TECHNOLOGY DIGEST
TD-11-047
©NOVEMBER 2011
TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

Frog Foundation Testing Under Heavy Axle Loads

Xinggao Shu, David D. Davis, Rafael Jimenez, and Muhammad Akhtar

Summary

Transportation Technology Center, Inc. (TTCI) conducted tests of frog design parameters to understand the relative effects of running surface, track stiffness, and track damping parameters. Prototype frog foundations were built and evaluated under heavy axle load traffic at the Facility for Accelerated Service Testing. Load measuring cars and wheelsets were used to measure the effects of these changes on vehicle performance and the frog service environment.

Findings from the study include:

- The shape of the running surface near and at the flangeway gap has a significant effect on maximum wheel-rail forces. Not only is the design flangeway gap important, but also the longitudinal shape of the running surface on either side of the flangeway from gage line of the crossing track to top of rail.
- Frog construction is also important in determining the wheel-rail loading and car vertical accelerations. Frogs with a joint in the flangeway have lower forces than ones without. Truck side frame accelerations were about 50 percent of the values measured on jointless frogs.
- TTCI engineers hypothesize that the running surface profiles of these two frogs are quite different under load. The jointed frog, acting as two pieces, provides some damping at the wheel interface, reducing the dynamic loading. Further testing is planned to quantify and better understand this effect.
    - Jointless frogs are typically used today because of their ease of construction and their ability to maintain alignment in track.
    - Further investigation is needed to determine how to provide the damping from jointed frogs, without having the joints.
- The effect of track stiffness over the range of 125,000 to 240,000 lbs/in was relatively small on truck side frame accelerations. Other frog design factors had a more significant effect. The effect of track stiffness also depends on the impact level.

Through funding provided by the Association of American Railroads' Strategic Research Initiatives Program, TTCI measured track properties and dynamic load environments at a variety of actual and simulated high angle frogs. The tests utilized onboard instrumentation (strain gaged wheelsets and accelerometers) to measure performance under 39-ton axle loads. These test results are also being used to build and calibrate vehicle-track models of frog foundations under a project funded by the Federal Railroad Administration, Office of Research and Development.

INTRODUCTION

Special trackwork consisting of turnouts, bridge joints, and crossing diamonds can have high dynamic load service environments. These locations are critical for safe and efficient operation of the railway. While frog performance has improved significantly in the past 20 years, the basic foundation of the mainline turnout and crossing diamond frog has remained the same. This *Technology Digest* describes recent testing and analytical work to benchmark current performance and improve new designs.

Frogs are devices that allow the flanged wheels to pass through the rails of a crossing track. Most frogs consist of a running surface gap. This flangeway gap is accompanied by wheelset guarding that keeps the train on its intended path. The flangeway gap can create high dynamic loading for the wheelset, as it can be unsupported in crossing the gap. The dynamic load produced is dependent on the train speed, frog angle, and wheel/frog contact conditions. Dynamic loading of 3-5 times static wheel load is typical for high angle frogs, with 2 times static wheel load being typical for worn No. 20 turnout frogs.[1,2]

Most frogs have been strengthened, as compared to open track, to withstand the high dynamic loading. This strengthening typically raises the stiffness and lowers the damping of the track at the frog. This can further increase maximum dynamic loads. But, it may be beneficial to the track downstream of the frog, as a result.

Effects of Frog Design Parameters on Dynamic Loads

Recent testing of frog design parameters was conducted to understand the relative effects of running surface, track stiffness, and track damping parameters. Prototype frog foundations were built and evaluated under heavy axle load traffic at the Facility for Accelerated Service Testing (FAST). Load measuring cars and wheelsets were used to measure the effects of these changes on vehicle performance and the frog service environment.

The effects of running surface shapes at the frog flangeway were evaluated in a series of tests using simulated frog structures. Figure 1 shows a track panel with flangeway gaps that was used for the tests. The panel is more economic than full frogs because it does not have provisions for crossing traffic. Yet, it retains the key features having a more massive structure and having flangeway gaps.

Previous work in this area by the Association of American Railroads (AAR) suggested that running surface ramping could provide benefits in lowering maximum wheel-rail forces at flangeway gaps.[3,4] Further, frog cross section profile shape changes could assist in accommodating a wider range of wheel profiles.

Figure 2 shows that a long wavelength dip in the running surface, like that of a battered thermite weld, can generate high dynamic loading. The shape is similar to the shape of a worn frog flangeway gap.

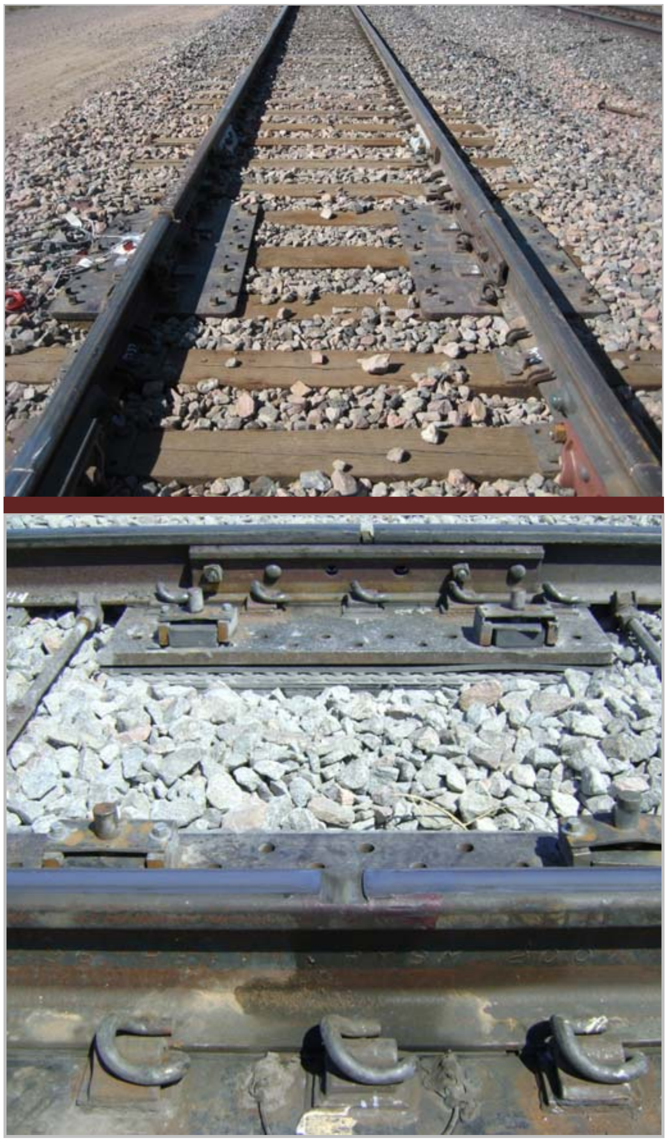

Figure 1. Track Panel with Flangeway Gaps

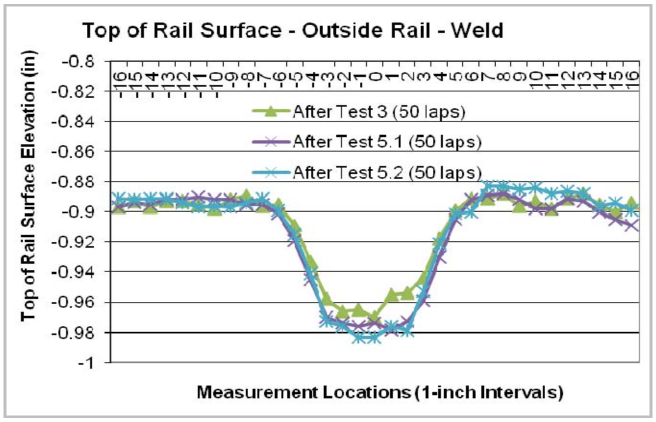

Figure 2. Dipped Weld Profile

The effective gap that a wheel has to jump on this type of running surface shape can be 4 to 8 inches in length. Figure 3, from previous AAR sponsored work, shows the theoretical relationship between maximum wheel load and effective flangeway gap.[5]

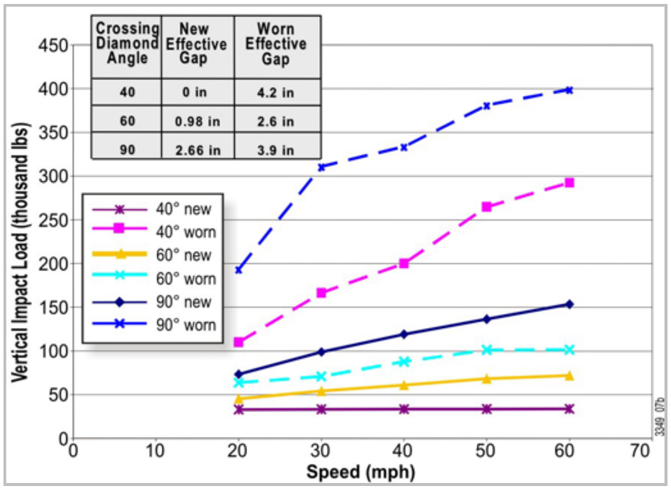

Figure 3. Theoretical Relationship of Wheel Force versus Speed at Frogs

A time series of wheel load measurements were made on a high angle crossing diamond. One rail had recently installed frog castings. The other rail had worn castings from revenue service. Figure 4 shows the running surface profiles for each casting.

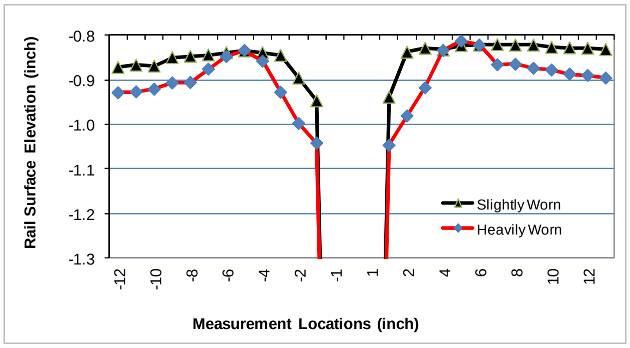

Figure 4. Running Surface Profiles of Frogs in Test at FAST

Figure 5 shows the measured wheel loads over a range of speeds from 10 to 28 mph. The static wheel load of the car is 39,000 pounds. Figure 5 shows the maximum vertical wheel force versus speed relationship for the slightly worn and more heavily worn crossing diamond frogs. Note that the trends are similar, but the magnitudes are different for the measured result as compared to the theoretical result in Figure 3. This is due to the measurement sampling rate and filtering done in the test.

The problem for the frog designer and frog maintainer is maintaining as small an effective gap as possible over the service life of the frog. In addition, the designer must optimize track parameters at the frog to minimize the effects of these high dynamic loads.

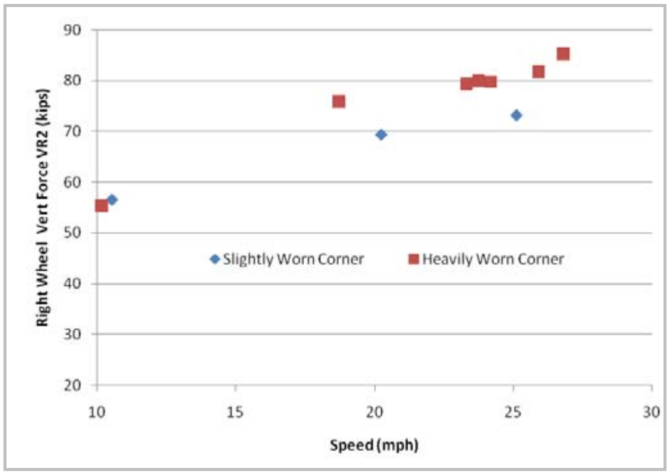

Figure 5. Measured Wheel Load versus Speed

Effect of Track Parameters on Dynamic Loads

The effect of track stiffness on dynamic loading was examined with a series of experiments and analytical modeling. The experiments also provided data on track properties used to calibrate the models developed under a companion study sponsored by the Federal Railroad Administration.[6]

A series of track panel tests were conducted with various track stiffness values and damping characteristics. Table 1 shows the test cases and the estimated track properties.

Table 1. Frog Foundation Tests and Results at FAST

Test Cases	1	2	3	4	5	6	7	8
Gap Type (J-Joint, R- Rigid)	J	J	R	R	R	R	J	J
Gap Width (in.)	1.5	2	2	2	2	2	2	2
Rail Seat Pad	Rubber	Rubber	Rubber	Steel	Rubber	Steel	Rubber	Steel
Panel Top	Plate	Plate	Plate	Plate	Plate	Plate	Plate	Plate
Panel Mid	Rubber	Rubber	Rubber	Rubber	Wood	Wood	Wood	Wood
Panel Bottom	Plate	Plate	Plate	Plate	N/A	N/A	N/A	N/A
Ballast Thickness (in.)	17	17	17	17	19	19	19	19
Side Frame Average P2P (g)	2.99	3.75	4.13	4.57	4.55	4.51	3.31	3.22
Standard Deviation (g)	0.32	0.32	0.83	1.35	1.41	1.3	0.39	0.36
Max P2P (g)	3.83	4.42	6.5	7.51	8.56	7.69	4.44	4.16
Track Stiffness (lbs/in)	125,000	125,000	125,000	135,000	150,000	240,000	150,000	240,000
Track Damping	High	High	High	Med	Med	Low	Med	Low

An instrumented freight car was operated over the test frogs. Side frame accelerations (average and maximum peak to peak) are reported. The side frame accelerations give the same trends as wheel-rail forces. The following comparisons were made.

The effect of track stiffness over the measured range was relatively minor for impacts with a 2 inch gap — an approximate 30 percent increase in maximum acceleration for an approximate doubling of track stiffness. Figure 6 shows these results. The equivalent track modulus of these sections was approximately 1,500 and 2,800 lbs/in/in. The track stiffness effect also depends on the level of the impact as a previous study has shown.[6]

Flangeway Type

A comparison was made between flangeways made by milling a continuous rail (rigid) and flangeways made by cutting the rail full section (joint). The rigid flangeways, representative of currently used frog castings, produced significantly higher accelerations than did the jointed flangeways. The jointed flangeways are representative of composite frogs made from rail. Figure 7 shows the comparison for timber and high damping rubber foundations. The effect was quite significant for both cases. TTCI engineers hypothesize that the running surface profiles of these two frogs are quite different under load. The jointed frog, acting as two pieces, provides some damping at the wheel interface, reducing the dynamic loading. Further testing is planned to quantify and better understand this effect.

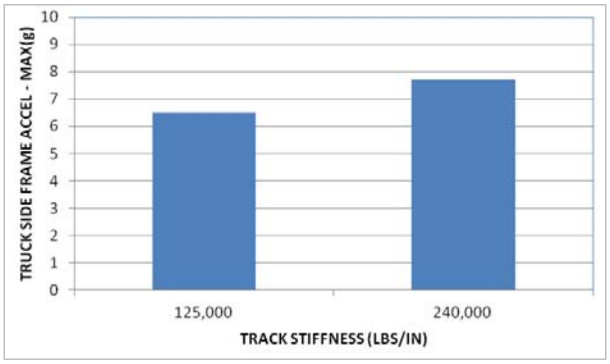

Figure 6. Side Frame Acceleration versus Track Stiffness

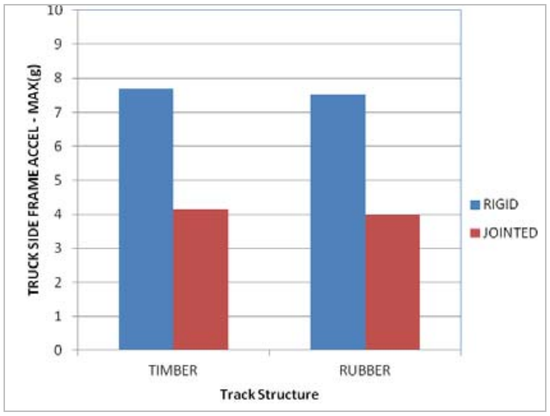

Figure 7. Side Frame Acceleration versus Flangeway Type

CONCLUSION

Some of the factors affecting dynamic loading at fixed point frogs were examined with a series of experiments at FAST. Vehicle performance measurements of various frog foundation configurations representing a range of track stiffness values and damping characteristics were conducted. Results showed that track stiffness and damping values can affect maximum wheel-rail forces. Equally important, the running surface longitudinal shape can affect measured forces. Additional testing will attempt to further clarify the relevant issues in frog foundation design and provide general guidelines for improving designs.

ACKNOWLEDGMENTS

The authors wish to thank the support of the TTCI FAST Program Manager Joe LoPresti, TTCI Track Crew Foreman Rick Montoya, and FAST Test Controller Manual Perez, and their staffs for the efforts to safely build and operate over some unique frog foundations.

REFERENCES

1. Davis, D. D. et al. February 2002. “Results from Special Trackwork Experiment at FAST.” Research Report R-954, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
2. Sasaoka, C. D., D. D. Davis, and D. Guillen. December 2003. “Service Evaluation of Improved Running Surface Profile Frogs.” Research Summary, RS-03-004, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
3. Sasaoka, C. D. and D. D. Davis. September 2005. “Crossing Diamond Dynamic Performance Study.” *Technology Digest* TD-05-020, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
4. Singh, S. P., D. Guillen, and D. D. Davis. July 1999. “Proof Tests of Crossing Diamond Surface Ramps in Heavy Axle Load Service.” *Technology Digest* TD-99-024, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
5. Shu, X. and D. D. Davis. December 2008. “Running Surface Profile Design for Intermediate Angle Diamond Crossing Frogs.” *Technology Digest* TD-08-052, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
6. Shu, X., D. Davis, and M. Akhtar. August 2011. “Next Generation Foundations for Special Trackwork – Phase I.” Transportation Technology Center, Inc. final draft to Federal Railroad Administration, Washington, DC.