Longitudinal Forces in a Long Railroad Trestle

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ABSTRACT
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 of the Burlington Northern Santa Fe Railroad located near Cameron, Texas. The objective of these tests was to measure longitudinal forces due to locomotive traction for a typical coal train with AC locomotives and particularly 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, it is distributed to a large number of bents through a large number of spans.

Other findings of this investigation are summarized:

- Longitudinal forces due to locomotive traction and dynamic braking are distributed over up to 40 bents.
- The magnitudes of longitudinal forces in bents of the trestle at a given time depended on the position of the locomotives on the bridge.
- Although some longitudinal forces are transferred through the rails, a significant portion of these longitudinal forces appear to be carried through by the superstructure (i.e., concrete spans) in axial compression or tension.
- The maximum shear force of 10.9 kips for a single bent occurred in Bent 55 and a maximum shear force of 39.0 kips occurred in double Bent 72 under the test train in tractive effort. By comparison, the current AREMA design guidelines recommend 132
kips for a single 28-foot span, neglecting any distribution to other spans. The 1996 AREA guidelines recommended 1.3 kips for a single 28-foot span.

- The maximum shear force of 8.0 kips for single bent occurred in Bents 2 and 29 and a maximum shear force of 19.3 kips for a double bent occurred in Bent 6 under the test train in dynamic braking.
- A full-service application (26-pound brake pipe reduction) from 24 mph produced a maximum shear force of 6.4 kips in a single bent and a maximum shear force of 18.2 kips in a double bent. The air brake forces were distributed over the entire length of the train.
- The total amount of longitudinal force reacted by bents is greatest when the tractive effort is applied near the center of the trestle.
- As the test train covered more of the bridge, the total applied longitudinal force from train air brake test runs increased resulting in increase in the forces in piles of bents.
- Forces in individual bents are quite small compared to the applied longitudinal force.
- Forces in the individual piles of the bent are nearly equal.
- The difference between a single bent and a double bent in terms of forces carried is more than twice because double bents actually responded in double curvature and so had four times as much stiffness as single bents.
- The maximum relative displacement between the end girder and the abutment backwall during these tests was about 0.15 inch.

**INTRODUCTION**
Since 1996, the Association of American Railroads (AAR) has been investigating the magnitudes of longitudinal forces by high-adhesion locomotives on different types of railroad bridges. The purpose of these tests has been to determine the magnitude of longitudinal loads
that are transferred from locomotives under tractive effort and dynamic braking into the railway bridges. These tests have indicated that the forces transmitted are considerably larger than previously believed.

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 of the Burlington Northern Santa Fe Railway located near Cameron, Texas. The objective of these tests was to measure longitudinal forces due to locomotive traction for a typical coal train with AC locomotives and particularly 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, it is distributed to a large number of bents through a large number of spans.

**BACKGROUND**

The new generation of locomotives can produce considerably more tractive effort than older locomotives and thus can subject some bridges to much greater magnitudes of longitudinal forces. On some railroads, damage to bridge components such as tower bracing, cross bracing, and floor beams have been attributed in part to these high longitudinal forces. These high longitudinal forces need to be considered in the design of new bridges and rating of existing bridges.

The previous tests involved five different bridges. Three had open decks while the other two were ballast deck bridges. The findings of these tests were used to develop new American Railway Engineering and Maintenance of Way Association (AREMA) rating and design guidelines for longitudinal forces in bridges.

**TEST PROGRAM**

The test plan was designed to quantify the longitudinal forces near each end of the bridge. As a consequence, 10 spans were measured extensively at each end of the bridge.
The test train consisted of a typical loaded coal train consisting of 120 cars powered by 6-axle AC locomotives (SD70MAC), with two locomotives at each end of the train as shown in Figure 1.

The measurements taken were longitudinal rail forces, bending strains in the flanges of piles of several single and double bents, shear strains in the webs of a few piles, and displacements between the end spans and the abutments. Figure 2 shows the strain gages to measure bending and shear on the piles of a double bent. Moments in piles were determined from the strains measured in the flanges.

Two different series of tests were performed using 10 runs of the test train. First, 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. Second, tests were run to determine train braking-induced forces. The train was stopped using the air brakes 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.

In addition to these tests, data was also taken as 12 revenue trains crossed the bridge.

**TEST RESULTS**
The longitudinal forces measured in the piles indicate that a significant portion of these forces are transferred to the substructure through a large number (about 40) of concrete spans acting in
axial tension or compression. The total amount of longitudinal force in the bents is greatest when the tractive effort is applied near the center of the trestle.

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 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.

Figure 3 shows the distribution of the longitudinal forces versus the bent number for different positions of 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 applied longitudinal force is reacted by a large number of bents.

Figure 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) is 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 could still be higher than this amount in some other bents.

Figure 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.

Figure 6 shows a typical plot of shear force (indicative of the longitudinal force transmitted to bents) versus time for a double-Bent 72 and a single Bent 70. 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 single bent occurred in Bent 55 and for double bents, the maximum shear of 39.0 kips in Bent 72. These forces in individual bents are relatively small compared to the applied longitudinal force.

Dynamic braking forces for different runs were 80-81 kips per locomotive (160-162 kips total). These are smaller than those developed under tractive effort. Under dynamic braking, the maximum shear of 8.0 kips for a single bent was measured in Bents 2 and 29. For double Bent 6, the maximum shear measured 19.3 kips.

The measured shear force data also displayed a small directional effect in that the measured forces in west-to-east runs were somewhat higher than those measured for east-to-west runs. This may be attributed to the difference in the grades at the ends of the bridge.

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 and so have about four times higher relative longitudinal stiffness compared to single bents.

The data collected under 12 revenue trains gave maximum shear forces carried by the bents ranging from 0.2 to 5.4 kips for the single bents and 1.1 to 20.4 kips for the double bents. These
forces although somewhat smaller are within the range compared to those measured during the controlled tests where the maximum tractive effort was applied.

Figure 7 plots the shear force in double Bent 60 and in single Bent 50 during the air brake tests. These air brake tests used a full-service application (26-pound brake pipe reduction). The test train speed approached 24 mph heading westward and brakes were applied as the lead locomotive was over Bent 79; stopping the train before it reached the other end of the trestle. The maximum shear force for a single bent was 6.4 kips and the maximum shear force for a double bent was 18.2 kips. Air brake forces are distributed over the entire length of the train.

**BRIDGE DESCRIPTION**

Bridge 185.6 is located on BNSF Galveston subdivision between the Texas towns of Hoyte and Cameron. 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 concrete caps and cast-in-place concrete 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?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?117 piles with two-story bracing. Bents numbered 6, 12, 18, 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 wood track ties. The CWR is box anchored at every other tie on the bridge and its approaches. The bridge has a walkway on both sides. Figure 8 shows a partial view of the
bridge and Figure 9 shows line diagram of the elevation of the end parts of the bridge. The trestle is located in a low spot and the grade rises beyond each end.

CONCLUSIONS
These tests showed that although a large amount of longitudinal force is transmitted to the trestle, it is distributed to a large number of bents through a large number of spans.

Based on the results of this investigation, the following conclusions can be drawn:

• Longitudinal forces due to locomotive traction and dynamic braking are distributed over up to 40 bents.

• Although some longitudinal forces are transferred through the rails, a significant portion of these longitudinal forces appear to be reacted by the superstructure (i.e., concrete spans) in axial compression or tension.

• The difference between a single bent and a double bent in terms of forces carried is more than twice because double bents actually responded in double curvature and so had four times as much stiffness as single bents.

• Forces in individual bents are quite small compared to the applied longitudinal force.

• Forces in the individual piles of the bent are nearly equal.
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REFERENCES


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• Figure 1. Test Train

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• Figure 3. Longitudinal Force in Bents vs. Bent Number

• Figure 4. Shear Force vs. Bent Number when Shear Force is at its Maximum for Bent # 20

• Figure 5. Shear Force vs. Bent Number when Shear Force is at its Maximum for Bent # 40

• Figure 6. Typical Shear Force vs. Time – Tractive Effort Test

• Figure 7. Shear Force versus Time for Air Brake Test

• Figure 8. Partial View of the Concrete Trestle

• Figure 9. Elevation of the Ends Parts of the Concrete Trestle
Figure 2.
Figure 3.

Longitudinal Forces Under Locomotive Tractive Effort

Bent Number

Longitudinal Force in Bent (Kips)
Figure 4.
Figure 5.
Figure 6.
Figure 7.
Figure 8.
Bridge 185.6, Second District, Southern Division Galveston Sub.

23 Channels
HP 14 x 117 Piles, 2 Story Bracing

29 Channels
HP 14 x 89 Piles, 1 Story Bracing

Double Bents 6 12 18 25 32 39 46 53 60 66 66-72
15 25 35 45 55 65

2 LF and M 15 Channels
Moment only 6 Channels

Figure 9.