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Comparison of Continuous Spans versus Simply Supported Spans

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Transportation Technology Center, Inc. (TTCI) performed a comparative study of continuous versus simply supported bridge spans. The study was performed for several span lengths and it addressed internal and external forces, as well as cyclic loading and fatigue evaluation. The analytical comparison of simply supported spans versus three-span continuous bridges is comprehensive and gives a multi-faceted picture of the considered types of structures.

BACKGROUND

In North America, simple, statically determinate spans are most often used for railway bridge construction. Continuous spans are seldom used due to the practice of avoiding statically indeterminate structures, which are thought to be more difficult to fabricate, construct, and erect, and generally result in increased installation time and costs. Secondary stresses develop due to time-dependent effects (e.g., creep, shrinkage, settlement, tempature variation) and interconnected components increase the difficulty in maintenance and replacement.

The study was performed for seven span lengths: 50, 62.5, 75, 87.5, 100, 125, and 150 feet. Internal forces were evaluated at 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 of each span length. The detailed results for a 75-foot span are included in this *Technology Digest*.

LOAD MODEL

The actual service loading is different than the design load, which is a crucial factor for bridge evaluation and fatigue analysis. To perform a fatigue analysis, it is important to approximate train loadings as closely as possible with axle and load configurations corresponding to current operating conditions. Maximum stress ranges on a bridge and the number of cycles influence overall performance of a bridge.

In 2011, Dick et al. presented research on the development of an appropriate loading for design and rating of a bridge for fatigue.[1] The model was developed using current loading conditions with characteristics that allow for general use

Key Findings:

- In continuous bridge spans, mid-span deflection and stresses are reduced, but negative moment is generated on the piers. This study compared continuous spans to simply supported spans for railway bridges.
- Uplift at supports is troublesome; particularly with the relatively high live-load-to-dead-load ratios common to railway bridges.
- The concurrence of maximum moment and shear near the supports needs special detailing considerations for reinforcement of concrete beams. For steel beams, special detailing of stiffeners and connections is required.
- Results of this study show that the potential savings using a continuous span with a slightly smaller section may not outweigh the disadvantages of continuous spans.

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both for rating and design. The load model has a relatively high magnitude of repetitive moment, sufficient overall maximum moment, resembles actual equipment in its configuration, and has simple dimensions.

Figure 1 shows dimensions of the theoretical railcar used in this study. The axle force was 71.5 kips. The analysis was conducted with a moving train load of 100 identical, fully loaded railcars.

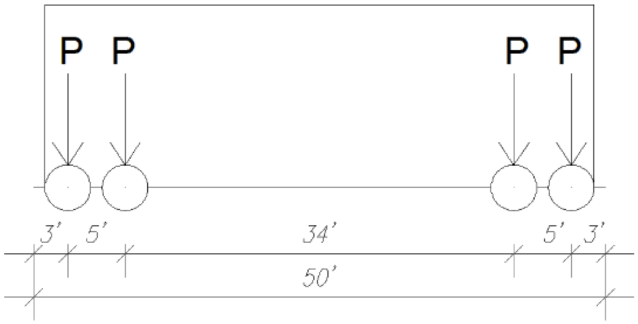

Figure 1. Railcar dimensions used for analysis

BENDING MOMENT

The study considered seven span lengths, from 50 to 150 feet. For each span, the moment envelope (due to a moving load of 100 railcars) was calculated and plotted. Figure 2 is an example of the moment envelope calculated for a 75-foot span for a three-span bridge. The moment reversal shown in Figure 2 adds to the complexity of design and analysis, which is particularly evident in seismic situations.

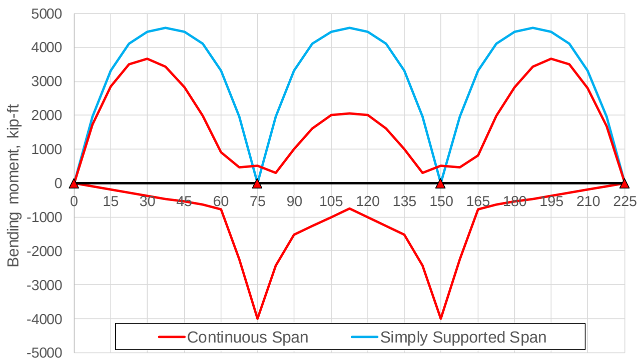

Figure 2. Moment envelopes of simply supported beam and three-span continuous bridge due to a moving load (each span is 75 feet)

The maximum moment and moment ranges were extracted from the moment envelopes. Figure 3 shows a comparison of moment ranges for simply supported spans and a three-span continuous beam, both with 75-foot spans. Moment range corresponds to the maximum amplitude of moments occurring at a certain point on the bridge due to moving load. For continuous spans, the moments change from positive to negative at each of the 10 locations calculated on the span as a train passes over the bridge.

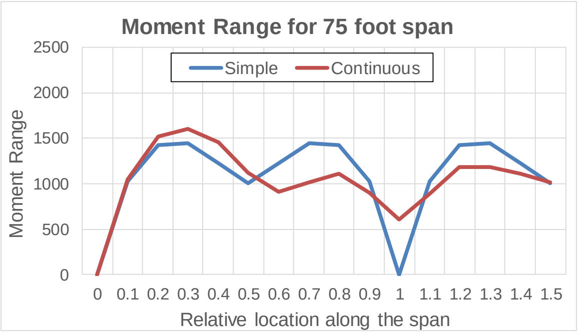

Figure 3. Comparison of moment range for simply supported spans and three-span continuous bridge (each span is 75 feet)

Figure 4 shows a comparison of maximum moments for simply supported spans and a three-span continuous bridge. Two locations were considered for the continuous span: at the middle of an end span and at an intermediate support. The simply supported spans have slightly bigger moments for most of the span lengths.

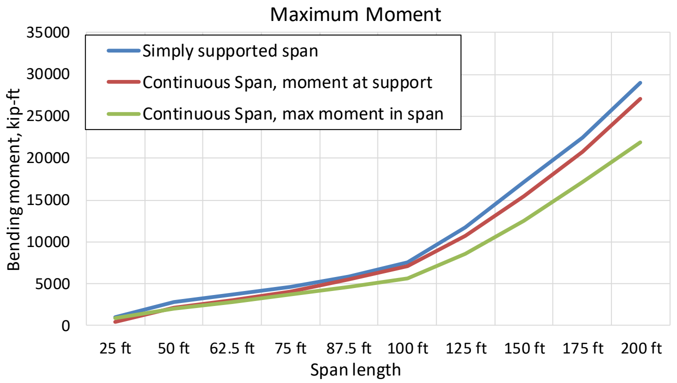

Figure 4. Comparison of maximum moment for simply supported spans and a three-span continuous bridge

SHEAR FORCE AND PIER REACTIONS

Shear force envelopes were developed for each span length for simple and continuous spans. Figure 5 shows the shear force envelope for 75-foot spans. As expected, in most locations on the span, shear force in continuous spans is slightly higher than shear force in simple spans. Figure 6 is a comparison of maximum shear force for different span lengths. The maximum shear force is always higher for continuous spans compared to simple spans of the same length.

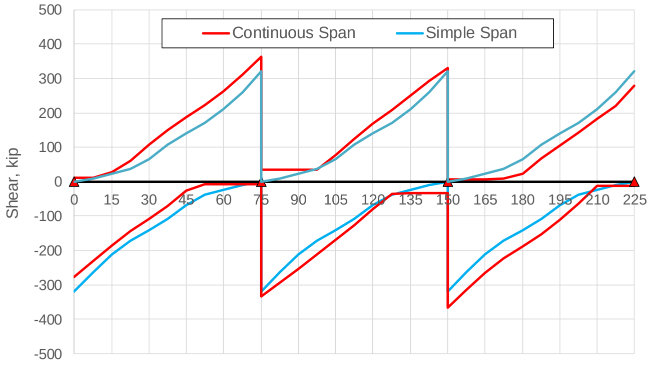

Figure 5. **Shear force envelopes of simply supported spans and a three-span continuous bridge (each span is 75 feet)**

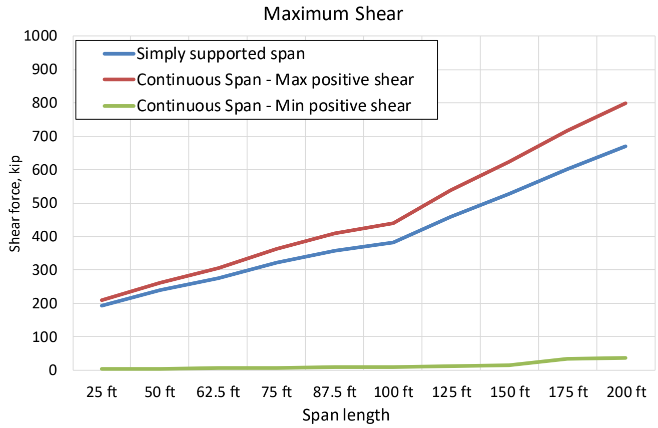

Figure 6. **Comparison of maximum shear force for simply supported spans and a three-span continuous bridge**

Figure 7 is a comparison of maximum and minimum pier reactions for different span lengths. The maximum pier reaction in continuous spans is comparable to the reaction of simple spans. The concurrence of maximum moment and shear near the supports in continuous spans requires special detailing considerations for reinforcement in concrete beams and for stiffeners and connections in steel beams.

The pier reactions at exterior supports of continuous spans are always smaller than the reactions for simple spans. Note also that the supports for continuous spans develop uplift, which is not a problem in simply supported spans. With that finding, the foundation, bearings, and anchors of continuous spans will require more capacity to resist the uplift. A cost-benefit analysis should be performed to evaluate the superstructure and foundation costs for both types of structures.

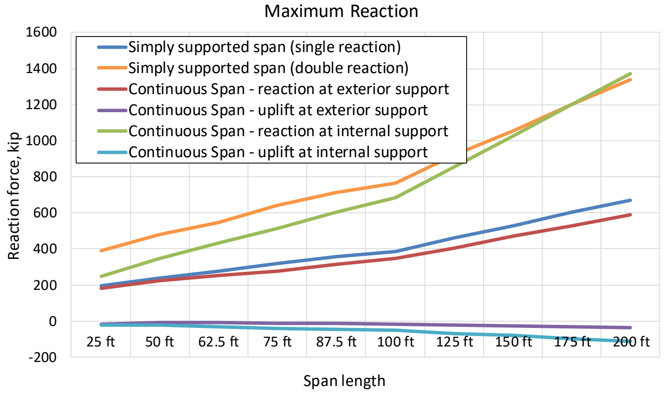

Figure 7. **Comparison of maximum pier reactions for simply supported spans and a three-span continuous bridge**

CYCLIC LOADING

The moment histories were calculated for each 0.1 length of a span for all seven span lengths and for both types of structures — continuous and simply supported. Figure 8 shows moment histories (developed for 10-unit train railcars to show the shape of the cycles) for one location on the bridge 30 feet from an exterior support. For other calculations, 100 unit train railcars were used.

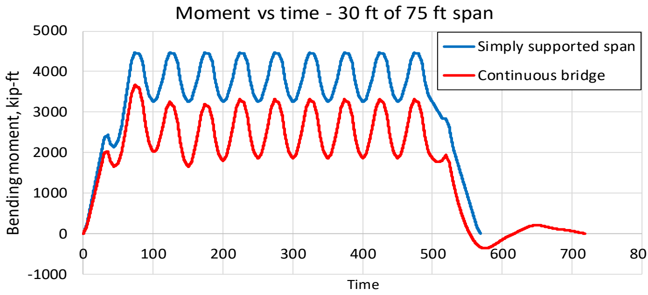

Figure 8. **Moment history for 75-foot, simply supported span and 225-foot, continuous three-span bridge 30 feet from an exterior support**

Rainflow counting was used to calculate the fatigue cycles. Then the effective moment was calculated, using the same method for calculating effective stress range. The number of cycles varies from simple spans to continuous spans. It is also different for different locations on the bridge. To compare the results, all effective moments were recalculated to a constant number of 100 cycles. Figure 9 shows the comparison of the effective moments for a simple span and for a continuous span.

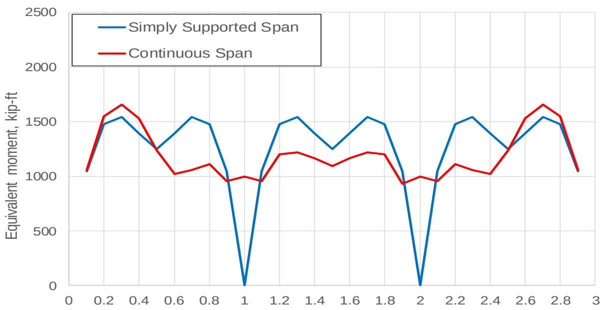

Figure 9. Comparison of equivalent moment calculated for simply supported beam and three-span continuous bridge (each span 75 feet)

BASIC COMPARISON

This study confirmed known disadvantages of a continuous beam as compared to a simply supported beam:

- More difficult analysis and design procedures.
- Difficulties in maintenance and replacement, which require more difficult structural engineering analysis to perform properly.
- Uplift at supports, particularly with the relatively high live-load-to-dead-load ratios common to railway bridges.
- Smaller sections will have more loss of capacity in case of corrosion.
- The concurrence of maximum moment and shear near the supports needs special consideration of detailing reinforcement for concrete beams and stiffeners and connections for steel beams.
- Reversal of moments due to seismic force requires additional analysis and design.

Sengupta and Menon reported the following advantages of continuous span bridges: "In continuous bridges the maximum bending moment is less than that in the simply supported span. Such reduction of bending moment might result in more economic sections for the bridge."[2] The potential savings using a more economical section may not outweigh well-known disadvantages of increased cost of fabrication, shipping, and installation for continuous beams. Simply supported spans provide the very important advanatage of easy and quick replacement that is more difficult with continuous spans.

CONCLUSIONS

Railway bridges are exposed to repetitive high stresses due to live loads and constant, relatively low stress due to dead loads. Repeated application of live loads may lead to increased maintenance demands even when the stress level is lower than the allowable stress. Therefore, fatigue performance must be considered when selecting a bridge design type, because it plays an important role in the maintenance and overall service life of a bridge.

The comparison of fatigue evaluation between simple span bridges and three-span continuous bridges was presented for one length of span, but the findings are true for all seven span lengths considered (50, 62.5, 75, 87.5, 100, 125, and 150 feet). In most of the cases, continuous spans developed effective moments lower than the simply supported spans. The only place where the effective moment was higher in a continuous span is on the interior support, because moment at a support in the simple span is always zero. On the continuous span, it is noticeable that the higher effective moments occurred in the exterior spans and the interior span had smaller, relatively uniform effective moments on the span.

The pier reactions of continuous spans were comparable to the reactions for simple spans. However, the continuous spans developed uplift on the piers, which means the foundation, bearings, and anchors of continuous spans require more capacity and may cost more. A cost-benefit analysis should evaluate the superstructure and foundation costs for both types of structures.

References

1. Dick, S. M., D.E. Otter, and R.J. Connor. 2011. "Comparison of Railcar and Bridge Design Loadings for Development of a Railroad Bridge Fatigue Loading." AREMA 2011 Annual Conference, Minneapolis, MN.
2. Sengupta, A. K., and D. Menon. 2012. "Prestressed Concrete Structures." Indian Institute of Technology Madras.

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