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Evaluation of eddy current and magnetic techniques for inspecting rebars in bridge barrier rails

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Abstract

This paper reports on a feasibility study of using eddy current (EC) and magnetic flux leakage (MFL) methods to detect corrosion damage in rebars that anchor concrete barrier rails to the road deck of bridge structures. EC and MFL measurements were carried out on standalone rebars with and without artificial defects of 25% and 50% material loss, using a commercial EC-based rebar locator and a MFL system that was developed using giant magnetoresistance sensors to detect leakage fluxes from the defects. Both techniques can readily detect the defects at a distance of 2.5″ (63.5 mm). The amplitudes of the EC and MFL signals vary monotonically with the amount of material loss, indicating the potential of using the techniques to quantify material loss of standalone rebars.

Keywords

corrosion, eddy currents, inspection, rebar, nondestructive evaluation, QNDE

Disciplines

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EVALUATION OF EDDY CURRENT AND MAGNETIC TECHNIQUES FOR INSPECTING REBARS IN BRIDGE BARRIER RAILS

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ABSTRACT. This paper reports on a feasibility study of using eddy current (EC) and magnetic flux leakage (MFL) methods to detect corrosion damage in rebars that anchor concrete barrier rails to the road deck of bridge structures. EC and MFL measurements were carried out on standalone rebars with and without artificial defects of 25% and 50% material loss, using a commercial EC-based rebar locator and a MFL system that was developed using giant magnetoresistance sensors to detect leakage fluxes from the defects. Both techniques can readily detect the defects at a distance of 2.5” (63.5 mm). The amplitudes of the EC and MFL signals vary monotonically with the amount of material loss, indicating the potential of using the techniques to quantify material loss of standalone rebars.

Keywords: Nondestructive Testing, Electromagnetic Testing, Eddy-Current Testing, Magnetic Devices, Giant Magnetoresistance
PACS: 81.70.Ex, 85.70.-w, 75.47.De

INTRODUCTION

One of the NDE challenges facing the nation’s aging infrastructure is to detect corrosion damage to rebars and U-bolts that anchor the concrete barrier railings to the road deck of bridge structures [1]. Concrete barrier rails provide protection of passing vehicles and are critical to public safety. A cold joint exists between the barrier rail and the bridge deck (Fig. 1), through which moisture or chloride ions can reach the rebar or U-bolt anchors, causing corrosion of the anchors and ultimately hampering the performance of the barrier. Inspection of barrier rails was identified as a high priority by Iowa Department of Transportation (DOT). Of specific interest to DOT is the ability to detect corrosion of anchoring rebars that are at least 2.5" deep in concrete (Fig. 1(b)), and to quantify the extent of material loss in terms of the reduction of rebar diameter, so that the damaged rebars can be repaired or replaced.

Previous studies have shown the potential of electromagnetic NDE techniques for inspecting rebars and other ferromagnetic components in civil structures [1]. Among them is the EC method that has been incorporated into commercial instruments for locating rebars in concrete [2]. EC signals depend on several factors, including the electrical and

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magnetic properties of the conductor under interrogation, the amount of conductive material present in concrete, and the stand-off distance between the conductor and the drive and/or sensing coils. The lift off signal forms the basis of commercial EC instruments for locating rebars. It is conceivable that any rebar damage, such as corrosion damage, will affect EC flow and lead to a change in EC field or coil impedance [3], which can be detected and used to characterize the extent of damage.

Magnetic inspection methods, such as magnetic flux leakage (MFL), offer an alternative method for inspecting ferromagnetic components in civil structures [4, 5]. The use of MFL for inspecting steels in prestressed concrete members was studied by Kusenberger *et al* [6] and Sawade *et al* [7], and was later extended to other on-site inspections [8]. Ghorbanpoor *et al* developed a MFL sensor using permanent magnets to magnetize steel components in concrete, and used the amplitude of detected MFL signals to determine empirically the flaw volume [4]. DaSilva *et al* also reported the use of MFL to estimate the amount of material loss of corroded steel strands in concrete [9]. In a comparison study of MFL and other NDE techniques, MFL was found to provide the closest and most reliable predictions of damage levels caused by corrosion and fractures [1].

This paper describes a laboratory-based feasibility study aimed at evaluating the potential of EC and MFL for detecting corrosion damage in rebars near the cold joint between road deck and barrier rails of bridges. The study was carried out as part of the project in which several NDE methods, including ground penetrating radar (GPR), radiography and electromagnetics, were evaluated for rebar inspection [10]. This work examined EC and MFL measurements that were made on standalone rebars with and without artificial defects of 25% and 50% material loss, using a commercial EC instrument and a proprietary MFL system. The MFL system was developed in this work, and uses giant magnetoresistance (GMR) sensors to detect leakage fluxes from defects in rebars. Both techniques were found to be capable of detecting the defects at the required inspection distance of 2.5” (63.5 mm). Field tests were carried out on a concrete bridge using these techniques, and the results will be published elsewhere.

EXPERIMENTAL DETAILS

Three standalone number 4 rebars with a nominal diameter of 0.5” (12.7 mm) and a length of 24” (609.6 mm) were used in this study. Two of them were machined to create artificial defects representing different amounts of material loss (Fig. 2(a)). The defects

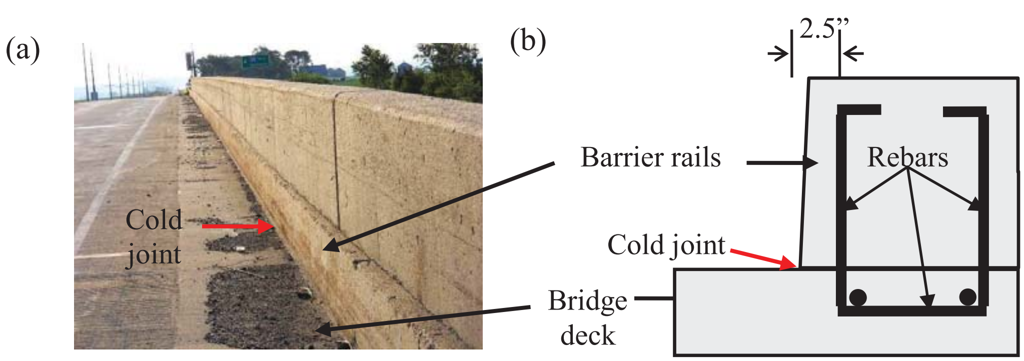

FIGURE 1. (a) A photograph of a highway overpass showing the cold joint between the road deck and the barrier rail. (b) A schematic showing the locations of rebars that anchor the barrier rail to the bridge deck.

are nominally 0.5” (12.7 mm) long, with diameters of 0.37” (9.5 mm) and 0.25” (6.4 mm) that correspond to 25% and 50% material loss, respectively.

A commercial EC-based rebar locator (model: Rebarscope III^{TM}, NDT James Instruments, Inc.) was used in this study. The instrument is typically used for locating rebars inside concrete if the rebar size is known. It was chosen as the instrument offers a large inspection depth up to 4.5” for relocating rebars, and can be used for sizing rebars with a resolution of one rebar size (i.e. 1/8”, or 3.2 mm) without prior knowledge of the rebar depth. The instrument can be operated either in the short mode for detecting rebars up to 2.5” (63.5 mm) in depth, or in the deep mode for measurement depths ranging from 2.5” to 4.5” (63.5 mm to 114.3 mm). Two types of readouts are displayed when it is used for locating rebars, namely (i) the signal level in an arbitrary unit and (ii) the distance between a rebar and the sensor probe. The outer dimensions of the probe are shown in the inset of Fig. 2. The probe was mounted onto a XYZ scanner stage (Fig. 2(a)) that was under computer control for performing line scans over the rebar samples at a perpendicular distance of 2.56” (65.0 mm). .

The experimental setup for the laboratory MFL studies is shown in Fig. 3(a). The sensor probe (Fig. 3(b)) consists of a c-core electromagnet which was driven by a bipolar power amplifier (Model: 20-20, Kepco, Inc.) to apply a low-frequency (20 Hz) sinusoidal magnetizing field to the rebar samples. Two commercial giant magnetoresistance (GMR) sensors (model: AAH002, NVE, Corp), which offer a substantially higher sensitivity than Hall Effect sensors, were mounted onto the pole-pieces to detect the magnetic field in the vertical direction. The MFL sensor probe was mounted onto a three-axis scanner stage for performing raster scans over the rebar samples (Fig. 3(c)).

RESULTS OF EC STUDY

Figure 4 shows the EC signal versus the vertical position of the sensor probe. For defect-free rebar sample R-1, the signal level remains relatively constant (Fig. 4(a)). The signal decreases slightly toward the ends of the scan as the probe approaches the ends of the rebars. For sample R-2 with a defect of 25% material loss, the signal detected near the defect are slightly weaker than those of R-1, and the signal level starts to drop off quickly when the probe center is about 2" (50.8 mm) off the defect.

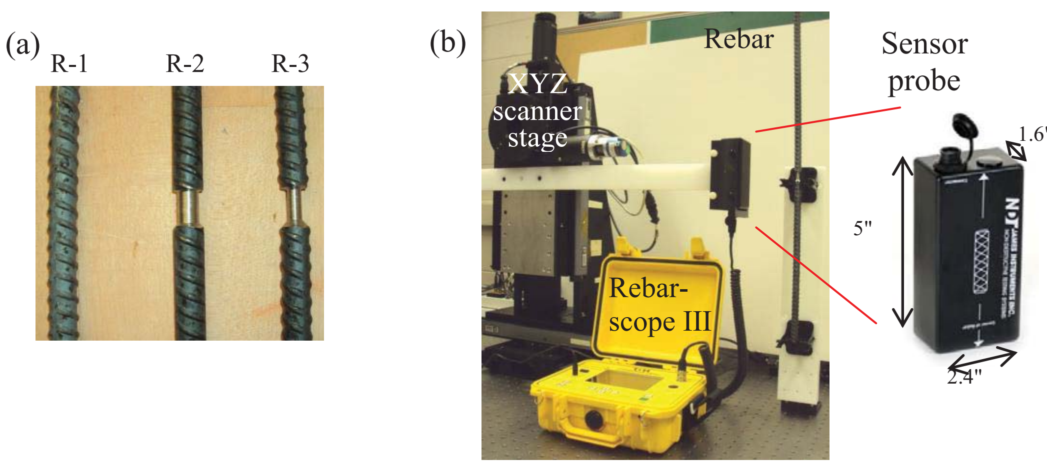

FIGURE 2. (a) Standalone rebar samples. Samples R-2 and R-3 were machined to produce artificial defects of 25% and 50% material loss, respectively. (b)Experimental setup for EC scans on the rebar samples using a commercial EC-based instrument. The outer dimensions of the sensor probe are shown in the inset.

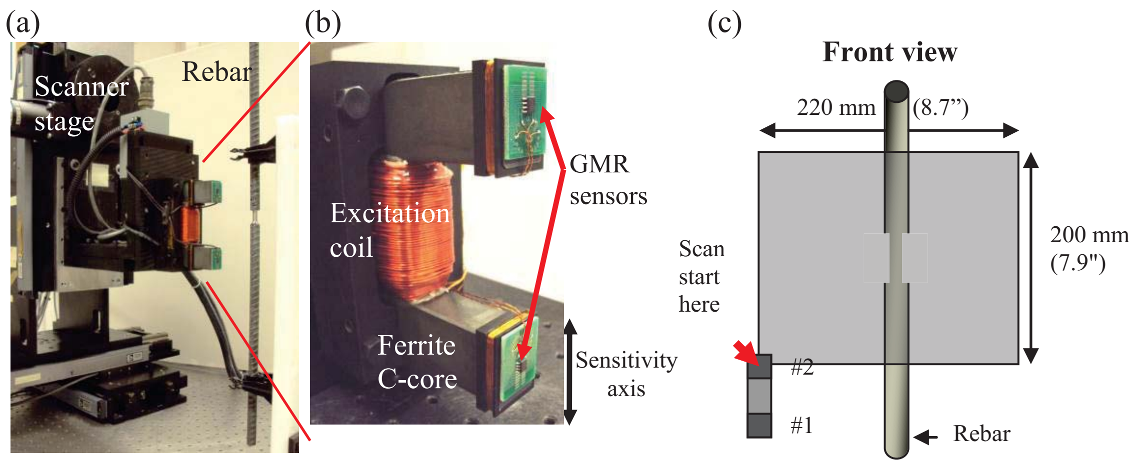

FIGURE 3. Experimental setup for performing MFL scans on the rebar samples. (b) Close-up of the MFL sensor probe. It consists of an electromagnet to apply magnetizing field, and two GMR sensors to detect the vertical component of leakage field at the pole-piece of the electromagnet. (c) A schematic diagram showing the size and coverage of the raster scans over the rebar samples. The perpendicular distance between the probe and rebar is 2.5” (63.5 mm).

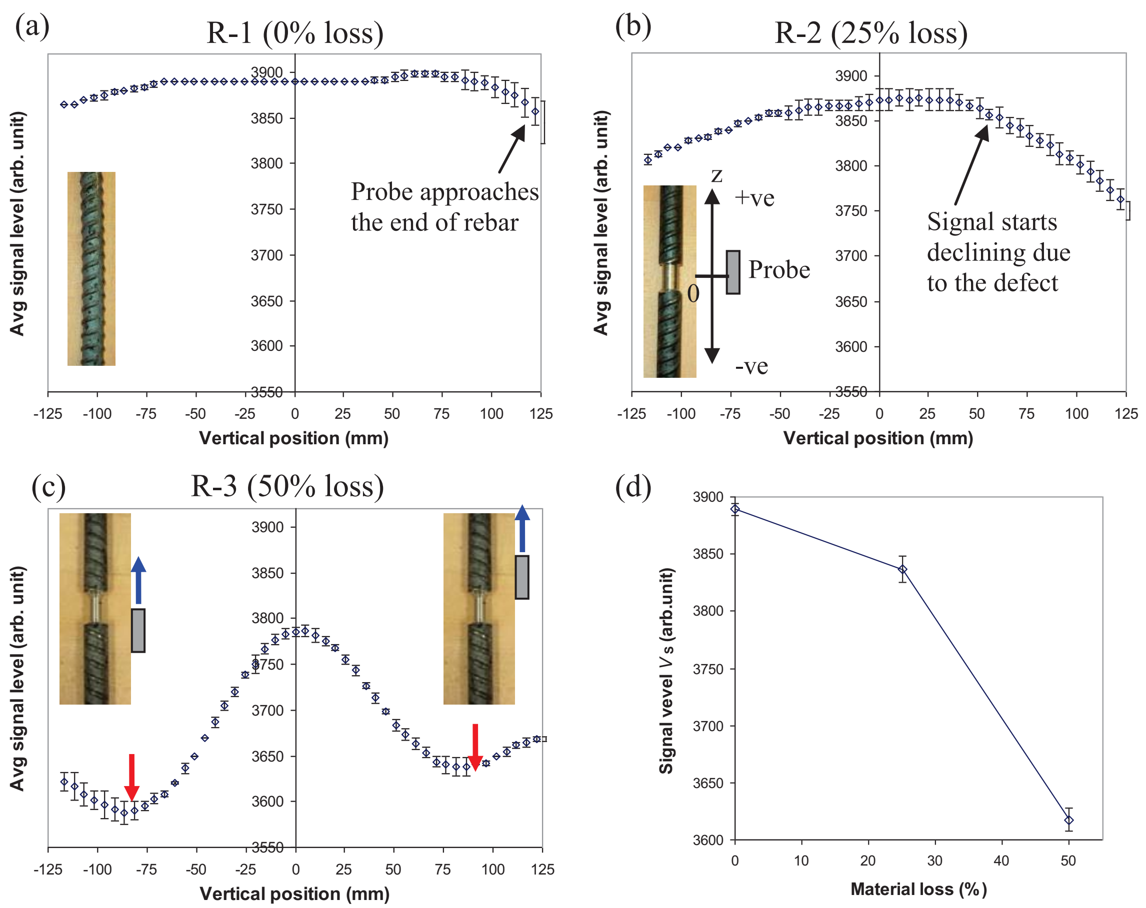

FIGURE 4. Plot of the EC signal level (in arbitrary unit) versus the vertical position of the sensor probe for rebar samples (a) R-1 (intact, see inset); (b) R-2 with 25% material loss; and (c) R-3 with 50% material loss. The insets of (c) show the vertical positions of the sensor probe relative to the defect when the detected signal shows a minimum. (d) Dependence of the averaged EC signal level detected at 3” from the defect on the amount of material loss. The error bars represent one standard deviation of three repeated scans over each rebar sample.

For sample R-3 with 50% material loss, the signals near the defect dropped off even further. Of special note is that the signal exhibits minima when the probe center is about 3" (76 mm) off to either side of the defect. This signal behavior is typical of EC signal patterns where an oversized coil is used to detect a defect which is much smaller in size than the coil diameter. Recall that, when a coil is placed on a conductor, the induced EC in the conductor is the strongest right underneath the coil winding, and the weakest at the coil center. Therefore, when scanning an oversized coil over a relative small defect, the signal change (e.g. changes in coil impedance) is the largest when the defect is directly underneath the coil winding. The situation is similar to the present EC tests on the rebar samples because in this case the coil length, which could be as much as 5” (127 mm), is substantially larger than the defect length of about 0.5”. Therefore, when the probe center is about 3" below the defect, the top edge of the probe and hence the coil windings are close to the defect (illustrated by the inset of Fig. 4(c)), resulting in the largest reduction of signal. Similarly, the bottom edge of the probe is close to the defect when the probe center is 3” above the defect. The present results indicate the feasibility of using the rebar locator to detect material loss in rebars. Once the defect is located, the signal level detected at 3” (76 mm) away from the defect, where the coil winding is in close proximity to the defect, can be used to quantify the amount of material loss (Fig. 4(d)).

RESULTS OF MFL STUDY

The c-scan images measured using the GMR sensor #2, which is mounted on the upper pole-piece of the electromagnet (Fig. 3(b)), are shown in Fig. 5. All the rebar

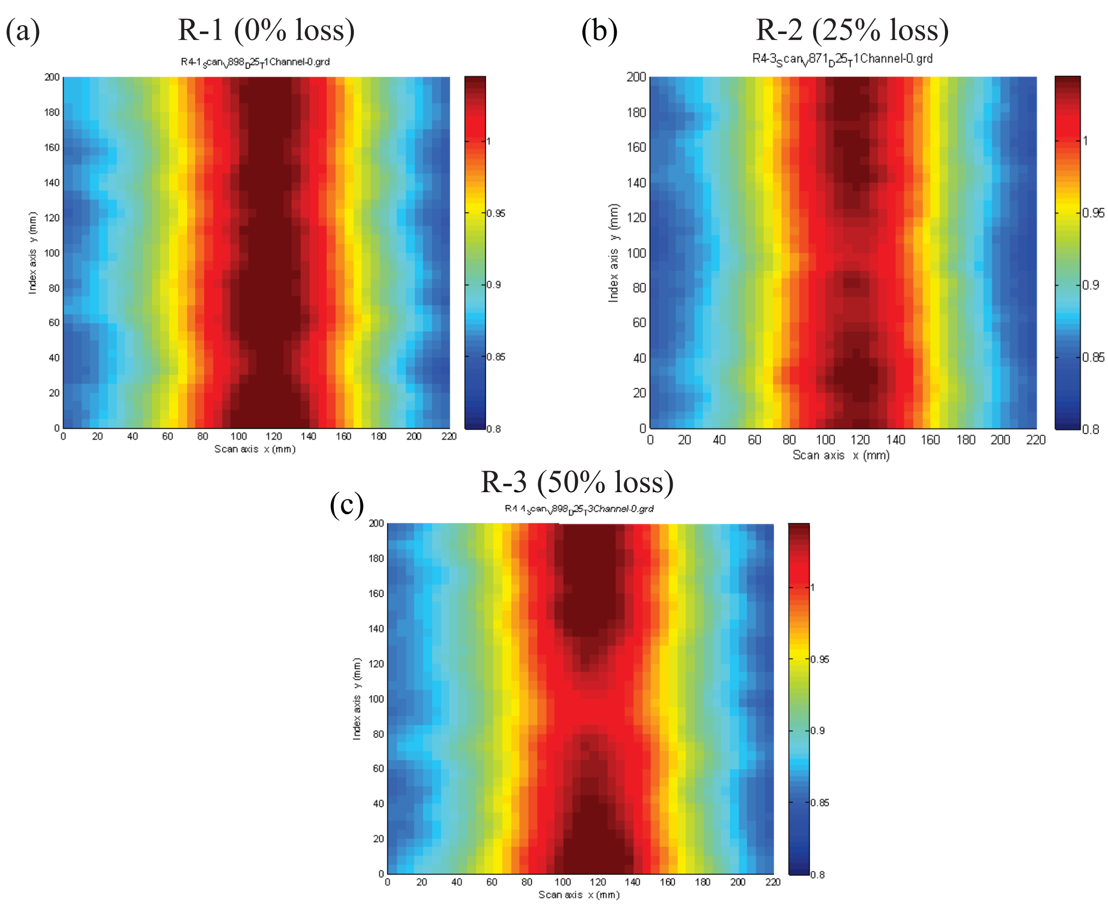

FIGURE 5. C-scan MFL images in the same color scale for rebar samples (a) R-1, (b) R-2 and (c) R-3, respectively.

samples are readily detected in the c-scan images. The image of sample R-1 shows a relatively uniform, continuous pattern of the rebar in the middle of the scan. For sample R-2 with a defect of 25% material loss, the GMR sensor output decreases significantly at the center of the scan when the GMR sensor was scanned in front of the defect. A stronger defect indication was observed for sample R-3 with a defect of 50% material loss. The present results indicate the capability of the MFL method to detect defects in rebars at the required inspection distance of 2.5".

CONCLUSIONS

A laboratory study has been carried out to evaluate the feasibility of detecting corrosion damage in rebars by the eddy current and magnetic flux leakage techniques. A sensor probe was developed using giant magnetoresistance sensors for the MFL study. EC and MFL measurements were carried out on a set of standalone rebars with and without artificial defects. Both EC and MFL can readily detect 25% and 50% material loss in the standalone rebars at the required distance of 2.5" (63.5 mm). The EC and MFL signals were both found to vary monotonically with the amount of material loss, indicating the potential of using the techniques to quantify material loss of standalone rebars.

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