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Modeling Imbalanced Loads

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Summary

Imbalanced loads and overloaded trucks cause increased stress on the railroad infrastructure as well as various car components. In 2006, the Transportation Technology Center, Inc., (TTCI), Pueblo, Colorado, launched an Association of American Railroads (AAR) sponsored Strategic Research Initiative for the purpose of determining an acceptable level of imbalance for cars operating in interchange service. The first step quantified the existing state of imbalanced loads for freight traffic.[1] The present study looks at NUCARS® modeling as a means to determine the limits of extreme imbalance or AAR condemnable notification limits. Future studies will include economic analysis of the effects of imbalanced loads and overloads. Models representing a matrix of imbalance were generated for three different car types. These models were run through a series of track geometry conditions representing AAR Chapter XI[2] perturbations, special trackwork, bridge approaches, and varying curvature. Preliminary findings from this analysis are as follows:

- Side-to-side imbalance of 21 percent for twist and roll modes of excitation will result in wheel lift
- End-to-end imbalance of 16 percent will cause wheel lift at 60 miles per hour in pitch and bounce excitation
- Overload of 14 percent results in dynamic wheel load factors exceeding 150 percent of normal dynamic load, as compared to the same vehicle when balanced

Imbalanced loads are an industry-wide concern with economic implications. The Imbalanced load project ultimately will determine a maximum tolerable imbalance and propose a guideline based on these findings. The analysis in this report is limited to 4-axle freight rail cars. While it is recognized that multi-platform intermodal traffic represents a significant portion of North American rail traffic, the results reported here do not include this type of traffic. TTCI will investigate multi-platform cars at a later time.

INTRODUCTION

Recent efforts in the railroad industry have focused on reducing the stress state in the railroad system. Work done in 2005 demonstrated that imbalanced loads could increase the dynamic forces imparted to the rails.[3] Imbalanced loads can have many of the same effects as overloads on track and bridge components and on vehicle components such as axles, bearings, side frames, and bolsters. The present research initiative is to determine the maximum tolerable imbalance and to suggest a guideline based on these findings. This step uses modeling to determine the forces and wear indices that result from imbalanced loads.

Two levels of notification are considered. The AAR condemnable limit represents significant imbalance conditions that should receive prompt attention. This could be considered for adoption as an industry standard. An Opportunistic Repair imbalance relates to an economic threshold. Actionable Threshold criteria may serve as a limit value for statistical control measures. Opportunistic Repair criteria are also suggested as a best practice to limit the degrading effects of imbalanced loads.

The state of imbalance is a direct function of how the lading is placed in the car. Two types of imbalance are defined in this study: side-to-side (STS) and end-to-end (ETE) imbalances. A STS imbalance occurs when the wheel forces on one side of the car are greater than on the other side when measured on tangent track. A STS imbalance will have a negative effect on vehicle steering and roll dynamics. An ETE imbalance occurs when the total truckload on one end of the car is greater than that on the other end. Excessive ETE imbalance may result in increased dynamic loads similar in effect to overloads.[3]

AAR CONDEMNABLE CRITERIA

The AAR Chapter XI guidelines were used as the primary consideration for AAR Condemnable criteria.[3] The guidelines represent the industry's best practice for determining acceptable dynamic behavior of rail vehicles. Several typical rail vehicles were modeled with increasing STS and ETE imbalances. Car types were transverse coil, mill gondola, and open top hopper. Worsening regimes were modeled until the Chapter XI criteria were exceeded. Table 1 summarizes the worst case results for all three body styles.

It should be noted that, for the sake of modeling, certain parameters were varied in ways that do not represent common practice. The results thus obtained should be viewed as typical of any car with similar parameters (truck center spacing, center of gravity (CG) height, body mass, and suspension).

Table 1. Maximum Allowable Imbalance before Exceeding Chapter XI Criteria

Regime	ETE	STS	Critical Value
Pitch and Bounce	16%	34%	ETE min Vertical
Twist/Roll	>35%	21%	STS min vertical
Dynamic Curve	26%	28%	ETE min Vertical
Yaw and Sway	>35%	38%	STS min vertical
Curve Entry Spiral	>35%	34%	STS min vertical
Curve Exit Spiral	>35%	41%	STS min vertical
Constant Curving	>35%	41%	STS min vertical
Hunting	>35%	>45%	N/A

Dynamic curving and pitch and bounce are the two situations most sensitive to end imbalance. The models were run with the heavy end both leading and trailing. Generally, there was not a significant difference between these cases. The imbalance levels reported in Table 1 represent the worst case from the three vehicle types tested.

One notable exception must be understood regarding the explicit worst case data. The Chapter XI pitch and bounce and twist and roll track inputs are based on a 39-foot rail with low joints. As this configuration is no longer common on mainline track, it was deemed acceptable to reconsider hopper car performance on track with alternate perturbation wave length. As an alternative, 44-foot perturbations were chosen. The issue is that any car with truck center spacing near the perturbation wavelength will be excited in pure bounce or pure lower center roll. This excitation mode will predict wheel lift (failure of the Chapter XI criteria) even with a perfectly balanced car at the critical speed.

Modeling with both 39-foot and 44-foot perturbations confirmed that bounce and roll response is more dependent on truck center spacing than vehicle height. Thus, the worst cases reported do not account for the specific instances where truck center spacing aligns with the track perturbation wavelength. This is justified by the matter that welded mainline rail is no longer as likely to present a specific 39-foot perturbation as in years past. So long as cars are properly sprung for their loads, most will perform within Chapter XI limits on well-maintained mainline.

Overload limits for AAR condemnable criteria are based on avoiding suspension bottoming in pitch and bounce. The dynamic factor is the ratio of the maximum dynamic wheel loads generated by an overloaded car and a properly loaded car. When the suspension is exhausted, due to this excess load and impact events that occur at the bottom of the suspension travel, the result is a dynamic factor greater than one. This factor, which compares the maximum dynamic loads between the normally loaded and the same car overloaded, exceeds unity when increased dynamic load is more than can be accounted for by just the increase in weight. The critical dynamic factor is the dynamic factor evaluated at the critical speed (where the maximal wheel loading occurs). For the hopper car (worst case), 14-percent overload is where the critical dynamic factor begins to significantly exceed unity. Therefore, the AAR condemnable limit for overload should be set at 14 percent. Figure 1 shows the critical dynamic factor for the hopper car in pitch and bounce.

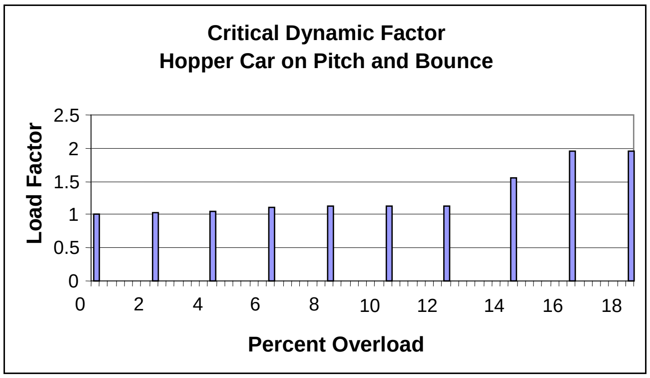

Figure 1. Dynamic Factors for the Hopper Car at Critical Speed

ACTIONABLE THRESHOLD CRITERIA

Economic guidelines are being established and will be reported at a later date. There are a number of considerations for establishing these guidelines; for example, TTCI has used NUCARS to model the wear indices for varying curvature with progressive levels of imbalance. These values will be fed into the Railway Track Life Model (RTLM™) to predict the degradation effects on track conditions. The resulting matrix will be discussed with the AAR member railroads to collectively determine a suitable threshold.

SPECIFYING IMBALANCE

Specifying the imbalance as a percent of car weight simplifies the implementation of an imbalance rule. The lateral and longitudinal location of the CG of the car, relative to the geometric centroid, will vary with the imbalance level. Rather than predicting the absolute position of the CG, which varies with the dimensions of the car and characteristics of the load, it is more straightforward to consider the percent shift from nominal. This normalizes the different car sizes and negates the need to account for the dimensions of every car as it passes a detector. This further simplifies the computation to that of computing the difference in position between the centroid of the car and the actual position of the CG and comparing this difference to the imbalance limits.

EFFECT OF CENTER OF GRAVITY HEIGHT

The CG location was defined by a three dimensional coordinate with a vertical component that may vary substantially depending on the lading. The effect of CG height on vehicle dynamics was accounted for with a parametric study near the critical regimes. The parametric study first modeled a centered load on twist and roll with varying CG height. The worst result showed a 25-percent loss of vertical wheel load between nominal and maximum height. This occurred near the critical speed of 20 miles per hour (mph). At other speeds, there was no significant, predictable dynamic effect due to raised CG.

Next, the vertical height was varied parametrically with nominal side imbalances. It is interesting to note that the vehicle response does not unilaterally degrade with increased CG height. As would be expected, the critical speed changes with CG height. But the relationship between CG height and vertical wheel unloading is not linearly related. There is a critical speed at which the vehicle dynamic response changes modes. This is known as a jump phenomenon in nonlinear dynamic systems. Figure 2 illustrates the jump phenomenon. The effect of this dynamic response can result in a sudden 60 percent reduction in vertical wheel load at the critical speed, regardless of the CG height. Although there is a significant nonlinearity in the response, the predicted response never falls below Chapter XI limits until after the CG height is beyond the maximum permissible value of 98 inches. Therefore, it should not be necessary to adjust the imbalance limit for CG height.

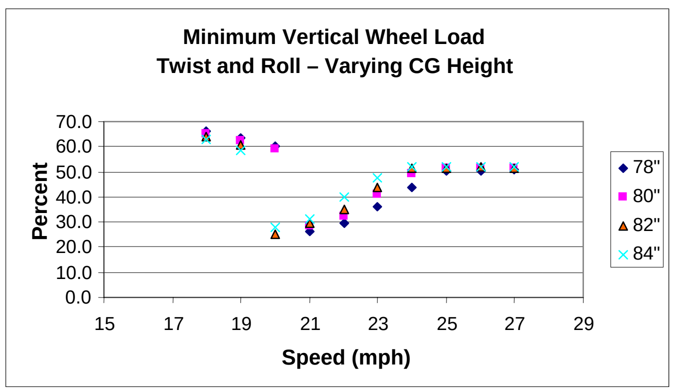

Figure 2. Illustration of the Dynamic Jump Phenomenon

VEHICLES MODELED

Car types for modeling were selected based on conversations with the AAR member railroads. The types modeled were the open hopper, mill gondola, and transverse steel coil car. These cars represent a reasonable cross section of car geometries for length and height. The weight of each car type was modeled at 286 kips to represent the heavy axle load condition. In addition, a 75-foot flatcar was modeled in Chapter XI curving to assure the performance of extremely long cars in this regime. The performance was acceptable for this car type within the proposed imbalance limits.

VALIDATION WITH ON-TRACK TESTING

Two of the carbody styles were tested on-track. The testing was directed at collecting a reasonable sample of the conditions to validate the models. The testing was not comprehensive. It is expected that if the results of modeling agree with the test results at the selected points, then the model represents the car type in all regimes. The test results are thus intended to bolster confidence in the analytical predictions.

Figure 3 shows the on-track test results for the coil car with STS imbalance in the twist and roll regime. Figure 4 shows the analytical predictions for similar conditions. The model predicted critical speed to within 2 mph and the imbalance level for wheel lift to within 5 percent. The numerical results generally agree to within 10 percent at the varying speed versus imbalance points. Similar results can be found in other regimes.

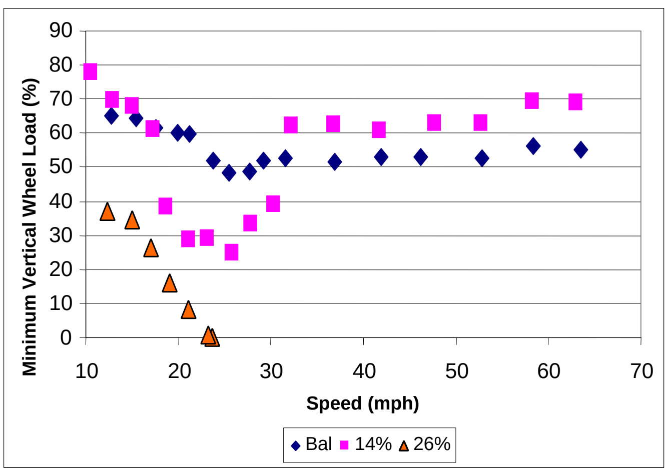

Figure 3. On-Track Test Data for a Coil Car with STS Imbalance

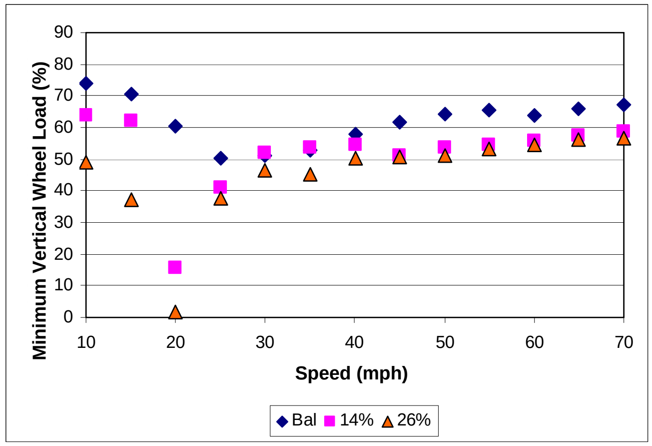

Figure 4. NUCARS Predictions for Coil Car with STS Imbalance

FUTURE WORK

Subsequent steps in this Strategic Research Initiative include developing the Actionable Threshold criteria. These limits will be based on economic models that represent the costs borne because of imbalanced loads. The economic considerations will include the effect on bridges, track, fuel, and mechanical components.

CONCLUSION

AAR condemnable imbalance criteria have been established as 21 percent STS imbalances, 16 percent ETE imbalances and 14 percent overload. Exceeding these levels of imbalance may result in exceeding Chapter XI limits or imparting excessive dynamic loads.

REFERENCES

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