

Longitudinal Forces in a Long Railroad Trestle Bridge

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Summary

Tests conducted by Transportation Technology Center, Inc. indicate that a large amount of longitudinal force applied by high-adhesion locomotives to a long trestle bridge is distributed through the spans to a large number of bents. The objective of the longitudinal force tests was to measure longitudinal forces for a typical coal train with AC locomotives, and particularly the distribution of the longitudinal forces in the substructure. The tests were carried out on a 78-span, 2,196-foot-long trestle on the Burlington Northern Santa Fe Railway near Cameron, Texas. The trestle was constructed using concrete spans and caps on steel H-piles.

Other findings of this investigation include:

- Longitudinal forces due to locomotive traction and dynamic braking are distributed over up to 40 bents.
- Double bents carried about four times as much longitudinal force as compared to single bents for this particular trestle.
- Although some longitudinal forces are transferred through the rails, a significant portion of these longitudinal forces appear to be carried by the superstructure (i.e., concrete spans) in axial compression or tension.
- Maximum shear forces of 10.9 kips for a single bent and 39.0 kips for a double bent were measured under the test train in tractive effort. These forces are similar to those that would be expected using American Railway Engineering and Maintenance of Way Association design guidelines scaled for actual train weights and distributed properly according to relative stiffness of the bents.
- Forces in the individual piles of a bent were nearly equal.

These results are being used to improve the design and ratings methods used for railroad bridges, so that bridges can continue to perform effectively under the new generation of high-adhesion locomotives. This work was conducted as part of the Association of American Railroads' strategic research initiative on bridges.

Suggested Distribution:

- Maintenance of Way
- Planning & Analysis
- Bridges & Structures
- Safety



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Transportation
Technology Center, Inc.

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INTRODUCTION AND CONCLUSIONS

Since 1996, the Association of American Railroads (AAR) has been investigating the magnitudes of longitudinal forces applied by high-adhesion locomotives on different types of railroad bridges. The purpose of these tests is to determine the magnitude of longitudinal forces transferred into railway bridges from locomotives under tractive effort and dynamic braking. These tests indicate that the forces transmitted are considerably larger than previously believed. (See Technology Digests 96-024, 98-007, 98-020, 99-026, 00-014, 00-018, and 00-020.)

The new generation of locomotives can produce about twice the tractive effort as older locomotives. Thus some bridges can be subject to much greater longitudinal forces. On some railroads, damage to bridge components such as tower bracing, cross bracing, and floor beams has been attributed in part to these high longitudinal forces. These high longitudinal forces must be considered in the design of new bridges and rating of existing bridges.

During 2000, the Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads (AAR), carried out longitudinal force tests on a 78-span, 2,196-foot-long trestle on the Burlington Northern Santa Fe Railway near Cameron, Texas. The objective of the tests was to measure longitudinal forces due to a typical coal train with AC locomotives, with emphasis on the distribution of the longitudinal forces in the substructure. These tests showed that although a large amount of longitudinal force is applied to the trestle, the effects are minimized because it is distributed to a large number of bents through a large number of spans.

TEST PROGRAM

The test plan was designed to quantify the longitudinal forces throughout this bridge. Ten spans were measured extensively at each end of the bridge. Measurements were also taken at every fifth intermediate span. The measurements taken were bending strains in the flanges of piles of several single and double bents, shear strains in the webs of a few piles, longitudinal rail forces, and displacements between end spans and abutments.

The test train was a typical loaded coal train consisting of 126 cars powered by four six-axle AC locomotives (SD70MAC), with two locomotives at each end



Exhibit 1. Test Train with Four Locomotives

of the train as Exhibit 1 shows. The train weighed 16,626 tons and measured 6,689 feet without power.

Two different series of tests were performed using 10 runs of the test train. Initially, tests were run to determine locomotive-induced forces. Locomotives at the leading end of the train were operated in dynamic braking. At the trailing end, locomotives were operated as closely as possible to their maximum tractive effort capacities (in excess of 150 kips per unit). No air braking was used while any portion of the train was on the bridge during these test runs.

Secondly, tests were run to determine forces induced by train air braking. The train was stopped using full-service air-brake applications as the leading end of the train approached the opposite end of the bridge. The train crew reported the tractive effort being applied for the first series of tests and amount of brake pipe reduction used for the second series of tests.

TEST RESULTS

The longitudinal forces measured in the piles indicate that the applied traction and braking forces were transferred to the substructure through a large number (about 40) of concrete spans acting in axial tension or compression. Exhibit 2 shows the distribution of the longitudinal forces versus the bent number for different positions of the train on the bridge. It can be seen that the magnitude of the longitudinal force in a particular bent depends on the position of the test train on the bridge. The amount of longitudinal force in an individual bent is greatest when the locomotives are directly over that bent. The total amount of longitudinal force in

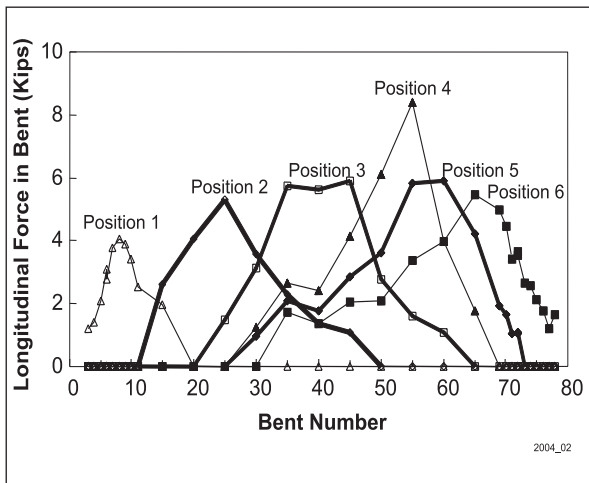


Exhibit 2. Distribution of Longitudinal Forces Vs. Bent Number for Different Train Positions

the bents is greatest when the tractive effort is applied near the center of the trestle.

Exhibit 3 shows a typical plot of longitudinal force in single Bent 35 as the test train traveled over the trestle. The effects of dynamic braking and tractive effort applied by the locomotives are perceptible when the locomotives are about 1,000 feet (35 spans) away in some cases. This indicates that the applied longitudinal force is reacted by many bents over the length of the trestle. Applied dynamic braking effort was about 160 kips total from the two locomotives at the head end of the train. Applied tractive effort was about 260 kips total from the two locomotives at the rear end of the

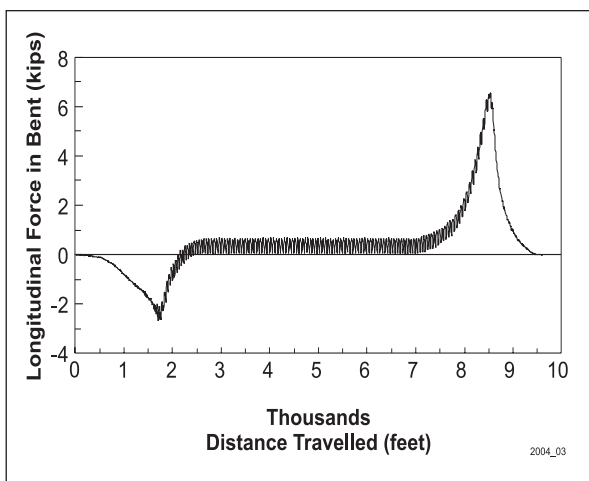


Exhibit 3. Typical Plot of Longitudinal Force in Single Bent 35

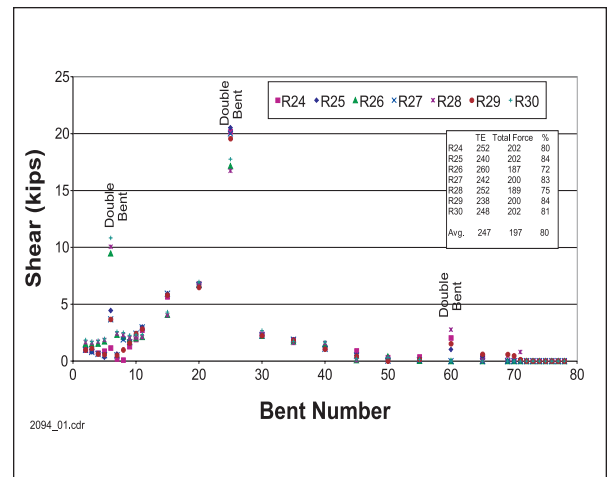


Exhibit 4. Typical Plot of Shear Force Vs. Bent Numbers for Bent 20 for 7 Test Runs

train. Note the magnitude of the longitudinal force in the bent was greater under the locomotives at the rear end of the train, as would be expected given the higher magnitude of applied force. Also note that the bent reacted in opposite directions to the dynamic braking and tractive effort forces, as would be expected. The oscillation under train loading is due to the train cars passing over the bent, introducing small moments in the cap as the reactions from the spans vary with train position.

Exhibit 4 shows a typical plot of shear force versus bent numbers for different train runs at times when the shear force at Bent 20 (a single bent) was at its maximum. The numbers preceded by the letter “R” in the plot legend indicate the runs of the test train. The table on the right-hand side shows the tractive effort as a percentage of the total applied force. The plot also shows that the shear force in a bent is dependent on the position of the test train on the bridge. Although this plot is for the maximum amount of shear at Bent 20, the shear forces are higher in some other bents.

Exhibit 5 is a similar plot of the shear force versus bent numbers for different runs at times when the shear force at Bent 40 (a single bent) is at its maximum. As opposed to Bent 20, (Bent 40 being in the middle of the trestle) there is quite a difference in distribution of the shear force in the other bents. Note that not all bents were measured.

The maximum combined tractive effort for the two locomotives for different test train runs varied from 218 to 260 kips. The maximum shear of 10.9 kips for a sin-

gle bent occurred in Bent 55 and for double bents, the maximum shear of 39.0 kips was measured in Bent 72. The shear forces in individual bents are relatively small compared to the applied longitudinal force.

The difference between a single bent and a double bent in carrying forces is more than twice because the double bents actually respond in double curvature (moment frame) and so have higher relative longitudinal stiffness compared to single bents. One would expect the amount of stiffness increase from single bent to double bent to depend on factors such as height of bent, stiffness of cap, spacing between rows of piles, and whether longitudinally battered piles are used. At a minimum, a double bent will have twice the stiffness of a single bent using the same pile configuration.

Forces in the individual piles in a bent are very nearly equal. This is because piles of a bent deflect the same amount due to a rigid concrete cap at the top and a concrete collar at the ground level. Since there is no bracing between the rows of piles, the bending moments in rows of piles in a double bent are also nearly equal.

BRIDGE DESCRIPTION

Bridge 185.6 is located on the BNSF Galveston subdivision between Temple and Galveston, Texas. The Atchison, Topeka & Santa Fe Railway constructed the bridge in three segments to replace a timber trestle. It is a single-track, 2,196-foot-long ballast deck trestle consisting of 78 pre-cast concrete spans resting on steel H-pile bents with cast-in-place concrete caps and ground collars. Most spans are 28 feet long. The bents are numbered from west to east. On the west end (towards Galveston), the bridge has HP 14 X 89 piles up to Bent 21. Of these, the first 15 bents have one-story bracing while the rest have two-story bracing. Bents 22 to 79 have HP 14 X 117 piles with two-story bracing. Bents 6, 12, 18, 25, 32, 39, 46, 53, 60, 66, and 72 are double bents. Single bents have three piles each and double bents have two rows of three piles each. Bents 1 and 79 are the abutments.

The bridge has a conventional ballasted track construction with 136-pound, continuously welded rail (CWR) on timber ties. The CWR is box anchored at every other tie on the bridge and approaches. The trestle is located in a low spot and the grade rises beyond each end.

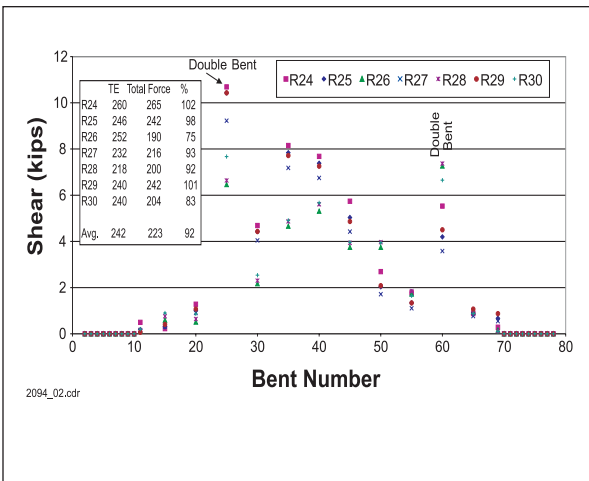


Exhibit 5. Typical Plot of Shear Force Vs. Bent Numbers for Bent 20 for 7 Test Runs

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