Longitudinal Forces in Bridges Due to Heavy Haul Freight Operations

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Summary: Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads, tested several open deck and ballast deck steel bridges to measure longitudinal forces from locomotives. Bridges tested were 15-120 m (50-400 ft.) long. Findings include:

- Longitudinal forces measured were much greater than those recommended for design from 1968 to 1996 in the American Railway Engineering and Maintenance of Way (AREMA) Manual for Railway Engineering.
- The greater the applied longitudinal force the greater the force into the bridge.
- Generally, the longer the span the greater the longitudinal force resisted by the span.

The results from these tests are being used to refine AREMA bridge design and rating guidelines.

Index Terms: Bridge, Longitudinal Force

1.0 INTRODUCTION

Transportation Technology Center, Inc. (TTCI), a wholly-owned subsidiary of the Association of American Railroads (AAR), conducted tests to determine longitudinal forces in several bridges on the Burlington Northern Santa Fe (BNSF) railroad. TTCI also conducted the same tests on a bridge constructed at the Facility for Accelerated Service Testing (FAST) at the U.S. Federal Railroad Administration’s Transportation Technology Center near Pueblo, Colorado, USA [1-10]. The new, high-adhesion diesel-electric locomotives are capable of producing more than twice the tractive effort of older locomotives. Bridge component failure and bridge maintenance problems associated with longitudinal forces have been reported by some North American railroads.

Chapters 8 and 15 of the AREMA (formerly AREA) Manual of Railway Engineering have been changed on the basis of these tests [11-14].

2.0 TRAIN OPERATIONS

For each test on the BNSF, Electro-Motive model SD70MAC locomotives were used to push or pull a coal train up a grade, typically about 1 percent. Dynamic braking was used to hold train speed coming down the same grade. The coal trains typically weighed about 13,000-15,000 tonnes (15,000-17,000 short tons). In each test, the locomotives were operated as closely as possible to their maximum capacity for many of the test runs. Traction effort was kept as constant as possible as the locomotives crossed the bridge. Typical modern North American high-adhesion locomotives have two 3-axle bogeys (trucks) each, and are 21-24 m (70-80 ft.) long. Maximum tractive effort is about 800-900 kN (180-200 kips). Maximum dynamic brake effort is about 500 kN (110 kips).

3.0 TEST RESULTS

Figure 1 shows the longitudinal force into each span and the entire bridge for a typical test train as two locomotives cross a 120-meter (400-foot), 4-span bridge. The zero distance corresponds to the first axle of the lead locomotive approaching the bridge and the 175-meter (575-foot) distance indicates the last axle of the trail locomotive has cleared. Note that the peak force occurs when the locomotives are approximately centered on the bridge. The curve for the total longitudinal force into the bridge is quite symmetric, but the curves for longitudinal force into each span are not. This is due to variations in span length, anchoring, and intermediate support configurations.

Figure 2 shows force into each span versus maximum force applied to that span for all tractive-effort runs. As expected, the 64-meter (210-foot) span had the largest forces. More than 900 kN (200 kips) goes into that span at the higher-tractive-effort levels. The maximum applied tractive effort
was about 1,600 kN (360 kips). This provided the worst-case condition for the three shorter spans on this bridge, but for spans longer than about 46 m (150 ft.), an additional locomotive could induce more force.

Generally the longer the bridge segment, the higher the longitudinal force reacted by that portion of the bridge. The longer the segment, the more locomotive axles and therefore the higher the applied tractive effort. One might expect the limiting longitudinal force due to locomotive tractive effort to be near the drawbar force capacity for a very long bridge.

Testing of a ballast-deck bridge yielded results very similar to those for the open deck bridges tested. Load-measuring bridge bearings were installed to determine the amount of longitudinal force in an 18-meter (60-foot) span. The longitudinal forces measured under test runs were in the same range as those measured for open deck spans of similar length. The ballast carried negligible longitudinal force away from the bridge. Based on the results of this test, any recommendations regarding longitudinal force levels for open deck bridges were also considered to be appropriate for ballast-deck bridges.

4.0 NEW DESIGN RECOMMENDATIONS

The findings of these tests have led to significant changes in the guidelines used to design and rate railroad bridges for longitudinal forces. The new guidelines recommend design forces that are in line with those used prior to 1968. But the new design forces are significantly greater than those used from 1969-1996. The new design forces are given by easy-to-use equations rather than the tedious Cooper train loading used in past guidelines.

The actual trains used in the tests were approximately equivalent to Cooper E-60 loadings on the spans tested. The measurements were scaled based on the Cooper E-80 design loading. The scaled data was used to develop the new design guidelines for longitudinal force due to locomotive traction. Rather than use the Cooper train, the suggestion was made to develop a formula that gave the design force as a function of length. For design purposes it is desirable to keep the formula relatively simple for ease of use. After experimenting with various empirical formulas, the following was selected for longitudinal force due to locomotive traction:

\[
\text{Longitudinal traction force (kN)} = 200 \sqrt{L}
\]

\[
\text{(Longitudinal traction force (kips)} = 25 \sqrt{L}
\]

where, L is the length in meters (feet) of the portion of the bridge under consideration. The square root function follows the same general trend as can be theoretically derived using the models [15, 16]. It follows the data reasonably well, and is easy to use.

The longitudinal force due to train braking is 15 percent of the Cooper E-80 train. It is based on the maximum adhesion
between wheel and rail for train braking, which is about 15 percent.

Figure 4 compares the various AREA and AREMA design guidelines for longitudinal forces. Note that the 1996 guideline for Chapters 8 and 15 is significantly lower, particularly for shorter lengths. Compared to the 1997 AREA guidelines, the new AREMA guideline recommends increased design longitudinal force for some lengths and decreased force for other lengths. The result is a more uniform level of design reliability over the range of lengths.

5.0 WHERE TO EXPECT HIGH LONGITUDINAL FORCES

In order to generate high longitudinal forces from a locomotive, a train must provide a reacting force. Under normal operating conditions, the largest forces occur during acceleration or pulling a heavy train upgrade, or conversely, when braking a heavy train downgrade. Therefore bridges in the vicinity of significant grades are more likely to experience high longitudinal forces. Highest forces in tractive effort are usually associated with unit-train drag service at speeds below 25 km/h (15 mph).

For bridges longer than a set of locomotives, the highest longitudinal forces might be due to train braking. For shorter bridges, the locomotive traction will govern because of the higher adhesion for the locomotives. For bridges

6.0 CONCLUSIONS

The new high adhesion locomotives are capable of producing very high tractive efforts. Of the total tractive effort applied by locomotives, bridges resist a significant portion. New AREMA design guidelines for longitudinal forces have been developed based on these tests.

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8.0 REFERENCES


