Finding the Australian Railway Load Spectrum

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ABSTRACT

One major challenge facing the Australian rail industry is to reduce the weight of rolling stock without compromising safety or durability. With the use of new materials and innovative design Australian engineers can meet the challenge.

Australian rail freight wagon design, testing and certification have been to the Association of American Railroads Standards which does not account for the significant differences between the Australian and United States environments.

Australian freight wagon bogie structures were strain gauged for vertical and lateral loads whilst the spring nests between the sideframe and bolster were instrumented for deflection. A National Instruments SCXI system umbilicalled to a data acquisition card and a laptop computer using LabView software processed and recorded the data.

An instrumented wagon was included in scheduled Freight Australia rakes carrying goods between Melbourne and Sydney, on the eastern Australian coast, and return. Monash University and Freight Australia staff rode on the train during the acquisition.

The science in this investigation is the fitment of strain gauges which were immune to noise and the data analysis to produce an Australian Spectrum in Road Environment Percentage Operational Spectrum format.

The data has been validated as sound, processed through a Fast Fourier Transformation and filtered to reduce high frequency noise before rainflow pair counting. The Fast Fourier Transformation showed all concentrations of energy were below 40 cycles per second.

The data has been arranged for display as a percentage occurrence distribution and a Road Environment Percentage Operational Spectrum (REPOS) matrix.

Background

Australian rail rolling stock is designed and tested to United States of America rail standards. The American Rocky Mountains are higher and more extensive than Australia's Great Dividing Range so that American designed rolling stock may be over designed for Australian conditions.

Australian rail companies may have been carrying excess weight in freight train wagons wasting payload capacity. To design Australian freight wagons for Australian fatigue conditions, designers must have an Australian Railway Load Spectrum.

Australian Cooperative Research Centre for Rail Technologies, in cooperation with Australian rail industries, agreed to fund a study to examine the prospects of utilizing current advances in design and materials to reduce the weight of Australian freight wagon bogies and wheels. One of the deliverables from that study was the Australian Railway Load Spectrum.

Test Structure

Australian rail freight wagons side frames and bolster experience lateral and vertical loads. Each side frame is a beam at the ends of which are cut-outs to hold bearing boxes, axles and wheels and in the middle of the side frame, a cutout to house the spring nest and the bolster tang. Side loads were measured by installing strain gauges on the vertical webs.

Vertical load measurement was more complex. Sloping tension flanges of the side frames were strain gauged, whilst the slope of strain change across this flange is judged to be small.

As well, the bolster connects the two sideframes together whilst transferring load to the freight car chassis and comprises a simple box beam thickened in the centre to resist bending. Gauges were placed on the tension flange of the bolster, one where the tang emerged from the spring nest and another closer to the area of maximum bending. Figure One is an assembled bogie less wheels and axles instrumented with strain gauges and deflection sensors.

Figure 1: Strain Gauged Test Freight Wagon Bogie

Strain Sensing

The axes of the Road Environment Percentage Operational Spectrum graph have the units of load (Newtons). By recording freight wagon structural strain and calibrating the data against known applied loads, wagon loads for any strains within the material elastic limit can be calculated.

Strain gauges selected on the basis of ruggardness, ease of application and size were attached. These gauges were encapsulated in a clear epoxy pack with the wires sealed into the epoxy for security. The surfaces were meticulousely cleaned and the gauges bonded with cyroacronate glue.

The selected electrical configuration of the wheatstone strain gauge bridge differed for lateral and vertical gauges. The lateral bridges were configured as full bridges and would be exposed to positive and negative strain as the bogie negotiated left and right turns. Two sensing gauges were used in the upper arms of the bridge whilst two dummy strain gauges of the same type formed the lower arms of the bridge, attached to a surfaced steel block, were mounted in the hollow side frame using silicon to prevent any transfer of strain to the dummy gauges.

The gauges mounted to sense vertical loads were attached to the tension surfaces of the sideframes and the bolster. Two gauges in each bridge sensed strain whilst two “dummy” gauges were mounted on surface steel blocks and buried in the hollow of the sideframe using silicon to prevent any strain transfer to the dummy gauges. The two sensing gauges were diagonally opposite thus multiplying the gauge sensitivity by two

Multicore, colour coded cable, was fed from the terminal blocks inside the hollow structure to emegre at the back of the bolster. The cable was shielded and connected to earth at only one end to reduce feedback loops. In the extreme electromagnetic environment of a diesel electric locomotive, the form of shielding employed and the gauge configuration all but eliminated the noise (noise equated to approximately 5 microstrain).

The external strain gauges were protected with silicon then covered with aluminium tape. During service, a strain gauge was hit by flying ballast but not destroyed. The silicon and aluminium tape were replaced, the assembly made water proof and a 16 gauge aluminium top hat shaped section installed over each gauge. Inside the hollow structure, each terminal block and dummy gauge was covered with sheet rubber and sealed as physical and water protection.

Instrumentation

A self contained ruggardised instrumentation system was required to process and store strain gauge and spring nest deflection data.

A National Instruments Signal Conditioning eXtensions for Instrumentation (SCXI) along with a companion instrumentation programming tool, LabView, was acquired. The instrumentation package was configured and programmed.

The instrumentation package comprised:

a. The SCXI chasis.
b. Eight channel universal strain gauge module
c. Eight channel analogue module
d. PCMCIA data acquisition card
e. Laptop Computer

The cabling between the gauges and the SCXI was over 10 metres and considered long. Any calibration using the internal system would have been compromised by the intervening cable length.

Reducing the collected data and eliminating the noise

The data used to generate the loading spectrum in a REPOS array form were obtained during 5 trips from Melbourne to Sydney and return.

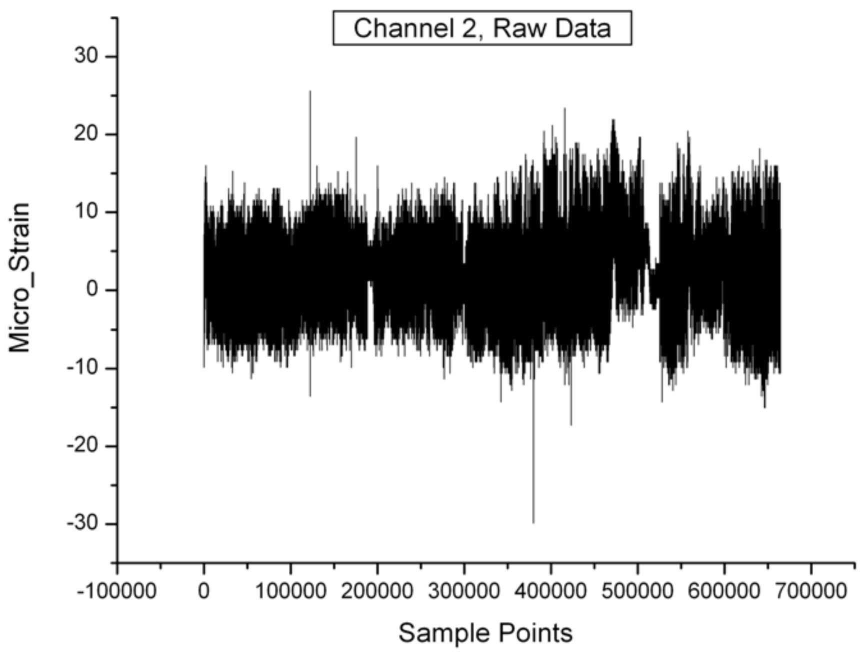

Figure 2. Strain history of gauge 2 on top of the sideframe.

The raw data samples are shown in Figure 2. The data was processed using Fast Fourier Transformation with a sample rate of 0.001 and a Nyquist frequency of 500Hz (see Figure 3). The dominant responses were well below 50 Hz. To remove residual noise, a low-pass digital filter with a “cutoff” frequency of 40Hz was applied. The data contained in the time series were taken at uniform time intervals. The time series must only contain the peaks and valleys with no data points in between. Therefore, a compression method called “peak and valley summary” has been used to delete these intermediate points from the time series, see Figure 4.

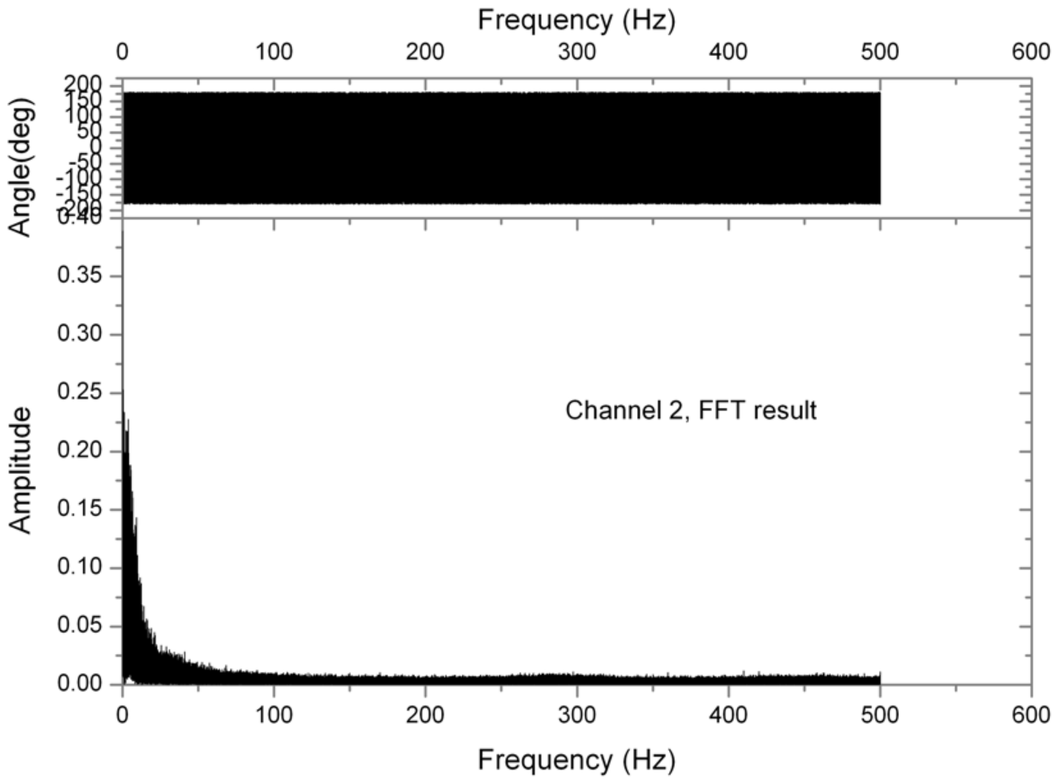

Figure 3 FFT of Channel 2 data

As well, when the train stopped, the instrumentation continued recording and samples of instrumentation noise were recovered. Typical raw data during train stopped times is shown in Figure 5. The noise only amplitude of these signals is very low (about 4~6 microstrain).

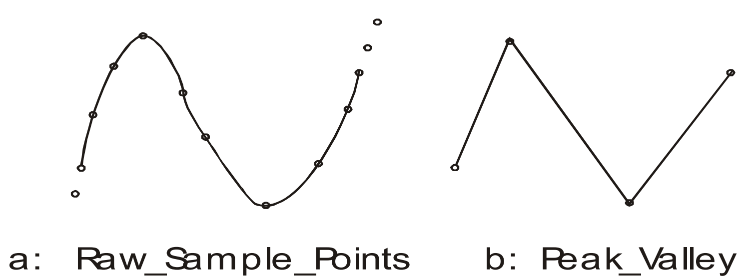

Figure 4. Peak and valley summary technique

The frequency filtering analysis techniques may not be sufficient to eliminate "train stopped" signals and another tool was used to remove this noise. This routine discards any cycles that are below a given a threshold value (The maximum amplitude of "train stopped" signal was chosen to be a threshold value) while retaining the overall sequence of the loading. After eliminating the noise, fatigue analysis was performed on the remaining data (Figures 7 and 8).

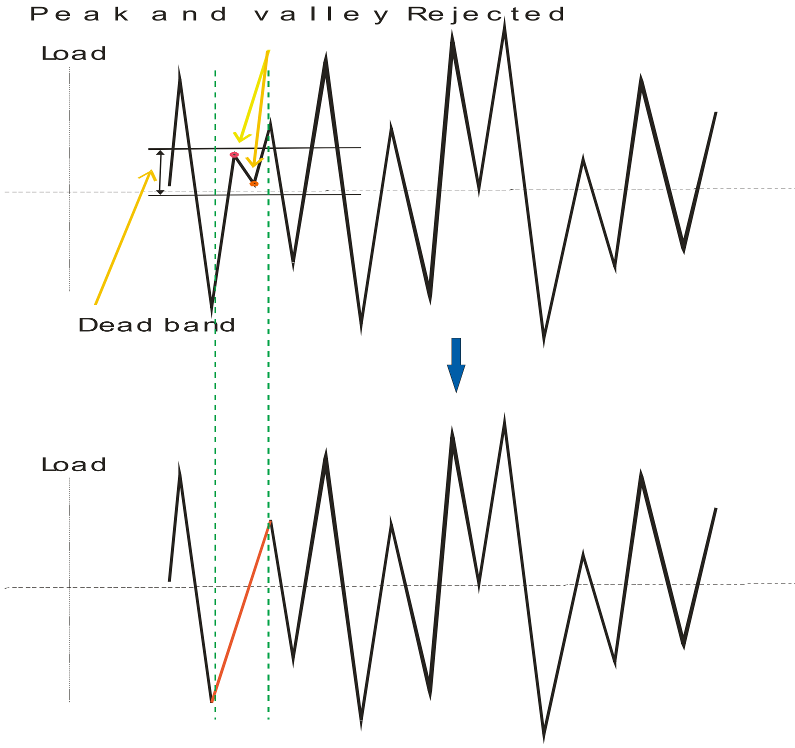

Figure 6. Small amplitude peaks and valleys eliminating

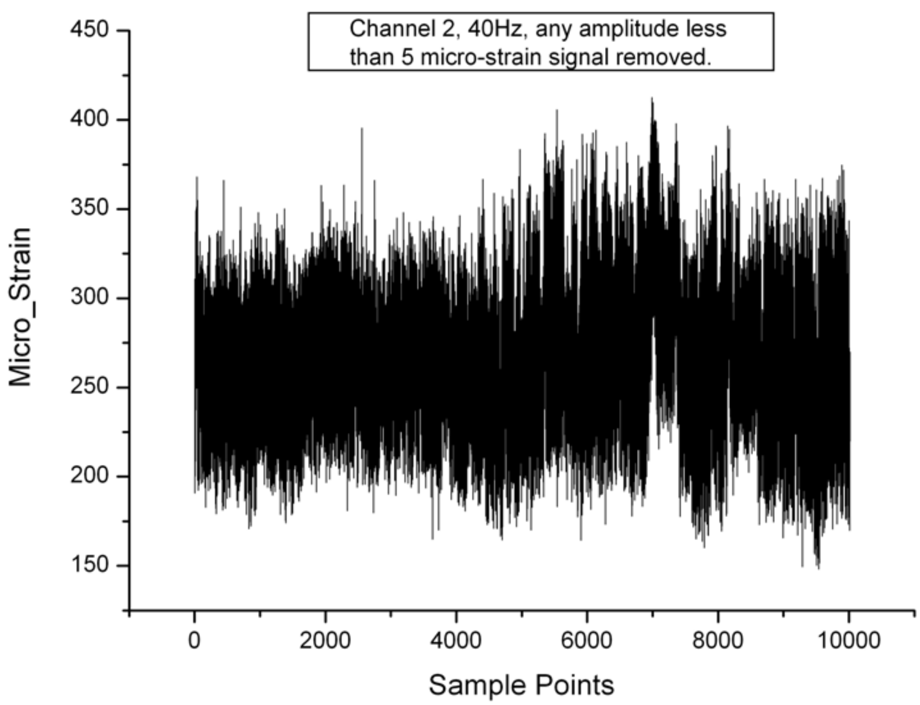

Figure 7. Peak and valley sequence for channel 2 data.

Test Structure Calibration

Strain gauge output was calibrated against known applied loads. Figure 9 gives the calibration results for strain gauge 2 (SG2). Three instrumented bogie calibrations were compared with exceptionally good linearity for each gauge. At 350kN, micro-strain on SG2 was 214. Therefore, one kN will cause 214/350=0.611429□□. For a load of 28.4 tonnes or 284kN, micro-strain will be 173.6457, say 174 micro-strains. For strain gauge 7, the loading convert factor equal to 1.214, i.e., the load of 1 kN on the bolster centreplate produces a predicted 1.214 microstrain at gauge no.7.

Cycle counting procedure

To reduce the cyclic histories to the form required to performed fatigue life prediction, various counting methods have been developed [1], viz: level crossing counting, peak counting, simple range counting, rainflow counting and etc. The rainflow counting [2] is a widely accepted method for the identification of fatigue critical events. This approach used rainflow counting as the cycle counting procedure. The assumption of this method is that there is no difference in the damage causes by a cycle which starts at negative value and goes positive versus a cycle which starts at positive value and goes negative. By using this technique a variable amplitude time history can be reduced to a series of half cycles whose maximum and minimum values are defined.

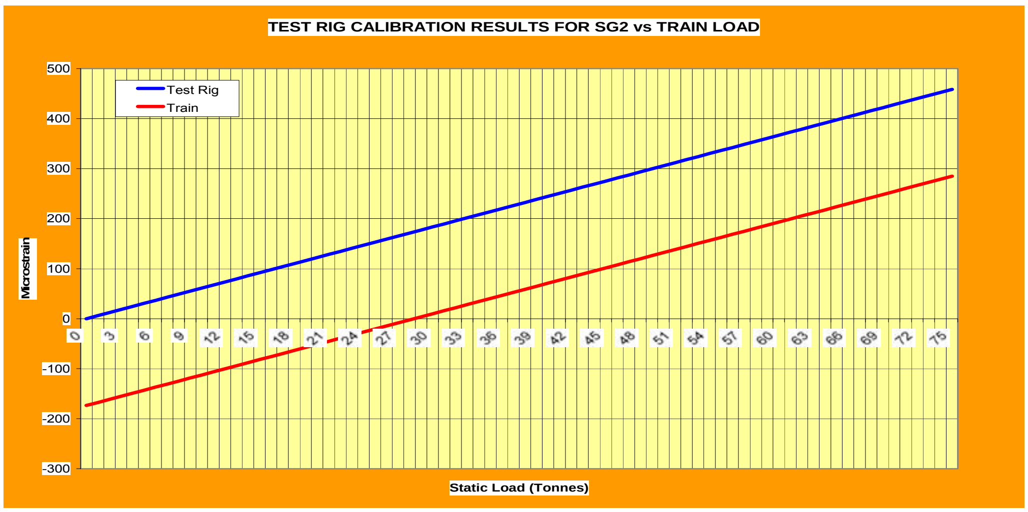

Figure 9. Calibration results for strain gauge 2.

Loading Spectrum

The REPOS array is a three-dimensional folded spectrum by plotting maximum loads versus minimum loads as coordinates. The third dimension entered is the percentage of occurrences with which the cycles are encountered in the environment to each maximum minimum load combination. Folding of the spectrum refers to the operation of transferring the counts (occurrences) into the upper left diagonal portion of the spectrum from the corresponding locations in the lower right diagonal portion. Figures 17 and 18 show the 3D distribution of the percentage of occurrences related to the “Australian Sydney-Melbourne Load Spectrum” represented by the REPOS arrays as shown in Table 1 and Table 2 respectively.

Assumptions are:

- The data (used to generate the REPOS array) from the strain gauges was filtered to 40Hz, and any signals with an amplitude less than 5□ε were removed.
- All REPOS arrays only represent the vertical loading cases.
- The results listed in both Table 1 and Table 2 were created by 5 run's data from Melbourne to Sydney.

A mean-range histogram contains a full cycle accumulation for a range-mean ordered pairs. The blocks spectrum is created by blocks of constant amplitude cycles.

Table 2: REPOS matrix of bolster under vertical loading

KN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
900																															1
870																															2
840																															3
810																															4
780																															5
750																															6
720																															7
690																															8
660																															9
630					0.00078																										10
600																			0.00078												11
570			0.00078				0.00078																								12
540						0.00078	0.00078	0.00078																							13
510					0.00078	0.00392	0.00235			0.00157		0.00157																			14
480				0.00078	0.00392	0.02978	0.0572	0.02508	0.00313	0.0047	0.00157	0.00157	0.00627	0.00392	0.00078																15
450					0.02586	0.12694	0.3346	0.33146	0.09482	0.05172	0.0384	0.04623	0.04545	0.01175																	16
420					0.0862	0.42393	0.93169	1.35248	0.67311	0.3346	0.27818	0.28758	0.10422	0.00627																	17
390					0.15985	1.34073	2.1447	2.83113	2.09847	1.25297	1.0845	0.47016	0.02978																		18
360				0.00078	0.12224	2.1588	3.87879	4.0551	3.91092	2.78803	1.21222	0.07836																			19
330			0.00235	0.00078	0.06661	1.82813	4.87004	5.42718	4.83086	2.17996	0.15672																				20
300			0.03761	0.0525	0.03448	1.08998	4.36854	5.91144	3.03565	0.23508																					21
270			0.08463	0.67624	0.31187	0.74285	3.00665	2.65717	0.24213																						22
240			0.05485	2.1063	2.19955	1.53663	1.41596	0.21706																							23
210			0.01411	1.86182	5.06202	2.47146	0.35575																								24
180			0.00313	1.03278	2.95494	0.93483																									25
150			0.00313	0.20217	0.36202																										26
120			0.00157	0.00313																											27
90																															28
60																															29
30																															30
		30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600	630	660	690	720	750	780	810	840	870	KN

β = 36.1 (CYC/KM)

Conclusion

A method of collecting strain data and a methodology for assessing operational load spectra in REPOS format have been developed. As well, a range of analytical tools and computer software that can be used for assessing the remaining life of ageing sideframes or bolsters has been developed. For complex components with rapidly varying stress fields, the stress life technique should be related to the time to crack initiation. Those techniques cannot provide information on the fatigue life of a rail structure because the total fatigue life of a structure depends explicitly on the stress field through which the crack will grow This was not considered in this evaluation. In addition the linear damage approach involved in a stress life method may not give a reliable total life as load interaction is not considered. Therefore, the approach developed by AAR in [3] for life prediction has several limitations. In contrast, the **FAST** program is built on fracture mechanics. It is believed that **FAST** is a proper tool for predicting the fatigue life of rail structures

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