TECHNOLOGY DIGEST
Timely Technology Transfer

Dynamic Response of the Track Structure to Impact Loads

by Semih Kalay and Ali Tajaddini
TD 93-001

Summary

A series of tests have been performed to investigate the dynamic response of the track structure to impact loads. These tests are part of a Research and Test program to establish economically viable guidelines for maximum sizes of wheel tread defects. The test results show that the impact load is transmitted from the wheel/rail interface into the ballast and subgrade. Contrary to expectations, tie plate load measurements show that the wheel/rail impact loads are distributed over a number of ties. Similarly, the ballast acting as a support serves to transmit and distribute the tie impact pressures into the subgrade.

Testing was conducted using four 100-ton cars with service-induced out-of-round wheels with large divots and machined flats over instrumented tracks at the Facility for Accelerated Service Testing (FAST). The vertical wheel/rail and tie plate loads, as well as ballast and subgrade pressures were measured at speeds of 10 to 40 mph.

As a result of impact forces, a wide range of track resonant frequencies are excited. Examination of the time histories of vertical tie plate loads revealed an apparent resonance condition associated with the fundamental natural frequency of the track structure. The rail seat unloading resulting from resonance may cause incremental movement of the spikes on wood ties and clip fallouts on concrete ties. The quantification of the impact signature in the ballast and subgrade suggests the imminent possibility of gradual track degradation in the form of ballast breakdown and subgrade settlement.

Additional tests have been performed with the Track Loading Vehicle to investigate the influence of impact frequency on the transmission of impact loads into the track structure. These tests will be the subject of a future technology digest.

Association of American Railroads
Research and Test Department

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INTRODUCTION AND CONCLUSIONS

Recently, the increased use of wheel impact load detectors demonstrated the existence of certain types of wheel defects which could generate very high impact loads on the rail. Although the effects of lower frequency loads (<10 Hz) on vehicle and track structures have been reported in recent literature, the effect of infrequent occurrence of high impact forces (>10 Hz) on the different track degradation modes is largely unknown.

Studies conducted on the Northeast Corridor showed that rail seat cracks can develop in concrete ties under high impact loads produced by long wave-length wheel defects. It is commonly believed that the higher frequency components of the impact force can be of greater concern for rail damage, especially at locations where internal defects may exist. In fact, the Canadian National Railways recently reported rail breakage due to impact loads in cold weather conditions.

Damage to track components lower in the track structure is not well quantified. Some researchers believe that the lower track structure is not affected by high frequency impact loads that are attenuated by the rail mass. However, the lower frequency components of wheel impact loads are believed to be transmitted to the track structure, and these are the forces which cause gradual degradation of ties, ballast, and subgrade.

As part of an overall program to determine the maximum allowable sizes of wheel tread defects, the AAR researchers conducted a series of tests to determine the extent of the transmission of impact loads into the vehicle and track structures. The transmission of the high frequency dynamic forces from the wheel/rail interface up to the truck and vehicle components was reported earlier in Technology Digest TD 92-001. The study reported here deals with the effects and transmission of impact loads into the track structure. The following conclusions are drawn from these tests:

- The impact loads due to wheel defects are transmitted from the wheel/rail interface into the track substructure. Analysis of tie plate loads show that the impact load under large flats and out-of-round wheels is shared by several ties.
- Contrary to expectations, the same impact signature was seen at the subgrade level under several ties. Impact pressures appeared to have been transmitted from the tie plates down into the ballast and distributed over the subgrade.
- Impact load and pressures increase with the size of the defect. The highest impact load and pressure was measured under the 4-inch machined flat at 40 mph.
- It is believed that contribution of impact forces to track degradation strongly depends on the frequency content of the impact as affected by the depth and the wavelength of the wheel defect.
- Frequencies of the impact forces and pressures measured in the ballast and subgrade under large flats were in the range of 10-60 Hz. As a result of impact forces, a wide range of track resonant frequencies are excited. Large motions resulting from resonance caused momentary rail seat unloading.
- The transmission of impact through the ballast, which is composed of non-cohesive particles, requires further studies.

Dynamic Response of the Track Structure to Impact Loads.

In an earlier series of tests (see TD 92-001), the dramatic effect of impact loads on wood-tie track was observed from the comparison of the measurements of track surface profiles taken at the beginning and at the end of the test program. The track where the impact load detector system was installed had settled about .25 inch at the center. This physical observation has prompted further investigation of the effects of impact loads on the track structure.

A new series of impact tests was conducted over the instrumented tangent track with wooden ties at FAST to determine the dynamic response to wheel impacts. The existing instrumentation from the FAST Load-path Experiment was utilized during testing. Exhibit 1 shows a schematic of the instrumented track, including the location of the instrumented tie plates, and ballast and subgrade pressure cells.

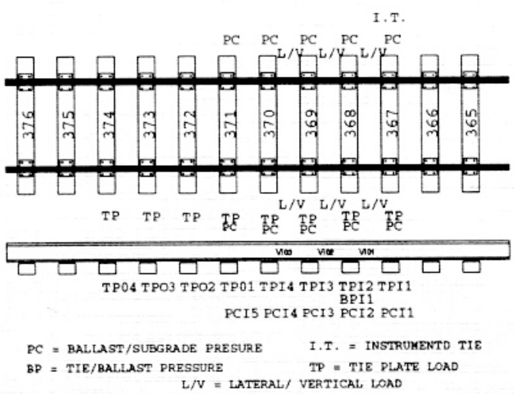

Exhibit 1. Instrumented Track Section at FAST.

A test consist was assembled with a locomotive and four loaded 100-ton cars. Wheels with 1, 2, 3, and 4-inch machined flats and service induced out-of-round wheels were installed under the leading axles of each truck. Good wheels were used in the trailing axle of each truck in order to obtain a base-line impact measurement for comparison purposes. The test consist was run over the instrumented track section at speeds up to 40 mph.

Exhibit 2 shows the variation of the impact load with speed on wood tie track. The peak impact load ranges from 43,000 pounds under the 1" flat to 97,000 pounds under the 4-inch flat at 40 mph. The dynamic response of the track to the 4-inch wheel flat at the tie plate and subgrade levels is shown in Exhibit 3.

The first two primary load pulses are from the wheel forces under the trailing truck of the second 100-ton car and the remaining two are from the leading truck of the following 100-ton car. As seen in Exhibit 3, the 4-inch flat landed near Tie Number 371 (Exhibit 1), but not the out-of-round wheel with a 50 mils deep divot.

The tie plate load trace under the 4-inch flat shows a sudden drop from its nominal level at 10,000 pounds, as the tie plate suddenly unloads and the wheel loses contact with the rail. The impact load rises dramatically to 35,000 pounds as the flat spot hits the rail. The duration of this

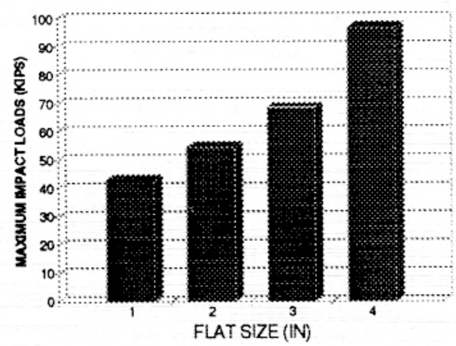

Exhibit 2. Effect of Wheel Flat Size on Impact Loads.

load pulse is about 17 milliseconds, corresponding to the impact frequency of 60 Hz. Following the initial impact, the tie plate experiences a complete unloading for a few milliseconds. This is followed by a second impact at a much lower amplitude and a frequency of 52 Hz. The total unloading of the tie suggests excitation of the fundamental natural frequency of the track structure.

The adjacent tie-plates respond to impact at identical frequencies but at lower amplitudes. Exhibit 4 shows a bar chart illustrating the low and high frequency components of the tie plate loads. Note that the signals were high pass filtered at 30 Hz to get the dynamic augment due to impact alone. The low frequency component of the tie plate load, obtained from a low pass digital filter set at 15 Hz, is from the wheel and truck pass frequencies at 40 mph.

The effect of impact is clearly seen in the response of the adjacent ties, where the nominal and impact components of the wheel/rail force are shared proportionately.

The effect of impact gradually diminishes at locations further away from the point of impact near Tie Number 371. The nominal rail seat load of about 35,000 pounds and the impact of 65,000 pounds comprises the total wheel/rail load of about 100,000 pounds.

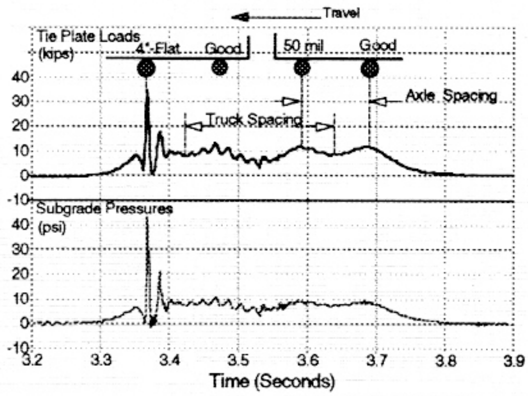

Exhibit 3. Transmission of Impact Under a 4-inch Flat into the Track Structure.

Contrary to expectations, the subgrade pressure response shows identical loading and unloading cycles. The response of the track to vehicle loading is very complex. The loads and pressures can vary considerably from location to location due to varying track support conditions under each tie. In order to account for such variation, the impact load and pressures measured under the defective wheels were normalized by those measured under the good wheels at each location.

The effect of wheel impact due to different sizes of machined flats is shown in Exhibit 5. The impact ratio both at the tie plate and subgrade levels increases with the size of the defect. The subgrade pressure measured under the 2-inch flat was about 14 psi while the subgrade pressure under the "good" wheel under the same tie was 6.5 psi. The corresponding tie plate loads were 21,000 and 13,100 pounds, respectively. The 4-inch machined flat produced subgrade pressures in excess of 4.5 times the pressure of 9.4 psi measured under the "good" wheel.

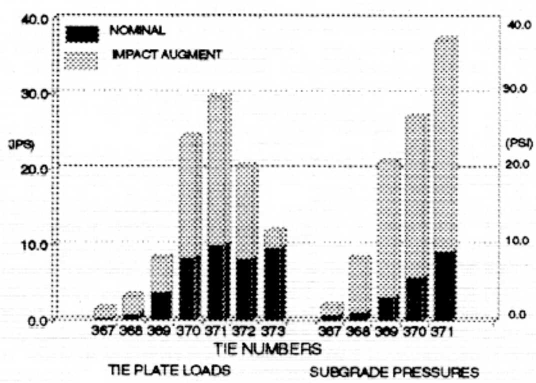

Exhibit 4. Distribution of Impact Load Along the Track.

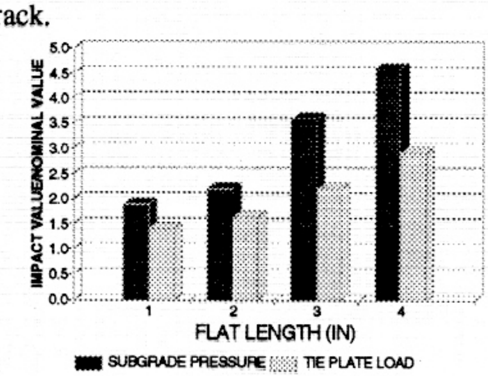

Exhibit 5. Effect of Flat Size on Rail Seat Load and Subgrade Pressures.

Note: Contact S. Kalay at (312) 808-5842 with questions or comments about this document.

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