Final Report

Condition Assessment of External P-T Tendons in the Mid Bay Bridge

by

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Introduction:

Under a contract from Granite Construction Company, a non-destructive evaluation (NDE) of post-tensioning (P-T) tendons of the Mid Bay bridge, in Destin, Florida, was made over the period of October 27 to November 2, 2000. This work was conducted in cooperation with the Florida Department of Transportation personnel. The NDE method used in this work was based on the concept of magnetic flux leakage (MFL). The equipment used to evaluate the Mid Bay bridge is a system developed by the author at the University of Wisconsin-Milwaukee and is called the Magnetic tendon-testing Device (MTTD). The Mid Bay bridge spans the Choctawhatchee Bay on State Route 293 in Destin, Florida. The bridge consists of 141 spans and is constructed of concrete segmental boxes. Each typical span is approximately 110 feet long, except one span, span 83, which is approximately twice as long as the other spans. The segmental boxes are externally post-tensioned with three tendons along each web. Two deviation blocks anchor the P-T tendons to the bottom flanges of the segmental boxes in each typical span. Additional tendons and deviation blocks are present in span 83.

A MFL test of a P-T tendon consists of measuring changes in an induced magnetic field in the close vicinity of the P-T tendon due to the presence of corrosion or fracture in the tendon. Prior to the field testing operation at the Mid Bay bridge, a laboratory study was performed, as a part of a separate study, to verify the accuracy, resolution, and reliability of the MTTD and to develop calibration data relevant to evaluating external P-T tendons. The calibration data was acquired to achieve a more reliable and accurate data interpretation capability during the field test.

Equipment Description:

The equipment used for field-testing of P-T tendons in the Mid Bay bridge consists of a mechanical frame that supports a pair of strong permanent magnets and a series of Hall-Effect sensors. The equipment is called the Magnetic tendon-testing Device (MTTD). During a test, the device is moved along the length of the tendons by an operator. A steady motion of the MTTD along the length of a P-T tendon is made possible through the use of a set of contact wheels that are installed on the frame of the equipment. These wheels maintain a constant distance of 0.25 inch between the face of the magnets/sensors assembly of the device and the surface of the polyethylene duct of the P-T tendon.

Maintaining this constant distance is important since the amplitude of MFL data is proportioned to the distance between the magnets/sensors assembly and the steel tendon. Data from four sensors is recorded and analyzed for the purpose of testing external P-T tendons. The signal outputs from these four sensors are displayed in the form of graphs of amplitude vs. longitudinal travel path of the magnets/sensors assembly along the length of the tendon. These data outputs are termed as channels 3, 4, 5, and 9. Sensor, or channel No. 4 is located along the centerline of the tendon, and sensors No. 3 and 5 are located 1.0 inch on either side of sensor No. 4. Sensor No. 9 is placed one inch above the center sensor No. 4. A contact-wheeled encoder device is installed on the frame of the MTTD to indicate the distance traveled as the equipment is moved along the length of a P-T tendon under test. In conjunction with the MTTD, specific data acquisition and analysis software are developed and used to facilitate data recording, displaying, and interpretation.

It has been shown that the amplitude of the MFL data from a flaw is proportioned to the amount of section loss in a steel component that is subjected to a MFL test. MFL data from tests conducted along the length of P-T tendons occasionally show a gradual decrease or increase, or shift, in the signal amplitude. This gradual shift in the data amplitude is normally caused by a gradual change in the position of the steel strands inside the polyethylene duct of the P-T tendon along its length.

Figure 1 shows a photograph of the magnetic tendon-testing device (MTTD) that is designed and developed to allow testing of external P-T tendons. As shown in the figure, the MTTD is installed on a laboratory sample that consists of a grouted P-T tendon.

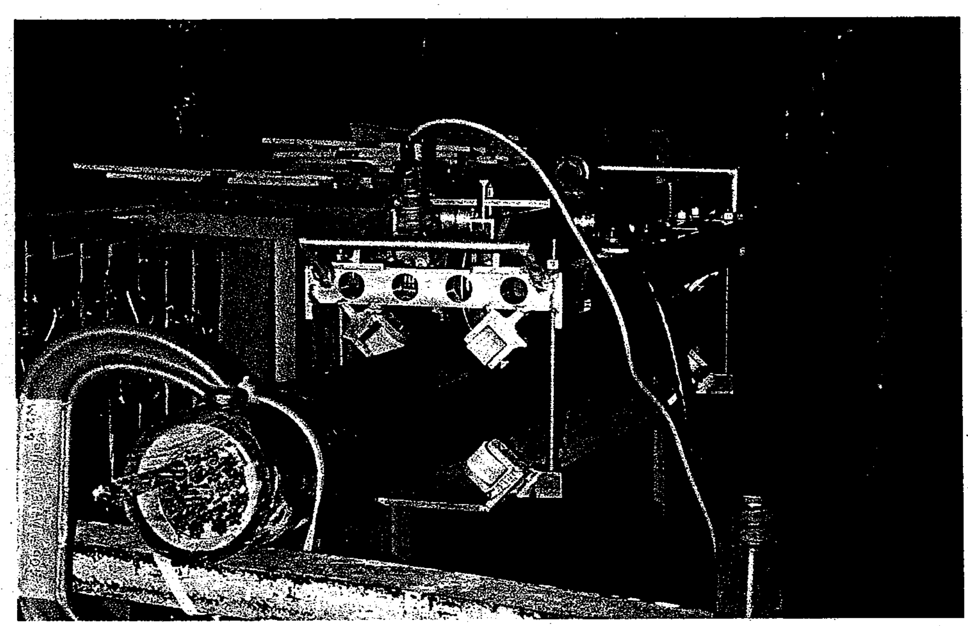

Figure 1. Photograph of the Magnetic Tendon-Testing Device (MTTD) installed on a laboratory sample consisting of a grouted P-T tendon

Laboratory Study:

A 12-foot long grouted post-tensioning tendon with 22 seven-wire strands was constructed in the laboratory to be used for the purpose of evaluating the capability of the magnetic tendon testing device (MTTD) for its accuracy, resolution, and reliability in testing external P-T tendons. Two strands in the tendon (one at the center and one at the edge of the strand bundle) were replaced with $^{5}/_{8}$-inch diameter copper tubes to allow insertion of undisturbed strands or those with various amounts of section losses. Due to the non-ferrous properties of copper, no magnetic influence is expected from the presence of the tubes in the tendon. The use of this laboratory specimen allowed for a verification of the system performance in detecting flaws with varying amounts of section losses in strands that were inserted inside of the copper tubes of the laboratory P-T tendon. Figure 2 shows a graphic display of MFL data from the four channels of the system for the laboratory sample when only a single fractured strand (seven wires cut with a gap of 0.25 inch) was inserted in the copper tube within the tendon. The fracture in the strand was located at 4.25 feet from the start of the test, and the tube was positioned at the edge of the strand bundle in the tendon. A distinct change in the MFL signal amplitude can be seen in the graph for each sensor or channel at the location of the fracture. The signal amplitude level is smaller in the graph for channel 9 since the physical position of the corresponding sensor inside the sensor assembly unit is one inch farther from the flaw compared with the positions of the other sensors. A complete fracture of a single strand out of the 22 strands that form the tendon is equivalent to a 4.5 percent loss of cross section of steel within the tendon. An examination of Figure 2 can indicate that the presence of fracture in a single strand within the tendon can be easily detected.

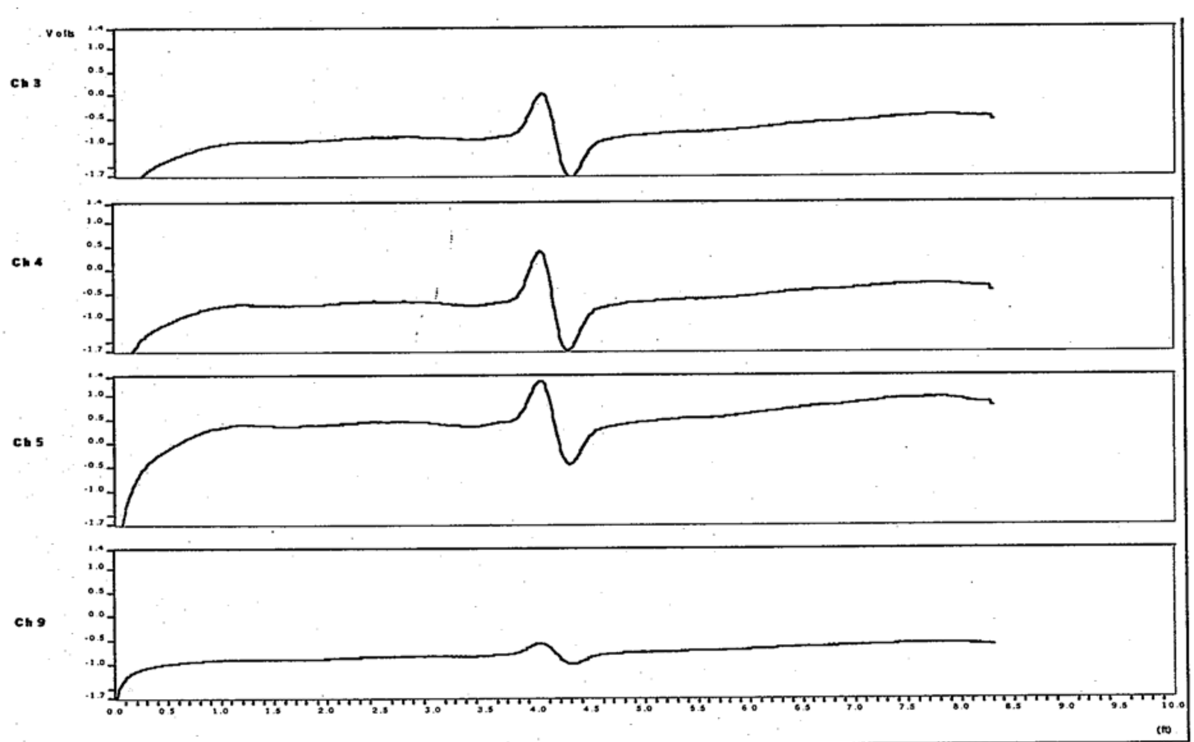

Figure 2 - MFL signals indicating fracture of a strand at 4.25 feet from the start of the test (seven wires cut in a single strand located at the edge of the strand bundle)

The amplitude of MFL signals normally decreases with increasing distance between the magnets/sensors assembly of the MTTD and the flawed steel. The signal amplitude also decreases by the masking effect of the steel surrounding the flawed strand. This effect may be observed as shown in Figure 3 where a fractured strand is located at the center of the strand bundle of the laboratory sample. An indication is shown for the fractured strand at 4.25 feet from the start of the test in the graph of data for each sensor. The decrease in the data amplitude is apparent in the figure when it is compared with Figure 2 where it shows the MFL data plots for the same flaw except when the flaw was located at the edge of the strand bundle.

The amplitude of MFL signals is further decreased with a decreasing amount of loss of section. Figure 4 shows graphs of MFL data when only three wires of a seven-wire strand are cut and the flawed strand is positioned at the center of the strand bundle of the laboratory sample. A comparison of the results with those shown in Figure 3 can indicate additional amplitude reduction due to smaller loss of section.

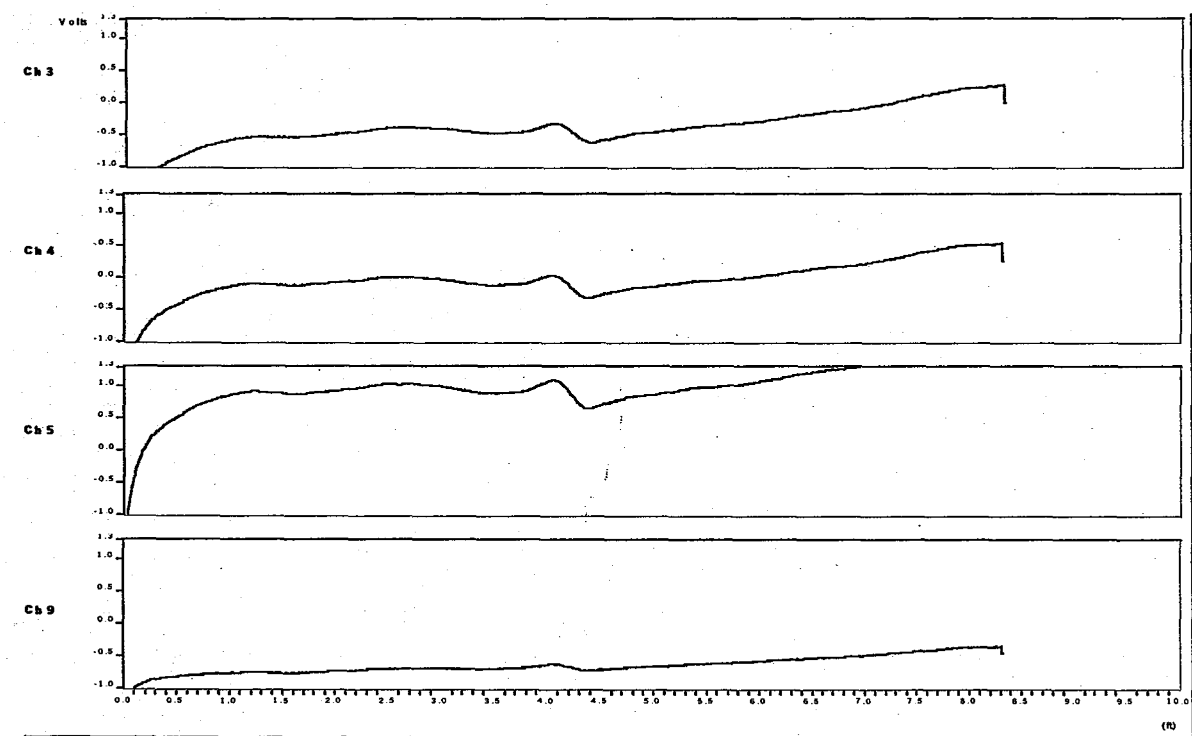

Figure 3 - MFL signals indicating fracture of a strand at 4.25 feet from the start of the test (seven wires cut in a single strand located at the center of the strand bundle)

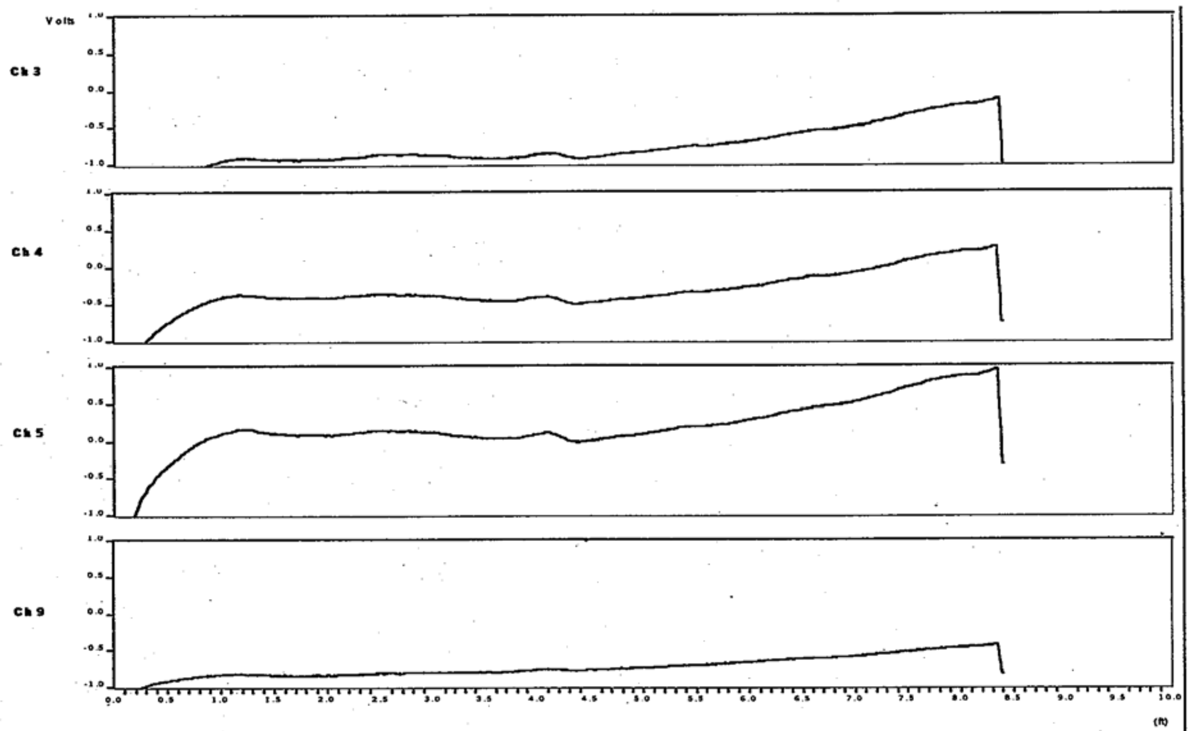

Figure 4 - MFL signals indicating fracture of a strand at 4.25 feet from the start of the test (three wires cut in a single strand located at the center of the strand bundle)

Based on the laboratory investigation, as well as field-testing performed under other projects, the MTTD system showed excellent detection capability for small flaws within external P-T tendons. During the laboratory experiment, it was found that flaws as small as 0.5 percent loss of cross sectional area of the tendon could be detected by the MTTD system. Figure 5 shows this capability of detection for a strand that has only a single wire broken when the strand was positioned at the edge of the strand bundle of the laboratory sample. An indication of loss of cross section can be observed in the figure at the location of 4.5 feet from the start of the test.

By an examination of the graphs shown in Figure 5 one can easily determine the presence of a flaw through observing the visual indications. However, it is also possible to use additional data analysis methods to achieve a more reliable determination for the presence of flaws. These data analysis methods would allow even smaller flaws (flaws smaller than the previously stated 0.5 percent loss of section) to be detected by the MTTD system. One such method is known as the correlation analysis. In the correlation analysis, a reliability index or value (called the correlation factor) is normally computed. The correlation factor is computed based on the extent of matching that exists between a MFL signal from a real flaw, and a mathematical signal that is constructed from the results of laboratory studies and calibrations. For example, a 100 percent (or perfect) match will result in a correlation factor of 1.00. Figure 6 shows the results of the correlation analysis for MFL data from sensor No. 4 from Figure 5. A correlation value of 0.975 is computed and shown in the lower part of the graph. Figure 6 also shows the graph of data from sensor No. 4.

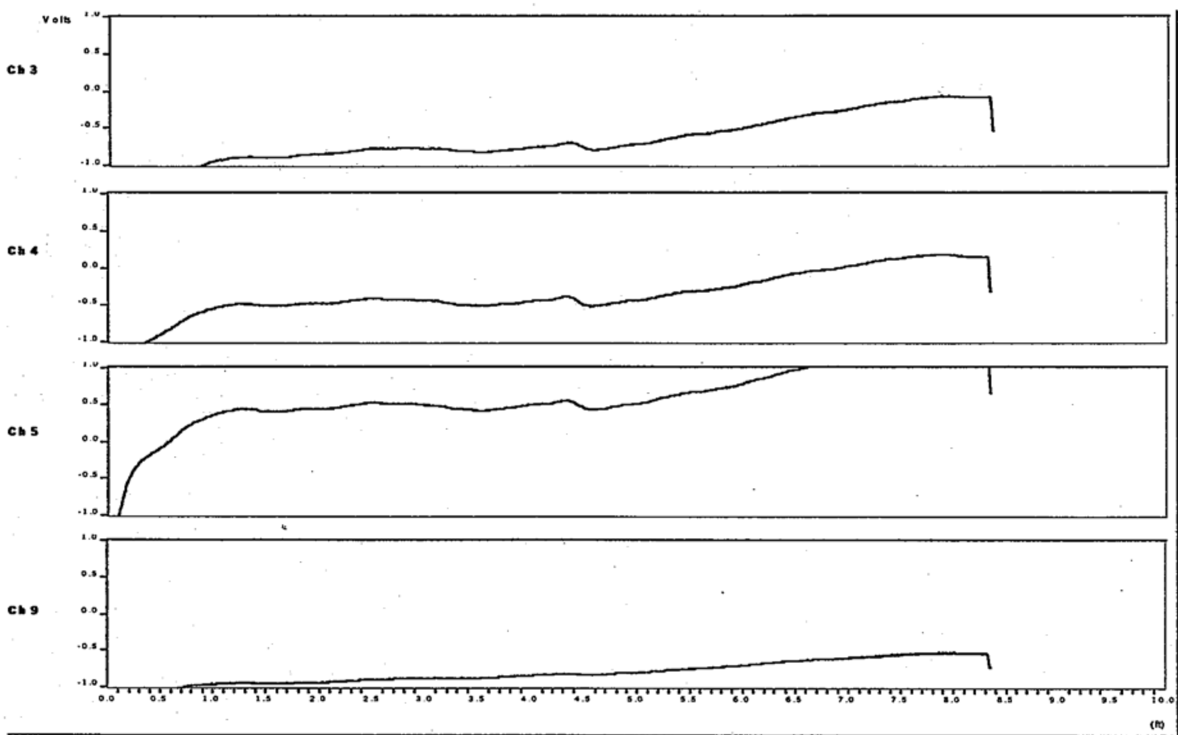

Figure 5 - MFL signals indicating fracture of a strand at 4.5 feet from the start of the test (one wire cut in a single strand located at the edge of the strand bundle)

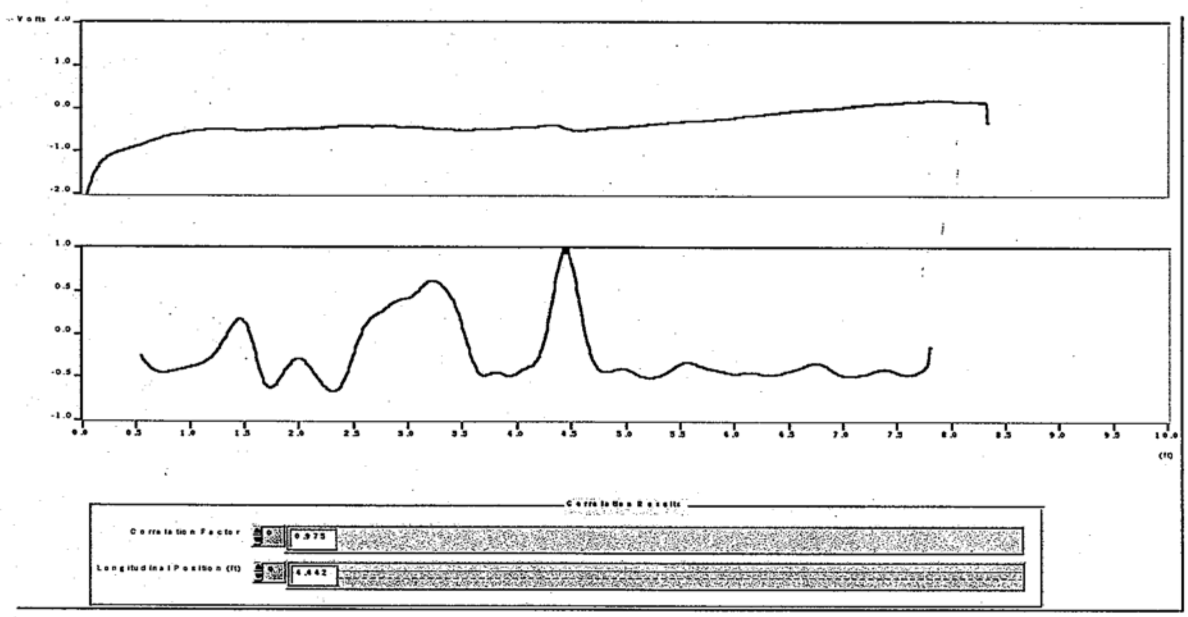

Figure 6 - MFL signals correlation results indicating fracture of a strand at 4.5 feet from the start of the test
(one wire cut in a single strand located at the edge of the strand bundle)

Field Tests:
The primary objective of the field-testing under this work was to determine if there was fracture or corrosion of prestressing steel in the tendons of the Mid Bay bridge. The results of the laboratory investigation, and previous relevant experience of the author, indicated that the application of the magnetic tendon-testing device (MTTD) is an appropriate non-destructive approach for detecting fracture or corrosion of P-T tendons.

The MTTD system was transported to the site of the Mid Bay bridge to perform field evaluations of its P-T tendons. The Mid Bay bridge is a concrete segmental box structure that is post-tensioned with external tendons. As a design requirement three P-T tendons are placed along each web of the box segments in all spans except span 83. Span 83 is approximately twice as long and contains additional tendons beyond those present in other spans. Each tendon consists of either 19 or 27 half-inch diameter seven-wire strands placed inside of a 4-inch diameter polyethylene duct. During the initial construction, strands in each tendon were stressed and a grouting operation was conducted with the objective of completely filling the voids inside of the polyethylene ducts: The grouting of the tendons were done with a cement grout and with the intention of providing protection for the tendons against corrosion.

The field test for each P-T tendon consisted of placing the magnets/sensors assembly of the MTTD on the tendon and moving it on its wheels along the length of the tendon. Figure 7 shows a photograph of the MTTD system during testing of an external P-T tendon inside of a concrete segmental box of the Mid Bay bridge.

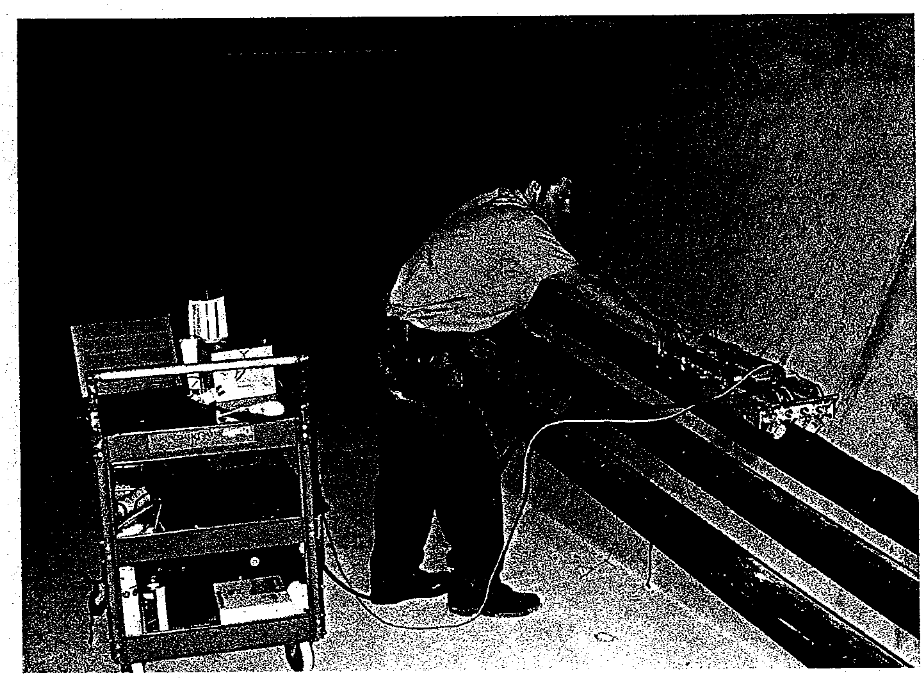

Figure 7 – Photograph of the MTTD system during a test of an external P-T tendon in the Mid Bay Bridge

MFL data from testing each tendon was transmitted to a computer and recorded. The data was also plotted and displayed on the computer screen in real time during each test. Figure 8 shows a photograph of a typical computer screen display for real time plots of MFL data.

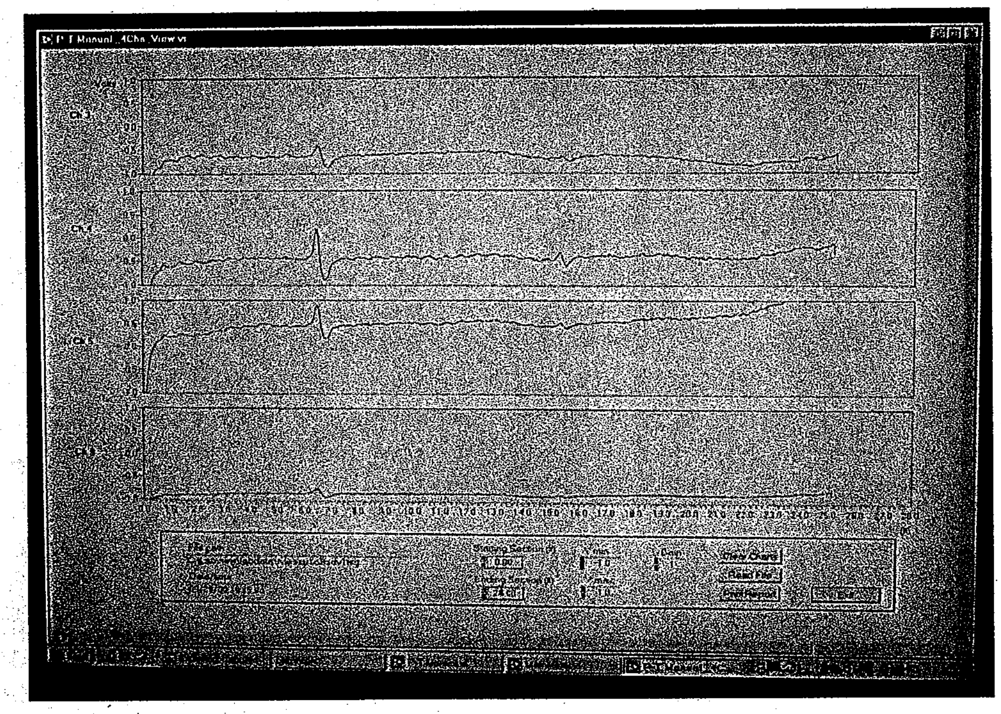

Figure 8 – Photograph of typical computer screen display for real time plots of MFL data

The real time data plots were monitored carefully, during each test, to identify signal features that were indicative of loss of cross sectional area of steel in the tendon under test. Tests on some tendons were repeated under same conditions to verify the reproducibility of the test results. In all such cases, the repeated tests produced the same results as those from previously conducted tests.

P-T tendons in all spans were subjected to the MFL test during the field-testing phase of this work. The total number of tendons that were tested during this field evaluation was approximately 870. A few tendons were being replaced at the time of this MFL field-testing and could not be subjected to tests by the MTTD system.

A majority of the tendons that were subjected to the MFL field-testing showed no indications of corrosion or fracture. Figures 9 and 10 show plots of typical MFL data in the Mid Bay bridge where no corrosion or fracture indications, in terms of signal amplitude changes, are observed in the plots. Where the distance between the strand bundle within the duct and the surface of the duct does not remain constant along its length, a change in the amplitude of the MFL data will result. This MFL amplitude variation can be seen in Figure 10 for the first 26 feet of the length of the graphs.

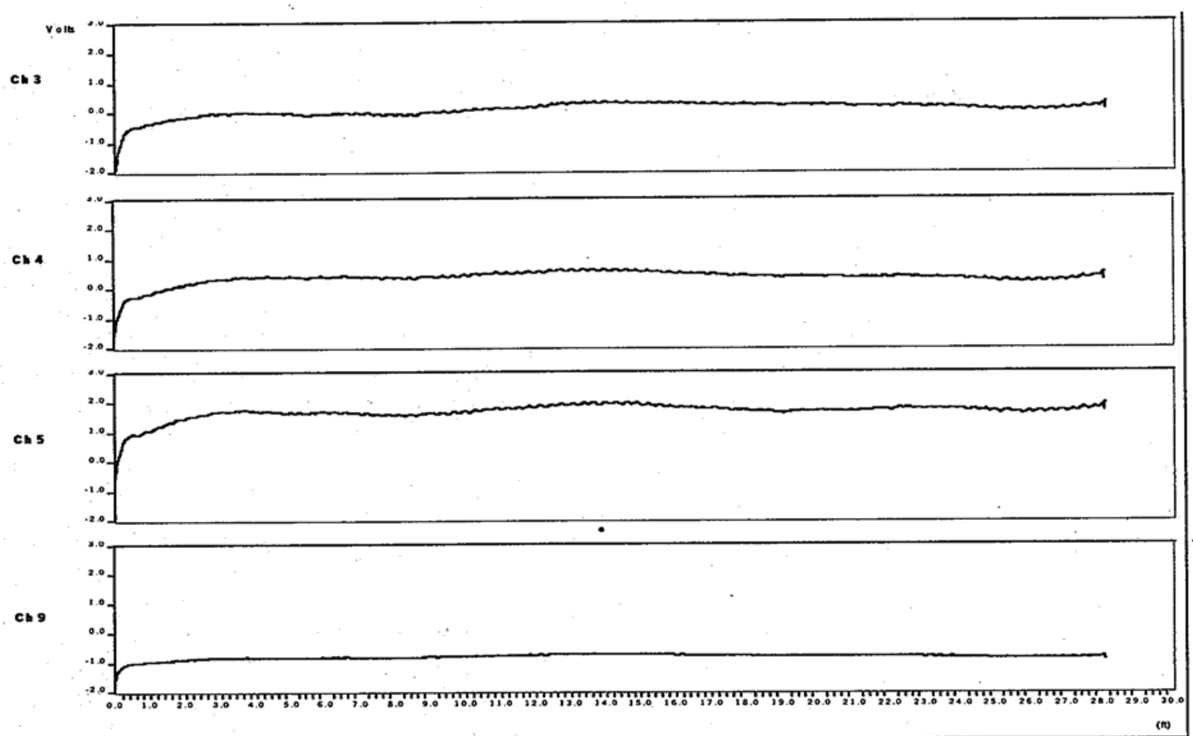

Figure 9 – MFL signals indicating no loss of cross sectional area (span 25, tendon 25-3b)

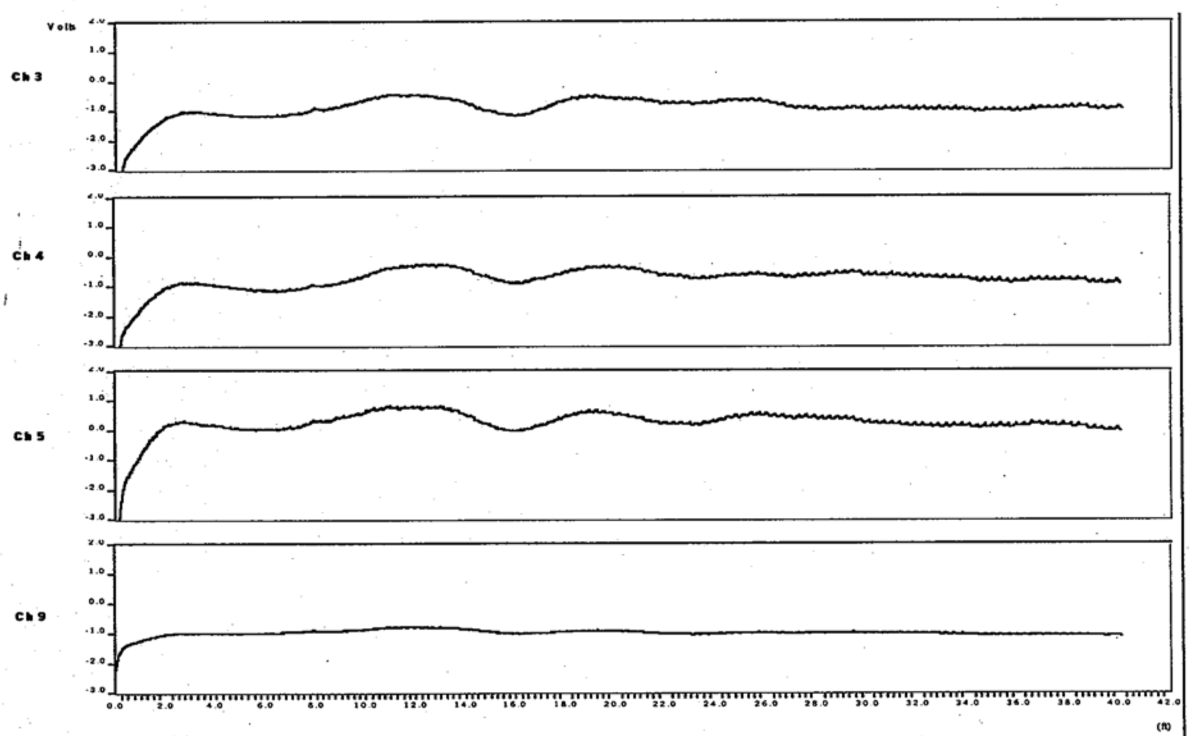

Figure 10 – MFL signals indicating no loss of cross sectional area (span 132, tendon 132-2c)

During the MFL testing of the tendons of the Mid Bay bridge, indications of corrosion of pre stressing steel were observed at two locations along the length of two tendons. The corrosion indications were recorded for tendons located in spans 71 and 98. The tendon with corrosion in span 71 is designated by FL DOT as tendon 71-1a and that in span 98 is identified as tendon 98-5c. The MFL data indicated that both tendon corrosion cases, particularly in span 71, were concentrated in a relatively localized length of each tendon. In span 71, a corrosion indication was recorded during the MFL testing of tendon 71 -1a. The location of the corrosion indication was at a distance of 30 feet from the start of the test. The starting point of this test was at the edge of the rubber boot at the first deviation block. The magnets/sensors assembly of the MTTD was moved along the tendon in the direction of the tendon's end-anchorage area. With the addition of a fixed distance of 1 foot and six inches, or the distance between the end wheels and the center of the magnets/sensors enclosures, to the measurement from the MFL data, the detected corrosion spot was identified to be located at an actual distance of 31 feet and six inches from the edge of the rubber boot at the first deviation block. The MFL corrosion indication can be easily seen in the data plots from channels 3 and 4 in Figure 11. Flaw indications from the graphs of channels 5 and 9 are not prominent in the figure due to the graphs' scale factor and farther distance of the flaw to these sensors. Considering the output and corresponding position for each sensor (or channel), as well as the short signal duration, one can conclude that the flaw consists of limited surface corrosion in a local area. Upon a physical examination of the P-T duct at the suspected spot, it was found that a small hole was present in the polyethylene duct. The indication of a small corrosion and its location for this tendon were reported to the FL DOT personnel as the MFL testing was underway for the tendon. The indicated location was marked with yellow paint for subsequent verification. The FL DOT personnel opted to cut a small window, or opening, in the polyethylene duct at the indicated location to verify the MFL corrosion indication. After an opening was made in the tendon, it was observed that localized corrosion was present in the tendon. The corrosion was limited to :four wires of a seven-wire strand in the prestressing bundle. Figure 12 shows the opening in the tendon at this location and a general view of the corroded tendon. The corroded area of the tendon was cleaned with a wire brush to observe the extent of the corrosion. Figures 13 and 14 show close up views of the corroded tendon. It is apparent that the cause of the corrosion at this location is due to the penetration of moisture and oxygen inside the tendon from the presence of the hole found on the polyethylene duct. The hole could have been made either to check the status of grout inside the duct during or after the grouting operation, or for other unknown reasons.

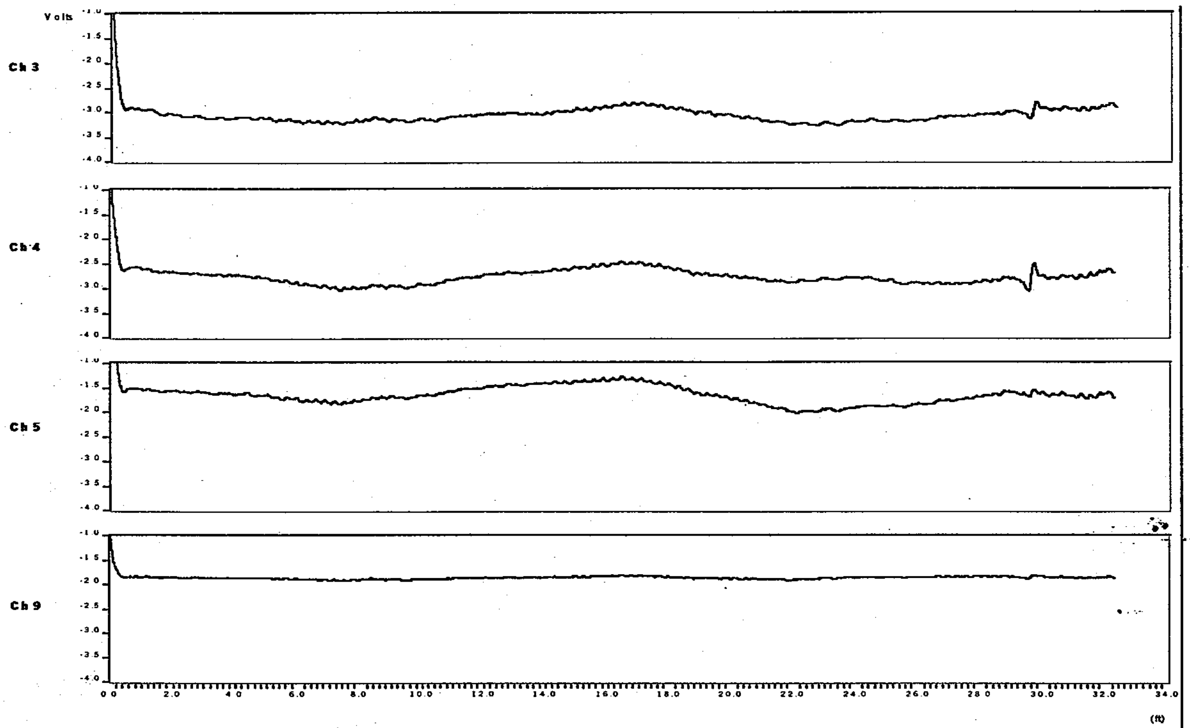

Figure 11 – MFL signals indicating localized corrosion at 30 feet from the start of the test (span 71, tendon 71-1a)

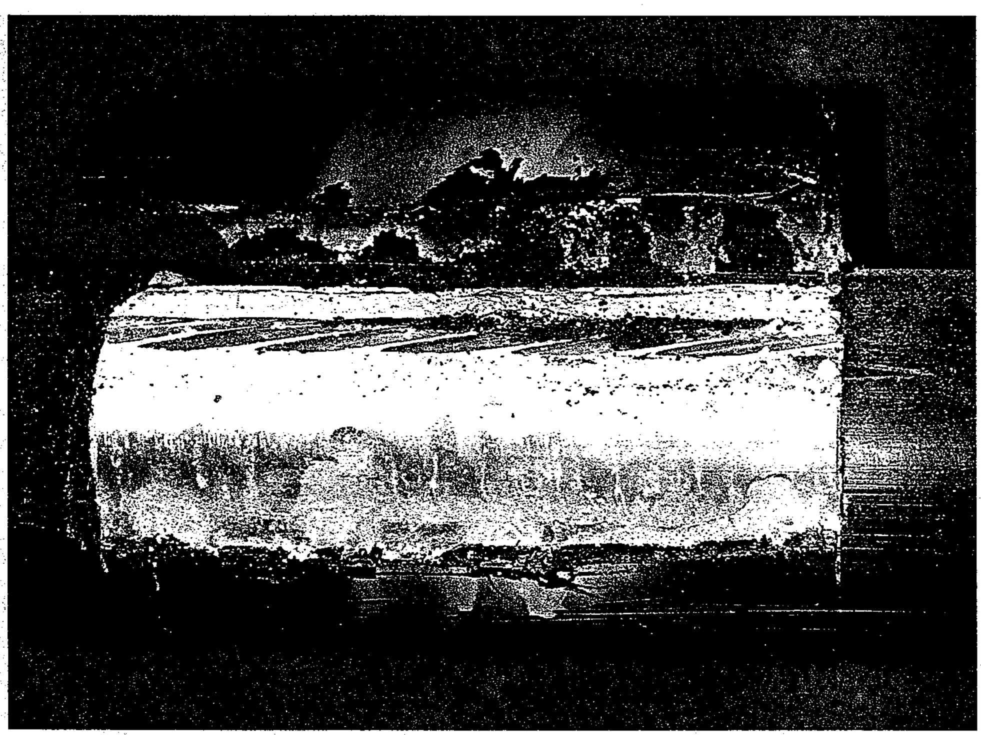

Figure 12 - Photograph of the opening in the P-T duct for MFL test verification (span 71, tendon 71-1a)

Figure 13 – Close up photograph of the corroded tendon
(span 71, tendon 71-1a)

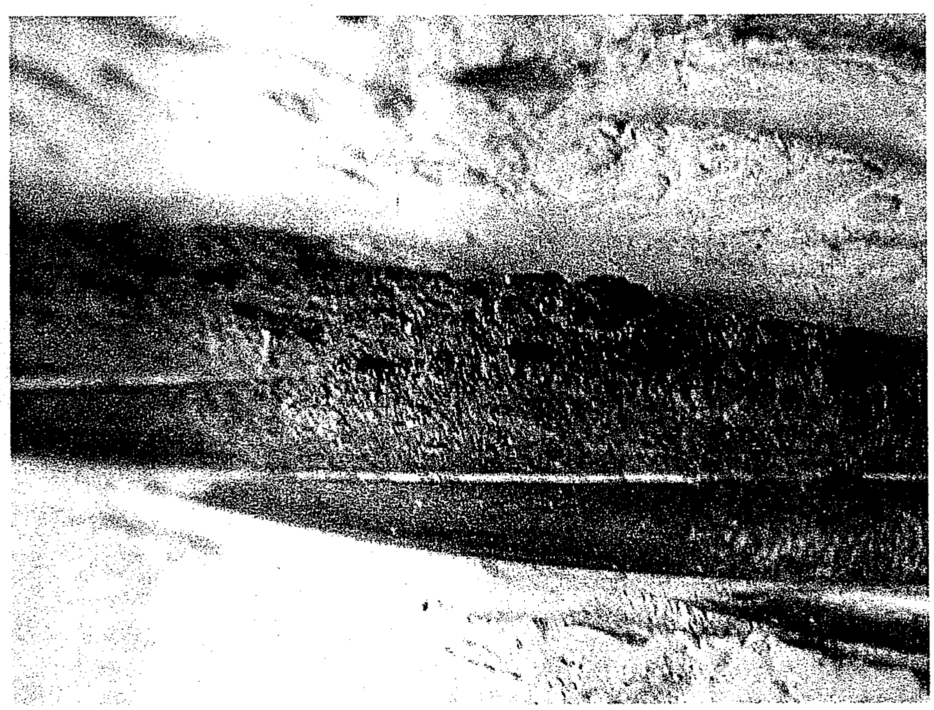

Figure 14 – Close up photograph of the corroded tendon
(span 71, tendon 71-1a)

In span 98, indications of corrosion were recorded during the MFL testing of tendon 985c at locations from 9.0 to 10.5 feet from the start of the test. The starting point of this test was at the edge of the rubber, boot at the end-anchorage-block of the span in section "C" of the span. The span section designations are given by FL DOT. The magnets/sensors assembly of the MTTD system was moved along the length of the tendon in the direction of the first deviation block. The MFL corrosion indication can be easily seen in the data plots from channels 3, 4, and 5 in Figure 15. Flaw indications in the graph of data from channel 9 are not as strong as those shown for the other channels due to the graphs' scale factor and farther distance of the flaw to this sensor. Although the primary flaw indication is at the location of 10.5 feet, one can also see signal amplitude changes in the plots starting approximately at 9.0 feet from the start of the test. This indicates that the corrosion in the tendon is not limited to only a localized point but it also exists at locations in advance of the 10.5 feet location. In addition, a change in the shape of the MFL flaw signal in terms of a longer peak-to-peak duration can indicate a more gradual corrosion of the tendon than a localized one. This can be easily observed by comparing the MFL flaw signals for the corroded tendons in spans 71 and 98 (Figures 11 and 15, respectively). Upon a physical examination of the P-T duct at the corrosion suspected area, it was found that a small hole was also present in the polyethylene duct. The indication of the corrosion and its location for this tendon were reported to the FL DOT personnel as the MFL testing was underway for the tendon. The indicated location was marked with yellow paint for subsequent verification. The FL DOT personnel decided to cut a window, or opening, in the polyethylene duct at the indicated location to verify the MFL corrosion indications. After an opening was made in the tendon, it was observed that corrosion was present in the tendon in the region indicated. It was verified that a more extensive corrosion was present at the 10.5 feet location and less extensive surface corrosion existed for a two-foot distance in advance of this location. The corrosion was limited to four wires of four seven-wire strands in the prestressing bundle. Figure 16 shows the opening in the tendon at this location and a general view of the corroded tendon. The corroded area of the tendon was cleaned with a wire brush to observe the extent of the corrosion. Figures 17 and 18 show close up views of the corroded tendon.

The cause of the corrosion at this location can also be associated with the presence of a small hole on the wall of the polyethylene duct that allowed penetration of moisture and oxygen inside the tendon. Again the hole could have been made either to check the status of grout inside the duct during or after the grouting operation or for other unknown reasons.

MFL test data for all P-T tendons of the Mid Bay bridge have been recorded and is available on a CD media for reference.

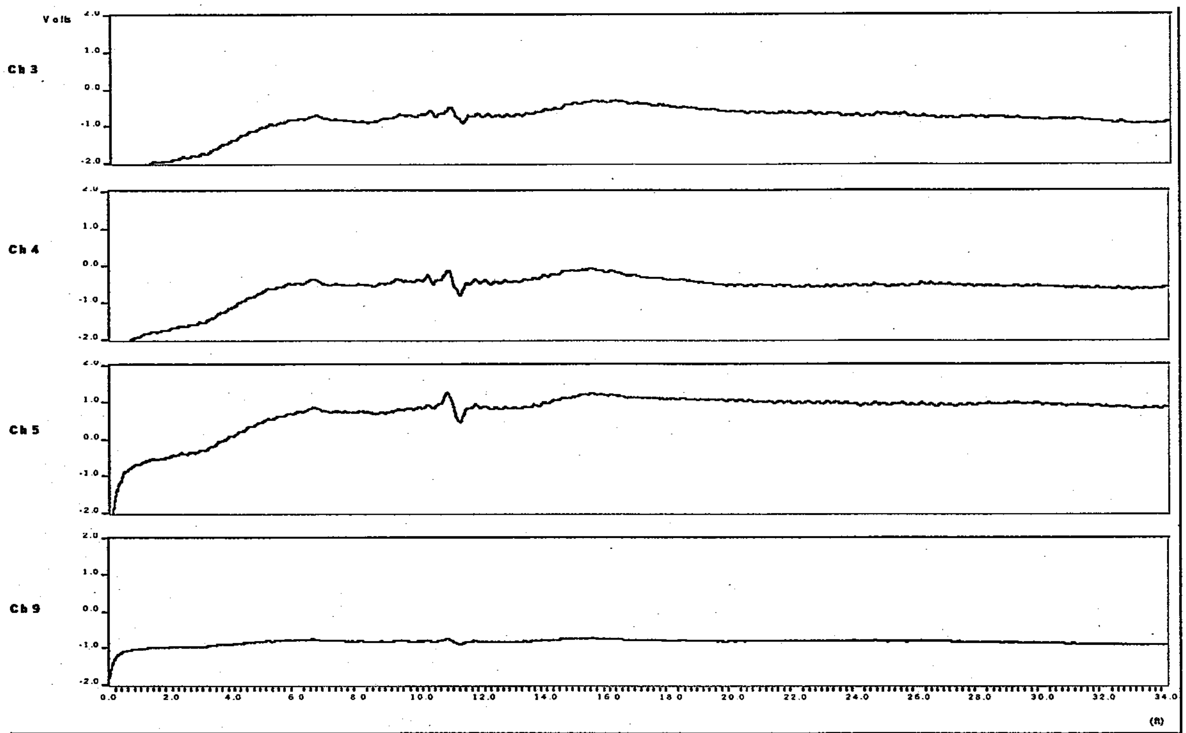

Figure 15 – MFL signals indicating corrosion at locations 9.0 to 10.5 feet (span 98, tendon 98-5c)

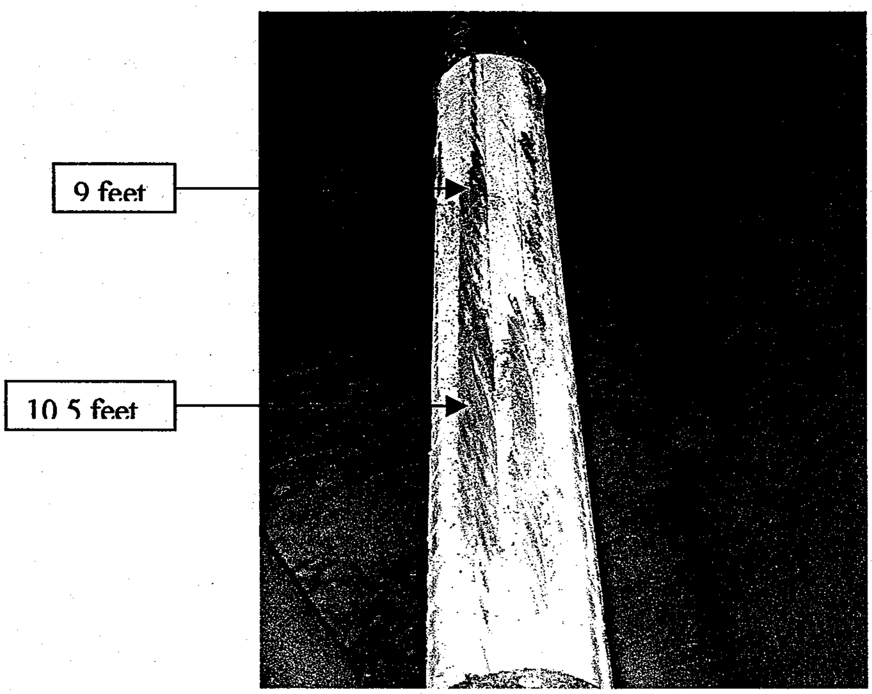

Figure 16 - Photograph of the opening in the P-T duct for MFL test verification (span 98, tendon 98-5c)

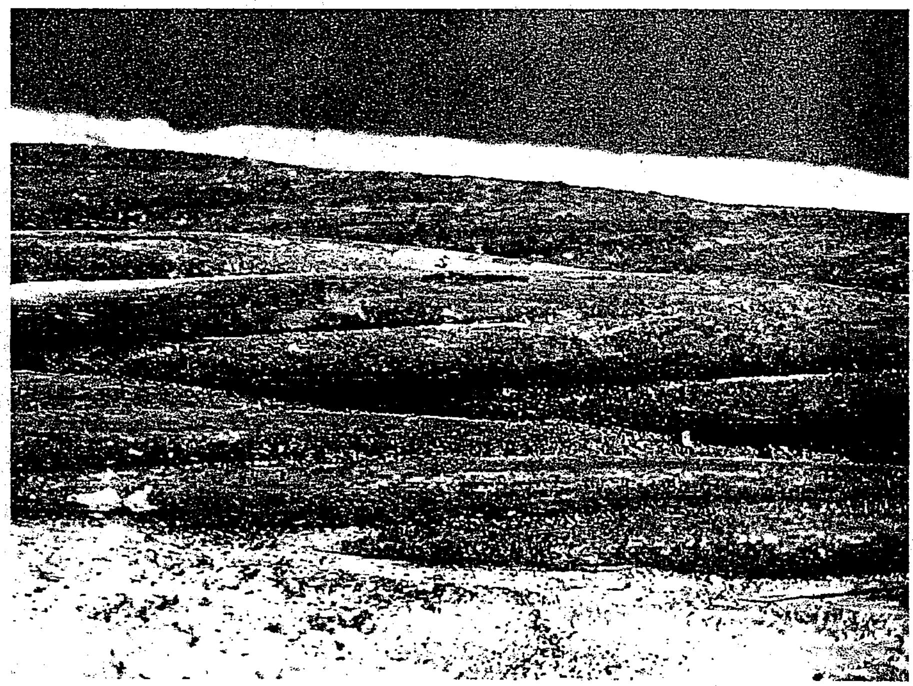

Figure 17 – Close up photograph of the corroded tendon at the 10.5 feet location (span 98, tendon 98-5c)

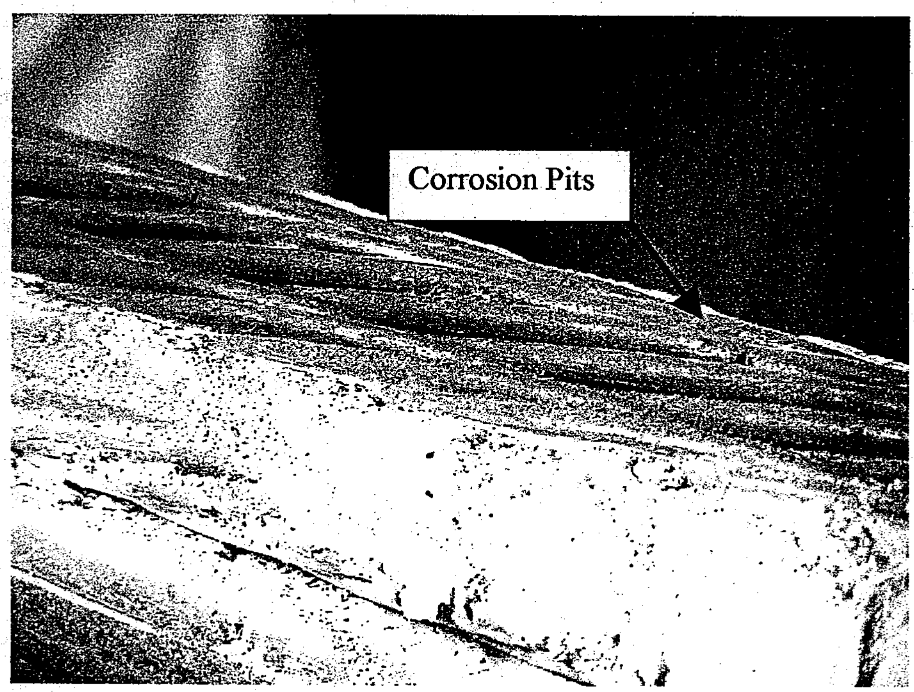

Figure 18 – Close up photograph of the corroded tendon cleaned with a wire brush (span 98, tendon 98-5c)

CONCLUSION:

A comprehensive field-testing of the P-T tendons of the Mid Bay bridge was conducted by using the magnetic tendon-testing device (MTTD) that is developed by the author. The device operates based on the concept of magnetic flux leakage (MFL).

During the field-testing, it was found that all, but two, P-T tendons in the Mid Bay bridge are free from MFL indications for corrosion or fracture. Field-testing results by the MTTD system indicated the presence of corrosion in two tendons located in spans 71 and 98. These tendons are identified as tendons 71-la and 98-5c, respectively. Florida DOT personnel made a decision to cut small openings in the polyethylene ducts of the two tendons at the specified locations. At the specified locations for both tendons, corrosion of the prestressing strands was present and the MFL indications were successfully verified.

The magnetic flux leakage (MFL) test results showed that a small amount of surface corrosion and corrosion pits in the external P-T tendons could be detected reliably with the MTTD system. Test results indicating the presence of corrosion in the tendons were verified by physically exposing the corroded prestressing strands.

During the field-testing phase of this work, it was shown that the magnetic tendon-testing device (MTTD) could be used successfully to evaluate the condition of post-tensioning tendons of a major concrete segmental box bridge. No major difficulties in the use or performance of the equipment were encountered and the testing operation was performed efficiently. MFL tests were repeated at several tendons to verify the reproducibility of the results, and in every case the repeated test produced identical results when it was compared with the results of the initial test.