MONITORING AND VISUAL INSPECTION OF NEW JERSEY REFERENCE BRIDGES

Di Su
University of Tokyo, Japan

Dionysius M Siringoringo
University of Tokyo, Japan

Tomonori Nagayama
University of Tokyo, Japan

Yozo Fujino
University of Tokyo, Japan

In 2010 the Federal Highway Administration (FHWA) Long-term Bridge Performance (LTBP) Program initiated an International Bridge Study (IBS) to formulate and demonstrate best practice guidelines for the integration and application of technology to diagnose, perform prognosis, and design treatments to mitigate performance deficiencies of bridges. As part of this program, a steel stringer bridge was selected in northern New Jersey for a round robin study as it displayed a number of performance deficiencies which are relatively common for the large population of steel bridges older than 25 years. The University of Tokyo team visited the bridge and made observations, conceptualized its performance, and hypothesized potential root causes of any indentified deficiencies.

In this paper, the visual inspection results as well as a series of experimental studies (including dynamic monitoring, image recognition) within the context of structural identification are described. The condition of the bridge after visual inspection is better than anticipated from the records. Deficiencies are mainly situated in dewatering and in the actual vibration intensities. Another interesting finding is that some bearings, especially at the border of the structure, have been found to be heavily corroded and deduced to lose the movable function, which can be clearly proved by the monitoring data.

The outcome of this study will be part of an internationally developed database of recommendations of best practices for the application of technology to bridges. It will be very helpful to study the socio-cultural differences between the approaches and compare the results among different countries.

Corresponding author's email: su@bridge.t.u-tokyo.ac.jp

MONITORING AND VISUAL INSPECTION OF NEW JERSEY REFERENCE BRIDGES

Di Su, Dionysius M Siringoringo, Tomonori Nagayama and Yozo Fujino
Department of Civil Engineering, the University of Tokyo, Tokyo, Japan

ABSTRACT: A steel stringer bridge was selected in northern New Jersey as part of an International Bridge Study (IBS) initiated by the Federal Highway Administration (FHWA) Long-term Bridge Performance (LTBP) Program. In this paper, the visual inspection results as well as a series of experimental studies (including dynamic monitoring, image recognition) within the context of structural identification are described. The condition of the bridge after visual inspection is better than anticipated from the records. Deficiencies are mainly situated in dewatering and in the actual vibration intensities. Another interesting finding is that some bearings, especially at the border of the structure, have been found to be heavily corroded and deduced to lose the movable function, which can be clearly proved by the monitoring data.

1 INTRODUCTION

A significant effort has been paid into the technology research and development for structural health monitoring of infrastructure and bridge in the world. With the rapid development of the sensors and other monitoring technique in recent years, there are more and more examples of monitoring practice on actual bridges. At the mean time, although there is a great need for objective and mechanistic approaches to bridge evaluation, maintenance and repair, and there are many aspiring technology providers, there have been very few applications, if any, providing insight, knowledge and actionable recommendations to the satisfaction of a bridge owner. For this objective, the Federal Highway Administration (FHWA) Long-term Bridge Performance (LTBP) Program initiated an International Bridge Study (IBS) to formulate and demonstrate best practice guidelines for the integration and application of technology to diagnose, perform prognosis, and design treatments to mitigate performance deficiencies of bridges. The goad of this collaborative effort is to demonstrate their respective best practices related to bridge inspection, structural identification by various techniques, and propose the internationally developed guidelines for the bridge technology application, which is expected to be suitable for different cultural backgrounds.

As part of this program, a steel stringer bridge was selected in northern New Jersey for a round robin study as it displayed a number of performance deficiencies which are relatively common for the large population of steel bridges older than 25 years. The

University of Tokyo team visited the bridge and made observations, conceptualized its performance, and hypothesized potential root causes of any indentified deficiencies.

In this paper, the visual inspection results as well as a series of experimental studies (including dynamic monitoring and image recognition) within the context of structural identification are described. The condition of the bridge after visual inspection is better than anticipated from the records. Deficiencies are mainly situated in dewatering and in the actual vibration intensities. Another interesting finding is that some bearings, especially at the border of the structure, have been found to be heavily corroded and deduced to lose the movable function completely, which can be clearly proved by the monitoring data.

2 BRIDGE DESCRIPTION

The criteria for the test bridge selection included (1) the significance and number of performance problems, (2) the commonality of the bridge type/form and of the performance problems, (3) the availability of documentation, (4) the significant of load rating and inspection challenges, and (5) the ease of access (Aktan, 2010). Following this criteria sister multi-girder steel stringer bridges that carry US 202/NJ 23 were selected (Figure 1). These structures were constructed in 1983 and 1984 and currently display very common problems associated with approach settlement, bearing alignment, substantial vibrations and fatigue cracking. By studying this typical bridge which can represent a large amount of bridge in US will help to answer the popular problems of bridge technology met during the daily maintenance.

Figure 1. View of tested bridge.

The object bridge is located in Wayne County. It is a highway bridge that supports the US 202 & NJ 23. The bridge consist of four spans, where each span consists of two separate bridge connected at the support. In each span, the girder is supported by several stringers made of I-shaped beams and connected laterally by bracings. Each bridge span is simply-supported either by moveable or fixed connection with pin and rocker bearings at one of its ends. The bridge ends are placed on concrete pier caps and supported by concrete cylindrical columns. They used a standard steel design of eight girders with variable section properties and geometries including straight, partially skewed and full skewed spans, which is shown in Figure 2. Except the north side of span 4W (the skew angle is 80 degree), the skew angles for all other spans are 66 degree.

According to the most recent inspection report of Department of Transportation in State of New Jersey (Weber, 2008), this bridge has an overall ranking of 5 (Fair), with 7 (Good) for deck and substructure; 5 (Fair) for superstructure condition. The inspection report (Weber, 2008) referred particularly that the superstructure is in fair condition due

to the common cracks in the welds connecting the lateral bracing horizontal gusset plates to the girder webs in spans 1, 2, and 4,

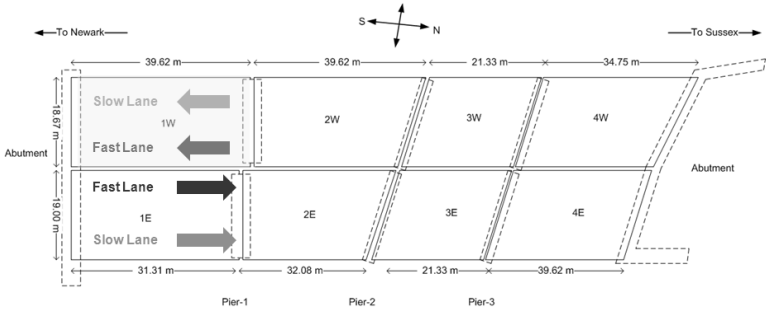


Figure 2. Layout of the tested bridge.

although cracks propagating into the girder webs observed in previous cycles have been arrested by drilling holes and installing bolts.

3 VISUAL INSPECTION ON BRIDGES

3.1 Introduction to Japanese inspection guideline of roadway bridges

Currently the bridge inspection in Japan should follow the inspection guideline of roadway bridges published by Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), revised on March 2004 (MLIT, 2004). Some bridges owners such as national highway companies have their own standards of rating for asset management based on natural one. In this paper all the inspection works were carried out according to natural inspection guideline.

Initial inspection should be done within 2 years after the bridge is opened to the traffic, after that the bridge should be inspected every 5 years. The method of periodic inspection has basically followed the precedent which is to evaluate every member considering every usual kinds of damage by close visual inspection. Two types of evaluation of inspection results were introduced during the inspection, i.e. classification of degree of damage and countermeasure assessment. The classification system of degree of damage adopts *a* as the best case, and *e* as the worst case, shown in Table 1. For countermeasure assessment, it is qualitative evaluation which can be called an advice for administrator about countermeasure in relation to performance of the bridge. The classification of evaluation is also shown in Table 1.

Either the degree of damage or contermeasure assessment is evaluated in the divided unit of each member. No overall rating (health index) for the bridge is provided in inspection as the standard in US (ASSHITO, 1994) and so on. This is because that the periodical inspection guideline in Japan mainly focused on preventive maintenance to avoid severe damage. So when severe damages are inspected, the detailed investigation with some kinds of measurements, loading tests and structural analysis will be carried out. The judgment or evaluation of the global structural performance is out of scope of this guideline. Another reason is that in Japan, the allowable stress design method is still adopted to highway design specification. Consequently, the ultimate strength of the bridge is not able to evaluate properly in a generic way.

3.2 Major findings from the visual inspection

Table 1. Classification of degree of damage and countermeasure assessment.

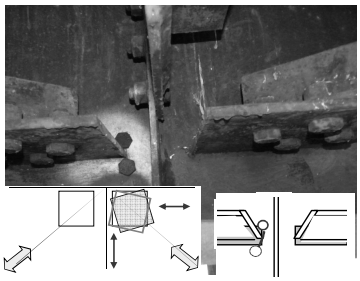
Degree of damage		Countermeasure assessment	
		Classification	Content of evaluation
a	No damage	A	Damage is not confirmed or little, so repair is dispensable.
b		B	Repair is needed according to the situation.
c		C	Repair is needed immediately.
d		E1	Emergency response is needed for structure safety.
		E2	Emergency response is needed for other reason.
e	Severe damage	M	Response through maintenance construction work is necessary.
		S	Detailed investigation is necessary.

Although the evaluation classification in inspection standard is different in various countries, the findings about the problems in the field are almost the same. In this paper, the description of the major findings will base on Japanese team. During the three days, the spans of 1E, 2E, 1W, 2W were inspected in detail. Overall, regardless of painting degradation and good construction environment, some local degradation has been found in anticorrosive function system in this bridge. This assessment indicated that no immediate or short term mitigation is necessary. An imminent threat of collapse is currently not recognizable.

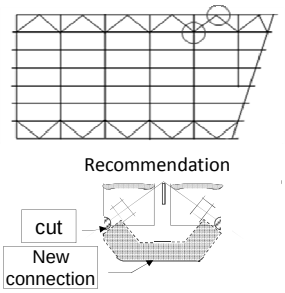
3.2.1 Fatigue crack

The bottom lateral bracing is the member to resist lateral load applying on the girder. Gusset plates were welded to the web of main girder, which were connected to the lateral bracing by high-strength bolts. Because the gusset plates were between the vertical stiffeners of the main girder and were welded to the web separately without the required respective stiffeners on the opposite side, the stress concentration was easily happened in welded toe induced by in-plane and out-of-plane deformation of the main girder Figure 3 (a). Fatigue cracks have been found in many parts of ending parts of welded toes, which is also pointed out in the inspection report of US (Weber, 2008).

Emergent action has been done, including introducing stop-drilled hole by providing additional holes where fatigue cracks happened and tightening the high-strength bolts. However, some bolts were installed in weld bead, thus their functionality decreased. Even the locations where there is no crack, it is very possible that the cracks will happen. Therefore, it is recommended to perform reduction of the stress concentration at all the gussets plates like Figure 3(b).



(a) Crack view and reason

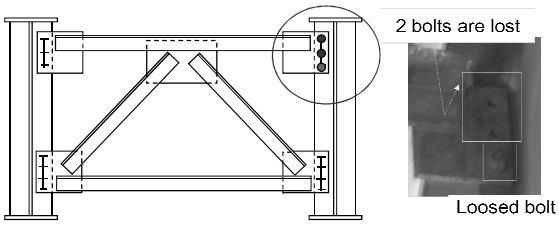


(b) Crack location and recommended countermeasure

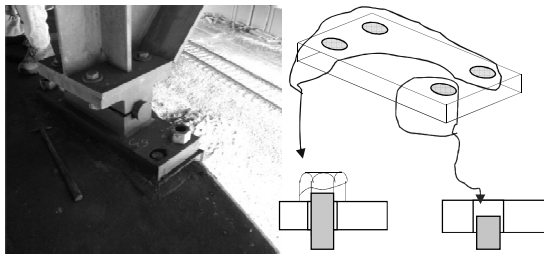
Figure 3. Fatigue crack in the bottom lateral bracing.

3.2.2 Dysfunctional bolts

One severe problem found in the inspection is that some bolts didn't function, loose or even totally lose in several locations. Two bolts connecting an intermediate bracing are lost. The left one is likely loose, shown in Figure 4(a). The deficiencies of axial force in high-strength bolts during construction led to the loose or drop of bolts. From other two dropped bolts, the looseness of the left one bolt is also in progress. Since the cross frame has load distribution function to the load applied on the main girders. If it moves up and down, or in out-of-plane direction, the load will change and lead to the damage of the structure. It is possible to the complete loss of load distribution function. Moreover, in one pier, there is no nut for one anchor bolt, and the other three bolts are almost out of threads of the nut, shown in Figure 4(b). They cannot resist the uplift force from the bearing any more. It is estimated as the construction defects. Both problems of dysfunction bolts are ranking as E1 for countermeasure assessment, which require immediate retrofit action.



(a) Bolts in intermediate bracing

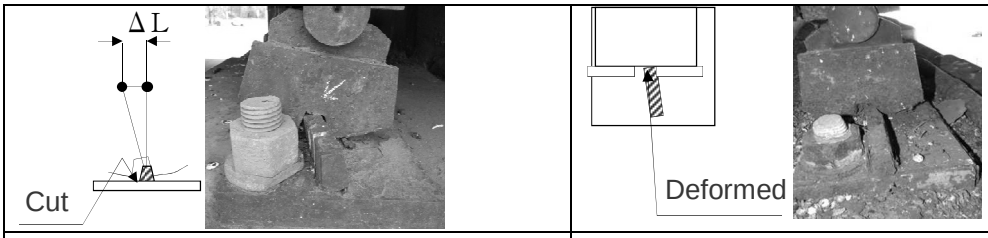


(b) Anchor bolts of bearing shoes

Figure 4. Dysfunctional bolts.

3.2.3 Bearing

Some bearings, especially at the border of the structure, have been found to be heavily corroded. Additionally some single units are slightly twisted. Bearing shoe stopper is cut or deformed as Figure 5. Here the movable function of the bearing seems totally lost because of the heavy corrosion, which could be proved using the measurement results and be described detailedly in the below section. Nevertheless the bearings still provide the required functions being assessed at the end of their life cycle. Some reasonable retrofit work will be necessary here. A surprise failure of a bearing is not really to be expected immediately and, if happening, would not lead to a progressive collapse without warning. It is recommended to retrofit the bearings soon to keep their function ensured.



(a) Bearing shoe stopper in cut status

(b) Bearing shoe stopper in deformed status

Figure 5. Bearing shoe stopper.

3.2.4 Crack and spalling of concrete

A long crack and spalling in concrete could be found in one of the piers, shown in Figure 6. The crack happened in the corbel part which supported the outermost beam. From the appearance of local corrosion, it is an ancient damage and hasn't been extended recently. As the loading in this particular place cannot be expected to be particularly excessive, there is sufficient redundancy at this particular place of the structure, no immediate action is required. But the leakage from the expansion joints might be estimated as the cause of the future severe corrosion problem.

4 INSPECTION BY IMAGE IDENTIFICATION

The image identification technique is used to detect and recognize the width of the cracks in the surface of concrete structures. Totally 1500 photos have been taken using the continuous shoot function of the camera, focusing on the abutment and the round concrete piers. Figure 7 shows the results of image identification in the abutment of south side, which are taken from 22 meters away. By combining separated photos automatically using computer, the size of this image is 4000×25000 pixels, with 100 million pixels totally.

(a) Location of degradation (b) Cracks (c) spalling of concrete

Figure 6. Degraded concrete pier cap (Crack and spalling of concrete).

The crack can be detected using special 'crack detection engine'. The successful ratio for automatic algorithm is about 70%. After the adjustment by the technicians, crack width is detected approximately based on the width corresponding to 1 pixel in the photos. The practical resolution can be expected to reach 0.1 mm/pix. In Figure 7, the maximum width of crack is 1.6 mm, which is smaller than the attention level in US standard. Even in Japan, nothing special countermeasure is necessary, except recording the results in the report.

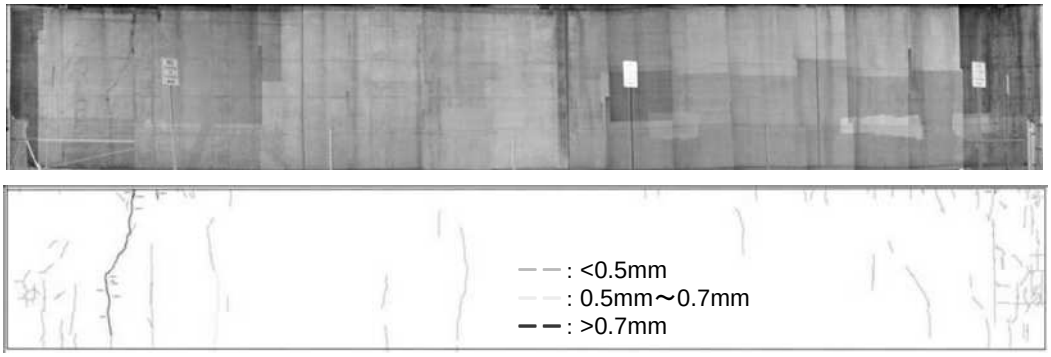


Figure 7. Concrete crack detection by image processing techniques.

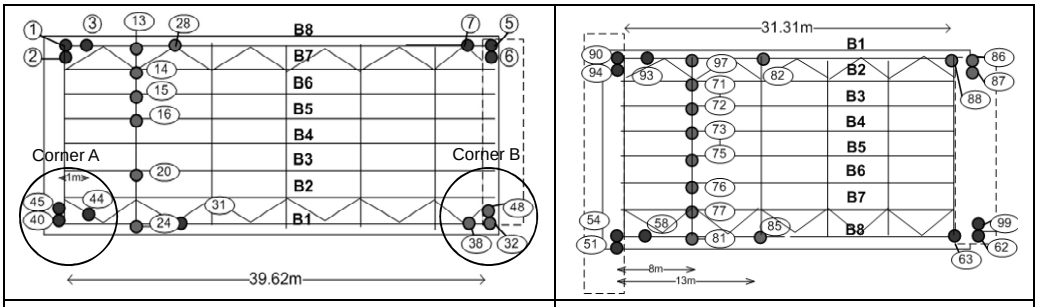
5 VIBRATION MEASUREMENT RESULTS

5.1 Sensor type and arrangement

Vibration measurement campaign was conducted in three consecutive days. The objective of measurement were twofold, namely, to obtain the dynamic characteristics of the bridge under traffic loading and to test the performance of wireless sensing system on the real bridge under operating condition. Due to limitation of access and considering bridge condition, only three spans were measured. The three spans are Span no.1 (1W and 1E), Span no.2 (2W and 2E), and Span no.4 (4W and 4E). Dynamic measurements were conducted by employing two types of sensors for wired sensors, namely the CV-373 triaxial accelerometers, and Rion 40C/10C uniaxial servo-type accelerometer. For wireless measurement, the triaxial Imote2 accelerometers were utilized.

5.2 Sensor configuration

For the reason of equipment transport and import into the U.S., depending on measured spans, several types of sensor configurations are used. Figure 8 shows a typical configuration on span 1W and 1E during this measurement campaign. The sensors were placed in the bottom face of the lower flange of the girders and the location of bearings.

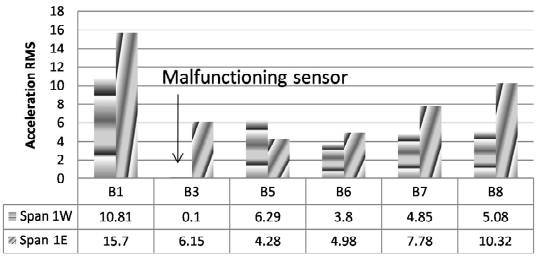


(a) Span 1W (b) Span 1E

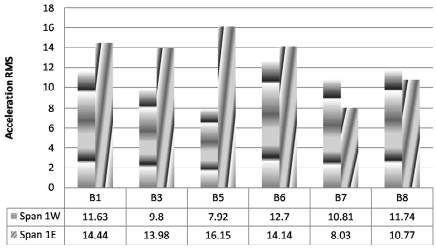
Figure 8. Typical sensor configuration.

5.3 Response Level of the Girder

The response level of the girder is represented by the Root Mean Squire (RMS) value of measured acceleration. For the outer I-beams (i.e. B1 and B8), the lateral vibration is generally larger than the vertical and longitudinal vibration. For the inner I-beams (i.e. B2 until B7), the vertical vibration is generally larger than the lateral and longitudinal vibration. Among the girders, lateral vibration is larger at outer girders, meanwhile vertical vibrations is similar for all girders, which is show in Figure 9. In the above section, inspection has found the fatigue cracks corresponding to the lateral motions. From Figure 9, the fatigue cracks are expected to happen in the outer girders B1 and B8 with high possibility, which has proved in the visual inspection process.



	B1	B3	B5	B6	B7	B8
Span 1W	10.81	0.1	6.29	3.8	4.85	5.08
Span 1E	15.7	6.15	4.28	4.98	7.78	10.32



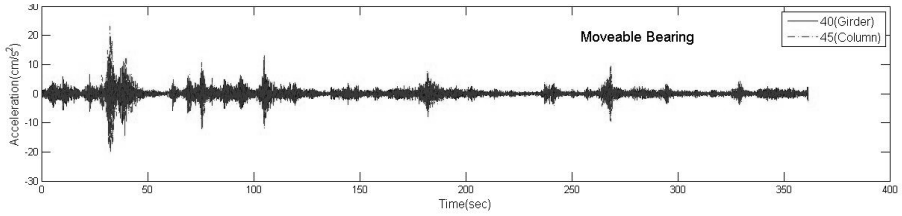
	B1	B3	B5	B6	B7	B8
Span 1W	11.63	9.8	7.92	12.7	10.81	11.74
Span 1E	14.44	13.98	16.15	14.14	8.03	10.77

(a) Lateral direction (b) Vertical direction

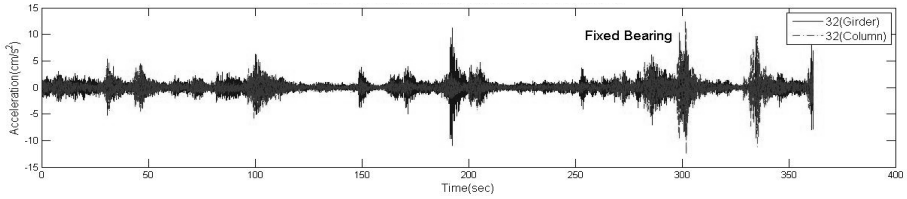
Figure 9. Vibration amplitude among girders.

5.4 Characteristics of Response at the bearing

To capture the responses near the bearing pair of sensor are placed on the girder and on the column at each corner bearing of the span. The characteristics of accelerations at these positions are expected to reveal the condition of bearing qualitatively. Figure 10 shows some typical results. In Figure 10, the longitudinal movement ability of the south-end bearings (corner A in Figure 8(a)) may be decreasing. This is indicated by the almost similar acceleration (both in amplitude and phase) of the girder and column sensors. Considering the moveable type of bearing at this end, larger girder longitudinal movement than the column might be expected. Meanwhile in the northwest corner (corner B in Figure 8(a)), quite large relative acceleration between girder and column is observed. This is not expected in the fixed type of bearing.



(a) Results in longitudinal direction



(b) Results in lateral direction

Figure 10. Motions below and above bearings.

In a word, movable condition is not always satisfied. Fixed condition is not necessarily satisfied either. It depends on the direction of the vibration even for the same bearing. Although direct relationship with the inspection results has yet to be found, it reveals the importance of understanding of the status of bearing during the design and maintenance.

6 CONCLUDING REMARKS

In this study, major findings from the visual inspection are the fatigue cracks, gusset plate bolts, bearing stoppers and bolts, and the concrete pier cap. Image processing has also been demonstrated for concrete crack detection. Vibration measurement revealed that the motions of bearings are not necessarily the same as the design conditions. The response level of different girders also indicates the possibility of the fatigue damages, which are confirmed in the visual inspection.

Acknowledgement

The authors are very grateful to the FHWA LTBP International Bridge Study program (chairman: Prof A. Emin Aktan) and would like to express their thanks for the support and help provided.

References

Aktan, AE. 2010. *NJ Bridge Preliminary Observations and Recommendations*. Philadelphia.

American Association of State Highway and Transportation Officials (AASHTO). 1994. *Manual for condition evaluation of bridges, AASHTO*. Washington, D.C., US.

James, GH, Carne, TG, Lauffer, JP and Nord, AR. 1992. *Modal testing using natural excitation*, Proceedings of 10th Int. Modal Analysis Conference, San Diego, CA.

Juang, JN and Pappa, RS. 1985. *An eigensystem realization algorithm for modal parameter identification and model reduction*. Journal of Guidance, Control, and Dynamics, 8(5):620-627.

Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT). 2004. *Inspection guideline of roadway bridges*. Tokyo, Japan.

Weber, C, Associates PC. 2008. *Bridge Re-evaluation Survey Report, Structure No.1618-150 - Cycle No. 12*. Phillipsburg NJ.