Effects of Short Cars on Bridges and Track

Anna M. Rakoczy, Ph.D.
Transportation Technology Center, Inc.
55500 DOT Rd
Pueblo, CO 81001
Telephone: 719-584-0782

Duane Otter, Ph.D., P.E.
Transportation Technology Center, Inc.
55500 DOT Rd
Pueblo, CO 81001
Telephone: 719-584-0594

Colin Basye
Transportation Technology Center, Inc.
55500 DOT Rd
Pueblo, CO 81001
Telephone: 719-584-0767

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ABSTRACT
Transportation Technology Center, Inc. is investigating the effects of minimum length interchange cars on infrastructure. Data from the railroad industry equipment database shows the number of cars shorter than 48 feet have increased during the last 5 years, and the majority are approximately 42-foot-long cars. The areas of particular focus are those that might be different as compared to standard 53-foot cars. Preliminary studies identified bridges and embankments as areas of research.

Analysis of various bridge span lengths was performed to select the spans with maximum difference in deflections and stresses due to short cars. The findings of the comparative analysis shows that shorter cars will cause larger maximum moment on bridge spans of 60 feet and longer.

Finite element models were developed for four steel spans at the Facility for Accelerated Service Testing (FAST) — measuring 24 feet, 4 inches; 31 feet, 10 inches; 55 feet, 6 inches; and 64 feet, 8 inches and three longer revenue service bridge spans. The three longer spans show 20-35 percent higher stresses due to short cars when compared to stresses due to longer cars. The four spans at FAST show similar effects under both short and standard length cars. As expected, only a slightly difference was observed on the longest span.

In 2015, four steel spans at FAST were tested under train operations with two different car lengths. The data confirmed the analytical calculation. The three longer spans will be tested in 2016 to verify the predictions of higher stresses under shorter cars.

1. INTRODUCTION
The increase in shipments in short railcars may increase the loading on some bridges. The short 42-foot cars are about a 25 percent increase in load per unit length compared to standard length (53-foot) rotary dump coal cars. For example, five 42-foot cars can fit on a 210-foot span, instead of only four 53-foot cars. Increased weight per foot of length can also affect track embankments and bridge approaches. Transportation Technology Center, Inc. (TTCI) has conducted research on the effects of short cars on bridges and track (1, 2). This paper focuses on: (1) identifying the most common type of short cars, (2) determining span lengths most likely to be affected by shorter cars, (3) calculating peak stresses for various span lengths of bridges that were tested or will be tested in the near future, (4) comparing the bridge performance under short 42-foot-long cars and standard 53-foot-long cars, (5) providing fatigue stress ranges for considered span lengths, and (6) presenting the effects of short and standard length cars on track subgrade.
2. SHORT RAILCAR SURVEY FINDINGS BASED ON UMLER® DATA

For the purpose of this study, heavy axle load (HAL) cars are considered to be cars with a gross rail load of 286,000 pounds or more. Since 2010, the overall number of railcars recorded in the UMLER® database increased about 5 percent, and the number of all HAL cars increased 19 percent. The biggest increase was seen in short HAL cars — the number of cars shorter than 42 feet doubled indicating that the vast majority of the increase in HAL cars is short cars. Figure 1 shows the increase in the portion of short cars (< 48 feet) as a percentage of the entire car fleet. Figure 2 shows the number of HAL cars in the UMLER® database from 2010 to 2015 that are less than 48 feet in length compared to the number of HAL cars less than 42 feet in length.

The covered hopper is the most common of all short HAL cars. UMLER shows 85+ percent in 2010 and 90 percent in 2015 of all HAL cars shorter than 42 feet are covered hoppers. HAL cars shorter than 48 feet are primarily covered hoppers — about 62 percent in 2010 and 70 percent in 2015. Figure 3 presents statistics of various car types shorter than 48 feet, and Figure 4 presents statistics of short covered hoppers of various lengths.

FIGURE 1. Car Statistics from 2010 to 2015

FIGURE 2. Quantity of Short Cars from 2010 to 2015

FIGURE 3. Statistics of Various Type Short Cars, 2010 to 2015
3. EQUIVALENT COOPER LOADING FOR VARIOUS BRIDGE SPAN LENGTHS

The equivalent Cooper loading is based on the design loading recommended by the American Railway Engineering and Maintenance of Way Association (AREMA) (3). The new railroad bridges are designed for Cooper E80 loads. However, a large portion of the current steel bridge inventory was designed for Cooper E60 and less. The equivalent Cooper loading due to short cars exceeds E60 for spans longer than 225 feet and this can be a problem for older bridges with Cooper ratings of E60 and less.

In this study, the equivalent Cooper loading was calculated for bridge spans from 5 to 400 feet long. The Association of American Railroads (AAR) allows three types of short cars: AAR 41 feet, 10.5 inches (with truck centers of 27 feet, 4 inches), AAR 41 feet, 11 inches (with truck centers of 28 feet, 4.5 inches), AAR 41 feet, 11.5 inches (with truck centers of 29 feet, 5 inches). Figure 5 shows the effect on spans less than 60 feet is lower for a 41-foot, 10.5-inch car with a truck center of 27 feet, 4 inches than for a 53-foot coal car. Also shown in Figure 5, short cars have greater equivalent Cooper loads compared to standard length 53-foot cars on spans 60 feet and longer. A typical six-axle locomotive governs for spans from 55 to 80 feet long.

4. FE MODELING AND ANALYSIS FOR DIFFERENT BRIDGE SPAN LENGTHS

Four steel spans at FAST — measuring 24 feet 4 inches; 31 feet 10 inches; 55 feet 6 inches; and 64 feet 8 inches — were modeled using LUSAS Software and analyzed under train operations with two different car lengths. The two shortest spans are located on a 5-degree curve with 4 inches of superelevation, and the two longer spans are on a tangent alignment. These four spans were instrumented to measure strain gages and deflection and tested to validate the FE models. In addition, three more spans were modeled: a 115-foot
deck plate girder (DPG) span, a 110-foot truss, and a 200-foot truss. The three longer spans will be tested in 2016.

Details of the bridge spans at FAST can be found in a previously published Technology Digest (4). The three-dimensional analysis provides results for the entire structure. The FE models include all members and the track structure (rail and ties).

Displacement and stresses were calculated under various loads for each entire span. Typical 53-foot cars and AAR 41-foot, 11.5-inch (with 29-foot, 5-inch truck centers) short cars were considered in the analysis. To validate the models, the same test train configuration as the planned test was used and the peak stresses were further analyzed and compared to the test data. Figures 6 and 7 present vertical displacements on the 64-foot, 8-inch DPG and 200-foot truss due to a train made up of short cars.

**FIGURE 6. Vertical Displacement of 64-foot, 8-inch Span**

**FIGURE 7. Vertical Displacement of 200-foot, Truss Span**

The peak stresses due to the two car types were compared and are presented in Figures 8 and 9. An increase in the loading effects for the short cars (~42 feet long) was evident on longer spans. All FAST spans were showing similar stresses due to short and standard length cars. Slightly larger maximum stresses were noticed for shorter cars on the 64-foot, 8-inch span. More significant differences between
maximum stresses of shorter cars and standard length 53-foot cars were observed on the 115-foot DPG span, and two trusses (110 feet and 200 feet in length).

The 115-foot DPG had 28 percent higher stresses at mid-span due to short cars when compared to the standard length cars. In the truss members, the difference between the two car lengths depends on the location of the member. In the 110-foot-long truss, diagonals and bottom chords have about 15 percent higher stresses due to short cars when compared to the standard length cars and a 26 percent difference is evident in the upper chords. The stresses in the 200-foot-long truss due to short cars are 20-35 percent higher than for standard length cars.

**Figure 8. Calculated Maximum Peak Stress at Mid-span**

**Figure 9. Calculated Maximum Peak Stress in 110 feet and 200 feet Trusses**

**5. Test at FAST and Validation of Modeling**

A member railroad provided 12 short cars for testing at FAST to determine the differences in bridge response in comparison to standard length cars (e.g., 53-foot coal gondola or open top hopper). The test train included one locomotive; one instrumentation car (passenger car); twelve covered hoppers...
(approximately 42 feet long representing AAR 41-foot, 11-inch (28-foot, 4.5-inch truck centers), weighing 286 kips); six coal gondola or open top hoppers (53 feet long, weighing 286 kips); and six coal gondola or open top hoppers (53 feet long, weighing 315 kips).

Test runs were made at 10, 20, 30, 40, and 45 mph to evaluate the effects of the different car types at various speeds. Variation in speed provides information about potential dynamic impact. The good conditions of the bridge approaches at FAST and the maximum allowable speed of 45 mph did not indicate any difference in the dynamic effect between the short and standard length cars. For each speed, two to three train passes were made in each direction (clockwise and counterclockwise). In addition, runs were made over all bridges at 2 mph, which is considered a static speed.

The test included many components: collection of wayside data using the FAST Truck Performance Detector system (to evaluate vertical and lateral forces), stresses and deflection measurements of all three bridges at FAST, instrumented wheelsets, and geotechnical transducers in a low track modulus section.

Strains and displacements were recorded for all four steel bridge spans. The strain gages were placed at mid-span and quarter point locations, while the displacements were measured only at mid-span. The train ran in clockwise and counterclockwise directions over the bridges at various speeds. Figure 10 presents typical stress histories for all four spans recorded during the test. Peaks in the blue box are due to short cars weighing 286,000 pounds, those in the red and green boxes are due to standard length cars weighing 286,000 pounds and 315,000 pounds, respectively. It should be noted that each pressure pulse shown includes four wheels under two adjacent trucks from adjacent cars, and each valley corresponds to the distance between two trucks under a single car.
Peaks were analyzed and average peak stresses were calculated for each data set. As predicted, the difference in magnitude of peak stresses measured under train operations with two different car lengths was not significant for the short bridge spans at FAST. In some cases, maximum stresses due to short cars were a bit lower than due to the standard length cars. The reason for that is to the resulting increase in spacing between adjacent trucks of coupled cars. The short cars used in the test were 42-foot cars with a truck center spacing of 28 feet, 4.5 inches. The only noticeable difference in stress magnitude is for the standard length 315,000-pound car, which was expected. The effect of direction (clockwise or counterclockwise) was very minimal and may be considered to be within the tolerance of the measurement. The influence of different speeds on bridge spans located on tangent track was also
The variation of stresses due to train speed is noticeable on the spans located on the curve. This variation, however, is correlated to account for the superelevation and it is consistent through both spans and for all four measurement locations within the span.

To validate previous developed FE models, the stresses from the models were compared to the test data collected at FAST. Figure 11 presents a comparison between the test data from the north and south girders and the FE models. In the test data, the stresses on the north and south girders are slightly different; while in the models, both girders are the same since the models are created to be symmetrical.

The simple analytical calculation indicated that the longest span at FAST (64 feet 8 inches) had slightly higher moment (about 5 percent) due to short cars as compared to standard length cars. FE modeling of the 64-foot, 8-inch span shows a negligible difference at the center of the span, but visible effects at quarter span locations (about 7 percent higher). The test data confirmed that the quarter span location of the 64-foot, 8-inch span has slightly higher stresses due to short cars when compared to stresses due to the standard length car (about 4 percent). However, the measurements also show a small variation between north and south girders.

6. FATIGUE STRESS RANGES FOR CONSIDERED SPAN LENGTHS

Equivalent moments were also calculated based on moment histories developed for each span length and due to the short and standard length cars. The stress range comparison is presented in Figure 12 and 13.

In terms of fatigue stress ranges, detrimental effects of shorter cars were not observed. For all DPG spans, 53-foot standard length cars caused larger equivalent moments due to larger intermediate cycles, as expected. On shorter spans, longer truck spacing in 53-foot cars caused intermediate cycles to be full range cycles, from 0 to peak stress. While, stress histories for longer spans show that the intermediate cycles are higher due to the 53-foot cars — the example of stress histories is shown on Figure 12 for 55-foot, 6-inch DPG. Longer truck spacing in 53-foot cars produced greater unloading, resulting in larger intermediate cycles. Comparison of stress ranges due to short and standard length cars at mid-span locations is presented in Figure 13.
In the truss members, the difference in stress ranges between short and standard length cars depends on the location of the member. Most of the members showed higher stress ranges due to short cars when compared to standard length cars. However, the stress ranges are very small – less than 1.5 ksi, as shown in Figure 14. In this case, the effect is negligible, because stress ranges that small do not produce fatigue damage.
The effects on subgrade were evaluated in the low modulus track section at FAST, comparing subgrade pressure transducer readings for short and standard length cars. The soil in the FAST low modulus track section is high plasticity clay with a current moisture content of approximately 26 to 28 percent, compared to the original 33 percent (5), and it is surrounded by a 30 millimeter liner on three sides to retain moisture. Competent native silty sand surrounds the clay on three sides. The track modulus is approximately 2,000 lb/in/in. Removable transducers were installed in this section to record lateral and vertical pressure at different locations to evaluate geotechnical track performance.

The shallow and deep lateral earth pressure transducers were located 18 and 30 inches, respectively, below the top of the clay with the vertically oriented sensors parallel to the longitudinal axis of the rail. Similarly, the shallow and deep vertical pressure transducers were also located 18 and 30 inches below the top of the clay, but they were positioned so that the sensors were parallel to the long axis of the rail and looking upwards towards the rail (Figure 15).

Lateral and vertical soil pressures were recorded for clockwise and counterclockwise train movement at various speeds. Overall, there was no significant difference in magnitude of peak subgrade stresses measured under train operations with two different car lengths. The effect of the speed and direction was very minimal, and it may be considered indiscernible with respect to the measurement accuracy.

It can be noted that the short cars exerted approximately the same peak pressure values as the standard length cars of the same weight, but the relaxation interval; i.e., the valleys between the pressure pulses, are closer together. Thus, the soil pressure is influenced by the interaction of both the overlying wheelsets.
and adjacent wheelsets. The closer truck wheel spacing of the 42-foot cars resulted in this “retained”
energy at all speeds observed (Figure 16), which results in residual stress in the soil.

![Deep Lateral Pressure](image)

**Figure 16. Example of Residual Retained in Soil**

The undissipated soil stress is immediately manifest between pressure pulses, and depending on soil
properties, may build, decrease, or remain constant. Figure 16 shows a slightly decreasing trend in the
state of the stress in the soil, but the residual stress is a relatively small component of the total induced
pressure. Additional work is planned in 2016 to understand the mechanisms of the residual stress and
how it may affect subgrade performance under other conditions.

8. SUMMARY AND CONCLUSIONS

Exploration of UMLER® data shows that the most common short HAL car is the 42-foot covered hopper.

The analysis of various span lengths, using simple supported beam assumptions, shows that short cars
have greater equivalent Cooper loads compared to standard length 53-foot cars for bridge spans 60 feet
and longer. The difference is more prominent on bridge spans 80 feet and longer, where they provide
higher moments than typical six-axle locomotives.

The peak stresses due to short and standard length cars were calculated using three-dimensional FE
models for seven bridge span lengths. An increase in the loading effects for short cars (42 feet) was
visible on longer spans only. All spans at FAST showed similar stresses due to short and standard length
cars. The significant differences between maximum stresses of 42-foot cars and 53-foot cars were
observed on 115-foot DPG spans and 110-foot and 200-foot trusses. The 115-foot DPG has 28 percent
higher stresses at mid-span due to short cars when compared to standard length cars. In the truss
members, the difference in stresses between the short and standard length cars depends on the location
of the member and range from 15 to 35 percent.

The test performed at FAST confirmed the calculation using structural software. The difference in
magnitude of peak stresses measured under train operations with two different car lengths was not
significant. The only noticeable difference in stress magnitude was for the 315,000-pound car, which was
expected. The effect of the direction was very minimal and it may be considered to be within the tolerance
of the measurement. The influence of speed on spans located on tangent track was also minimal. The
test data was used to validate the FE models.

In addition, stress ranges, used for fatigue evaluation, were calculated. It was observed that the stress
ranges are higher due to short 42-foot cars for longer spans only. For shorter spans, 53-foot cars create
larger effective moment ranges and have smaller predicted fatigue lives. However, the stress ranges
were very small and are considered negligible, because they likely will not produce fatigue damage.

The effect in magnitude of subgrade stresses measured under train operations with two different car lengths
was not significant. Also, soil pressure values did not appear to be influenced by train speeds of 10 to 45
mph. However, temporary residual stress was observed in the subgrade that was apparent due to train operations of short cars, but it was not observed under train operations of standard length cars.

9. FUTURE WORK
It is recommended that future testing be done on longer bridge spans under unit train traffic with different length cars.

ACKNOWLEDGMENTS
The authors acknowledge Union Pacific Railroad for providing 12 short HAL cars for testing at FAST and allowing TTCI to prepare tests in revenue service.

REFERENCES
Effects of Short Cars on Bridges and Track

Anna M. Rakoczy, PhD
Duane Otter, PhD, PE
Colin Basye, PE
1. Background

Questions addressed:
- What are the most common types of short cars? Dimensions?
- What lengths of bridges will show maximum effects due to short cars?
- How does the vehicle performance of short cars compare to typical 53-foot cars?
- How will short cars influence embankments?

End products: Guidelines to minimize effects of short cars on track and structures

2. Statistics of the short cars

- Statistics were developed based on Umler database for North American rolling stock.
- Since 2010 the number of cars shorter than 42 ft. doubled.
3. Equivalent Cooper Loading

- The equivalent Cooper loading is based on the design loading recommended by AREMA.
- The new railroad bridges are designed for Cooper E80 loads. However, a large portion of the current steel bridge inventory was designed for Cooper E60 and less.

4. FE modeling and analysis

- 3D finite element model of 64’ 8” bridge at FAST
  - Displacement and stresses are calculated under various loads and critical locations on the structure.
  - Typical 53-foot cars and short 42-foot cars are considered in analysis.

- Calculated maximum peak stress at Mid-span of DPG
  - All FAST spans were showing similar stresses due to short and standard length cars.
  - The 115-foot DPG has 28% higher stresses at mid-span due to short cars when compared to the standard length cars.
4. FE modeling and analysis

3D finite element model of Revenue Service Bridges
- Two trusses with ballasted steel decks - lengths of 110 feet and 200 feet

Calculated Maximum Peak Stress in Trusses:
- In the 110-foot-long truss, stresses are higher 15-26% due to short cars when compared to the standard length cars.
- The stresses in the 200-foot-long truss due to short cars are 20-35% higher than for standard length cars.

Recommendation for bridge measurements - strain gages to evaluate axial forces will be installed on bottom and upper chords close to the center-span and diagonals.

Outline
1. Background
2. Statistics of the short cars
3. Equivalent Cooper Loading
4. FE modeling and analysis
5. Test findings
6. Fatigue stress range
7. Effect on Track subgrade
8. Summary and Conclusions

5. Test findings

The test train at FAST included:
- one locomotive
- one instrumentation car (passenger car)
- twelve covered hoppers (approximately 42 feet long, weighing 286 kips);
- six coal gondola or open top hoppers (53 feet long, weighing 286 kips);
- and six coal gondola or open top hoppers (53 feet long, weighing 315 kips).

The test at FAST included many components:
- Collection of wayside data using the FAST Truck Performance Detector system
- Stresses and deflection measurements of all bridges at FAST,
- Instrumented wheelsets,
- and geotechnical transducers in a low track modulus section.
5. Test findings

- Test runs were made at 10, 20, 30, 40, and 45 mph.
- For each speed, two to three train passes were made in each clockwise and counterclockwise direction.
- In addition, runs were made at 2 mph, which is considered a static speed.

Strains and displacements were recorded for all four steel bridge spans.

The strain gages were placed at mid-span and quarter point locations, while the displacements were measured only at mid-span.

Comparison of the Test Data and FE Model

Equivalent moments were calculated based on moment histories developed for each span length and due to the short and standard length cars.

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1. Background
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6. Fatigue stress range

Equivalent moments were calculated based on moment histories developed for each span length and due to the short and standard length cars.

Stress Histories on 55 feet 6 inches long
6. Fatigue stress range

- Comparison of stress ranges due to short and standard length cars at mid-span locations
- In the truss members, the stress ranges are very small - less than 1.5 ksi

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Comparison of stress ranges due to short and standard length cars at mid-span locations
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7. Effect on Track subgrade

- Increased weight per foot of length
- The 42-foot cars are about a 25 percent increase in load per unit length compared to coal cars.

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Increased weight per foot of length
The 42-foot cars are about a 25 percent increase in load per unit length compared to coal cars.
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420 feet = eight 53-foot cars = 5.4 kip/ft line load
420 feet = ten 42-foot cars = 6.8 kip/ft line load
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7. Effect on Track subgrade

- The effects on subgrade were evaluated in the low modulus track section at FAST
- The soil in the FAST low modulus track section is high plasticity clay with a current moisture content of approximately 26 to 28 percent,
- The track modulus is approximately 2,000 lb/in/in.

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The effects on subgrade were evaluated in the low modulus track section at FAST
The soil in the FAST low modulus track section is high plasticity clay with a current moisture content of approximately 26 to 28 percent,
The track modulus is approximately 2,000 lb/in/in.
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Pressure histories due to test train
Temporary residual soil stresses were observed due to train operations with short cars
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8. Summary and Conclusions

The observations from the tests on FAST Bridges:
- All four bridges at FAST were tested under train operations with two different car lengths.
- The modeling was validated with the test on FAST.
- As predicted, the short cars produced similar stresses on all spans when compared to the standard 53-foot cars.
- In terms of fatigue, all four spans have smaller fatigue stress ranges due to short cars when compared to standard 53-foot cars.

The observations for longer spans:
- The significant differences between maximum stresses of 42-foot cars and 53-foot cars were observed on longer spans.
- The 115-foot DPG has 28 percent higher stresses at mid-span due to short cars when compared to standard length cars.
- In the truss members, the difference in stresses between the short and standard length cars ranges from 15 to 35 percent.
- The preliminary results from revenue service test confirm the analytical prediction.

The observations from tests on soft subgrade:
- No significant difference in magnitude of subgrade stresses measured under train operations with two different car lengths.
- The effect of speed and direction on average maximum peak stresses was very minimal.
- Temporary residual stress was observed in the subgrade that was apparent due to train operations with short cars; but not with standard length cars.

TBC...
- Future research will consider testing of longer bridge spans under unit train traffic with different length cars.

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8. Summary and Conclusions

References:

TD-15-044  Vehicle Performance of Short Heavy Axle Load Cars
TD-16-002  Effects of Short HAL Cars on Subgrade
TD-16-013  Short Heavy Axle Load Cars: Analysis
TD-16-014  Short Heavy Axle Load Cars: Bridge Test at FAST

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