

# **ULTRASONIC INSPECTION OF BRIDGE HANGER PINS**

Benjamin A. Graybeal<sup>1</sup>, Richard A. Walther<sup>2</sup>, SE, PE, and Glenn A. Washer<sup>3</sup>, PE

<sup>1</sup>Research Engineer – Wiss, Janney, Elstner Associates, Inc.  
bgraybeal@wje.com

<sup>2</sup>Consultant – Wiss, Janney, Elstner Associates, Inc.  
rwalther@wje.com

<sup>3</sup>Research Structural Engineer – Federal Highway Administration  
glenn.washer@fhwa.dot.gov

NDE Validation Center  
Turner-Fairbank Highway Research Center  
6300 Georgetown Pike  
McLean, VA 22101-2296

## **ABSTRACT**

Recently, a pin-and-hanger connection on a heavily traveled truck route in the Midwest showed visual indications of being deficient. The pins in this connection were replaced and field contact ultrasonic inspections were performed on the remaining pin connections in the bridge. The field inspections indicated that a number of the pins contained cracks and/or significant wear grooves at the pin shear planes. These pins were replaced and were sent to the Federal Highway Administration's Nondestructive Evaluation Validation Center for further testing. The testing included further ultrasonic studies using an immersion tank, radiographic studies, and computed tomography.

The results of all four types of testing correlated well. The contact and immersion tank ultrasonic studies provided nearly identical results. The radiographic and tomographic investigations also provided conclusive evidence of the location and severity of defects present in the pins. Specifically, two pins were found to contain transverse cracks at the level of a shear plane, with one of these cracks encompassing a majority of the pin cross-section.

## **INTRODUCTION**

A failed hanger pin initiated the collapse of one span of the Mianus River Bridge in June of 1983, resulting in the deaths of three motorists. Following the collapse, there was an immediate increase of interest in the inspection and condition evaluation of bridge hanger pins. This report focuses on four different methods that can be used for the inspection of hanger pins. Ultrasonic inspection has become the primary method of performing a detailed inspection of an in-service hanger pin. As such, field ultrasonics as well as ultrasonic immersion tank inspections of hanger pins are discussed. Additionally, inspection of pins using computed tomography and radiography is discussed.

## **BACKGROUND**

Hanger pins are the structural elements connecting the suspended span of the bridge to the fixed cantilever arm of that same bridge. The primary function of a pin-and-hanger connection is to allow for longitudinal thermal expansion and contraction in the bridge superstructure. These connections are designed to support the transfer of shear forces from the suspended span into the anchor span. As long as the connection is operating properly, neither shear forces from the anchor span nor moments from either span can be transmitted across the connection. A diagram of a pin-and-hanger connection is shown in Figure 1.

Pin-and-hanger connections are typically located directly beneath bridge deck expansion joints. Consequently, they are frequently exposed to water and debris that falls through the joint. Water and debris can accumulate behind hanger plates and around pins. The presence of moisture in the confined region between the hanger plates and girder web can lead to corrosion of these elements including the pin at critical shear planes. This corrosion can have two detrimental effects on the pin. First, the cross-section of the pin can

decrease due to corrosive section loss. This corrosion can produce pitting that may act as crack initiation sites. Second, corrosion can effectively lock the pin within the connection such that no rotation about the pin is permitted. This can lead to large torsional stresses within a reduced section of the pin. The torsional stresses, combined with the shear stresses, provide a likely location for the development and propagation of cracks and the eventual failure of the pin.

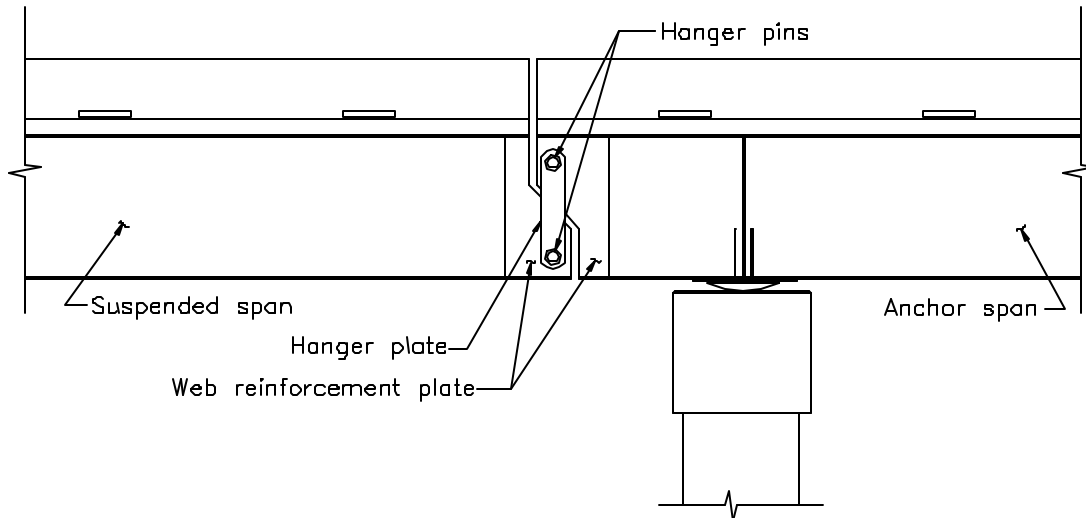


Figure 1. Schematic diagram of a pin-and-hanger connection.

Locating cracks that initiate on the pin barrel at the shear plane perimeter is a difficult task. The shear plane is not visible unless the pin is removed from the connection, a labor and equipment intensive task. Given these circumstances, ultrasonic field inspection has become the primary method through which hanger pins are inspected.

A photograph of one of the hanger pins examined for this study is shown in Figure 2. Note that one of the exterior faces and the shear planes are identified in the figure. The exterior faces are the only surfaces through which ultrasonic pulses can be transmitted while the pin is in situ. The shear planes are the likely locations of defect initiation.

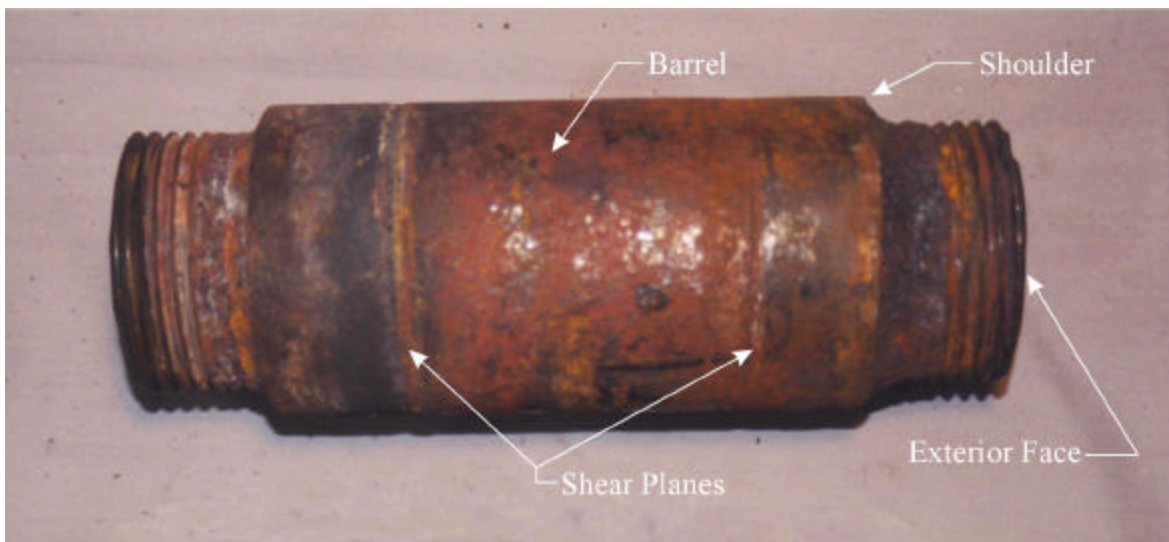


Figure 2. Photograph of hanger pin following removal from bridge.

## BRIDGE DESCRIPTION

The bridge studied for this research is a twelve span, 324.5-m (1064-ft) long structure providing access to a heavy freight transfer facility in the Midwestern United States. The bridge deck accommodates two lanes of traffic and is supported by a superstructure consisting of four welded steel plate girders. The bridge contains 12 pin and hanger connections, all of which occur at expansion joints approximately 1.5-m (5-ft) from an adjacent pier. There are a total of 24 pins and hangers in the structure. The hanger pins in the bridge all have a barrel diameter of 76-mm (3-in) and an overall length of 216-mm (8.5-in). The distance from the exterior face of the pin to the pin shoulder is 32-mm (1.25-in) and the distance from each exterior face to the closer shear plane is 76-mm (3-in). The bridge is owned and maintained by a state Department of Transportation (DOT).

Given the bridge location, it is subject to extremely heavy and frequent truck traffic. Permit loads routinely use this structure. A structural analysis of the bridge conducted in 1994 revealed that the pin-and-hanger detail was being subjected to higher stresses than originally intended. In 1994 an NBIS routine inspection was conducted on the bridge. In conjunction with this routine inspection, the DOT contracted a consulting engineer to perform a special inspection of the pin-and-hanger detail, which included detailed measurement of member sizes and expansion joint gaps. The purpose of these measurements was to determine if the pin-and-hanger detail was "frozen" or locked. A field ultrasonic inspection of the pin members was also carried out. The ultrasonic testing and visual examination revealed shallow defects in some of the pins and no defects in the hanger links. In general, these shallow defects were reported as wear grooves and/or corrosion section loss having depth ranging from minimal to 3-mm (1/8-in).

In the spring of 1998, a DOT employee noted that one of the hangers was no longer aligned correctly with its lower pin. An immediate close-up inspection confirmed that the pin had fractured. As a result, both pins were removed from that connection and replaced with new pins.

In the summer of 1998, Wiss, Janney, Elstner Associates, Inc. (WJE) had the opportunity to view the salvaged pin, which had been removed by flame cutting. The flame cutting had obscured most of the failure surface; however, enough was visible to conclude that fatigue had played a part in the failure mechanism. The state DOT agreed to permit FHWA Nondestructive Evaluation Validation Center (NDEVC) staff members access to the remaining pins to investigate if additional pins within the structure were cracked.

## FIELD ULTRASONIC INSPECTION

With the State's permission, the FHWA NDEVC conducted ultrasonic testing of the remaining 22 pins on the bridge. The inspection team was led by an ASNT certified Level III ultrasonic inspector. The ultrasonic testing was conducted with the intent of identifying cracked or failed pins [1]. The inspections were conducted from a boom lift positioned below the structure. Prior to ultrasonic testing, the pin exterior faces were prepared by grinding to remove paint and smooth the surface to facilitate sound transmission into the pin. The procedures for ultrasonic testing as outlined in the Bridge Welding Code [2] were followed throughout this inspection.

Ultrasonic examinations were performed using a Krautkramer/Branson USN 52 model ultrasonic flaw detector. Preliminary scans were performed using a straight beam ( $0^\circ$ ) transducer, with subsequent scans using an incident angle of  $15^\circ$ . An incident angle of  $15^\circ$  was selected to avoid the pin shoulder and provide a better angle of incidence to the near side shear plane. Transducer frequencies of 5-MHz and a 12.7-mm (0.5-in) element size were used throughout the testing. Prior to testing, the transducer and flaw detector were calibrated to establish sensitivity and time base. Standard AWS calibration blocks and specially prepared pin calibration standards developed by WJE were used.

A straight beam scan was initially used to confirm pin geometry. Measurements of component thickness were made using a tape measure to corroborate the ultrasonic findings. The straight beam scan was also used to identify large cracks or complete failure. The angled beam scans were then conducted to more accurately resolve reflectors located near the pin barrel surface and to examine areas shielded from the straight beam scan, such as the pin shoulder region. Angled beam scans were concentrated on pin shear planes where the potential for wear grooves, corrosion, and cracking indications is greatest. All scanning proceeded in a systematic fashion in order to assure complete coverage of the pin interior. Scanning included movement of the transducer over the entire pin end, with the angle oriented toward the pin barrel. All pins were examined from

both exterior faces. In several instances, the nut was not fully seated on the pin end, thereby limiting transducer positioning near the perimeter of the pin end. After testing, all pin ends were painted using a rust inhibitive primer.

The field inspection indicated that two of the 22 original pins were cracked. This inspection also found five additional pins that had wear groove indications at the shear plane. All seven of these pins were removed from the bridge structure and shipped to the NDEVC. These pins, labeled S104 through S110, are now part of the NDEVC's Component Specimen Database.

This study primarily focused on the two cracked pins. The results from field ultrasonic testing of the two cracked pins, labeled S106 and S108 are shown in Figure 3. The approximate defect profile at the shear plane is indicated in the figure for each pin. The original sketches were produced in the field by hand sketching.

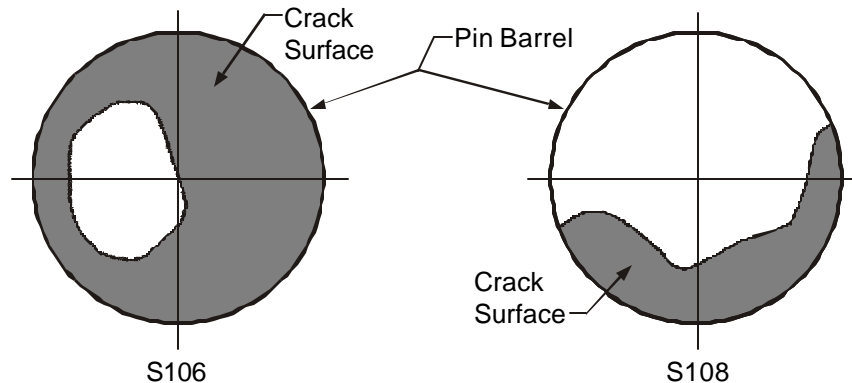


Figure 3. Cracked section results from field ultrasonic inspection.

### IMMERSION TANK ULTRASONIC TESTING

Immersion tank ultrasonic testing of the seven hanger pins was performed at the NDEVC. The purpose of this testing was to accurately detect and quantify crack-like defects that may be present in any or all of the pins. The immersion tank ultrasonic examinations were performed using the following setup. The pin was placed on end while immersed in a water-filled tank. The ultrasonic transducer was positioned above the pin with its face parallel to the end face of the pin. A 5-MHz, 12.7-mm (0.5-in) unfocused transducer was used, with a 60-mm (2.35-in) separation between the transducer face and the pin face. The movement of the transducer for the scanning process was computer controlled allowing the electric motors to systematically move the transducer within the plane parallel to the exterior face of the pin.

Initial scans were performed on all seven pins. The pins were scanned from both exterior faces so as to provide full coverage within the pin barrel. This setup allowed for the detection of virtually all reflectors, including most defects shrouded from direct detection by the shoulder of the pin. The identification of defects in the shrouded area through the use of beam spread is critical, as this portion of the pin is not directly visible to the straight beam ultrasonic transducer.

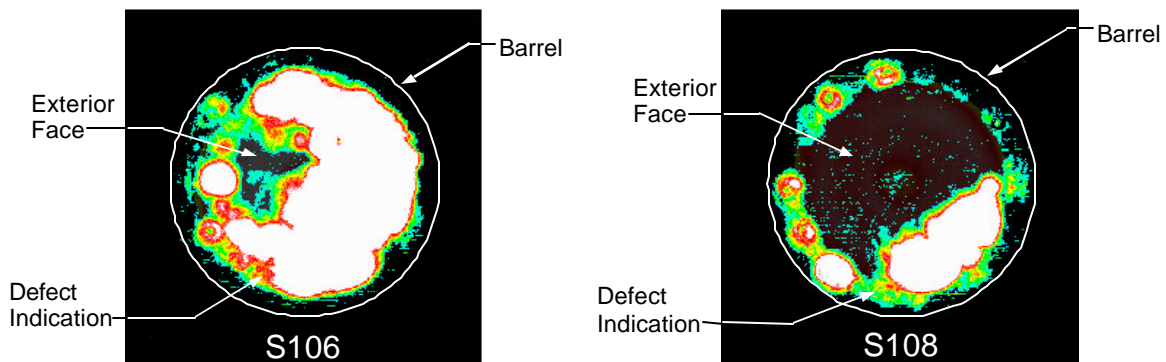
These initial scans indicated that only pins S106 and S108 contained cracks and that the cracks in these pins occurred at the level of the shear plane. Detailed scans were then performed on these two specimens to precisely locate the defects. This additional testing was conducted in two phases. First, the testing apparatus was setup to generally locate small defects near the perimeter of the pin body, below the shoulder. Second, the testing apparatus was setup to precisely locate any defect that occurred within the body of the pin directly under the exterior face.

The specimen preparation and test setup for the detailed phases of testing was as follows. First, the end of each pin that was closer to the defect was milled flat and perpendicular to the body of the pin. This was done so as to optimize transmission of the ultrasonic pulses into the pin. Additionally, since the approximate location of the defects had been determined by the previous scans to be at the level of the shear plane, these further scans were focused in a 19-mm (0.75-in) deep zone at the level of the shear plane. Finally, these scans were set to provide a fine spatial resolution (0.25-mm x 0.25-mm).

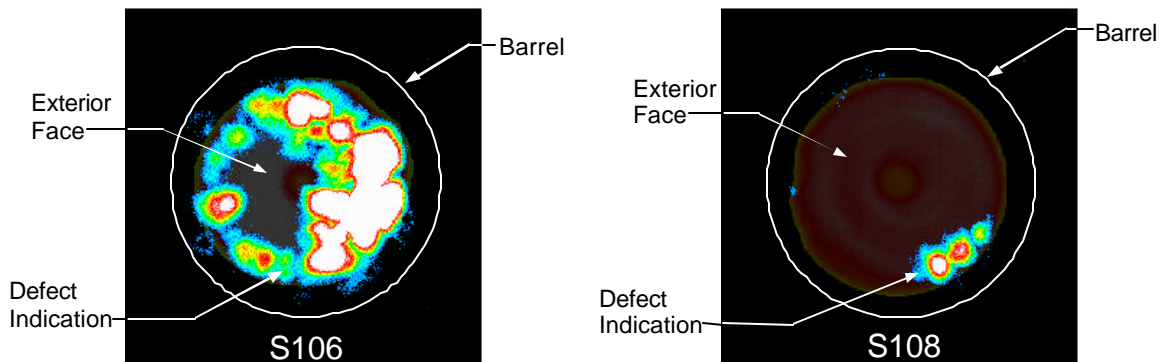
As mentioned previously, the first phase of the detailed testing focused on the identification of the location of defects near the perimeter of the body of the pin. These scans used the same gain, attenuation, and threshold settings as were used for the initial preliminary scans of all seven pins. Through the use of a calibration block, it was determined that these settings allowed for the scan to receive a reflection from a defect at the level of the shear plane which was 6.4-mm (0.25-in) outside of the direct path of the transducer. Accordingly, the procedure could detect a defect that was near the perimeter of the pin body at the level of the shear plane. However, it must be noted that crack-like indications at the limits of this range were difficult to differentiate from wear grooves or corrosion. The results of these scans are presented in the form of a Cscan image in Figure 4a. For reference, the Cscan image of the defects has been superimposed over a darkened Cscan image of the exterior face of the pin. This allows for clear identification of the travel path of the ultrasonic pulse. The outline of the pin barrel is also presented.

The second phase of the detailed investigation of the cracked shear plane regions was then conducted. The goal of this set of scans was to accurately locate the defects that lay directly under the exterior face of the pin. Using the calibration block, the scans were setup such that only defects that were at least partially under the transducer were reported. The Cscan results for these tests are shown in Figure 4b. Once again, for reference, the exterior face of the pin and the pin barrel are presented.

Using the results shown in Figures 4a and 4b, a schematic representation of the defects present at the shear plane level of S106 and S108 can be determined. These results are shown in Figure 5. The cracked portion of the shear plane is shaded in the figure.



a. Defects under pin shoulders at the shear plane level.



b. Defects under the pin exterior face at the shear plane level.

Figure 4. Cscan images of defect indications in hanger pins S106 and S108.

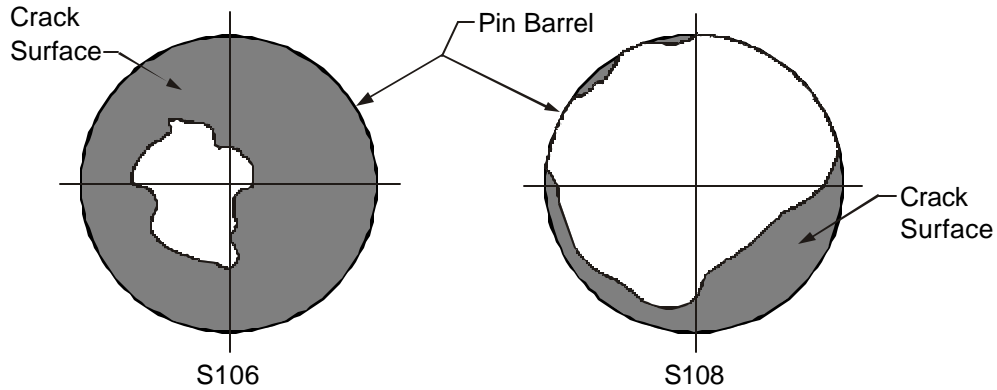


Figure 5. Cracked section results from immersion tank ultrasonic inspection.

### COMPARISON OF FIELD AND IMMERSION TANK ULTRASONIC RESULTS

Comparison between the field ultrasonic results (Figure 3) and the immersion tank ultrasonic results (Figure 5) indicates that the two methods provide similar conclusions as to the extent of cracking at the shear plane level in these two specimens. In pin S106, the immersion tank findings indicated that 79 percent of the cross-section was cracked and the field ultrasonics indicated that 83 percent of the section was cracked. For S108, the immersion tank and field ultrasonic findings indicate 30 and 22 percent of the section was cracked, respectively. Due to the automated nature and the higher spatial resolution of the immersion tank scan, the results from this portion of the testing are believed to provide a more refined and more accurate representation of the extent of the cracking. However, the results from the field ultrasonic testing were found to be quite accurate, given the logistical challenges present in the acquisition of field ultrasonic data.

### RADIOGRAPHIC AND COMPUTED TOMOGRAPHIC TESTING

Radiographic imaging was also performed on pins S106 and S108 in an attempt to characterize any defects that may be present. The radiographs were acquired using a 6-MV betatron and a film detector. The images created through this testing show a slight indication of a shear plane defect in S108 and a clear indication of a defect in S106. This correlates well with both the ultrasonic findings as well as visual indications that can be seen on the exterior of the pin barrel. However, due to the type of radiographic testing performed, no quantitative assessment of the size of the defect could be rendered.

Computed tomography (CT) was also used to inspect pin S106. The CT scans were conducted by Lawrence Livermore National Laboratory (LLNL). The CT data was acquired with a 9-MV LINAC x-ray source and an area-array digital detector. The images produced by the CT scans clearly show that a significant crack exists at the level of the shear plane in this specimen. At this time, a full reconstruction of the data has not been performed and therefore, a quantitative assessment of the size of the crack is not possible. However, the location, general shape, and general size of the crack correspond well with the results obtained from the ultrasonic testing.

### SUMMARY

Field and immersion tank ultrasonic inspection as well as radiographic and computed tomographic inspection techniques were used to investigate possible defects within hanger pins removed from an in-service bridge. The field inspections identified crack-like defects within two pins. The results from the immersion tank testing correlated well with the field ultrasonic testing. Both the defect location and defect size findings show a high level of consistency between the two ultrasonic techniques. The results from the radiographic and tomographic portions of the study also correlated well with the field ultrasonic findings.

## ACKNOWLEDGEMENT

The research which is the subject of this paper was funded by the Federal Highway Administration and the United States Government. The authors gratefully acknowledge this support. The publication of this article does not necessarily indicate approval or endorsement of the Federal Highway Administration or the United States Government, the findings, opinions, conclusions, or recommendations either inferred or specifically expressed herein.

The authors would like to acknowledge Robert Gessel and Habeeb Saleh, WJE, and Amy Waters, LLNL, for the data that they contributed to this paper.

## REFERENCES

1. R.A. Walther and R.D. Gessel, Ultrasonic Inspection of Bridge Pin and Hanger Assemblies, *Proceedings of Structural Materials Technology, An NDT Conference*, 1996, San Diego, CA, p23-28.
2. Bridge Welding Code, ANSI/AASHTO/AWS D1.5-98, *American Association of State Highway and Transportation Officials*, Washington, D.C., 1998, 236 pp.