Evaluation of the Use of IRI Data to Estimate Bridge Dynamic Impact Factor (DIF), Part II: Verification of Proposed DIF Estimation Equation

Addendum Report
October 2023

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
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16. Abstract

This research described in this report was conducted to supplement a previous project sponsored by the Iowa Department of Transportation (DOT) and completed by the Iowa State University Bridge Engineering Center, Evaluation of the Use of IRI Data to Estimate Bridge Dynamic Impact Factor (DIF) (InTrans Project 21-757).

The overarching goal of the previous project was to develop a process that could be used to determine the DIF for any bridge in Iowa based on strain and international roughness index (IRI) data. A key result was an equation for predicting the DIF values of existing bridges in consideration of bridge skew and the maximum IRI value near the bridge deck approach. Although the equation was validated using data from 13 bridges, the researchers found that the actual bridge dynamic response could deviate ±10% from the predicted DIF value and therefore recommended further validation using data from additional bridges.

The objective of the present research was to further validate the equation developed in the previous project using data from nine additional bridges. The same approach used in the previous study was employed to process the field-collected data for these bridges, and the resulting DIF data associated with the bridge IRI data were used to verify the prediction equation. For the nine bridges included in this study, the proposed equation showed a deviation of ±5% from the actual bridge dynamic response. This relationship is considered to be quite good and accurate and thus validates the proposed equation for determining DIF when IRI data are available.

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Co-Principal Investigators
Brent M. Phares, Bridge Research Engineer
Bridge Engineering Center, Iowa State University

Justin Dahlberg, Director
Bridge Engineering Center, Iowa State University

Research Assistants
Zhengyu Liu, Adjunct Assistant Professor
Karthian R. Jadhav, Graduate Research Assistant
Bridge Engineering Center, Iowa State University

Authors
Zhengyu Liu, Justin Dahlberg, and Karthian R. Jadhav

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A report from
Bridge Engineering Center
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
https://bec.iastate.edu/

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The research team would like to thank the Iowa DOT for sponsoring this work.

CHAPTER 1. INTRODUCTION

1.1 Background and Problem Statement

A previous project completed by the Iowa State University Bridge Engineering Center, Evaluation of the Use of IRI Data to Estimate Bridge Dynamic Impact Factor (DIF) (Liu et al. 2022), developed a process for determining the dynamic impact factor for any bridge in Iowa.

To achieve the project objectives, 40 bridges having a variety of bridge lengths, skew angles, girder materials, deck conditions, structure types, etc., were identified and verified to be representative of the Iowa bridge population. A smaller sample of 20 of these bridges was then selected for bridge monitoring to collect dynamic strain data. To estimate the static strain data for these bridges, the locally weighted scatterplot smoothing (LOWESS) function was used to smooth the dynamic strain time history. The bridges' DIF values were then calculated using the maximum dynamic and static strain data.

International roughness index (IRI) data were extracted from PathWeb, a web-based application available through the Iowa Department of Transportation (DOT), for all bridges considered in the field monitoring program. Each bridge was identified in PathWeb, and the IRI data from four locations near the bridge deck approach were extracted and used to study the relationship between the IRI data and the bridges' DIF values. The key findings from this research were as follows:

- The DIF decreases as bridge skew angle increases. Based on linear regression, the DIF value decreases about 0.037 to 0.043 per every 10-degree increment of bridge skew.
- The DIF decreases as the bridge deck condition index value increases, meaning that the dynamic response is lower when the bridge deck condition is better.
- For bridges with zero skew, the DIF value increases by 0.006 per every 100 in./mile increment of the bridge's IRI value.

Given that it is not possible to perform a live load test or conduct an instrumentation and monitoring program for all existing bridges to determine their DIFs, the development of an approach to predict DIF based on the available bridge information was an important project goal. Because the results from this research indicated that both bridge skew and bridge surface roughness have a significant effect on the bridge dynamic response, it was determined that the new approach should include both parameters.

Based on the results from Liu et al. (2022), the following equation was developed to correlate the DIF to IRI for bridges with skew:

$$DIF = 1.061 + 0.00006 \times IRI - 0.004 \times S \qquad (1)$$

where S is the bridge skew in degrees. Note that the equation was developed utilizing the maximum IRI data near the bridge deck approach extending from 40 ft before the bridge to 80 ft on the bridge. Therefore, the data within the same range should be used during the implementation of this equation for the prediction of the DIF value on other bridges.

1.2 Objective

The work described in this report was conducted to supplement the previous project. The objective was to provide further verification of the DIF estimation equation proposed by Liu et al. (2022) using strain and IRI data from additional bridges. It is recommended to read this report in conjunction with the previous report because the latter is referred to in numerous locations. The previous report is available at https://intrans.iastate.edu/app/uploads/2022/11/use_of_IRI_data_to_estimate_bridge_DIF_eval_w_cvr.pdf.

To achieve the objective, nine additional bridges were selected, and data were collected during ambient traffic conditions. The field-collected data were processed using the same approach as was used in the previous phase of research. The resulting DIF data associated with the bridge IRI data were used to verify the prediction equation developed by Liu et al. (2022).

CHAPTER 2. BRIDGE INFORMATION AND FIELD WORK

2.1 Bridge Selection and Details

In total, nine bridges were selected for the field monitoring. These bridges consist of four steel continuous girder bridges and five prestressed concrete girder bridges. These bridges were selected according to the bridge distribution characteristics observed in Liu et al. (2022). Because it was also necessary to ensure that a sufficient amount of data could be collected from each selected bridge, the average daily truck traffic was taken into account. Table 1 lists the details of the nine selected bridges.

Table 1. General information for the selected bridges

No.	Bridge ID	Year Built	Skew Angle	Superstructure Material	Structure Type	Total Length (ft)	Span Length (ft)
1	4050.0S017	1974	4	Prestressed Concrete	Stringer/Multi-beam	268	40.75
2	9965.3S017	1933	0	Steel Continuous	Stringer/Multi-beam	213	64
3	7774.0L065	1997	3	Steel Continuous	Stringer/Multi-beam	297	76
4	9106.6S028	1983	0	Prestressed Concrete	Stringer/Multi-beam	238	76.58
5	2510.3S006	2015	0	Prestressed Concrete	Stringer/Multi-beam	389	91
6	0831.6L030	1963	0	Steel Continuous	Stringer/Multi-beam	724	85.25
7	2527.2S141	1976	0	Steel Continuous	Stringer/Multi-beam	425	22
8	2534.1R141	1997	0	Prestressed Concrete	Stringer/Multi-beam	229	72.5
9	8523.4S210	1988	15	Prestressed Concrete	Stringer/Multi-beam	340	70.75

2.2 Field Work

The instrumentation plan documented in Liu et al. (2022) was adopted for this project to maintain consistency. Accordingly, the strain gauges were mounted at the bottom flange of each girder at the bridge mid-span. For multi-span bridges, one of the first spans was chosen for instrumentation placement.

Each bridge was monitored for 10 to 15 minutes to collect data from a number of different truck types. Videos of the field tests were captured to identify the time at which each truck passed, the lane each truck used, and the types of trucks passing and to ensure that no other moving vehicles were on the bridge so the data could be isolated to single-vehicle events.

CHAPTER 3. GENERATION OF DIF DATA

3.1 Determination of Static Strain

The data collected during the bridge monitoring captured the dynamic response resulting from the passing traffic loads, but the bridge static response resulting from the same traffic loads is needed to calculate the DIF. It is not possible to measure the static strain resulting from passing vehicles due to the logistical requirement of having to stop traffic while individual vehicles slowly pass over the bridge. To estimate the bridge static strain, the LOWESS function was used to find the static strain response from the dynamic response data.

It is essential to choose a suitable f-value when using the LOWESS function. An f-value that is too small selects an insufficient amount of data around the selected data point, resulting in a large variance. An f-value that is too large makes the regression overly smooth, which results in a loss of data. Therefore, it is necessary to pick a reasonable f-value to minimize the variability in the smoothed points without distorting the data (Cantieni 1983).

To estimate an f-value that would best reduce error, other areas of the data where no vehicles were on the bridge were analyzed to determine the best fit. The f-value that created a static response close to zero when no vehicles were on the bridge was used as the best fit. An example of a static strain curve fit using the LOWESS function on dynamic strain data is shown in Figure 1.

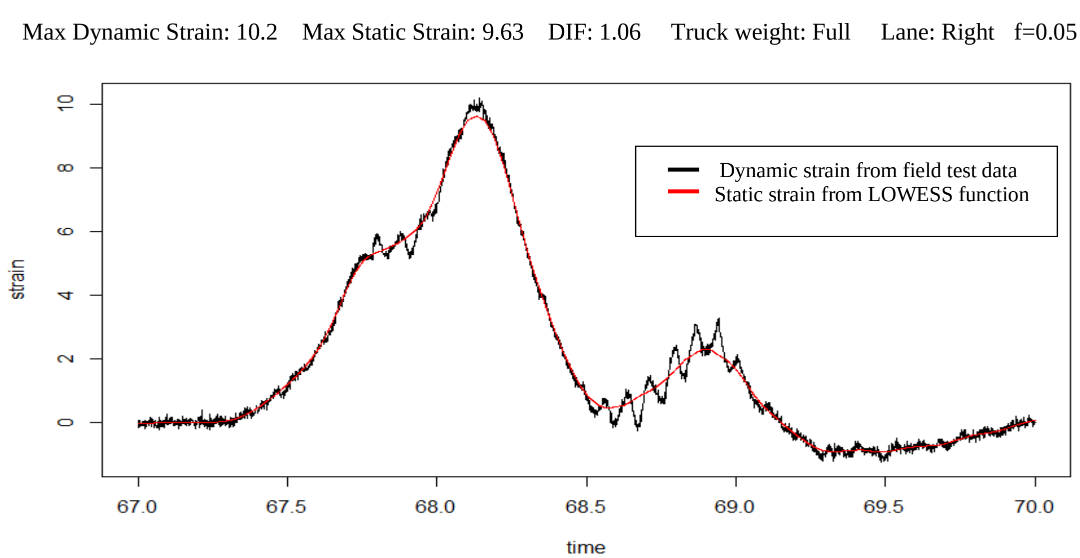

Figure 1. Data from vehicle 1 on bridge 4050.0S017

3.2 DIF Calculation

The dynamic strain curve from the field test data and the curve fit to estimate the static strain were used to calculate the DIF. Specifically, the maximum dynamic strain obtained from the field test data and the corresponding maximum static strain were used in equation 6 from Liu et al. (2022) to calculate the actual DIF. Table 2 provides the calculated DIF for each bridge for each truck event.

Table 2. Calculated DIF values for the nine tested bridges

Bridge No.	Bridge ID		Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
1	**4050.0S017**	**DIF**	1.06	1.11	1.13	1.05	1.03
		Lane	Right	Right	Right	Right	Right
		Load	Non-empty	Empty	Empty	Non-empty	Non-empty
2	**9965.3S017**	**DIF**	1.19	1.08	1.07		
		Lane	Right	Right	Right		
		Load	Non-empty	Non-empty	Non-empty		
3	**7774.0L065**	**DIF**	1.09	1.16	1.2	1.17	1.15
		Lane	Right	Right	Right	Right	Right
		Load	Non-empty	Non-empty	Non-empty	Non-empty	Non-empty
4	**9106.6S028**	**DIF**	1.14	1.07			
		Lane	Right	Right			
		Load	Empty	Non-empty			
5	**2510.3S006**	**DIF**	1.35	1.05	1.35	1.04	
		Lane	Right	Right	Right	Right	
		Load	Empty	Non-empty	Empty	Non-empty	
6	**0831.6L030**	**DIF**	1.08	1.05	1.11	1.11	
		Lane	Right	Right	Right	Right	
		Load	Non-empty	Empty	Empty	Empty	
7	**2527.2S141**	**DIF**	1.15	1.09	1.16	1.23	1.12
		Lane	Right	Right	Right	Right	Right
		Load	Non-empty	Empty	Non-empty	Empty	Non-empty
8	**2534.1R141**	**DIF**	1.08	1.21	1.15	1.23	1.14
		Lane	Right	Right	Right	Right	Right
		Load	Non-empty	Non-empty	Empty	Non-empty	Empty
9	**8523.4S210**	**DIF**	1.09				
		Lane	Right				
		Load	Empty				

Note that the monitoring of bridge 8523.4S210 did not provide DIF data from a non-empty truck. Therefore, this bridge was eliminated from consideration while verifying the DIF estimation equation. Additionally, DIF data from all empty trucks and from trucks that traveled over a lane where IRI data had not been extracted were eliminated from further investigation.

CHAPTER 4. IRI DATA GENERATION

The method for obtaining IRI data described in Liu et al. (2022) was used for these nine bridges. The IRI data were extracted from PathWeb, a web-based application, in collaboration with the Iowa DOT. The IRI data were extracted from four locations at each bridge. The reader is referred to Section 4.2 in Liu et al. (2022) for these four locations. Table 3 lists the maximum of the average IRI data (for both the left and right wheel paths) within each region at all four locations on the nine tested bridges. The maximum overall IRI data are also listed from within the 1st Point, Entry, and After Entry regions. The 2nd Point region was excluded because it was found to have little correlation with the DIF.

Table 3. IRI data collected at the nine bridges

			IRI Data (in./mile)				
Bridge No.	**Bridge ID**	**Bridge Skew**	**1st Point**	**2nd Point**	**Entry**	**After Entry**	**Max IRI (2nd Point Data Excluded)**
1	4050.0S017	4	46	205	32	139	141
2	9965.3S017	0	323	618	105	89	327
3	7774.0L065	3	119	98	809	110	809
4	9106.6S028	0	59	332	350	400	439
5	2510.3S006	0	89	123	68	158	159
6	0831.6L030	0	98	194	113	49	122
7	2527.2S141	0	117	250	302	50	352
8	2534.1R141	0	95	133	184	193	218
9	8523.4S210	15	179	102	76	419	456

Although IRI data were extracted from four locations, Liu et al. (2022) emphasized using the maximum IRI to verify the DIF estimation equation. Therefore, only the maximum IRI data were used for further verification.

CHAPTER 5. VERIFICATION OF THE PROPOSED EQUATION

The proposed equation developed from the previously completed work for this study is stated in equation 8 in Liu et al. (2022) and in equation 1 above. The DIF for each of the eight bridges with non-empty loads was calculated using the proposed equation and compared with the DIF calculated using the field test data. Figure 2 exhibits the relationship between the DIF calculated using the proposed equation and the field test data. As a further point of reference, the DIF calculated per American Association of State Highway and Transportation Officials (AASHTO) design specifications (AASHTO 2010) is also shown in Figure 2.

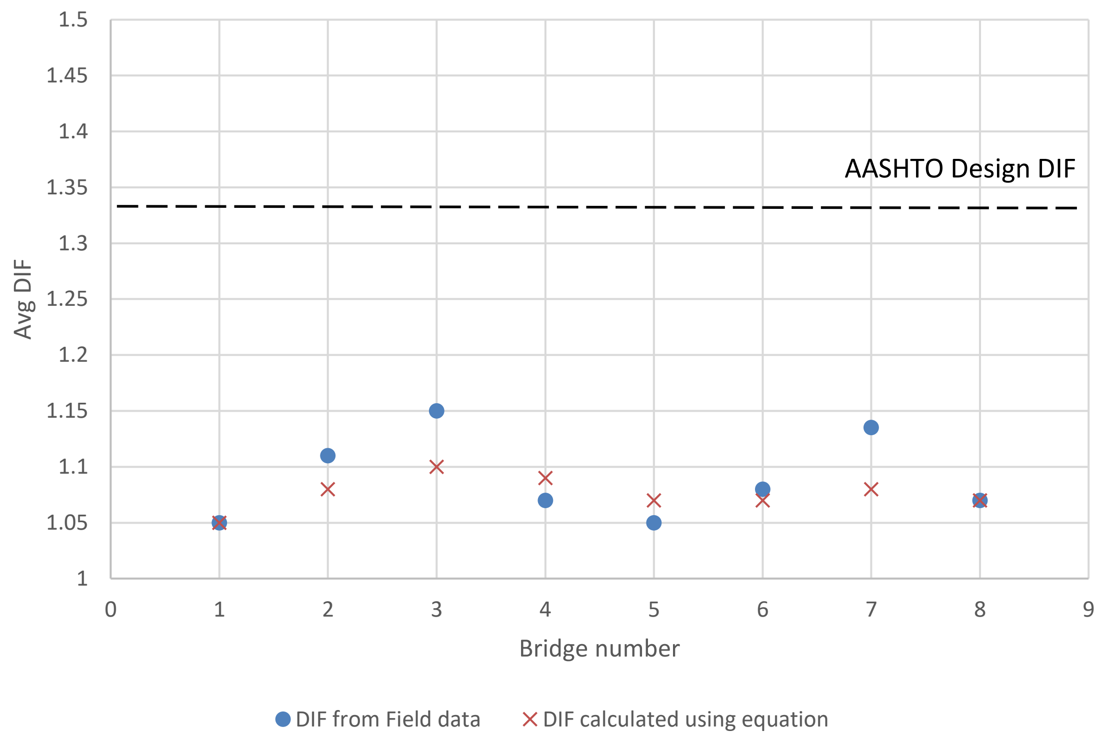

Figure 2. Verification of the proposed DIF equation

The data used to plot Figure 2, along with the error rate, are given in Table 4. The error rate was used to determine the difference between the field-determined DIF and the DIF predicted by equation 8 in Liu et al. (2022). The error rate was calculated using equation 9 in Liu et al. (2022).

Table 4. Data used to verify the proposed DIF equation

Bridge No.	Bridge ID	Bridge Skew	Max IRI (in./mile)	DIF Data: Determined by Field-Collected Strain Data	DIF Data: Predicted by Equation 8	DIF Data: Error Rate (%)
1	4050.0S017	4	141	1.05	1.05	0.7
2	9965.3S017	0	327	1.11	1.08	-2.9
3	7774.0065	3	809	1.15	1.10	-4.9
4	9106.6S028	0	439	1.07	1.09	1.6
5	2510.3S006	0	159	1.05	1.07	2.4
6	0831.6L030	0	122	1.08	1.07	-1.1
7	2827.2S141	0	352	1.14	1.08	-4.7
8	2534.1R141	0	218	1.07	1.07	0.7

The results indicate that the DIF values predicted using the DIF estimation equation proposed by Liu et al. (2022) have high accuracy. This accuracy can be verified by the small error rate range of ±5%.

CHAPTER 6. SUMMARY AND CONCLUSIONS

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. However, in the current bridge codes there is no equation to determine the dynamic response for a bridge. Quickly and accurately determining the dynamic response for a bridge is important for load rating engineers because it allows data-driven and knowledgeable decisions to be made with respect to heavy loads on bridges and the need for overweight vehicles to reduce speed when crossing.

The need to determine the DIF of bridges without large-scale field testing led to the research described in Liu et al. (2022). In that study, a sample of 20 bridges was selected for bridge monitoring to collect dynamic strain data. To estimate the static strain data for these bridges, the LOWESS function was used to smooth the dynamic strain time history. The bridges' DIF values were then calculated using the maximum dynamic and static strain data. IRI data for the bridges were extracted from PathWeb and correlated with the DIF data. Linear regression of the data plots was used to develop the DIF estimation equation presented in Liu et al. (2022).

The equation proposed by Liu et al. (2022) was developed to predict the DIF of existing bridges in consideration of bridge skew and the maximum IRI value near the bridge entrance. Because Liu et al. (2022) found that the actual bridge dynamic response deviated by ±10%, the proposed equation was recommended to be used with limitations.

Liu et al. (2022) validated the proposed equation using data from 13 bridges but also recommended that dynamic response data be collected from additional bridges to further validate the equation. For this reason, nine more bridges were selected for the present study and evaluated for their dynamic response to calculate their DIF values. Maximum IRI data near the bridge entrance were extracted using the same approach recommended in Liu et al. (2022). These IRI data and the skew angle values of the bridges were used in the proposed equation to estimate the bridges' DIF values.

When used to predict the DIF values of the nine additional bridges using the recommended approach in Liu et al. (2022), the proposed equation showed a deviation of ±5% from the actual bridge dynamic response. This relationship is considered to be quite good and accurate and thus validates the proposed equation for determining DIF when IRI data are available.

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