TECHNOLOGY DIGEST

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New Rating Guidelines for Longitudinal Forces in Steel Bridges

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Summary

Steps taken to develop new guidelines used to design and rate railroad bridges for longitudinal forces are discussed in this digest. 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 new rating guidelines recommend the use of forces that are more appropriate than those used from 1969 through 1996 by American Railway Engineering and Maintenance of Way Association (AREMA, formerly AREA), and are consistent with the AREA recommended practice used from 1905 to 1968.

Highlights of the new rating guidelines include:

- Longitudinal forces that are consistent with the vertical load rating of a bridge.
- Consideration given to locations where longitudinal traction forces are normally low.
- Load combinations appropriate for various bridge components.
- Provisions for the rare event of an emergency brake application or start up on a bridge.

The economic impact of this work is to provide savings in bridge upgrade costs and preserve the operating efficiencies generated by high-adhesion locomotives and heavy axle load equipment.

The new rating guidelines will result in a better assessment of the ability of a railroad bridge to withstand the higher tractive efforts applied by new generations of locomotives. This will help to better evaluate bridge capacity and prioritize bridge maintenance, upgrade, and replacement work.

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INTRODUCTION

Beginning in 1996, the AAR and TTCI conducted 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 and rate railroad bridges for longitudinal forces. This digest summarizes the new rating guidelines and rationale behind them. Since the changes in the guidelines are primarily related to the longitudinal forces developed by locomotives, the generation of these forces in terms of locomotive tractive effort is also discussed.

Bridge rating procedures are used to calculate bridge capacity for both regular traffic and occasional heavy load movements. Ratings are also used to prioritize bridge maintenance and upgrade needs. After bridges are upgraded, ratings are used to determine increased capacity.

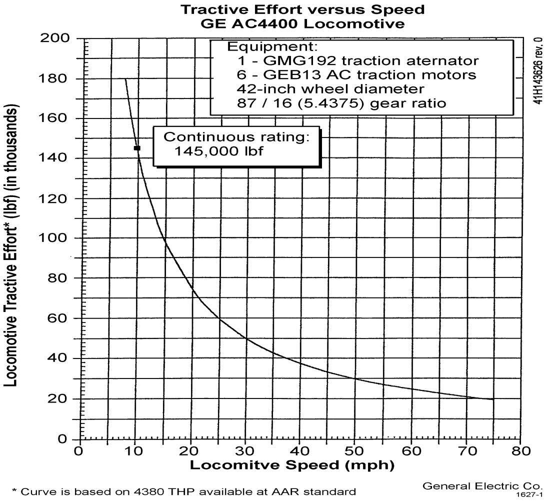
Because of the recent changes in the longitudinal forces used for bridge design, new provisions also became necessary for rating of bridges for longitudinal forces. Longitudinal force guidelines used for rating existing steel bridges are covered in Chapter 15 of the American Railway Engineering and Maintenance of Way Association (AREMA) Manual. The old guidelines simply recommended using the design longitudinal forces for rating. With the increased design forces, the ratings of many existing bridges might have been inappropriate without revision of the guidelines.

NEW GUIDELINES FOR RATING

The new guidelines attempt to provide more realistic bridge ratings for longitudinal forces. For bridges rated less than the current design load for vertical live loadings (for example, a rating of E-70 rather than E-80), the longitudinal forces used for rating can be scaled proportionally (for example, 70/80 times the E-80 design longitudinal forces). This helps to make the longitudinal force rating consistent with the vertical live load rating.

Also, the new guidelines recommend that the scaled design longitudinal forces are to be used for rating where maximum locomotive tractive effort at speeds below 25 mph is likely to occur. This includes locations where maximum braking effort is likely to be used. At speeds above 25 mph, locomotive tractive effort will be limited by available horsepower and be less than the maximum possible.

Exhibit 1 shows a typical locomotive tractive effort characteristic that illustrates the drop in available tractive effort as speed increases. The example shown is for an older four-axle locomotive. The characteristic for a modern six-axle unit is similar in nature, except that the tractive effort values are significantly higher.



* Curve is based on 4380 THP available at AAR standard

General Electric Co.

Exhibit 1. Typical Locomotive Tractive Effort Characteristic

At all other locations (where operation below 25 mph is not likely), the longitudinal force due to locomotive traction used for rating may be reduced again to reflect more realistic longitudinal forces for bridge evaluation. The rating longitudinal force may be reduced by the ratio of the actual locomotive tractive effort used at the bridge location, to the maximum rated tractive effort of locomotives used system-wide. For example, if the actual locomotive tractive effort at a bridge location is 50 kips, but the most powerful locomotives used on the system are rated for 150 kips, then the rating required for longitudinal force may be taken as 50/150 times the rating longitudinal force used at locations where maximum locomotive tractive effort is likely to occur.

Exhibit 2 helps to illustrate this provision. It shows the applied locomotive tractive effort from the head-end over a 30-mile territory. Note the variations in tractive effort due to variations in grade, throttle position, and train speed along the route. Near milepost 40 the applied tractive effort is significantly less than that applied near milepost 46. Near milepost 40, the applied tractive effort for a single unit is about 50 kips. The maximum rated tractive effort of locomotives used on this line is 150 kips. The longitudinal force for rating a bridge in this location could be reduced by the factor 50/150, assuming this is typical of the highest locomotive tractive effort to be applied near this location. However, near milepost 46, where the applied tractive effort is 125 kips, no reduction can be taken. In order to attain that tractive effort, the locomotive was moving at less than 25 mph in maximum throttle position.

To cover instances where operation over a bridge would normally be at speeds exceeding 25 mph, but

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

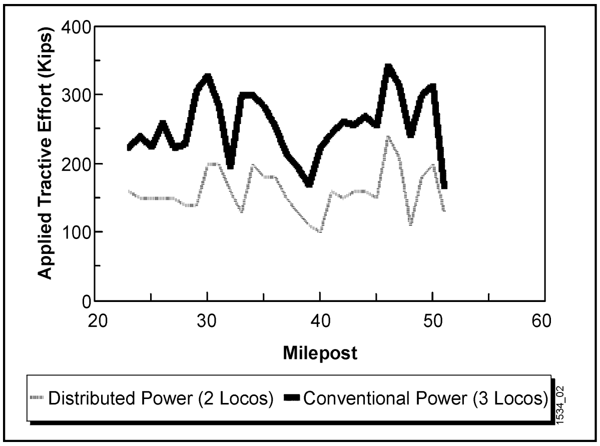


Exhibit 2. Locomotive Tractive Effort Recorded over 30 Miles

where for unusual reasons a rare instance of extreme longitudinal force occurs, a bridge must be capable of withstanding the proportioned longitudinal force at 1.5 times the normally recommended rating stresses. An article is included to cover the extreme event at such locations of emergency braking, or the case where a train stops on such a bridge and then must start from a still position. Note that modern locomotives are designed to start at their maximum tractive effort.

In addition to these more realistic longitudinal forces for rating, the new guidelines also include provisions for combinations of longitudinal forces with other forces on the structure. These provisions are to be applied to different components of a steel bridge, depending on the intended design function of the component.

For the combination of longitudinal force, wind force, and lateral force from equipment, components are to be rated using the recommended stresses normally used, for the full effects of these forces. This load combination will generally govern for components such as bracing members, the main function of which is not to carry vertical forces.

For the combination of longitudinal force with dead load, live load, impact and centrifugal force, components are to be rated using 1.25 times the unit stresses normally recommended. This load combination will generally govern for members that carry vertical forces as their main function. The increased allowable stress accounts for the improbability of all these forces being at their maximums simultaneously. This is particularly true since impact generally increases with train speed, while locomotive tractive effort decreases with speed.

In the event that longitudinal forces are higher than the calculated capacity of the structure, operating restrictions for the bridge need to be discussed with operating and mechanical personnel.

The new AREMA longitudinal force rating guidelines are in the process of being balloted and approved by Committee 15 for inclusion in an upcoming revision of the AREMA Manual.

EFFECTS OF LONGITUDINAL FORCES

Longitudinal forces can have a variety of effects on bridges. Maintenance items attributed to longitudinal forces include:

- Out-of-plane bending in floor beams
- Stresses in bracing members
- Span contacting backwall
- Pier and/or backwall movement
- Deck movement
- Distress at viaduct tower column tops
- Distress in bearings and anchorages

Most of these items are influenced by other loadings as well, so the effects of longitudinal loading alone are difficult to isolate.

Although longitudinal forces for design were relatively low from 1969 through 1996, the actual longitudinal force capacity of many bridges designed during that time is much higher due to other design forces as well as the use of standard details with much higher capacity. For this reason, many bridges built using lower longitudinal design forces might rate reasonably well even under the new provisions.

LONGITUDINAL FORCES OF LOCOMOTIVES

Longitudinal forces due to train traffic on railway bridges are due to either locomotive traction or braking. Locomotive traction forces are applied only by the locomotives of a train. Longitudinal forces due to braking can be applied by dynamic braking of locomotives, as well as air braking of an entire train.

The amount of locomotive longitudinal tractive force (tractive effort) produced at a particular location depends on a number of factors, including the type of motive power used, total train tonnage and associated rolling resistance, grades, and curves. Of these conditions, grades create the largest train resistance forces when attempting to keep a train rolling.

The tractive effort available depends on many factors including the locomotive horsepower, the type of traction motor, gear ratio, and weight on the axle. The characteristics of the diesel-electric locomotive are such that the highest available tractive effort is developed at low speeds, with tractive effort decreasing with increasing speed. The newer models of locomotives using either AC traction systems or advanced DC traction systems can develop much higher tractive efforts per locomotive unit than locomotives from the previous generation. This has a direct effect on what longitudinal forces are imparted to a bridge. Exhibit 3 shows AC locomotives pulling a coal train over a bridge.

To start a train rolling, the locomotives must apply tractive effort greater than the train resistance. The resistance of the train increases with increasing speed and varies with encountered grades and curves. As long as the applied tractive effort is in excess of the train resistance the train will accelerate. If the train resistance is greater than the applied tractive effort, the train will decelerate until the resistance is equal to the applied tractive effort.

For heavy trains, such as unit coal or grain trains with 100 cars or more, high tractive efforts are needed to move the trains because the train resistance is relatively high. The same high tractive effort could also be generated by a single locomotive pulling a string of heavy cars which forces the locomotive close to its tractive effort limit. The total amount of horsepower per ton may be low (less than or equal to approximately1.0), but the tractive effort available will sustain train movement at low speeds.

For high-speed trains such as intermodal trains or passenger trains, a different situation is created. The high speed necessary to maintain schedules means operation at higher speeds where locomotives are able to generate only a small portion of their maximum tractive effort. To be able to generate the necessary tractive effort, a higher number of units are required. This results in a horsepower-to-ton ratio that is considerably higher than for a unit coal or grain train operating at low speeds.

Exhibit 3. AC Locomotives Crossing Bridge

For general merchandise freight or local trains, the conditions can be variable and depend upon the operational practices of the railroad. These types of trains can either be operated similarly to unit coal trains or operate at medium speed. Operation at medium speed requires more horsepower to be able to develop the necessary tractive effort, hence more locomotives.

The effects on bridges from these types of train operations need to be examined for each particular situation. For heavy unit trains, especially on steep grades, the amount of longitudinal force applied to a bridge can be high for either short or long bridges, given the use of modern motive power which minimizes the number of units required. On short bridges, a low number of locomotives means a high amount of tractive effort per unit. This translates into a high tractive effort per truck on a locomotive for which short bridges are susceptible. On long bridges subject to high tractive effort from a heavy train, the complete locomotive consist can apply its tractive effort which can create a high longitudinal force. If the bridge is long enough, the type of motive power used is inconsequential given that all of the locomotives can be on the bridge.

For high-speed service, the effect on short bridges does not translate into the high forces generated by the high-tonnage trains. The high horsepower-to-ton ratio required by high-speed service requires more locomotives which decreases the tractive effort per unit. This translates into a lower tractive effort per truck. For long bridges, the total tractive effort can be high, given that the total train resistance is higher with higher speed. What must be taken into consideration, however, is that the total train resistance for a high-speed train will usually be less than what is experienced by a unit coal train because the overall tonnage is considerably less.

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