Investigation of the Effect of Speed on the Dynamic Impact Factor for Bridges with Different Entrance Conditions

Final Report
May 2016

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Federal Highway Administration
Iowa Department of Transportation
(InTrans Project 14-521)

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The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

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Technical Report Documentation Page

1. Report No. InTrans Project 14-521	2. Government Accession No.	3. Recipient's Catalog No.

4. Title Investigation of the Effect of Speed on the Dynamic Impact Factor for Bridges with Different Entrance Conditions	5. Report Date May 2016
	6. Performing Organization Code
7. Author(s) Yaohua Deng and Brent M. Phares (orcid.org/0000-0003-0779-6112 and orcid.org/0000-0001-5894-4774)	8. Performing Organization Report No. InTrans Project 14-521
9. Performing Organization Name and Address Bridge Engineering Center Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Organization Name and Address Iowa Department of Transportation 800 Lincoln Way Ames, IA 50010 Federal Highway Administration U.S. Department of Transportation 1200 New Jersey Avenue SE Washington, DC 20590	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code SPR RB11-015

15. Supplementary Notes

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16. Abstract

The dynamic interaction of vehicles and bridges results in live loads being induced into bridges that are greater than the vehicle's static weight. To limit this dynamic effect, the Iowa Department of Transportation (DOT) currently requires that permitted trucks slow to five miles per hour and span the roadway centerline when crossing bridges. However, this practice has other negative consequences such as the potential for crashes, impracticality for bridges with high traffic volumes, and higher fuel consumption. The main objective of this work was to provide information and guidance on the allowable speeds for permitted vehicles and loads on bridges.

A field test program was implemented on five bridges (i.e., two steel girder bridges, two pre-stressed concrete girder bridges, and one concrete slab bridge) to investigate the dynamic response of bridges due to vehicle loadings. The important factors taken into account during the field tests included vehicle speed, entrance conditions, vehicle characteristics (i.e., empty dump truck, full dump truck, and semi-truck), and bridge geometric characteristics (i.e., long span and short span). Three entrance conditions were used: As-is and also Level 1 and Level 2, which simulated rough entrance conditions with a fabricated ramp placed 10 feet from the joint between the bridge end and approach slab and directly next to the joint, respectively. The researchers analyzed and utilized the field data to derive the dynamic impact factors (DIFs) for all gauges installed on each bridge under the different loading scenarios. Based on the calculated DIFs and the change trends for the associated important factors, the conclusions were as follows:

- The DIF increases with the increase of truck speed, entrance condition level, and bridge span length.
- For all investigated bridges under Level 1 and Level 2 entrance conditions, the DIFs exceeded 0.3; under the As-is entrance condition, the DIFs were less than 0.3 for the steel and concrete girder bridges and less than 0.1 for the concrete slab bridges.
- The empty dump truck induced the greatest impact factors, followed by the full dump truck and then the semi-truck.
- To limit the DIF to no more than 0.1, for all bridge types, the allowable truck speeds are 30 mph for As-is entrance conditions and crawl for bridges with Level 1 and Level 2 entrance conditions.
- The researchers recommend that currently collected road roughness information be examined for use as an indicator of entrance condition. If successful, the international roughness index (IRI) data could then be used to determine the speed limitation to put in place as well as which DIF values to use in permitting analysis.

17. Key Words bridge approaches—bridge speed limits—dynamic bridge loads—dynamic impact factors—live bridge loads—load permits—permitted vehicles	18. Distribution Statement No restrictions.

19. Security Classification (of this report) Unclassified.	20. Security Classification (of this page) Unclassified.	21. No. of Pages 51	22. Price NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

INVESTIGATION OF THE EFFECT OF SPEED ON THE DYNAMIC IMPACT FACTOR FOR BRIDGES WITH DIFFERENT ENTRANCE CONDITIONS

Final Report
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Sponsored by
the Iowa Department of Transportation and
the Federal Highway Administration
(InTrans Project 14-521)

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement
with the Institute for Transportation

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ACKNOWLEDGMENTS

The research team would like to acknowledge the Iowa Department of Transportation (DOT) for sponsoring this research and the Federal Highway Administration (FHWA) for state planning and research funding. In addition, the authors would like to acknowledge the support of the Iowa DOT Office of Bridges and Structures staff, who continually provide great insight, guidance, and motivation for practical and implementable research like this.

EXECUTIVE SUMMARY

The dynamic interaction of vehicles and bridges results in live loads being induced into bridges that are greater than the vehicle's static weight. Consideration of this phenomena has been included in the American Association of State Highway Transportation Official (AASHTO) Bridge Design Specifications for many years. While the specifications have been modified over the years, questions remain about how much of an effect dynamic interaction plays.

In recognition of this interaction, the Iowa Department of Transportation (DOT) currently requires that, in some instances, permitted trucks slow to five miles per hour and span the roadway centerline when crossing bridges. Such a slowing is consistent with current specifications, which indicate that a lower dynamic impact factor may then be used for permitted vehicles. The positive effect of this is that larger loads may be allowed to cross Iowa's bridges.

However, this practice has other negative consequences. For example, the reduction in speed increases the potential for crashes, uses additional fuel, and, in some cases, may be downright impractical for bridges with high traffic volumes. In addition, the reduction in speed can have an impact on the orderly flow of traffic. There is a need to evaluate the Iowa DOT policy and perhaps develop updated guidelines to refine current practice related to bridge-vehicle interaction.

The primary objective of this work was to provide information and guidance on the allowable speeds for trucks, and permitted vehicles and loads in particular, on bridges.

A field test program was implemented on five bridges (two steel girder, two pre-stressed concrete girder, and one slab) to investigate the dynamic response of bridges due to vehicle loadings. The important factors taken into account during the field tests included vehicle speed, entrance conditions, vehicle characteristics (i.e., empty dump truck, full dump truck, or semi-truck), and bridge geometric characteristics (i.e., long-span or short-span). These were the three entrance conditions that the researchers used: As-is and also Level 1 and Level 2, which simulated rough entrance conditions with a fabricated ramp placed 10 feet from the joint between the bridge end and approach slab and directly next to the joint, respectively.

The researchers analyzed and utilized the field data to derive the dynamic impact factors (DIFs) for all gauges installed on each bridge under the different loading scenarios. Based on the calculated DIFs and the change trends for the associated important factors, the conclusions were as follows:

- The DIF increases with the increase of truck speed, entrance condition level, and bridge span length.

- For all investigated bridges, under Level 1 and Level 2 entrance conditions, the DIFs exceeded 0.3; and under the As-is entrance condition, the DIFs were less than 0.3 for the steel and concrete girder bridges and less than 0.1 for the concrete slab bridges.

- The empty dump truck induced the greatest impact factors, followed by the full dump truck and then the semi-truck.

- To limit the DIF to no more than 0.1, for all bridge types with entrance conditions similar to those tested in this study, the allowable truck speeds are 30 mph for As-is and crawl for Level 1 and Level 2.

- The researchers recommend that currently collected road roughness information be examined for use as an indicator of entrance condition. If successful, the international roughness index (IRI) data could then be used to determine the speed limitation to put in place as well as which DIF values to use in permitting analysis.

- Furthermore, the long-term bridge monitoring systems installed on Interstate 80 should be used to study impact factors and stress levels for actual permitted vehicles. Utilizing these data will provide the best information as to what level permitted vehicles traveling at highway speeds induce dynamic effects in bridges.

CHAPTER 1 INTRODUCTION

1.1 Background

It is widely accepted that the dynamic interaction of vehicles and bridges can sometimes result in live loads being induced that are greater than the vehicle’s static weight. In fact, consideration of this phenomena has been included in the American Association of State Highway Transportation Official (AASHTO) Bridge Design Specifications for many years. While the specifications have been modified over the years, questions remain about how much of an effect dynamic interaction plays.

In recognition of this interaction, the Iowa Department of Transportation (DOT) currently requires that, in some instances, permitted trucks slow to five miles per hour and span the roadway centerline when crossing a bridge. Such a slowing is consistent with current specifications, which indicate that a lower dynamic impact factor may then be used for permitted vehicles. The positive effect of this is that larger loads may be allowed to cross Iowa’s bridges.

However, this practice has other negative consequences. For example, the reduction in speed increases the potential for crashes, uses additional fuel, and, in some cases, may be downright impractical for bridges with high traffic volumes. In addition, the reduction in speed can have an impact on the orderly flow of traffic. There is a need to evaluate the Iowa DOT policy and perhaps develop updated guidelines to refine current practice related to bridge-vehicle interaction.

1.2 Objective and Scope

The main objective of this work was to provide information and guidance on allowable speeds for trucks, and permitted vehicles and loads in particular, on bridges. The research needed to take into account the many factors that affect the dynamic response of a bridge under vehicular traffic including vehicle speed, vehicle characteristics, bridge dynamic characteristics, and roughness of the bridge approach. To achieve the project goal, a field test program was developed to investigate the influence of the different factors on the dynamic response of bridges, and the field-measured data were then analyzed to draw conclusions with respect to the dynamic impact factor (DIF) for bridges. Three types of common Iowa bridges (i.e., steel girder, pre-stressed concrete girder, and concrete slab) were selected for field testing to facilitate the development of conclusions from this study.

1.3 Work Plan

The following general tasks were completed during this study. It should be noted that it was the collection of information that led to the development of the final study conclusions. As noted above, understanding bridge/vehicle interaction is a very complex topic that has resulted in an ever-evolving set of codified provisions.

Task 1 – Literature Review

During Task 1 a brief literature search and review was conducted to investigate other work related to DIFs for bridges. Of special interest was previous work related to the establishment of DIFs for permitted loads and recommendations for limiting permitted vehicle speeds when crossing bridges.

Task 2 – Analysis of Factors Influencing Dynamic Impact Factors

To provide information and guidance on recommended dynamic impact factors and allowable permitted vehicle speeds, field testing was conducted on five bridges in Iowa. During testing, the researchers installed instrumentation on each bridge and then monitored as a series of trucks crossed over the bridge. The researchers calculated DIFs by comparing the high speed results to those obtained from testing at low (crawl) speeds. Five different factors were considered: bridge type, entrance condition, span length, truck type, and speed.

Task 3 – Documentation and Information Dissemination

The work completed during this project was summarized in this final report, which has five chapters.

CHAPTER 2 LITERATURE REVIEW

2.1 Impact Factor Definition

Vehicles exert a dynamic response on bridges. This is caused by vibration of the traveling vehicle, which causes the vehicle mass to interact, in a complex manner, with the bridge. This dynamic response must be included in the design, as it often produces greater live load moments and shears than the static response alone. To quantify the dynamic live load response, specifications make use of the so called dynamic impact factor (*IM*). The IM can be determined as follows:

$$IM = \frac{R_{dyn} - R_{sta}}{R_{sta}} \tag{1}$$

where, R_{dyn} and R_{sta} are the maximum dynamic and static responses, respectively, regardless of whether the two responses occur with the truck at the same longitudinal position (Deng et al. 2014). The *IM* is also often times referred to as the dynamic load allowance (DLA).

According to the *AASHTO LRFD Bridge Design Specifications*, the dynamic load allowance (*IM*) is additionally applied to the static wheel load for taking into account wheel load impact for moving vehicles. For strength designs of most bridge components (except for deck joints), an *IM* of 0.33 should be applied (AASHTO 2010).

2.2 Previous Research Findings

Several studies of this nature have been performed in the past. A brief summary of a collection of these studies in provided in this section.

Deng et al. (2014) conducted a large-scale literature review on the use of DIFs in several countries. They found that each country’s bridge code specifies the calculation of impact factors in slightly different ways, in terms of span length, flexural mode frequencies, load configurations, and vehicle suspension, among others. They also reviewed parametric studies on the calculation of IM.

The Deng study showed that road surface condition has a large influence on the DLA. The authors also determined that vehicle speed is an important factor, but the direct relationship to IM remains unclear. A third conclusion was that IMs decrease with increasing vehicle weights, derived from the fact that greater static strains tend to yield smaller increases in dynamic strains and, hence, smaller IMs (Deng et al. 2014).

Wekezer and Taft (2011) conducted a study that aimed to produce dynamic loading data—in order to better understand dynamic impact factors—without having to carry out numerous, expensive field tests. Three prestressed reinforced concrete bridges were selected for physical tests to obtain a base understanding of the behavior of bridges under heavy dynamic loads. The researchers conducted both static and dynamic tests (at 48 and 80 km/hr). From the data, they were able to develop finite element (FE) models of both the truck and the bridge. The FE models enabled them to determine several factors that produce relatively large dynamic load allowance factor values: surface imperfections, the "hammering effect" produced by loose cargo in a vehicle, and vehicle suspension (Wekezer and Taft 2011).

Caprani (2013) studied the dynamic effects of free-flow and congested traffic. By way of a critical traffic index, the author found that the dynamic amplification factor is very sensitive to the model used, and congested or free-flow traffic may be the controlling factor on either short- or long-span bridges (Caprani, 2013).

The Florida Department of Transportation (FDOT) sponsored a large-scale study on impact factors for permitted vehicles (Wekezer et al. 2008). The researchers developed FE models of a tractor-trailer and a crane. These models were then validated and used for analysis of dynamic loading on bridges. The results from the analytical study correlated well with those obtained from a physical test on an actual bridge.

With these models, the researchers determined that impact factors are significantly affected by the vehicle's suspension system. The researchers found that heavy vehicles with stiff suspension systems tended to create higher IMs. The impact factor can be further increased by the presence of loose cargo on the vehicle and by vehicle vibration caused by road surface conditions (Wekezer et al. 2008).

Szurgott et al. (2011) looked at the dynamic response of two tractor-trailer systems and a midsized crane crossing speed bumps on a bridge in Northwest Florida. The researchers concluded that surface imperfections, vehicle suspension, and vehicle wheelbase all play a significant role in the development of dynamic effects. They also suggest that modern vehicle suspensions are relatively effective tools for controlling dynamic impact. Similarly, vibrations can also be controlled by evenly distributing the load over multiple axles (Szurgott et al. 2011).

CHAPTER 3 FIELD TESTING

Field testing was conducted to investigate the dynamic effects on one concrete slab, two steel girder, and two prestressed concrete girder bridges in Iowa.

During testing, the researchers installed strain gauges and then collected data as a series of trucks crossed over each bridge. Important factors considered during the field tests included vehicle speed, vehicle characteristics, bridge characteristics, and roughness of the bridge approach.

3.1 Factors and Loading Scenarios

In view of the influence of important factors on the dynamic response of a bridge, these five different factors were considered during field testing: bridge type, entrance condition, span length, truck type, and speed. The steel girder and prestressed concrete girder bridges either had short or long maximum spans. This was because long span bridges are more flexible under the dynamic vehicle loading and have lower dynamic effects compared to short span bridges.

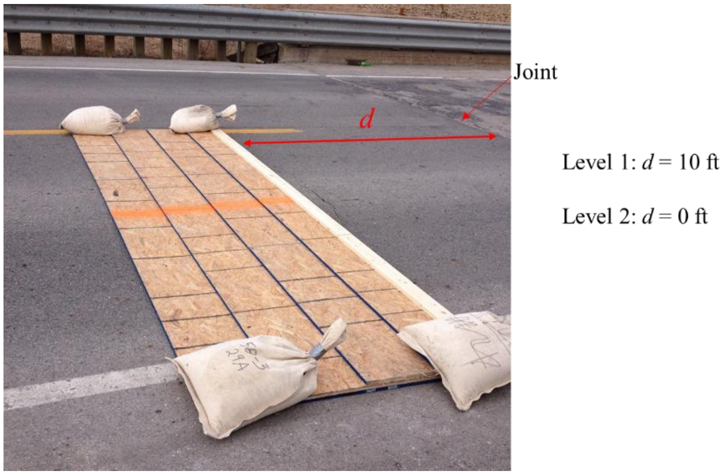
Basic information about the five selected bridges is shown in Table 3.1. Additional details about each bridge are presented later.

Table 3.1 Bridges selected

Bridge Type	Bridge Number	Number of Spans	Maximum Span Length
Concrete slab	30790	1	30
Steel girder	23370	4	85 (short)
	600770	4	180 (long)
Prestressed concrete girder	40320	3	50 (short)
	608580	2	140 (long)

To simulate rough entrance conditions (due to tilting of the approach slab, failed corbel, etc.), often times referred to as the bump at the end of the bridge, three types of entrance conditions were used during testing: As-is (or Level 0), Level 1, and Level 2. The Level 1 and Level 2 entrance conditions were simulated by placing a timber ramp 10 feet away from the joint and directly next to the joint, respectively. Figure 3.1 illustrates the Level 1 and Level 2 conditions with the variable, *d*, equal to 10 ft and 0 ft, respectively.

Dimensions of the ramp



Level 1 and Level 2 ramp distances from joint

Figure 3.1 Entrance conditions

Three types of test vehicles were utilized: empty dump truck, full dump truck, and semi-truck, with typical examples shown in Figure 3.2.

Dump truck **Semi-truck**

Figure 3.2 Field test trucks

Each test vehicle crossed each of the three entrance conditions at a crawl speed, 10 mph, 20 mph, 30 mph, and 50 mph. One passage was conducted for each type of loading scenario. This resulted in a total of 45 loading scenarios (see Table 3.2), which were then used to investigate the influence of the different factors on DIF levels.

Table 3.2 Field testing bridge loading scenarios

	Factors				Total Loading Scenarios
	Entrance condition (3)	**Truck type (3)**	**Speed (5)**	**Load type (1)**	
Considered variations	(1) Level 0 (2) Level 1 (3) Level 2	(1) Empty dump truck (2) Full dump truck (3) Semi-truck	(1) Crawl (2) 10 mph (3) 20 mph (4) 30 mph (5) 50 mph	(1) Single Lane	3 × 3 × 5 × 1 = 45

Level 0 = Entrance condition as it currently exists (As-is condition)
Level 1 = Simulated by placing a timber ramp 10 ft away from the joint
Level 2 = Simulated by placing a timber ramp directly next to the joint

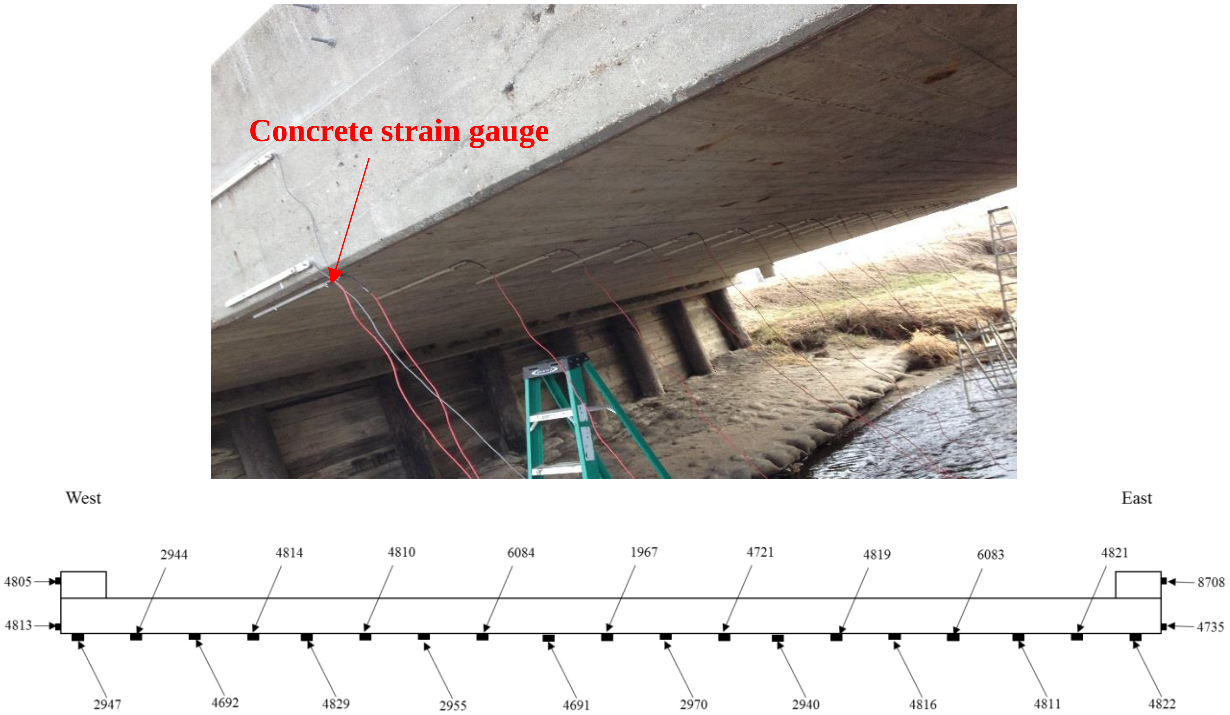
3.2 Bridge Descriptions and Instrumentation

Five bridges were tested in this study: one concrete slab bridge (30790), two steel girder bridges (23370 and 600770), and two prestressed concrete girder bridges (40320 and 608580). This section contains descriptions of each bridge, the instrumentation scheme, as well as the characteristics of the three trucks used for each bridge.

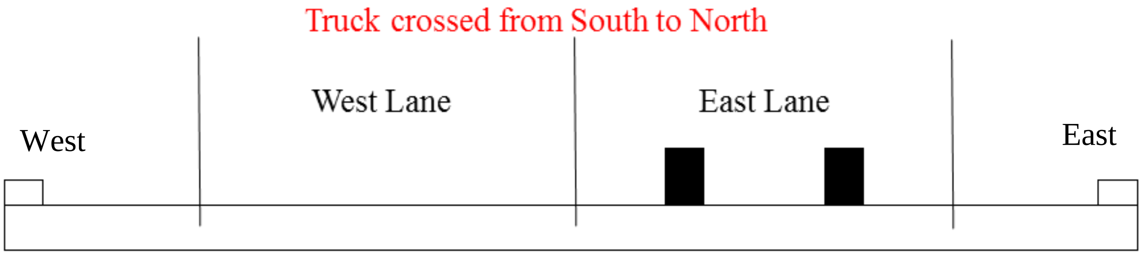
3.2.1 Concrete Slab Bridge 30790

Bridge 30790 is a single-span concrete slab bridge with a span length of 30 ft. Figure 3.3(a) and Figure 3.3(b) show the bridge and a general view of the location of the installed strain gauges at mid-span, respectively. As shown in Figure 3.3(c), the test trucks crossed the bridge in the east lane driving from the south to north.

a) View



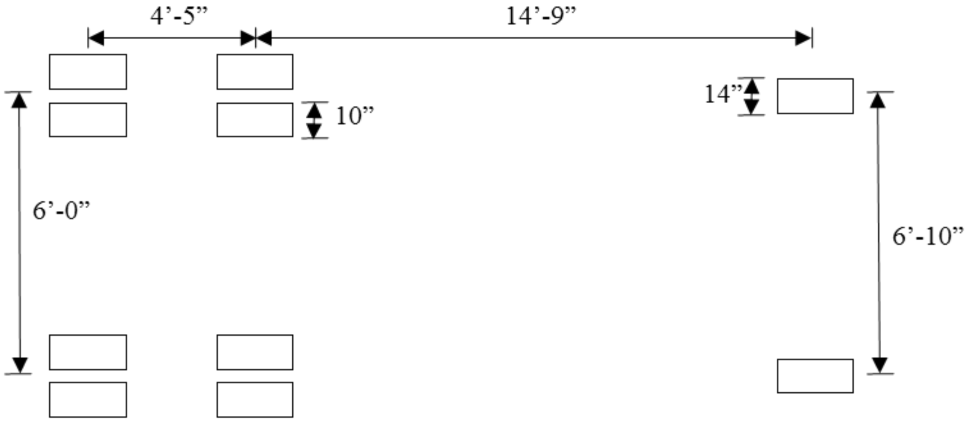
b) Strain gauge locations at mid-span



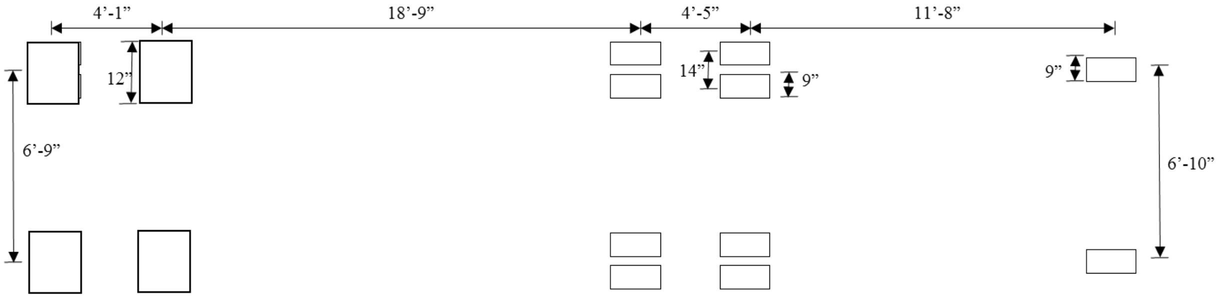
c) Travel lane

Figure 3.3 Concrete slab Bridge 30790

Figure 3.4 illustrates pertinent information about the geometry of each test truck.



Empty and full dump truck

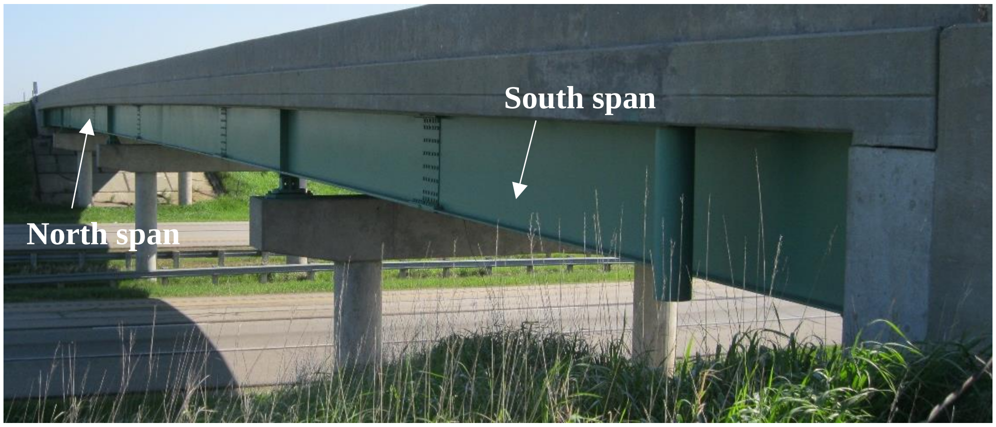


Semi-truck

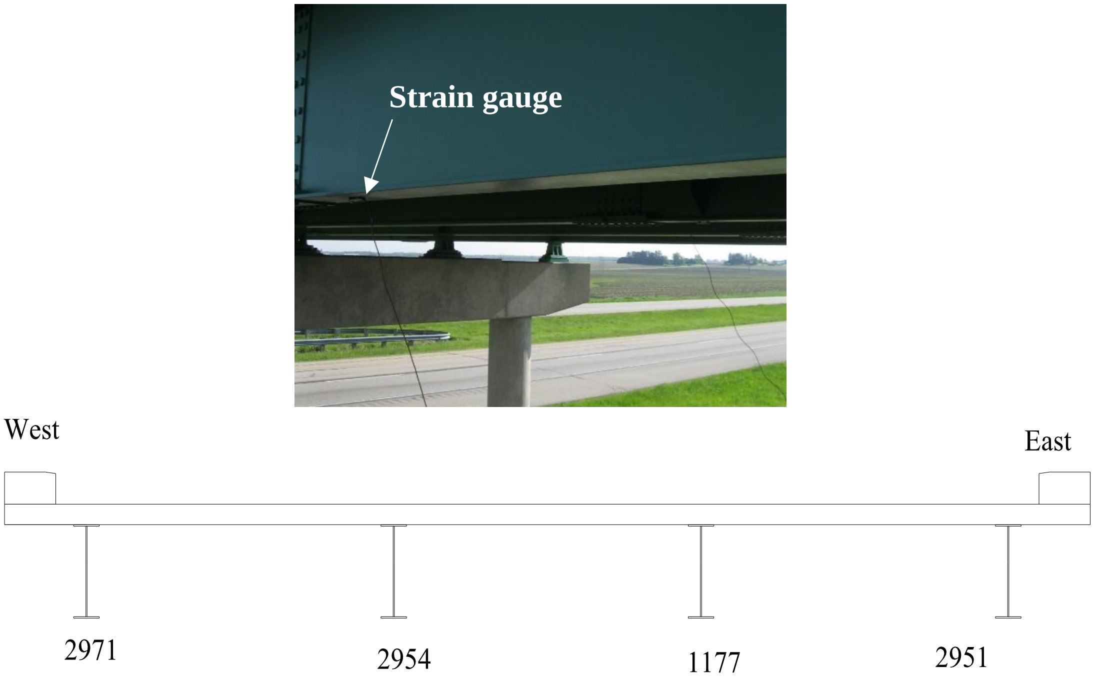
Figure 3.4. Trucks on concrete slab Bridge 30790

3.2.2 Short-Span Steel Girder Bridge 23370

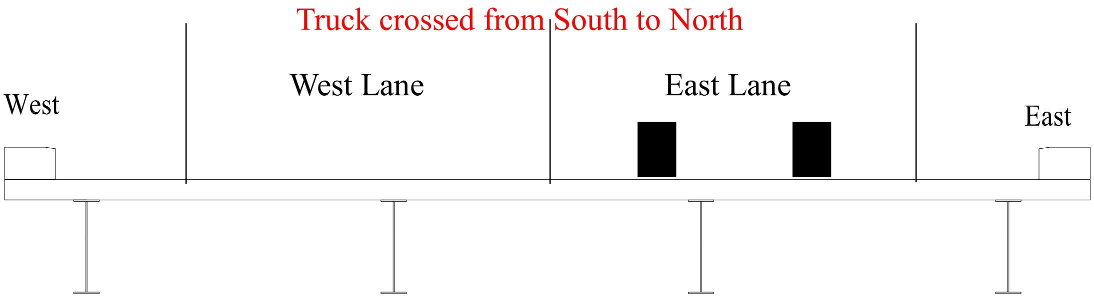
Bridge 23370 is a continuous welded steel girder bridge with four girders and four spans, as shown in Figure 3.5(a). The lengths of the two center spans are 85 ft 6 in. and the lengths of the end spans are 47.5 ft 6 in. The four girders are spaced at 9 ft 4 in. center-on-center. The strain gauges were installed at mid-span of the south span. Figure 3.5(b) illustrates the locations of the installed strain gauges. As shown in Figure 3.5(c), the test trucks crossed the bridge in the east lane from the south to north.



a) View



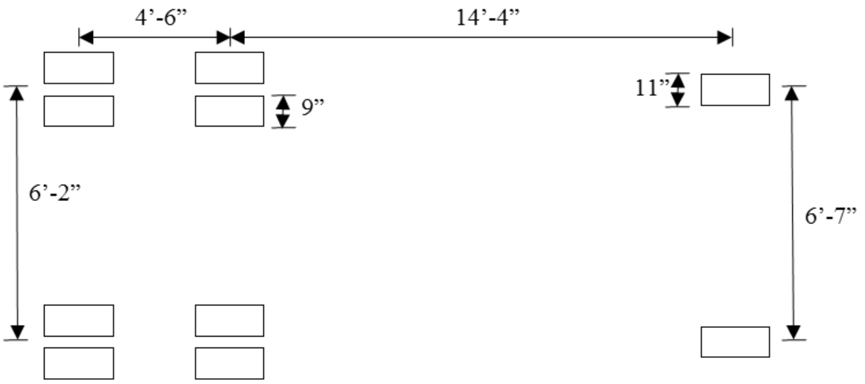
b) Strain gauge locations



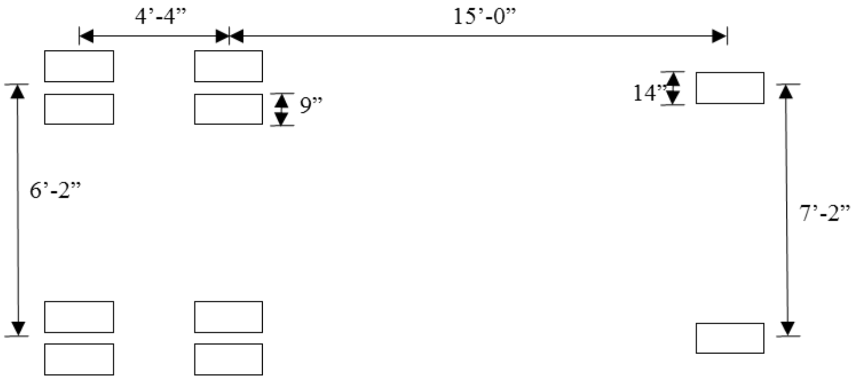
c) Travel lane

Figure 3.5 Short-span steel girder Bridge 23370

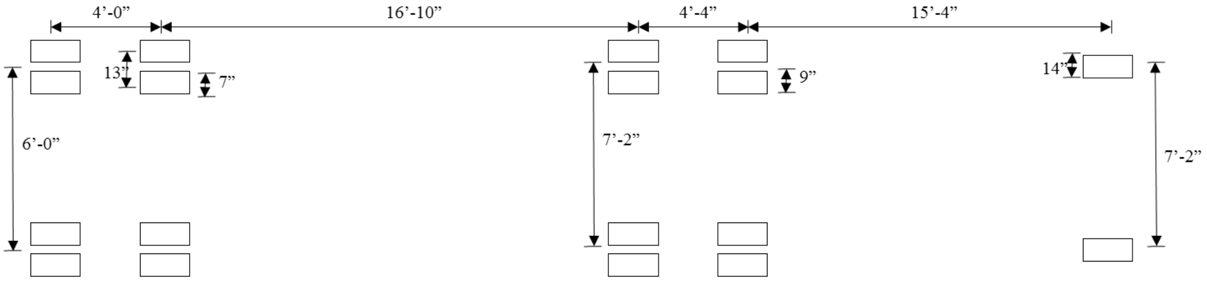
Figure 3.6 illustrates pertinent information about the geometry of each test truck.



Empty dump truck



Full dump truck



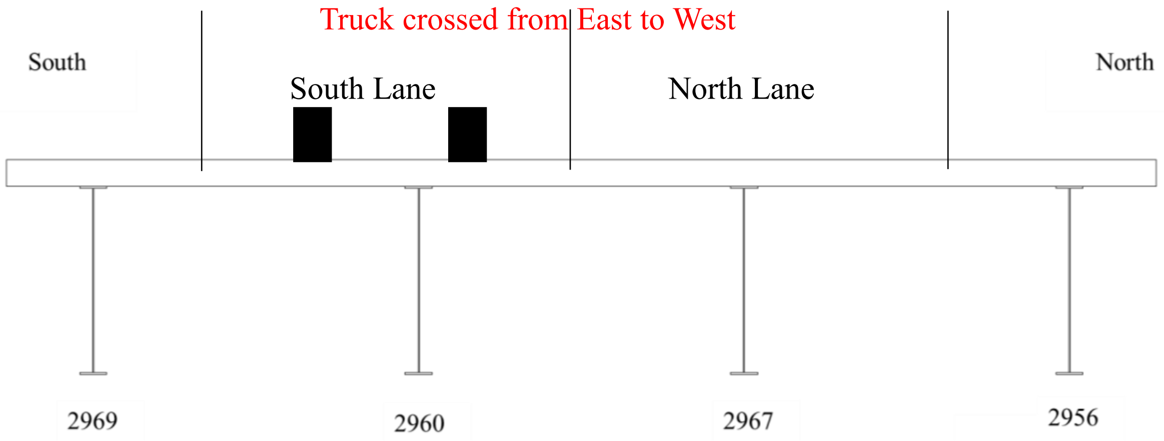
Semi-truck

Figure 3.6. Trucks on short-span steel girder Bridge 23370

3.2.3 Long-Span Steel Girder Bridge 600770

Bridge 600770 is continuous welded steel girder bridge with four spans as shown in Figure 3.7(a). The span lengths of the four spans from the west to the east are 100 ft, 180 ft, 180 ft, and 115 ft. The four girders are spaced at 10 ft 0 in. on center. Figure 3.7(b) illustrates the location of the installed strain gauges on the girder bottom flanges at mid-span of the second west span.

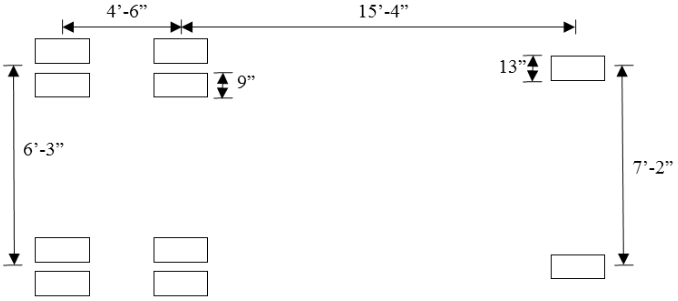
a) View



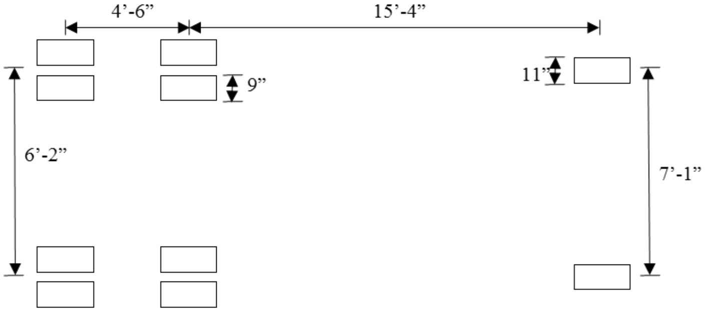
b) Strain gauge locations and travel lanes

Figure 3.7 Long-span steel girder Bridge 600770 strain gauge locations

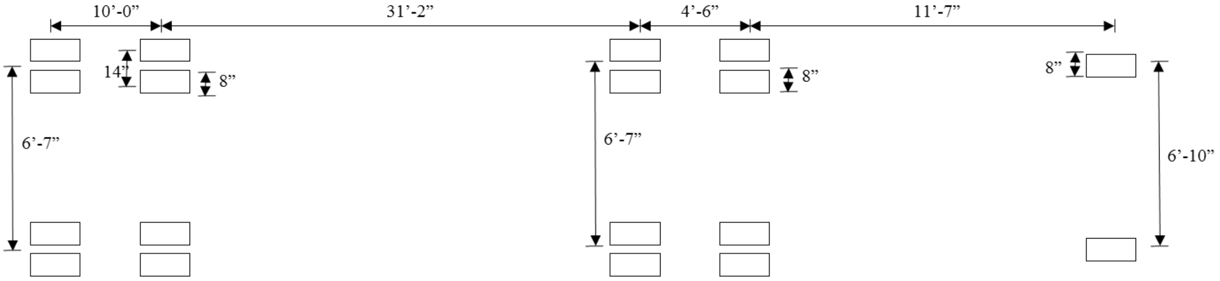
Figure 3.8 illustrates pertinent information about the geometry of each test truck.



Empty dump truck



Full dump truck



Semi-truck

Figure 3.8. Configurations of trucks on long-span steel girder Bridge 600770

3.2.4 Short-Span Prestressed Concrete Girder Bridge 40320

Bridge 40320 is a pretensioned, prestressed concrete girder bridge with four spans. The span lengths from the south to the north are 30.5 ft, 50 ft, and 30.5 ft. The eight girders are spaced at 4 ft 3 in. on center. Figure 3.9 illustrates the locations of the installed strain gauges.

Figure 3.10 illustrates pertinent information about the geometry of each test truck.

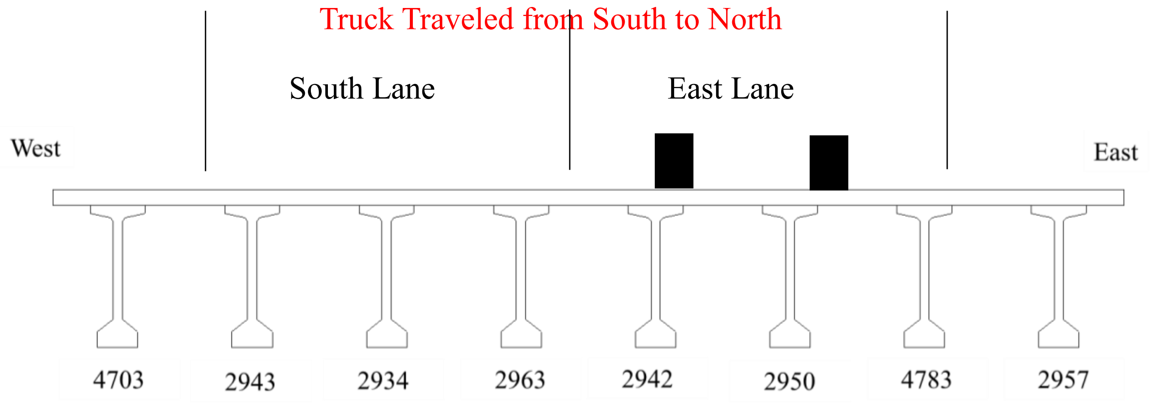
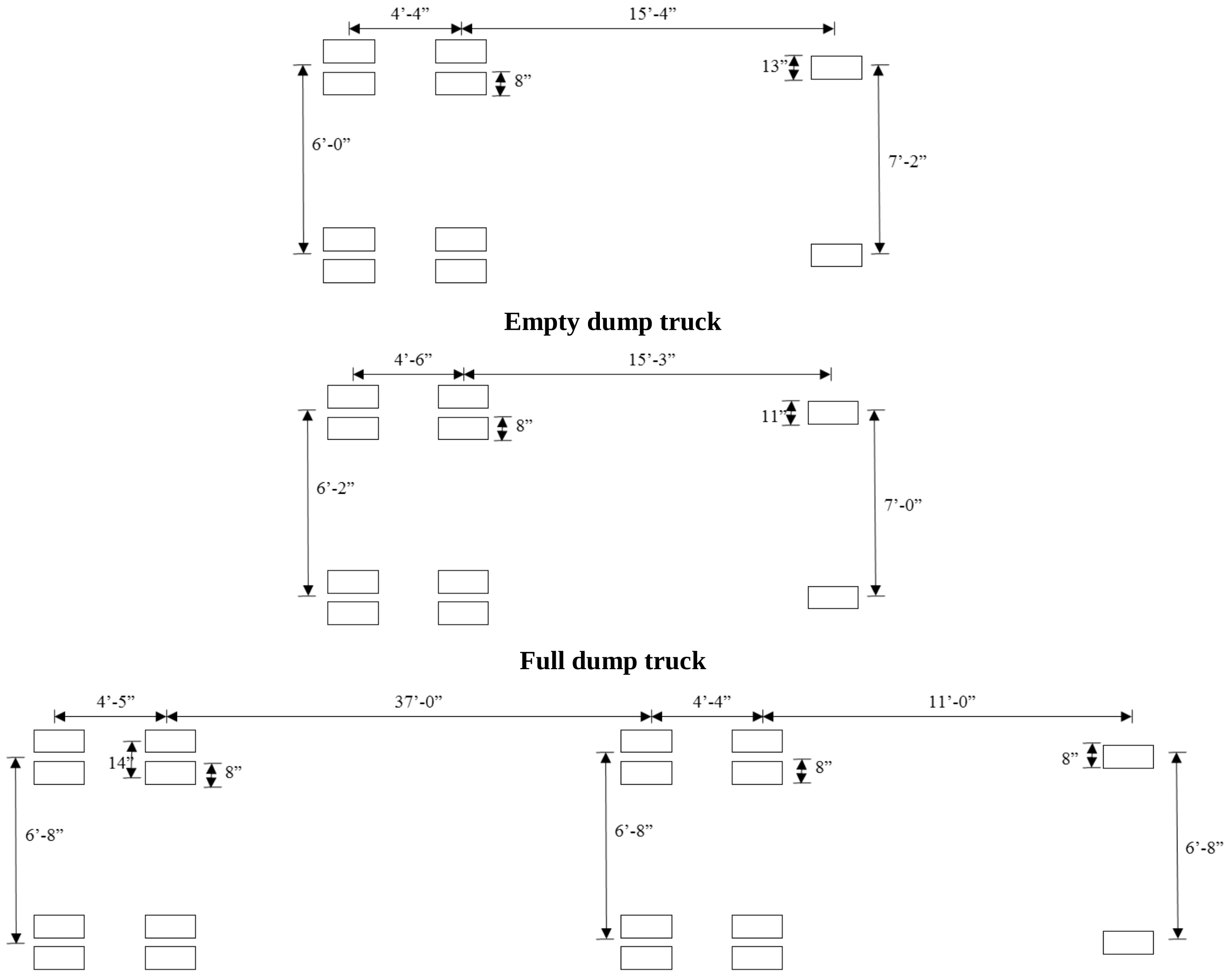


Figure 3.9 Short-span concrete girder Bridge 40320 strain gauge locations and travel lanes



Empty dump truck

Full dump truck

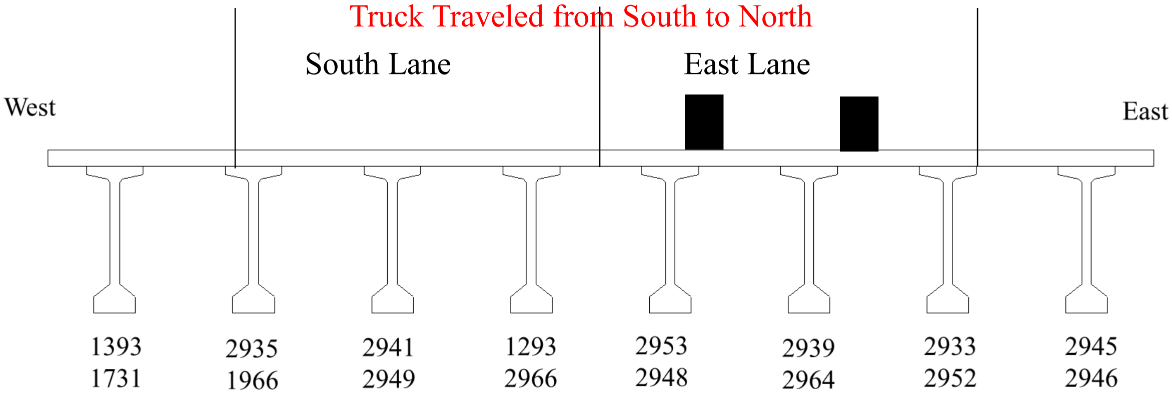
Semi-truck

Figure 3.10 Configurations of trucks on short-span concrete girder Bridge 40320

3.2.5 Long-Span Prestressed Concrete Girder Bridge 608580

Bridge 608580 is a pretensioned, prestressed concrete girder bridge with two spans as shown in Figure 3.11(a). The south and north spans are 140 and 111 ft, respectively. The eight girders are spaced at 7 ft 3 in. on center. Figure 3.11(b) illustrates the locations of the installed strain gauges at mid-span of the south span.

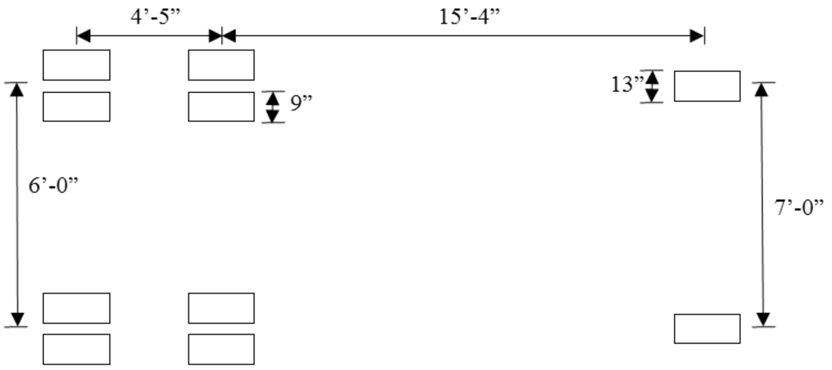
a) View



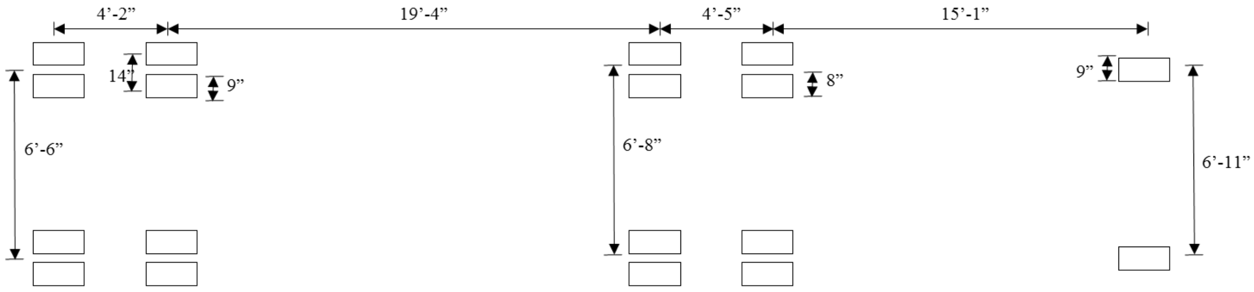
b) Strain gauge locations and travel lanes

Figure 3.11. Long-span concrete girder Bridge 608580 strain gauge locations

Figure 3.12 illustrates pertinent information about the geometry of each test truck.



Empty and full dump truck



Semi-truck

Figure 3.12 Dump truck and semi-truck on long-span concrete girder Bridge 608580

CHAPTER 4 TEST RESULTS AND DISCUSSIONS

Based on the measured strain data from all field tests on the five bridges, the researchers calculated DIFs by comparing the results due to a truck crossing each bridge at high speed to those due to the truck crossing each bridge at a crawl speed. Subsequently, the influence of the important factors (i.e., vehicle speed, vehicle characteristics, bridge dynamic characteristics, and roughness of the bridge approach) on the DIF were further studied.

4.1 Calculations of DIFs under Different Loading Scenarios

For each type of truck, a total of 15 test cases were conducted as summarized in Table 4.1.

Table 4.1 Loading scenarios of field testing

Load case	Entrance condition	Truck type	Speed
LC1	As-is	Empty dump Full dump Semi	Crawl
LC2			10 mph
LC3			20 mph
LC4			30 mph
LC5			50 mph
LC6	Level 1	Empty dump Full dump Semi	Crawl
LC7			10 mph
LC8			20 mph
LC9			30 mph
LC10			50 mph
LC11	Level 2	Empty dump Full dump Semi	Crawl
LC12			10 mph
LC13			20 mph
LC14			30 mph
LC15			50 mph

The crawl speed As-is load cases (LC1 for each of the three truck types) were the baselines for the determination of DIFs for the other cases shown in Table 4.1.

To derive the DIF from the bridge response for each load case, the strain time histories were first plotted for each strain gauge to examine the general behavior. Figure 4.1 shows the time histories for a strain gauge being loaded by a dump truck at both 50 mph and the crawl speed for example.

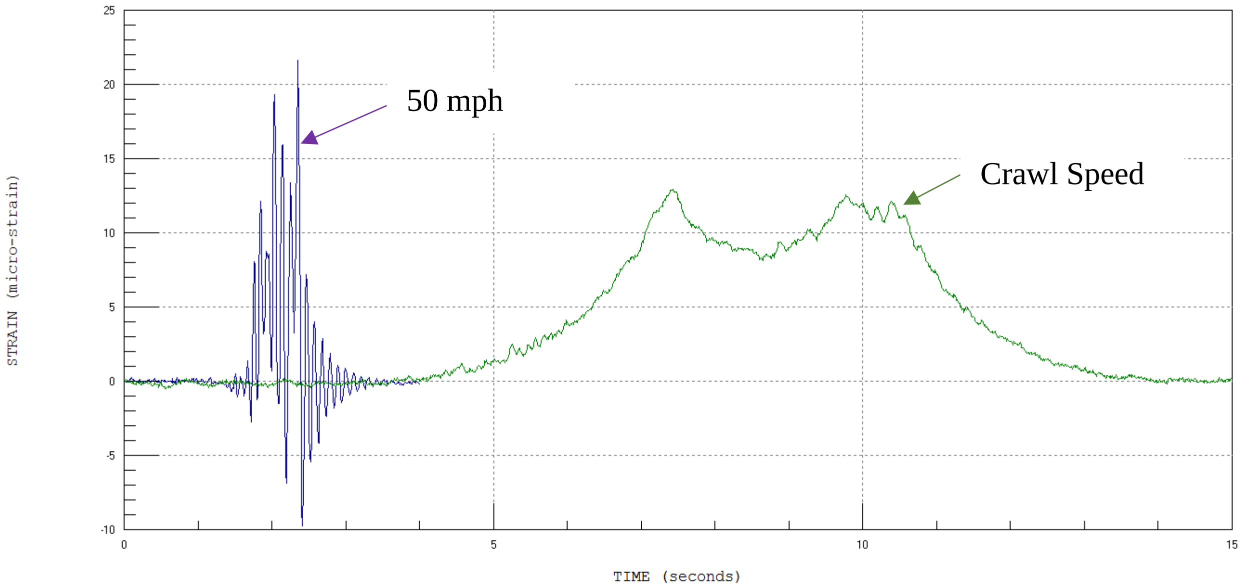


Figure 4.1 Strain time histories for a dump truck crossing a bridge at 50 mph and at crawl speed for the As-is entrance condition

The DIF was then determined by dividing the maximum strain from a higher speed test run by that from the crawl speed test run. For example, the DIF for the 50-mph run shown in Figure 4.1 is equal to 22 (which was the maximum strain at 50 mph) divided by 13 (which was the maximum strain at the crawl speed), or 1.69. Following the same procedure, the DIFs associated with different speeds, entrance conditions, and truck types can be calculated (i.e., 15 load cases of each truck type). The measured DIFs for the five bridges under the considered loading scenarios are summarized in the following sections.

4.2 DIFs for the Five Bridges

For reference some general information for the five bridges is shown below:

- Steel girder bridges
  - 600770: 4 spans and longest span of 180 ft
  - 23370: 4 spans and longest span of 85 ft
- Prestressed concrete girder bridges
  - 608580: 2 spans and longest span of 140 ft
  - 40320: 3 spans and longest span of 50 ft
- Slab bridge
  - 30790: 1 span and span length of 50 ft

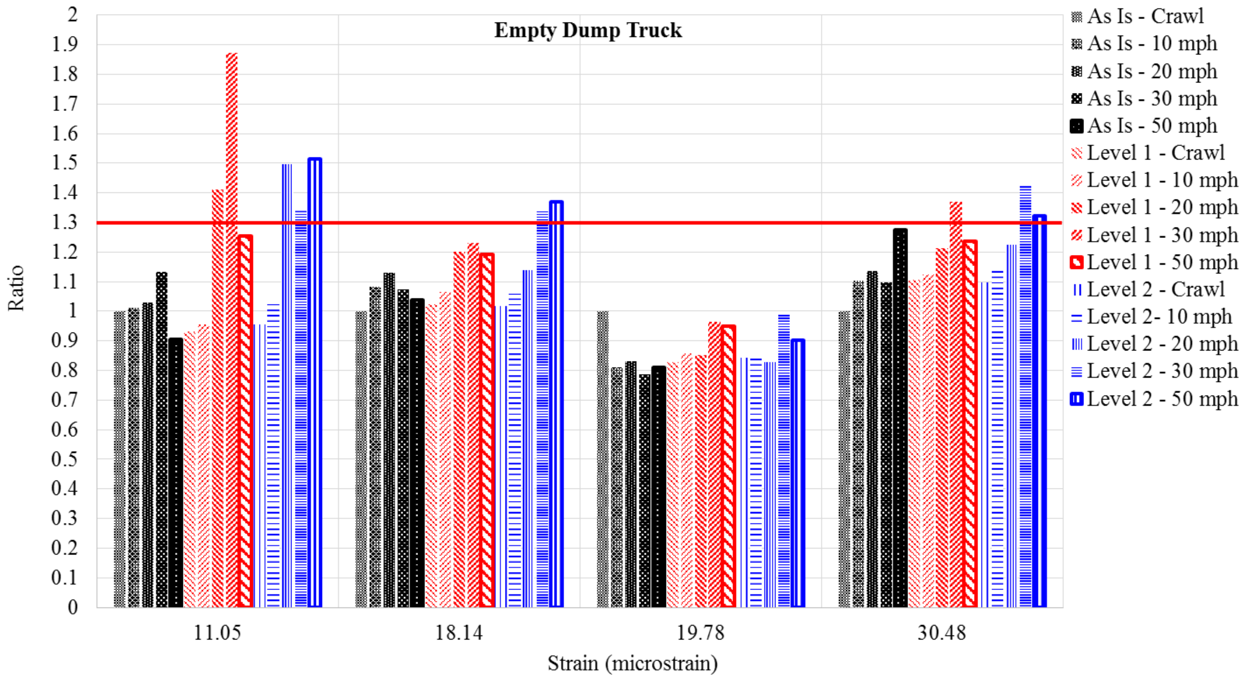
The derived DIFs for steel girder bridge 600770, steel girder bridge 23370, concrete girder bridge 608580, concrete girder bridge 40320, and concrete slab bridge 30790 are illustrated in Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5, and Figure 4.6, respectively. The figures show relatively different results but also some similar trends. These trends include an increase of the DIF as the static strain decreases, speed increases, and entrance condition gets rougher. It should also be noted that a few strains gave extremely high DIF values due to relatively low measured strains.

As shown in Figure 4.2 through Figure 4.6, the greatest DIFs are generally associated with the lowest measured strains and the higher strains result in lower DIFs. In light of this, the DIFs related to the higher strains were deemed to be the most applicable because this study was focused on permitted (e.g., heavy) loads, and the researchers utilized these cases for further analysis (which is covered in the next section). For this reason, only a small number of data were available for the slab bridge due to the relatively low measured responses. Note that in the case of the steel and concrete girder bridges, a larger number of data were available and are included in Figure 4.2 through Figure 4.5.

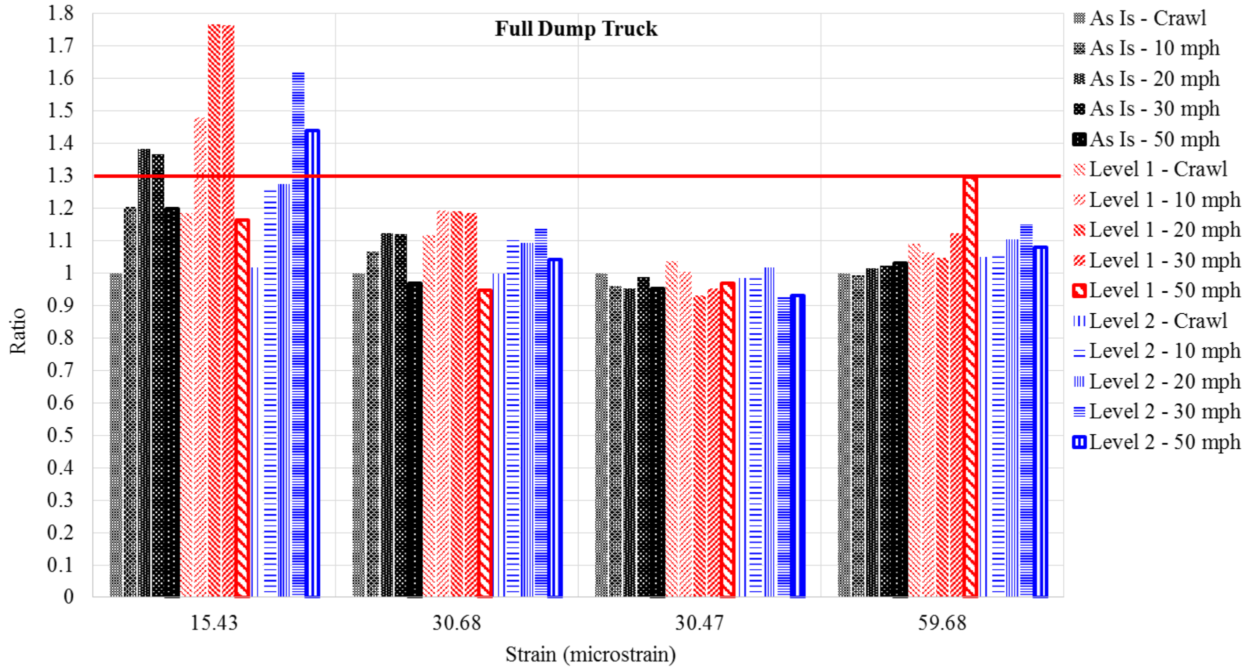
As shown in Figure 4.2 through Figure 4.6, the DIF increases with an increase of the truck speed, especially for the 30 and 50 mph speeds. And, rougher entrance conditions generally resulted in higher DIFs. Commonly, the Level 2 entrance conditions, with the ramp placed at the joint, showed the highest impact factors of all the test runs; conversely, the As-is entrance conditions produced the lowest impact factors in most cases. However, Level 2 entrance conditions do not always induce the largest DIFs.

As shown in Figure 4.2 through Figure 4.6, of all the vehicle types studied, the empty dump truck tends to create the highest impact factors, followed by the full dump truck and finally the semi-truck. This is consistent with findings in the literature that DIFs decrease with increasing vehicle weight.

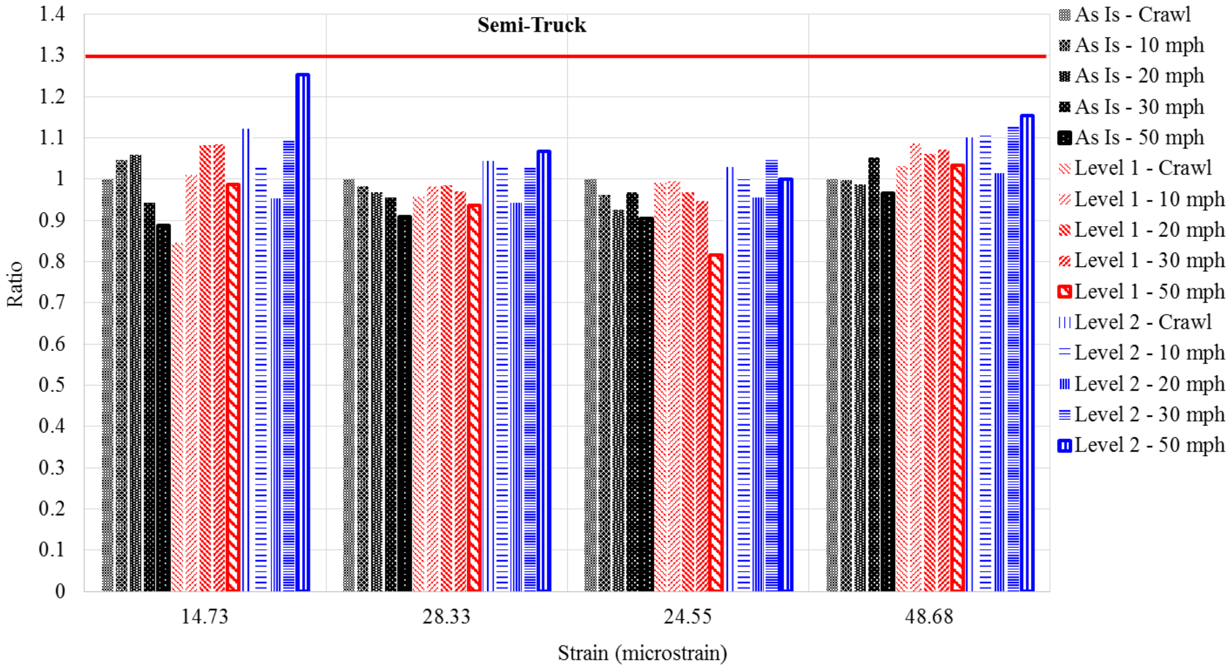
Figure 4.2 through Figure 4.6 indicate that the DIFs exceeded 1.3 for all of the investigated bridges, and especially those determined from relatively lower strains. Under the As-is entrance condition, the DIFs are less than 1.3 for steel and concrete girder bridges and less than 1.1 for slab bridges. With Level 1 and Level 2 entrance conditions, the DIFs exceeded 1.3 for all bridges. Figure 4.2 through Figure 4.5 indicate that the longer span bridges (600770 and 608580) had lower DIFs; this is likely due to the fact that the longer span bridges are more flexible.



Empty dump truck on long-span steel girder Bridge 600770

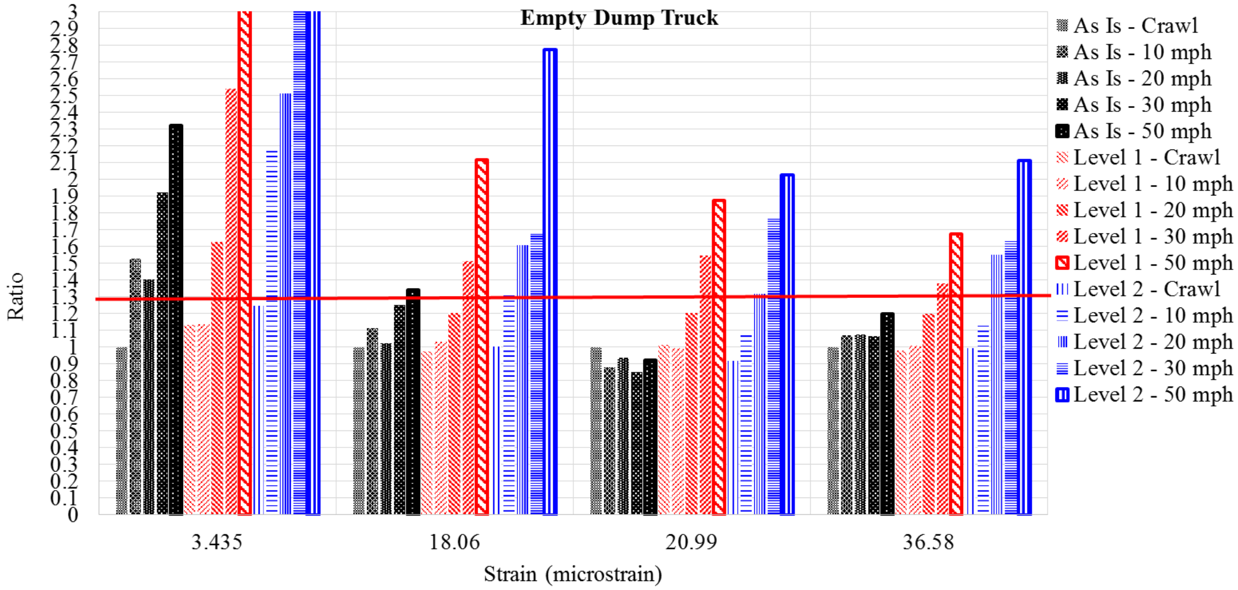


Full dump truck on long-span steel girder Bridge 600770

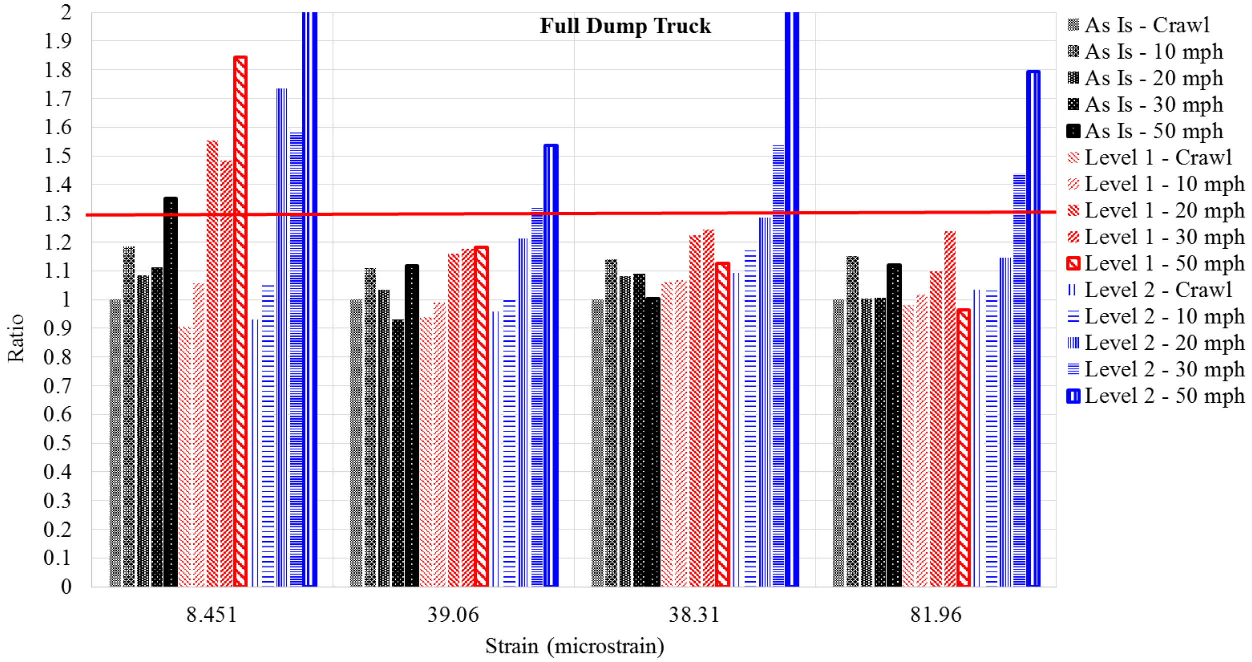


Semi-truck on long-span steel girder Bridge 600770

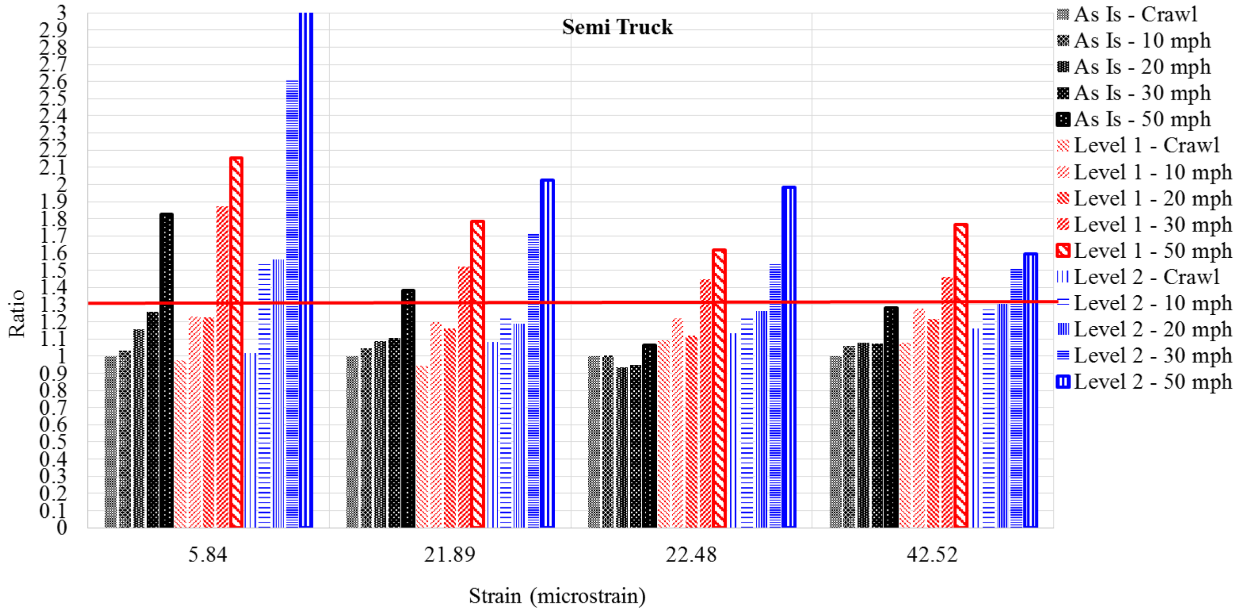
Figure 4.2 DIFs for long-span steel girder Bridge 600770 under different loading scenarios



Empty dump truck on short-span steel girder Bridge 23370

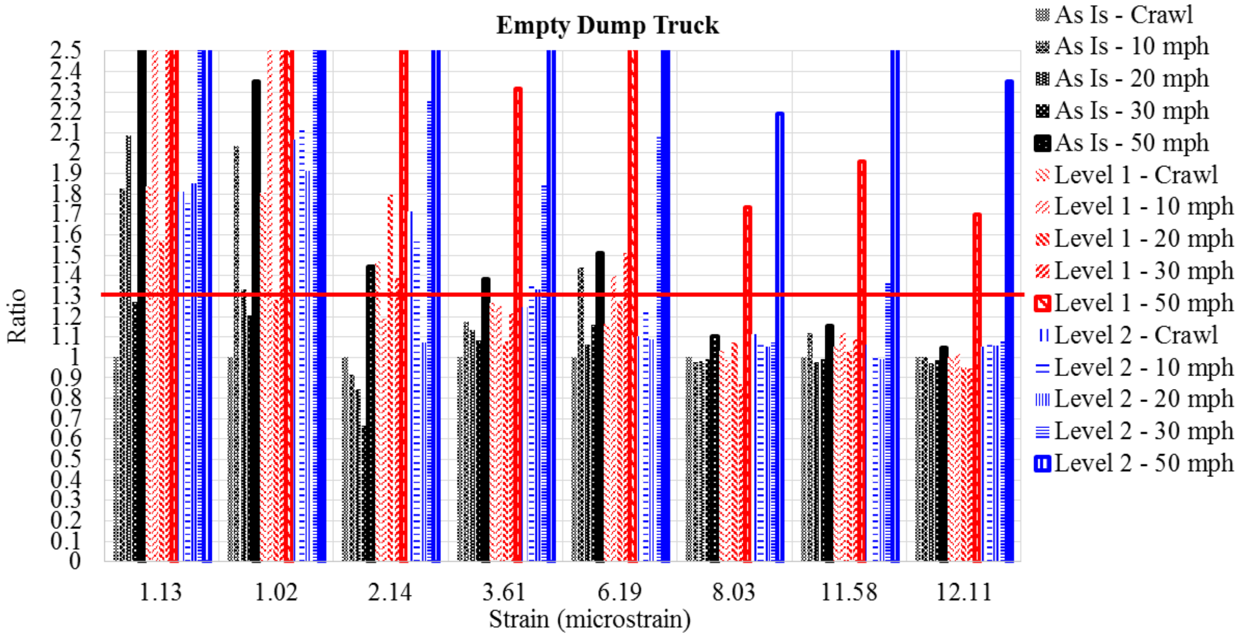


Full dump truck on short-span steel girder Bridge 23370

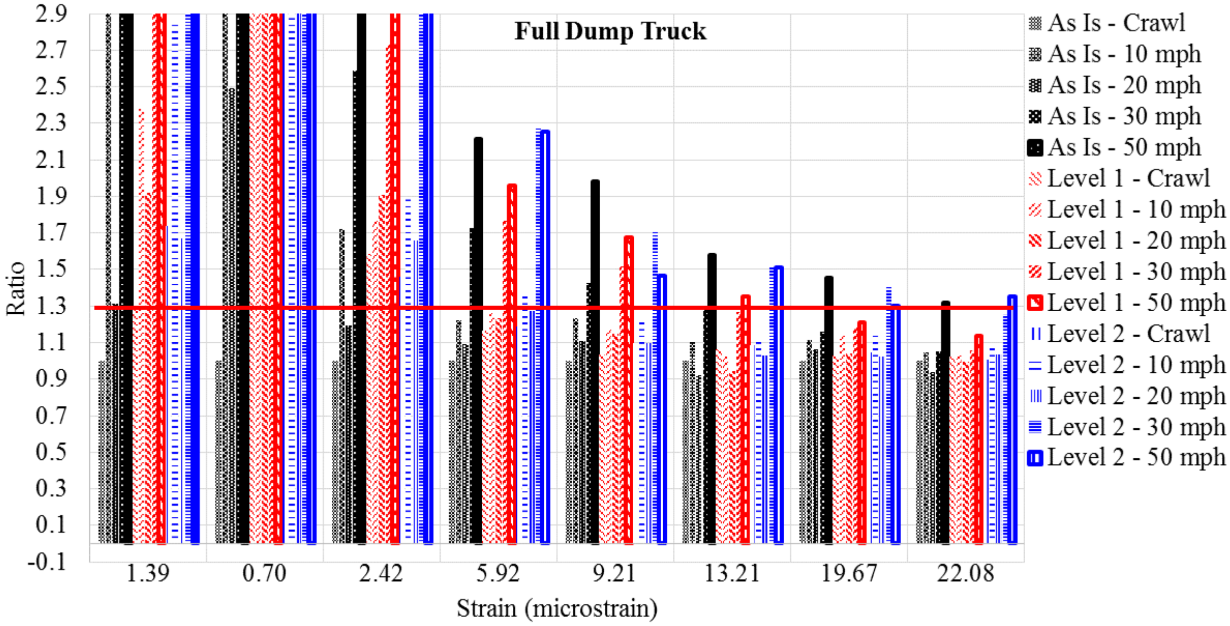


Semi-truck on short-span steel girder Bridge 23370

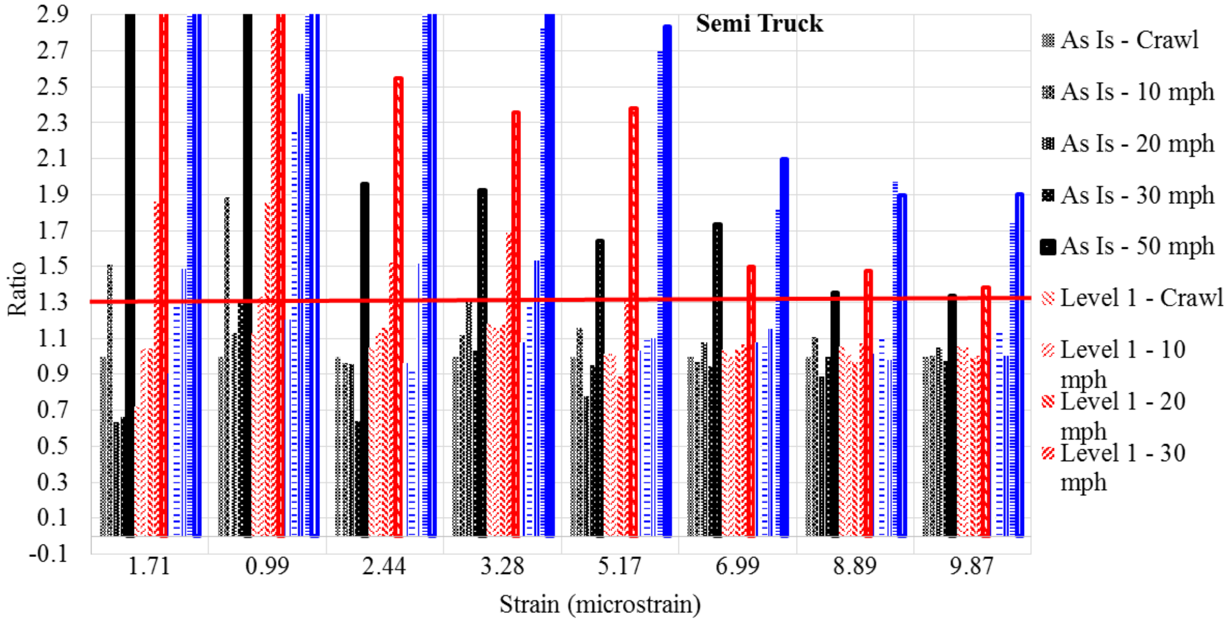
Figure 4.3 DIFs for short-span steel girder Bridge 23370 under different loading scenarios



Empty dump truck on long-span pre-stressed concrete girder Bridge 608580

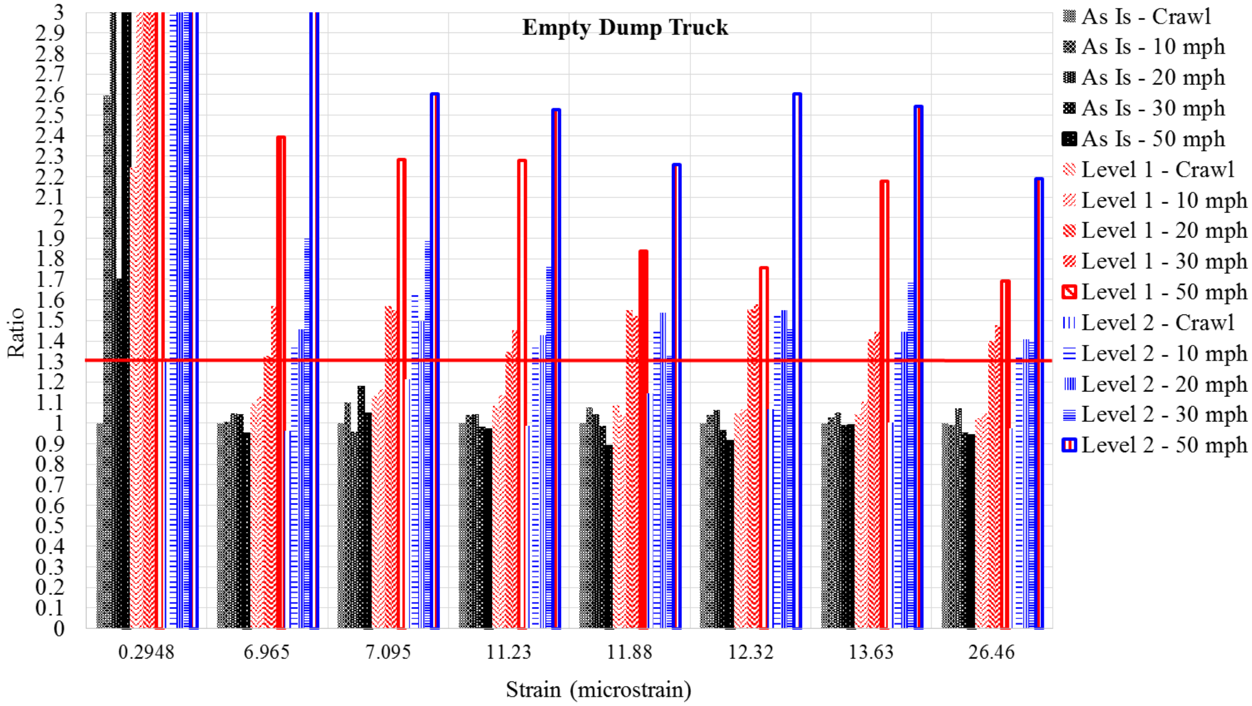


Full dump truck on long-span pre-stressed concrete girder Bridge 608580

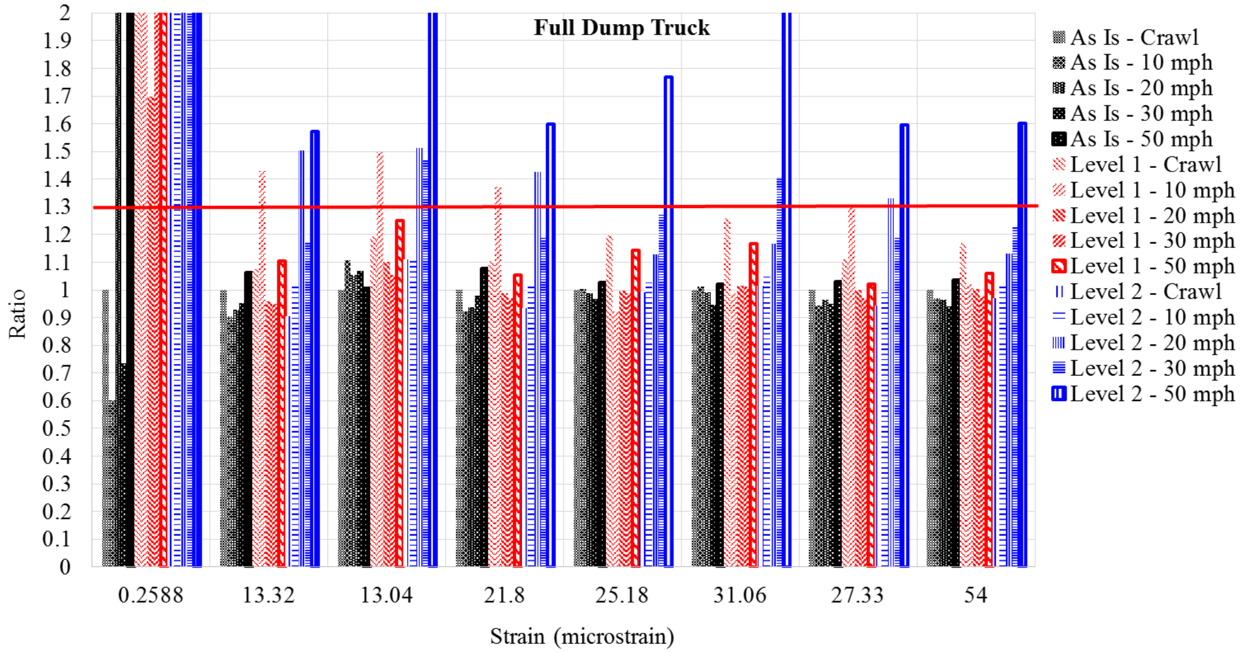


Semi-truck on long-span pre-stressed concrete girder Bridge 608580

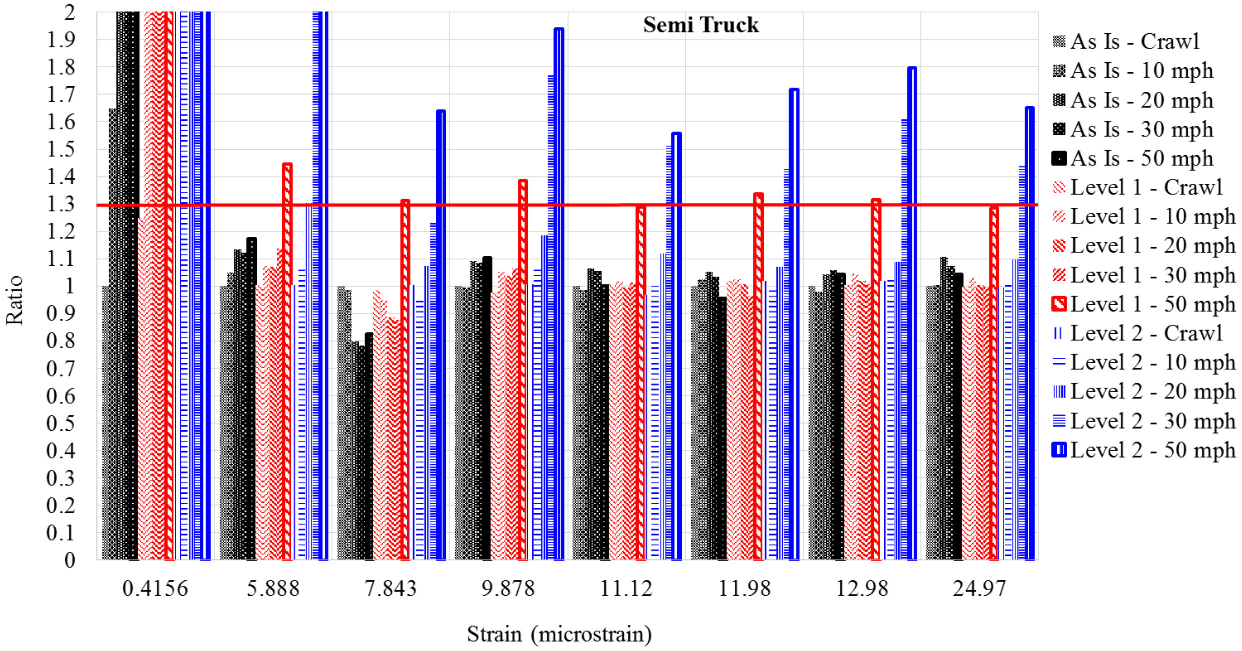
Figure 4.4. DIFs for long-span pre-stressed concrete girder bridge 608580 under different loading scenarios



Empty dump truck on short-span pre-stressed concrete girder Bridge 40320

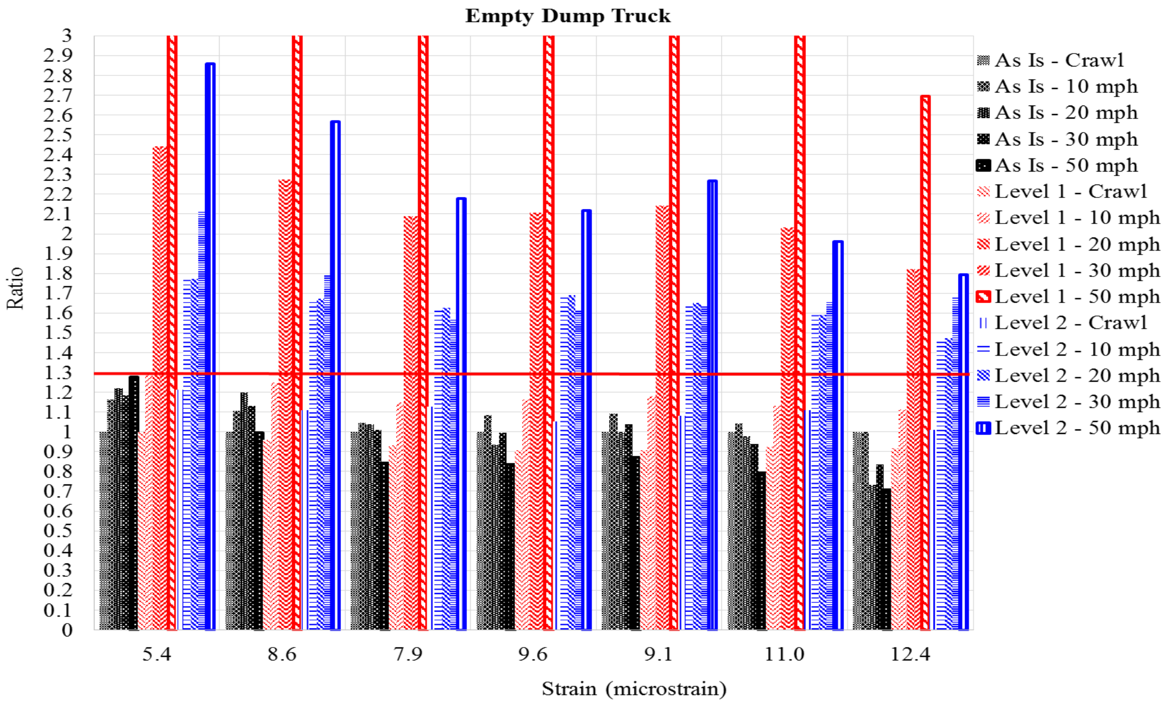


Full dump truck on short-span pre-stressed concrete girder Bridge 40320

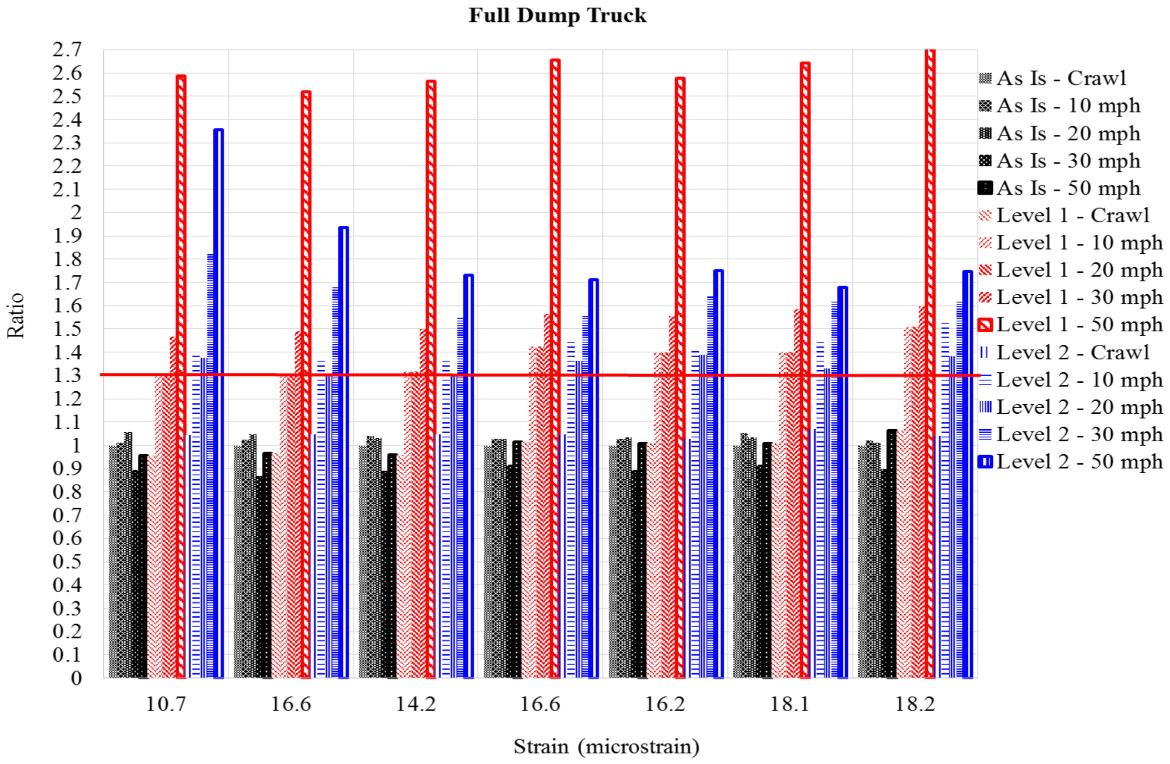


Semi-truck on short-span pre-stressed concrete girder Bridge 40320

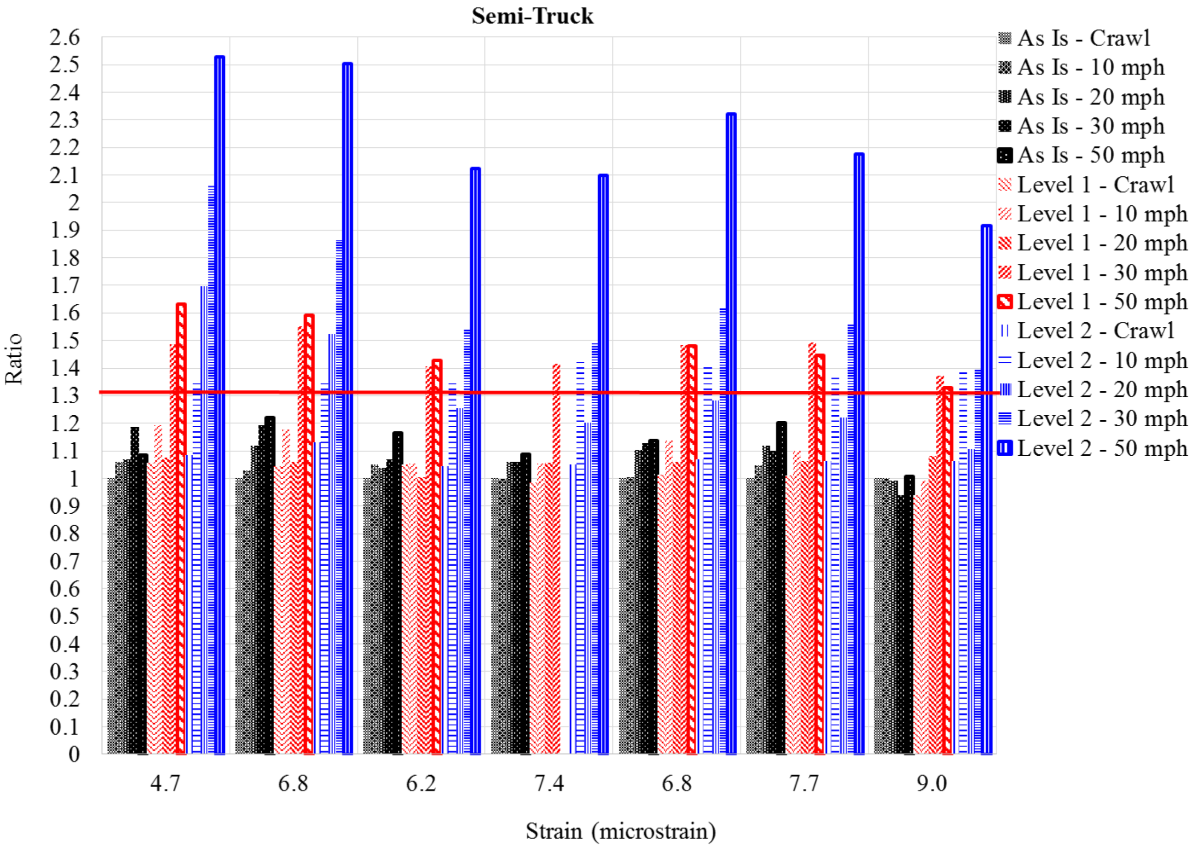
Figure 4.5. DIFs for short-span pre-stressed concrete girder Bridge 40320 under different loading scenarios



Empty dump truck on concrete slab Bridge 40320



Full dump truck on concrete slab Bridge 40320



Semi-truck on slab concrete Bridge 40320

Figure 4.6. DIFs for concrete slab Bridge 30790 under different loading scenarios

4.3 Recommendations for the DIF of 0.1

The Iowa DOT currently requires that permitted trucks slow to five miles per hour and span the centerline when crossing select bridges. To provide guidelines on the relationship between DIFs and truck speed limits, the research team studied the DIFs derived from the five bridges further.

Given that the higher strains result in more reliable DIFs, the researchers selected the DIFs due to the largest strains measured at each bridge to further analyze the relationship of DIFs to truck speed. Note that other parameters also influence the results and include entrance condition, truck type, bridge type, and span length.

To study the conditions required to limit the DIF to 0.1 for the studied bridges and truck types, the researchers created the relationship between DIFs and truck speed as shown in Figure 4.7 through Figure 4.11 for the five bridges. For each bridge, the researchers determined which truck speeds result in DIFs less than 1.1 with the three types of trucks.

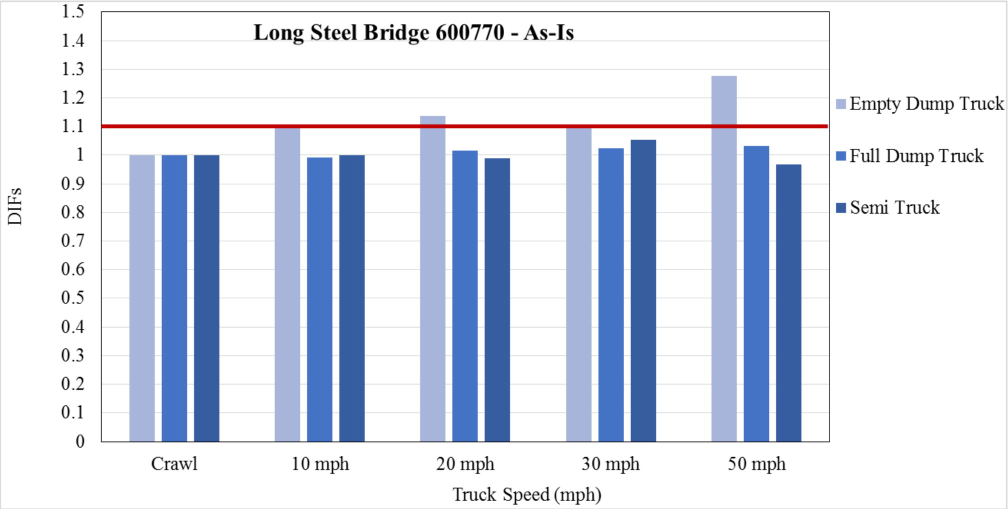
Figure 4.7 indicates that, for long-span steel girder Bridge 600770, the allowable truck speed is 30 mph for the As-is condition, 10 mph for the Level 1 condition, and 10 mph for the Level 2 condition.

Figure 4.8 indicates that, for short-span steel girder Bridge 23370, the allowable truck speeds are 30 mph, crawl, and crawl for the As-is, Level 1, and Level 2 entrance conditions, respectively.

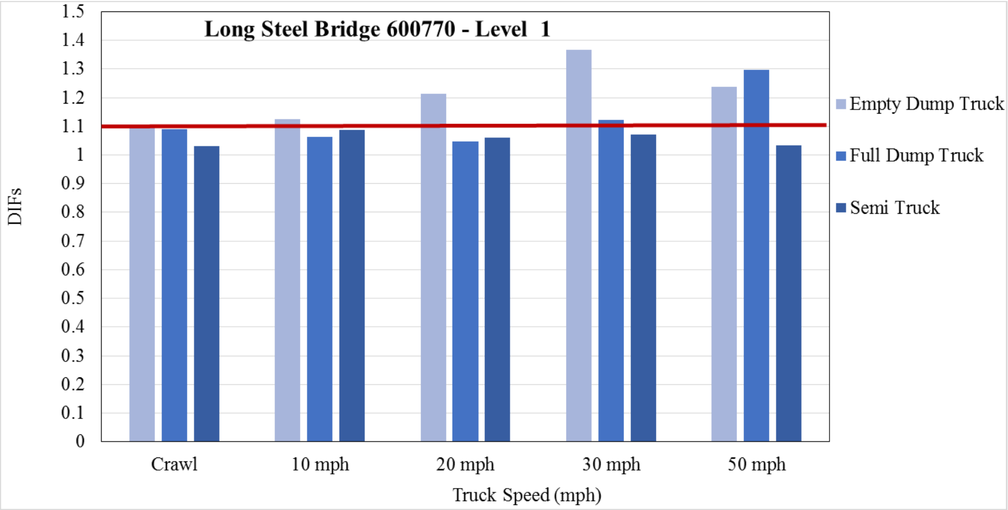
Figure 4.9 indicates that, for long-span concrete girder Bridge 608580, the allowable truck speeds are 30, 30, and 20 mph for As-is, Level 1, and Level 2 entrance conditions, respectively.

Figure 4.10 indicates that, for short-span concrete Bridge 40320, the allowable truck speeds are 50 mph, 10mph, and crawl for As-is, Level 1, and Level 2 entrance conditions, respectively.

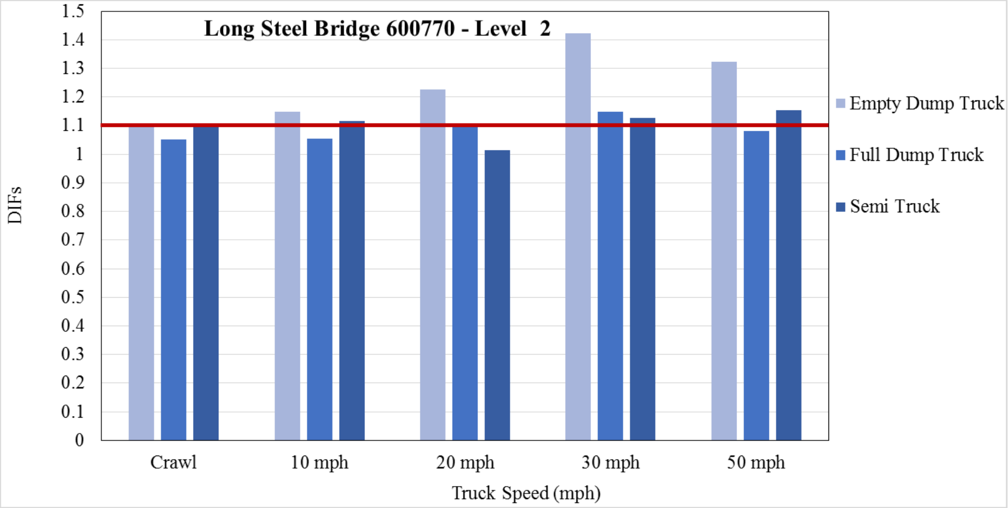
Figure 4.11 indicates that, for slab Bridge 30790, the allowable truck speeds are 50 mph, crawl, and crawl for As-is, Level 1, and Level 2 entrance conditions, respectively.



As-is

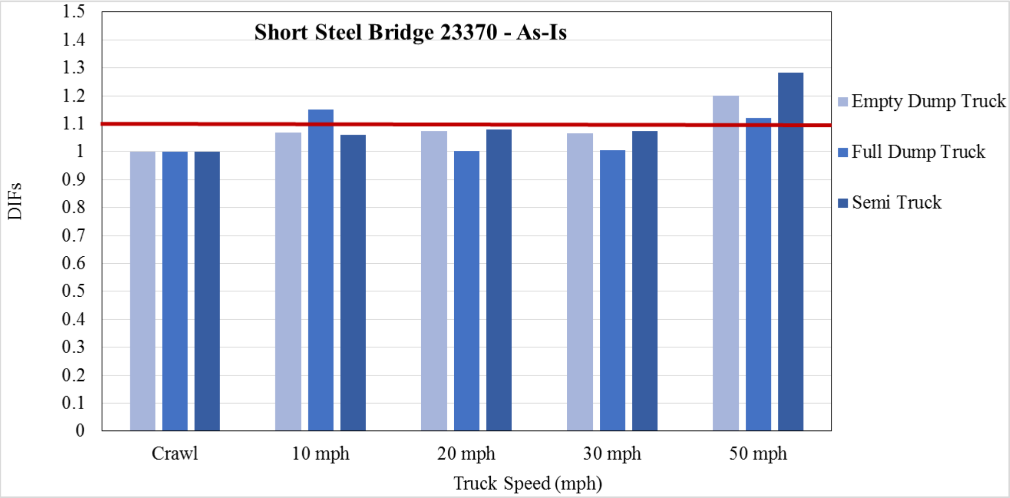


Level 1

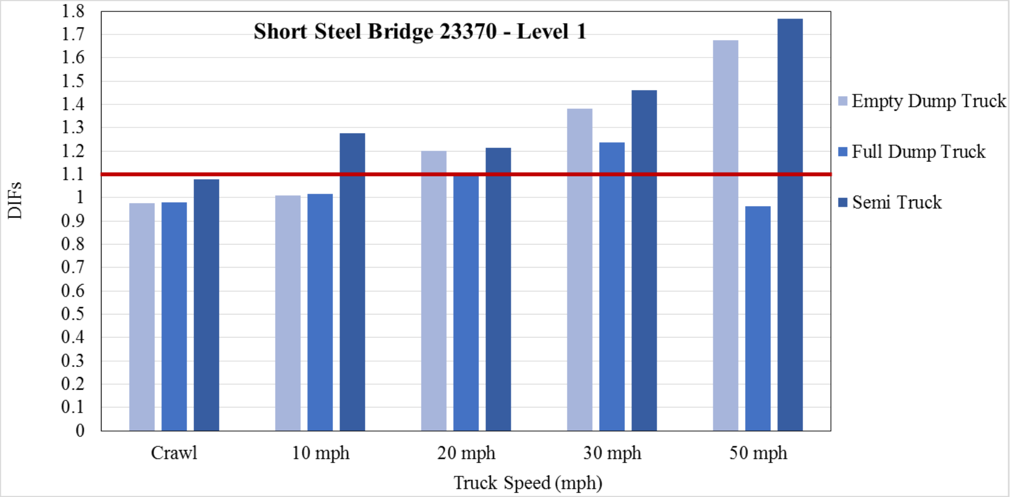


Level 2

Figure 4.7. DIFs based on largest strain in long-span steel girder Bridge 60770



As-is



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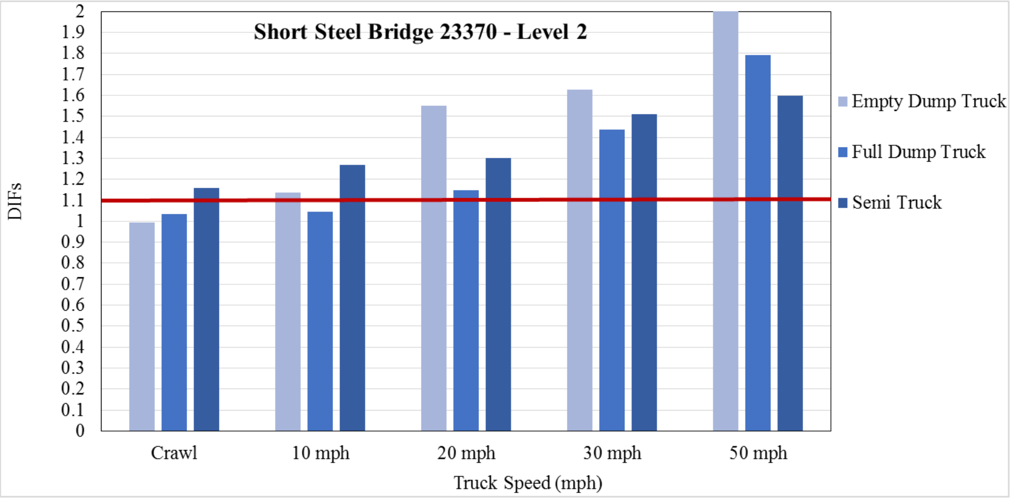
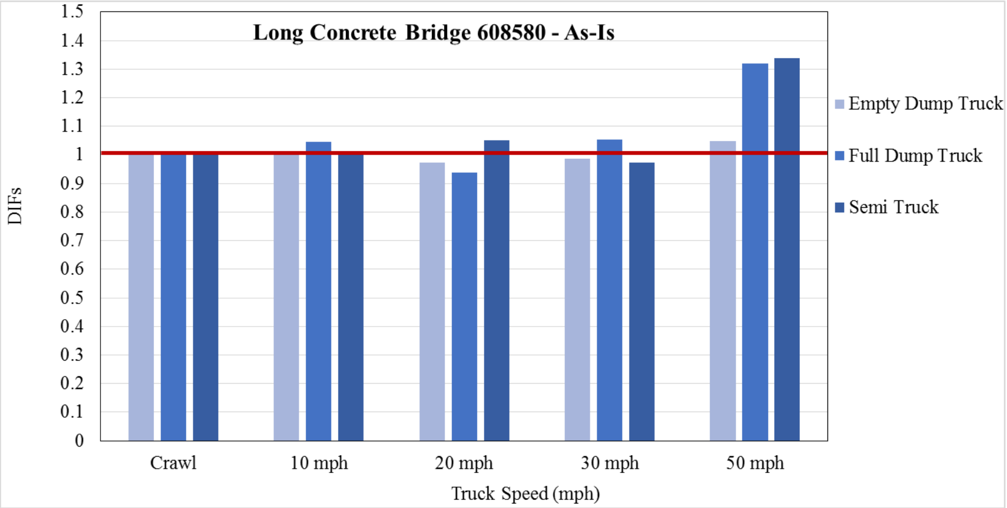
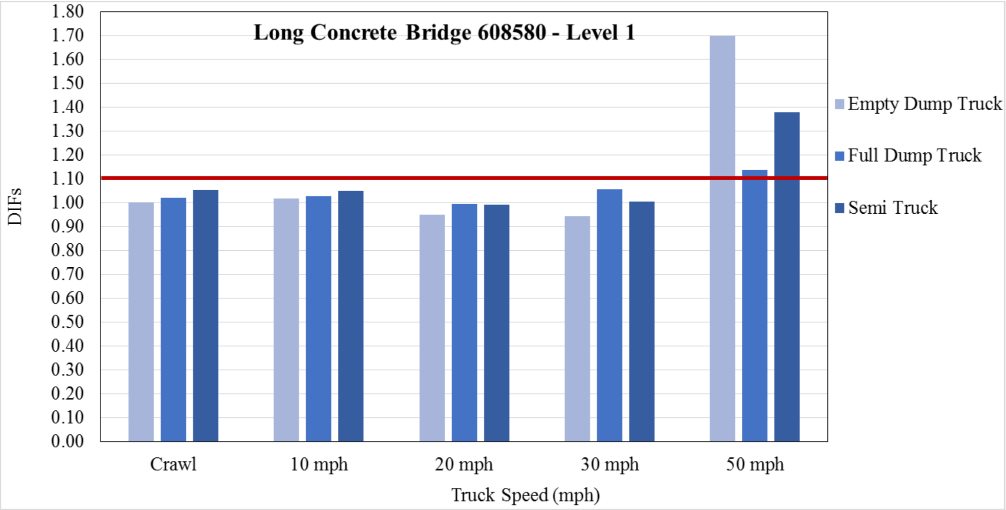


Level 2

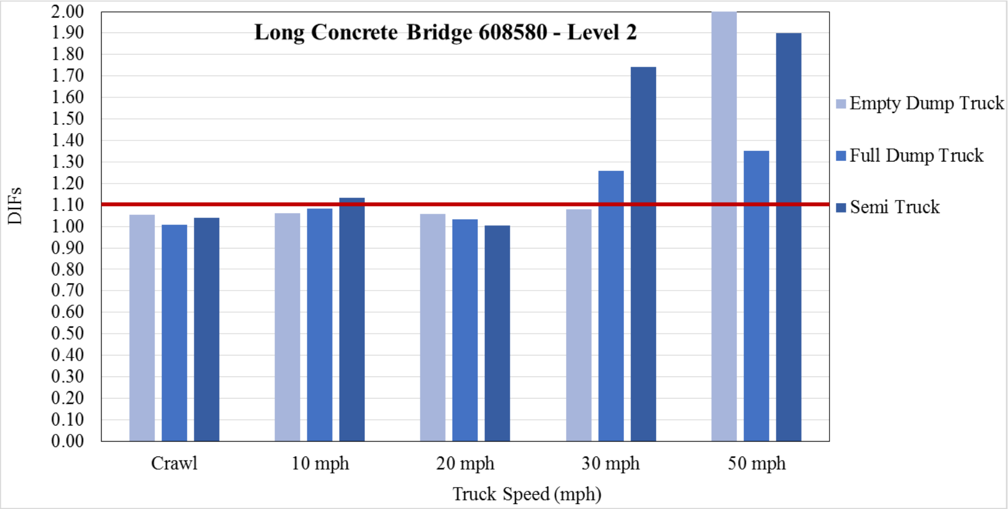
Figure 4.8. DIFs based on largest strain in short-span steel girder Bridge 23370



As-is

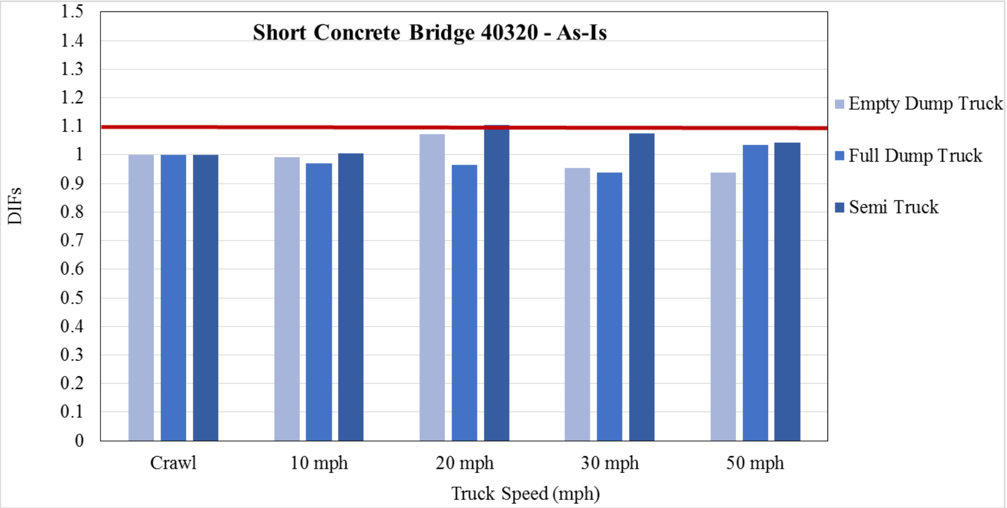


Level 1

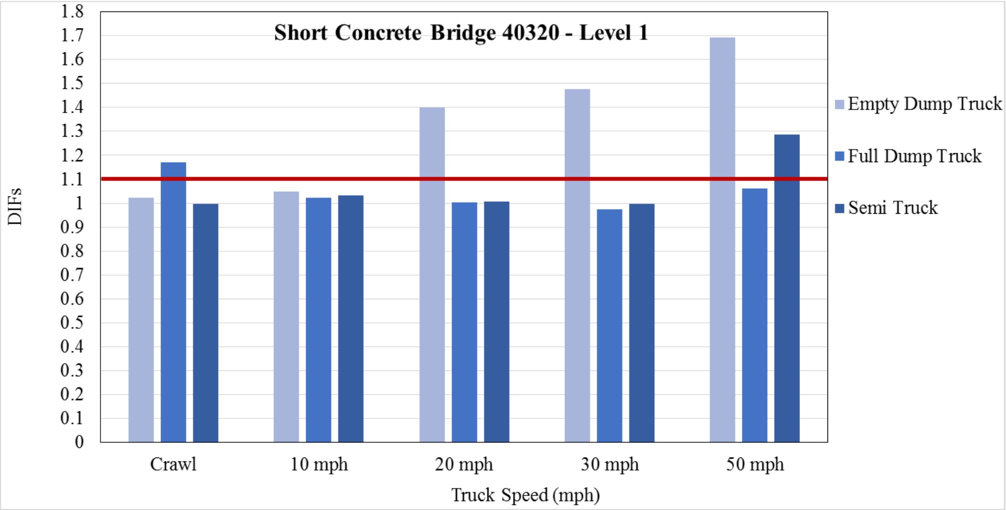


Level 2

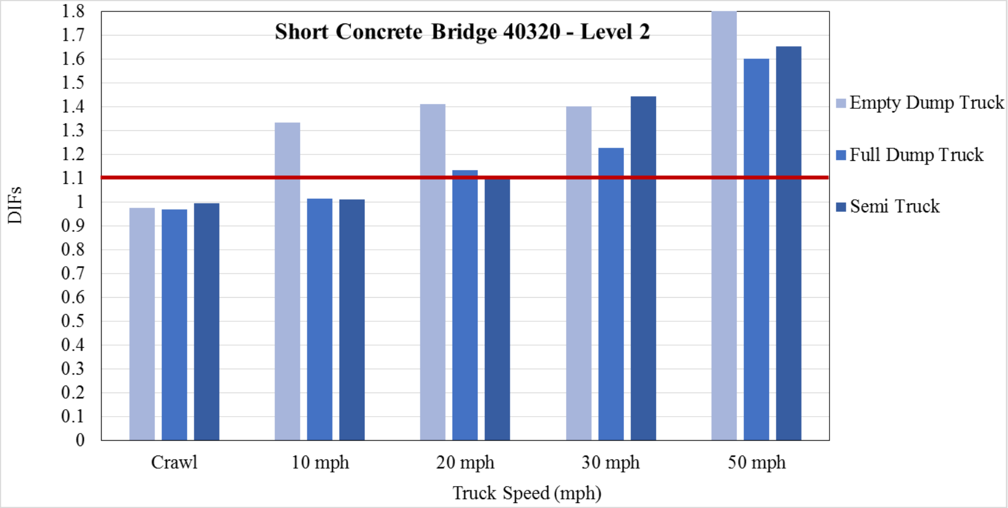
Figure 4.9. DIFs based on largest strain in long-span concrete girder Bridge 608580



As-is

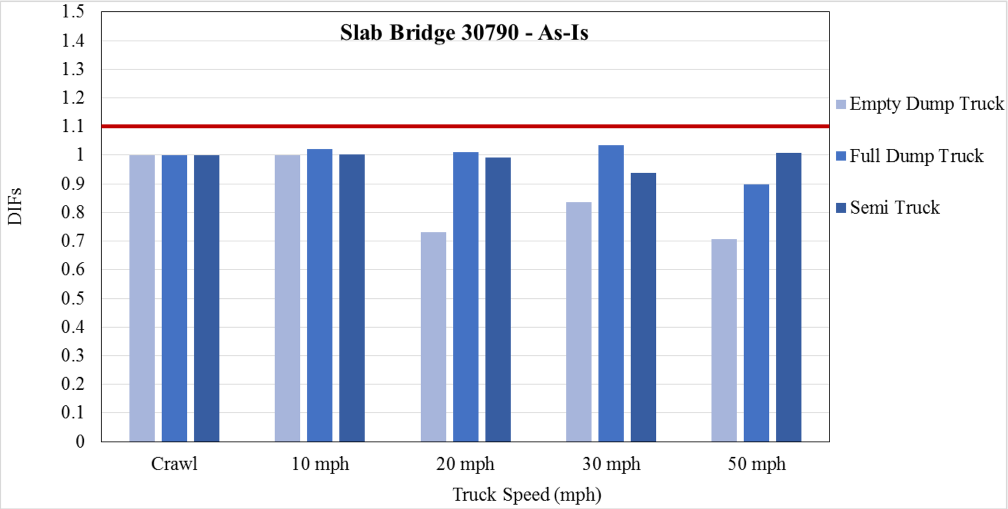


Level 1

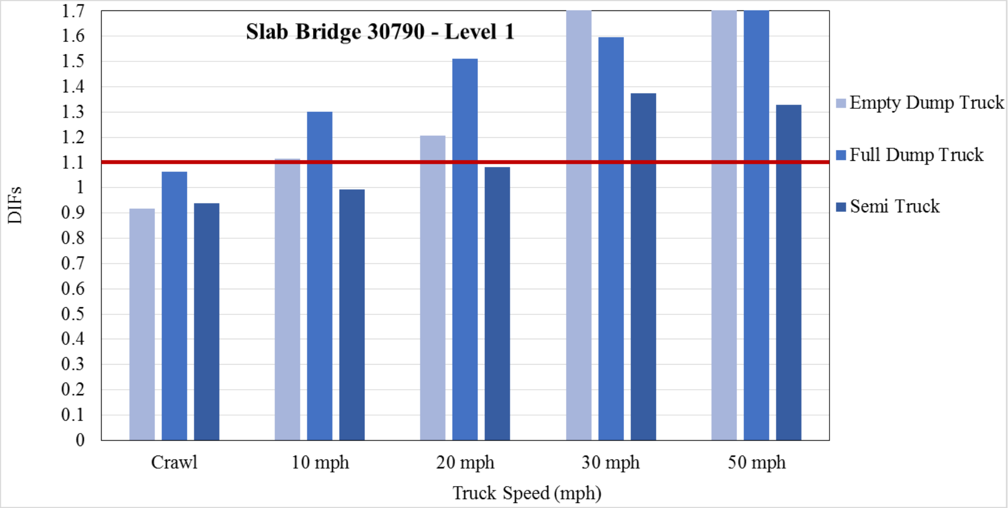


Level 2

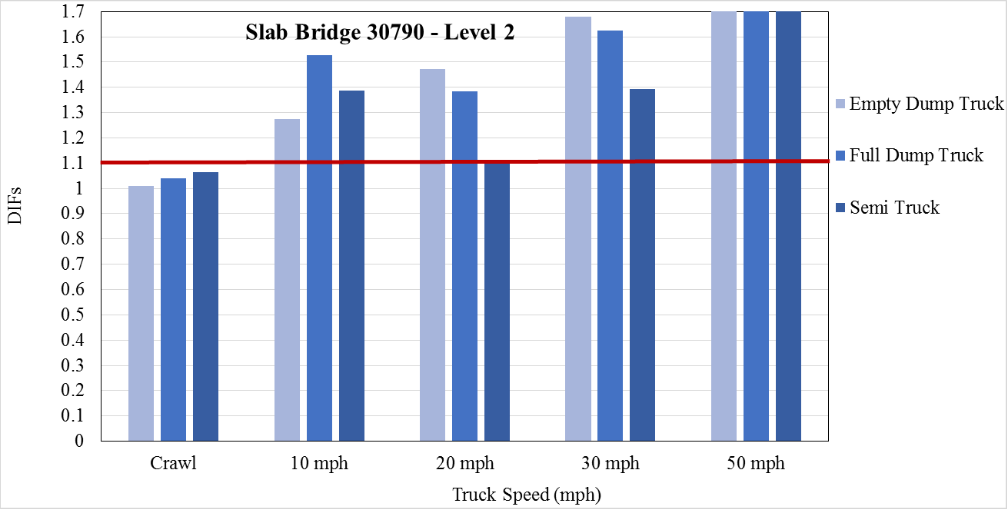
Figure 4.10 DIFs based on largest strain in short-span concrete girder Bridge 40320



As-is



Level 1



Level 2

Figure 4.11. DIFs based on largest strain in concrete slab Bridge 30790

The allowable truck speeds for bridges under different conditions are summarized in Table 4.2.

Table 4.2 Allowable truck speeds for different conditions

Bridge Type	As-is (mph)	Level 1 (mph)	Level 2 (mph)
Long Steel Bridge 600770	30	10	10
Short Steel Bridge 23370	30	Crawl	Crawl
Long Concrete Bridge 608580	30	30	20
Short Concrete Bridge 40320	50	10	Crawl
Slab Bridge 30790	50	Crawl	Crawl
ALL	30	Crawl	Crawl

Based on the results shown in Table 4.2, for short steel girder bridges, the allowable truck speeds are 30 mph, crawl speed, and crawl speed for As-is, Level 1, and Level 2 entrance conditions, respectively; for short prestressed concrete girder bridges, the allowable truck speeds are 30 mph, 10 mph, and crawl speed for As-is, Level 1, and Level 2 entrance conditions, respectively.

4.4 Conclusions

Based on the measured DIFs from the two steel girder bridges, two concrete girder bridges, and the slab bridge, the influence of various factors, including vehicle speed, roughness of the bridge approach, vehicle characteristics, and bridge dynamic characteristics, on DIFs are summarized as follows:

- The DIFs increase as the static strain decreases and the DIFs are sensitive to low strains, and particularly those less than 10 microstrains, which is likely due to the measurement error, noise, and mathematical division. Accordingly, the DIFs related to the greater strains were deemed more reliable. Given the project objectives were related to permitted trucks, DIFs from higher strain readings were utilized for this part of the study.

- The DIF increased with an increase of the truck speed, particularly for the 30 and 50 mph speeds.

- Increased entrance condition roughness generally resulted in higher DIFs. However, the roughest entrance condition (Level 2, with the ramp placed at the joint) did not always induce the largest DIFs. With Level 1 and Level 2 entrance conditions, the DIFs exceeded 0.3 for all investigated bridges for truck speeds up to 50 mph. With As-is entrance conditions, the DIFs were less than 0.3 for the steel and concrete girder bridges and less than 0.1 for the slab bridge with truck speeds up 50 mph.

- The empty dump truck induced the greatest impact factors, followed by the full dump truck and then the semi-truck.

- Longer span bridges had lower DIFs than shorter span bridges, likely due to the higher flexibility of longer span bridges.

To complement the Iowa DOT policy, the researchers determined allowable speeds for each of the bridges where the DIFs did not exceed 0.1 as follows:

- For the long steel girder bridge, the allowable truck speeds were 30, 10, and 10 mph for As-is, Level 1, and Level 2 entrance conditions, respectively. For the short steel girder bridge, the allowable truck speeds were 30 mph, crawl speed, and crawl speed for As-is, Level 1, and Level 2 entrance conditions, respectively.

- For the long concrete girder bridge, the allowable truck speeds were 30, 30, and 20 mph for As-is, Level 1, and Level 2 entrance conditions, respectively. For the short concrete girder bridge, the allowable truck speeds were 50 mph, 10mph, and crawl speed for As-is, Level 1, and Level 2 entrance conditions, respectively.

- For the slab bridge, the allowable truck speeds were 50 mph, crawl speed, and crawl speed for As-is, Level 1, and Level 2 entrance conditions, respectively.

CHAPTER 5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary and Conclusions

A field test program was implemented on five bridges (two steel girder, two pre-stressed concrete girder, and one concrete slab) to investigate the dynamic response of bridges due to vehicle loadings. The important factors taken into account during the field tests included vehicle speed, entrance condition, vehicle characteristics (i.e., empty dump truck, full dump truck, or semi-truck), and bridge dynamic characteristics (i.e., long-span or short-span). Three entrance conditions were evaluated: As-is and also Level 1 and Level 2, which were simulated by placing a ramp 10 feet from the joint between the bridge end and approach slab and directly next to the joint, respectively.

The researchers analyzed and utilized the collected field data to derive the DIFs for all gauges installed on each bridge under the different loading scenarios. Based on the calculated DIFs and observed trends for the associated important factors, the conclusions were as follows:

- The DIF increases with an increase in truck speed, the level of entrance conditions, and the bridge span length.
- For all investigated bridges, with Level 1 and Level 2 entrance conditions, the DIFs exceeded 0.3; and, with As-is entrance conditions, the DIFs were less than 0.3 for the steel and concrete girder bridges and less than 0.1 for the slab bridge.
- The empty dump truck induced the greatest impact factors, followed by the full dump truck and then the semi-truck.

5.2 Recommendations

In order to limit the DIF to 0.1 for steel, concrete, and slab bridges subject to permitted loads, the allowable truck speeds are 30 mph for bridges with As-is entrance conditions similar to those tested and crawl for bridges with Level 1 and Level 2 entrance conditions similar to those tested..

The researchers recommend that currently collected road roughness information be examined for use as an indicator of entrance condition. If successful, the international roughness index (IRI) data could then be used to determine the speed limitation to put in place as well as which DIF values to use in permitting analysis.

5.3 Future Work

From this study, the researchers found that heavier trucks induce greater strains in bridges on which the measurement error, noise, and mathematical division have less impact. In the future, additional field tests can be conducted using heavier trucks (i.e., the truck weight close to the AASHTO design truck) to obtain more realistic DIFs for design or rating purposes.

Furthermore, the long-term bridge monitoring systems installed on Interstate 80 should be used to study impact factors and stress levels for actual permitted vehicles. Utilizing these data will provide the best information as to what level permitted vehicles traveling at highway speeds induce dynamic effects in bridges.

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