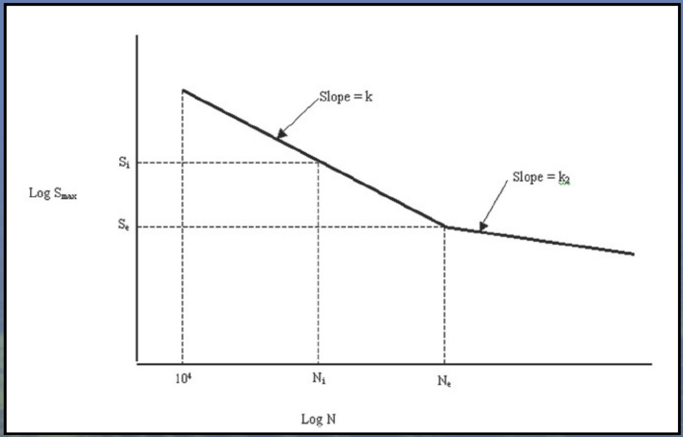


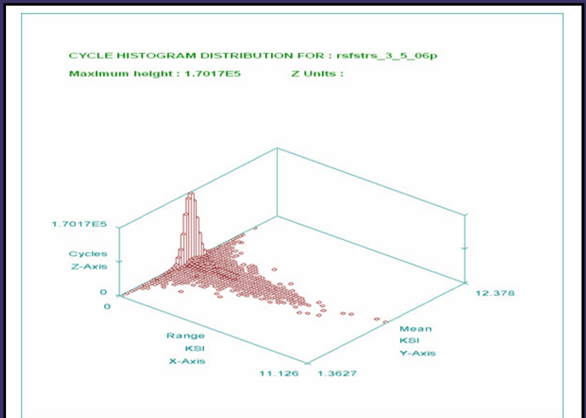



AAR/ARCI
Freight Car
Fatigue Task Force II

September 2008

John Coulborn, Trinity Industries, Inc.

David Cackovic, AAR/TTCI



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

Background

- The railroad environment is a moving target
- The birth of railcar design requirements centered mostly around Impact and Tensile Loads
  - 1,250,000 pound impact
  - 1,000,000 pound squeeze
  - Vertical bounce
- The goal was to avoid sudden catastrophic failures
- The solution was: Make it Heavier
- GRL's have steadily increased
  - 100K to 200K to 220K to 250K to 263K to 268K to 286K (Some 315K)
- The need for more efficient designs (lighter cars) also increased
- About the late 60's to early 70's the industry awoke to the need to design for fatigue
- Guidelines for fatigue design were put in place with the understanding that would need to be kept up-to-date

- ## Today's Presentation:
  - **Why Updating is Needed (Coulborn)**
  - How we are updating the Fatigue Guidelines and Prioritizing Car Types (Coulborn)
  - Test Program Funding and Execution (Cackovic)

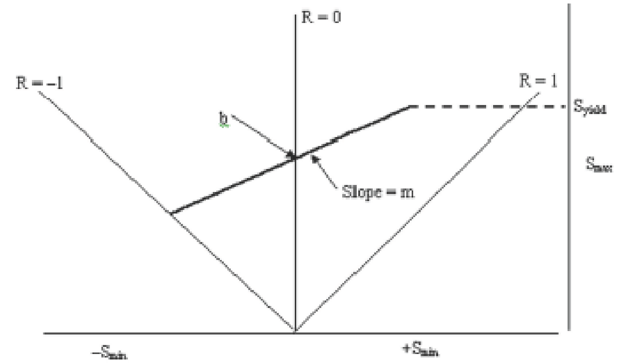


Fig. 7.2 Idealized modified Goodman diagram

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

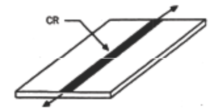
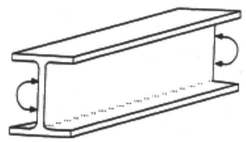
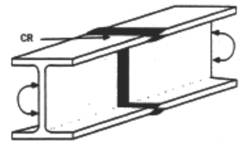
Current Guidelines Based on:

- 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 Inter-cept 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

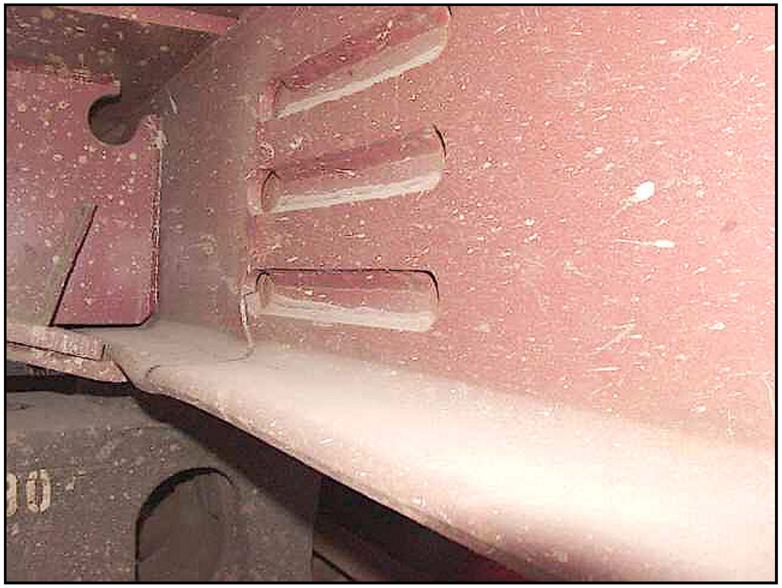
Why Updating is Needed

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

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

Approach Taken / This Task Force's Goals

- Today's Presentation:
  - Why Updating is Needed (Coulborn)
  - **Updating the Fatigue Guidelines and Prioritizing Car Types (Coulborn)**
  - Test Program Funding and Execution (Cackovic)

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
  - 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):

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

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

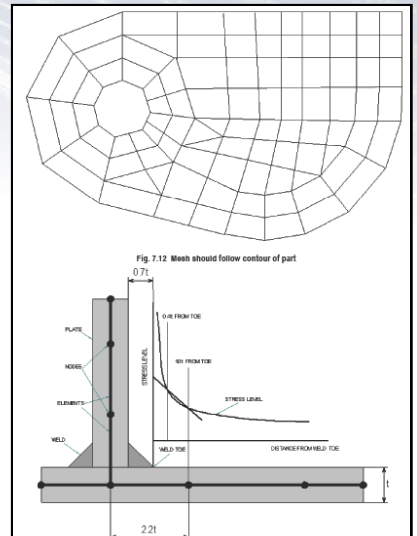


Fig. 7.12 Mesh should follow contour of part

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 (S_e)
CR	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	
CR	36			0.14	15
	50			0.23	15
	100			0.23	15

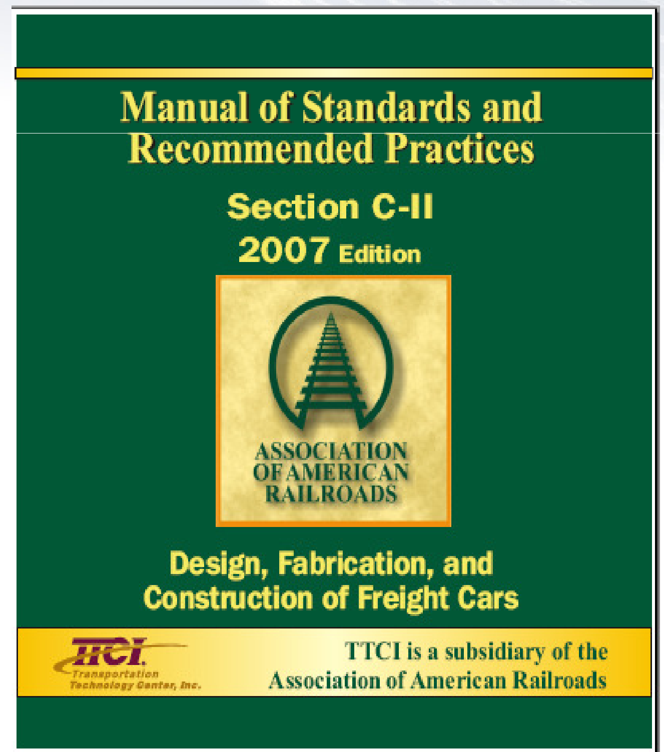
( ) = estimated value

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 Recently 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 (Coulborn)
  - Updating the Fatigue Guidelines and Prioritizing Car Types (Coulborn)
  - **Test Program Funding and Execution (Cackovic)**

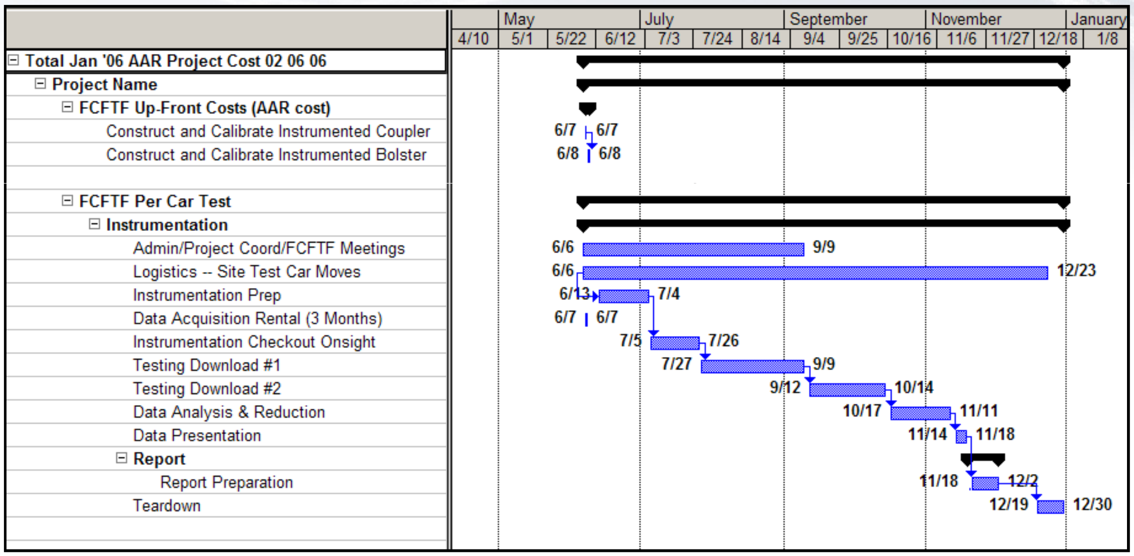
Test Program

Fatigue Test Requirements for Updating Freight Car REPOS (Road Environment Percent Occurence 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.

- 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

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

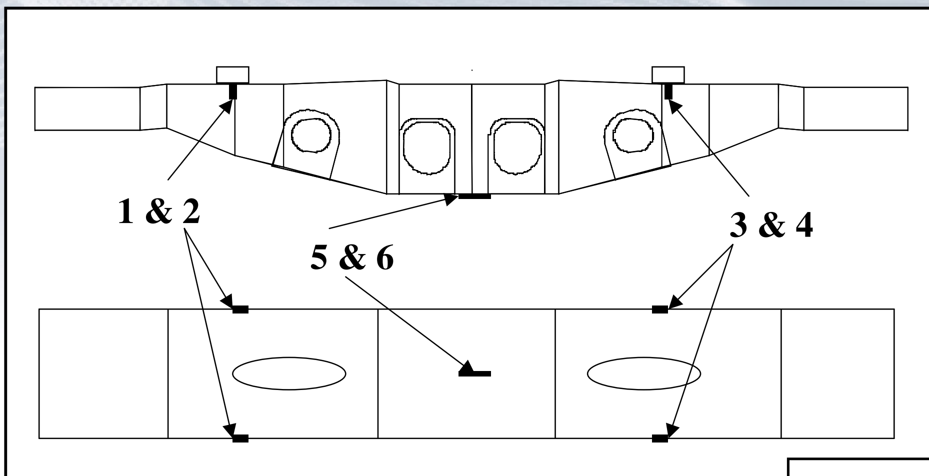
Test Program – Coal Car

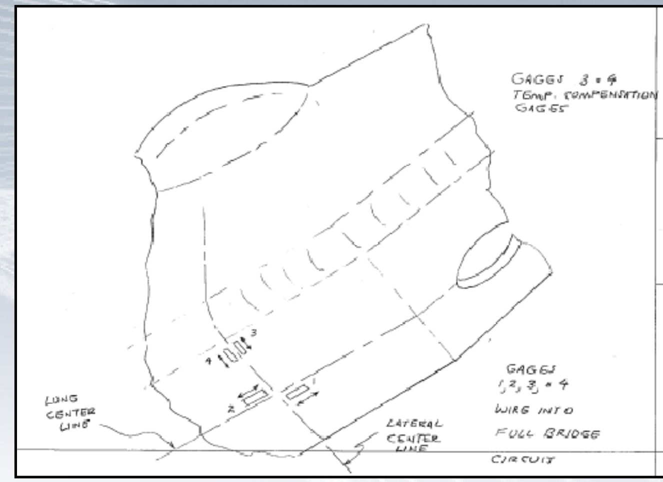
- **SRI 14D Instrumentation**
  - 2 Force measuring wheels
  - 2 Axles to measure strain
  - Accelerations on body both ends
    - One brake valve
  - Brake beam strains
  - Top chord strains
- **FCFTF Instrumentation**
  - Bolster strains and forces
  - Side bearing loads
  - Coupler Force
  - Side frame loads
  - Top chord strains

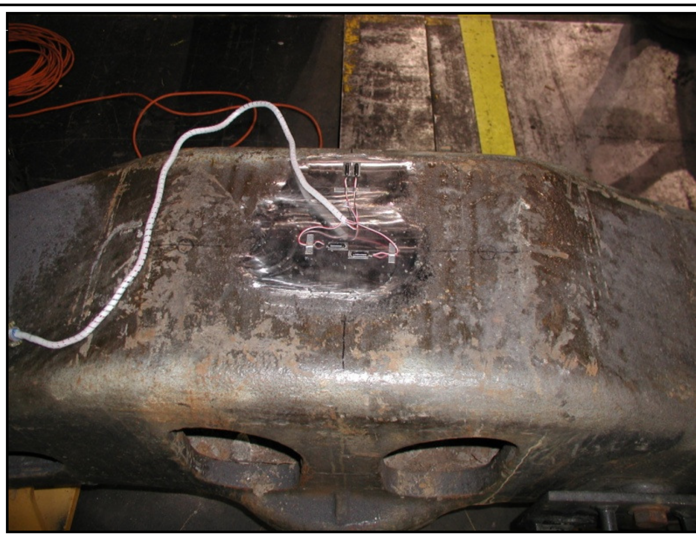
Test Program – Coal Car

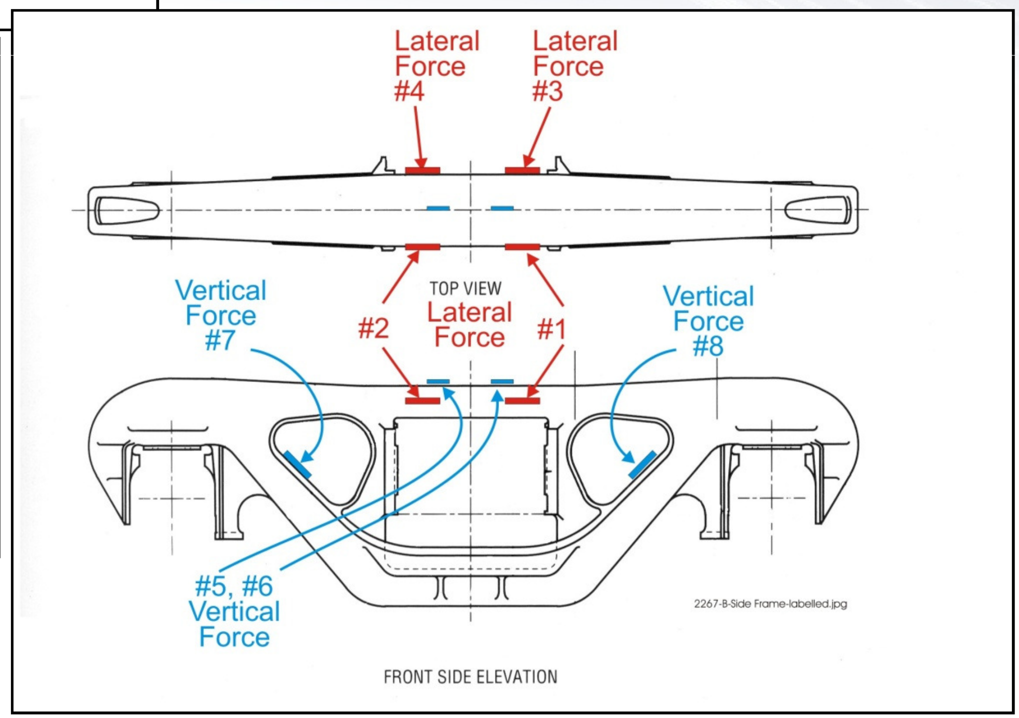
MEASUREMENT	Transducer Type, Comment	Data Type, Analysis
MEASURMENT		
Center Plate Vertical Load	Strain Gage, calibrated in load frame	Time History, Rainflow Cycle Counting Post Test Processing
Side Bearing Load Bridge		
Longitudinal Coupler Load	Instrumented Coupler	
SYSTEM MEASUREMENTS		
Power	System	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





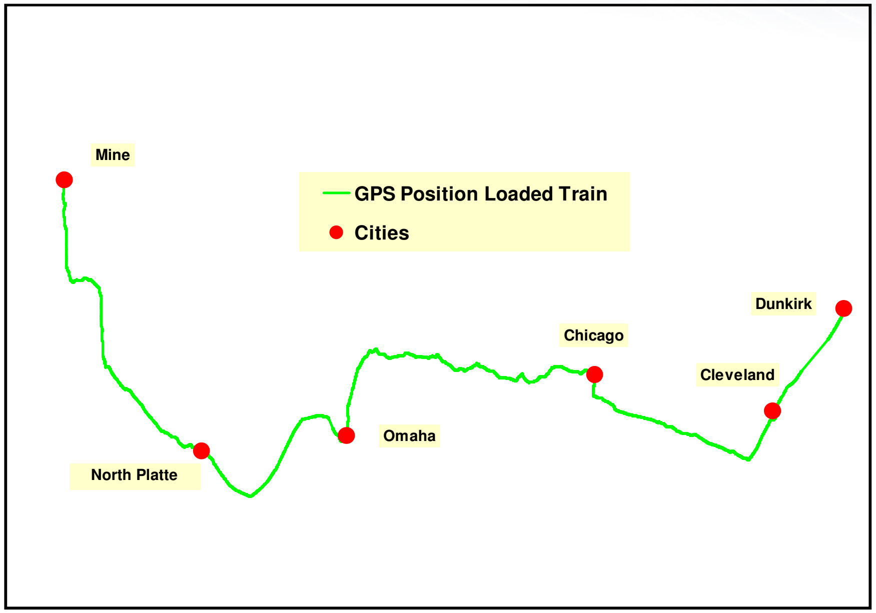




Test Program – Coal Car

- 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.



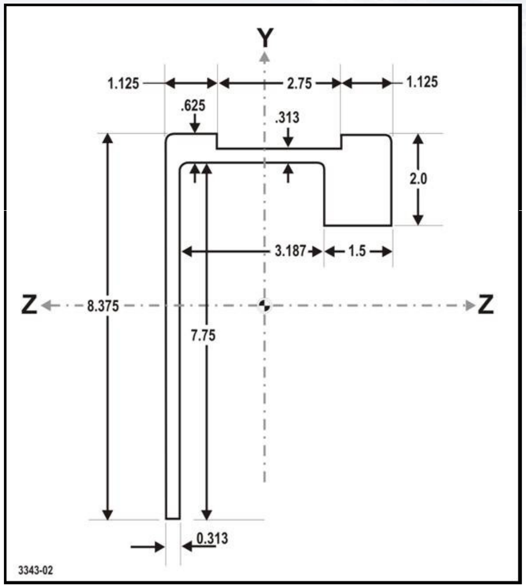
Test Program – Coal Car

- **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

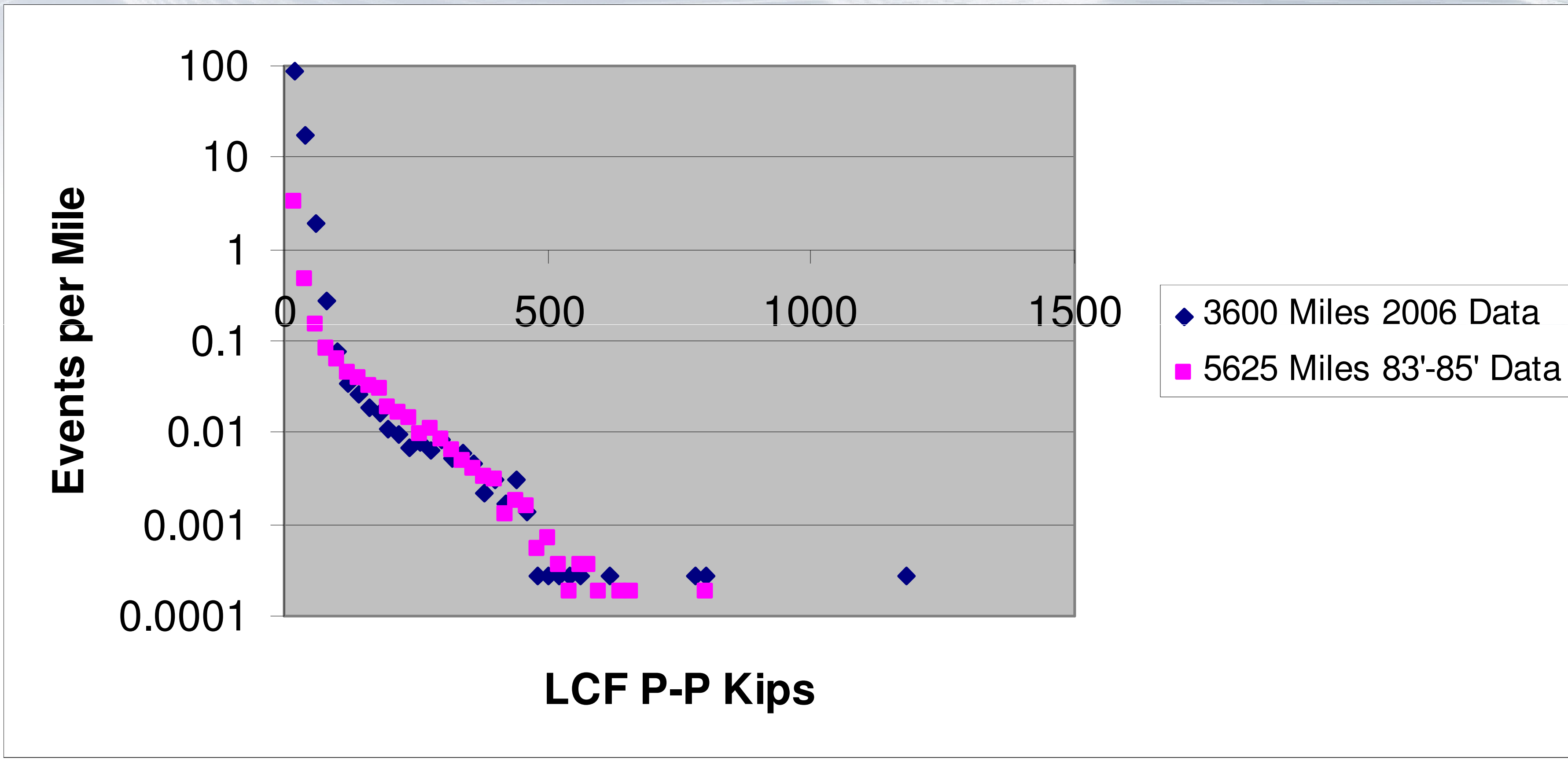
Top Chord



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.				

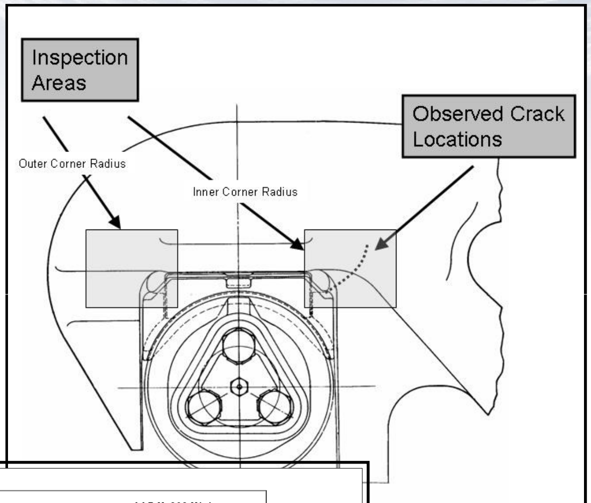
Maximum compressive stress 93% of calculated limit

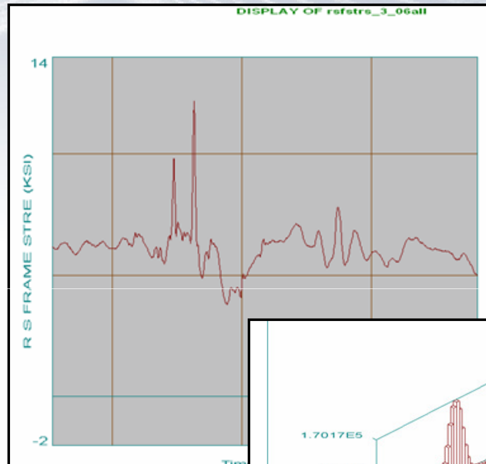
Test Program – Coal Car

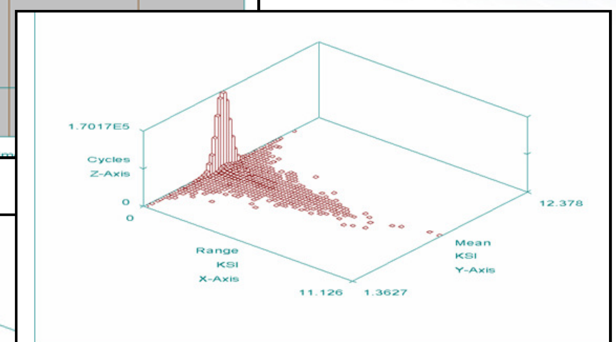


Test Program – Coal Car

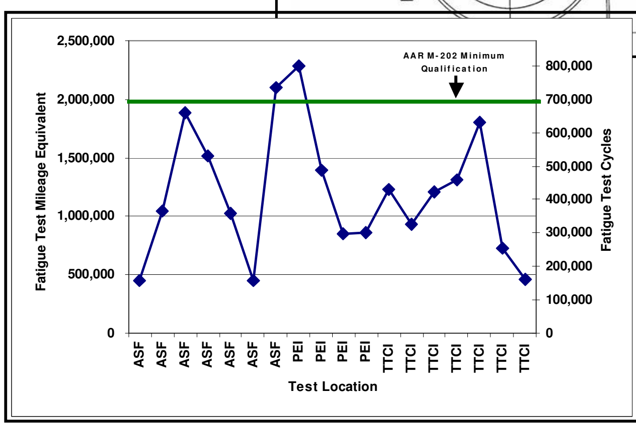
- **Bolster and side frame loads have been useful for AAR Coupling System & Truck Castings Committee (CS&TCC) efforts**

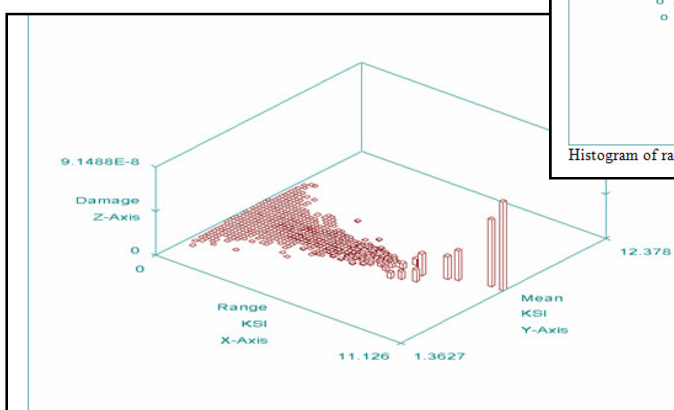






Histogram of rainflow counted stress cycles in critical area – March 5, 2006 PM





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

Test Program – Coal Car

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

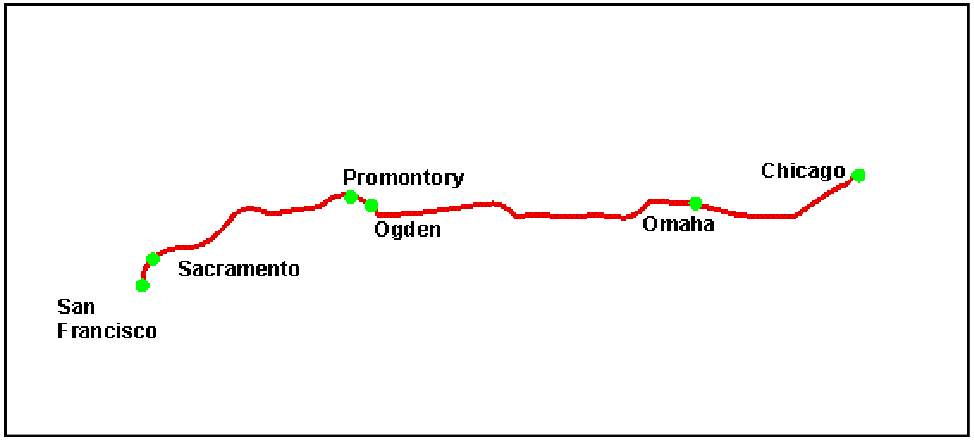
Proposed Draft M-216 Specification
Knuckle Fatigue Test Load Cycles Proposed

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

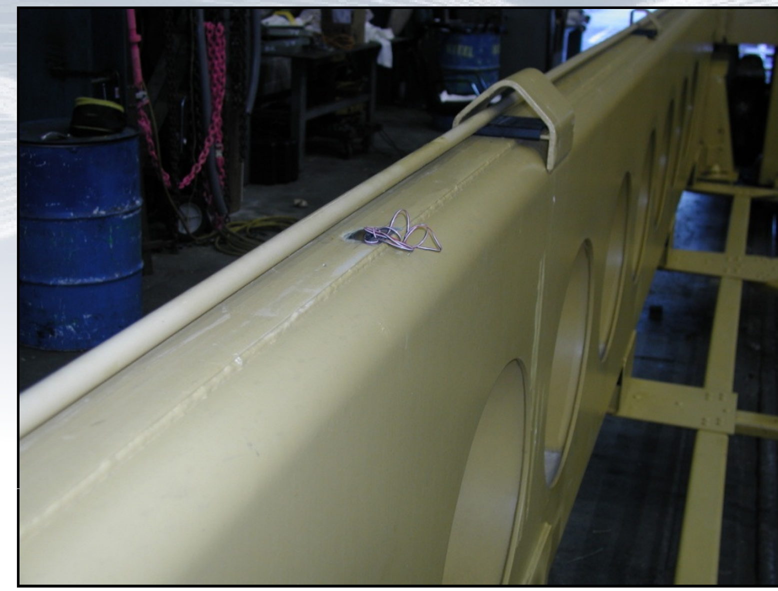
Thanks to NS for significant effort on this test plan development!

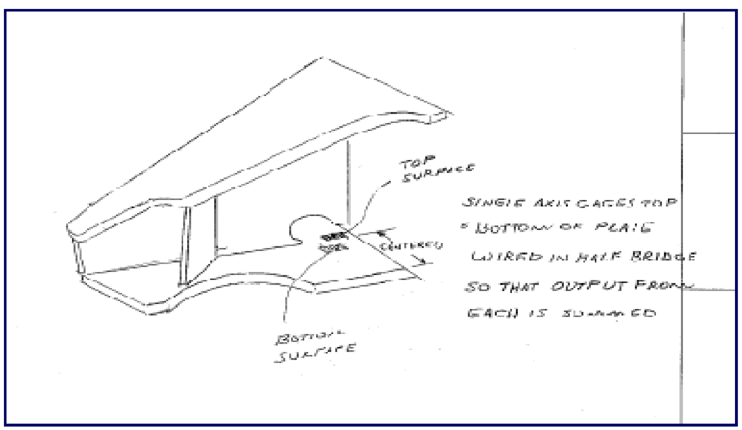
Test Program – Intermodal Car

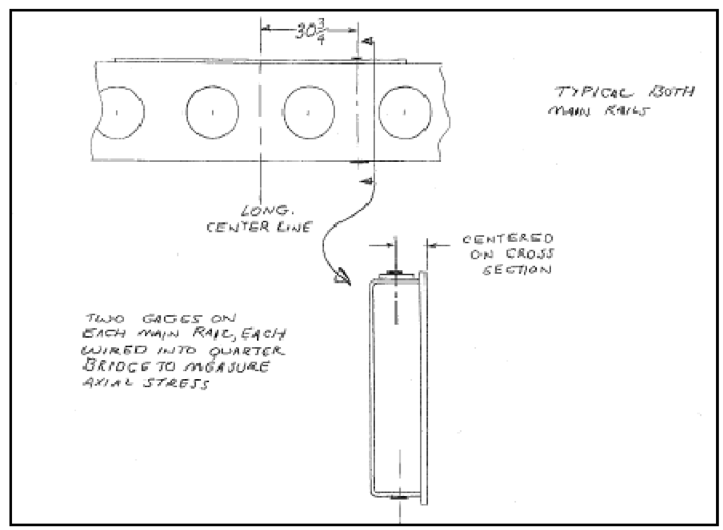
- Instrumentation installed
  - Truck (100-ton)
    - Truck bolster load
    - Side Bearing (brackets)
    - Centerbowl load
  - Car body strain measurements selected by FCFTF members
  - Additional measurements for TTX use:
    - 70-ton truck dynamics
    - Dynamic forces beneath 20 foot containers
- 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







Test Program – Intermodal Car

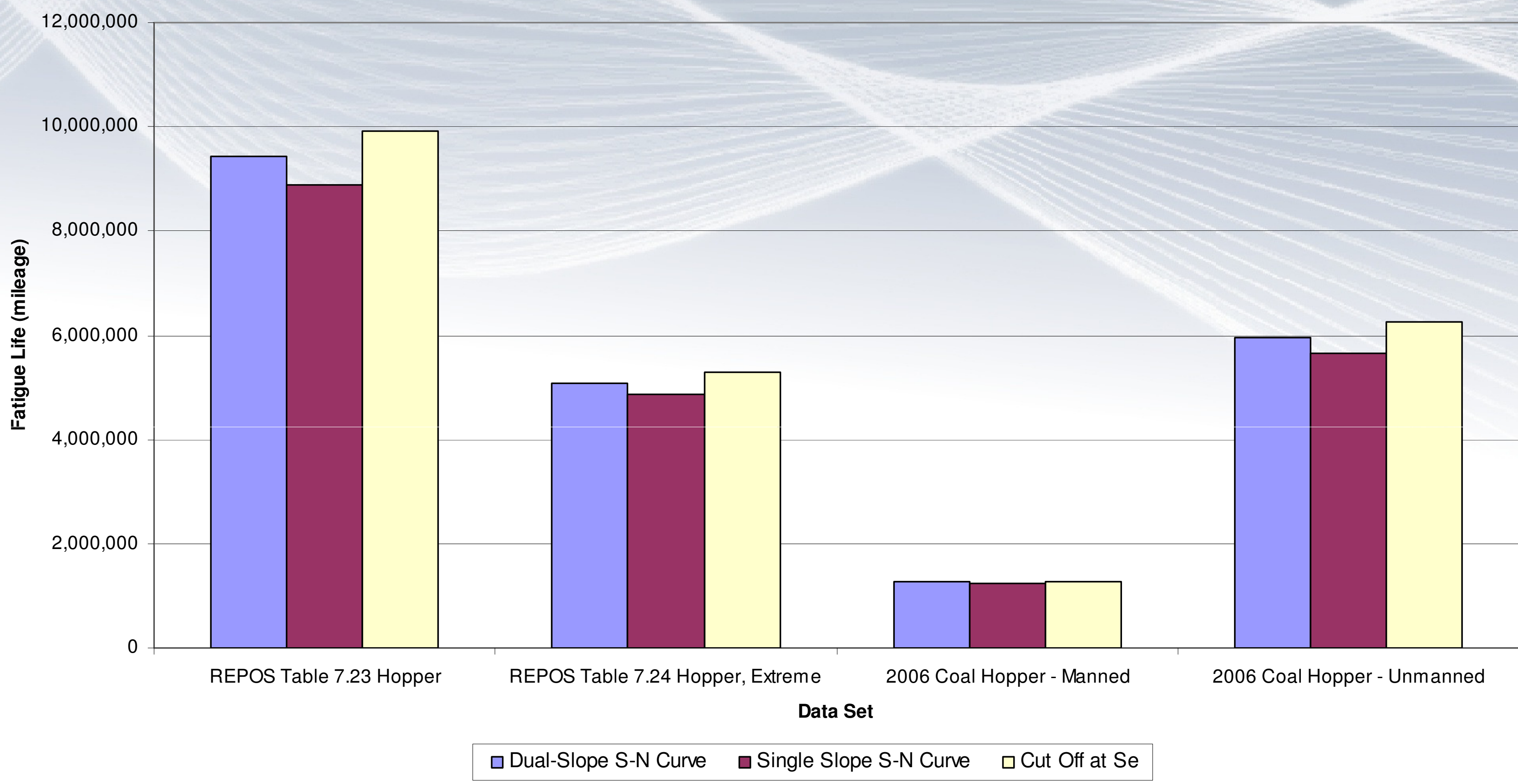
Test Load

- The B end unit held two 40 ft. containers loaded to 62,000 lb. each (total load 124,000 lb.).
- The adjacent C unit held two 20 ft. boxes each loaded to 53,000 lb. and one 16,000 lb. 40 ft. container stacked on top of the 20 ft. containers. The 40 ft. container held 16,000 lb. bringing the total in the C unit to 124,000 lb. This provided a higher vertical center of gravity for the C unit load.
- The other three units held one 40 ft. container each, loaded to 40,000 to 60,000 lb.

Data Validation

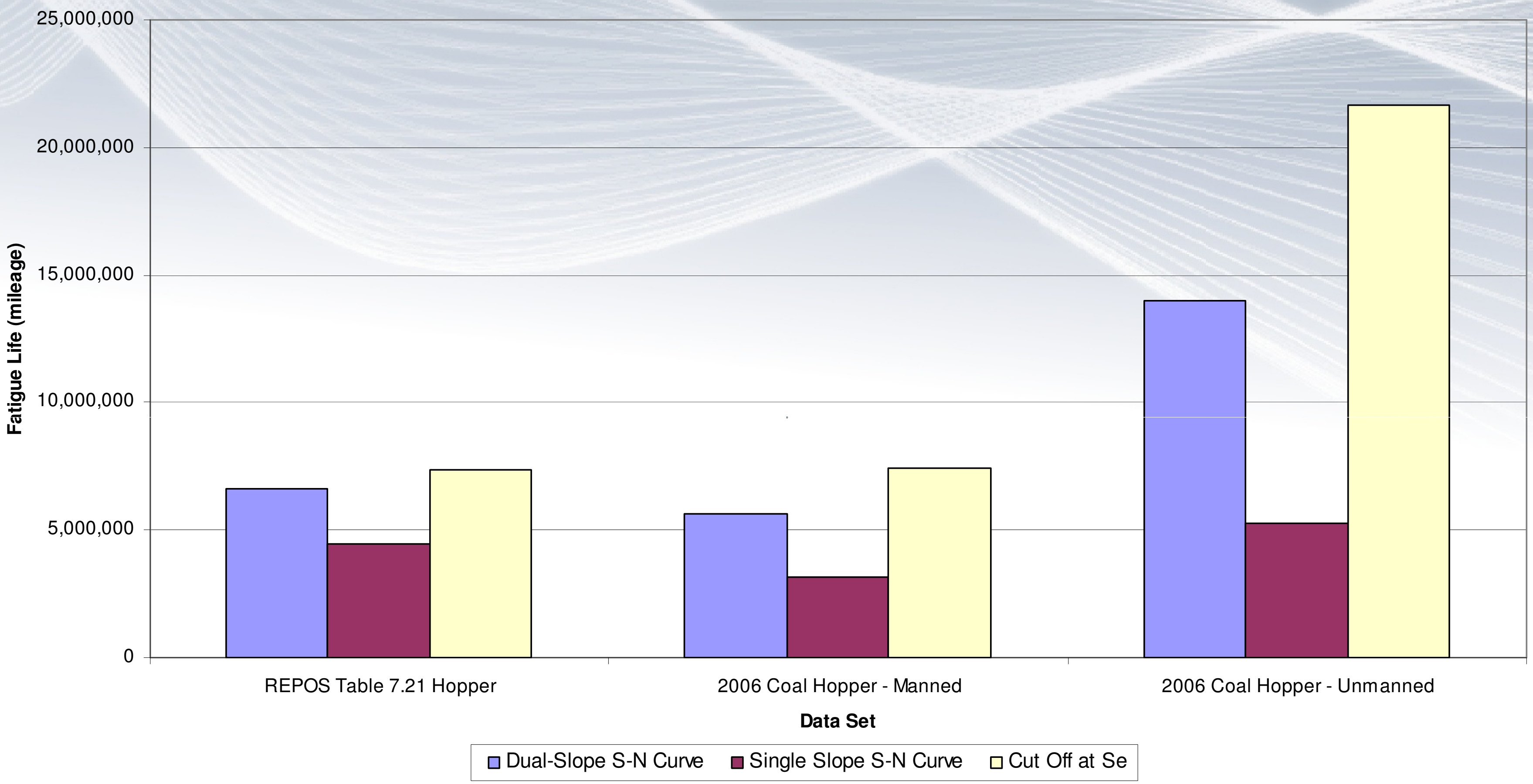
- **Sims Professional Engineers is reviewing fatigue analyzes from builders using various joint designs, unit stresses & test regimes**
- **The analysis/presentation is a first cut at understanding the influences of the variables involved**
- **Chapter 7 techniques were employed unless otherwise noted**

Figure 1: Coal Hopper Coupler Fatigue



Note: Analysis performed per Ref. A

Figure 3: Coal Hopper Bolster Fatigue



Note: Analysis performed per Ref. A

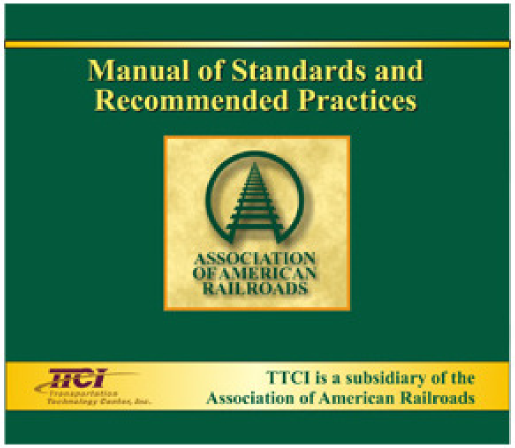
Preliminary Conclusions: Coal Hopper

- **The coupler REPOS from the new manned test is more severe than the unmanned & more severe than existing Ch. 7 similar REPOS.**
- **However, for vertical loads on the bolster, the new manned data is about the same as existing REPOS but the unmanned is not nearly as severe.**

Status: Coal Hopper

- **An AAR Technical Digest report is being compiled summarizing the results of the testing to accumulate coupler force data for this coal hopper. The report will show comparisons of the with the "standard" and "severe environment" data currently in Chapter 7, Section C, Part II, Volume 1 of the MSRP.**

- **FCFTF analysts will meet Friday, September 26, to begin final determination on publishing the coal car results in the AAR MSRPs.**

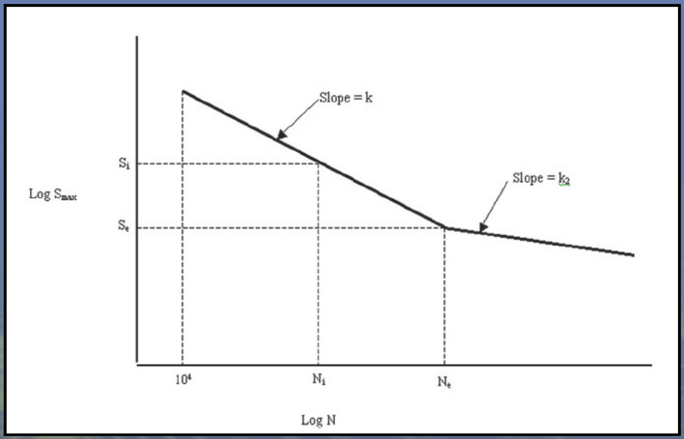


Status: Intermodal Car

- Testing now complete.

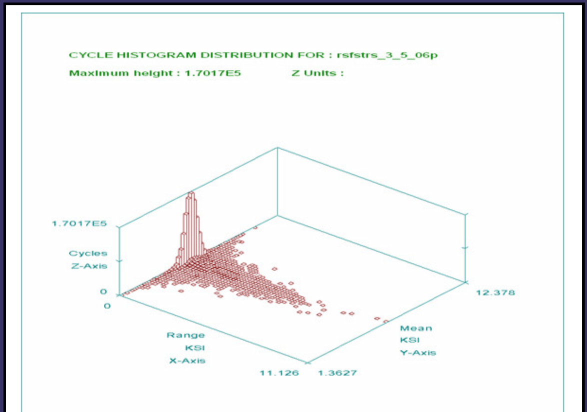
- FCFTF analysts will meet Friday, September 26, to begin final determination on publishing the Intermodal car results.

AAR/ARCI Freight Car Fatigue Task Force II



QUESTIONS?

(TIME PERMITTING)



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