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Development of Design Guidelines for Longitudinal Forces in Bridges

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Summary

Beginning in 1996, the Association of American Railroads (AAR) sponsored several tests of longitudinal forces on bridges under unit trains powered by AC locomotives. The findings of those tests have led to significant changes in the guidelines used to design railroad bridges for longitudinal forces. This digest summarizes the changes and the steps taken to develop the new guidelines. The new guidelines recommend design forces which are in line with those used prior to 1968. But the new design forces are significantly greater than those used from 1969-1996.

The objective of this research program is to enhance the understanding of the effects of heavy axle loads and high tractive efforts and to minimize these effects in order to extend the life of bridge structures. Results of the first test in 1996 were used to make changes to the 1997 American Railway Engineering Association (AREA) manual. Subsequent testing of seven additional spans in three additional bridges verified the initial findings and provided additional data for the formulation of a new design recommendation.

The new design forces are given by easy-to-use equations rather than the tedious Cooper train loading used in past guidelines.

The new design guidelines will result in new railroad bridges built to better withstand the higher tractive efforts applied by new generations of locomotives. They will also be used to develop cost effective strengthening and repair methods for existing bridges.

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Suggested Distribution:
- ❑ Maintenance of Way
- ❑ Planning & Analysis
- ❑ Track Maintenance
- ❑ Bridges

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INTRODUCTION

Beginning in 1996, the AAR sponsored several tests of longitudinal loads on bridges under unit trains powered by AC locomotives. The tests were conducted by the Research and Test Department of the AAR and Transportation Technology Center, Inc. The findings of those tests have led to significant changes in the guidelines used to design railroad bridges for longitudinal forces. This digest summarizes the changes and the steps taken to develop the new guidelines. The new guidelines recommend design forces which are in line with those used before 1988. But the new design forces are much greater than those used from 1969-1996.

HISTORICAL BACKGROUND

The longitudinal design force recommended in the American Railway Engineering Association (AREA, now Railway Engineering and Maintenance-of-Way Association (AREMA)) manual has changed over time. In the 1905 edition, the design force was 20 percent of the specified total live load. By the 1920 edition, reductions were permitted for ballast-deck spans and for short structures. In the 1932 edition, the locomotive traction force of 25 percent of the Cooper driving axles was introduced, and the braking force of 15 percent of the Cooper train was introduced.

The AAR conducted a number of tests with the secondary objective of measuring longitudinal forces in the 1950s and 1960s. None of these tests was conducted under conditions that would approach the maximum possible longitudinal force available at that time and low longitudinal forces were measured in the bridges. It became the practice of some railroads to use one half the specified force.

In the 1968 edition of Chapter 15, Steel Structures, a factor L/1200 (where L is the length of the bridge in feet) was introduced to be applied to the 15 percent of the Cooper train load with an exception for bridges with non-continuous rail (as with movable spans, expansion joints, or switches). This resulted in a vastly reduced longitudinal force requirement, particularly for short bridges. The traction force of 25 percent of the weight on driving axles was eliminated. A similar change was made to Chapter 8, Concrete Structures and Foundations. Committee 7, Timber Structures, did not make changes to the Chapter 7 recommended practice.

RECENT TESTS

With the introduction of high-adhesion locomotives and improved braking systems, concern was expressed that recommended design forces might not be high enough. At least one railroad acknowledged cracking in bridge components due to longitudinal forces.

In 1996, the AAR conducted a test specifically to investigate longitudinal forces under the newly-developed alternating current (AC) diesel-electric freight locomotives.[1] The test on a 50-foot open-deck span demonstrated a longitudinal force of more than 100 kips, more than 25 times that indicated by Chapters 8 and 15 of the 1996 AREA Manual.

AREA revised Chapters 8 and 15 for the 1997 edition of its recommended practice to conform to this test result. The longitudinal force due to braking was reinstated as 15 percent of the Cooper train load. The longitudinal force due to traction was reinstated as 25 percent of the Cooper locomotive load, except that all locomotive axles were to be used, not just driving axles. Chapter 7 was considered to be appropriate and not warrant a change at the time.

The AAR sponsored further tests,[2,3,4] all of which confirmed the high longitudinal forces, and the high percentage of those loads which went into the structure. All tests used sets of two or three AC locomotives, operated near their maximum tractive effort capabilities. The results of these studies indicated:

- Longitudinal forces on ballast-deck spans can be as high as on open-deck spans.
- The majority of the longitudinal force is not carried off a span by the rails.
- There has been considerable lack of understanding about the force distribution and load path.
- High longitudinal forces are not necessarily related to grade.
- High longitudinal forces are related to lower speeds for tractive effort and dynamic braking situations. When a train is maintaining a speed that exceeds 15 mph, the locomotives typically cannot exert the maximum tractive effort.
- High longitudinal forces due to braking can occur at any location, even on a bridge, particularly if an emergency brake application occurs.

Analytical confirmation of the above behaviors has been shown by Foutch et al[1,3,5] and is also explained by Fryba.[6] Unfortunately, these formulations are too cumbersome for routine work.

NEW GUIDELINES FOR DESIGN

Exhibit 1 shows a plot of maximum measured longitudinal forces for the various bridges tested under the AAR research program. The measurements in Exhibit

TTCI = Transportation Technology Center, Inc.; AAR = Association of American Railroads

1 have been scaled based on the Cooper E-80 design loading. The actual test trains were approximately equivalent to Cooper E-60 loadings on the spans tested. Included are measurements from two-span and three-span segments of multi-span bridges. This data was used in the development of the new design guideline for longitudinal force due to locomotive traction. Rather than use the Cooper train, the suggestion was made to develop a formula which 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:

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

where L is length in 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. It follows the data reasonably well. And it is easy to use.

The longitudinal force due to train braking remains essentially the same as the 1997 version at 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. For ease of use, the design load has been expressed using the following formula:

$$\text{Longitudinal braking force (kips)} = 45 + 1.2\ L.$$

In the ranges of lengths where the braking force governs, this formula eliminates the tedious calculation of the Cooper train loading on the bridge.

Exhibit 2 compares the various AREA and AREMA design guidelines for longitudinal forces. Note that the 1996 guideline for Chapters 8 and 15 is significantly lower than any of the others, particularly for shorter lengths. Compared to the 1997 AREA guideline, 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. Exhibit 3 compares the measured force levels (under Cooper E-60 train loadings) with the various guidelines (for Cooper E-80 design loadings).

For the greater lengths listed in Exhibit 3, the longitudinal braking forces for design are greater than the longitudinal traction forces for design. The measured forces are from traction loading only. On a long bridge the braking forces can be greater because they are applied by all cars in a train, whereas tractive forces are applied by locomotives only.

The new AREMA longitudinal force guidelines are in the process of being balloted and approved by Committees 8 and 15 for inclusion in upcoming revisions of the AREMA Manual.

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1. **Foutch, Douglas A., Tobias, Daniel H., Otter, Duane E., LoPresti, Joseph A., and Uppal A. Shakoor,** Experimental and Analytical Investigation of the Longitudinal Loads in an Open-Deck Plate Girder Railway Bridge, Report R-905, Association of American Railroads, November 1997.

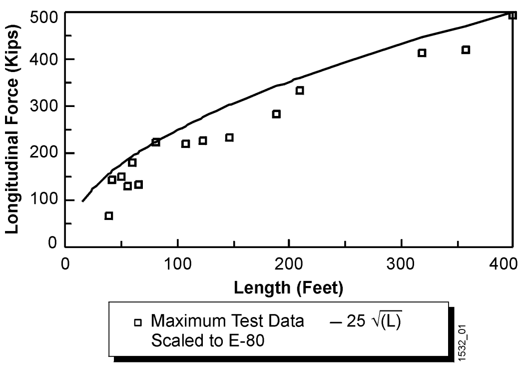

Exhibit 1. Maximum Measured Longitudinal Traction Forces in Bridges Tested

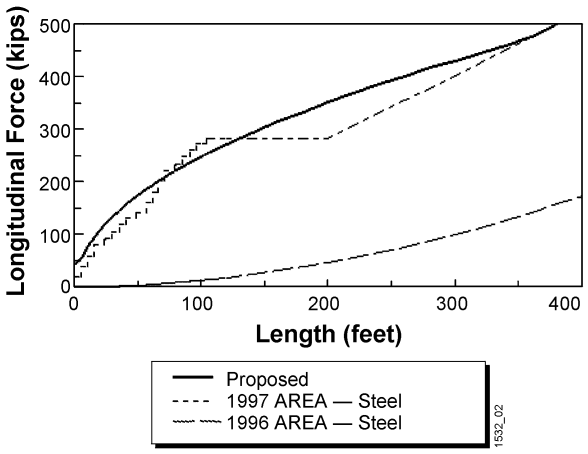

Exhibit 2. Comparison of Design Guidelines for Longitudinal Forces (Traction and Braking)

Length (feet)	Measured Force (kips)	1969-1996 AREA Force (kips)	1997 AREA Force (kips)	AREMA Force (kips)
39	49	2	119	156
42	113	3	132	162
50	110	4	142	177
56	96	5	162	187
60	117	5	155	194
65	76	6	182	202
107	123	15	284	259
122	140	19	284	276
210	223	51	292	362
400	330	173	523	525

Exhibit 3. Maximum Longitudinal Forces Compared to Chapter 15 Guidelines

2. **LoPresti, Joseph A., and Otter, Duane E.,** Longitudinal Forces in a Two-Span Open-Deck Steel Bridge at FAST, Technology Digest 98-020, Transportation Technology Center, Inc., August 1998.
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6. **Fryba, Ladislav,** Dynamics of Railway Bridges, Thomas Telford Services Ltd., London, 1996.

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