

Nondestructive Testing of Steel Bridge Members Using the Time of Flight Diffraction Method

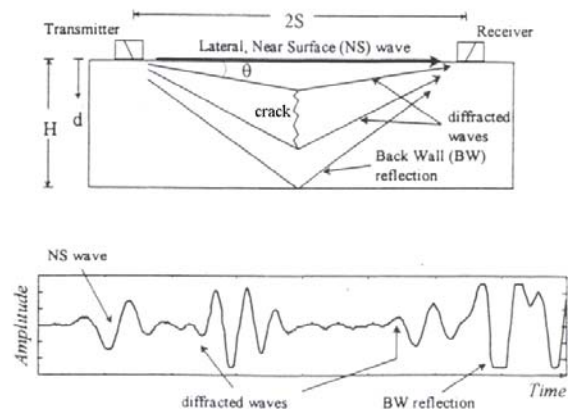
by

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The number of highway, railway, and mass transit steel bridges with welded details in the U.S. has been estimated at 123,000 with between 2,500 and 5,000 of these bridges having low fatigue resistant details¹. Fatigue cracks that go undetected can lead to larger cracks and in some cases cause structural failure. Cracks that can be detected and accurately measured can be repaired or retrofitted. Typically, bridge inspectors will conduct a visual inspection to determine if a structure is experiencing detrimental cracking. However, detecting and sizing cracks cannot always be done with a purely visual inspection.

Many non-destructive testing (NDT) methods can be used to supplement the visual inspection of structures. However, ultrasonic testing is one of the most versatile NDT methods. It can be used to detect defects beneath the surface of a material and is relatively inexpensive. The Time of Flight Diffraction (TOFD) method is an ultrasonic technique that has promise in the area of steel bridge inspections. In this method, one transducer transmits an ultrasonic signal through the material being inspected. This signal is then received by a second transducer. This produces a single waveform or plot of signal amplitude versus time. If there is a defect in the material between the transmitter and the receiver, the ultrasonic signal will be diffracted and this will alter the waveform. The time of arrival of diffracted ultrasonic signals is used to calculate crack location and depth. Since identifying a flaw from a single waveform can be difficult, multiple waveforms are “stacked” together to create what is called a D-scan. A D-scan is a three dimensional colorscale plot showing location of the transducer-receiver pair on the test surface and the waveform collected from that location. Additionally, the time scale of the waveform can be converted to a depth scale through the thickness of the test piece. This allows flaws to be readily identified and sized directly from the D-scan. The advantages of the TOFD method over other ultrasonic methods are that it allows large volumes of material to be inspected efficiently, produces permanent records of data, and reduces operator misjudgment and subjectivity.

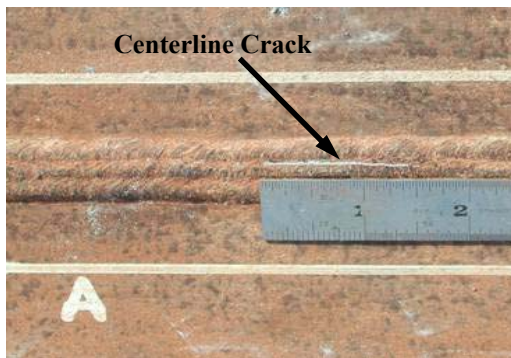
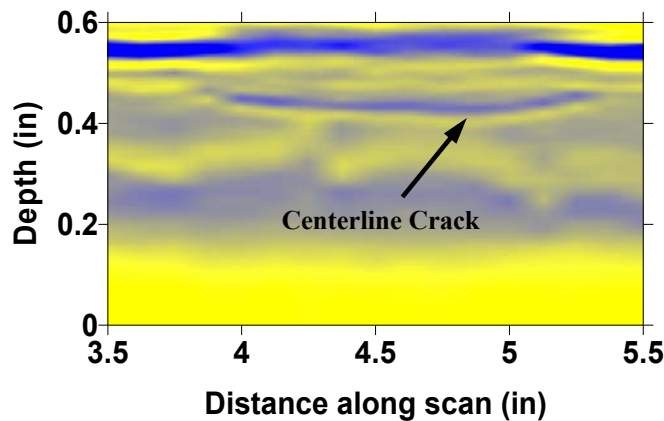


Test set-up for TOFD method. Possible wave paths through test piece are shown with the corresponding waveform.

A previous study at the University of Wisconsin-Madison showed that the TOFD technique was successful in both locating and sizing cracks accurately². In that study

however, a limited number of samples with simple geometries (flat plates with implanted fatigue cracks) were available for testing and a larger set of data is required before the procedure can be recommended for the use in bridge inspections. One objective of the current research is to extend the use of the TOFD method to the inspection of complex geometries such as changes in flange thickness, welded cover plates, and welded T-sections, all typical of what might be encountered in an in-service steel bridge. Another objective is to determine if surface conditions typical to what might be encountered in the field, such as paint or corrosion, affect the accuracy of the method. The final goal in this research project is to develop a set of guidelines for the use of the TOFD method in field inspections.

The results that have been obtained to date indicate that the TOFD method could be a very useful tool in the inspection of steel bridges. A series of flat plates with saw-cuts and implanted fatigue cracks was inspected to test the setup and equipment. The lengths and depths of these cuts were determined to within 3% of the reported values. The shallowest crack that was detected extended approximately 2 mm into a plate from the surface. This has been defined as the limit of method since specimens with smaller cracks were inspected but the cracks were not detected. These results indicated that the setup and equipment are capable of producing acceptable results. The next step was to



Top: Colorscale D-scan of plate with implanted fatigue crack. *Bottom:* Same crack identified with MT.

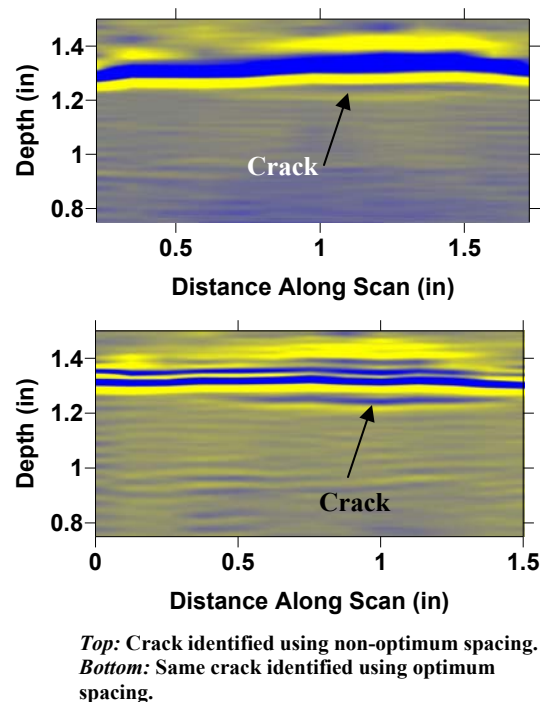
inspect several plates with light corrosion on the surface and implanted fatigue cracks in blind tests. All the cracks were detected using the TOFD method and the length was measured to within 5% of the reported value. For comparison, these plates were also inspected using another nondestructive testing method, magnetic particle testing (MT). While MT was capable of detecting the flaws, the depth of the flaws could not be measured with this method. The figure at the left shows the colorscale image produced from a TOFD scan of one of the cracks and a photograph of the MT test of the same crack. The length of the flaw was found to be approximately the same using both methods.

To meet the objective of extending the TOFD method to more complicated geometries and surface conditions, several specimens were taken from girders of a formerly in-service bridge that was being replaced. One of these

was a portion of the girder flange with a change in thickness. This piece was also painted

on one side. While there were no known cracks in this specimen, it was inspected with the TOFD method to determine if the paint or change in thickness affected the method. Neither the paint nor the varying thickness seemed to inhibit the use of the method. In addition to this specimen, a T-section and a rolled section with a welded cover plate are also being inspected. This type of geometry presents a particular challenge because relatively few other studies have attempted to use the TOFD method for inspection of these types of sections. This work is currently being conducted and a major part of the work is to identify the paths that the ultrasonic waves travel in these geometries. Once this has been completed satisfactorily, specific transducer locations will be recommended for inspection of each type of geometry.

In addition to locations of the transducers, spacing between the transducers is important in acquiring accurate test results. A series of tests were done on flat plates with cracks in order to optimize the setup to get the most accurate results for any thickness of steel and for any depth of crack, within the detectable limits. The main conclusion which could be drawn from these tests was that optimum spacing of the two transducers was a function of flaw depth, thickness of material, and the angle at which the ultrasonic signal enters the material. The two figures at the right show scans of the same crack, one with a non-optimum spacing and the other with an optimum spacing between the transducers. The crack is shallow, only about 2 mm deep, so it is difficult to identify. However, it is much easier to see the crack in the scan that was performed with the optimum spacing.



The TOFD method has so far proven to be a useful tool in detecting and sizing cracks in simple geometries. Through this research more complex geometries will be tested to determine the capabilities of this method. By accurately detecting and sizing cracks, engineers can make better decisions about how to deal with the cracking. While this research focuses on the inspection of bridges, this method could be used to inspect many types of steel structures.

¹ Fisher, J.W., *The Evolution of Fatigue Resistant Steel Bridges*, Transportation Research Board, 76th Annual Meeting Lecture Preprint.

² Zippel, W.J., Pincheira, J.A., and Washer, G., "Measurement of Cracks in Steel Elements Using the Ultrasonic Time of Flight Diffraction Method," *ASCE Journal of Performance of Constructed Facilities*, May 2000, pp. 75-82.