TECHBRIEF

Magnetic-Based NDE of Prestressed and Post-Tensioned Concrete Members—The MFL System

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This technical summary presents the key findings of a Federal Highway Administration (FHWA) study that is fully documented in a separate report of the same title (FHWA-RD-00-026). See the report ordering information provided on the last page of this summary.

Purpose

In October 1995, FHWA initiated a study on "Magnetic-Based System for NDE of Prestressing Steel in Pre-Tensioned and Post-Tensioned Concrete Bridges." The objectives of the study were to design, fabricate, and demonstrate a nondestructive evaluation (NDE) system based on an application of the principle of magnetic flux leakage (MFL) to detect corrosion and fracture of prestressing steel in prestressed and post-tensioned concrete bridge members. The system was to be developed based on a modular concept allowing application to bridge members with differing geometrical configurations. Efficiency of field operation was sought for both the system's overall operation and its installation on and removal from various bridge components.

The primary aim of the study was to use and extend the available knowledge and capability obtained through past studies and developments in the related area. The initial focus of the study was a review of the available literature to evaluate the capabilities and shortcomings of past magnetic-based methodology and equipment. Primary emphasis was to be placed on the reliability and field-worthiness of the system to be developed.

Approach

A review was made of past studies and developments in magnetic-based NDE, and relevant capabilities and shortcomings of the method were identified. The MFL concept showed excellent potential for use as an NDE tool for detection of corrosion and fracture of steel in prestressed and post-tensioned concrete members. This determination was based on the results of extensive laboratory and field testing of prestressed

The structures research and technology program aims to foster increased durability of new bridges and observable increases in the service life of existing structures, placing an emphasis on increasing highway safety while preserving the environment. The program focuses on researching nondestructive evaluation technologies to identify structural deficiencies and support bridge management systems. It also uses high-performance materials to repair and rehabilitate the existing inventory of deficient bridges. This find-it-and-fix-it program is supplemented by research that examines all aspects of bridges and foundations, including planning, design, construction, management, maintenance, inspection, and demolition.

Specific expertise areas include bridge coatings, bridge infrastructure, bridge management, nondestructive evaluation, corrosion protection, foundations, scour, geotrechnical research, high-performance materials, aerodynamics, seismic research, and structures instrumentation.

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concrete members. Test specimens with mechanically induced flaws, such as cutout cross-sectional areas, and with real corrosion from accelerated corrosion tests were also used in the study. It was shown that the MFL technique could detect flaws in prestressing steel equivalent to a 5–10 percent loss of cross-section.

The primary shortcomings of the previously developed equipment included the following:

- Excessive equipment weight
- Difficulties in system installation and removal
- Operational difficulties due to a low speed of testing and inefficient data acquisition and interpretation
- Outdated electronics and computing devices.

This study took the approach of removing the shortcomings listed above. The new system design and fabrication were based on the use of a modular concept that allows structural members with varying geometrical configurations to be tested. To improve and enhance the system's installation and removal, efforts were made to keep the weight of the new system to a minimum. Relatively lightweight permanent magnets were selected to provide the required magnetic field. By introducing a DC magnetic field in proximity to the prestressing or post-tensioning steel, the magnets allow monitoring of the variations of the field due to loss of cross-sectional area of steel from corrosion or fracture. A set of ten Hall-effect sensors measure variations in the magnetic field due to the presence of flaws in prestressing or post-tensioning steel.

The system was designed and fabricated to offer ease of use during field operation. A lightweight aluminum structural frame was fabricated to carry the magnets, electronic components, and control devices. The system's installation on and removal from a concrete girder require the efforts of two persons and take only a few minutes; no special equipment is required. After its installation is complete, the system is capable of traveling the length of a concrete member under its own power. The frame remains positioned on the girder through the frictional forces developed by a series of spring-loaded contact wheels compressed against the sides of the girder.

A test is conducted by attaching the structural frame to a test beam and controlling it from a remote notebook computer via wireless communication. By allowing control of the equipment and acquisition of test data, wireless communication makes it possible to scan the length of the girder and record and display test data. The test data reflect the variations in a magnetic field induced in the concrete by the presence of discontinuities such as corrosion or fractures of the embedded prestressing steel. The computer next analyzes the recorded data to assess the condition of the steel. Software was also developed to acquire and analyze the MFL data as well as to control all hardware, including mechanical and electrical components of the system.

Most of the effort in the current study was devoted to development and fabrication of the new system. Performance evaluation of the new system was accomplished at various stages of the equipment development. Some limited laboratory tests were conducted to evaluate the capability of the new system to detect man-made flaws and real corrosion in prestressing steel. The laboratory study test specimens included steel prestressing strands with different localized cross-sectional area losses from 7 to 100 percent. Prestressing strands with real corrosion were also used for the same purpose. Specimens were placed at distances ranging from 51 mm (2 in) to 128 mm (5 in) from the magnet/sensor unit. Tests were performed on specimens with and without the presence of other unflawed prestressing steel strands. The intent was to evaluate the magnetic masking effect of other steel members, as in the condition of congested steel in concrete, on the MFL data obtained for the flawed test specimens. It was found that the MFL system is capable of detecting a 7 percent or larger reduction in the cross-sectional area of the strands. This capability was demonstrated for strands placed at a distance of up to 128 mm (5 in) from the system's magnet and sensor assembly. In addition, in two demonstration field tests, field installation, removal, and overall operation of the new system were performed after the system was completely fabricated. Based on the findings and experience from the laboratory and field tests, system optimization was performed during the study. Although the potential of successful application of MFL for detecting corrosion and fracture in reinforcing or prestressing steel within concrete bridge members has been demonstrated through this and past studies, additional laboratory and field evaluations of the new system are recommended to follow this study. The new efforts should include additional system development and optimization, and extensive laboratory and field investigations to develop a database of various possible flaws.

Conclusions

MFL signals from flaws in test specimens of prestressing steel could be identified easily from the graph displaying the signal amplitude as a function of the test member's length. This was accomplished when the flaw size was larger than approximately 10 percent of the cross-sectional area of a specimen. For flaws smaller than 10 percent of the cross-sectional area, the correlation method, a signal analysis method based on the correlation concept, was shown to be effective. In the correlation method of analysis, a predefined signal is compared with the recorded test data for the entire length of the specimen. Depending on the degree of similarity between the two signals, a correlation factor, with values between –100 percent and 100 percent, is calculated and displayed for the location of interest along the length of the test specimen. The correlation method of analysis may be performed for data recorded directly from one Hall sensor or for the result of subtraction of data from two Hall sensors. This has proved effective in minimizing the magnetic masking effects of stirrups or other ferromagnetic artifacts. A range of predefined MFL signals representing various flaws and conditions were constructed based on the results of laboratory efforts during this and past studies. A selected flaw signal could be used in the correlation analysis by defining two parameters: the length of the flaw, as measured in total number of points, and the peak-to-peak separation distance for the flaw. These parameters are identified as N and B, respectively, and are used as input data for the analysis. Different values for N and B were identified for various flaws and conditions and presented during the laboratory work of this study. In addition to the methods described earlier, a new data interpretation capability was developed that allows simpler and more reliable identification of flaws at the presence of stirrups and other ferromagnetic artifacts. The method is based on constructing and evaluating a three-dimensional image of the magnetic field variation for the entire length of the member subjected to test. Software was developed and used in this study to permit this additional analytical capability.

During the laboratory investigation, optimum operational parameters were established for the use of the MFL system. These included parameters affecting system installation, removal, scanning of the length of a member under test, data acquisition, and data analysis and interpretation. A linear relationship was found between the volume of the flaws considered and the amplitude of the corresponding MFL signals. The amplitude of the MFL signals from the flaws was also shown to be related to the inverse of the power of 2.8 of the distance between the flaw and the magnet/sensor positions. During the field investigation, the beam-rider unit was evaluated for its overall ease of use, including the installation, removal, and testing of prestressed concrete girders. From the field investigation, it was determined that the system could operate safely, reliably, and efficiently. Only a few minutes and the efforts of two persons were required to install or remove the system from the bridge's prestressed concrete I-girders.

It is recommended that, beyond this study, additional laboratory and field investigations be conducted using the new MFL system, in order to fully evaluate its capabilities and limitations. This would also facilitate the establishment of a more comprehensive database to enhance the system's data interpretation capability and overall reliability.

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