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# Rail Car Vertical Forces for Bridge Design and Rating

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## Summary

Through the Association of American Railroads' Strategic Research Initiatives Program, Transportation Technology Center, Inc. (TTCI) is developing guidelines for assessing and extending the life of steel railroad bridges. As a part of the process, TTCI quantified the current vertical force environment using over-the-road (OTR) data from load measuring wheelsets and wayside measurements from wheel impact load detectors (WILD).

The following results were obtained from this study:

- Freight car truck vertical loads totaling 160,000 pounds and 6-axle locomotive truck loads totaling 220,000 pounds travel over mainline routes daily. The Cooper E-80 design level is 160,000 pounds on two axles and 240,000 pounds on three axles (at 60-inch spacings).
- Dynamic measurements of net truck vertical forces from OTR and wayside data from 2-axle freight car trucks show that 99.95 percent of the forces are less than about 175,000 pounds at most locations.
- Dynamic measurements of net truck vertical forces from wayside data from 6-axle locomotives show that 99.95 percent of the forces are less than about 220,000 pounds at most locations.
- Two-axle freight car truck loads are significantly higher than 2-axle locomotive truck loads.

The 286,000-pound gross rail load car was introduced around 1990, and in 2003 was allowed in unrestricted interchange. But current American Railway Engineering and Maintenance of Way Association (AREMA) guidelines still recommend designing bridges for a Cooper E-80 design load as first recommended in the late 1960s.<sup>1</sup> With the increase in allowable car load, it is prudent to assess the current vertical load environment with respect to bridge design loads.

The WILD data used in this study includes traffic from intermodal, mixed freight, passenger, and various unit trains. The OTR data includes two different trips of about 1,500 miles each with a loaded coal hopper car.<sup>2</sup>

Results from these tests are being used to review the vertical force guidelines used by AREMA for design and rating of railway bridges. The data from this research should promote safer design and rating of these bridges. More accurate ratings allow for more rational prioritization of limited maintenance funds.

These forces are also applied to railroad track throughout the North American network. As such, this information is also of value to designers of various track components.



**INTRODUCTION**

TTCI measured actual net truck vertical forces using OTR and wayside data. The purpose of the measurements was to determine the vertical forces that are currently being imparted onto railway bridges.

The wayside data provides forces measured at specific track locations by millions of rail car passes. The OTR data provides dynamic forces measured under a single rail car operated over hundreds of miles of track.

In the 1960s, the interchange allowable car load was increased from 220,000 pounds to 263,000 pounds for 4-axle cars. In conjunction with that load increase, American Railway Engineering Association (now AREMA) bridge design loads increased from Cooper E-72 to E-80. The 286,000-pound gross rail load car was introduced around 1990 and in 2003 was allowed in unrestricted interchange. But current AREMA guidelines still recommend designing concrete and steel bridges for a Cooper E-80 design load. With the increase in allowable car load, it is prudent to assess the current vertical load environment with respect to bridge design loads.

The Cooper E-80 design load used for concrete and steel bridges has vertical forces of 80,000 pounds on the four heaviest axles. Design of shorter steel spans may be governed by an alternate live load, with vertical forces of 100,000 pounds on four axles. The alternate design load for steel bridges is intended to improve fatigue performance of floor systems and short spans.

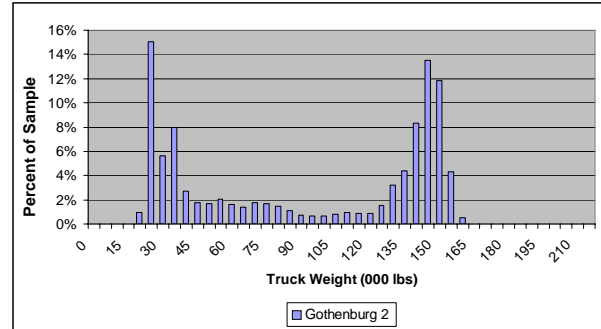
**Test Measurements – Wayside**

Wayside measurements are capable of gathering data from a large number of passing trains including different types of equipment. Wayside detectors are currently in use at many locations on several railroads throughout North America. This study uses measured net truck vertical (NTV) forces from WILDs on tangent track from both cars and locomotives.

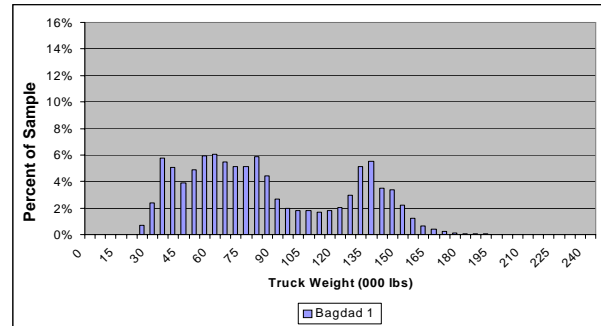
Wayside wheel force data was obtained from 12 different sites, at least one on each of the six largest railroads in the USA and Canada. Data was collected over a period of 12 months to minimize any seasonal effects. The NTV force was calculated by taking the sum of the average wheel loads for each wheel of the truck as it passed through the multiple measurement locations of a WILD site. Average wheel load data was used from each detector to minimize car dynamics and speed effects. (These detectors are typically located on smooth tangent track with welded rail to minimize vehicle dynamics.) Therefore, the data should closely resemble the static vertical load distribution. The data excludes effects of wheel defects that result in high impact forces.

The traffic included in the wayside data consisted of unit, intermodal, mixed freight, and passenger trains. Locomotives with four axles and locomotives with six axles were analyzed separately. Over 20 million 2-axle truck passes and over 600,000 locomotive truck passes (from both 6-axle and 4-axle locomotives) were analyzed. Wayside data was sorted by 10 mph speed increments up to the maximum recorded speed. The maximum allowable speed was governed by the railroad timetable for each location. Figure 1 shows the truck weight

distribution for 2-axle freight car trucks from a wayside site. Traffic at this site includes a considerable number of coal cars, empty and loaded. Figure 2 shows the truck weight distribution for a site with a considerable amount of intermodal traffic. Note the more even distribution in Figure 2. This is due to intermodal cars carrying containers or trailers that may reach volume capacity before weight capacity (cube out).

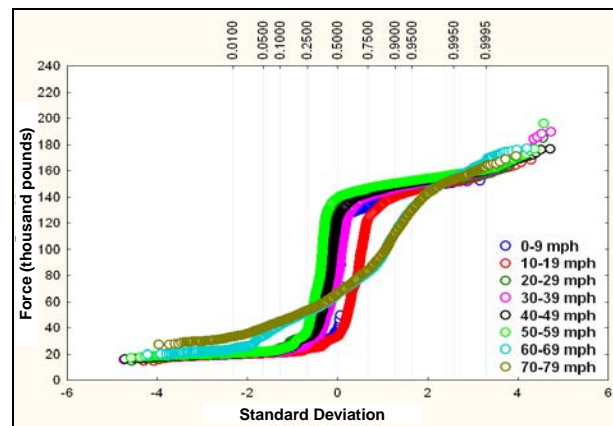


**Figure 1. Truck Weight Distribution for 2-axle Trucks from a Typical Wayside Detector**



**Figure 2. Truck Weight Distribution for 2-axle Trucks from Wayside Detector with More Intermodal Cars**

Figure 3 shows the cumulative distribution plot for net truck vertical forces for 4-axle cars for each speed range for a typical wayside site. And Figure 4 shows the cumulative distribution plot for net truck vertical forces for a wayside detector with more intermodal cars. Note the data points for train speeds greater than 80 mph, presumably from Amtrak passenger cars and express cars.



**Figure 3. Net Truck Vertical Forces from 2-axle Trucks from a Typical Wayside Detector Site**

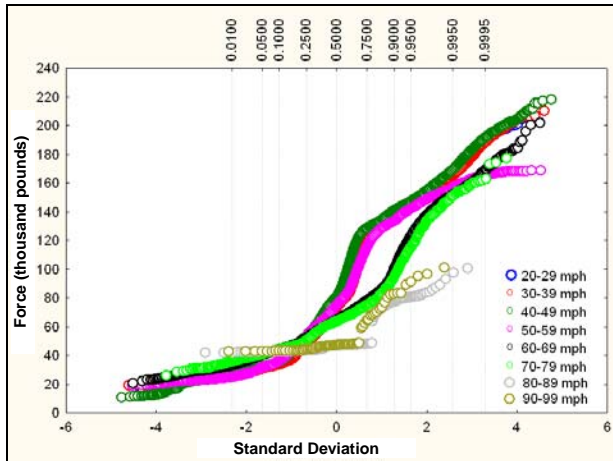


Figure 4. Net Truck Vertical Forces from 2-axle Trucks from a Wayside Detector with More Intermodal Cars

The values shown in Table 1 are for 2-axle trucks where the truck loads can be as high as 193,000 pounds. Note that for many of the wayside detectors, the NTV forces at the 99.95-percent level are very near or exceed 160,000 pounds, which is the design level of two Cooper E-80 axles.

Table 1. Net Truck Vertical Forces from 2-Axle Trucks from Wayside Detectors (Thousand Pounds)

Wayside Sites	95.0% NTV	99.5% NTV	99.95% NTV	Number of Trucks
BC1	146.1	152.4	159.7	1,346,880
BC2	145.7	151.4	157.1	1,870,474
CA1	145.0	165.2	188.2	1,527,969
CA2	136.0	158.4	177.6	1,446,744
TX	140.9	151.9	162.3	830,860
GA	142.1	151.2	160.4	1,294,001
PA	141.1	151.5	162.6	962,709
AR	136.9	149.7	155.7	1,176,512
NE1	132.2	150.2	157.4	3,558,536
NE2	149.9	155.1	159.7	1,709,420
NE3	152.3	156.5	159.7	3,211,479
MN	143.1	152.2	156.4	1,459,446
Total				20,395,030

Figure 5 shows the NTV forces for 12 wayside sites for 2-axle trucks, excluding locomotives. The three frequency levels are as follows:

- 95-percent NTV or 5-percent probability level, approximately five occurrences per train
- 99.5-percent NTV or 0.5-percent probability, approximately one occurrence per train
- 99.95-percent NTV or 0.05-percent probability, 1 to 10 occurrences per day, depending on traffic

Figure 5 shows that each of the 12 wayside sites experiences a net truck vertical force of nearly 160,000 pounds on a daily basis.

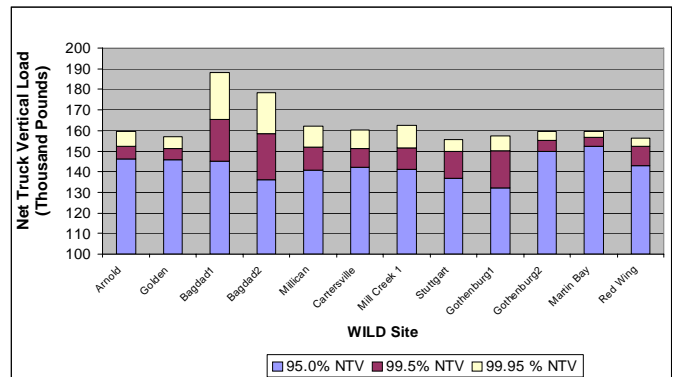


Figure 5: Net Truck Vertical Forces for 2-Axle Trucks at 12 Mainline Locations for 3 Probabilities of Occurrence

The values shown in Table 2 are for 4-axle locomotives where the truck loads can be as high as 156,000 pounds. Clearly these forces are less than those from freight cars.

Table 2. Net Truck Vertical Forces from 4 Axle Locomotives from Wayside Detectors (Thousand Pounds)

Wayside Sites	95.0% NTV	99.5% NTV	99.95% NTV	Number of Trucks
BC	138.3	143.1	143.1	246
BC	141.8	144.1	144.9	343
CA1	144.7	148.2	151.2	5,020
CA2	148.6	152.5	154.4	5,348
TX	144.3	147.7	151.6	2,370
GA	143.3	147.2	151.7	2,894
PA	138.2	144.0	152.3	1,580
AR	148.8	150.9	154.6	3,482
NE1	142.1	148.9	153.2	800
NE2	149.1	154.0	154.9	598
NE3	149.7	155.8	155.8	196
MN	140.7	147.5	152.8	7,268
Total				30,145

The values shown in Table 3 are for 6-axle locomotives where the net truck vertical forces can be as high as 240,000 pounds.

Table 3. Net Truck Vertical Forces from 6 Axle Locomotives from Wayside Detectors

Wayside Sites	95.0% NTV	99.5% NTV	99.95% NTV	Number of Trucks
BC	210.9	215.2	219.2	26,541
BC	215.3	219.3	222.1	47,873
CA1	210.1	215.1	219.9	96,664
CA2	216.1	220.9	227.7	60,268
TX	211.8	216.9	220.5	27,409
GA	213.1	217.9	220.7	44,116
PA	205.6	211.7	217.1	30,422
AR	210.9	216.2	220.8	39,273
NE1	210.3	215.3	220.0	76,374
NE2	212.8	219.0	224.8	46,008
NE3	210.7	215.4	219.2	65,682
MN	218.2	222.3	225.9	30,666
Total				591,296

**Test Measurements – Over-the-Road**

OTR data provides an excellent picture of the load spectrum applied by a single rail car traveling over many miles of route. The load variation is due to vehicle dynamics and impacts experienced en route. It complements the wayside data by providing data for a representative route in the railroad network.

Instrumented wheelsets (IWS) measuring the wheel/rail interaction forces were also used to gather data on about 1,500 miles of track over two major railroads. The onboard IWS system is capable of capturing the variation in loads on a single car due to vehicle dynamics in response to track geometry and train handling. The following load environments were obtained from two recent tests as part of other Association of American Railroads’ research programs that gather data on two different 286,000-pound coal hopper cars.

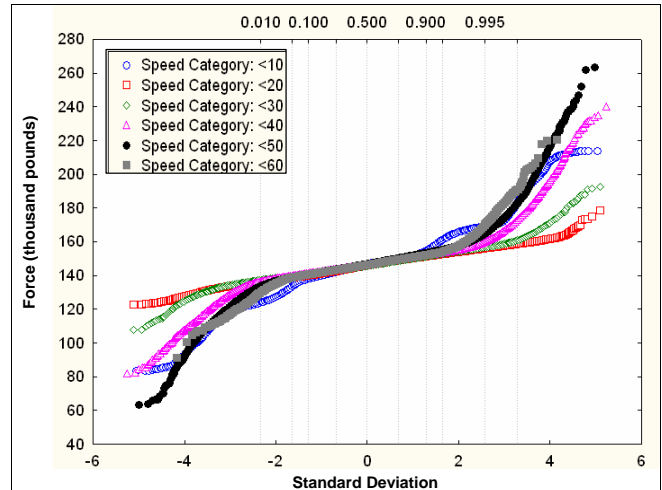
Table 4 shows the average, standard deviation (68 percentile), 95-, 99.5-, and 99.95-percentile values of the NTV for the two vehicles used in this study. The average measured NTV force was about 2 percent over the nominal static truck load (143,000 lb) in 2004 and about 2 percent under in 2005. This loading difference is likely responsible for most of the differences throughout the table. Note that the highest values measured each year, and also the 99.5-percentile value in 2004 exceeded the Cooper E-80 design level of 160,000 pounds on two axles. Approximately 1,500 miles of data were obtained for each vehicle tested.

Figures 6 and 7 show the cumulative distribution plot of net truck vertical forces for each of the two vehicles tested. The OTR data was categorized by 10-mph increments.

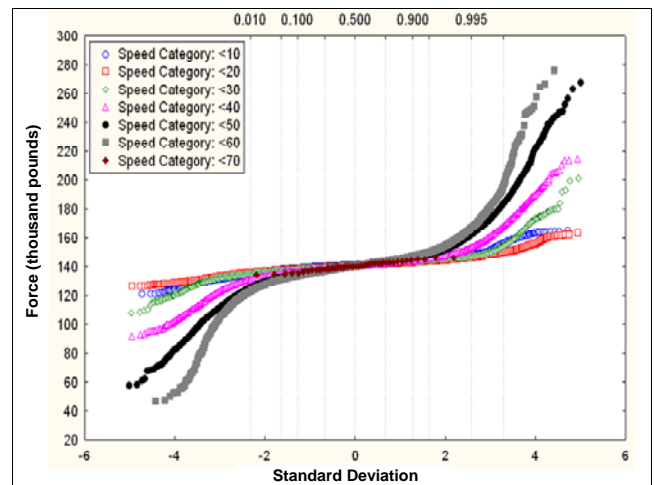
**Table 4. Net Truck Vertical Forces for Two Vehicles in Revenue Service**

Vehicle	Average NTV Force (kips)	68.0% NTV Force (kips)	95.0% NTV Force (kips)	99.5% NTV Force (kips)	99.95% NTV Force (kips)	Miles
2004 data	146.1	148.2	153.7	164.6	173.2	1,500
2005 data	140.5	141.7	145.8	154.8	172.8	1,500

As would be expected, the higher the speed, the higher the extreme loads. This data validates the use of speed restrictions or slow orders to reduce impacts and forces on bridges and track components.



**Figure 6. Net Truck Vertical Forces from 2004 OTR Measurements**



**Figure 7. Net Truck Vertical Forces from 2005 OTR Measurements**

**REFERENCES**

1. American Railway Engineering and Maintenance of Way Association. 2008. *Manual for Railway Engineering*.
2. Otter, Duane, Brian Doe, and Steven Belpoort. January 2005. “Rail Car Lateral Forces for Bridge Design and Rating,” *Technology Digest* TD-05-002, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.