Network Bridge Deck Surface Friction Testing: Issues and Performance Evaluation

Shuo Li, Ph.D., PE, Research Engineer
Division of Research and Development
Indiana Department of Transportation
West Lafayette, IN 47906
Tel: (765) 4631521
Email: sli@indot.in.gov

Guangyuan Zhao, Graduate Research Assistant
Department of Building Construction Management
Purdue University
West Lafayette, IN 47907
Tel: 765-494-5602
Email: zhao179@purdue.edu

Junlin Liang, Ph.D., Visiting Scholar
Department of Building Construction Management
Purdue University
West Lafayette, IN 47907
Tel: 765-494-5602
Email: liang130@purdue.edu

And

Yi Jiang, Ph.D., P.E., Professor
Department of Building Construction Management
Purdue University
West Lafayette, IN 47907
Tel: 765-494-5602
Email: jiang2@purdue.edu

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ABSTRACT

Bridges play a significant role in providing safe and efficient roadway transportation. Friction performance on bridge decks is believed to be critical due to potential early freezing of precipitation on the deck surface and because accidents on bridges, in a confined space, may create more significant mobility issues. In addition, bridge deck friction is becoming one of the key factors in bridge deck preventative maintenance. As a result, the friction performance of bridge decks is becoming an increasing concern. The Indiana Department of Transportation (INDOT) formally started annual inventory bridge deck friction testing at the network level in 2013, which has resulted in additional efforts to enhance travel safety. This paper presents the test procedures utilized by INDOT to undertake annual inventory friction testing for bridge decks at the network level. In particular, this paper addresses the critical issues associated with friction testing on bridge decks, including test reliability, accuracy, and network performance evaluation. It was concluded that a single friction test in accordance with ASTM E274 is capable of providing a reliable test result to accurately characterize the deck surface friction performance for a typical bridge. In addition, it was found that bridge decks on interstates tend to have more friction issues than those on conventional roads such as US highways and State routes.
INTRODUCTION

The Indiana Department of Transportation (INDOT) conducts annual network inventory pavement friction testing every year to ensure public travel safety, particularly to reduce wet pavement skidding crashes. Also, the friction test results have been used by INDOT pavement engineers to assess candidates for pavement resurfacing and preservation treatments. However, like other state transportation departments, the INDOT network pavement friction inventory test program was initially established to cover roadway mainline pavements. Some critical locations, including bridge decks and interchange ramp pavements, might have been overlooked in the past due to the limitations of technologies and resources. In 2008, as an initiative to address potential concerns over ramp pavement friction performance, the INDOT Division of Research and Development (R&D) conducted friction testing on a total of 42 selected interstate ramps that account for approximately 13% of total interchange of ramps in Indiana. It was found that for these tested interchange ramps, the 15th percentile friction number was 29 that was measured with the standard smooth tire at 40 mph. This was extended to indicates that overall, the interchange ramp pavements in Indiana were in good friction conditions and capable of providing sufficient skid-resistance in wet weather (1).

However, it was not until recently that INDOT started annual inventory friction testing on bridge decks at the network level. No other state transportation agencies have been reported to conduct annual inventory bridge deck friction testing so far. It is well known that most state transportation agencies have been conducting annual inventory pavement friction testing using a locked trailer in accordance with the ASTM Standard E274-97, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (2). This method is intended to evaluate pavement test sections of uniform age and uniform composition subjected essentially to uniform tire pressure and does not specifically address the friction measurement of bridge decks. In addition, the calculation of friction or skid number is made in lights of the horizontal and vertical forces recorded over a time interval of 1.0 to 3.0 s (typically 1.5 s for INDOT’s friction test trailers). In other words, the test section should be on average 90 to 150 feet (30 to 45 meters) long for friction testing, depending on the test speed. This makes it difficult for the operator to judge if a bridge is long enough to conduct the test while travelling at a test speed that typically varies between 30 and 50 mph (48 and 80 km/h).

Bridges play a significant role in providing safe and efficient roadway transportation. Friction numbers on bridge decks are believed to be critical due to potential early freezing of precipitation on the bridge deck surface and because accidents on bridges, in a confined space, may create significant mobility issues. In addition, bridge deck friction is becoming one of the key factors in bridge preventative maintenance, particularly bridge deck surface treatment. As a result, the frictional performance of bridge decks is becoming an increasing concern. The INDOT Division of Research and Development conducted field trials to evaluate the feasibility of annual inventory bridge deck friction testing in 2012. Due to the success of test trials, the INDOT formally started annual inventory bridge deck testing in 2013. All bridge deck locations with friction numbers equal to or lower than 25 were reported to the corresponding districts for necessary actions. This paper presents the test procedures utilized by INDOT to undertake annual inventory friction testing for bridge decks at the network level. To the authors’ knowledge, this kind of information may be very useful for other state transportation departments that are interested in providing seamless friction information to cover not only mainline pavements, but bridge decks as well.
The ASTM E274-97 standard test method requires a total of at least five tests at intervals not greater than 0.5 mile (1 km) in length to evaluate the frictional properties of a test section. However, this does not work for inventory bridge deck friction testing at the network level due to two main reasons. First, as pointed out earlier, the INDOT friction test trailers typically calculate the friction number in lights of the average vertical and horizontal forces over a time period of 1.5 s. When friction testing is undertaken at the standard test speed of 40 mph (60 km/h), the bridge should be at least 88 feet (27 m) long to ensure a successful test. Therefore, a total of five tests may require a test section of at least 440 feet (135 m) long. This implies that friction testing can only be conducted on some long-span bridges. However, a large number of bridges in Indiana are short- and medium-span bridges. Second, if five tests are conducted in the same segment, it will be very time consuming to make U-turns to repeat the test, particularly when the exit or entrance is located far away from the bridge. In reality, friction testing with an ASTM E274-97 locked wheel trailer is different from other pavement non-destructive (NDT) testing such as the falling weight deflectometer (FWD) test. For example, one FWD test may only indicate the strength of a localized pavement structure. Nevertheless, a friction number taken at 40 mph (60 km/h) is the average frictional property for a segment of 88 feet (27 m) long. For medium- and even long-span bridges, a segment of 88 feet (27 m) long may provide a result representative of the entire bridge.

To examine if a single test can provide a reliable friction result, the authors conducted a field verification test at a bridge in Lafayette, Indiana. This bridge is located on SR-25 next to the interchange of I-65 and SR-25, which makes it very easy to make U-turns to repeat testing rapidly. In addition, this bridge is a two-lane concrete bridge with concrete deck. During the verification test, friction numbers were measured in two scenarios. In Scenario I, only two test runs were conducted in the northbound. However, the second test was conducted after the previous test so that the deck surface was dried out. In Scenario II, a total of six test runs were conducted over the same deck segment in the southbound. The time interval between two consecutive tests was very short so that the deck surface was still wet due to the water applied in the previous test. It should also be pointed out that the deck surface was treated in 2010 to restore friction performance. The treatment was made by applying one layer of binder, and then one layer of sands onto the deck. The average friction number was 82 after installation. However, field visual inspection in 2012 revealed that most of the sands in the wheel path were lost due to the tire wearing action. Seemingly, this type of treatment may not provide a durable friction surface for bridge decks.

Presented in Table 1 are the detailed results from the verification test using a standard smooth tire (3), including test time, air temperature, test speed, vertical force, horizontal force, and friction number. According to ASTM E274, the friction number is calculated as follows:

$$\text{FN} = \frac{\text{F}}{\text{W}} \times 100$$  \hspace{1cm} (1)

where FN = friction or skid number;
F = horizontal force applied at the tire-pavement contact interface; and
W = vertical force on the locked test wheel.
### TABLE 1 Results of Reliability Verification Test

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Test Run</th>
<th>Test Time</th>
<th>Air Temp. (°F)</th>
<th>Vert. Force (lbs)</th>
<th>Hor. Force (lbs)</th>
<th>FN</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1st</td>
<td>9:59</td>
<td>74</td>
<td>1058</td>
<td>244</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>10:21</td>
<td>75</td>
<td>1046</td>
<td>249</td>
<td>23.8</td>
</tr>
<tr>
<td>II</td>
<td>1st</td>
<td>10:01</td>
<td>75</td>
<td>1043</td>
<td>253</td>
<td>24.2</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>10:04</td>
<td>75</td>
<td>1044</td>
<td>238</td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>10:08</td>
<td>75</td>
<td>1050</td>
<td>225</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>4th</td>
<td>10:11</td>
<td>75</td>
<td>1053</td>
<td>211</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>5th</td>
<td>10:14</td>
<td>75</td>
<td>1065</td>
<td>204</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>6th</td>
<td>10:18</td>
<td>75</td>
<td>1039</td>
<td>207</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Eq. 1 is established with respect to the classic Coulomb’s friction law. However, care should be taken to measure both F and W when friction testing is conducted on the curves or grades. It is shown that in Scenario I, the friction number taken in the second test is very close to that in the first test. This is because that the second test was conducted roughly 22 minutes after the first test, and the deck surface wetted in the first test was completely dried out. In Scenario II, however, the first test produced the greatest friction number, and the fourth test produced the least friction number, which is mainly due to the effect of water applied during testing. Because the subsequent test was conducted shortly (less than 4 minutes) after the previous test, the water applied in the previous test remained on the surface, resulting in a thicker water film in the subsequent test. In reality, this is illustrated by the vertical and horizontal force measurements. For these five tests, the variations between the vertical forces were all less than 11.5%, except for the fifth test, in which, the vertical force was 2.4% greater than that in the forth test. However, the horizontal forces exhibited a decreasing trend of around -5%, which continued until the fifth test. The horizontal force in the sixth test was slightly greater than that in the fifth test. This indicates that the effect of remained water became negligible in the sixth test. Overall, the friction number taken in the first test in the southbound is very close to those in the northbound. It can be concluded that a single test is capable of providing a friction number that is reliable for inventory bridge deck friction test at the network level.

### ACCURACY OF A SINGLE TEST

INDOT inventory friction test program requires that the low friction numbers together with their locations should be reported to districts for necessary actions. Therefore, the accuracy of test result, particularly low friction numbers, is of great importance for decision making. A great effort has been made by INDOT to enhance the repeatability and reproducibility of the network pavement inventory friction test (4). To validate the accuracy of a single test result, surface texture testing was conducted on a bridge with concrete deck on I-90. In reality, the purpose of the texture test was two-fold. First, during the bridge deck test trials at the network level, this bridge exhibited poor friction performance. Therefore, the texture test was conducted to verify the surface friction so as to provide the detailed information at the project level. Second, it was intended by the authors to convince the bridge engineers the accuracy of the inventory bridge deck friction test at the network level. It is well known that the surface texture test produces the mean profile depth (5) used to characterize the surface macro-texture that has been proven to be
the dominant factor affecting surface frictional properties at high speed and in wet weather. In this paper, the mean profile depth measurements were made using a laser scanner. The detailed information on this laser scanner can be found elsewhere (6). In this paper, ten scan lines were utilized in each test to cover a nominal scan area of 100 mm long and 75 mm wide.

Presented in Table 2 are the surface friction and texture test results. The friction number (FN) was measured on July 9, 2012, and the surface texture mean profile depth (MPD) was measured on September 27, 2012. It is shown that the measured FN is 22.7 and the measured MPD is 0.172 mm. It has been reported that the macro-texture is a poor predictor of overall pavement friction (7). To the authors’ knowledge, this is probably due mainly to the lack of information on the surface micro-texture, particularly when pavement surface is very smooth. However, a general rule of thumb is that FN decreases as MPD decreases. It was indicated that when a pavement surface exhibits a friction number of around 20 measured at 40 mph with a smooth tire (8), its surface MPD is typically less than 0.25 mm. Also, visual inspection revealed that while the bridge deck exhibited good integrity, the deck surface in the wheel path in the middle lane had experienced medium polishing as shown in Figure 1. Therefore, it can be concluded that a single test is capable of producing accurate test result on the deck surface friction performance. In reality, the authors did examine both the macro- and micro-textures. Figure 2 shows the 3-D graphs of the macro-texture and micro-texture scans. Apparently, the micro-texture varies differently from the macro-texture, which decides the roles of macro- and micro-textures. Since the laser scanner is only capable of capturing the micro-textures with a wavelength ranging between 0.03 mm and 0.5 mm, the authors are hesitant to make conclusive remarks.

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Test Date</th>
<th>Test Parameter</th>
<th>Average of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Friction</td>
<td>07/09/2012</td>
<td>FN</td>
<td>22.7</td>
</tr>
<tr>
<td>Surface Texture</td>
<td>09/27/2012</td>
<td>MPD</td>
<td>0.172 mm</td>
</tr>
</tbody>
</table>

FIGURE 1 Photo of the bridge deck for texture scan testing
There are about 6066 bridges on the public roads under INDOT’s jurisdiction, including short-, medium- and long-span bridges. A bridge is defined as a structure having an opening of more than 20 feet (9). However, the classifications of short-, medium, and long-span bridges depend on the type of bridges and superstructure materials. Presented in Table 2 are the numbers of bridges in three different categories. Category I consists of bridges having a deck length of less than 88 feet, which are not long enough for a single friction test. Category II includes bridges having a deck length of 88 to 150 feet, which are long enough for a single friction test. The bridges in Category III are those bridges having a deck length of more than 150 feet. Apparently, one or more tests may be conducted for the bridges in category III, which depends on the traffic and bridge conditions. It should be pointed that the above categories are defined solely for the purpose of this task. In reality, field friction testing may be conducted at variable speeds. Therefore, the required length for a single test changes from speed to speed.

As mentioned earlier, INDOT started network bridge deck inventory friction testing in 2013. A total of 1225 bridges were successfully tested, including 970 bridges on interstates, 125 bridges on US highways, and 130 bridges on State routes, which account for approximately 20% of all bridges and 30% of the bridges in categories II and III. During field testing, the typical test speeds utilized by INDOT are 30 mph, 40 mph, and 50 mph. The target test speed is 40 mph to
Table 3 shows the summary of bridge deck friction performance by highway system at the network level. The bridges on interstates demonstrated the lowest average friction number and the bridges on State routes demonstrated the highest average friction number. However, the bridges on interstates and State routes experienced the same extent of variation (see coefficient of variation in Table 3). To further examine the friction performance of bridge decks on different highway systems, the bridge decks were divided into five groups such as Poor (FN<20), Fair (FN=20 to 25), Good (FN=25-35), Very Good (FN=35-45), and Excellent (FN≥45) as shown in Figure 3. It is shown that a large portion of bridge decks with poor friction performance were located on interstates. This indicates that the bridges on interstates tend to have more issues associated with the deck surface friction than those on US highways and State routes. Indiana is a concrete bridge deck state. While transverse tines are commonly produced on the deck surface, the deck surface friction performance is very sensitive to the wearing action of vehicle tires.

**TABLE 4 Statistics of Bridge Deck Friction Numbers at Network Level**

<table>
<thead>
<tr>
<th>Highway System</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate</td>
<td>35.1</td>
<td>10.3</td>
<td>29 %</td>
</tr>
<tr>
<td>US Highway</td>
<td>41.4</td>
<td>9.0</td>
<td>22 %</td>
</tr>
<tr>
<td>State Route</td>
<td>47.2</td>
<td>13.8</td>
<td>29 %</td>
</tr>
</tbody>
</table>

**FIGURE 3 Distributions of bridge decks with different friction performance**
CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the verification tests and network tests, several conclusions can be drawn as follows:

One of the main concerns associated with friction testing on bridge decks is the length of bridge (deck). If tested at the standard test speed of 40 mph, the bridge should be at least 88 feet long. However, the minimum length varies with the test speed used in testing. Multiple test runs were conducted to verify the reliability of bridge deck friction testing and evaluate the effect of water. It can be concluded that a single test is capable of providing a friction number that is reliable for inventory bridge deck friction test at the network level.

Surface texture was utilized to verify the accuracy of bridge deck friction testing. While poor correlation between macro-texture and friction has been reported, a general rule of thumb is that FN decreases as MPD decreases. In this paper, the average MPD of 0.172 is very small, which agrees well with the low friction numbers. Based on the test results together with field visual inspection, it can be concluded that a single test is capable of producing accurate test result on the deck surface friction performance.

Based on the INDOT experience, network bridge deck testing may cover up to 30% of bridges having a deck length of more than the minimum length. This provides very good representation at the network level. In addition, it was indicated that the bridges on interstates tend to have more deck surface friction issues than those on US highways and State routes.

It is recommended that network bridge deck friction testing should be conducted at 30 mph, 40 mph or 50 mph, depending on the highway speed and traffic condition. A higher speed such as 60 mph is not recommended because of the potential errors, safety concerns and tire damage. More effort should be made to investigate the nature and effect of micro-texture that plays an important role in producing long-term friction performance with HFST overlays on bridge decks.

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