressive stress 93% of calculated limit

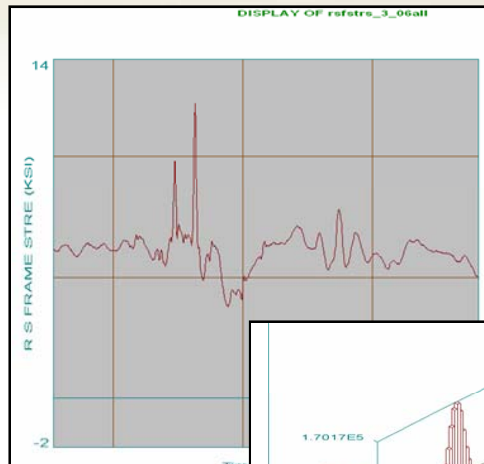
Test Program – Coal Car

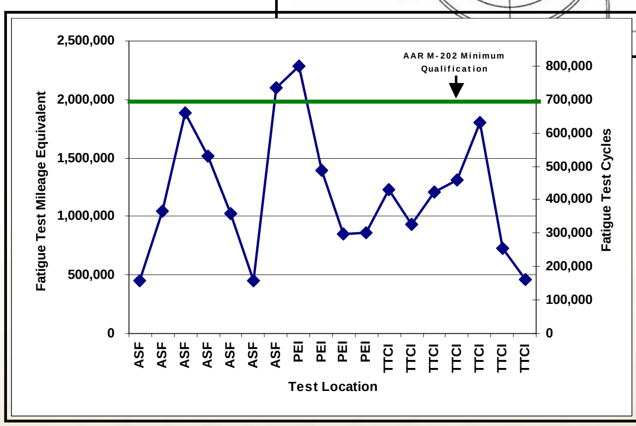


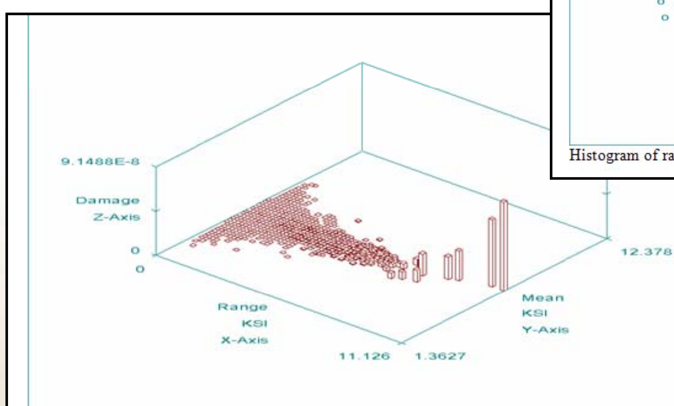
Test Program – Coal Car

- **Bolster and side frame loads have been useful for AAR Coupling System & Truck Castings Committee (CS&TCC) efforts**

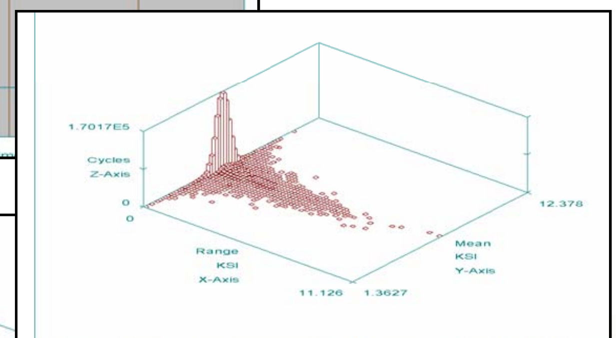








Histogram of fatigue damage in critical area – March 5, 2006 PM



Histogram of rainflow counted stress cycles in critical area – March 5, 2006 PM

Test Program – Coal Car

- **Coupler loads have been useful for AAR CS&TCC efforts**

M-216 Specification
Knuckle Fatigue Test Load Cycles Proposed

Segment	Number of Cycles (Sinusoidal form)	Total Elapsed Cycles	Cycle Load Range
1	4	4	10 – 300 kips
2	2	6	10 – 280 kips
3	7	13	10 – 260 kips
4	10	23	10 – 240 kips
5	31	54	10 – 220 kips
6	77	131	10 – 200 kips
7	65	196	10 – 180 kips
8	73	269	10 – 160 kips
9	89	358	10 – 140 kips
10	105	463	10 – 120 kips
11	129	592	10 – 100 kips
12	187	779	10 – 80 kips
13	279	1058	10 – 60 kips

Thanks to NS for significant effort on this test plan development!

Test Program – Intermodal Car

5-Unit Intermodal Well Car

This car was a combination of five well units, supported by six trucks. Each unit was designed to carry 40 ft. or 20 ft. long freight containers.

A special non-revenue, dedicated payload was used for this test. Standard freight containers loaded with 55 gallon barrels, filled with concrete were utilized. The payload for each unit was as follows:

- B Unit – 56,400 lb. 40 ft. container mounted on top of a 69,400 lb. 40 ft. container
- C Unit – Empty 10,000 lb. 40 ft. container mounted on top of two 50,000 lb. 20 ft. containers.
- D, E, and A Units – A single 40 ft. 49,000 lb. unit in each.

Concrete Filled Barrels Used as Payload

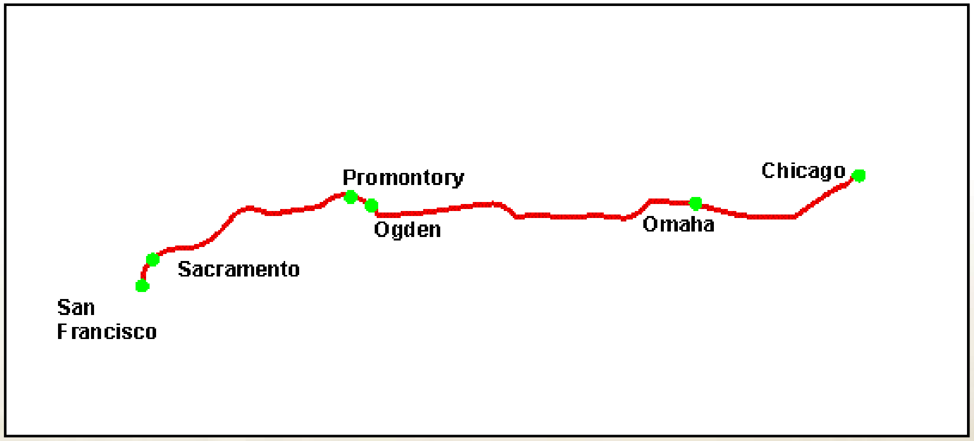
Test Program – Intermodal Car

Instrumentation installed
- Truck (100-ton)
  - Truck bolster load
  - Side Bearing (brackets)
  - Centerbowl load
- Car body strain measurements

Began over-the-road testing December 3, 2007

Placement target is rear two-thirds of the train consists, in Chicago to west cost

Approximately 8,900 – 12,000 miles of data has been collected, depending on measurement reliability

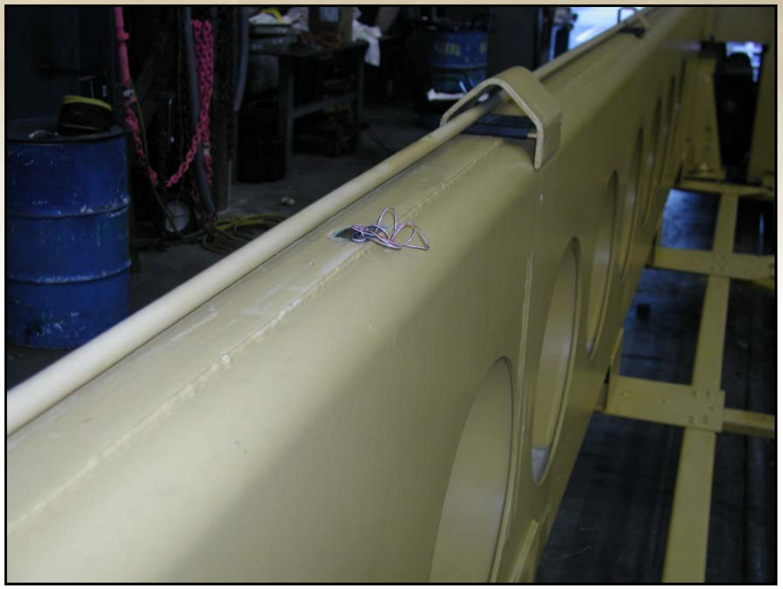


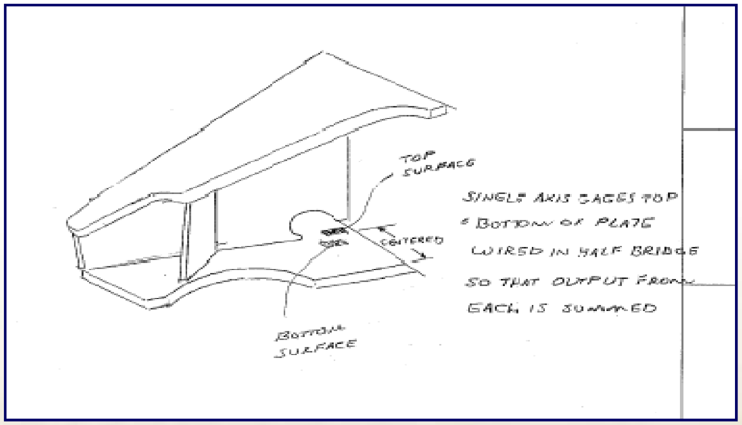
Test Program – Intermodal Car

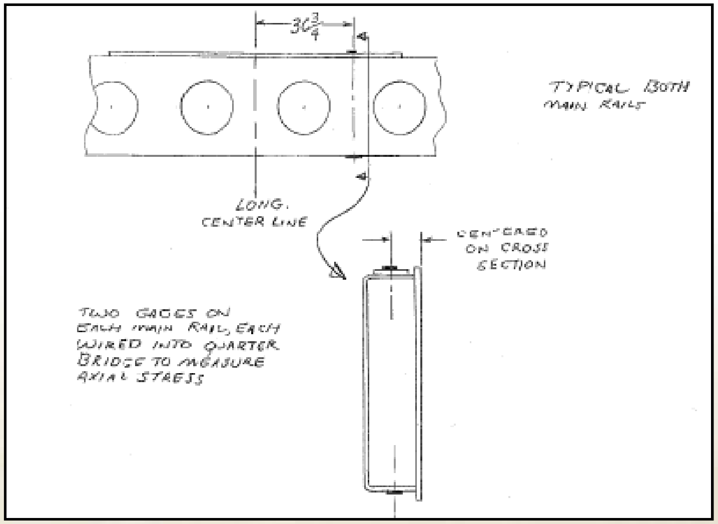

Typical Strain Gage Installation on Side Bearing Bracket


Side Bearings and Side Bearing Brackets Between B & C Units

Test Program – Intermodal Car







Results for Intermodal Car Testing

The primary result of the data processing was a set of cycle counted histograms containing the maximum value, minimum value and number of cycles for each load magnitude "bin".

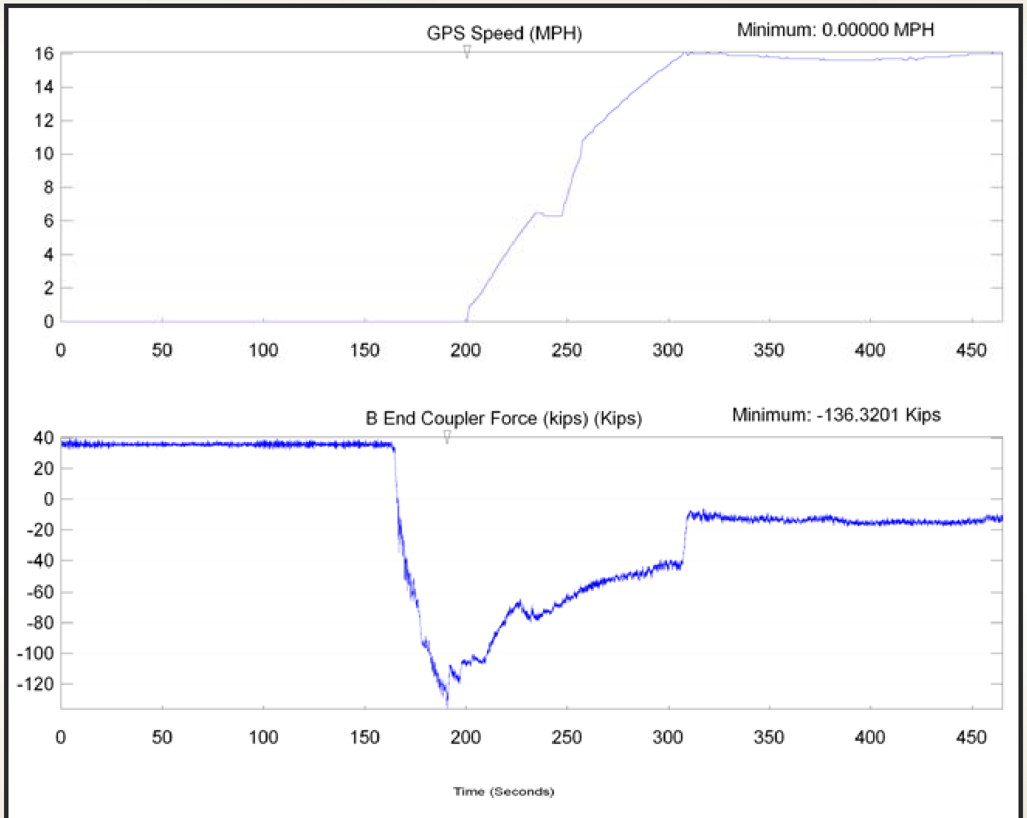
- This data can then be used in fatigue damage calculations for critical areas of each car design. An example of a few rows of a longitudinal coupler force histogram is shown.

MAX VALUE	MIN VALUE	CYCLES	PERCENT OCCURANCE
390	20	1	0.0000035
380	30	1	0.0000035
380	25	1	0.0000035
370	365	1	0.0000035
370	20	1	0.0000035
365	360	2	0.0000071
365	45	1	0.0000035
360	355	1	0.0000035
360	350	2	0.0000071

Results for Intermodal Car Testing

Test “Percent Occurrence” the number of cycles counted for a particular maximum and minimum value divided by the total number of cycles counted.

- Time domain data was always available to confirm maximum or minimum values that were observed in the histogram data. Examples of time domain coupler force data are shown.

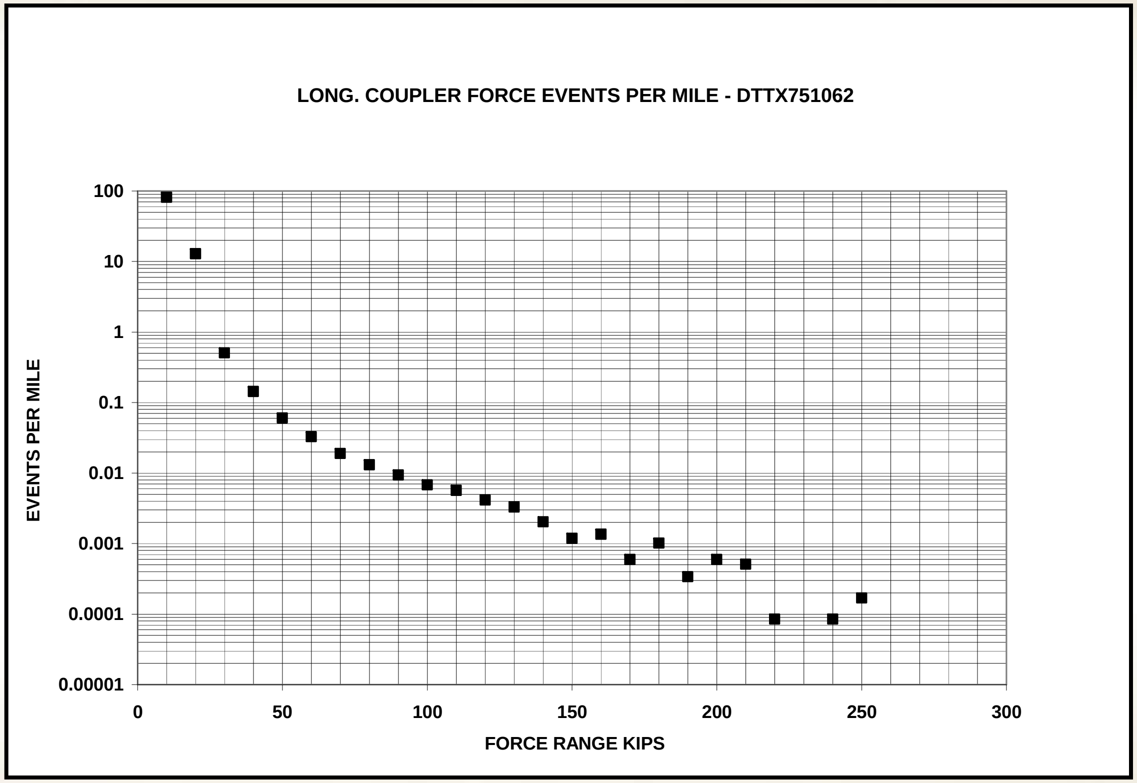


Long. Coupler Force & Train Speed, 5 Unit Well Car

Results for Intermodal Car Testing

In order to observe the character of the data and perhaps compare results with those of similar tests, the histograms were converted to two-dimensional, force range versus event per mile form.

- The range is just the minimum value of a cycle subtracted from the maximum value. All cycles from each range “bin” are then added together.
- The cycles for each range bin are then divided by the total test mileage for that particular channel to produce a cycle or “event per mile” number.
- Stress range is a significant factor in the calculation of fatigue damage.



Testing and Simulations for the Development of New AAR Rail Car Fatigue Design Spectra

Data Validation

The data collected through these tests, while using technically rigorous testing methods, must be validated prior to being required for freight car design.

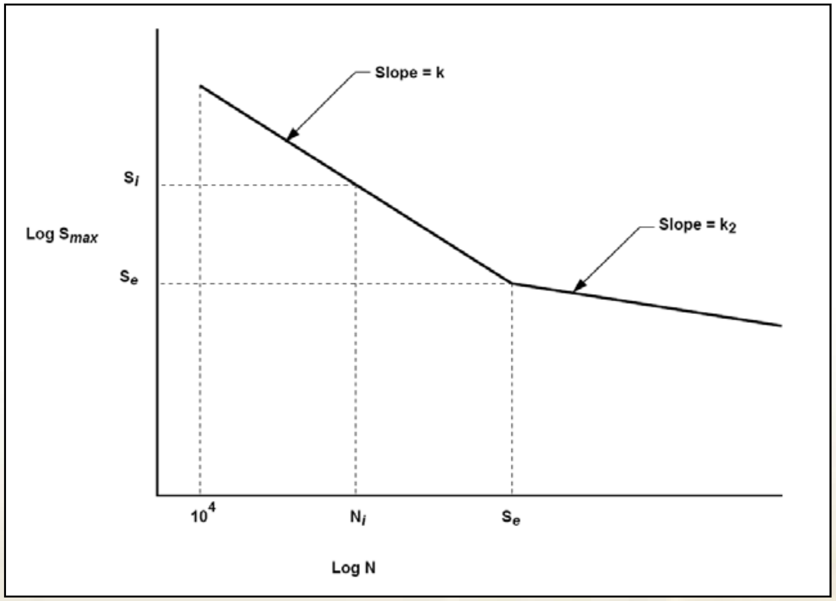
In the case of each car type, steps were taken to:

- Check the realism of predicted fatigue life of various welded joints in the design (of each car type)
- Check the lives of members where owners/builders had experienced shortened fatigue life in the field
- Evaluate differences in calculation methodology to determine appropriate industry techniques

Testing and Simulations for the Development of New AAR Rail Car Fatigue Design Spectra

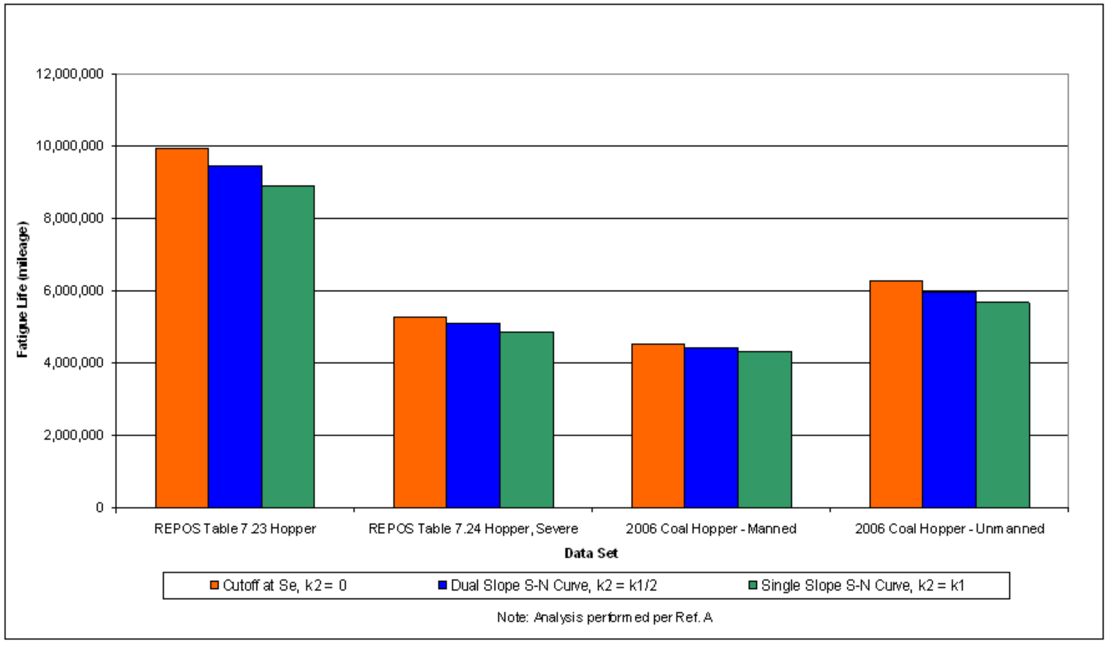
Methodology

Regarding the issue of how to treat the S–N diagram in the application of Miner's Rule of Accumulated Damage (reference AAR MSRP M-1001, Chapter VII), the figure below shows the two portions of the curve for a typical welded joint.



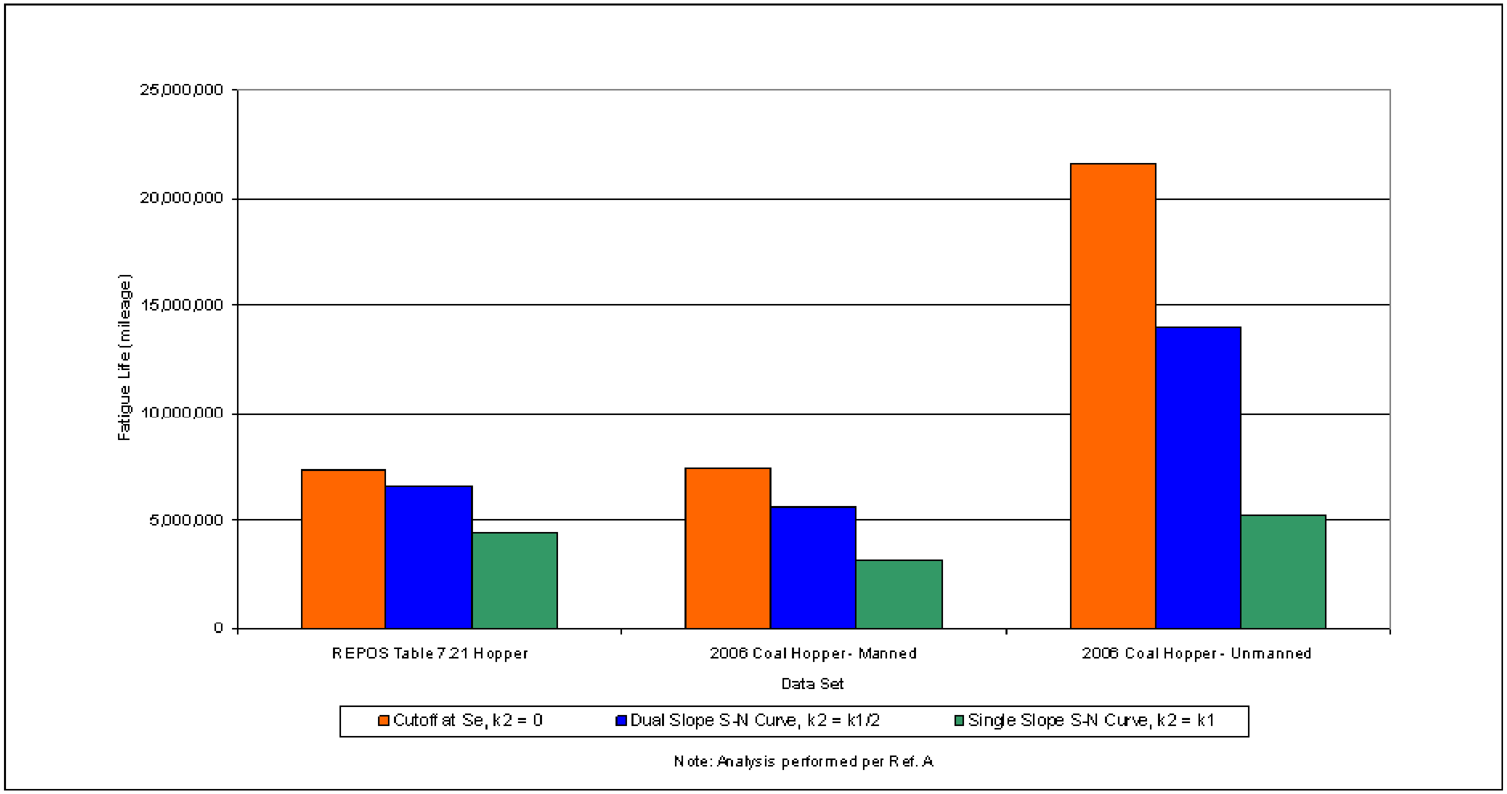
Testing and Simulations for the Development of New AAR Rail Car Fatigue Design Spectra

To revisit the fatigue analysis procedures in Chapter VII of M-1001 – three (3) calculations with variations in method were made to predict lives of a particular coal car welded joint. The fatigue results were very similar thus proving that the M-1001 methods were still appropriate and the Coal Car data was valid.



Coal Hopper Coupler Fatigue with Data Spectrum Fixed

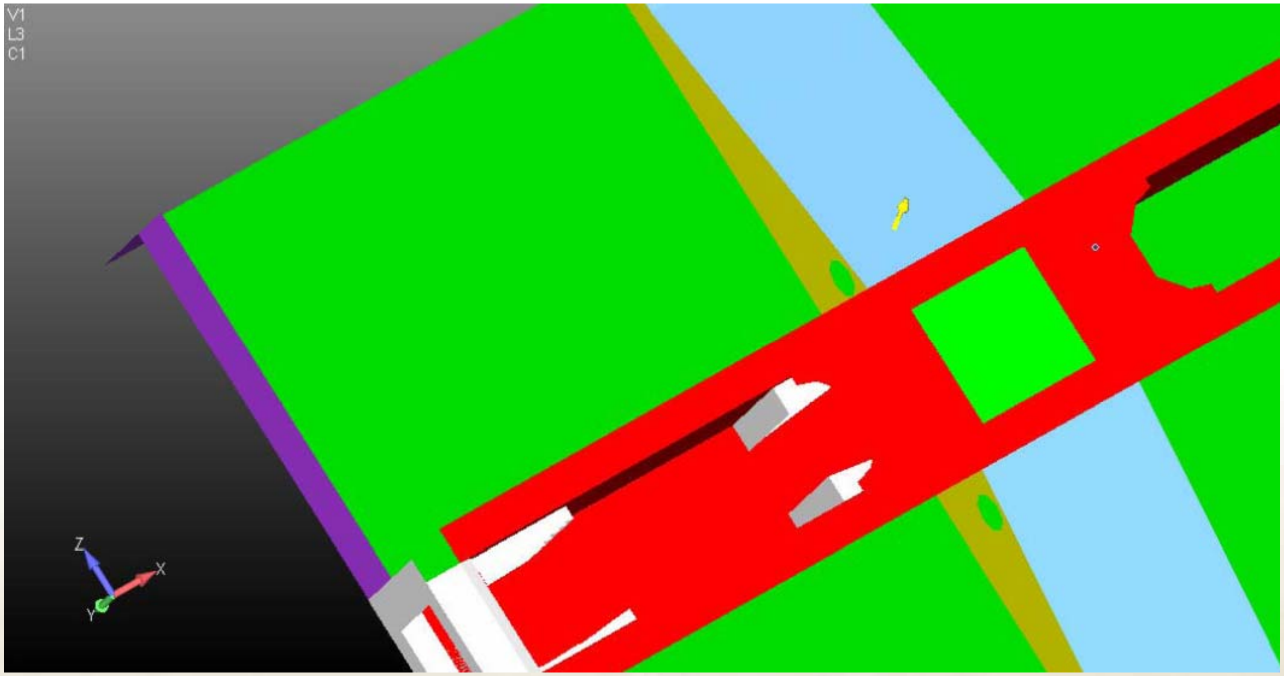
Testing and Simulations for the Development of New AAR Rail Car Fatigue Design Spectra



Coal Hopper Bolster Fatigue

Testing and Simulations for the Development of New AAR Rail Car Fatigue Design Spectra

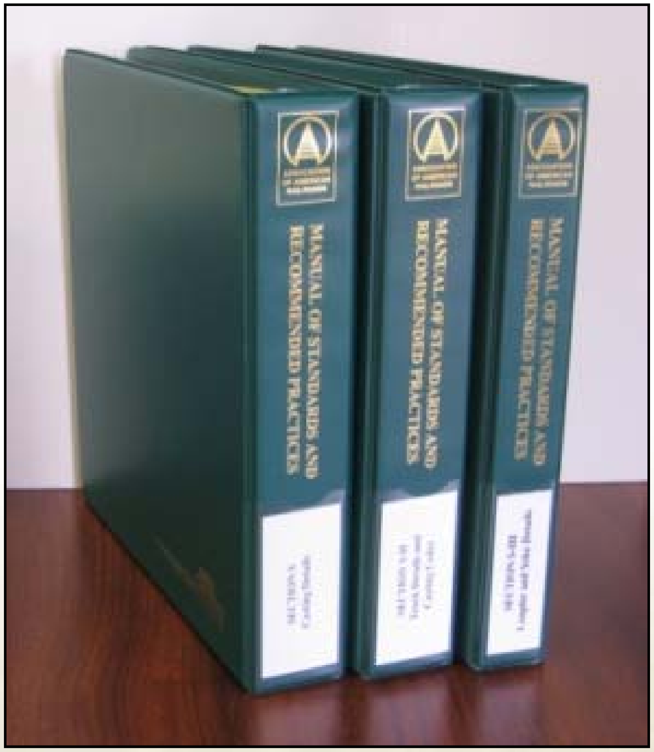
For the intermodal car data validation, much more was required because the predicted lives of well car joints near center of car (pictured) were too high. After vehicle dynamic's analysis, it was determined to do more testing at TTC, and to use the coal car longitudinal coupler load data for designs in the interim.

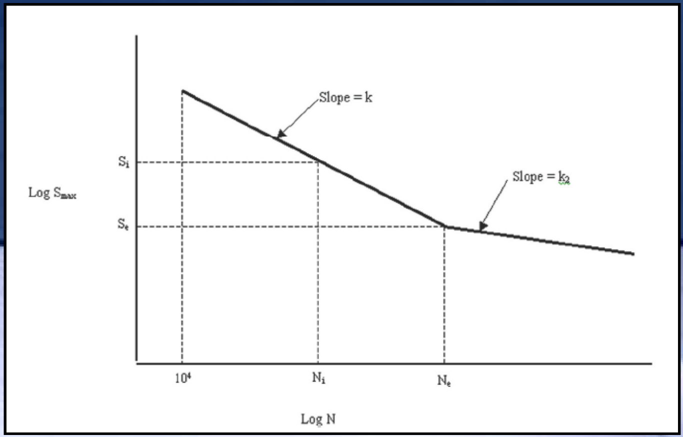


Status:

Chapter 7, Section C, Part II, Volume 1 of the MSRP is in the final stages for release for industry comment, and then for reprinting.

New coal and five-unit intermodal car designs will be required to meet the new data requirements. In addition, new data for tank cars will be included.





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-- MARTS
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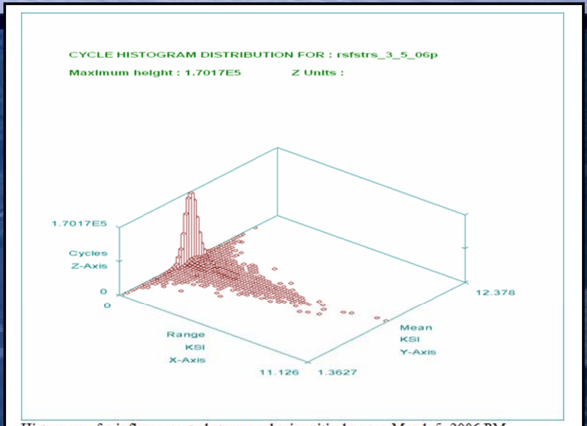
-- John Coulborn, Trinity

QUESTIONS?



Histogram of rainflow counted stress cycles in critical area – March 5, 2006 PM