TECHNOLOGY DIGEST
Timely Technology Transfer

A NEW APPROACH TO THE FATIGUE ANALYSIS OF CAR STRUCTURES

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Summary

An innovative, low cost methodology to generate longitudinal coupler force and vertical bolster load environment data has been developed by the AAR. This methodology will be used in proposing an alternate approach to the fatigue analysis of freight car structures. The proposed approach will provide significant cost and time savings over the current requirements in the AAR M-1001 Standards. In addition, this approach will facilitate the fatigue analysis of car structures to be conducted in the pre-prototype stage and promote better safer designs to be introduced in revenue service. As part of the methodology, when finalized, a set of representative revenue track routes as well as track geometry files will be provided. A car designer and builder can use these files as inputs to the simulation models. The outputs will produce car design and car type specific fatigue load environment spectra which can then be used for fatigue analysis.

The bulk of the methodology relies on simulation models along with an initial use of revenue test load environment data for validation purposes. The technique to generate coupler forces uses a combination of the Train Energy Model (TEM) and Train Energy Operations Simulator (TOES). The technique to generate vertical bolster loads uses a family of measured track geometry processing software routines and the vehicle dynamics model, New and Untried Analytical Car Regime Simulation (NUCARS).

In its initial stage, the methodology addresses fatigue damaging longitudinal impact and train action forces as a separate feature. The damage causing track geometry parameters, currently limited to vertical irregularities, are treated as a separate feature. The final version will incorporate both of these features as an integral part of the overall methodology.

A preliminary set of test data and simulation results are provided to confirm the validity of the methodology. Further work includes a final validation and demonstration effort by conducting a revenue service test in 1995.

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INTRODUCTION AND CONCLUSIONS

The AAR Manual of Standards and Recommended Practices, M-1001, Section C - Part II, Chapter VII, details the required fatigue analysis of freight car structures. The analysis uses the appropriate fatigue load environment data collected for various car types. The environment data presented in the form of REPOS (Road Environment Percent Occurrence Spectrum) was measured during revenue service tests. Load environment data was collected under the Freight Equipment Environment Sampling Test (FEEST) program. The data was collected for five car types over several thousand miles of revenue service track.

The current methodology depends on the availability of load environment data collected by conducting revenue service tests which are time consuming and expensive. For each new design or a non-typical car type, a load environment REPOS is required to perform the fatigue analysis. Advances in rolling stock design and changes in train make-up and handling practices have created a need for load environments for car types and service beyond the available FEEST data. To meet this need, a more time and cost effective approach is being developed by the AAR to be recommended as an alternative to field testing.

The new approach is based on the use of easily available track geometry (vertical and lateral rail profile) and track chart (route profile) data and judicious use of AAR's well documented and industry supported simulation software packages, NUCARS, TEM and TOES.

NUCARS (New and Untried Car Analytical Regime Simulation) is a multi-body system for the analysis of rail vehicle transient and steady state response.

TOES (Train Operation and Energy Simulator) is a structured program capable of modelling the longitudinal dynamics of conventional and integral trains.

TEM (Train Energy Model) is a train performance simulator designed to predict fuel consumption for any train on any route. Although TEM is not a train-action model, like TOES, it provides the user with an estimate of the coupler force distribution in a train. It also provides train handling commands which can be used in TOES.

This approach will permit fatigue analysis to be conducted before a prototype is built and/or during a re-design of a car structure. The methodology for longitudinal environment identification is based on the use of TEM and TOES. The methodology to generate load environment for vertical bolster loads is based on the use of NUCARS. Future plans are to include the capability to extend this to any component in the car structure.

The following conclusions can be drawn from the longitudinal coupler force based effort:

- TOES can be used to calculate longitudinal coupler force load environments.
- Total route simulation appears to have greater potential than simulations using selected discrete events for capturing the majority of the significant load cycles.
- TEM can be successfully used to generate reasonable train handling for TOES for the calculation of load environments.
- Simulating proper train handling is necessary in order to obtain an accurate load environment.
- The distribution and amount of free slack is a key factor in the prediction of accurate coupler forces.

The inclusion of impact generated forces is necessary to provide the proper environment. The following conclusions can be drawn from the track geometry based effort:

- A set of processing software routines has been successfully implemented to reduce hundreds of miles of track geometry data into manageable synthesized files to be used as input for simulation models.
- Actual speed used in the simulations needs to be matched with the test data speeds for accurate

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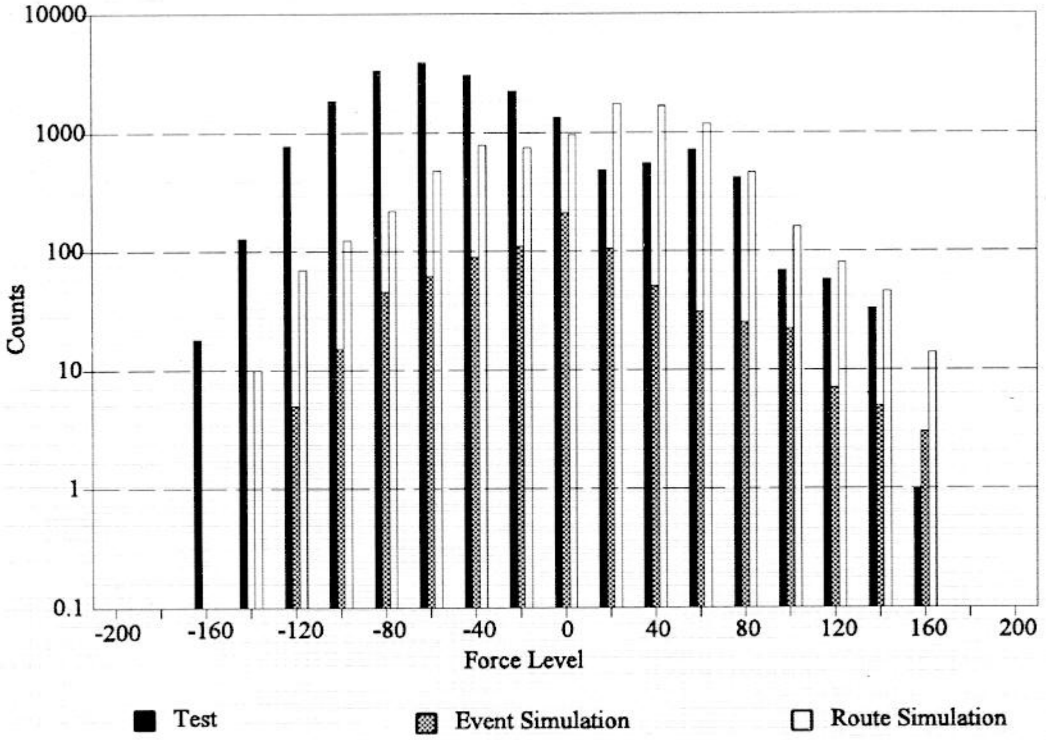

EXHIBIT 1. DRAWBAR FORCE OCCURRENCES

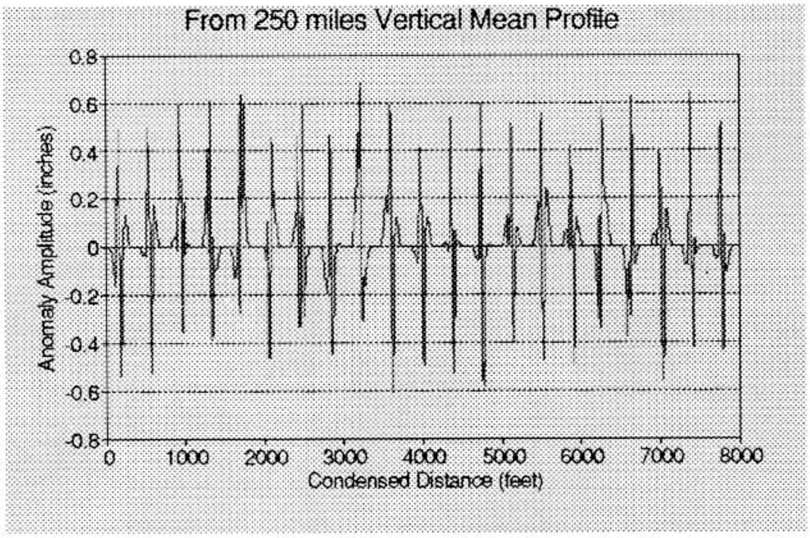

EXHIBIT 2. SYNTHESIZED TRACK

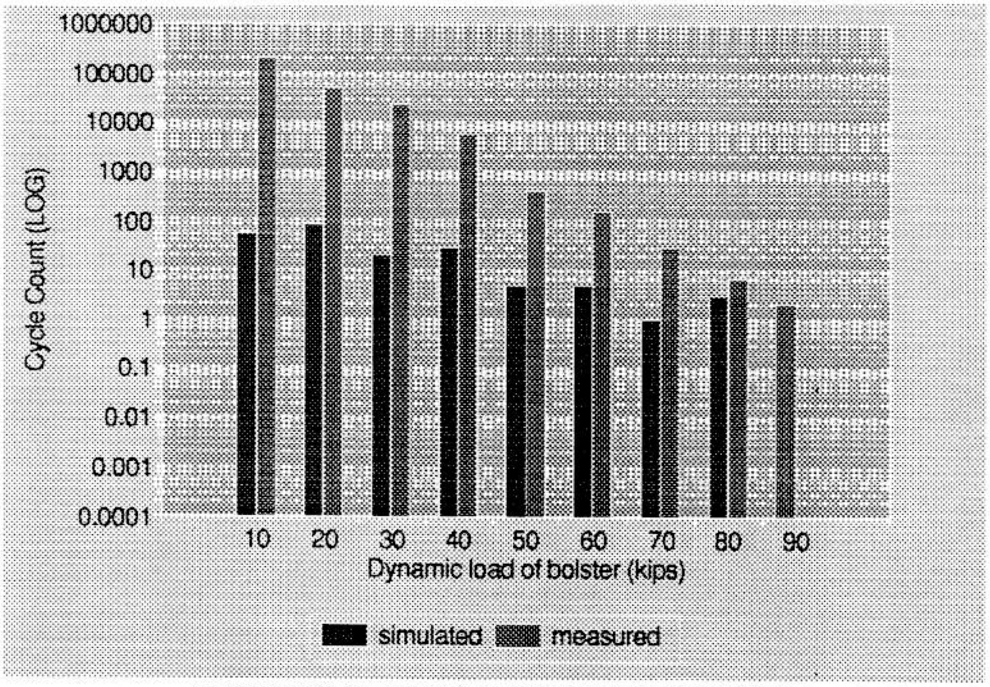

EXHIBIT 3. DYNAMIC LOAD COUNTS

Note: Contact Firdausi D. Irani (312) 808-5830 with questions or comments about this document.

A more detailed report, which may contain revised information, will be available at a later date through the document distribution center, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. A report list is available upon request.

simulation results.
- Preliminary results show that the vehicle vertical load environment, necessary for vehicle component fatigue analysis, can be generated by numerical simulations with little or no revenue service testing.

Longitudinal Train-Action Force Based Fatigue Analysis

An overview of the analysis:

1. Simulate the train over the desired route with TEM.
2. Convert the train handling in the TEM output file to TOES format.
3. Simulate the train with TOES to obtain peak-valley (REPOS) coupler force in any car in the simulated train.

In order to include yard impacts, an approximate number of impacts per route mile and the associated speed of yard impacts is required. This data will be made available in the future allowing inclusion of yard impact simulations in TOES. The latest release of TOES does not include a means to automatically handle the train. TEM does have an automatic train controller and that train handling output can be used as input to TOES. Additionally, TOES was modified to identify the peak-valley coupler forces.

There are two ways to obtain the peak-valley coupler force counts. The first method assumes that the significant cycles for fatigue analysis occur only in discrete events which are due to terrain and train handling changes. TEM provides an estimate of the coupler force at all drawbar locations. The events can be located by comparing the change in coupler force between two adjacent output intervals with a user defined coupler force threshold. Only these events need to be simulated in TOES, and the cycle counts from all events summed to obtain a composite "significant" load environment.

The drawback with this technique is that the coupler force may change slightly slower than the time interval between calculated output steps. Thus it is possible that the resulting coupler force change, calculated over several simulation steps would not produce a "significant" result. A computer program to search the TEM output file for these coupler force changes was written in order to automate the process. The final step is to determine the amount of time which would be required before and after the event in order to capture a meaningful portion of the load cycles. It may turn out that some events lie within the selected simulation duration, and hence two or more events may be combined into a composite event.

The second method is to simulate the entire route in TOES. The advantage here is that all cycles are captured, except for the small stick-slip variations in the draft gears, which cannot be modelled. The disadvantage is that the amount of time required for a simulation of this duration is considerable, although less than performing an actual revenue service test.

COMPARISON WITH MEASURED TEST DATA

Revenue service test data from a previous TOES validation effort was used to demonstrate the validity of the new methodology. The test was conducted for a mixed intermodal train consisting of 70 cars. This train was 7400 feet in length and weighed 5733 tons. The train contained 5-pack doublestack, piggyback, and end-of-car cushioning unit-equipped autoracks. The coupler force was measured continuously at the head-end drawbar and mid-train.

The load cycles for the measured coupler force data were tabulated. Total route simulation, as well as discrete event simulation, was used for calculating the load cycles using TOES and TEM. Exhibit 1 shows the comparison of the peak force occurrences for these two methods with the measured counts. It can be seen that the event simulation method under predicts the number of cycles for all levels. The route simulation method under predicts the number of cycles in the buff region (negative coupler force), but slightly over predicts the draft cycles.

The discrepancies in the number of counts for the route simulation method are due to three key differences:

1. the train handling is not identical with the actual train handling,
2. the amount of free slack in each coupler is not known precisely, and
3. yard impacts are not included.

It is expected that if the train handling was simulated identically the number of counts predicted by TOES would more closely match the measured coupler force counts.

Track Geometry Based Fatigue Analysis

This part of the approach addresses the generation of vertical load environment for any rail vehicle due to vertical track irregularities. It enables the designer to perform the appropriate fatigue analysis. In order to collect track geometry data (vertical profile, cross level and gage) and car response data (vertical bolster, side bearing and center plate loads) for a preliminary validation of the technique, a 636 mile revenue service test was conducted.

A series of software programs were used to identify significant anomalies (user defined thresholds of vertical rail irregularities) in the 636 miles of measured track data. The same set of programs were used to string together the identified anomalies to form a synthesized track which is approximately 8 miles long.

A full vehicle/suspension simulation model was developed using NUCARS for the vehicle used in the validation test.

PROCEDURE FOR GENERATING VERTICAL BOLSTER LOAD ENVIRONMENT

An overview of the procedure to estimate the significant (fatigue damaging) load cycle count consists of the following four steps:

1. Vertical anomaly identification
   a. Identify all measured vertical track surface anomalies which exceed certain user defined thresholds. This was set to 0.9 inch peak to peak vertical track surface deviation for results shown in Exhibit 3.
   b. By using another program, each identified anomaly is viewed and automatically strung together to form the synthesized track, Exhibit 2.
2. Vehicle model
   NUCARS system model was developed for the test vehicle (box car on 70-ton trucks) whose vertical response was measured for the 636 miles of track. The vertical response of this model was validated by comparing the measured and simulated responses at selected sections of the test track.
3. Vehicle simulation
   The synthesized track in Step 1 was used as an input to the vehicle model in Step 2 for a dynamic simulation using NUCARS. The vehicle's simulated speed was adjusted to the measured speed of the test vehicle while traversing each anomaly.
4. Rainflow cycle counting
   Using a rainflow (peak/valley counting routine) program, the number of cycles at each user specified (peak to peak) load level were counted. This was done both for simulated and measured vertical bolster loads.

Exhibit 3 shows the counts from the measured and simulation generated vertical bolster loads. In Exhibit 3, it appears that for large magnitude loads the cycle counting from test and simulation match favorably. The low magnitude loads (such as 10 to 20 kips peak to peak) do not compare as well. Future simulations will reduce the vertical profile anomaly threshold (from 0.9 to 0.5 inch) which should lead to a better fit for the low as well as the high bolster load magnitude cycle counts.

Future Work

The AAR plans to further refine the methodology and demonstrate its validity by conducting a full train test in 1995. Recommendations for a more cost and time efficient approach will be made to the appropriate AAR committee to be included as an alternative to the use of load environment data obtained by field tests.