Bump Determination at Bridge Approach Transitions Using Inertial Profilers

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ABSTRACT

The bump at the start and end of a bridge has long been studied for highways and railways, yet experts from across the transportation industry continue to identify it as one of the most prevalent substructure factors affecting bridge performance. Often, rideability is a subjective measurement used by transportation agencies to define the presence of a bump. User complaints typically drive maintenance schedules; however, the bump is not just an annoyance on the traveling public. The dynamic impact of vehicles resulting from the bump causes distress, fatigue, and long-term damage to the bridge deck. The bump also causes damage to vehicles and potentially creates an unsafe condition for drivers if this issue is not addressed in a timely manner. To ensure the bump is within tolerable limits based on safety, rideability, and long-term bridge performance, analysis tools are necessary to measure and assess the bridge approach transition.

This paper presents an evaluation of bridge approach transitions using Continuous International Roughness Index (IRI) and Rolling Straight Edge (RSE) simulation analysis on data collected by high speed inertial profilers. A comparison was made between conventional bridges and Federal Highway Administration (FHWA) developed Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS). This paper presents the quantifiable and measurable results based on the analysis performed at each interface between the two bridge types.

Introduction

Stantec Consulting Ltd. (Stantec) was retained to undertake an engineering pilot project of eight bridges in New York State to evaluate bridge approach transitions. A comparison was made between three conventional bridges and five Federal Highway Administration (FHWA) developed Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) bridges. This paper presents the quantifiable and measurable results based on the analysis performed at each interface between the two bridge types using Continuous International Roughness Index (IRI) and Rolling Straight Edge (RSE) simulation analysis on data collected by high speed inertial profilers.

Background

The bump at the end of the bridge has long been studied for highways and railways, yet experts from across the transportation industry continue to identify it as one of the most prevalent substructure factors affecting bridge performance. Often, rideability is a subjective measurement used by transportation agencies to define the presence of a bump. User complaints typically drive maintenance schedules; however, the bump is not just an annoyance on the traveling public; the dynamic impact of vehicles resulting from the bump causes distress, fatigue, and long-term damage to the bridge deck. In addition, the bump also causes damage to vehicles and potentially creates an unsafe condition for drivers if this issue is not addressed in a timely manner. To ensure the bump is within tolerable limits based on safety and rideability as well as to achieve long-term bridge performance for transportation agencies, tools are necessary to measure and assess the bridge approach transition. These products can ultimately be used to help transportation agencies manage and preserve their bridge inventory.

The high speed inertial profiler is an excellent tool to determine the smoothness or lack thereof due to differential differences between the pavement, bridge approach and bridge structure. These devices can collect profile data without interruption to the travelling public, have sample rates of 1-inch or less, produce profiles that are consistent and repeatable, and provide data sets that are useable for producing numerous indices for riding comfort and pavement profiles. For profile data collection at bridge approach transitions, the high speed inertial profiler can provide all the information needed to detect bump or dip locations and produce IRI and RSE statistics to evaluate and compare bridge transition performance. While a high speed inertial profiler will detect a bump or dip at bridge approach transitions with a high level of accuracy, the longwave profile shape will not match that of the true profile. As such, bump heights can be obtained but are a representative value.

Pavement Data Collection

The bridge profile data collection procedure was developed using the Federal Highway Administration Long Term Pavement Performance (FHWA-LTPP) high speed inertial profiler. Survey units built by Ames Engineering (Model 8300) device are equipped with three laser height sensors with an accelerometer located above each height sensor to collect data to compute the longitudinal profile. The profile sensors are mounted on a sensor bar that is installed on the front of the vehicle. One profile height sensor is located at the center of the vehicle, while the other two profile height sensors are located along each wheel path. The longitudinal distance measuring instrument (DMI) is mounted on the rear left wheel of the vehicle, and measures the distance traveled by the vehicle.

Profile height sensors measure the distance from the sensor to the road while the accelerometers measure vertical acceleration. Signals from the profile height sensors, accelerometers, and DMI are used to compute the profile of the pavement along the path traversed by each profile height sensor in real time. Data is post-processed to obtain the longitudinal profile along the path that was traversed by each sensor at 25 mm intervals. This device can measure road profiles at speeds ranging from 10 to 112 km/h. The test speed used to collect profile data at bridge sections was 80 km/h.

Three LMI-Selcom laser sensors are designated as SLS5000 200/300-RO. The 200 in the designation indicates the sensor has a 200 mm measurement range, the 300 indicates the sensor has a stand-off height of 300 mm, and the term RO indicates the sensor is optimized for road applications. The closest distance the sensor can see from the sensor glass is 200 mm, and the furthest distance the sensor can see from the glass is 400 mm. The stand-off height of 300 mm is the center point of the sensor's range and should be approximately at the ground surface. The profile height sensors are rated as 16 kHz lasers. The SLS sensor contains a light source and a detector integrated with optics and electronics. The laser light source illuminates a spot on the pavement surface, and the reflected light from the spot is detected by the detector that uses the signal to calculate the height.

An accelerometer is located on top of each profile height sensor to measure accelerations. The accelerometers are manufactured by Colibrys and can measure accelerations between ±5g. Circuit boards manufactured by Ames Engineering located within each sensor box process the data collected by the height sensor and the accelerometer and combine these data elements with the DMI data to compute the profile in real time.

Results

Five runs were collected for each section to ensure consistent results would be compared. To meet the standard acceptance criteria, a cross-correlation was performed for each section using the Profiler Certification module in FHWA software; ProVAL (with an applied 250 mm IRI filter).

According to the AASHTO standard, R56, "Standard Practice for Certification of Inertial Profiling Systems", a value of 92% or greater is desired for equipment reliability. Based on this standard, one set of runs barely failed to meet this value (91% in the right wheel path of bridge 2). Results are shown in Table 1.

Profiles were graphically presented from the bridge survey that showed the elevation profile for the length of the survey (the bridge plus 60.96 m or 200 feet on either side of the bridge). Profiles from both directions were shown overlapping each other. The procedure used was:

1. Load raw (ARD) data into FHWA-LTPP ProQual 2012 software
2. Generate ERD files using ProXport software using ARD data and ProQual 2012 sectioning information
3. Reverse elevations for opposite lane (Microsoft® Excel® was used)
4. Load ERD files into ProVAL software

Photocell events are used to identify the start and end of the bridge. Using these events it is possible to isolate the location of the bridge approach structures to determine if there are bumps, dips or settlement associated with the bridge approach. Figure 1 and Figure 2 are examples of the graphical presentation for a GRS-IBS bridge and conventional bridge structure, respectively. These were collected as part of the pilot project in St. Lawrence County, New York. Other than the application of a 91 m (300 foot) upper wavelength filter, no corrections have been made. Applying normalization at various spans yielded insignificant results. The 'Edge of bridge' locations in Figure 1 vary as the bridge is located on a curve. A photo of this bridge is shown in Figure 3. A photo of a conventional bridge is also provided (Figure 4).

Bump Determination and Analysis

The profile data collected with the Ames Engineering inertial profiler was used to evaluate the smoothness of the transition between the pavement, the approaches and bridge deck. The profile data was also used to determine if settlement has occurred at the deck approaches that may or may not be evident through cracking or faulting at the interface between the different structures.

To assess the condition and existence of a bump at approach locations, two methods of analysis were performed: Continuous IRI and Rolling Straight Edge.

Continuous International Roughness Index (IRI)

IRI is a statistic used to estimate the amount of roughness in a measured longitudinal profile. The IRI is computed from a single longitudinal profile using a quarter-car simulation. The standard for most highway agencies is to collect 2 profiles, one in each wheel path and calculate the average IRI for each wheel path to represent the roughness for a section of roadway. The HPMS Field Manual, Appendix E, May 2005 lists advantages of using IRI to document pavement performance:

- It is a time-stable, reproducible mathematical processing of the known profile
- It is broadly representative of the effects of roughness on vehicle response and user's perception over the range of wavelengths of interest and is thus relevant to the definition of roughness
- It is a zero-origin scale consistent with the roughness definition
- It is compatible with profile measuring equipment available in the U.S. market
- It is independent of section length and amenable to simple averaging

- It is consistent with established international standards and able to be related to other roughness measures

The FHWA has determined ranges of IRI that fit particular categories (very good to very poor) of road roughness (Table 2).

For most highway agencies, the smoothness of the pavement excludes the area of the bridge approach and bridge. Agencies have monitored smoothness at bridge locations using IRI but there does not appear to be a widely accepted standard based on IRI covering the bridge area. In general it can be expected that the roughness at a bridge will be greater than the road surface due to the transition zones and variance in construction. This does not appear to be the situation for the GRS-IBS structures as the travelling public response has been that the bridge area is undetectable from the roadway pavement. For evaluating the bridge location performance based on IRI, a value of 2.68 m/km (170 in/mi) would apply to separate smooth from rough bridge locations.

ProVAL can be used to plot continuous IRI profiles and identify locations where the IRI exceeds a tolerable limit. For the bridge study, plotting the IRI locations based on a tolerable limit would allow identifying any issues that could be associated with the bridge transition zones. The IRI Threshold was set to 170 in/mi, while the Segment Length was set to 0.3048 m (1 foot).

An IRI graph (showing areas that are acceptable and out of tolerance for an approach structure) is provided for the GRS-IBS (Figure 5) and conventional (Figure 6) bridges examples. The plot range is 20 feet before and after the bump. By plotting IRI in this manner it is easy to determine if there are smoothness issues at the approach structure.

While reasonable for average values, it was determined that a higher value is more applicable for localized bumps. A bump IRI of 15.78 m/km (1000 in/mi) was selected as a localized threshold. Table 3 summarizes the results from all eight bridges (showing left and right average IRI).

Rolling Straight Edge (RSE)

Traditional smoothness specifications for newly constructed pavements for most highway agencies have been based on the output from a RSE. The process requires pushing a rubber tire wheeled device of 3.05 m (10 foot) length along the wheel path of the pavement to obtain the deviation at the mid-point of the profiling device. An acceptable tolerance for this deviation, which varies from agency to agency, is used to calculate the percentage of defective length and locate areas that require improvement.

Profiles collected using inertial profilers can be used to simulate the RSE measurement by determining the vertical deviation between the center of the straightedge and the profile for every increment in the profile data. In order to simulate the straightedge, the length of the straightedge and the deviation threshold value is required to determine out of range locations. For this study, the suggested specification of 3.2 mm in 3.05 m (0.125 inch in 10 feet) rolling straightedge was used.

A RSE module in ProVAL allows for the processing and reporting of the rolling straightedge results from inertial profile data. The outputs can include a plot of the surface deviations (with shaded thresholds) and a defective segments table (i.e. hot-spots or out-of-spec areas and maximum surface deviations). The peak deformation value can be used to quantify the bump/dip height at the approach transition. Surface deviation plots are provided for the GRS-IBS (Figure 7) and conventional (Figure 8) bridges examples.

A summary of the results for surface deformation and representative bump height (left and right average) is listed in Table 4.

Discussion

Continuous IRI results indicated that using the 2.68 m/km (170 in/mi) threshold is too stringent and that an increased, more-localized representative value should be used. Using the 15.78 m/km (1000 in/mi) threshold for approach and leave, no GRS-IBS bridges failed. All three conventional bridges failed at least one threshold. A segment length of 1 foot was used to capture a more localized IRI profile.

Rolling Straight Edge analysis provided similar results. Using the 3.2 mm (0.125 inch) threshold for approach and leave, two GRS-IBS bridges failed at least one of the thresholds. All three conventional bridges failed at least one threshold. Representative bumps heights for failed GSR-IBS bridges ranged from 4.1 mm to 5.4 mm. The range for conventional bridges was 4.4 mm to 14.9 mm.

Recommendations

The greatest challenge encountered was locating the approach and leave interface locations. A method to obtain these with greater accuracy should be established.

Analysis thresholds were determined for the pilot project (based on a set of eight bridges). Additional testing should be performed, both on quantity and bridge type, to validate IRI and RSE analysis thresholds.

The profile data used was filtered using a 91 m (300 foot) upper wavelength cut-off. Unfiltered data should be used to obtain true profiles that could result in more accurate bump heights.

Other profile data types should be considered. Data types such as Texture data have a much smaller sample interval (0.5 mm) that may result in a more precise analysis of localized areas.

References

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Tables

Table 1: Cross Correlation Results using 250 mm IRI Filter

Filename	Left			Right		
	Average	Max	Min	Average	Max	Min
1-North	**93%**	99%	85%	**98%**	99%	96%
1-South	**95%**	99%	92%	**97%**	99%	96%
2-East	**98%**	99%	98%	**91%**	97%	86%
2-West	**98%**	99%	97%	**95%**	98%	93%
3-North	**98%**	99%	96%	**96%**	99%	94%
3-South	**98%**	99%	97%	**98%**	100%	96%
4-East	**93%**	99%	86%	**97%**	99%	94%
4-West	**96%**	98%	93%	**97%**	99%	97%
5-East	**99%**	99%	98%	**97%**	99%	95%
5-West	**99%**	99%	98%	**98%**	99%	97%
6-North	**95%**	97%	92%	**94%**	97%	90%
6-South	**98%**	98%	97%	**93%**	98%	86%
7-North	**96%**	99%	93%	**98%**	99%	97%
7-South	**99%**	100%	99%	**99%**	100%	99%
8-North	**96%**	98%	93%	**96%**	98%	92%
8-South	**98%**	99%	96%	**98%**	99%	97%

Table 2: FHWA Condition Rating and IRI ranges

Condition Rating	IRI Thresholds	
	m/km	in/mi
Very Good	IRI < 0.95	IRI < 60
Good	0.95 < IRI < 1.50	60 < IRI < 95
Fair	1.50 < IRI < 2.68	95 < IRI < 170
Poor	2.68 < IRI < 3.47	170 < IRI < 220
Very Poor	IRI > 3.47	IRI > 220

Table 3: Summary of Continuous IRI Results

Section	Bridge Type	Approach Threshold		Leave Threshold	
		2.68 m/km	15.78 m/km	2.68 m/km	15.78 m/km
1-North	GRS-IBS	Fail	Pass	Pass	Pass
1-South		Fail	Pass	Pass	Pass
2-East	GRS-IBS	Fail	Pass	Fail	Pass
2-West		Fail	Pass	Pass	Pass
3-North	GRS-IBS	Fail	Pass	Fail	Pass
3-South		Pass	Pass	Fail	Pass
4-East	GRS-IBS	Pass	Pass	Fail	Pass
4-West		Pass	Pass	Fail	Pass
5-East	Conventional	Fail	Fail	Fail	Pass
5-West		Fail	Fail	Fail	Pass
6-North	Conventional	Fail	Pass	Fail	Pass
6-South		Fail	Pass	Fail	Fail
7-North	Conventional	Fail	Fail	Fail	Pass
7-South		Fail	Fail	Pass	Pass
8-North	GRS-IBS	Pass	Pass	Pass	Pass
8-South		Pass	Pass	Pass	Pass

Table 4: Summary of Rolling Straight Edge Surface Deviation Results

Section	Bridge Type	3.2 mm (0.125 inch) Threshold		Representative Bump Height (mm)	
		Approach	Leave	Approach	Leave
1-North	GRS-IBS	Pass	Pass	-	-
1-South		Pass	Fail	-	4.1
2-East	GRS-IBS	Pass	Pass	-	-
2-West		Pass	Pass	-	-
3-North	GRS-IBS	Pass	Pass	-	-
3-South		Pass	Pass	-	-
4-East	GRS-IBS	Fail	Pass	5.4	-
4-West		Fail	Pass	5.1	-
5-East	Conventional	Pass	Fail	-	14.9
5-West		Pass	Fail	-	9.4
6-North	Conventional	Fail	Fail	4.4	10.6
6-South		Fail	Fail	5.8	8.8
7-North	Conventional	Fail	Fail	13.9	10.2
7-South		Fail	Fail	10.2	12.9
8-North	GRS-IBS	Pass	Pass	-	-
8-South		Pass	Pass	-	-

Figures

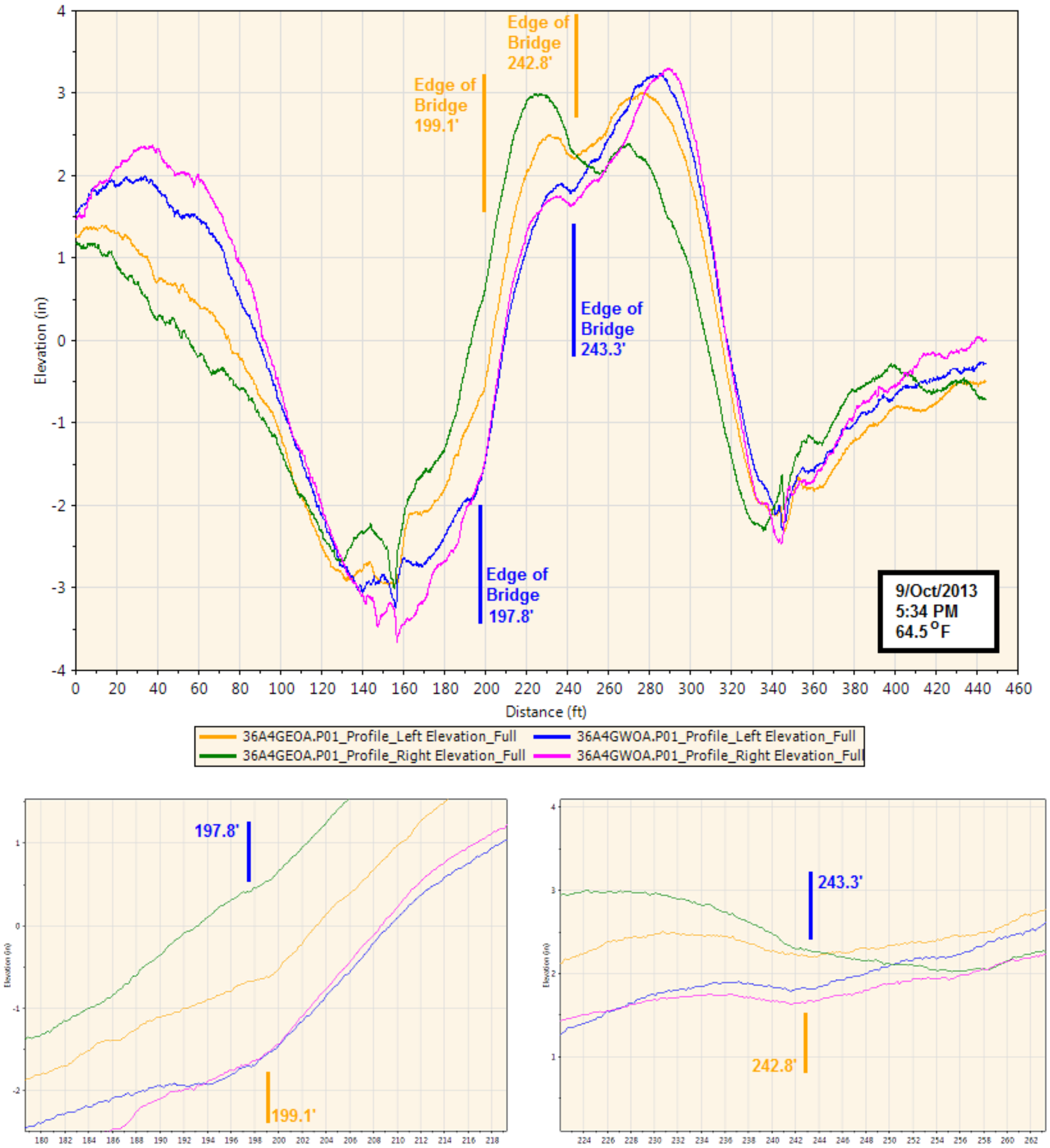

Figure 1: An example of a GRS-IBS Bridge (4) profile in St. Lawrence County, NY (eastbound direction)

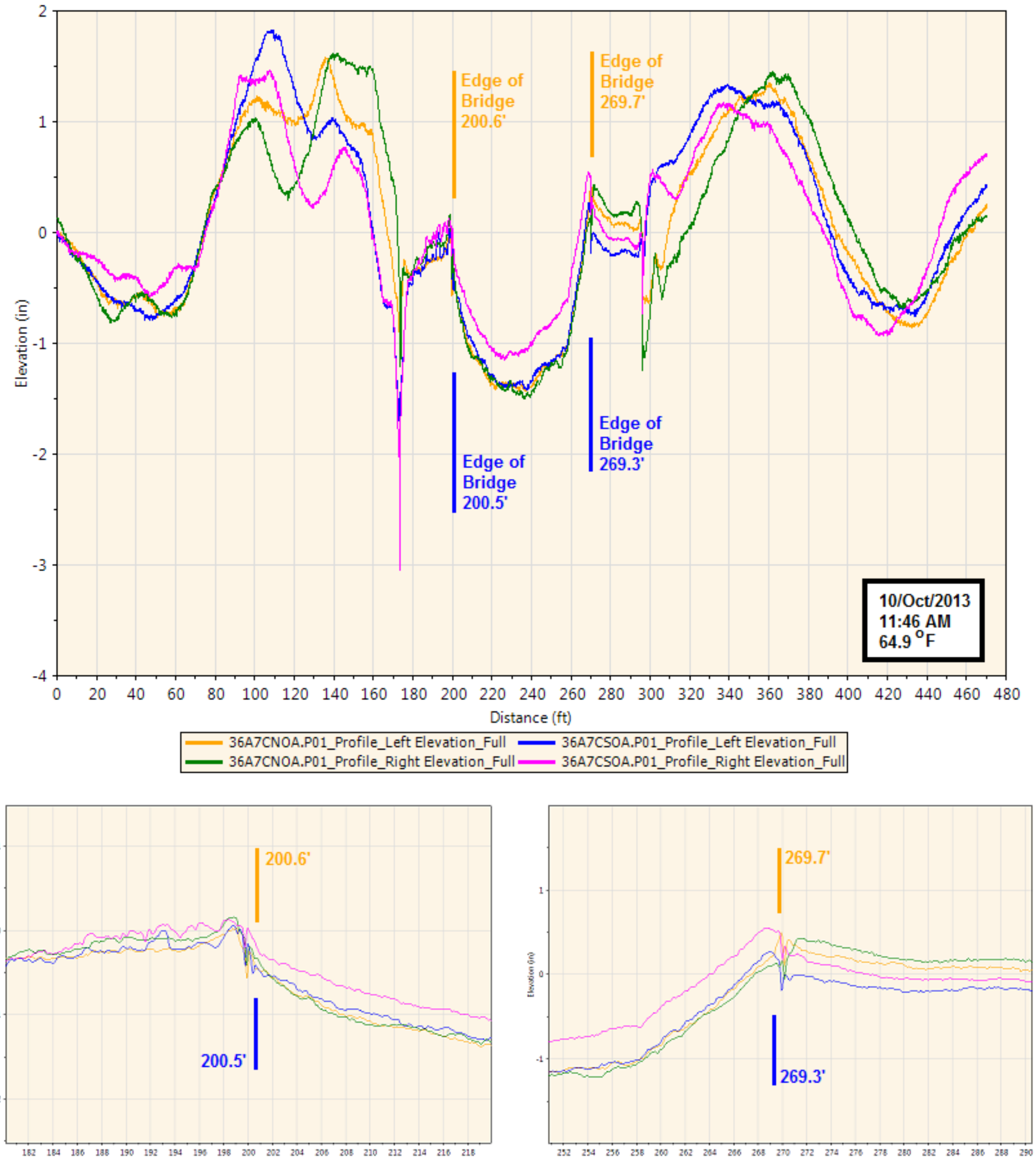

Figure 2: An example of a Conventional Bridge (7) profile in St. Lawrence County, NY (northbound direction)

Figure 3: A GRS-IBS bridge (4) in St. Lawrence County, NY (eastbound direction)

Figure 4: A conventional bridge (7) in St. Lawrence County, NY (northbound direction)

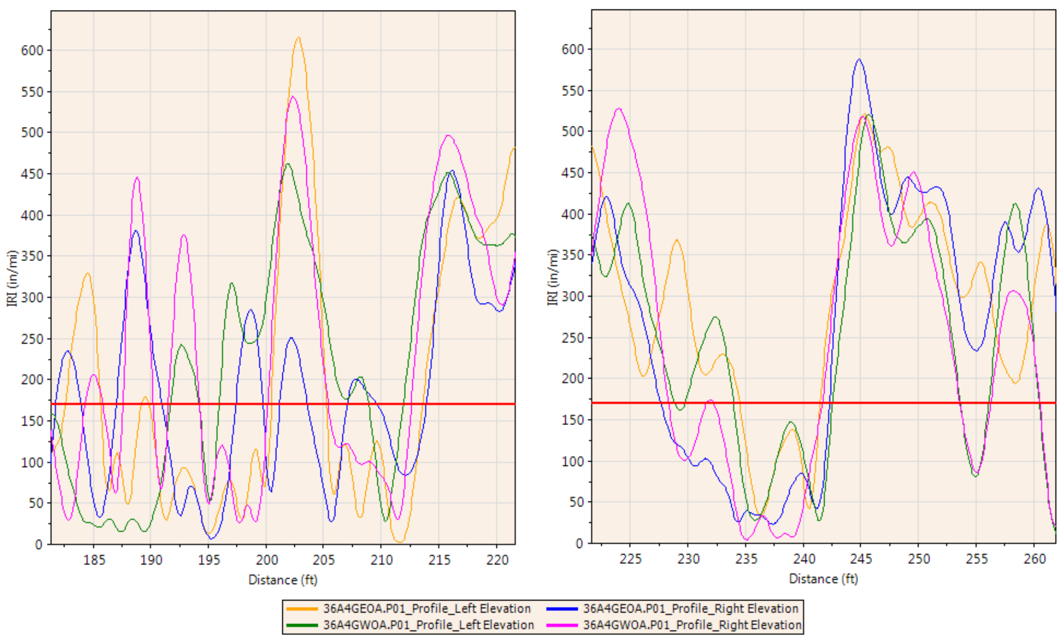

Figure 5: IRI plot using ProVAL software of GRS-IBS Bridge 4 in St. Lawrence County, NY

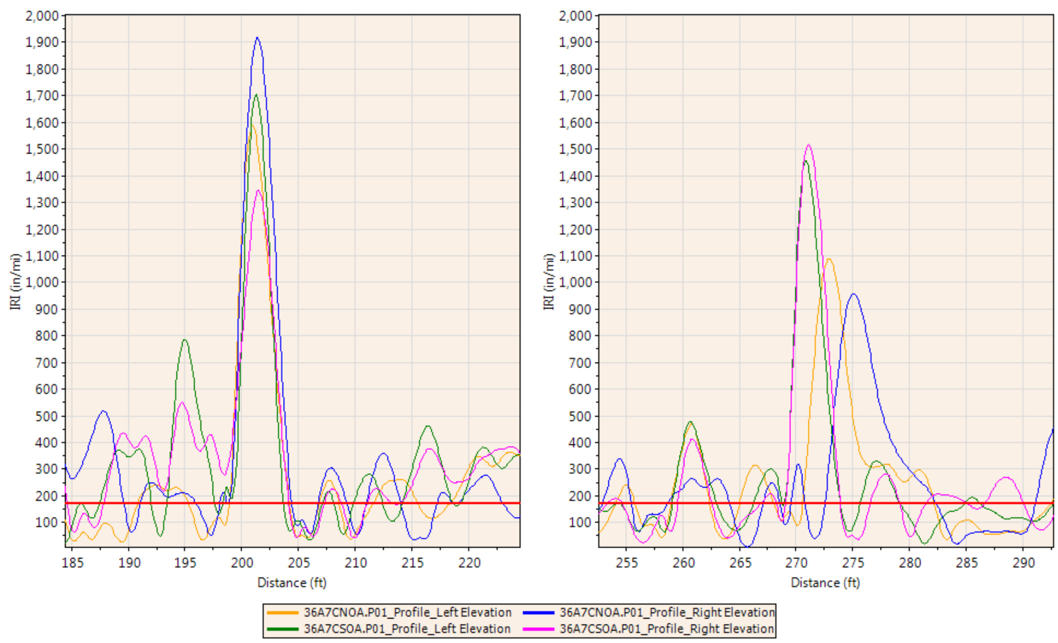

Figure 6: IRI plot using ProVAL software of Conventional Bridge 7 in St. Lawrence County, NY

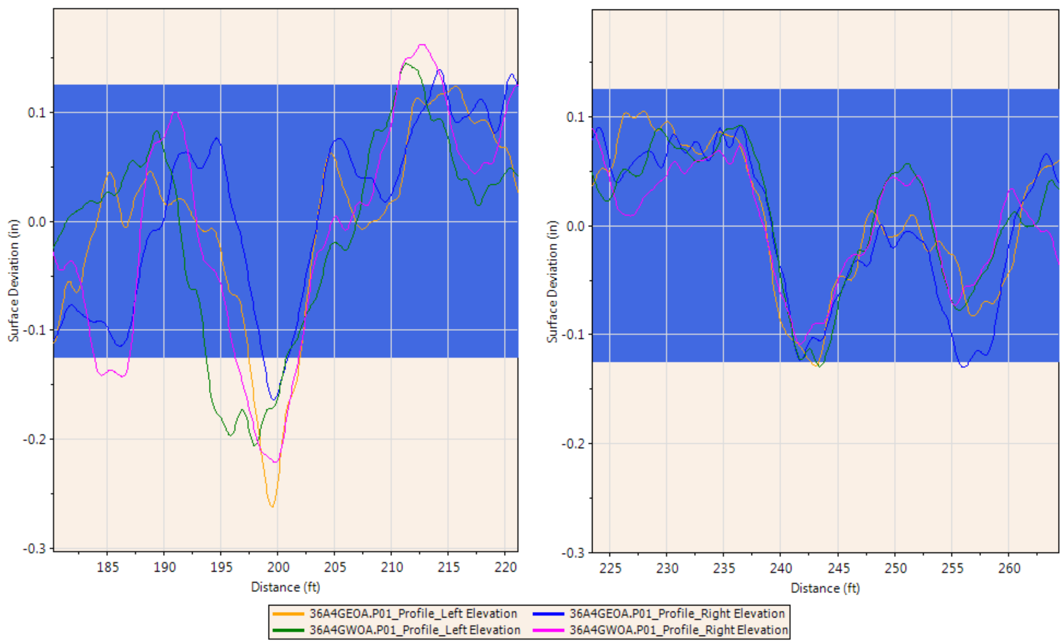

Figure 7: RSE Surface Deviations plot using ProVAL software of GRS-IBS Bridge 4 in St. Lawrence County, NY

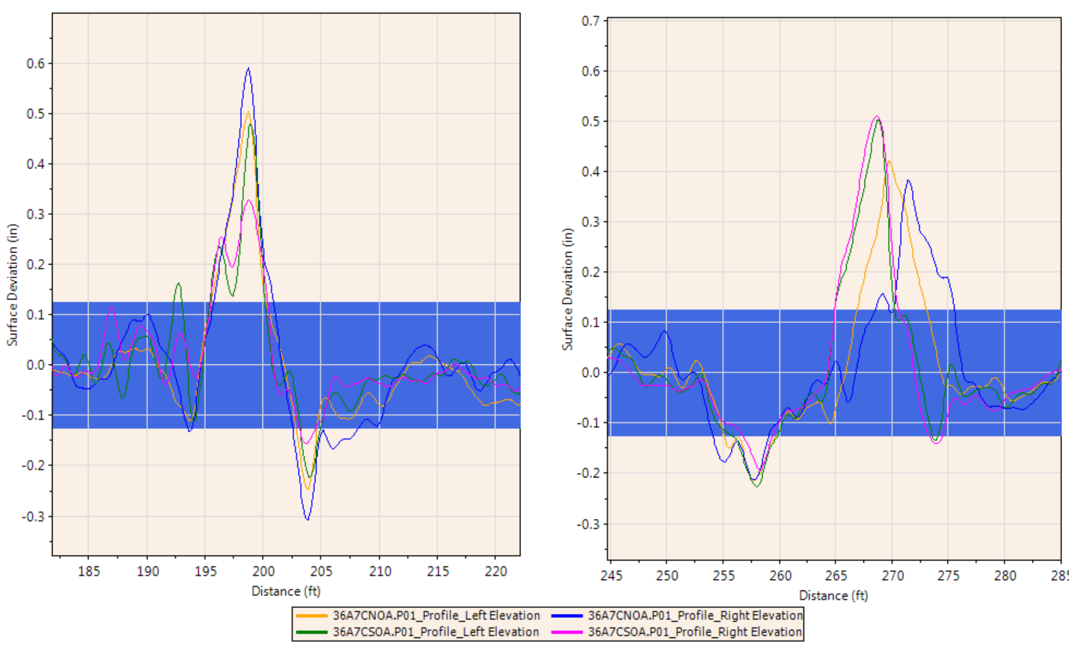

Figure 8: RSE Surface Deviations plot using ProVAL software of Conventional Bridge 7 in St. Lawrence County, NY