EVALUATION OF NDT METHODS FOR CONDITION ASSESSMENT OF POST-TENSIONING TENDONS IN PRECAST BALANCED CANTILEVER CONCRETE BOX GIRDER BRIDGES

Juan José Goñi, Ph.D., P.E., DMJM+HARRIS, Inc., Tallahassee, FL
Rafael Foinquinos, Ph.D., P.E, DMJM+HARRIS, Inc, Coral Gables, FL
Larry Sessions, P.E., Florida Department of Transportation, Tallahassee, FL

ABSTRACT

The need to assess the condition of post-tensioning tendons in existing Florida bridges has prompted the Florida Department of Transportation to fund a study, with collaboration from the FHWA, on the accuracy of several Non-Destructive Testing (NDT) methods in a real case scenario. The program involves the use of selected NDT methods to assess the status of the top slab post-tensioning tendons of Ramp D located in the interchange at the Fort Lauderdale-Hollywood International Airport. The NDT methods examined are: Impulse Radar, Impact-Echo, Magnetic Flux Leakage and High-Energy X-Ray Imagining. This paper provides a description of the procedures used by the testing companies and an assessment of their reliability based on the results of the program. The findings indicate that these methods can provide relatively accurate information about the condition of tendons in the deck.

Keywords: Bridges, Concrete, Precast, Segmental, Post-tensioning, Endoscope, Impulse Radar, Impact-Echo, X-Ray Imagining.

INTRODUCTION

The State of Florida has recently experienced grouting related problems in several bridges. In the spring of 1999, a corrosion related failure of an external tendon was found in the Niles Channel Bridge near Key West. Similarly, in August 2000, one failed external tendon and one partially failed external tendon (5 failed strands out of 19) were found in the Mid-Bay Bridge near Destin, Florida. Subsequent inspections resulted in the removal and replacement of nine additional tendons. These problems appear to be related to lack of corrosion protection due to the absence of grout at the tendon anchorages. In September 2000, corrosion damage was found in two vertical external tendons in pier 22N of the Sunshine Skyway Bridge near Tampa, Florida. The cantilever concrete segmental bridge at I-75/I-595 Sawgrass Interchange located near Fort Lauderdale, Florida has shown efflorescence at some of the tendon anchor blocks, leakage at some joints, and water leakage at some closure joints. Routine inspection of the bridges has indicated the lack of grout and the presence of water in some tendon ducts.

The grouting related problems have prompted the Florida Department of Transportation (FDOT) to fund a field study (with the collaboration of the Federal Highway Administration) to evaluate the capability of several Non-Destructive Testing (NDT) methods to detect grout voids and strand corrosion in internal post-tensioning tendons. The NDT methods examined are: Impulse Radar, Impact-Echo, Magnetic Flux Leakage (MFL) and High-Energy X-Ray Imaging (High Energy Linear Accelerator). The results of the study will assist the FDOT in the development of recommendations for appropriate inspection methods of internal tendons.

The project participants are as follows:

- **Funding** — **FDOT Central Structures Design Office**
  Tallahassee, FL
  FHWA , NDE Validation Center
  McLean, VA

- **Project Manager** — **DMJM+HARRIS, Inc.**
  Tallahassee, FL

- **Consultants** — **Construction Technology Laboratories, Inc**
  Skokie, Ill
  Al Ghorbanpoor, Ph.D., P.E. Consulting Engineer
  Milwaukee, WI
  High Energy Services Corporation
  La Honda, CA

In addition, the **FDOT District Four Structures and Facilities Department** provided very substantial manpower and heavy-duty equipment during all testing and maintenance of traffic phases. Coordination with the Airport and field construction was accomplished with the assistance of **O'Brien Kreitzberg (URS)**, the airport Consultant; and **PCL Civil**

Contractors, the Contractor for the Airport roadway expansion, which also provided equipment for supporting the X-Ray testing machinery.

To develop conclusions about their capabilities, the testing methods need to be applied to a real structure under real field conditions and their findings are to be compared with visual inspection of the dissected tendons at the test locations. The opportunity to perform the study under very real field conditions presented itself with the work to be performed during the expansion of the Fort Lauderdale-Hollywood International Airport. A critical component of airport infrastructure expansion is the improvements to the terminal area roadways to provide basic circulation capacity. In order to develop this enhanced access, the plan included the construction of eight cantilever concrete segmental bridges and the demolition of three of the existing cantilever concrete segmental bridges. This allowed the FDOT to use one of the bridges to be demolished (Ramp D Bridge) as a testing ground without the future consequences caused by the damage induced in the structure by the dissection of the tendon locations tested.

BRIDGE DESCRIPTION – RAMP D FORT LAUDERDALE-HOLLYWOOD INTERNATIONAL AIRPORT

The Ramp D Bridge is a curved continuous balanced cantilever concrete segmental box girder superstructure consisting of seven spans, ranging from 87 feet to 145.5 feet in length (Figure 1. and 2). The NDT evaluation was limited to the post-tensioning cantilever tendons in the top slab in spans 5, 6, and 7, that have span lengths of 125.8, 145.5, and 97.5 feet, respectively.

Figure 1 - Aerial photo of the Fort Lauderdale-Hollywood International Airport before Expansion. Ramp D Bridge is shown at the left above U.S. 1.

The bridge was erected using the balanced cantilever construction method with precast concrete boxes that were post-tensioned with internal longitudinal and transverse tendons. The longitudinal post-tensioning tendons generally consisted of 12 – ½ inch diameter 270 ksi low relaxation strands that were placed inside of 2-5/8 in. diameter galvanized ducts. The available structural drawings indicate that the deck thickness over the wing segments and between the webs of each box varies between 8 and 9 inches and the distance between the center of each duct and the top of the deck is 5.25 inches. Ten to fourteen longitudinal tendons were located in the deck at the vicinity of each web of the box cross section. Each tendon is anchored at a segment face in the vicinity of the web.

Figure. 2 - View of Ramp D Bridge Span 6 over U.S. 1.

ASSESSMENT OF TENDON INTEGRITY - STRAND INDUCED DAMAGE

The integrity of the tendons embedded in the to slab concrete could only be reliably assessed by using techniques that are not considered non-destructive such as endoscope inspection and core-drilling. The endoscope inspection was performed before any of the non-destructive methods were employed at a few selected locations to obtain an initial record of the type and magnitude of the tendon flaws (grout voids, strand corrosion, etc.). The core-drilling program was used to verify the results of the impact-echo testing. In addition, given that no strands were found with any significant section loss during the endoscope inspection, some strands were cut at selected locations to provide testing data for the MFL and the X-Ray testing methods.

ENDOSCOPE INSPECTION

A set of testing points in the top slab cantilever tendons and their anchors at spans 5, 6 and 7 were inspected using a flexible endoscope to locate areas where tendons contain voids and other flaws. The Florida Department of Transportation, District 4 Structures and Facilities Department provided the equipment and the personnel to perform the inspection work, while the consultant provided a structural engineer to oversee and direct the inspection operation: locating the tendons, evaluating the video images, taking notes of the findings and making decisions regarding the need for further inspection.

No as-built drawings were available. Therefore, the information in the contract drawings was used to find the tendons. The tendons were located in the field by first identifying the segments. This was done without much difficulty, since the segment joints were clearly visible along the bridge deck. Once the segment was identified the location of the tendon was found by measuring their offset from the centerline of the box. The centerline of the box

Figure 3 – Locating the tendons in the top deck

was located from the remains of the original hairpin stirrups in the concrete deck that were used for the horizontal geometric control of the bridge construction. The tendons were located at 1½" from the segment joints in order to avoid conflicts with the segment reinforcing bars, this distance was increased to 12" at tendon anchor locations. Figure 3 illustrates the process of locating the tendon in the field.

Once the tendon locations were marked on the deck surface, a ¾"∅ hole was drilled into the deck. Drilling was typically required to a depth of 4" before reaching the tendon duct. In most cases, the tendon ducts were located by determining the difference in resistance to drilling provided by the tendon grout or tendon void as compared to drilling in the segment concrete. After the drilling operation was complete, the holes were cleaned with pressurized air.

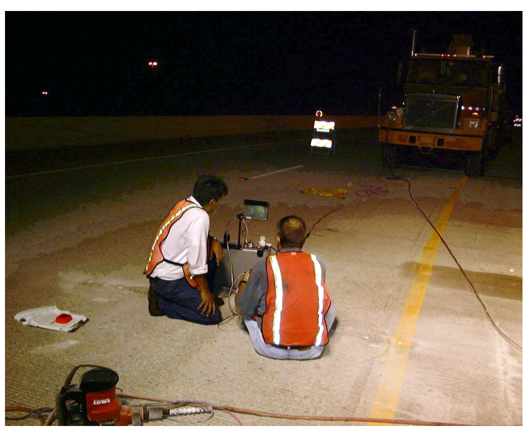


Figure 4 – Viewing the Endoscope video

A typical inspection team consisted of one inspector that operated the endoscope in the drilled hole with an inspector controlling the video recording equipment. Two or three other members of the team provided support services: drilling and cleaning the holes, moving the light stands, etc. The consultant engineer kept a written log documenting the inspection including the depth and length of voids, conditions of the strands if they were visible, etc. Figure 4 shows the endoscope inspection operation while Figure 5 shows photographs of an endoscope inspection of different tendons.

The results of the inspection are detailed below:

Tendon locations inspected:		156
Fully grouted tendons		95
Voided tendons		61
Small voids	48	
Large voids with exposed tendons	10	
Voids with water present	3	

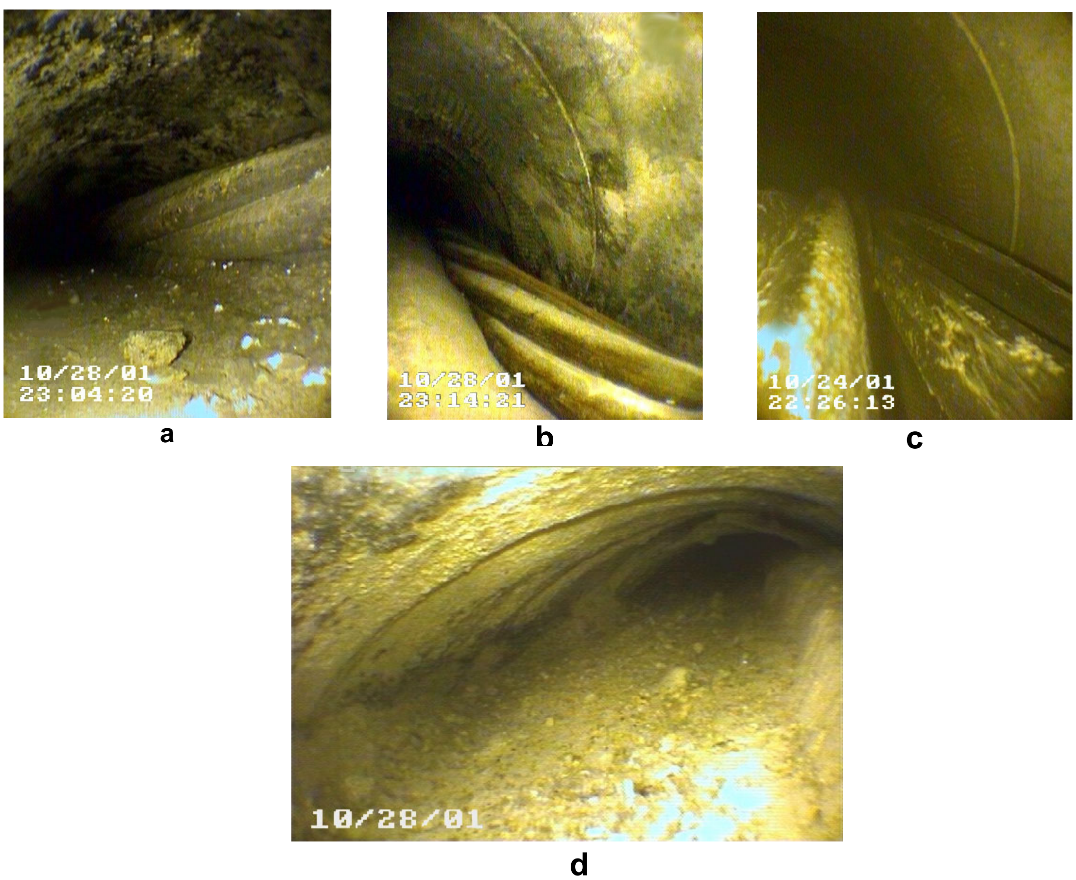


Figure 5 – Photos a and b show duct partially grouted with strand exposure. Photo c shows voided duct with strands fully exposed. Photo d shows partially grouted duct, no strands exposed.

It appears that the small voids are the result of bleed water accumulation and subsequent evaporation. The large voids with exposed tendons were the obvious result of poor grouting procedure. In most of these locations the strands presented moderate signs of superficial corrosion. Voids with water present were probably due to deck cracks at duct joint locations, and in these cases it was not possible to assess the conditions of the strands (exposure and signs of corrosion) due to the difficulties of using the endoscope in a humid environment.

The inspections were performed at night during the week of October 21, 2001. The total inspection operation was completed in 5 nights. The work was performed with traffic on the bridge. The FDOT District Four Structures and Facilities Department provided the maintenance of traffic blocking the half portion of the roadway where the inspection was being performed.

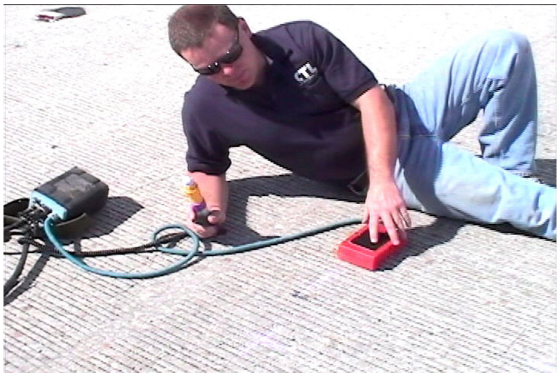
IMPULSE RADAR TESTING

The Impulse Radar testing method was employed in the project by CTL to locate the top slab tendons. While the endoscope testing program indicated that the contract drawings could provide the location of the tendons in the top slab at the segment joints, the location of the ducts between segment joints could not be ascertained with sufficient precision for use in the assessment of the Impact Echo, the MFL and the High-Energy X-Ray non-destructive tests.

The impulse radar is a valuable method to quickly evaluate large concrete areas and qualitatively provide information about the existence of reinforcing steel, tendon ducts and voids. The principles of impulse radar are similar to those for the radar used in air traffic control or when the police detect the speed of a car. A signal is transmitted from an antenna which, in turn, is partially reflected back to the antenna by objects in its path. Then, the reflected signal is analyzed immediately to provide a image of the objects encountered. The signal, for concrete applications, is formed by FM waves typically in the range of 500 MHz to 1.5GHz. The image can be viewed in either a 2-D or 3-D mode on a computer screen.

CTL's scope of work included the use of impulse radar testing to locate and layout the tendon ducts along the top flange of Spans No. 5, 6 and 7. This step would speed up the testing process using the Magnetic Flux Leakage equipment. It was noticed that locating the tendon ducts is a time consuming operation. It took approximately 40% of CTL's testing time. CTL mapped the location of all the ducts with spray paint along the top of the deck on the southern section of the ramp, while only spotting locations across each segment on the northern section of the deck.

Figures 6 and 7 illustrate the use of the impulse radar testing. Typically half of a span, on the northern or southern portion of the deck would contain 12 to 14 tendons which were located and mapped on the structure in approximately 1.5 to 2 hrs.



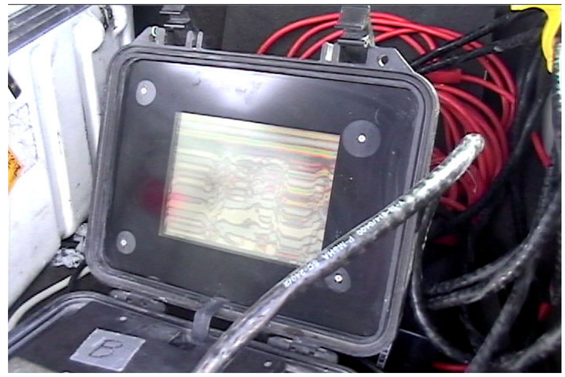


Figure 6 and 7 - Impulse Radar Testing.

Assessment of the accuracy of the method to locate tendon ducts can be made using the results of the core-drilling program. The data involved a total of 50 cores drilled at points where CTL had performed Impact-Echo. Of these 50 points, the core drilling inspection found 38 (76% of the 50 total) ducts associated with longitudinal tendons. At 6 additional locations, the program located transverse tendons, which can be considered a failure of the method. Finally, at two locations no ducts were found and at one point the core was left unfinished for lack of time.

The Impulse Radar Testing method is a quick and economical technique to locate tendons embedded in the concrete. The results of the testing performed at Ramp D indicate that it has a high degree of accuracy and, therefore, it could be very valuable as part of an in-depth bridge inspection program.

IMPACT-ECHO TESTING

The impact-echo test method is a nondestructive testing technique currently used to test the structural conditions of concrete and masonry structures. The method uses transient stress waves generated by a mechanical impact on the surface of the structure being tested. The stress waves induced by the impact propagate through the structure and are reflected from external boundaries and discontinuities inside the medium. The surface displacements or accelerations caused by the passage and the reflections of the stress waves are monitored at a location near the impact point and are used to find the depth of interfaces and boundaries. The method has been used in a variety of applications such as, measuring member thickness, identification of concrete delamination, cracks, honeycombing, poor quality concrete and the location of air voids within tendon ducts of grouted post-tensioned structures. A diagram of the impact-echo test is shown in Figure 8.

When testing plate like structures using the impact-echo, the response at points very close to the receiver can be treated as a one dimensional wave propagation problem involving reflection of only P-waves; this fact is what makes the results of the impact-echo testing method very simple to interpret. Figure 9 illustrates the use of impact-echo test to detect tendon voids; qualitative response spectra are also shown.

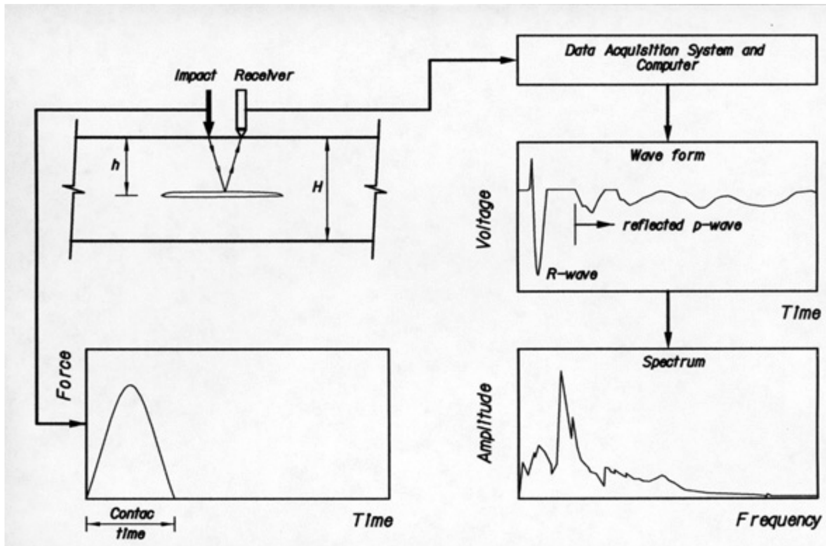


Figure 8 - Diagram of the Impact-Echo method

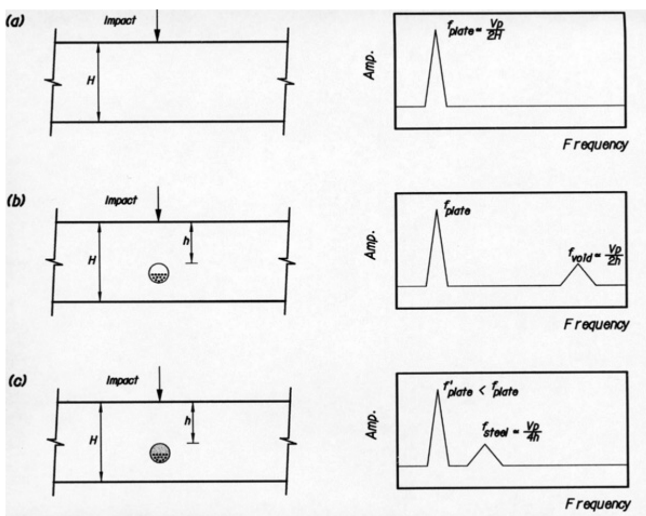


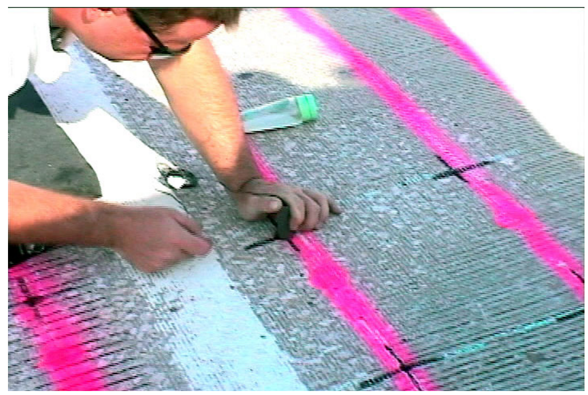
Figure 9 - Basic impact-echo for a plate containing post-tensioning ducts (a) solid plate, (b) duct containing a void, and (c) grouted duct.

CTL IMPACT-ECHO TESTING

The testing was performed from March 18, 2002 to March 22, 2002. CTL initially performed a series of I-E calibration tests to obtain a typical base reflection and to measure the compression wave velocity of the concrete applicable to the testing program. The tests were performed at the cantilevered wing where the slab thickness is a constant 8 inches (per contract documents). The thickness was confirmed by direct measurement at some drainage

openings. The base frequency found was approximately 8.8 kHz, which corresponds to a P-wave propagation speed of 11,700 ft/s
The peak frequencies expected in the amplitude spectrum for the case of a fully grouted duct and for a completely voided duct are on the range of 10kHz and 20kHz respectively. The calibration was also performed to choose the proper size of steel impactor ball that would excite these frequencies.

A typical test will consist of first, locating the testing point using impulse radar and then, performing the impact-echo test. Normally three I-E tests are performed at each location. The operator will look at the result, which includes the time history and the frequency spectrum of amplitudes and then accept or disregard the test. In some cases the tests are disregarded due to background noise or double impact of the impactor ball. An average result is compounded from the three test results and if there is good correlation between the three signals, it is accepted, otherwise the test is repeated. Figures 10, 11 and 12 show the actual I-E testing process. Typically the average production rate was approximately 20 test points per hour or a test point every 3 minutes.



Figures 10 and 11 - Impact-Echo testing.

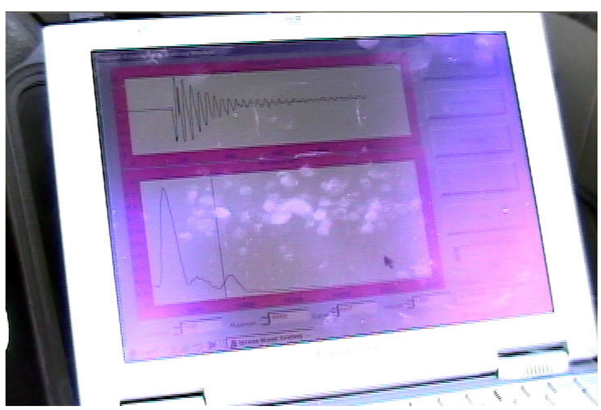


Figure 12 - Impact-Echo testing, computer screen showing the time history of the signal and its frequency amplitude spectrum

A total of 290 duct points were tested. According to CTL's interpretation of the test results, 103 test points were reported as voids. This represents 35.5% of the total tested points while 29 test points were reported as small voids representing 10% of the total number of test points. It should be noted that CTL did not specify what is the difference between a small void and a void. They state that when there is a clear reflection from the duct shown in the frequency spectrum as a significant peak, then a significant void exist but the degree of voiding is not determined.

To corroborate these results a program of core drilling was performed. A total of 50 cores were drilled at locations in which CTL reported a small or large void. Four additional cores were drilled at other locations to corroborate Professor Ghorbanpoor results. CTL did not perform tests at these last four locations.

A comparison between the core drilling findings and the ones reported by CTL is as follows:

Core findings		Corresponding CTL findings	
Grouted	= 17	Void	= 16
		Small void	= 1
Small Voids	= 21	Void	= 21
Void	= 2	Void	= 2
No Data	= 10	Void	= 10

The comparison tends to indicate that in the cases where the core findings indicated the existence of small voids CTL reported them to be fairly larger voids. In general, during the core drilling inspection, voids smaller than ½" were reported as small voids, and the strands were mostly grouted. Assuming, that the grout surface in these small voids is horizontal, then for a void ½" deep the horizontal dimension along the chord is 2.12" (duct diameter is 2.75"), while for a void ¼" deep the chord is 1.58", which correspond to 77% and 57% of the duct diameter respectively. Consequently these voids will provide a reflecting boundary, which will clearly be detected in the I-E amplitude frequency spectrum of the time signal and will be reported as a significant void. From the previous discussion we can state that even small voids will provide a reflecting surface that will clearly be detected with the impact-echo test. Therefore, CTL's effort was effective in detecting voids of various sizes.

Figure 13 and 14 - Inspection of the segments removed from bridge

In addition to the core drilling, a total of nine segments from span 5 and 6 were inspected after their disassembly. Most of the bridge was demolished using a concrete crushing machine that demolished the concrete segments in place. Only sections of the bridge on spans 5 and 6 were disassembled by cutting across the bridge cross section at the segment joints using a wire cutting machine. Some of these segments were visually inspected before the demolition. Figure 13 shows one of the disassembled segments, and Figure 14 shows a tendon duct with a small void, which was typically found in most of the ducts. A total of 216 points were inspected and, again, voids smaller than ½" deep were reported as small voids. The statistics of this inspection shows that approximately 70% of the locations were classified as small voids, 10% as voids and 20% as fully grouted ducts. It should be noted that the strands in the ducts with small voids were mostly encased within the grout.

PROFESSOR AL GHORBANPOOR IMPACT-ECHO TESTING

Professor Ghorbanpoor performed impact-echo testing at four areas of the bridge deck in Spans No. 5, 6 and 7. He performed calibration tests at three different locations on the structure, where no longitudinal post-tensioning tendons were present and where the slab was of constant thickness. The speed of longitudinal wave propagation was computed based on these calibration tests (resonance frequency of the plate). This speed was found to be 140,000 in/sec, which coincides with the value reported by CTL.

The first test location was at Tendons No 8 and No 10, which are close to the joint between bridge segments No. 86 and 87, in the Northern portion of the bridge. At this location Professor Ghorbanpoor reports evidence of voids in the grout at Tendon No 8, and "no conclusive evidence" in Tendon No 10. During the endoscope inspection, Tendon No 10 was found fully grouted, and Tendon No 8 was found to have voids with trapped water.

The second test location was at Tendon No 4 of Segment No. 69 in the Northern portion of the bridge. At this location CTL found voids within the duct, which was a depth greater than 5", which exceeds the expected 3 ½" of concrete cover. At this location, Professor Ghorbanpoor reports evidence of grout voids and detected the duct at a depth of 5.7" from the surface.

Figure 15. Tendon No. 10, core drilled at segment No. 54.

The third test location was at Segment No. 69, on the Southern portion of the bridge. All the tendons (10 tendons in total) were tested with 4 to 5 testing points per tendon; for a total of 58 testing points. Both, CTL and Professor Ghorbanpoor performed tests at all these testing points. Professor Ghorbanpoor reports that no significant voids were observed at Tendons No 9, 10, 11 and 12. During the endoscopy inspections these tendons were found fully grouted while the subsequent visual inspection of this segment shows that these tendon ducts were either fully grouted or with a very small voids. Indications of grout voids are also reported for Tendons No. 3, 4, 5, 6, 7 and, 8.

The last test location was at Tendon No 10 in Segments No. 54, 55 and 56 in the Southern portion of the bridge (a total of 22 points were tested). This tendon was found completely voided during the endoscopy inspection and, later, during the inspection of the segments after deconstruction. Picture No. 15 shows this tendon at the hole drilled in Segment No 54. The strands can clearly be seen with no sign of grout. Although this tendon was completely ungrouted, no signs of corrosion were found. In this location professor Ghorbanpoor reported evidence of grout voids in Segment No. 56, and no strong indications of any significant void in Segment No. 55. Possibly, some of the points tested were not located exactly over the tendon ducts which would explain why no clear wave reflection from the voided ducts were found in some areas.

CONCLUSIONS

The Impact-Echo testing method appears to be an efficient and economical technique to find voids in tendons in concrete located close to the surface. It requires a small crew to be performed and the equipment necessary can be transported in the trunk of a car. To be effective, the location of the tendons needs to be precisely known. This can be accomplished by other NDT methods like Impulse Radar. Its reliability is high but it does not indicate if the void size actually exposes the strands.

MAGNETIC FLUX LEAKAGE TESTING

By applying an external magnetic field to a ferromagnetic component, such as a post-tensioning tendon, a constant directional flow of magnetic flux will be introduced in the component. If the magnetic flux encounters a flaw such as a corroded region or fracture in the component, some or all of the flux will leak out of the component. This magnetic flux leakage is detected by a series of sensors that produce electrical voltage proportionate to the field amplitude at a specific location. The signals detected by the sensors are then analyzed to determine the extent or severity of the flaw that caused the magnetic flux leakage.

The equipment especially configured for testing of internal post-tensioned tendons in a bridge deck is shown in Figure 16. The testing equipment consists of an aluminum push-cart frame that supports a pair of strong magnets and a series of Hall-effect sensors, a computer, a data acquisition unit, and a DC power source. The cart is rolled on its rubber wheels along the tendon lines that are marked on the surface of the concrete deck

Figure 16 – Photograph of the MFL equipment as configured for testing internal P-T tendons in a bridge deck

Prior to the MFL field testing the location of the tendons within the top of the concrete deck at spans 5, 6 and 7 were marked with spray paint. The tendons were located using ground penetration radar in the South part of the bridge. The operation involved locating 4 or 5 points per segment in each one of the tendons and spray painting along the points by linear interpolation without using any straight edge or similar assistance. This last operation resulted in an imprecise location of the tendon path.

Professor Ghorbanpoor performed the test during the period of March 27 to March 30, 2002. A technician provided by the consultant assisted him. During the testing period all marked tendons in spans 5, 6 and 7 were tested, the effective time to perform this operation was approximately 2.5 days in this time frame a total of 52 post-tensioned tendons were tested. The length of each tendon varied from approximately 30 feet to 150 feet. The starting point for the test was either at the anchored end of the tendon or at the centerline of a pier (half-length of the tendon). In general, the actual test can be performed quickly. The operator guides the equipment along the marked tendon walking at a normal pace. During the test the MFL data is displayed on the computer screen that is monitored by the operator. The MFL data collected at each location is then saved in the computer for post-processing and analysis. This procedure is repeated at each tendon location. At the end of the testing program Professor Ghorbanpoor performed an overall evaluation of the MFL data recorded in the field. He indicated to the consultant that the data did not reveal any obvious indication of the presence of major flaws

Since Professor Ghorbanpoor could not identify any flaws from his initial inspection of the test results, the consultant requested a comparative analysis to be conducted on pairs of tendons, where each pair would consist of one tendon with flaws and another without flaws. These flaws (strands with cuts) had been previously created by the consultant. The consultant provided Professor Ghorbanpoor with a list of the pair of tendons to be compared (the control tendon and the one with the flaw). This list identified the segment number in which the flaw was located and if the flaw was in the trumpet region or the duct region.

The first three locations were in the trumpet region of the tendons. Professor Ghorbanpoor indicated that no reliable MFL interpretation could be made in these areas. As previously mentioned, a tendon must be magnetic flux saturated in order for a flaw to leak flux. However, at these locations the tendons were located deep into the concrete approximately 8 inches from the surface of the concrete deck. Thus magnetic flux saturation could not be achieved with the magnets used. In addition to the problem of the strength of the magnet, the trumpet regions of the tendons are generally difficult to evaluate due to the high congestion of reinforcement steel (spiral and stirrups) and the end anchor plate, which produces signals difficult to interpret.

The next four pairs of tendon locations were in duct regions. At these locations, Professor Ghorbanpoor provided a comparison between the signals of the pair of tendons and identified the flawed tendons. He indicated that the test interpretation was given by somewhat pushing the capability of the system for this application to its limits. He indicated that the factor contributing to this difficulty are variations and uncertainties in the location of the tendons, greater depth of the tendons in the deck and smaller than 33% cross sectional losses in the tendon. The results of his comparison study are as follows:

<u>*Location 1:*</u> Two strands were cut in tendon 7 (16.7% of tendon area) in the North (left) part of the bridge at the up station edge of segment 89. Tendon 9 was chosen as the control tendon. In this case, the starting point for the test was the centerline of pier No. 7. Figures 17 and 18 graphically display the MFL data for tendons 7 and 9, respectively. The data shown represents the 10 ft length beginning at a distance of 30 ft from the starting point of the test. Professor Ghorbanpoor explains that the data for tendon 7 reflects an indication for

the possible presence of a flaw at approximately 35 ft from the starting point of the test. This point corresponds exactly to the location of the man-made flaw. He indicates that the signal amplitude pattern at that location is similar to that observed in the laboratory tests. He also indicates that the MFL data for tendon does not reveal a pattern associated with a flaw. The results of his comparative analysis correctly identify the flawed and control tendon.

Location 2: One and a half strands were cut in tendon 13 (12.5% of tendon area) in the North (left) part of the bridge at the up station edge of segment 86. Tendon 11 was chosen as the control tendon. The flawed and control tendon were correctly identified.

Location 3: One and a half strands were cut in tendon 13 (12.5% of tendon area) in the North (left) part of the bridge at the down station edge of segment 79. Tendon 11 was chosen as the control tendon. The flawed and control tendon were correctly identified.

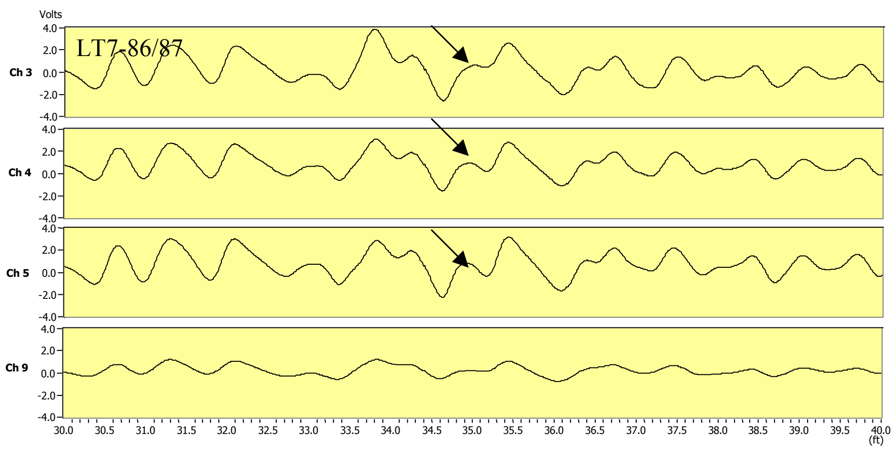


Figure 17 - MFL signals (4 channels) for tendon # 7 between segments 86 and 87 (data for 5 feet of the tendons on both sides of the joint between segments 86 and 87

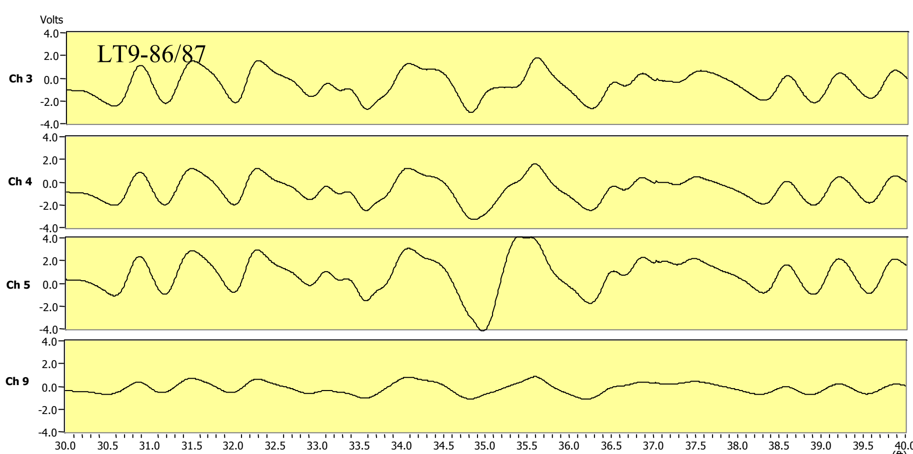


Figure 18 - MFL signals (4 channels) for tendon # 9 between segments 86 and 87 (data for 5 feet of the tendon on both sides of the joint between segments 86 and 87)

Location 4: Two strands were cut in tendon 13 (16.6% of tendon area) in the North (left) part of the bridge at the down station edge of segment 76. Tendon No. 14 was chosen as the control tendon. The flawed and control tendon were correctly identified.

Professor Ghorbanpoor was able to identify the tendons with the man-made flaw and their exact positions at all of these locations. The MFL data for these tendons revealed characteristic variations of signal amplitudes similar to the ones observed at flaw locations in the laboratory tests.

CONCLUSIONS

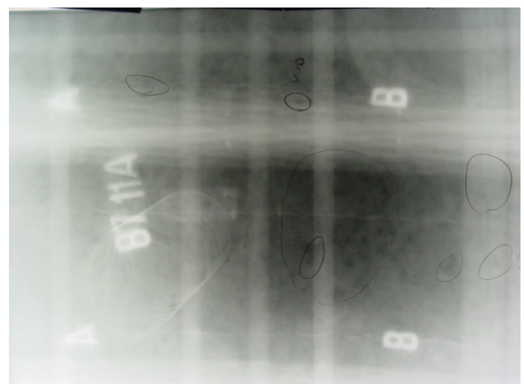
The Magnetic Flux Leakage Testing Method appears to be able to locate loss of section in top slab tendon located close to the surface. To be effective, it requires a precise description of the tendon path painted on the deck. This task can be performed using the Impulse Radar Testing method, which can be a very time consuming operation. The Magnetic Flux Testing method was found to be unsuccessful in locating flaws in tendon trumpets deep in the concrete deck. It requires a small crew and equipment. The interpretation of the test data is very difficult for the inexperienced user. Consequently, it is recommended the test be performed by expert personnel.

HIGH-ENERGY X-RAY IMAGINING

The X-Ray inspection was performed by High Energy Service Corporation (HESCO) in March of 2002. The procedure was performed to determine the accuracy of the x-ray testing system on identifying defects or flaws in post-tensioned structures. The consultant determined 16 testing points in the last three spans (approximately 300') of the bridge prior to the arrival of HESCO. These points were marked on the top of deck and the inside of the box girder. The x-ray testing locations were determined based on the findings during endoscope inspection, impact echo testing, and areas where damage was induced to strands for the magnetic flux testing procedure.

The HESCO equipment used for this procedure consisted of a portable linear accelerator. The Contractor (PCL) provided HESCO with a forklift for the mobility of the testing equipment (Figure 19). A portable film developing company was hired by HESCO to develop the film onsite during the testing procedure. The remaining equipment, provided by FDOT District 4 Facilities, consisted of a Snooper, a power generator and night lighting. Also, the Florida Highway Patrol provided traffic control of the roadway traveling underneath the bridge during the testing procedure to prevent radiation exposure to the traveling public.

The testing took place at night to minimize the effect on the traffic traveling underneath the bridge. The procedure was conducted with two technicians, one technician operated the x-ray equipment and the other set the film on the inside of the box girder. Inside the bridge multiple 14"x17" sheets of film were arranged at each shot location on the inside of the box to ensure that the picture was captured. This was due to the uncertainty that the top shot location coincided exactly with the placement of the film on the inside of the box. The film was held in place by telescoping poles and duct tape. The film for each shot location was identified and marked with lead lettering to coincide with the consultants point labeling convention. At the same time the x-ray source equipment was set-up on top of the deck using the provided forklift (as seen in Figure 19). Once the equipment and film was set-up, people were cleared from the testing location and the traffic traveling on the roadway underneath the bridge was stopped a few hundred yards before the bridge. The time it took to take each shot varied from approximately 3 to 15 minutes depending on the thickness of the slab at the testing location



Figures 19 and 20 – Linear Accelerator suspended by the forklift and X-Ray film

A film processing truck was used for onsite film developing during the time of testing. The truck developed the film in a short period of time and provided a good light source for inspecting the pictures. Viewing the pictures onsite enabled the technicians to determine if the film was located in the correct position inside of the box. Also, it enabled them to determine if another shot at the same testing location was required. The images were accurate with flaws and defects easily detectable (Figure 20). Defects detected with the x-ray consisted of voids, damaged strands, damaged ducts, and flaws induced in the concrete. Due to the nighttime work limitations and the initial time set-up of the equipment only 12 of the 18 points could be completed. The testing results were compared with the consultant's findings and placed in a table (Table 1). Note that some defects identified by HESCO within the report are not a clear interpretation of the actual defects. From HESCO interpretation of the x-ray pictures it seems recommendable that for future x-ray inspection of post-tensioned structures, the technician should analyze the pictures with the assistance of a structural engineer to clarify the defects or flaws.

Table 1

Seg.	Hole I.D.	Defects Reported by HESCO	Defects Reported by Consultant
89	S1	Broken and cut strands, voids in grout	A 10”x8” saw cut in deck was made at trumpet location, trumpet was cut open and 21 wires (3 strands) were cut.
88	SS1	Voids in grout, ground strands	An 8”x6” saw cut in deck was made at trumpet location, trumpet was cut open and 11 wires (1.5 strands) were cut.
88	13C	Voids in conduit at left, voids in concrete	Void reported by impact-echo.
88	13D	Voids in grout, ground strands, strands have been separated, broken conduit casing	Point tested with impact-echo and void was not evident.
87	11A	1" x 1/2" void in center of film w/smaller 1/4" voids surrounding, possible broken cable B-B, coil of wire	Void reported by impact-echo.
86	SS3	Cable has been ground/cut in two, partial pcs of rebar, pulled back conduit sheeting is visible	An 8”x6” saw cut in deck was made at duct location, duct was cut open and 14 wires (2 strands) were cut.
86	SS9	Cable conduit on right contains large void and is ground and cut, cable in center of view is ground and cut, missing sections of cable, strands of center cables or broken at bottom of view. Partial pcs of rebar, large "staple" in lower left also electrical wire, voids in grout	An 8”x6” saw cut in deck was made at duct location, duct was cut open and 10 wires (1.5 strands) were cut.
85	5A	Film moved, not readable	Void reported by impact-echo.
79	SS9	Saw cut from A to A, cable conduit and some cable cut, missing section of rebar, saw cut from B to B, voids in concrete	An 8”x6” saw cut in deck was made at duct location, duct was cut open and 10 wires (1.5 strands) were cut.
79	5B	Small voids in grout	Void reported by impact-echo.
79	13A	Large void in concrete by wire IQI, breaks in conduit wall, broken cable strand below "B" on right, voids in grout	Void reported by impact-echo.
77	11B	Voids in concrete, cable in center has large strands	Void reported by impact-echo.
76	S1	Not tested	A 12”x8” saw cut in deck was made at trumpet location, trumpet was cut open and 21 wires (3 strands) were cut.
76	SS3	Not tested	An 8”x6” saw cut in deck was made at duct location, duct was cut open and 14 wires (2 strands) were cut.
69	11B	Not tested	Point tested with impact-echo and void was not evident.
56	S5	Not tested	An 8”x6” saw cut in deck was made at duct location, duct was cut open and 21 wires (3 strands) were cut.

CONCLUSIONS

The High-Energy X-Ray Imagining is an effective testing method to evaluate the status of tendons deep inside concrete. The results of the testing program at Ramp D indicate that it has potential for practical applications. Unfortunately, at this stage it is cumbersome (it requires heavy-duty equipment) and expensive (the cost for two days of testing was $30,000). In addition, the safety of the public in the immediate area of the test requires a careful implementation of a maintenance of traffic program. Future, more compact, equipment may facilitate its use for practical applications.

RECOMMENDATIONS

The results of the evaluation of NDT methods suggest the following steps for the assessment of the tendons at a segmental bridge:

- Initial Screening
    1. Statistically select a set of tendon locations to be evaluated based on the number of tendons and their structural importance.

- Inspection
    1. Use a combination of as-built plans and impulse radar to locate the ducts and the trumpets.
    2. Use impact-echo to locate potential relevant voids.
    3. Verify void relevance and strand integrity by drilling and inspecting with a flexible shaft endoscope.
    4. Based on the results of the initial inspection, determine the need for additional testing locations to obtain the desired confidence level.
    5. At each drilled hole determine the volume of the void using a vacuum or pressure device.
    6. Upon completion of the inspection clean the hole and repair the drilled hole with type E epoxy.

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