Progress Energy

CTLGroup Project No. 059169

Nondestructive Evaluation of Delamination in a Concrete Containment Wall Structure

Crystal River Nuclear Plant Unit 3
Crystal River, Florida

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NONDESTRUCTIVE EVALUATION OF CONTAINMENT WALL STRUCTURE CRYSTAL RIVER NUCLEAR PLANT UNIT 3, CRYSTAL RIVER, FLORIDA

by

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EXECUTIVE SUMMARY

A scheduled refueling outage at the Crystal River Nuclear Plant Unit 3 (CR3), located at 15760 West Powerline Street in Crystal River, Florida commenced in early October, 2009. During the outage, an opening was cut in the 42-in. thick wall of the reactor containment building, to remove and replace the two steam generators, installed during Unit 3 construction. The containment building is approximately 137 ft in outer diameter and 192 ft tall, measured from the base mat top elevation, to top of the roof dome. The concrete wall structure contains a large number of circumferential and vertical tendons, mild-steel reinforcing bars, and a 3/8-in. thick internal steel liner. The Steam Generator Replacement (SGR) opening was 25 ft by 27 ft. Following post-tensioning tendon de-tensioning and removal, it is understood that the rectangular wall opening was created using high pressure water jets; a technique previously used at a number of other nuclear facilities undergoing SGR. During the cutting process, a significant anomaly in the plane of the wall, resembling a crack or delamination was discovered, visible along the perimeter of the opening. The delamination was located approximately in the plane of circumferential tendons, parallel to the wall surface, approximately 7 to 12 in. deep from its exterior face. The width of the anomaly was variable, and measured to be as wide as ½ in., around the SGR opening perimeter.

CTLGroup was retained by Progress Energy Florida, Inc. in accordance with the Contract (Progress Energy Contract No. 468833) signed on November 11, 2009, to provide nondestructive testing (NDT) and evaluation services of the containment wall structure at CR3.

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The main objectives of the services, were to characterize the extent of the delamination around the opening, and assess whether similar delamination existed elsewhere within the wall structure.

To achieve the objective, CTLGroup performed site-specific trial testing to evaluate the suitability of several available nondestructive testing techniques for detecting a delamination in this containment wall structure. The Impulse Response (IR) technique was selected as the primary method in the NDT program. Subsequently, CTLGroup developed a written detailed NDT procedure and following approval of the procedure, performed NDT at nearly all exposed exterior surface areas of the containment wall structure and at accessible surface areas from inside the adjacent buildings. Cursory testing was also performed on a portion of the roof dome structure which was reportedly repaired in 1970's after experiencing subsurface delaminations. CTLGroup's field testing effort took place between October 8 and November 24, 2009.

Based on the NDT results, verified by core sampling and boroscope examination of core holes, CTLGroup concluded that the large delamination visible along the perimeter of the SGR opening was isolated to the wall element between buttresses #3 and #4 horizontally, and from top of the equipment hatch opening to approximately 10 ft below the ring girder vertically, and resembling an hour glass shape centered at the SGR opening. Delaminations of a similar nature were not identified in other areas of the containment wall structure. Approximately eighty (80) core samples were removed from the structure to confirm NDT findings.

BACKGROUD AND OBJECTIVES

A refueling outage began in early October, 2009 at the Crystal River Nuclear Plant Unit 3 (CR3), located at 15760 West Powerline Street in Crystal River, Florida. One of the objectives of the scheduled outage was to remove and replace two steam generators. This part of work was identified as Steam Generator Replacement (SGR). The SGR required an opening in the reactor containment wall. The containment wall is a reinforced post-tensioned concrete structure of cylindrical shape with a dome roof and a 3/8" thick steel liner covering the interior of the structure. The outer diameter of the structure is approximately 137 ft and its height is approximately 192 ft tall, measured from the base mat top elevation, to top of the roof dome. The wall consists of a 3/8-in. steel liner and 42-in. thick post-tensioned concrete wall. The circumferential (hoop) post-tensioning tendon ducts are positioned alternately at 1 ft and 2 ft on center in vertical direction, and vertical tendon ducts are placed at 3 ft on center in horizontal direction. The diameter of the tendons ducts is 5-1/8 in. In addition, the wall is reinforced with mild steel bars. The containment wall structure is divided by six (6) buttresses into six bays, referenced as Bays 0010 to 0015. The distance along the wall outer surface between faces of the adjacent buttresses in each bay is approximately 60 ft. (Related structural drawings are included in Appendix A.)

Following post-tensioning tendon de-tensioning and removal, the SGR opening was cut to approximately 25 ft by 27 ft. High pressure water jetting was used to remove concrete for the wall opening. During the water jetting operations, a delamination was visibly discovered in the wall along the perimeter of the opening. The delamination was observed approximately at a depth of 7 to 12 in., which coincides with the plane of horizontal post-tensioning tendons parallel to the wall surface. Reportedly, the width of the delamination was measured up to approximately ½ in.

CTLGroup was retained by Progress Energy Florida, Inc. to provide nondestructive testing (NDT) and evaluation services of the containment wall structure at CR3. The main objectives of the services, were to characterize the extent of the delamination around the opening, and assess whether similar delamination existed elsewhere within the wall structure.

SCOPE OF WORKS

CTLGroup's scope of works on this project included:

1) Initial trial testing to evaluate suitability of several nondestructive testing in detection of the delamination in this containment wall structure.
2) Develop a test procedure / program of the selected test method(s).
3) Provide documentation and procedure to comply requirements related to quality control, safety training, qualification requirement, equipment calibration.
4) Perform NDT at all accessible areas, including nearly all of the exposed exterior wall surface areas, portions of wall areas accessed inside adjacent buildings and a portion of the roof dome.
5) Perform petrographic examination of a core sample to evaluate general quality of the concrete and observed cracking. The report has been submitted on November 2, 2009. (Not included in this report.)
6) Prepare a project report presenting the test program and findings.

METHODOLOGIES AND TEST PROGRAM

At the initial stage of testing, several candidate nondestructive test methods were considered. These test methods included Impulse Response (IR) testing, Impact Echo (IE) testing, and Ground Penetrating Radar (GPR) testing. Each test has its advantages and limitations in evaluation of internal defects in concrete. A round of trial testing and core sampling verification was performed on the containment wall structure, to evaluate the individual suitability and accuracy of test methods. Based on the trial test results and the specific condition of the wall structure, coupled with CTLGroup's experience on other projects, the Impulse Response test was selected as primary NDT method for detecting the delamination in this containment wall. In addition, core sampling and borescope examination of core holes were to be used to correlate and verify IR results. General description of test methods are enclosed in Appendix B, and the key aspects of the IR test are summarized below. The trial test program is described in detail in Appendix C (Test Procedure Development).

IR Test Method

The Impulse Response (IR) technique was developed based on refinement of the vibration method for deep foundation testing in the 1970's, and has been called the transient dynamic response (TDR), mobility or impedance method. The method was extended to the inspection of general concrete structures, other than deep foundation in 1990's, principally through the efforts of the late Dr. Allen Davis and others. The technique is particularly effective for plate-like elements such as floor slabs, walls and large cylindrical structures. The method employs a low strain transient impact, generated using a 1.5-kg hammer, to send a stress wave into the test element. The resultant bending behavior of the element is analyzed to characterize the integrity of the structure.

Average Mobility is the principal parameter that the IR test produces. Average Mobility is defined as the structure's surface velocity in response to the impact, divided by the force input [a measure of flexibility] in the frequency domain. The mean mobility value over the 0.1-1 kHz range is directly related to the modulus, density and most importantly the thickness of a plate-like element. In general, presence of significant voiding or an internally delaminated or

unbonded layer will result in an increased average mobility value. On the other hand, a sound concrete element without distress will produce a relatively low average mobility value. The application of this method for detecting delaminations is directly analogous to thickness evaluation. When a plate-like structure contains a significant delamination it behaves like two independent plates. The effective thickness is defined as distance from the test surface to a crack parallel to the surface if delaminated, or the full structural thickness if no internal separations exist. The presence of delamination will effectively reduce the thickness of wall or slab responding to the impact, which results in a drastically increased average mobility value.

The test results can be analyzed and presented in the form of contour plots. The suspect, anomalous areas can be identified through a scaled color scheme. In practice, the IR method is utilized on a comparative basis, which allows the engineer to compare the difference in dynamic responses between test areas, within the same structure or between similarly-constructed structures. The measured response data are correlated to condition via intrusive sampling such as core drilling or chipping.

Based on CTLGroup's experience using IR method evaluating similar structures for the similar type of defect, IR testing was estimated to be effective to an approximate 20 in. depth from the exterior wall face, with an influence range encompassing an approximately 1 to 1.5 ft radius surrounding each test point. A test grid of 2 ft x 2 ft is considered adequate to detect delamination in the wall.

Test Procedure Guidance

In cooperation with Progress Energy, CTLGroup developed the following procedure guidance for nondestructively testing the containment wall structure. The justification for this guidance is included in Appendix C (Test Procedure Development):

1. Perform **Impulse Response** (IR) testing to gather Average Mobility data. An orthogonal coordinate grid, with a 2-ft square spacing is established prior to data gathering in each containment wall section. The following threshold values were initially established based on calibration between Average Mobility values collected using IR equipment system B at four general areas, and five (5) core sample verifications:

- $M \leq 0.4$: sound concrete
- $0.4<M<1.0$: "gray" area, evaluate the need for further testing or coring
- $M \geq 1.0$: potentially delaminated concrete or other type of anomaly may exist, evaluate the need for further coring

After completion of all the testing and examination of approximately eighty (80) core sample verification locations, analysis of the large amount of data revealed that the initially-established mobility values appeared to be overly conservative. To more accurately reflect the condition of the containment wall structure, the threshold values were modified as follows for the data analysis / interpretation and presentation in this report:

- $M \leq 0.5$: sound concrete
- $0.5<M<1.0$: "gray" area, evaluate the need for further testing or coring
- $M \geq 1.0$: potentially delaminated concrete or other type of anomaly may exist, evaluate the need for further coring

The details of core sample verification observations and corresponding IR Average Mobility values are presented in the Appendix C "Test Procedure Development" of this report. It is important to note that the threshold values are only applicable to the wall structure. Since the roof dome structure is different from the wall structure in several aspects, such as thickness, orientation, materials, amount and configuration of tendons and reinforcement, the threshold values for the dome would be different. In this exercise, the testing on roof dome was for information only, no specific threshold values were established. Areas with higher mobility values were verified by coring. See the test result section on Page 13.

Based on previous experience, the potential performance difference exists between different sets of Impulse Response (IR) systems, each comprised of a geophone sensor, an instrumented hammer and a data acquisition unit. The raw Average Mobility values collected using an equipment system other than B were normalized by applying a pre-established correction factor. The process employed was as follows:

When a different system is used, a cross checking process shall be conducted at areas that have been previously tested using IR system B, to obtain a baseline comparison. If the average value of Average Mobility (M) differs more than 10% from the previous results, all of the values obtained from the second system shall be normalized using the ratio of the average values, so that the data analysis can be made consistently, based on the established thresholds. An experienced CTLGroup engineer should analyze the data using the thresholds as a guide, taking other related information into consideration, and any adjustments to the thresholds are documented.

2. In areas where Average Mobility values fall within 0.4 and 1.0 (the criteria was revised to 0.5 to 1.0 after analysis of more data), the condition and test results were evaluated and core bore verification were needed at some areas. Ground Penetrating Radar (GPR) testing was performed to locate the reinforcement and tendons prior to the coring.

3. In some areas where potential delaminations were identified, core samples were removed to verify condition. The core locations were selected jointly by Progress Energy and CTLGroup. GPR scans were made prior to the coring operation, to locate embedded reinforcement and tendon ducts.

4. In sound areas, judged based on IR test results, core samples were randomly removed to confirm conditions.

FIELD TESTING

After initial trial testing was completed and a test procedure was developed, CTLGroup performed testing at nearly all exposed exterior surface areas of the containment wall structure, and at accessible surface areas at various elevations from inside the adjacent buildings, i.e. intermediate building and auxiliary building. Access was obtained via four automated working platforms (Sky Climbers) installed around the circumference of the cylindrical containment building, the chipping platform at the SGR opening, and erected staging at various locations. The access was provided by Progress Energy through Bechtel. Two teams from CTLGroup were mobilized and performed the testing. Each team consists of a NDT leader and an assistant, with a set of IR equipment and a GPR unit.

The IR data collected were preliminarily analyzed on site, and core locations were laid out on the surface, where deemed necessary. The sizes of cores were primarily 2-in. or 4-in. diameter, depending on the tendon and reinforcing steel configuration in the area. GPR testing was performed to locate reinforcing bars, circumferential and vertical tendon ducts, to avoid damage during the coring process. While the GPR testing was successful in most of the core locations, however, in areas where reinforcing bars are closely spaced, such as near the equipment hatch where the reinforcing bars were approximately 6 in. on center in both the horizontal and vertical directions, and in bay 0015 where a delamination was present, it was difficult to locate the vertical tendons using GPR. The depths of cores were mostly 20 in., with a small number of cores were drilled to approximately 12 in. Core sample removal and borescope examination of core holes were performed by others. As requested by Progress Energy, IR testing was also performed on a portion of the roof dome, between buttresses #3 and #4. The pie-shaped test area covered both original concrete and a previously repaired section. The purpose of these tests was to examine the bond condition between the repair concrete and the original concrete substrate. A number of core samples were also removed from the roof slab to verify conditions.

IR tests were performed at approximately 9,500 test points on the containment structure. A total of approximately 80 core samples were removed for NDT calibration and result confirmation.

TEST RESULTS AND DISCUSSION

Contour plots showing Average Mobility values in all test areas are presented in Figures 1 to 3 in Appendix D. In accordance with the calibration results and the test procedure, areas with Average Mobility values exceeding 1.0 (shown in red color) typically indicate the presence of delamination within an approximate depth of 20 in. from the exterior face. Areas with Average Mobility values below 0.5 (shown in gray color) indicate the sound concrete free of delaminations. Localized areas with Average Mobility values between 0.5 and 1.0 (depicted by a yellow color) indicate either the transition from sound to delaminated concrete (Bay 0015) or inconclusive preliminary interpretation of IR results, which required further investigation. In accordance with the test procedure, core samples were removed at various locations to verify or correlate the NDT results. The core sample locations and boroscope observations are provided by Progress Energy and included in Appendix E.

Bay 0015 Areas Exposed to Outside

The SGR opening was made in containment wall bay 0015 between buttresses #3 and #4. A large delamination with an hour glass shape centered at the opening was defined by the NDT program. The delamination was concluded to be within an area of approximately 80 ft by 60 ft, extending between the edges of the two buttresses in horizontal direction, and from top of the equipment hatch opening to approximately 10 ft below the ring girder in vertical direction. Average Mobility values all exceeded 1.0 in the delaminated area. Based on core sampling and borescope examination of core holes, the depth of delamination ranged from 3 to 10 in., with an average delamination depth between 7 and 8 in. from the exterior face. The delamination appeared to be associated with the plane of circumferential post-tensioning tendons in the wall. Forty-five (45) core samples were removed from this bay at locations selected by Progress Energy. Core selections were made based on the Average Mobility plots. The extent of the delamination was confirmed by the core samples and borescope examination.

Bays 0010~0014 Areas Exposed to Outside

The overwhelming majority of the areas tested in these bays showed Average Mobility values below 0.5, indicating sound concrete. Significant delamination similar to that noted in bay 0015 was not found in other areas of the containment wall structure. However, a small portion of the tested areas showed elevated Average Mobility values from 0.5 to 1.0. Very isolated points had Average Mobility values slightly above 1.0. These areas were small in size. CTLGroup investigated the causes of the higher mobility values, through visual inspection, GPR testing, hammer sounding and core sampling. The following are potential causes of these apparent higher Average Mobility values:

1) In some areas where IR test points were located directly over a circumferential or hoop tendon duct, and this tendon duct has less concrete cover than typical, the Average Mobility value could be elevated.
2) When a row of IR test points was located between two closely spaced circumferential tendons (typically 12 in. on center), the Average Mobility values appeared elevated due to the presence of two unbonded tendon ducts (greased) within the zone of influence, but no defect is present. For example, elevated Average Mobility values were encountered at lower section in Panel K of bay 0011, the row #1 of IR test grid fit in between two closely spaced circumferential tendons. Core #33 removed in this area showed no significant defect in the concrete wall.
3) Variations in the material properties, such as modulus of elasticity of concrete material can influence IR testing as can internal defects or changes in thickness. For example, Core #13 removed from bay 0014 showed lack of coarse aggregate in the concrete at this location, which is within an area showing higher Average Mobility values.
4) Conservative correction factor used to normalize the Average Mobility values. A factor of 2 was applied to the raw data collected using IR system C. This factor was relatively conservative. See Appendix C (Test Procedure Development) for details.
5) Shallow spalls (~ 1 in. deep) at the corners of a couple of panels were noted, such as Panel 0012-W lower left corner. Typically the size of this defect is very small (less than a square foot) and adjacent to a corner or construction joint, and can be easily removed with a chipping hammer.

Test Data Collected from Inside Adjacent Buildings

These IR test results did not reveal the presence of delaminations, except for one localized area below the equipment hatch opening in bay 0015. Core #54 was removed from this location, a small crack or delamination at approximately 8 in. deep was encountered. The crack was directly over a horizontal tendon duct. In addition, concrete at this location appeared to contain less aggregate than normal. Based on the borescope record, the characteristic of this defect is not a continuation of the delamination at bay 0015 above the equipment hatch opening. The defect was later removed to sound concrete. Reportedly, the defect was within approximately 8 in. diameter.

Roof Dome Structure

The post-tensioned roof dome structure was reportedly repaired in 1970's, after discovery of a delamination. A drawing showing a section through the repaired roof is included in Appendix A. The repair drawing indicated that the outermost 12 in. of the 3-ft. thick roof slab had been removed and replaced. The IR test results (see Figure 3) showed relative differences in the Average Mobility values measured in the test area. However, thresholds established for the containment wall testing could not be used for interpretation of roof data due to the differences in various aspects such as thickness, orientation, materials, amount and configuration of tendons and reinforcement. Nevertheless, areas with consistently high Average Mobility values were of interest. A total of seven (7) core samples up to approximately 14 in. long, with 2 in the original, non-repaired area and 5 in the repaired portion of the roof, were removed from the roof dome to evaluate the significance of IR results. Core location drawings are included in Appendix D. According to the core sample and borescope records provided by Progress Energy, all 7 locations showed no evidence of cracking or delamination in the roof structure. The apparent variation could be the result of changes in slab thickness, material properties, surface conditions and amount of reinforcement.

APPENDIX A

Structural Drawings Provided by Progress Energy

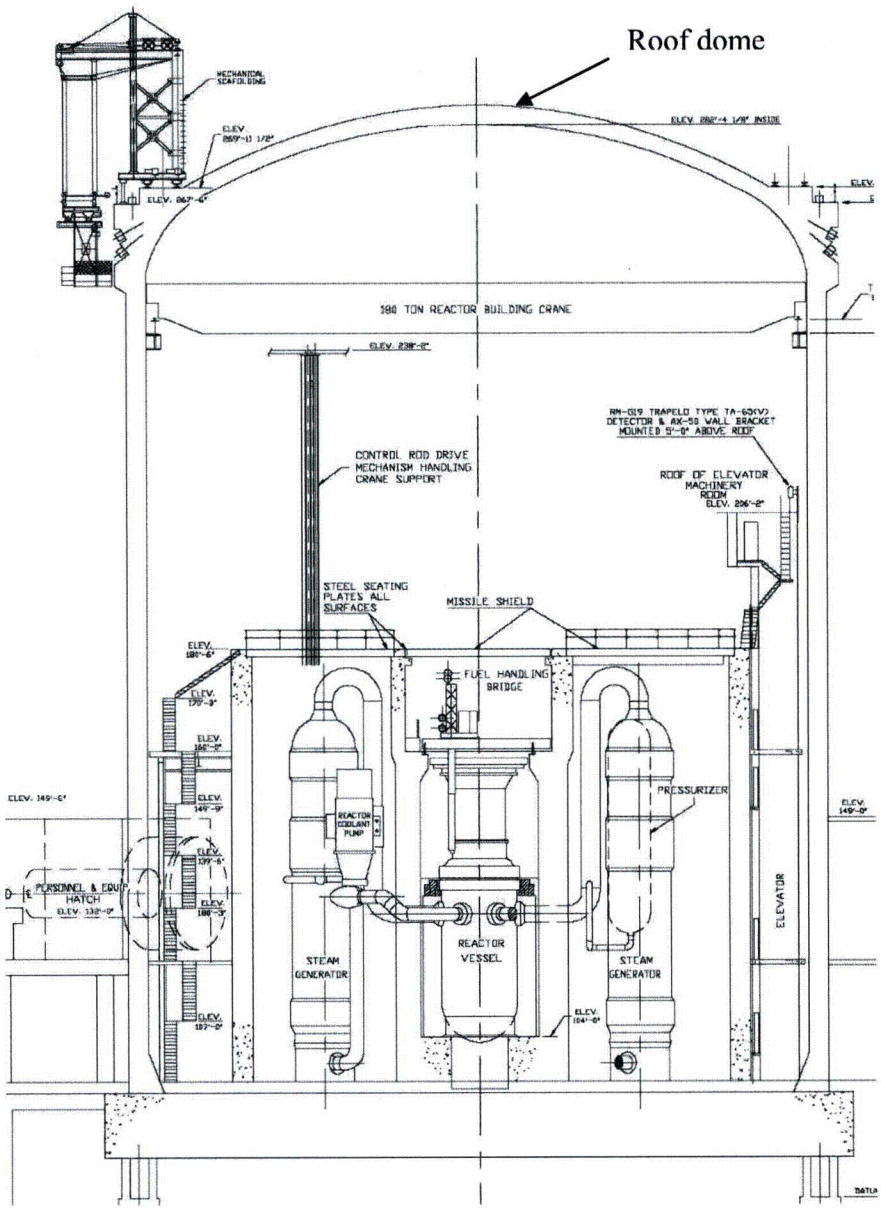


Figure A.1 Overall diagram of the containment building.

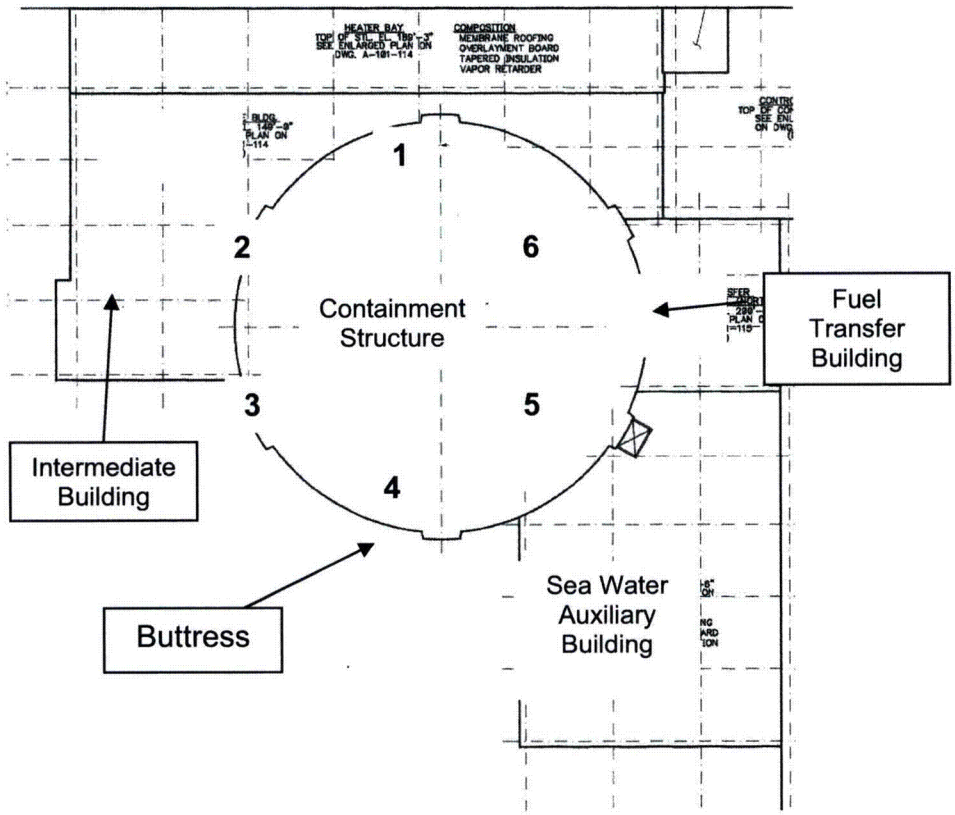


Figure A.2 Plan view and buttress layout of the containment structure.

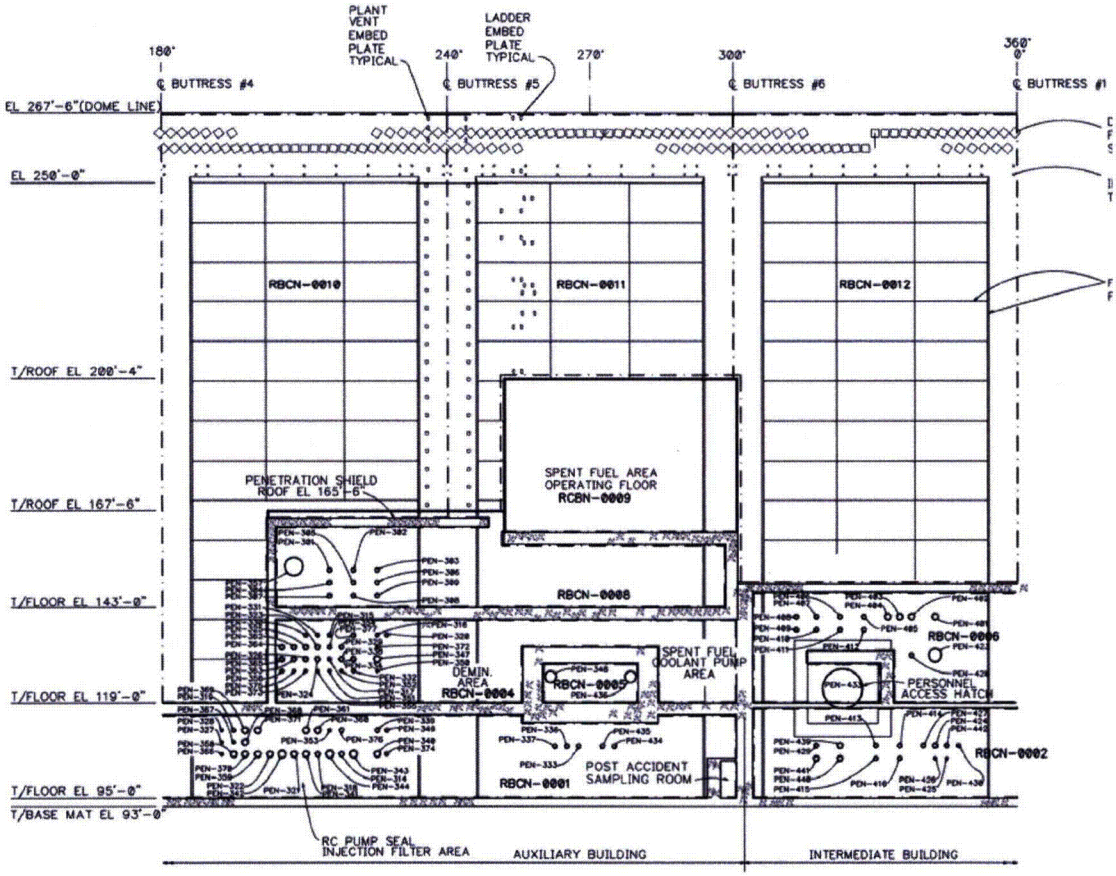


Figure A.3 Unwrapped Elevation of the exterior of the containment structure between buttresses 4 and 1

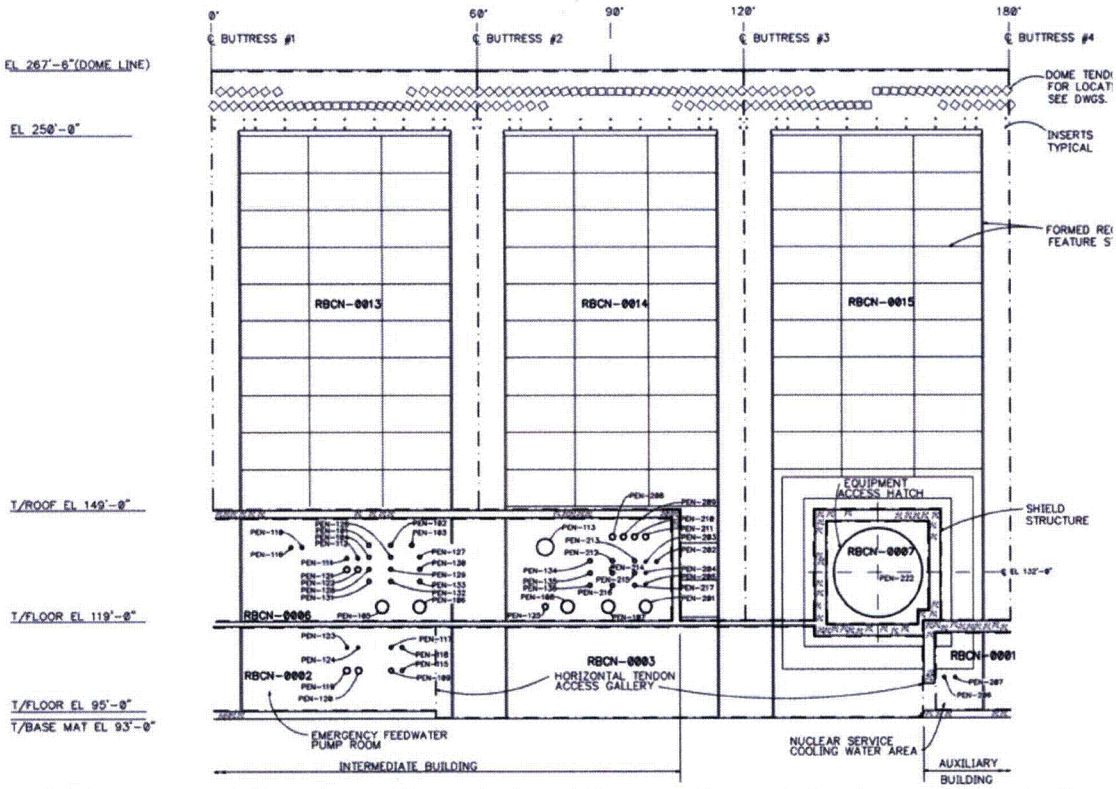
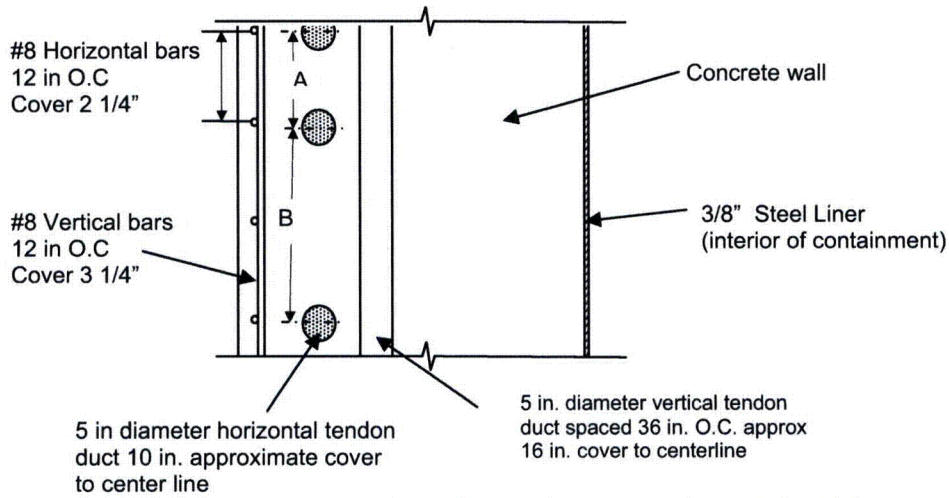


Figure A.4 Unwrapped Elevation of the exterior of the containment structure between buttresses 1 and 4



A= Spacing between horizontal tendons (1' ¾" or 1'1")
B= Spacing between horizontal tendons (2'1-1/2" or 2'1")
Note: spacing of horizontal tendons may vary depending on elevation of tendons and openings or penetrations within the wall.

Figure A.5 Typical reinforcement and tendon layout within the wall.

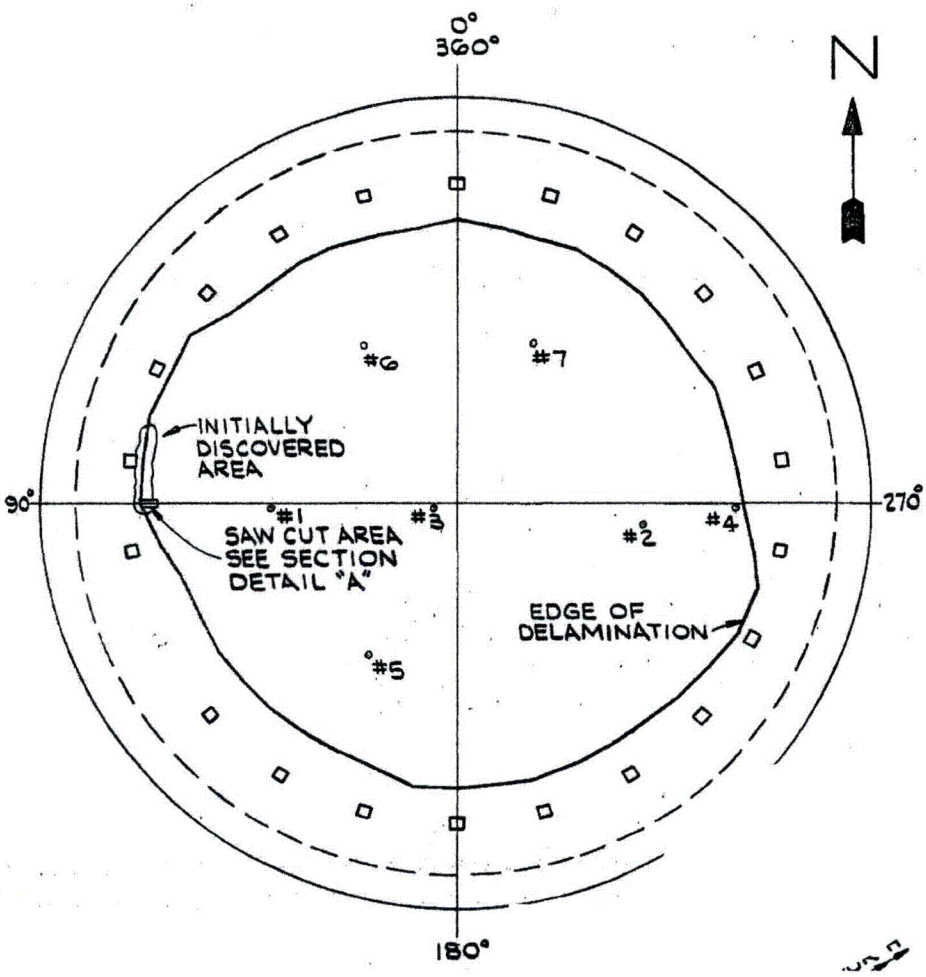


Figure A.6 Plan view of the delaminated region of the dome

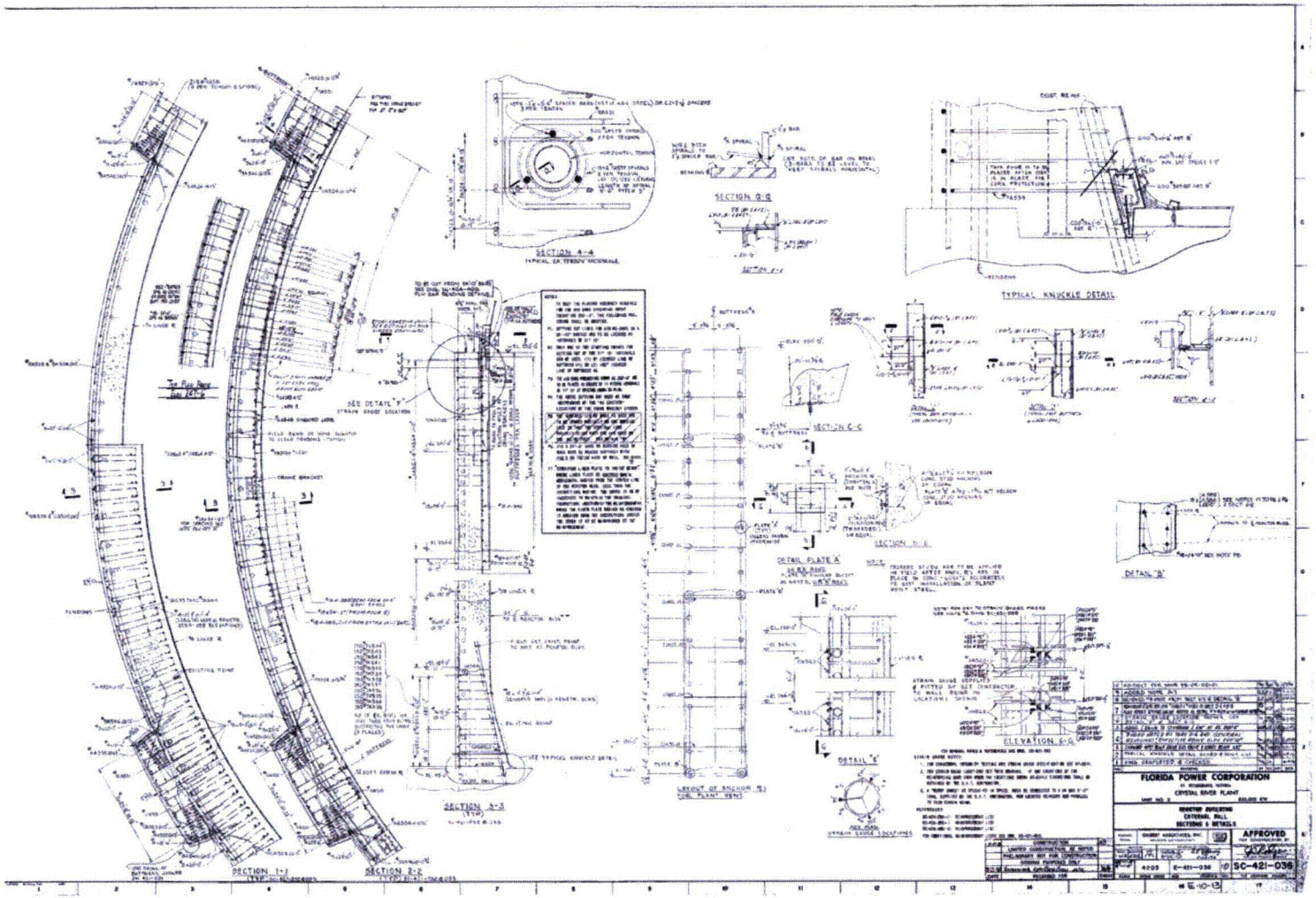


Figure A.7 Cross Section of Containment Wall

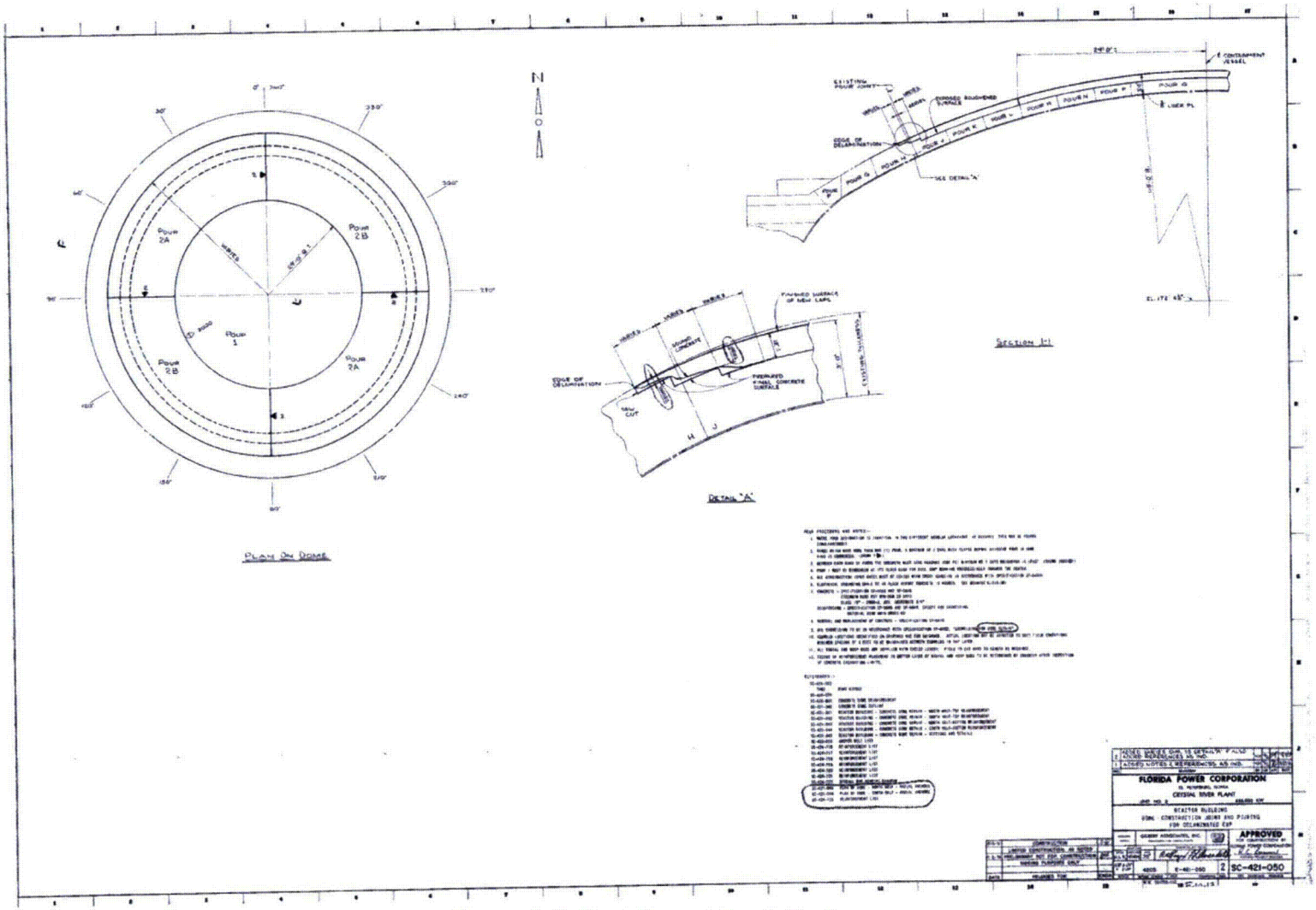


Figure A.8. Roof Dome Repair Section

APPENDIX B

Test Method Description

- **Appendix B.1 – Impulse Response (5 pages)**
- **Appendix B.2 – Impact Echo (2 pages)**
- **Appendix B.3 – Ground Penetrating Radar (2 pages)**

APPENDIX B.1

Impulse Response

Impulse Response (IR) Test Method.

The IR test method was initially developed in the 1970's for testing of deep foundations and its application to general concrete structures occurred in the1990's. Its application is based on the propagation of stress waves produced by the impact of a hammer and the measurement of the velocity response of the structure. Typical applications of the technique in structure testing include detection of: voiding or loss of support beneath concrete pavements and floor slabs; delamination in concrete plate-like structures; presence of low density concrete within a structural member; debonding of asphalt and concrete overlay, etc. The different applications of the test method use the same basic theory and functions. Furthermore, some of the parameters obtained with the testing equipment could be more relevant than others depending on the type of structure and features found within the structure.

Test Equipment

The IR test equipment is comprised of a 1 kg impact hammer equipped with a load cell, a receiving transducer, a twin channel data acquisition/processing system and a laptop computer installed with a special software. A diagram of the test equipment is shown in Figure B.1.1. Typical stress levels generated using the hammer range from 5 MPa for hard rubber tips to more than 50 MPa for aluminum tips. The receiving transducer is generally a directional geophone that is used only for either vertical or horizontal surfaces. In the case of special structures, such as sloped walls and dome structures, a multi-directional geophone could be used. Geophones are typically used because they are more stable at low frequencies generated by the impact of the hammer and its robust performance in the field. The data acquisition system is connected to a computer that stores the data and performs the analysis. The processed result is displayed on the computer screen immediately after the test is completed.

Principle

When testing plate-like structures, the IR test method uses a low strain impact to produce a stress wave to propagate through the tested element. The rubber tip of the hammer produces a long duration impact by which the structure responds in a bending vibration mode at a frequency range between 0 to 1000 Hz. The time and force history of the hammer is recorded and digitized by the data processing card. Simultaneously, the geophone measures the surface velocity response generated by the transient stress pulse from the impact of the hammer. Both the time records for the hammer force and the geophone velocity response are processed in the field computer using the Fast Fourier Transform (FFT) algorithm. The resulting velocity spectrum is divided by the force spectrum to obtain a transfer function, referred to as the *Mobility* of the element under test. The test graph of Mobility plotted against frequency over 0-1 kHz contains information on the condition and the integrity of the concrete in the tested elements.

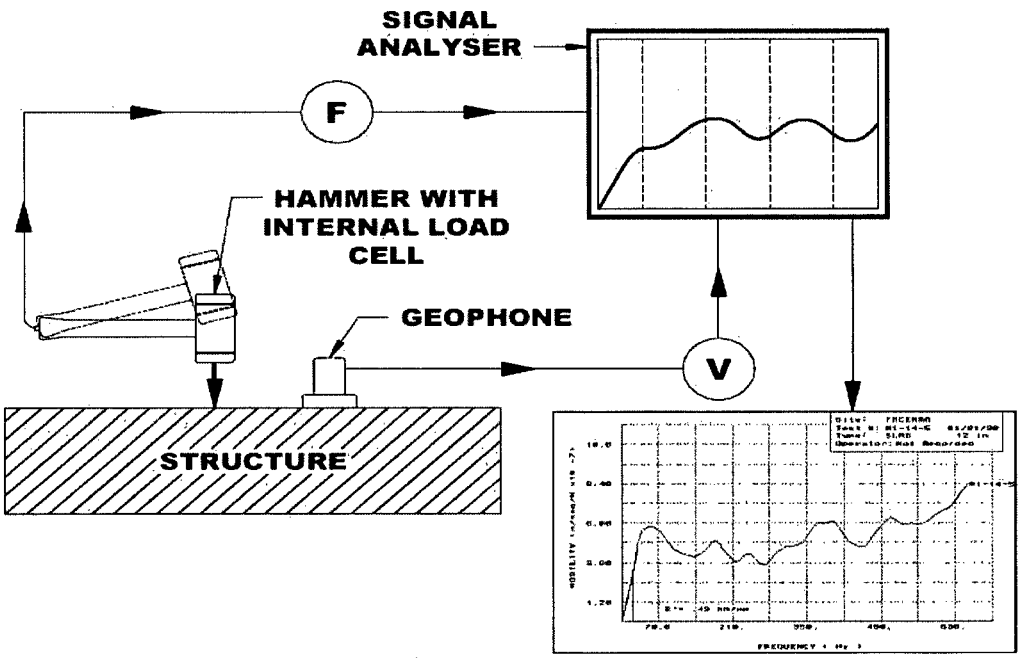


Figure B.1.1

Average Mobility is a principal parameter that IR test produces. The Average Mobility is defined as the structural surface velocity responding to the impact divided by the force input [a measure of flexibility] in frequency domain. The main variable that influences the average mobility parameter is the "effective" thickness of the structure. The effective thickness is defined as distance from the test surface to a crack parallel to the surface (if delaminated) or the full structural thickness if no internal separations exist.

Dynamic Stiffness is another parameter the IR test produces. The slope of the portion of the mobility plot below 0.1 kHz indicates the compliance or flexibility of the area around the test point for a normalized force input. The inverse of the compliance is the dynamic stiffness at the test point. The value depends on the thickness, density and elastic modulus of the material, and the support condition.

The evaluation of Impulse Response test results is typically performed in a comparative manner, with the change or variation in results between test points used to identify anomalous conditions. Ideal condition for using this method to detect any potential flaws requires that the structural elements being tested have similar geometrical characteristics and are made of relatively similar concrete material. A significant increase in average mobility within an element or structure could indicate that flaws exist within the structure.

The IR test method for concrete structure evaluation is in the process of being standardized by ASTM Committee C09 (Concrete & Concrete Aggregate) and its sub-committee C09.64 (Nondestructive In-place Testing). In addition, ACI Committee 228 (Nondestructive Testing) is revising the committee report 228.2R "Nondestructive Test Methods for Evaluation of Concrete in Structures" which will include IR testing for concrete structure evaluation in addition to pile integrity evaluation.

Limitations:

The potential limitations about IR testing in detecting delamination in plate-like structure include: 1) the absolute size or width of the crack could not be evaluated, other method such as core hole examination using boroscope shall be used; 2) the absolute depth of

the delamination from surface can not be readily determined, the depth can only be ascertained by coring or other NDT method; 3) The depth of influence is typically up to 20 in. based on CTLGroup's experience using this method evaluating similar structures for the similar type of defect. However, this depth of effectiveness was considered sufficient for the CR3 evaluation. (See Page 7 of the report.)

Significant and/or recent references:

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APPENDIX B.2

Impact Echo

Impact Echo Method

The Impact Echo (IE) technique was developed in the mid 1980's for testing concrete structural members. Its main applications include: determination of the thickness of slab or plate-like structures; detecting internal flaws in concrete structures; assessing the quality of bond of an overlay; evaluation of depth of delamination; and void detection in grouted post tensioning ducts, etc. IE test and its recommended use for plate-like structure thickness determination are described in ASTM C1383. The test method is also included in American Concrete Institute (ACI) report 228.R2 "*Nondestructive Test Methods for Evaluation of Concrete in Structures*".

Test Equipment

An Impact Echo system is composed of three components: an impact source; a receiving transducer; and a data acquisition system used to capture, store and analyze the signals. The impact source is typically a spherical impactor used to produce a short duration impact. As the impact duration is shortened, higher frequency components are generated.

Principle

Impact Echo is based on the use of transient stress wave generated by elastic impact. A diagram of the method is shown in Figure B.2.1 A short-duration mechanical impact, produced by tapping a small steel sphere against a concrete or masonry surface, is used to generate stress wave that propagate into the structure and are reflected by flaws and/or external surfaces. Surface displacement or acceleration caused by reflections of these waves is recorded by a displacement transducer or accelerometer, located adjacent to the impact. The resulting displacement or acceleration versus time signals is transformed into the frequency domain by Fast Fourier Transform (FFT), and plots of amplitude versus frequency (spectra) are obtained. This spectrum has a periodic nature, which is a function of the depth to the reflective boundary (either the back of the element, or some anomaly such as a crack in the element under test). The depth of a concrete/air interface (internal void or external boundary) is determined by:

$$d = Vc / 2f$$

d is the interface depth, Vc is the primary stress wave velocity and f is the frequency due to reflection of the P wave from the interface. If the material beyond the reflective interface is acoustically stiffer than concrete (e.g. concrete/steel interface), then the following equation applies:

$$d = Vc / 4f$$

The difference in the acoustic impedance of the two materials at an interface determines whether the presence of an interface could be detected by an IE test. For example, a concrete/grout interface gives no reflection of the stress wave because the acoustic impedance of concrete and grout are nearly equal. In contrast, at a concrete/air interface, nearly all the energy is reflected, since the acoustic impedance of air is very much less than concrete.

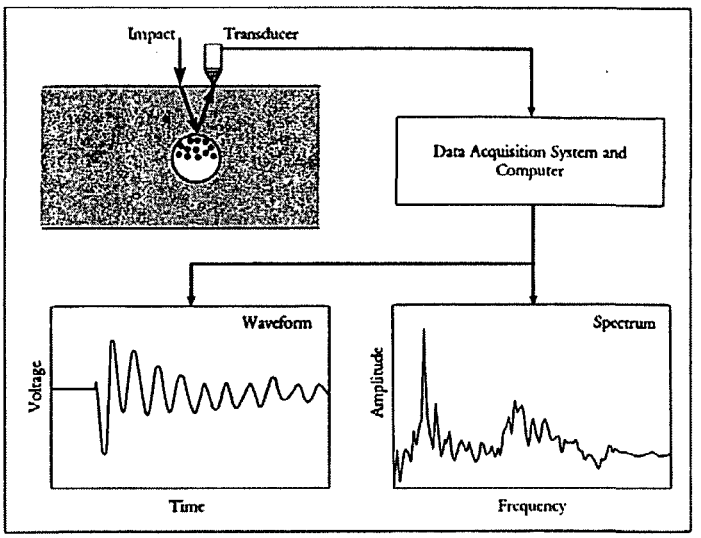


Figure B.2.1

Limitations

The potential limitations of IE testing in evaluating the delamination in CR3 containment wall structure include: 1) relative slow process which requires laying out the PT ducts and reinforcement at every test point prior to testing; 2) the test data is affected by the surrounding tendons in the vicinity of test points which frequently cause false-positive indications of delamination.

APPENDIX B.3

Ground Penetrating Radar

Ground Penetrating Radar Method

Ground Penetrating Radar (GPR) has been successfully used in a variety of civil and structural engineering applications, including evaluation of embedded reinforcement locations; evaluation of grouted and ungrouted cells in masonry block walls; locating embedded foreign objects in concrete pavements; evaluation of dowel bars alignment and the consolidation of concrete, etc. The principle of operation is based on signal reflection of high frequency electromagnetic waves from varying dielectric constant boundaries in the material being probed. The GPR test method and its applications are included in the American Concrete Institute report 228.2R "Nondestructive Test Methods for Evaluation of Concrete in Structure".

Test Equipment

A GPR system consists of a main computer unit, a high frequency antenna and a shielded connecting cable. By changing the antenna with different center frequency, the depth of penetration and corresponding resolution will change. The antenna transmits and also receives the radar signals. The raw data can be stored in the computer unit for post analysis.

Principle

High frequency, short pulse electromagnetic wave is transmitted into the element under test. Each transmitted pulse travels through the material, and is partially reflected when it encounters a change in dielectric constant. For example, the dielectric constant of concrete typically ranges between 6 and 12, the dielectric constant of air is 1 and steel is considered as infinity. Steel does not allow the waves to penetrate through and thus results in almost complete reflection of the waves. The location and depth of the dielectric constant boundary is evaluated by using recorded transit time from start of pulse to reception of reflected pulse and the velocity of wave propagation. Boundary depth is proportional to transit time. Since concrete to air, water, and/or backfill interfaces etc., are electronically detected by the instrument as dielectric constant boundaries, the GPR method is capable of assessing a variety of reinforced concrete, masonry and environmental characteristics.

Limitations

The limitations of GPR testing in evaluating locations of reinforcement and tendon ducts in concrete wall structure include: 1) an embedded metallic feature may not be detected if it is placed immediately behind another metallic embedment; 2) the depth of penetration is limited depending on concrete quality, amount of reinforcement, and antenna frequency. The resolution will reduce considerably when using lower frequency antenna for deeper penetration.

APPENDIX C

Test Procedure Development

APPENDIX C – TEST PROCEDURE DEVELOPMENT

A nondestructive testing (NDT) trial program was conducted to evaluate the suitability of two promising nondestructive testing techniques in detecting the delamination in the CR3 containment wall structure. The techniques included Impulse Response (IR) testing and Impact Echo (IE) testing. The initial trial testing was performed by CTLGroup from October 13 to 21, 2009. A preliminary test program and respective evaluation criterion was developed. While the production type of testing was in progress in accordance with the preliminary test procedure, the evaluation criterion was modified after more IR data were available and a refined correlation was established.

METHODOLOGY

Impulse Response (IR) testing and Impact Echo (IE) testing were evaluated in the trial testing. In addition, Ground Penetrating Radar (GPR) testing was used to locate post-tensioning tendon ducts and reinforcing steel in the containment wall structure prior to IE testing and to facilitate coring operations. Descriptions of the test methods are included in Appendix B.

1. INITIAL TRIAL TEST PROCESS

The initial trial testing was performed at the following areas:

- Area 1: Immediately west of the existing SGR opening in bay 0015, panel S, approximate elevations 180 ft to 190 ft.
- Area 2: Bay 0011, panels N and O, between elevations 200 ft and 210 ft, accessed from the Fuel Transfer Auxiliary Building (North) roof top.
- Area 3: Bay 0010, panels W and X, between elevations 170 ft and180 ft, accessed from Seawater Auxiliary Building rooftop.
- Area 4: Bays 0012 and 0013, Panels 0012-AD and 0013-AC, accessed from Intermediate Building roof top.

Each test area included individual panels of approximately 10 ft to 20 ft wide by approximately 6 ft tall wall section.

IR testing was performed using IR system B at intersections of a gridline system of 1 ft x 1 ft or 2 ft x 2 ft at various locations. IE testing was performed at the same test points where IR was performed in Areas 1 to 3 listed above. IE testing was not performed in Area 4.

The initial NDT in Areas 1 to 4 was completed by October 16, 2009. Based on the preliminary analysis of the NDT results, five coring locations were identified to correlate NDT test data. GPR testing was performed to identify layout of the reinforcing steel and tendon ducts in the vicinity of the identified core sample locations. Progress Energy procured five core samples on October 18 and 19, 2009.

Results

1) IR Testing

At the west side of the existing SGR opening where the delamination was visible in the plan of circumferential tendons along the perimeter of the opening, IR test results showed Average Mobility values ranging from approximately 1.03 to 2.40 with an average of approximately 1.5. Higher average mobility values typically indicate higher probability of existence of delamination or reduced effective thickness. In general, test results in Areas 2 to 4 showed significantly lower average mobility values, typically ranging from 0.16 to 0.72, with an average ranging from approximately 0.25 to 0.35 for various areas.

Cores #1 to 3 were removed in test area 2, Core #4 was removed from test area 3, while Core #5 was removed from test area 1 (west side of opening). Correlations between core observations and IR test results are shown below:

Core #	IR Average Mobility Value	Depth of Core (in.)	Core Observation
1	0.233	16-1/2	Sound concrete
2	0.420	13-1/2	Sound concrete
3	0.292	13	Sound concrete
4	0.166	12	Sound concrete
5	1.690	8-1/2	Delamination noted at 8-1/2 in. deep

Based on the limited sampling size and test result information, the IR test results indicated relatively good correlation between the Average Mobility values and internal condition of the containment wall structure. The following threshold values were initially recommended to be used to determine the existence of potential delaminations or other significant anomalies in the concrete wall structure:

$M \leq 0.4$:	solid concrete
$0.4<M<1.0$:	"gray" area, further test or coring is needed
$M \geq 1.0$:	potential "delaminated" concrete or other type of anomaly may exist

It was recognized that the correlation between IR and presence of delaminations was preliminary in view of the limited areas tested, and a small number of core samples removed for correlation of the IR test data. The fact of the preliminary nature of the above classification criteria was communicated with Progress Energy. Additional IR testing and verification coring were needed for a refined correlation between the NDT results and physical condition of the wall structure. In addition, several IR tests were performed directly over a located tendon duct, or in between two closely spaced tendon ducts (typically 12 in. on center). In such cases, the average mobility values could be slightly elevated to the range of approximately 0.4 to 0.7. CTLGroup communicated that a modification could be necessary once more data became available.

2) IE Testing

Impact Echo tests performed with a small ball bearing impactor showed distinct responses on the frequency spectra from the existing delaminations at all of the test points at the west side of opening area where delaminations were noted. The IE estimated depths of detected delaminations ranged from approximately 6.5 to 11.8 inches, and showed good correlation to the physically measured depth through a core hole. For example, the depth of existing delamination measured using Core #5 is 8.5 in., the corresponding IE resonant frequency is 9000 Hz, assuming a typical stress wave propagation velocity of 13,100 ft/s for regular concrete, the estimated depth of reflector (delamination) is estimated at approximately 8.4 inches. The IE frequency spectrum at this test point is shown in Figure C.1.

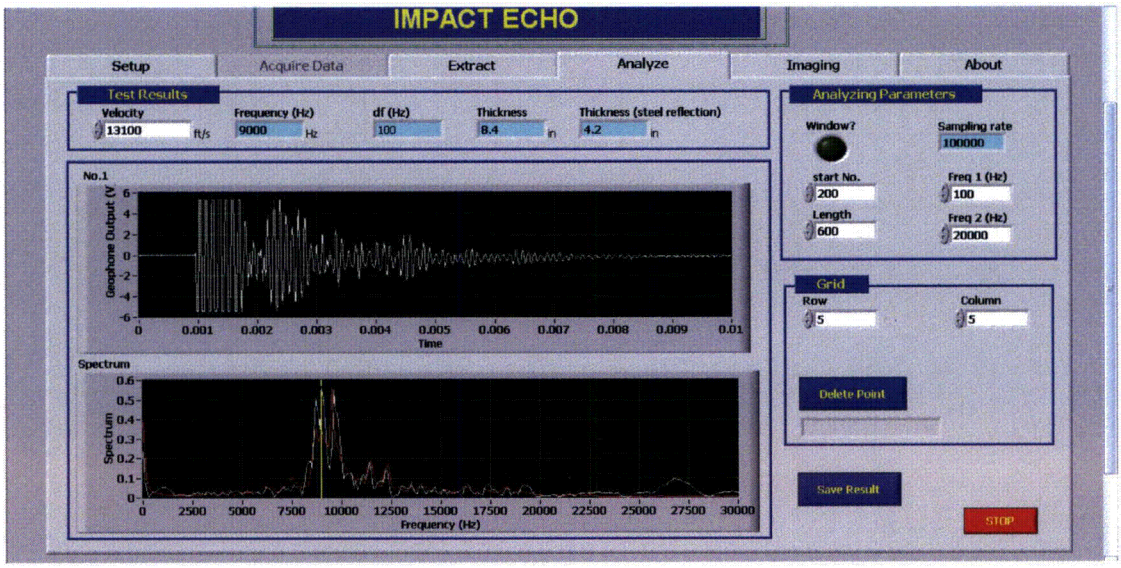


Figure C.1: IE test signal at Point (5, 5) in Area 1 – In the vicinity of Core #5

The IE test appeared to correlate well with the known delamination depth based on one verification core sample in this test area.

Impact Echo testing was performed in Areas 2 and 3 using a small ball bearing impactor. Majority of the test results obtained in these areas suggested a potential reflector at approximately 5 to 10 in., even though the resonant frequency appeared to be less pronounced compared to the signal obtained from Area 1. Although the corresponding IE results at locations in the vicinity of Cores #1 to 4 suggested potential reflectors at depths of approximately 6.3 in. to 10 in., the core samples did not indicate signs of any cracking or defects at those depths. Analysis of the test locations with regard to the tendon locations suggested high possibility of strong influence from the 5-1/8 inches diameter unbonded tendon ducts to the signal propagation. The apparent reflectors could be false positive readings.

Impact Echo test was also performed in all the above areas using a regular hammer with a rounded head in order to excite the back wall reflection of the 42-in.thick wall. (The previously utilized ball bearing impactor could not provide enough energy to excite the back wall reflection.) Test results in Areas 2 and 3 showed clear back wall responses at approximately 42 to 58 in. (see Figure C.2), while the results in Area 1 typically showed complex low frequency responses where the back wall reflection was not readily discerned (see Figure C.3). It should be noted that the apparent thicker back wall responses (greater than 50 in.) with a downward shifted

resonant frequency were obtained when the test points were close to or directly above a tendon duct (see Figure C.4.)

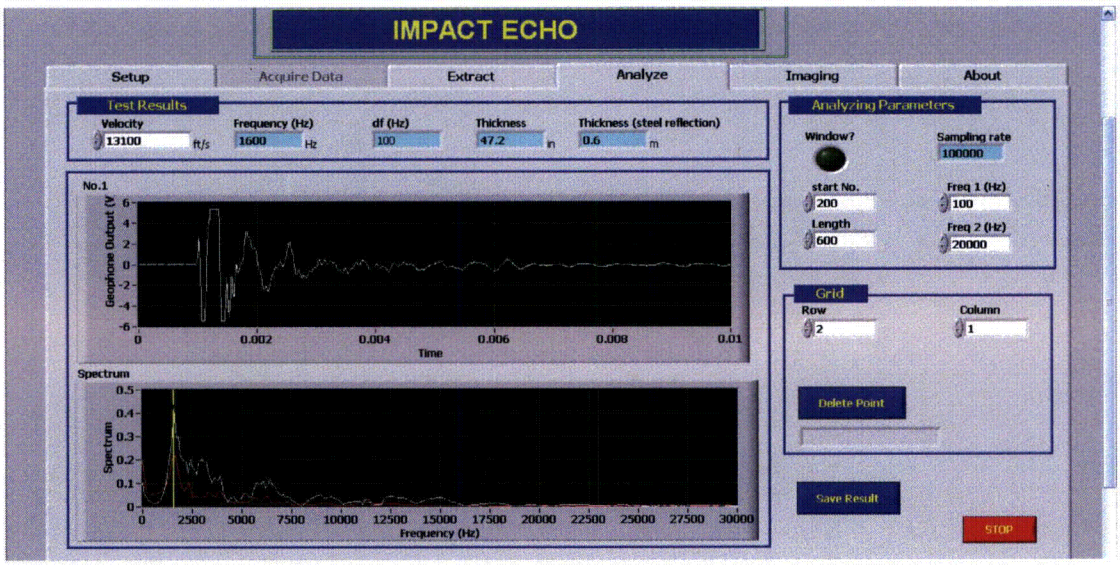


Figure C.2: Typical IE test signal obtained using hammer impact (Area 2) showing distinct back wall reflection

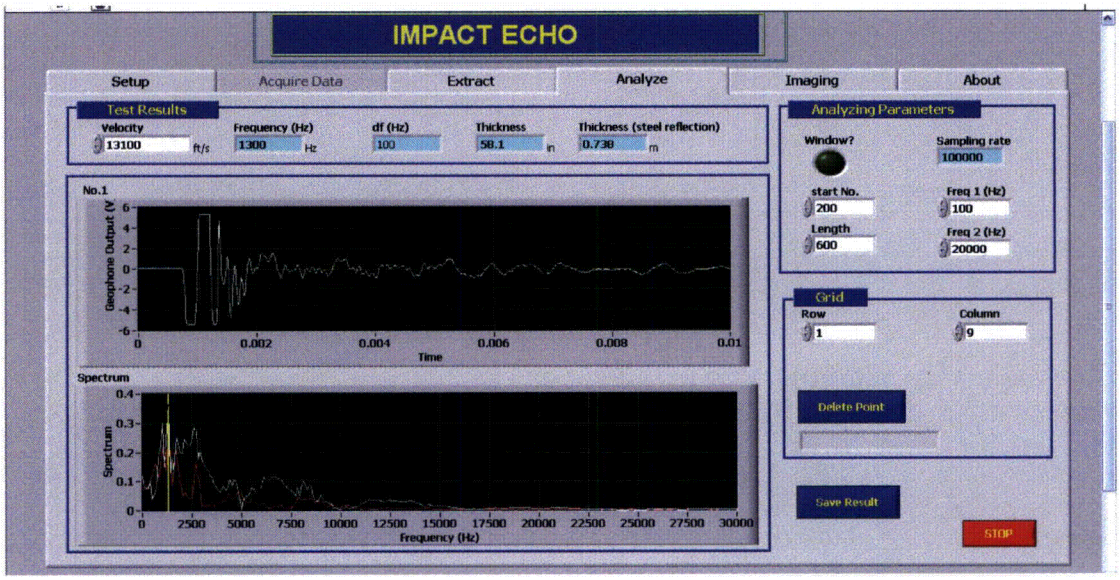


Figure C.3: Typical IE test signal obtained in Area 1 using hammer impact showing complex back wall reflection

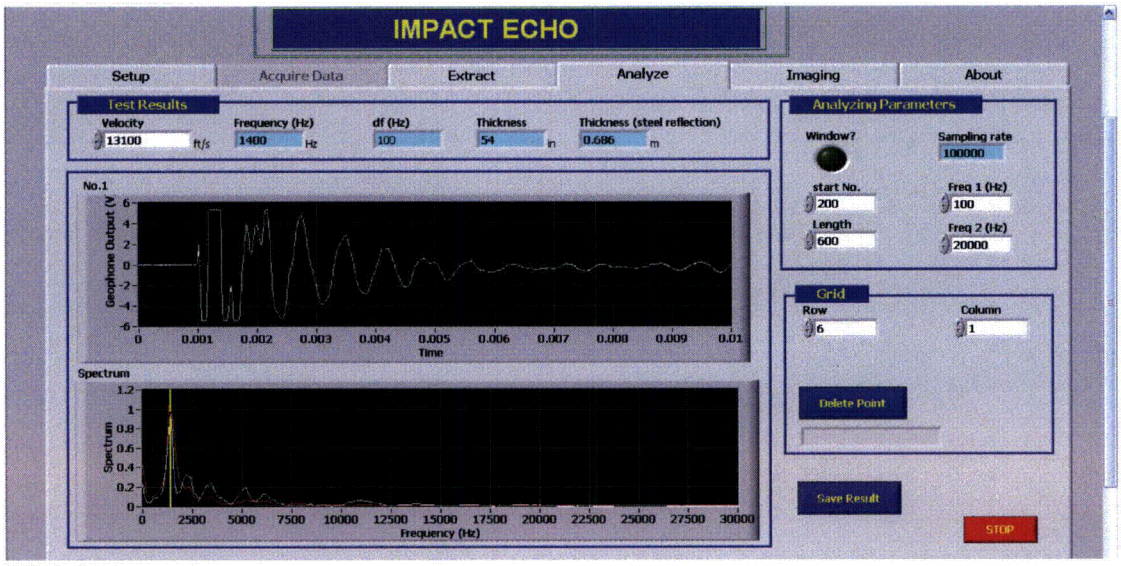


Figure C.4: Typical IE test signal obtained (Area 2) using hammer impact showing distinct but apparently thicker wall, the test point is close to a horizontal tendon

Summary of Initial Trial testing

Findings based on NDT results, field observations and limited core samples suggested a good correlation between IR average mobility values and concrete condition. The proposed evaluation criterion was preliminary and modification could be necessary when more data became available.

IE testing had potential to evaluate the depth of delamination, however, the test was not recommended due to the following:

- The test tended to produce false positive results which were likely influenced by the presence of adjacent 5-1/8 in. diameter unbonded post-tensioning duct(s).
- In order to perform an accurate IE test, the post-tensioning tendons and reinforcement in the wall need to be mapped out at every test point prior to testing. This process is time consuming and still could not eliminate the potential false positive readings.

Core sampling coupled with boroscope examination of core holes were recommended to evaluate the depth of delamination when indicated by IR testing, and this process could also be used to verify the IR results.

2. IR SYSTEM NORMALIZATION

Recognizing the potential performance difference between different Impulse Response (IR) systems, a correction (or normalization) factor need to be applied to the data collected using a different system other than IR system B used in the initial testing. Each IR system comprised a geophone sensor, an instrumented hammer, and data acquisition (DAQ) system. The threshold values stated in the existing procedure were established based on the data collected using the IR system B (Geophone S/N: 4003, Hammer S/N: 26088, DAQ: CTL-1). When a different IR system was first used, a cross checking procedure was conducted at areas that have been previously tested using system B with a minimum of 100 test points. This formed a baseline comparison. If the mean value of Average Mobility (M) differed by more than 10% from the previous results, all of the values obtained from the second system were normalized using the ratio between the average values. The correction factor was recorded for future analysis of data collected using IR system different than system B.

Three (3) different IR systems were used in the wall testing. (Dome testing using an Omni-Geophone was for information only, not listed in this table.) The tests were primarily performed using systems B and C. The component serial references of each system and corresponding normalization factors applied are shown below:

Table C.1

System #	Computer	DAQ box	Geophone	Hammer *	Normalization factor
A	Panasonic CF-Y2	CTL-1	1010	PCB 26088	1
B	Panasonic CF-Y2	CTL-1	4003	PCB 26088 PCB 23054	1
C	Panasonic CF-T1	CTL-2	1010	PCB 22610 PCB 26519	2; 0.86 (while power switch button turned on in several locations)

Note: * - System B had originally a hammer SN 26088, swamped with SN 23054 at later phase.
- System C had originally a hammer SN 22610, swamped with SN 26519 at later phase.

The comparison tests between systems B and C were performed at the following panel locations: 0013-AB, 0013-AC, 0013-AD, 0011-N, 0011-O, 0010-W, 0010-X, 0014-AB, 0014-AC, 0015-X and 0009-A (Spent Fuel Area). Approximately 500 points were tested. The average ratio

(C/B) obtained from different test locations between the two systems was 1.77. The correction factor was conservatively chosen as 2.0. In very few locations the power switch button on the DAQ unit was turned on, the correction factor changed to 0.86 based on comparison tests of a hundred points performed at panels 0014-AB and 0014-AC. (The voltage switch function of the DAQ unit was designed to limit the voltage input for some older version data cards to avoid saturating the channels, however, the newer data cards used in these IR system do not indeed require this function.) The raw data comparisons between the systems are shown in Table C.2.

As a relative test method, the Impulse Response test is typically used to compare the parameter (such as Average Mobility) values between different points collected with the same test system. Performance of different systems is subject to influence from various factors, such as: hammer impact angle, geophone unit, DAQ box design and wiring, temperature, and sometimes operator. When a test program requires use of multiple systems, a comparison test is normally performed to evaluate differences between raw data and correlation is established so that all results can be analyzed using the same criteria. In addition, due to the heterogeneous characteristics of concrete material, the Average Mobility values typically vary within a narrow range or band (in this case, the range is approximately 0.2 to 0.4). When condition of a concrete element changes significantly, such as existence of a delamination or changes in geometry, the Average Mobility values would increase or decrease significantly beyond the typical range. Therefore, a small variation due to the above mentioned factors does not impact data analysis. On this project, the typical Average Mobility value in areas where delaminations were noted exceeded 1.0 (with the Average Mobility values approaching 15 depending on the depth of delamination), while in solid concrete areas the Average Mobility values were typically below 0.4. There is large difference in structural response to the hammer impact when comparing a solid 42-in. wall to a concrete wall with delamination at approximately 6 to 12 in. from the surface.

3. Adjustment of Evaluation Criteria

As stated previously, the slightly elevated Average Mobility values between 0.4 and 0.7 could result if the test point is directly over a circumferential tendon duct or between two closely spaced tendons. After a larger amount of data was collected, more core samples were removed and boroscope examinations of core holes were performed, the previously developed threshold values for IR data interpretation were modified. The correlation information between Average Mobility and core observations obtained within bays 0010 to 0014 is presented in Table C.3. A complete core observation provided by Progress Energy is included in Appendix D. Additional IR data, core and core hole examination, field observations, and GPR testing strongly suggested that the previously chosen value of 0.4 as upper bound for solid concrete appeared to be overly conservative. Therefore, the threshold values were modified as follows:

- $M \leq 0.5$: sound concrete
- $0.5<M<1.0$: "gray" area, evaluate the need for further testing or coring
- $M \geq 1.0$: potentially delaminated concrete or other type of anomaly may exist, evaluate the need for further coring

The above threshold values are intended for evaluation of delaminations in the containment wall structure within approximately 20-in. depth from the exterior face. The above values are used in the data presentation included in this report.

Table C.2 Normalization Test Data

Panel #	0013-AB			0013-AC			0013-AD		
IR System #	B	C	Ratio	B	C	Ratio	B	C	Ratio
Average Mobility	0.06	0.135	0.44	0.143	0.146	0.98	0.58	0.14	4.14
	0.235	0.123	1.91	0.263	0.096	2.74	0.202	0.13	1.55
	0.092	0.199	0.46	0.357	0.106	3.37	0.206	0.26	0.79
	0.195	0.17	1.15	0.284	0.172	1.65	0.455	0.136	3.35
	0.075	0.112	0.67	0.263	0.126	2.09	0.224	0.134	1.67
	0.267	0.181	1.48	0.194	0.09	2.16	0.12	0.161	0.75
	0.121	0.103	1.17	0.291	0.067	4.34	0.167	0.196	0.85
	0.228	0.159	1.43	0.209	0.112	1.87	0.235	0.139	1.69
	0.315	0.097	3.25	0.209	0.135	1.55	0.47	0.189	2.49
	0.209	0.089	2.35	0.292	0.099	2.95	0.216	0.102	2.12
	0.316	0.083	3.81	0.462	0.176	2.63	0.24	0.136	1.76
	0.136	0.094	1.45	0.198	0.119	1.66	0.177	0.142	1.25
	0.311	0.066	4.71	0.219	0.105	2.09	0.215	0.191	1.13
	0.185	0.181	1.02	0.205	0.14	1.46	0.341	0.173	1.97
	0.226	0.099	2.28	0.194	0.077	2.52	0.208	0.145	1.43
	0.18	0.209	0.86	0.182	0.141	1.29	0.249	0.231	1.08
	0.159	0.139	1.14	0.188	0.071	2.65	0.446	0.098	4.55
	0.254	0.171	1.49	0.234	0.095	2.46	0.531	0.211	2.52
	0.307	0.056	5.48	0.29	0.06	4.83	0.384	0.211	1.82
	0.084	0.1	0.84	0.111	0.09	1.23	0.226	0.15	1.51
	0.231	0.117	1.97	0.195	0.123	1.59	0.354	0.113	3.13
	0.104	0.084	1.24	0.192	0.067	2.87	0.232	0.205	1.13
	0.288	0.199	1.45	0.16	0.066	2.42	0.374	0.219	1.71
	0.255	0.121	2.11	0.248	0.144	1.72	0.24	0.188	1.28
	0.203	0.18	1.13	0.137	0.098	1.40	0.107	0.118	0.91
	0.223	0.132	1.69	0.225	0.193	1.17	0.397	0.163	2.44
	0.2	0.16	1.25	0.108	0.052	2.08	0.074	0.124	0.60
	0.112	0.141	0.79	0.197	0.096	2.05	0.316	0.074	4.27
	0.24	0.085	2.82	0.28	0.13	2.15	0.271	0.208	1.30
	0.252	0.13	1.94	0.158	0.068	2.32	0.267	0.15	1.78
	0.142	0.194	0.73	0.183	0.123	1.49	0.154	0.136	1.13
	0.161	0.089	1.81	0.238	0.087	2.74	0.496	0.076	6.53
	0.193	0.093	2.08	0.3	0.138	2.17	0.205	0.224	0.92
	0.308	0.143	2.15	0.294	0.131	2.24	0.206	0.121	1.70
	0.09	0.117	0.77	0.267	0.09	2.97	0.167	0.096	1.74
	0.168	0.163	1.03	0.258	0.172	1.50	0.339	0.117	2.90
	0.175	0.075	2.33	0.215	0.127	1.69	0.172	0.077	2.23
	0.202	0.143	1.41	0.236	0.127	1.86	0.282	0.141	2.00
	0.366	0.176	2.08	0.263	0.121	2.17	0.425	0.099	4.29
	0.17	0.103	1.65	0.272	0.101	2.69	0.139	0.092	1.51
	0.28	0.094	2.98	0.384	0.207	1.86	0.268	0.108	2.48
	0.156	0.188	0.83	0.213	0.11	1.94	0.328	0.113	2.90
	0.183	0.154	1.19	0.204	0.103	1.98	0.157	0.106	1.48
	0.167	0.096	1.74	0.213	0.13	1.64	0.497	0.156	3.19
	0.241	0.114	2.11	0.265	0.118	2.25			
	0.253	0.145	1.74	0.366	0.233	1.57			
	0.169	0.081	2.09	0.236	0.068	3.47			
	0.368	0.197	1.87	0.423	0.136	3.11			
	0.2	0.176	1.14	0.221	0.113	1.96			
	0.224	0.107	2.09	0.29	0.091	3.19			
Average	0.21	0.13	**1.75**	0.24	0.12	**2.22**	0.28	0.15	**2.09**

Table C.2 Normalization Test Data (Cont'd)

Panel #	0011-N			0011-O			0010-W		
IR System #	B	C	Ratio	B	C	Ratio	B	C	Ratio
Average Mobility	0.269	0.178	1.51	0.162	0.098	1.65	0.204	0.129	1.58
	0.488	0.261	1.87	0.372	0.125	2.98	0.233	0.169	1.38
	0.19	0.399	0.48	0.437	0.236	1.85	0.079	0.092	0.86
	0.288	0.173	1.66	0.287	0.213	1.35	0.357	0.147	2.43
	0.16	0.111	1.44	0.135	0.148	0.91	0.426	0.371	1.15
	0.176	0.152	1.16	0.294	0.237	1.24	0.242	0.092	2.63
	0.376	0.162	2.32	0.341	0.249	1.37	0.425	0.177	2.40
	0.29	0.177	1.64	0.265	0.23	1.15	0.343	0.28	1.23
	0.286	0.199	1.44	0.212	0.11	1.93	0.283	0.221	1.28
	0.283	0.298	0.95	0.174	0.156	1.12	0.251	0.084	2.99
	0.344	0.202	1.70	0.364	0.297	1.23	0.159	0.117	1.36
	0.388	0.181	2.14	0.426	0.224	1.90	0.235	0.125	1.88
	0.348	0.193	1.80	0.11	0.068	1.62	0.238	0.094	2.53
	0.259	0.226	1.15	0.188	0.142	1.32	0.198	0.072	2.75
	0.437	0.304	1.44	0.256	0.221	1.16	0.36	0.069	5.22
	0.606	0.344	1.76	0.303	0.133	2.28	0.157	0.081	1.94
	0.642	0.182	3.53	0.217	0.16	1.36	0.402	0.133	3.02
	0.454	0.391	1.16	0.253	0.164	1.54	0.326	0.112	2.91
	0.319	0.216	1.48	0.237	0.163	1.45	0.124	0.078	1.59
	0.226	0.328	0.69	0.4	0.221	1.81	0.244	0.084	2.90
	0.351	0.364	0.96	0.179	0.133	1.35			
	0.425	0.301	1.41	0.255	0.118	2.16			
	0.414	0.257	1.61	0.203	0.13	1.56			
	0.543	0.461	1.18	0.338	0.151	2.24			
	0.243	0.203	1.20	0.415	0.121	3.43			
	0.339	0.26	1.30	0.23	0.185	1.24			
	0.517	0.292	1.77	0.369	0.097	3.80			
	0.43	0.376	1.14	0.246	0.131	1.88			
	0.261	0.123	2.12	0.431	0.115	3.75			
	0.449	0.247	1.82	0.273	0.117	2.33			
	0.649	0.473	1.37	0.297	0.222	1.34			
	0.323	0.308	1.05	0.292	0.118	2.47			
	0.178	0.177	1.01	0.201	0.112	1.79			
	0.345	0.445	0.78	0.31	0.133	2.33			
	0.235	0.367	0.64	0.232	0.196	1.18			
	0.276	0.311	0.89	0.22	0.275	0.80			
	0.324	0.176	1.84	0.21	0.283	0.74			
	0.514	0.365	1.41	0.22	0.154	1.43			
	0.609	0.46	1.32	0.455	0.173	2.63			
	0.44	0.223	1.97	0.156	0.163	0.96			
Average	0.37	0.27	**1.45**	0.27	0.17	**1.77**	0.26	0.14	**2.20**

Table C.2 Normalization Test Data (Cont'd)

Panel #	0010-X			0014-AB			0014-AC		
IR System #	B	C	Ratio	B	C	Ratio	B	C	Ratio
Average Mobility	0.521	0.22	2.37				0.152	0.092	1.65
	0.348	0.091	3.82				0.233	0.109	2.14
	0.42	0.096	4.38	0.209	0.101	2.07	0.237	0.119	1.99
	0.252	0.079	3.19	0.223	0.08	2.79	0.33	0.097	3.40
	0.384	0.254	1.51	0.27	0.24	1.13	0.178	0.11	1.62
	0.283	0.139	2.04				0.25	0.098	2.55
	0.21	0.144	1.46				0.221	0.079	2.80
	0.196	0.083	2.36	0.18	0.104	1.73	0.132	0.093	1.42
	0.25	0.175	1.43	0.153	0.116	1.32	0.306	0.095	3.22
	0.417	0.119	3.50	0.178	0.184	0.97	0.269	0.084	3.20
	0.088	0.105	0.84	0.226	0.082	2.76	0.148	0.093	1.59
	0.284	0.144	1.97	0.202	0.158	1.28	0.173	0.099	1.75
	0.28	0.298	0.94	0.137	0.078	1.76	0.221	0.098	2.26
	0.325	0.143	2.27	0.217	0.082	2.65	0.278	0.144	1.93
	0.213	0.127	1.68	0.252	0.114	2.21	0.226	0.168	1.35
	0.214	0.142	1.51	0.176	0.113	1.56	0.218	0.094	2.32
	0.206	0.128	1.61	0.219	0.118	1.86	0.236	0.095	2.48
	0.238	0.188	1.27	0.233	0.139	1.68	0.147	0.106	1.39
	0.414	0.091	4.55	0.227	0.094	2.41	0.282	0.064	4.41
	0.329	0.095	3.46	0.251	0.079	3.18	0.218	0.105	2.08
	0.246	0.182	1.35	0.176	0.077	2.29	0.198	0.113	1.75
	0.331	0.173	1.91	0.142	0.116	1.22	0.256	0.097	2.64
	0.188	0.13	1.45	0.233	0.071	3.28	0.107	0.088	1.22
	0.486	0.27	1.80	0.214	0.094	2.28	0.204	0.086	2.37
	0.288	0.159	1.81	0.299	0.096	3.11	0.24	0.094	2.55
	0.359	0.134	2.68	0.145	0.085	1.71	0.179	0.084	2.13
	0.139	0.122	1.14	0.135	0.066	2.05	0.2	0.101	1.98
	0.41	0.272	1.51	0.216	0.065	3.32	0.199	0.086	2.31
	0.138	0.14	0.99	0.256	0.142	1.80	0.253	0.078	3.24
	0.195	0.1	1.95	0.182	0.171	1.06	0.266	0.108	2.46
	0.091	0.112	0.81	0.207	0.11	1.88	0.206	0.091	2.26
	0.305	0.272	1.12	0.132	0.173	0.76	0.318	0.067	4.75
	0.165	0.162	1.02	0.212	0.125	1.70	0.354	0.095	3.73
	0.407	0.113	3.60	0.237	0.117	2.03	0.224	0.13	1.72
	0.19	0.135	1.41	0.135	0.134	1.01	0.191	0.073	2.62
	0.405	0.214	1.89	0.138	0.074	1.86	0.268	0.096	2.79
	0.192	0.133	1.44	0.21	0.091	2.31	0.21	0.074	2.84
	0.162	0.058	2.79	0.18	0.12	1.50	0.224	0.113	1.98
	0.264	0.127	2.08	0.235	0.12	1.96	0.264	0.118	2.24
	0.413	0.289	1.43	0.323	0.082	3.94	0.245	0.123	1.99
				0.164	0.069	2.38	0.26	0.078	3.33
				0.172	0.149	1.15	0.279	0.087	3.21
				0.138	0.09	1.53	0.219	0.097	2.26
				0.148	0.127	1.17	0.326	0.107	3.05
				0.189	0.126	1.50	0.27	0.135	2.00
				0.124	0.14	0.89	0.218	0.116	1.88
				0.219	0.176	1.24	0.327	0.099	3.30
				0.091	0.078	1.17	0.189	0.129	1.47
				0.244	0.149	1.64	0.348	0.209	1.67
				0.221	0.229	0.97	0.316	0.133	2.38
Average	0.28	0.15	**2.01**	0.20	0.12	**1.87**	0.24	0.10	**2.39**

Table C.2 Normalization Test Data (Cont'd)

Panel #	0015-X			0009A - Spent fuel		
IR System #	B	C	Ratio	B	C	Ratio
Average Mobility				0.157	0.101	1.55
				0.277	0.266	1.04
				0.257	0.162	1.59
				0.171	0.128	1.34
				0.257	0.189	1.36
				0.277	0.275	1.01
				0.201	0.259	0.78
				0.163	0.15	1.09
				0.077	0.209	0.37
				0.164	0.193	0.85
				0.163	0.247	0.66
				0.25	0.232	1.08
				0.283	0.332	0.85
				0.238	0.203	1.17
				0.14	0.154	0.91
				0.214	0.144	1.49
				0.186	0.228	0.82
				0.216	0.216	1.00
				0.194	0.085	2.28
				0.137	0.258	0.53
				0.172	0.166	1.04
				0.113	0.147	0.77
				0.28	0.29	0.97
				0.14	0.277	0.51
				0.229	0.188	1.22
	1.989	1.354	1.47	0.257	0.146	1.76
	3.142	1.333	2.36	0.23	0.134	1.72
	1.961	1.49	1.32	0.237	0.215	1.10
	1.257	1.061	1.18	0.242	0.166	1.46
				0.2	0.13	1.54
	1.657	1.718	0.96	0.269	0.217	1.24
	1.929	1.706	1.13	0.16	0.189	0.85
	2.09	1.986	1.05	0.196	0.202	0.97
	1.698	1.515	1.12	0.182	0.228	0.80
				0.279	0.256	1.09
	4.446	5.702	0.78	0.157	0.144	1.09
	5.554	7.254	0.77	0.146	0.274	0.53
	5.22	4.412	1.18	0.238	0.138	1.72
	5.991	3.265	1.83	0.356	0.196	1.82
				0.226	0.226	1.00
	9.445	8.903	1.06	0.134	0.134	1.00
	6.85	8.99	0.76	0.231	0.246	0.94
	8.527	7.058	1.21	0.171	0.309	0.55
	11.131	7.709	1.44	0.113	0.168	0.67
				0.242	0.136	1.78

	5.031	12.287	0.41	0.308	0.187	1.65
	9.92	9.086	1.09	0.271	0.323	0.84
				0.31	0.379	0.82
				0.214	0.335	0.64
				0.126	0.147	0.86
				0.08	0.18	0.44
				0.217	0.139	1.56
				0.258	0.176	1.47
				0.243	0.12	2.03
				0.283	0.225	1.26
				0.165	0.195	0.85
				0.14	0.208	0.67
				0.203	0.182	1.12
				0.205	0.172	1.19
				0.21	0.234	0.90
				0.194	0.159	1.22
				0.197	0.177	1.11
				0.22	0.181	1.22
				0.165	0.152	1.09
				0.174	0.209	0.83
				0.285	0.238	1.20
				0.221	0.212	1.04
				0.136	0.121	1.12
				0.123	0.219	0.56
				0.275	0.155	1.77
				0.176	0.116	1.52
				0.143	0.212	0.67
				0.161	0.269	0.60
				0.154	0.272	0.57
				0.307	0.25	1.23
				0.103	0.126	0.82
				0.19	0.263	0.72
				0.234	0.142	1.65
				0.087	0.141	0.62
				0.197	0.187	1.05
				0.207	0.218	0.95
				0.205	0.207	0.99
				0.193	0.139	1.39
				0.168	0.202	0.83
				0.189	0.172	1.10
				0.303	0.217	1.40
				0.267	0.257	1.04
				0.155	0.244	0.64
				0.20	0.15	1.33
				0.30	0.213	1.38
				0.15	0.253	0.58
				0.14	0.208	0.65
				0.20	0.175	1.15
				0.228	0.237	0.96

				0.195	0.111	1.76
				0.16	0.148	1.08
				0.181	0.178	1.02
				0.217	0.164	1.32
Average	4.88	4.82	**1.17**	0.20	0.20	**1.09**

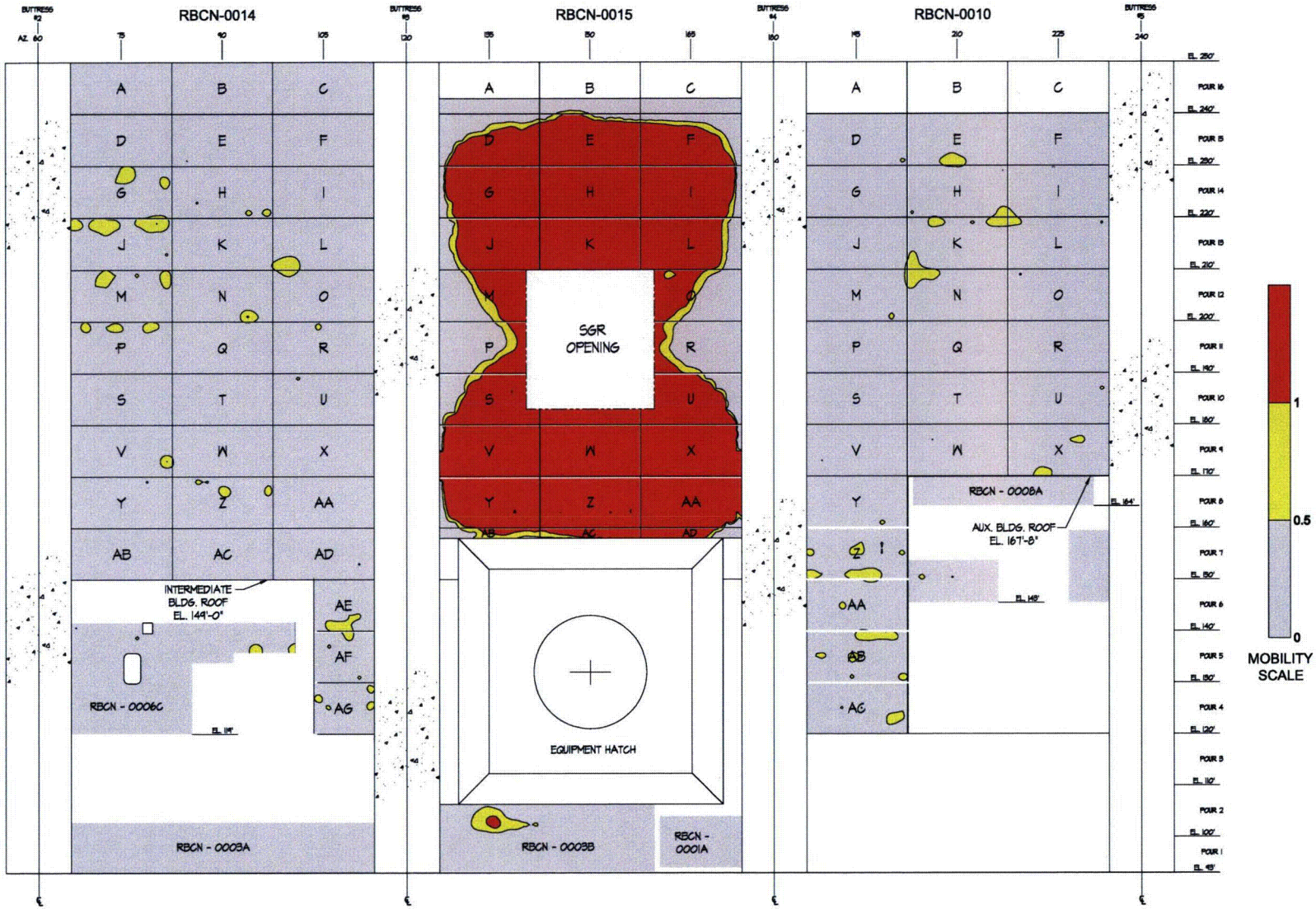
Table C.3: Concrete Core Examination Log

Core No.	RBCN Location	Panel Designation	Core Dimensions Diameter x Length	Core Location on Panel (X, Y) (from left hand upper corner)	IR Test Point (Col, Row)	Normalized Mobility Value	Core Condition
1	0011	N	4" x 16.5"	181.5", 39"	8, 3	0.649	G
2	0011	N	4" x 17"	228.5", 76"	10, 2	0.514	G
3	0011	O	4" x 13"	169", 38.5"	7, 3	0.369	G
4	0010	W	4" x 13"	154", 96"	7, 1	0.426	G
11	0011	N	1" X 20"	197", 25"	9, 4	0.276	G
12	0014	K	2" X 12"	165", 91"	8, 2	0.152	G
13	0014	N	2" X 12"	193", 114"	(8,1) to (9, 1)	1.102 to 0.375	*
20	0010	D	2" x 12"	107", 41"	5, 4	0.168	G
24	0011	H	2" X 20"	11.5", 99.5"	1, 1	0.944	G
29	0011	L	2" X 12"	119", 51"	5, 4	0.471	G
30	0010	K	8" X 15"	80", 73"	4, 2	0.398	G
31	0010	K	2" X 10"	17", 106"	1, 1	0.673	G
33	0011	K	2" X 20"	113", 110"	5, 1	0.830	G
40	0010	N	4" X 30"	15", 25"	1, 4	0.707	G
42	0011	Q	2" X 12"	68", 40"	3, 4	0.252	G
43	0014	U	2" X 12"	168", 34"	7, 4	0.197	G
44	0014	I	2" X 12"	65", 57"	3, 3	0.285	G
45	0014	L	2" X 12"	17", 109"	1, 1	0.705	G
50	0010	AA	1" x 12"	96", 50"	4, 3	0.602	G
62	0013	H	1" x 20"	56", 60"	3, 3	0.258	G
63	0013	H	4" x 20"	158.5", 37"	7, 4	0.311	G
64	0013	N	1" X 20"	158", 10"	7, 5	0.270	G
65	0013	Q	4" x 20"	163", 23"	8, 4	0.328	G
66	0013	W	4" x 20"	77", 97"	4, 2	0.215	G
67	0012	H	4" X 20"	186", 24"	8, 4	0.238	G
68	0012	G	2" x 20"	58", 32"	3, 4	0.320	G
69	0012	P	2" x 20"	62", 84"	3, 2	0.210	G
70	0012	Y	2" X 12"	185", 9"	8, 5	0.648	G
71	0014	G	2" x 20"	111", 34"	5, 4	0.520	G
72	0014	J	2" X 20"	205", 30"	9, 4	0.368	G
73	0011	C	2" X 20"	148", 63"	7, 3	0.580	G
74	0014	E	2" X 12"	42", 98"	3, 1	0.286	G
75	0012	W	2" X 20"	184", 41"	8, 4	0.508	G
76	0012	Q	2" X 20"	195-3/4", 14-1/2"	9, 4	0.550	G
77	0012	L	2" x 20"	52", 99"	3, 1	0.240	G
85	0012	W	2" X 12"	22" x 113"	2,1	0.344	G

G – Good Condition
* - lack of course aggregate and presence of a gouge at 12 in. deep

APPENDIX D

IR Test Result Figures



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Crystal River, FL

ISSUE

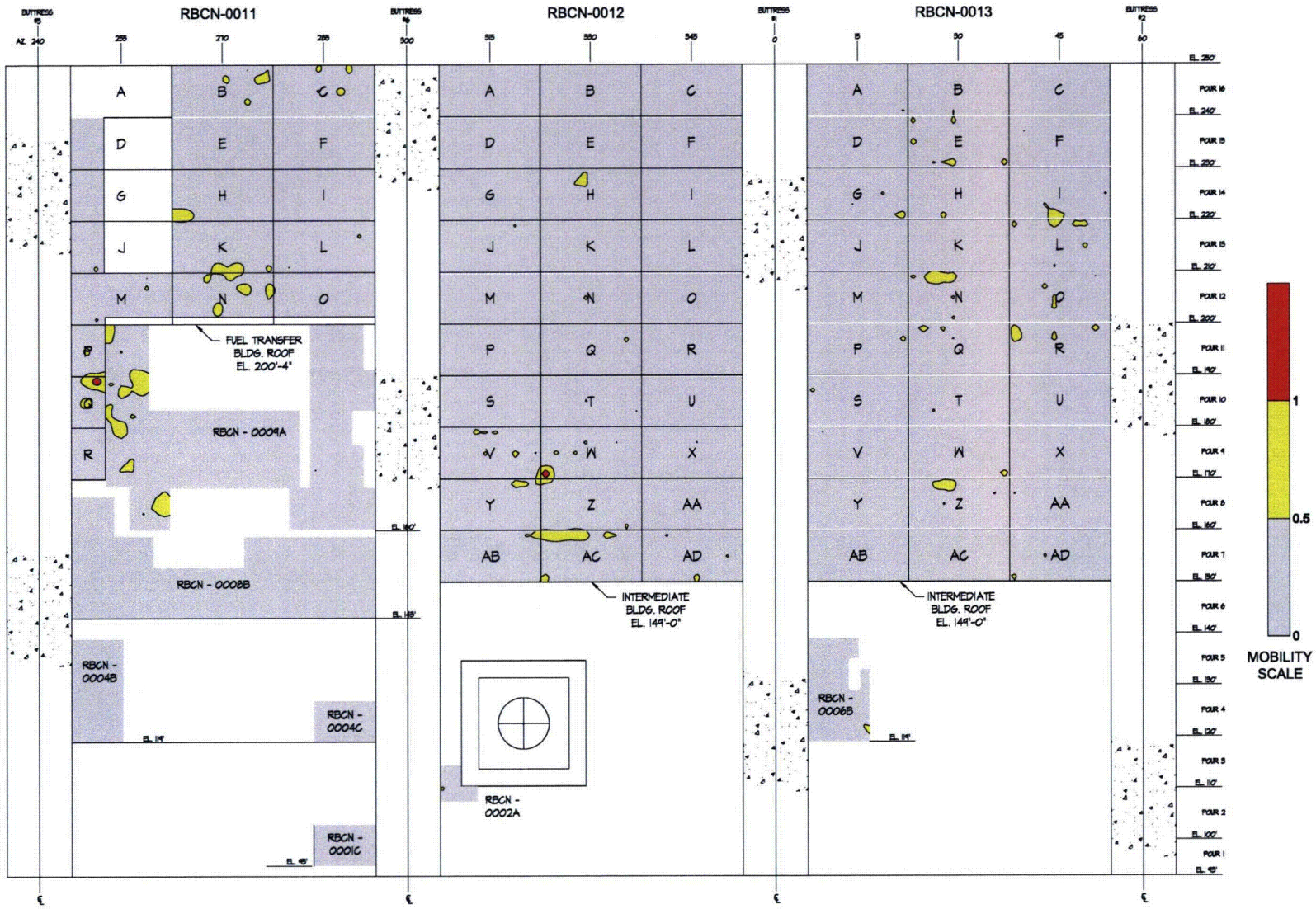
No.	Description	Date

CTLGroup No.:	059169
Drawn:	DRA
Checked:	SVC/HGC
Date:	22JAN10
Scale:	NTS

Impulse Response Mobility Plot

FIG. No.:

1



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Crystal River, FL

ISSUE

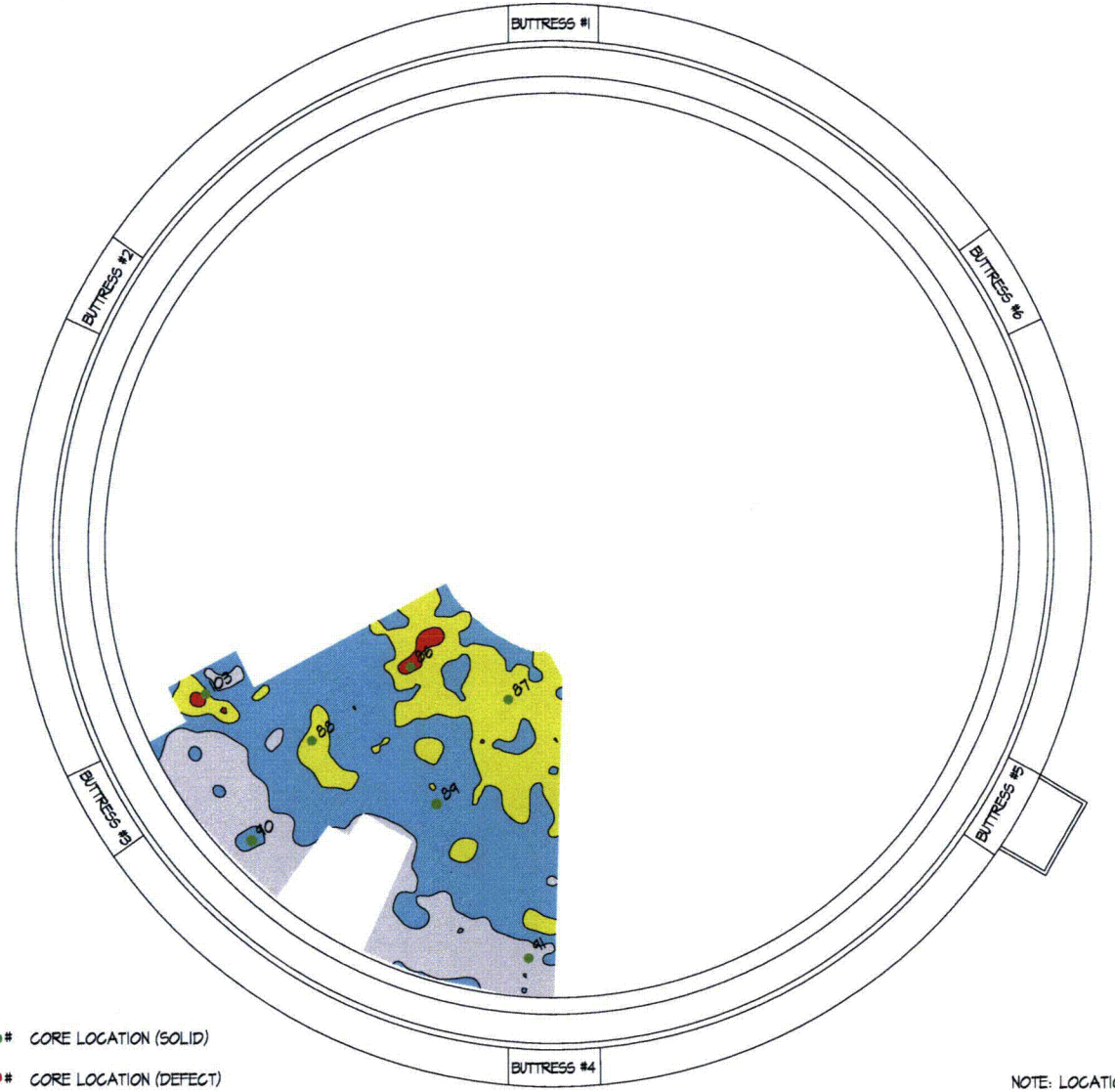
No.	Description	Date

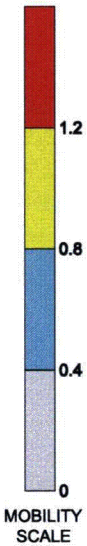
CTLGroup No.:	059169
Drawn:	DRA
Checked:	SVC/HGC
Date:	22JAN10
Scale:	NTS

Impulse Response Mobility Plot

FIG. No.:

2





● # CORE LOCATION (SOLID)

● # CORE LOCATION (DEFECT)

NOTE: LOCATION OF CORES IN THE FIELD SHOULD GOVERN.

N

1 CONTAINMENT STRUCTURE DOME

NTS

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No.	Description	Date

CTLGroup No.:	059169
Drawn:	DRA
Checked:	SVC/HGC
Date:	22JAN10
Scale:	NTS

Impulse Response Mobility Plot and Core Locations

FIG. No.:

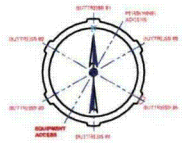
3

APPENDIX E

Core Locations and Borescope Observations

(Provided by Progress Energy)

KEY NO.: E



● CORE BORE WITH DELAMINAITON
● CORE BORE NOT DELAMINATED

NO.	DESCRIPTION	DRAWN
A	ISSUED PER EC 74801	

REVISIONS

Progress Energy

NUCLEAR ENGINEERING

CRYSTAL RIVER UNIT 3

CORE BORE LOCATIONS

DRAWN	CHKD.	APRVD.	DATE	SCALE
-	-	-	12/03/2009	3/16" = 1'-0"

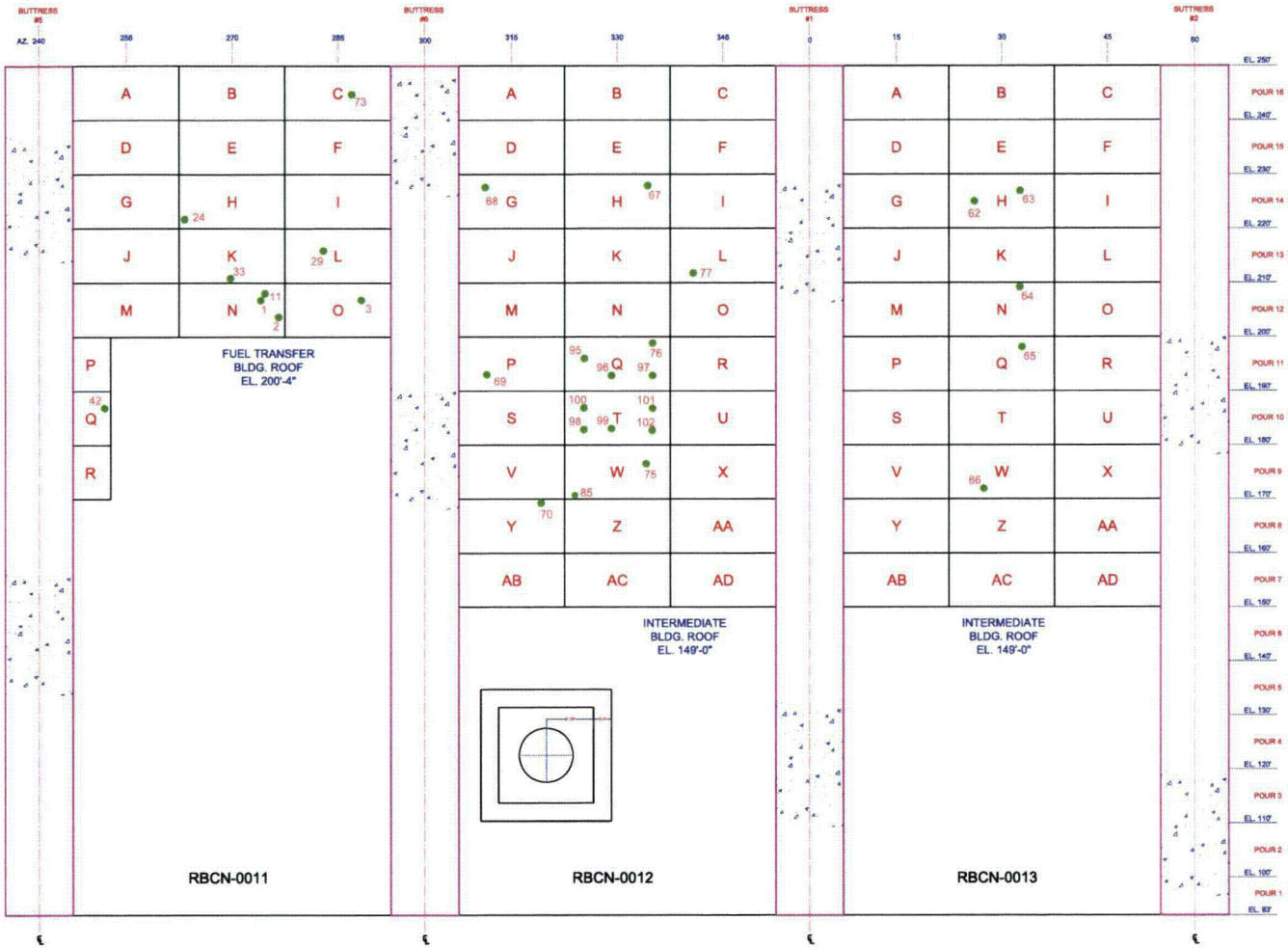
DISCP.	SHEET	DWG.	REV.
-	SH-001	SK-74801-2	A

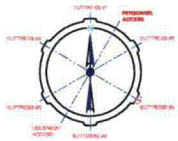
SCALE TO PRINT
3/16" = 1'-0"
(PAPER SIZE: 36x60)

FILE

D

KEY NO.: E





● CORE BORE WITH DELAMINATION
● CORE BORE NOT DELAMINATED

NO.	DESCRIPTION	DRAWN
A	ISSUED PER EC 74801	

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CORE BORE LOCATIONS

DRAWN	CHKD.	APRVD.	DATE	SCALE
-	-	-	12/03/2009	3/16" = 1'-0"

DISCP	SHEET	DWG.	REV.
-	SH-002	SK-74801-2	A

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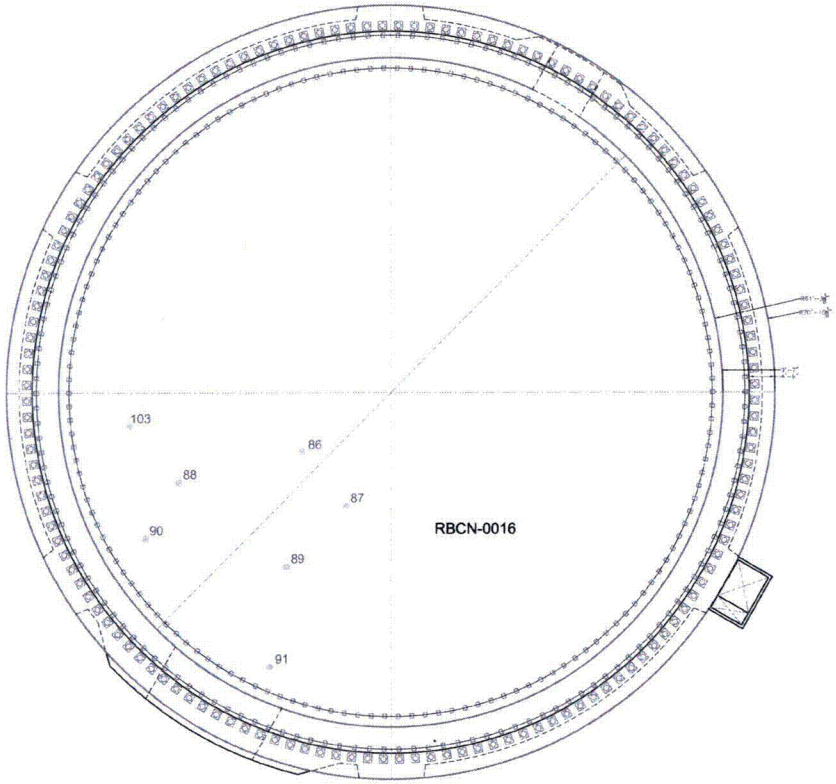
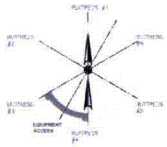
FILE

KEY NO.: E





SCALE TO PRINT
3/16" = 1'-0"

● CORE BORE WITH DELAMINATION
⊗ CORE BORE NOT DELAMINATED
TO BE CORE BORED
● CORE BORE DRILLED

DOME CORE BORE LOCATIONS			
CORE BORE #	SOUTH	NORTH	DIMENSIONED FROM CENTER OF DOME IN SOUTH/NORTH DIRECTION
86	10'-9"	16'-6"	---
87	20'-10"	8'-4"	---
88	16'-6"	30'-3"	---
89	31'-11"	19'-5"	---
90	26'-9"	45'-6"	---
91	50'-4"	22'-7"	---
103	6'-3"	48'-4"	---

NO.	DESCRIPTION	DRAWN.
A	ISSUED PER EC 75000	

REVISIONS

Progress Energy

NUCLEAR ENGINEERING

CRYSTAL RIVER
UNIT 3

CONTAINMENT DOME
CORE BORE LOCATIONS

TDF DRAWN	– CHKD.	– APRVD.	X DATE	N.T.S. SCALE
S DISCP.	1 OF 1 SHEET	SK-75000-C00 DWG.		A REV.

FILE:

Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
1	-0011	N	4 x 16.5	181-1/2 x 39	10/17/09	11/8/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	NO CRACKS, HOLES, GAPS, OR IMPERFECTIONS
2	-0011	N	4 x 13.5	228-1/2 x 76	10/18/09	11/8/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	NO CRACKS, HOLES, GAPS, OR IMPERFECTIONS
3	-0011	O	4 x 13	169 x 38-1/2	10/18/09	11/8/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	SMALL BUG HOLES NO CRACKS, HOLES, GAPS, OR IMPERFECTIONS
4	-0010	W	4 x 13	154 x 96	10/18/09	11/10/09	11/10/09	-	-	-	-	-	-	-	-	-	-	-	-	NO CRACKS, HOLES, GAPS, OR IMPERFECTIONS
5	-0015	S	4 x 9	151 x 40	10/18/09	11/6/09 & 11/16/09	11/21/09	8 TO 9	-	7/16	-	-	-	3-7/8	-	-	-	-	-	Hairline fracture running in and out of wall in direction of liner plate.
6	-0015	J	4	149 x 64	10/23/09	-	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	See core # 6aa
6a	-0015	J	8 x 12	149 x64	10/30/09	-	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	See core # 6aa
6aa	-0015	J	8 x 18	149 x64	11/5/09	11/20/09	11/29/09	6 to 8-1/2	9 to 10-1/2	1	1/4	-	-	-	-	-	-	-	-	Drilled 8" dia. hole 6" deeper
7	-0015	J	4 x 8	99-1/2 x 63	10/28/09	11/14/09	11/21/09	7	7-3/8	½ to 1/4	1/8									
8	-0015	W	2 x 10	48 x 39	10/24/09	11/11/09	11/21/09	6	8-3/8	3/4	1-5/8	-	-	-	-	-	-	-	-	Drilled to 11".
9	-0015	W	2 x 9	188 x 39	10/24/09	11/11/09	11/21/09	7-1/8	-	1-1/2	-	*	-	-	-	-	-	-	-	* Out of plane crack at the end of the hole along the perimeter. Drilled to 8-1/2.
10	-0010	E	-	-	-	-	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	Unable to core due to inferences

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
11	-0011	N	1 x 20	197 x 25	11/08/09	11/10/09	11/21/09	-	-	-	-	*	-	-	-	-	-	-	-	* One crack out of plane at the end of the hole (crack is around the entire perimeter and running into the building).
12	-0014	K	2 x 12	164-1/2 x 91	10/28/09	11/11/09	11/12/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
13	-0014	N	2 x 12	193 x 114	10/28/09	11/11/09	11/21/09	-	-	-	-	-	-	-	-	-	12-1/2	-	-	Object noted at 1200. Light gouge from 0700 to 1200 9-1/2" in < 1/32". Small amount of aggregate present.
14	-0015	D	2 x 12	206 x 14	10/28/09	11/14/09	11/21/09	-	-	-	-	*	-	-	-	-	-	-	-	Small out of plane crack at the end of the hole, ~1/4 of the circumference of the hole
15	-0015	J	2 x 12	24 x 62	10/28/09	11/14/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
16	-0015	M	2 x 20	60 x 60	11/6/09	11/14/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
17	-0015	M	2 x 12	132-1/2 x 53	10/30/09	11/14/09	11/24/09	10	11-1/2	1/8	3/8	-	-	-	-	-	-	-	-	
18	-0015	J	2 x 14	59-1/2 x 63-1/2	11/3/09	11/14/09	11/24/09	7-1/2	-	1/16	-	-	-	-	-	-	-	-	-	
19	-0015	D	2 x 14	201-1/2 x 36	11/3/09	11/14/09	11/24/09	7-1/8	-	1/8	-	-	-	-	-	-	-	-	-	
20	-0010	D	2 x 12	107 x 41	11/14/09	11/14/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
21	-0015	AC	1 x 6	86 x 4	11/9/09	11/11/09	11/24/09	4-1/4	-	< ¼	-	-	-	-	-	-	-	-	-	Drilled to 11-1/2".
22	-0015	X	1 x 6	208 x 79	11/4/09	11/10/09	11/24/09	2	3-1/4	3/8	¼	-	-	-	-	-	-	-	-	Drilled to 12".

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
23	-0015	U	2 x 12	223 x 88	11/4/09	11/10/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Drilled to 19.5". No imperfections found.
24	-0011	H	2 x 20	11-1/2 x 99-1/2	11/16/09	11/16/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Drilled to 20-1/2". No imperfections found.
25	-0015	R	2 x 20	148-3/4 x 93	11/4/09	11/10/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Drilled to 19.5". No imperfections found.
26	-0015	O	2 x 20	177 x 52	11/4/09	11/10/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
27	-0015	L	2 x 20	177 x 104	11/4/09	11/10/09	11/24/09	7-1/2	-	1/32	-	-	-	-	-	-	-	-	-	Drilled to 18".
28	-0015	L	2 x 20	210 x 103	11/4/09	11/10/09	11/24/09	-	-	-	-	-	-	13	¼ - 3/8	-	-	-	-	No other imperfections found.
29	-0011	L	2 x 12	119 x 51	11/14/09	11/17/09	11/23/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes throughout hole. Pilot hole penetrated core. No other imperfections found.
30	-0010	K	8 x15	80 x 73	11/2/09	11/19/09	11/20/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes throughout hole. Strain gauge installation partially obscured hole. No abnormalities seen around perimeter of epoxy.
31	-0010	K	2 x 10	17 x 106	11/2/09	11/14/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
32	-0015	F	2 x 12	212 x 35	11/4/09	11/10/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
33	-0011	K	2 x 20	113 x 110	11/16/09	11/16/09	11/23/09	-	-	-	-	-	-	-	-	-	*	-	-	Drilled to 19-11/16". Noticeable grooves in and out of plane of wall. Appears to be caused by drilling process. Small voids/bug holes seen throughout hole. No other abnormalities.

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
34	-0015	E	1 x 20	201 x 12	11/12/09	11/13/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
35	-0015	P	2 x20	139 x 52	11/6/09	11/14/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
36	-0015	Y	2 x 12	42 x 79	11/5/09	11/06/09	11/24/09	5-3/4	-	1/4	-	-	-	-	-	-	-	-	-	No other imperfections found.
37	-0015	Y	2 x12	19-1/2 x 115	11/5/09	11/06/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
38	-0015	Y	1 x 20	7 x 18	11/9/09	11/11/09	11/24/09	-	-	-	-	-	-	*	-	-	-	-	-	* Several small holes < ¼" long.
39	-0015	V	2 x 12	37 x 41	11/7/09	11/12/09	11/24/09	3-1/2	-	¾	-	-	-	-	-	-	-	-	-	
40	-0010	N	4 x 30	15 x 25	11/7/09	11/14/09	11/23/09	-	-	-	-	-	-	*	-	-	-	-	-	*Small voids/bug holes seen throughout hole. No other imperfections found.
41	-0015	V	1 x 12	12 x 22-1/2	11/7/09	11/12/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Drilled to 20".
42	-0011	Q	2 x 12	68 x 40	11/11/09	11/12/09	11/24/09	-	-	-	-	-	-	*	-	-	-	-	-	Small bug holes.
43	-0014	U	2 x 12	168 x 34	11/8/09	11/12/09	11/24/09	-	-	-	-	-	-	*	-	-	-	-	-	Drilled to 12-1/4". Bug holes.
44	-0014	I	2 x 12	65 x 57	11/8/09	11/12/09	11/24/09	-	-	-	-	-	-	*	-	-	-	-	-	Bug holes.
45	-0014	L	2 x 12	17 x 109	11/8/09	11/12/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
46	-0015	AC	3/8 x 20 PILOT HOLE	-	-	11/13/09	11/24/09	-	-	-	-	-	-	11	3/16	-	-	-	-	Deleted due to proximity to #21. Lower left pilot hole scoped.

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
47	-0015	AD	1 x 20	43 x 19	11/9/09	11/11/09	11/24/09	3/8	-	1/32	-	-	-	11-3/4	<1/4	-	-	-	-	Crack identified by visual inspection on 12/16/09 after the boroscope was performed. Upper right pilot hole inspected with no crack visible.
48	-0015	AD	1 x 14	43-1/2 x 34-1/2	11/5/09	11/13/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	Bug holes.
48	-0015	AD	3/8 x 20 PILOT HOLE	43-1/2 x 34-1/2	11/5/09	11/18/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	4 pilot holes examined with no imperfections found.
49	-0015	Y	4 x 12	209-1/2 x 102	11/5/09	11/06/09	11/25/09	9-1/4	10	1/16	1/8	-	-	-	-	-	-	-	-	Drilled to 12". One crack seen after review with multiple facets. Depth adjusted to locate a single crack.
50	-0010	AA	1 x 12	96 x 50	11/12/09	11/13/09	11/24/09	-	-	-	-	-	-	*	-	-	-	-	-	Bug holes.
51	-0015	AA	4 x 9	167 x 92-1/2	11/9/09	11/10/09	11/25/09	5-1/4	6-1/2	1/8	½	-	-	-	-	-	-	-	-	Drilled to 7-1/2".
52	-0015	AA	1 x 20	219-1/2 x 116	11/9/09	11/10/09	11/25/09	-	-	-	-	-	-	*	-	-	-	-	-	Drilled to 19". Small hole less than ½" long. No other imperfections found.
53	-0015	F	1 x 20	184 x 108	11/13/09	11/13/09	11/25/09	6	-	1/8	-	-	-	-	-	-	-	-	-	
54	-0003B	N/A	2 x 12	129" RIGHT OF B3 x 136" FROM FLOOR	11/11/09	11/13/09	11/25/09	8	-	-	-	-	-	-	-	-	-	-	-	Small crack 360°. No other imperfections found.
	-0003B	N/A	3 ea. 3/8 x 12 Pilot Holes	Below core bore	11/17/09	11/18/09	11/22/09	-	-	-	-	-	-	9-1/4	-	-	-	-	-	Small void, possible rock pocket from boring. No cracks or other abnormalities observed.
54a	-0003B	N/A	4 x 12	132" RIGHT OF B3 x 136" FROM FLOOR	11/23/09	11/23/09	11/29/09	8 to 9	-	1/32	-	-	-	-	-	-	-	-	-	Crack runs partially out of plane of wall. No other signs of distress or anomalies.

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
55	-0015	K	4 x 12	201 x 42	11/12/09	11/13/09	11/25/09	9-1/2	-	2	-	-	-	-	-	-	-	-	-	
56	-0015	E	1 x 10	201 x 36	11/12/09	11/13/09	11/25/09	7	-	¾	-	-	-	-	-	-	-	-	-	
57	-0015	R	2 x 20	94 x 53	11/13/09	11/13/09	11/21/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
57a	-0015	R	8 x 14-1/2	94 x 53	11/19/09	11/25/09	11/25/09													
58	-0015	U	1 x 10	173 x 89-1/2	11/12/09	11/13/09	11/25/09	7	-	¾	-	-	-	-	-	-	-	-	-	
59	-0015	Shield Wall	4 x 12	115 x 55 (from top right)	11/12/09	11/13/09	11/25/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
60	-0015	Shield Wall	4 x 12	68 x 64 (from bottom right)	11/11/09	11/18/09	11/25/09	-	-	-	-	-	-	-	-	-	-	-	-	
61	-0015	Y	2 x 12	222 x 100	11/9/09	11/11/09	11/25/09	9-3/4	-	1	-	-	-	-	-	-	*	-	*	Drilled to 13". There is rebar or metal at the end of the hole.
62	-0013	H	1 x 20	56 x 60	11/08/09	11/17/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
63	-0013	H	4 x 20	158-1/2 x 37	11/08/09	11/17/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
64	-0013	N	1 x 20	158 x 10	11/09/09	11/17/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Small voids/bug holes seen. No other imperfections found.
65	-0013	Q	4 x 20	163 x 23	11/09/09	11/17/09	11/25/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
66	-0013	W	4 x 20	77 x 97	11/08/09	11/17/09	11/25/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
67	-0012	H	4 x 20	186 x 24	11/12/09	11/12/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
68	-0012	G	2 x 20	58 x 32	11/13/09	11/17/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Small voids/bug holes seen. Pilot hole penetrated side wall of core. No other imperfections found.
69	-0012	P	2 x 20	62 x 84	11/13/09	11/17/09	12/6/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
70	-0012	Y	2 x 12	185 x 9	11/15/09	11/15/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections. Pilot hole penetrated side wall of core.
71	-0014	G	2 x 20	111 x 34	11/16/09	11/16/09	11/25/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
72	-0014	J	2 x 20	205 x 30	11/16/09	11/16/09	11/25/09	-	-	-	-	-	-	16-3/4	< 1	shallow	-	-	-	No other imperfections found.
73	-0011	C	2 X 20	148 x 63	11/16/09	11/16/09	11/23/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes throughout hole. No other imperfections found.
74	-0014	E	2 x 12	42 x 98	11/16/09	11/16/09	11/25/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
75	-0012	W	2 x 20	182 x 41	11/13/09	11/28/09	12/7/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes throughout hole. No other imperfections found.
76	-0012	Q	2 x 20	195-3/4 x 14-1/2	11/13/09	11/17/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	No imperfections found.
77	-0012	L	2 x 20	52 x 99	11/13/09	11/17/09	11/24/09	-	-	-	-	-	-	-	-	-	-	-	-	Small voids/bug holes seen in hole. Pilot hole penetrated core. No other imperfections found.
78	-0015	Z	2 x 12	105 x 32	11/15/09	11/15/09	11/25/09	9-1/4	-	2-1/8	-	-	-	4-5/8	¼	-	-	-	-	
79	-0015	V	2 x 12	178 x 40	11/15/09	11/15/09	11/26/09	8-7/16	-	1-5/8	-	-	-	-	-	-	-	-	-	

Note: X,Y coordinate from top left corner of panel

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Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
80	-0015	X	2 x 12	58-1/2 x 41-3/4	11/15/09	11/15/09	11/26/09	8-1/2	-	1-5/8	-	-	-	-	-	-	-	-	-	
81	-0015	H	2 x 12	204 x 28	11/14/09	11/15/09	11/26/09	8-1/4	9-3/4	¼	1	-	-	-	-	-	-	-	-	
81a	-0015	H	4 x 15	204 x 28	11/19/09	11/20/09	11/30/09	8-9 to 3/8	9-5/8 to 11	1/2	1	-	-	-	-	-	-	-	-	Over core of #81. Pilot holes penetrate core.
82	-0015	H	2 x 12	33 x 30	11/14/09	11/15/09	11/29/09	8	10	1	¾	-	-	-	-	-	-	-	-	Drilled at 10-3/4" deep.
83	-0015	G	2 x 12	112 x 65	11/15/09	11/16/09	11/29/09	7-7/16	-	1-1/8	-	-	-	-	-	-	-	-	-	Drilled at 8-5/8" deep.
84	-0015	I	2 x 12	95 x 64	11/15/09	11/16/09	11/29/09	7-3/8	-	1-1/8	-	-	-	-	-	-	-	-	-	Drilled at 8-1/2" deep.
84A	-0015	I	8 x 15	95 x 64	11/19/09	11/20/09	11/29/09	7-3/4	-	1	-	-	-	-	-	-	-	-	-	It appears that loose material has filled a portion of the crack.
85	-0012	W	2 x 12	22 x 113	11/15/09	11/15/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
86	-0016	A	2 x 14	129S x 198W from dome center	11/17/09	11/17/09	11/18/09	-	-	-	-	-	-	-	-	-	11-3/8	-	Bonding adhesive	Repair material/original concrete interface identified with a good seal/bond between the repair material and the original concrete.
87	-0016	A	2 x 14	250S x 100W from dome center	11/17/09	11/17/09	11/18/09	-	-	-	-	-	-	-	-	-	11-3/8	-	Bonding adhesive	Repair material/original concrete interface identified with a good seal/bond at interface. No separation seen.
88	-0016	A	2 x 14	198S x 471W from dome center	11/17/09	11/17/09	11/18/09	-	-	-	-	-	-	-	-	-	10	-	Bonding adhesive	Repair material/original concrete interface identified with a good seal/bond at interface. No separation seen.

Note: X,Y coordinate from top left corner of panel

L:\Shared\CR3 Containment\CONDITION ASSESSMENT Files\Core Examination Log.docx

Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
89	-0016	A	2 x 14	383S x 233W from dome center	11/17/09	11/17/09	11/18/09	-	-	-	-	-	-	-	-	-	12-1/8	-	Bonding adhesive	Repair material/original concrete interface identified with a good seal/bond at interface. No separation seen.
90	-0016	A	2 X 14	321S x 546W from dome center	11/18/09	11/19/09	11/20/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes seen throughout hole. Residue at break location is not consistent with appearance of bonding adhesive observed in the 4 cores made in the repair area.
91	-0016	A	2 X 14	604S x 271W from dome center	11/18/09	11/19/09	11/20/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes seen throughout hole.
92	-0010	G	8 x 14	65 x 74	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
93	-0010	G	4 x 22	138 x 74	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
94	-0010	G	4 x 22	186 x 73	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
95	-0012	Q	4 x 10	44 x 48	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
96	-0012	Q	4 x 10	105 x 86	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
97	-0012	Q	4 x 14	196 x 86	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	Pilot hole penetrated core. No cracks, voids, or imperfections.
98	-0012	T	4 x 10	43 x 86	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes seen throughout hole.
99	-0012	T	4 x 14	105 x 84	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	Pilot hole penetrated core. No cracks, voids, or imperfections.
100	-0012	T	4 x 14	43 x 38	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.

Note: X,Y coordinate from top left corner of panel

L:\Shared\CR3 Containment\CONDITION ASSESSMENT Files\Core Examination Log.docx

Core Examination Log

Core #	BAY (RBCN)	PANEL ID	Dia. x Length (in.)	Core Location (X,Y) (in.)	Core Date	Boroscope Date	Reviewed Date	Crack depth from face (in.)		Avg. crack width (in.)		Out of plane Crack length (in.)		Voids (in.)			Abnormality (embedded object, tendon grease)			Comments
								Near	Far	Near	Far	Start	End	Distance from face	Axial/ Circum. Dim.	Depth	Distance from face	Axial/ Circum. Dim.	Metallic/ organic	
101	-0012	T	4 x 14	196 x 39	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	No cracks, voids, or imperfections.
102	-0012	T	4 x 14	195 x 88	11/21/09	11/23/09	11/29/09	-	-	-	-	-	-	*	-	-	-	-	-	Small voids/bug holes seen throughout hole.
103	-0016	A	1 x 14	75S x 580W from dome center	11/23/09	11/23/09	11/29/09	-	-	-	-	-	-	-	-	-	-	-	-	Core drilled over pilot hole. No cracks, voids, or imperfections.

Note: X,Y coordinate from top left corner of panel

L:\Shared\CR3 Containment\CONDITION ASSESSMENT Files\Core Examination Log.docx

APPENDIX F

Equipment Calibration Records

- **F.1 – Calibration Records Of Impulse Hammers**
- **F.2 – Calibration Records Of Geophones**
- **F.3 – Calibration Records of Accelerometers for IE**

APPENDIX F.1

Calibration Records of Impulse Hammers

- **Hammer Model 086M91 SN 23054 (1 page)**
- **Hammer Model 086D20 SN 26519 (1 Page)**
- **Hammer Model 086M91 SN 26088 (1 Page)**
- **Hammer Model 086M91 SN 22610 (1 Page)**

~Calibration Certificate~

Model No.: 086M91 Customer:

Serial No.: 23054

Description: Impulse Force Hammer PO No.:

Manufacturer: PCB Calibration Method: Impulse (at-303-1)

Data

Output Bias: **10.2** Temperature: 70 °F 21 °C Relative Humidity: 55 %

HAMMER SENSITIVITY:

Hammer Configuration	Tip	Medium (Red)		
	Extender	None		
Hammer Sensitivity	mV/lb	1.02		
	(mV/N)	0.23		

Above data is valid for all supplied tips.

Condition of Unit:

As Found In Tolerance, Cable Connection Looks Weak.

As Left

Special Note: Hcs-2

Notes:

1. Calibration is N.I.S.T traceable through project No. 822/274086 and PTB Traceable thru Project 1060.
2. This certificate may not be reproduced, except in full, without written approval from PCB Piezotronics, inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI/NCSL Z540-1-1994.
4. See Manufacturer's specification sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with a coverage factor of 2) is +/-3.8%.

Technician: Brian Kemp Date: 3/13/2009

ACCREDITED
CALIBRATION CERT # 1962.01

PCB PIEZOTRONICS INC.
3425 Walden Avenue
Depew, N.Y. 14043

TEL: 716-684-0001 FAX: 716-684-0987 www.pcb.com

Calibration Station: 47

~Calibration Certificate~

Model No.: 086D20 Customer:

Serial No.: 26519

Description: Impulse Force Hammer PO No.:

Manufacturer: PCB Calibration Method: Impulse (at-303-1)

Data

Output Bias: **9.2** Temperature: 73 °F 23 °C Relative Humidity: 54 %

HAMMER SENSITIVITY:

Hammer Configuration	Tip	Medium (Red)		
	Extender	None		
Hammer Sensitivity	mV/lb	1.06		
	(mV/N)	0.24		

Above data is valid for all supplied tips.

Condition of Unit:

As Found Non-operational, Intermittent Bnc Conn.

As Left In tolerance, after repair.

Special Note: Hcs-2

Notes:

1. Calibration is N.I.S.T traceable through project No. 822/274086 and PTB Traceable thru Project 1060.
2. This certificate may not be reproduced, except in full, without written approval from PCB Piezotronics, inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI/NCSL Z540-1-1994.
4. See Manufacturer's specification sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with a coverage factor of 2) is +/-3.8%.

Technician: Luke Rogers L.R. Date: 7/16/2009

ACCREDITED
CALIBRATION CERT # 1862.01

PCB PIEZOTRONICS
3425 Walden Avenue
Depew, N.Y. 14043

TEL: 716-684-0001 FAX: 716-684-0987 www.pcb.com

Calibration Station: 47

~Calibration Certificate~

Model No.: 086M91 Customer:

Serial No.: 26088

Description: Impulse Force Hammer PO No.:

Manufacturer: PCB Calibration Method: Impulse (at-303-1)

Data

Output Bias: **8.9** Temperature: 69 °F 21 °C Relative Humidity: 49 %

HAMMER SENSITIVITY:

Hammer Configuration	Tip	Medium (Red)		
	Extender	None		
Hammer Sensitivity	mV/lb	1.03		
	(mV/N)	0.23		

Above data is valid for all supplied tips.

Condition of Unit:

As Found Non-operational

As Left In tolerance, after repair.

Special Note: Hcs-2

Notes:

1. Calibration is N.I.S.T traceable through project No. 822/274086 and PTB Traceable thru Project 1060.
2. This certificate may not be reproduced, except in full, without written approval from PCB Piezotronics, inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI/NCSL Z540-1-1994.
4. See Manufacturer's specification sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with a coverage factor of 2) is +/-3.8%.

Technician: Luke Rogers L. R. Date: 7/22/2009

ACCREDITED
CALIBRATION CERT # 1662.01

PCB PIEZOTRONICS

3425 Walden Avenue
Depew, N.Y. 14043

TEL: 716-684-0001 FAX: 716-684-0987 www.pcb.com

Calibration Station: 47

~Calibration Certificate~

Model No.: 086M91 Customer:

Serial No.: 22610

Description: Impulse Force Hammer PO No.:

Manufacturer: PCB Calibration Method: Impulse (at-303-1)

Data

Output Bias: **10.0** Temperature: 70 °F 21 °C Relative Humidity: 47 %

HAMMER SENSITIVITY:

Hammer Configuration	Tip	Medium (Red)		
	Extender	None		
Hammer Sensitivity	mV/lb	1.06		
	(mV/N)	0.24		

Above data is valid for all supplied tips.

Condition of Unit:

As Found Non Operational, Damaged Cable.

As Left In tolerance, after repair.

Special Note: Hcs-2

Notes:

1. Calibration is N.I.S.T traceable through project No. 822/274086 and PTB Traceable thru Project 1060.
2. This certificate may not be reproduced, except in full, without written approval from PCB Piezotronics, inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI/NCSL Z540-1-1994.
4. See Manufacturer's specification sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with a coverage factor of 2) is +/-3.8%.

Technician: Luke Rogers Date: 11/24/2008

ACCREDITED
CALIBRATION CERT # 1867.01

PCB PIEZOTRONICS INC.
3425 Walden Avenue
Depew, N.Y. 14043

TEL: 716-684-0001 FAX: 716-684-0987 www.pcb.com

Calibration Station: 47

APPENDIX F.2

Calibration Records of Geophones

- **Calibration Of Impulse Response Geophones dated 10/24/2009 (8 pages)**
- **Calibration Of Impulse Response Geophones dated 10/26/2009 (7 pages)**
- **Calibration Certificate of Omniphone (1 page, for information only)**

AECOM

Calibration of Impulse Response Geophones

CTL Group
Skokie, Illinois

October 24, 2009

Prepared by:
Sean B Brady
Instrumentation Specialist
AECOM USA, Inc.
Telephone: 847-279-2500

AECOM

750 Corporate Woods Parkway, Vernon Hills, IL 60061
T 847.279.2500 F 847.279.2510 ww.aecom.com

October 24, 2009

CTL Group
Honggang Cao P.E, S.E
5420 Old Orchard Road
Skokie, Illinois 60077

RE: Annual Calibration of Impulse Response Geophones s/n

Dear Mr. Honggang Cao:

We are pleased to present our calibration report for the Impulse Response geophones that AECOM calibrated on Saturday October 24, 2009.

Geophones with serial numbers 4001, 4002, 4010, and 1010 are within calibration specifications for the Smash Impulse Response Testing System. Please find attached to this letter the calibration records for each Geophone calibrated the equipment used to perform this calibration and.

We thank you for this opportunity to be of service to you, and remain available for any further consultation or discussion that you may require. If you have any questions concerning the contents of the attached calibration documents, please call Sean Brady at 847.279.2425.

Respectfully,

Sean B Brady
Instrumenttion Specialist

Attachments:

Calibration Sheet's CTL Impulse Response Geophones

Calibration Sheet Nicolet Phazer 4 Channel Acquisition System

Calibration Sheet PCB 393B12 Accelerometer

AECOM

Calibration Report for Vertical Geophone: CTL s/n **4001**

Time and Date of Calibration: Saturday, October 24, 2009 09:22:46

Calibrated by:	SBB
Signal Analyzer Brand:	Nicolet
Signal Analyzer Model Number:	Photon Phazer
Signal Analyzer Serial Number:	5317454
Signal Analyzer Traceability Certificate Number:	AECOM 5317454 Dated March 3, 2009
Signal Analyzer Certificate Date:	03-03-09
Signal Analyzer Certificate Due Date:	03-03-10
Accelerometer Brand:	PCB
Accelerometer Model Number:	393B12
Accelerometer Traceability Certificate Number:	24462
Accelerometer Certificate Date:	June 6, 2008
Accelerometer Certificate Due Date:	June 6, 2010

****

Initial (as received)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)
20	0.02102	0.02170
22.5	0.02009	0.02162
25	0.02118	0.02265
27.5	0.02105	0.02419
30	0.02146	0.02485

Final (calibrated)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)	Result
20	0.02032	0.02054	PASS
22.5	0.02011	0.02045	PASS
25	0.02127	0.02105	PASS
27.5	0.02090	0.02136	PASS
30	0.02105	0.02171	PASS

Overall calibration result: Pass

*********end of calibration report *********

AECOM

Calibration Report for Vertical Geophone: CTL s/n **4002**

Time and Date of Calibration: Saturday, October 24, 2009 09:22:46

Calibrated by:	SBB
Signal Analyzer Brand:	Nicolet
Signal Analyzer Model Number:	Photon Phazer
Signal Analyzer Serial Number:	5317454
Signal Analyzer Traceability Certificate Number:	AECOM 5317454 Dated March 3, 2009
Signal Analyzer Certificate Date:	03-03-09
Signal Analyzer Certificate Due Date:	03-03-10
Accelerometer Brand:	PCB
Accelerometer Model Number:	393B12
Accelerometer Traceability Certificate Number:	24462
Accelerometer Certificate Date:	June 6, 2008
Accelerometer Certificate Due Date:	June 6, 2010

****

Initial(as received)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)
20	0.02102	0.02010
22.5	0.02009	0.01985
25	0.02118	0.01921
27.5	0.02105	0.01818
30	0.02146	0.01928

Final (calibrated)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)	Result
20	0.02032	0.02082	PASS
22.5	0.02011	0.02011	PASS
25	0.02127	0.02090	PASS
27.5	0.02090	0.02111	PASS
30	0.02105	0.02178	PASS

Overall calibration result: Pass

********* end of calibration report ********

AECOM

Calibration Report for Horizontal Geophone: CTL s/n **4010**

Time and Date of Calibration: Saturday, October 24, 2009 10:12:03

Calibrated by:	SBB
Signal Analyzer Brand:	Nicolet
Signal Analyzer Model Number:	Photon Phazer
Signal Analyzer Serial Number:	5317454
Signal Analyzer Traceability Certificate Number:	AECOM 5317454 Dated March 3, 2009
Signal Analyzer Certificate Date:	03-03-09
Signal Analyzer Certificate Due Date:	03-03-10
Accelerometer Brand:	PCB
Accelerometer Model Number:	393B12
Accelerometer Traceability Certificate Number:	24462
Accelerometer Certificate Date:	June 6, 2008
Accelerometer Certificate Due Date:	June 6, 2010

****

Initial(as received)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)
20	0.02031	0.02079
22.5	0.02113	0.02056
25	0.02198	0.02118
27.5	0.02076	0.02210
30	0.02123	0.02236

Final (calibrated)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)	Result
20	0.02022	0.02077	PASS
22.5	0.02036	0.01963	PASS
25	0.02023	0.01984	PASS
27.5	0.02076	0.02021	PASS
30	0.02109	0.02048	PASS

Overall calibration result: Pass

********* end of calibration report ********

AECOM

Calibration Report for Horizontal Geophone: AECOM s/n **1010**

Time and Date of Calibration: Saturday, October 24, 2009 010:12:03

Calibrated by:	SBB
Signal Analyzer Brand:	Nicolet
Signal Analyzer Model Number:	Photon Phazer
Signal Analyzer Serial Number:	5317454
Signal Analyzer Traceability Certificate Number:	AECOM 5317454 Dated March 3, 2009
Signal Analyzer Certificate Date:	03-03-09
Signal Analyzer Certificate Due Date:	03-03-10
Accelerometer Brand:	PCB
Accelerometer Model Number:	393B12
Accelerometer Traceability Certificate Number:	24462
Accelerometer Certificate Date:	June 6, 2008
Accelerometer Certificate Due Date:	June 6, 2010

****

Initial(as received)

Frequency (Hz)	PCB Range (V)	Geophone Range V)
20	0.02031	0.02193
22.5	0.02113	0.02211
25	0.02198	0.02129
27.5	0.02076	0.02276
30	0.02123	0.02189

Final (calibrated)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)	Result
20	0.02022	0.02103	PASS
22.5	0.02088	0.02137	PASS
25	0.02023	0.02074	PASS
27.5	0.02076	0.02098	PASS
30	0.02109	0.02177	PASS

Overall calibration result: Pass

********* end of calibration report ********

Calibration Report for Photon serial number: 5317454

Calibration software library version: 6.050

FEB version: 1.50

Time and Date of Calibration: Monday, March 02, 2009 13:35:11

Calibrated by: BHH

Signal Analyzer Brand: HP

Signal Analyzer Model Number: HP3560

Signal Analyzer Serial Number: 3019A00190

Signal Analyzer Traceability Certificate Number: N/A

Signal Analyzer Certificate Date: 01-31-05

Signal Analyzer Certificate Due Date: 01-31-10

Front end DSP box Serial Number = 5317454

Number of Settings to Test for Output Channels = 1

Number of Output Channels = 1

Number of Settings to Test for Input Channels = 2

Number of Input Channels = 4

****

Initial (uncalibrated) Output Channel Offsets (volts)

Channel	10.0 Volt Range
Drive	-0.004800

Initial (uncalibrated) Output Channel Gain Error (percentage)

Channel	10.0 Volt Range
Drive	-1.380674

Final (calibrated) Output Channel Offsets (volts)

Channel	10.0 Volt Range	Results
Drive	0.000000	Pass

Final (calibrated) Output Channel Gain Error (percentage)

Channel	10.0 Volt Range	Results
Drive	0.000000	Pass

****

Initial (uncalibrated) Input Channel Offsets (volts)

Channel Number	10.0 Volt Range	1.0 Volt Range
1	0.026743	0.002197
2	0.014310	0.001674
3	-0.035599	-0.004321
4	0.070274	0.007020

Initial (uncalibrated) Input Channel Gain Error (percentage)

Channel Number	10.0 Volt Range	1.0 Volt Range
1	3.185332	3.990946
2	6.228880	7.156713
3	4.975634	5.288795
4	7.071058	7.858483

Final (calibrated) Input Channel Offsets (in volts)

Channel Number	10.0 Volt Range	1.0 Volt Range	Results
1	0.000128	0.000006	Pass
2	0.000076	0.000018	Pass
3	0.000028	0.000006	Pass
4	0.000067	0.000012	Pass

Final (calibrated) Input Channel Gain Error (percentage)

Channel Number	10.0 Volt Range	1.0 Volt Range	Results
1	0.009708	0.011301	Pass
2	0.013952	0.015712	Pass
3	0.009127	0.008249	Pass
4	0.012102	0.011861	Pass

Overall calibration result: Pass

********* end of calibration report *********

AECOM

Calibration of Impulse Response Geophones

CTL Group
Skokie, Illinois

October 26, 2009

Prepared by:
Sean B Brady
Instrumentation Specialist
AECOM USA, Inc.
Telephone: 847-279-2500

AECOM

750 Corporate Woods Parkway, Vernon Hills, IL 60061
T 847.279.2500 F 847.279.2510 ww.aecom.com

October 26, 2009

CTL Group
Honggang Cao P.E, S.E
5420 Old Orchard Road
Skokie, Illinois 60077

RE: Annual Calibration of Impulse Response Geophones s/n

Dear Mr. Honggang Cao:

We are pleased to present our calibration report for the Impulse Response geophones that AECOM calibrated on Monday October 26, 2009.

The Horizontal Geophone with serial number 4003 is within calibration specifications for the Smash Impulse Response Testing System. Please find attached to this letter the calibration records for the Geophone calibrated and the equipment used to perform this calibration and.

We thank you for this opportunity to be of service to you, and remain available for any further consultation or discussion that you may require. If you have any questions concerning the contents of the attached calibration documents, please call Sean Brady at 847.279.2425.

Respectfully,

Sean B Brady
Instrumenttion Specialist

Attachments:

Calibration Sheet's CTL Impulse Response Geophones

Calibration Sheet Nicolet Phazer 4 Channel Acquisition System

Calibration Sheet PCB 393B12 Accelerometer

AECOM

Calibration Report for Vertical Geophone: CTL s/n **4003**

Time and Date of Calibration: Monday, October 26, 2009 12:14:23

Calibrated by:	SBB
Signal Analyzer Brand:	Nicolet
Signal Analyzer Model Number:	Photon Phazer
Signal Analyzer Serial Number:	5317454
Signal Analyzer Traceability Certificate Number:	AECOM 5317454 Dated March 3, 2009
Signal Analyzer Certificate Date:	03-03-09
Signal Analyzer Certificate Due Date:	03-03-10
Accelerometer Brand:	PCB
Accelerometer Model Number:	393B12
Accelerometer Traceability Certificate Number:	24462
Accelerometer Certificate Date:	June 6, 2008
Accelerometer Certificate Due Date:	June 6, 2010

****

Initial (as received)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)
20	0.02120	0.02061
22.5	0.02119	0.02009
25	0.02087	0.02111
27.5	0.02072	0.02310
30	0.02112	0.02253

Final (calibrated)

Frequency (Hz)	PCB Range (V)	Geophone Range (V)	Result
20	0.02066	0.02097	PASS
22.5	0.02138	0.02106	PASS
25	0.02088	0.02105	PASS
27.5	0.02039	0.02038	PASS
30	0.02146	0.02082	PASS

Overall calibration result: Pass

*********end of calibration report *********

Calibration Report for Photon serial number: 5317454
Calibration software library version: 6.050
FEB version: 1.50
Time and Date of Calibration: Monday, March 02, 2009 13:35:11

Calibrated by: BHH
Signal Analyzer Brand: HP
Signal Analyzer Model Number: HP3560
Signal Analyzer Serial Number: 3019A00190
Signal Analyzer Traceability Certificate Number: N/A
Signal Analyzer Certificate Date: 01-31-05
Signal Analyzer Certificate Due Date: 01-31-10

Front end DSP box Serial Number = 5317454
Number of Settings to Test for Output Channels = 1
Number of Output Channels = 1
Number of Settings to Test for Input Channels = 2
Number of Input Channels = 4

****

Initial (uncalibrated) Output Channel Offsets (volts)

Channel	10.0 Volt Range
Drive	-0.004800

Initial (uncalibrated) Output Channel Gain Error (percentage)

Channel	10.0 Volt Range
Drive	-1.380674

Final (calibrated) Output Channel Offsets (volts)

Channel	10.0 Volt Range	Results
Drive	0.000000	Pass

Final (calibrated) Output Channel Gain Error (percentage)

Channel	10.0 Volt Range	Results
Drive	0.000000	Pass

****

Initial (uncalibrated) Input Channel Offsets (volts)

Channel Number	10.0 Volt Range	1.0 Volt Range
1	0.026743	0.002197
2	0.014310	0.001674
3	-0.035599	-0.004321
4	0.070274	0.007020

Initial (uncalibrated) Input Channel Gain Error (percentage)

Channel Number	10.0 Volt Range	1.0 Volt Range
1	3.185332	3.990946
2	6.228880	7.156713
3	4.975634	5.288795
4	7.071058	7.858483

Final (calibrated) Input Channel Offsets (in volts)

Channel Number	10.0 Volt Range	1.0 Volt Range	Results
1	0.000128	0.000006	Pass
2	0.000076	0.000018	Pass
3	0.000028	0.000006	Pass
4	0.000067	0.000012	Pass

Final (calibrated) Input Channel Gain Error (percentage)

Channel Number	10.0 Volt Range	1.0 Volt Range	Results
1	0.009708	0.011301	Pass
2	0.013952	0.015712	Pass
3	0.009127	0.008249	Pass
4	0.012102	0.011861	Pass

Overall calibration result: Pass

********* end of calibration report *********

~ Calibration Certificate ~

Per ISO 16063-21

Model Number: 393B12

Serial Number: 24462

Description: ICP® Accelerometer

Method: Back-to-Back Comparison (AT401-3)

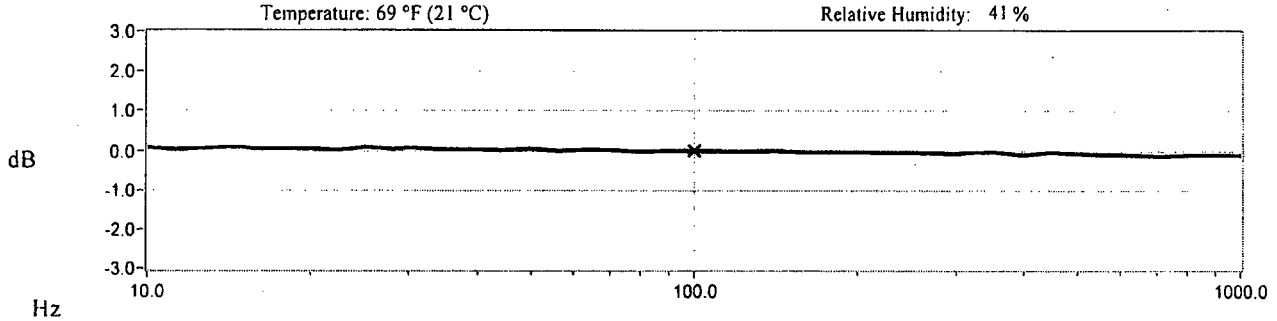
Manufacturer: PCB

Calibration Data

Sensitivity @ 100.0 Hz	**10.34**	**V/g**	Output Bias	11.6	VDC
	(1.054	**V/m/s²)**	Transverse Sensitivity	2.6	%
Discharge Time Constant	6.9	seconds	Resonant Frequency	12.4	kHz

Sensitivity Plot

Temperature: 69 °F (21 °C) Relative Humidity: 41 %



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10.0	0.9	300.0	-1.0
15.0	0.9	500.0	-0.9
30.0	0.8	1000.0	-1.3
50.0	0.5		
REF. FREQ.	0.0		

Mounting Surface: Stainless Steel w/Silicone Grease Coating Fastener: Stud Mount Fixture Orientation: Vertical
Acceleration Level (rms)[1]: 0.100 g (0.981 m/s²)[2]
[1]The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.010 x (freq)².
[2]The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 822/274086 and PTB Traceable thru Project 1060.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI/NCSL Z540-1-1994 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz: +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%.

Technician: Brian Kemp BK Date: 06/18/08

ACCREDITED
CALIBRATION CERT #1862.02

PCB PIEZOTRONICS™
VIBRATION DIVISION
Headquarters: 3425 Walden Avenue, Depew, NY 14043
Calibration Performed at: 10869 Highway 903, Halifax, NC 27839
TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

cal48 - 3296652306.97

TruCal International

605G Country Club Dr.
Bensenville, IL 60106
(630) 238-8100

Work Order/ Cert Number
103238 - 5357 - 103248

ELECTRONIC MEASUREMENT SERVICES
CALIBRATION CERTIFICATE AND DATA SHEET

No certificate or any parts of, shall be reproduced, without written approval from Tru Cal Int'l Inc.

SHIP TO ADDRESS

STS Cosultants
750 Corporate Woods Pkwy
Vernon Hills, IL 60061

Charles Brown

P.O. Number | Release Number

Dynamic Signal Analyzer (Description)	3109A00190 (Serial No.)
Hewlett Packard (Manufacturer)	TC12807 (Control No.) / Asset No.
3560A (Model Number)	Department
365 (Cycle) / 1/31/2005 (Cal Date)	Location.cust

Received Condition	Returned Condition	Special Services	Accessories
☒ In Tolerance	☒ In Tolerance/Cal Only	☐ Field Service Required	☐ Power Cord
☐ Out Of Tolerance	☐ Limited Use	☐ Data Required	☐ Service Manual
☐ Inoperative/Req. Repair	☐ Service Only	☐ Outside Service	☐ Test Probes
☐ Service Only	☐ Return As Is	☒ Non Accredited Service	☐ Cable Assembly
☐ Evaluation Only	☐ Repair Only	☐ Add To Agreement	☐ Connectors
	☐ In Tolerance/After Repair	☐ Warranty Service	☐ Supplemental Cert

Enviromental Conditions
32.99 °F 39.55 %RH

Procedure Used
☒ Mfg.
☐ Other HP 3560A

UL REGISTERED FIRM Certificate A3651

Fault/Symptom

Technical Evaluation

Work Performed
Verified Manufacturers Specifications.

Qty.	Description	List	Ext	Qty.	Description	List	Ext

Asset No.	Asset Model	Due Date	Traceability Number
A460	Fluke 5500 SC Calibrator	10/27/2005	1899.01 QA
A569	HP 3325B Generator	10/6/2005	101437-0142-101447

Parameters Tested/Test Specification	Nom. Applied	- Limit	+ Limit	As Found	As Left

☐ This calibration is in compliance with 45662A,ISO9001:2000. ☐ ANSI Z-540,ISO 10012, ISO/IEC 17025-1999***All services provide a 4:1 uncertainty ratio unless otherwise stated. The uncertainty ratio was calculated using the expanded measurement uncertainty at the 95% confidence level and with a coverage factor K=2. Traceable to N.I.S.T. and or Fundamental or Natural physical constants, or by accepted ratiometric techniques.

Received By | Rec'd Date | Tech Initial be | Certified By | Inspected By

WO-000KC

GERMANN INSTRUMENTS, INC.

8845 Forest View Road · Evanston, Illinois 60203-1924 USA
Phone: (847) 329-9999 · Fax: (847) 329-8888
E-mail: germann@germann.org · Web site: http://www.germann.org

October 22, 2009

Calibration certificate for s'MASH omniphone No. 7051 for 360° testing.

Calibration Value: 20 mV/(m/s)

Technician: BH

Next recommended calibration date: October 22, 2010 or sooner if damaged.

APPENDIX F.3

Calibration Records of Accelerometers for IE

- **PCB Accelerometer 352A60 SN 106253 (1 page)**
- **PCB Accelerometer WJ352A78 SN 69808 (1 page)**

~ *Calibration Certificate* ~

Per ISO 16063-21

Model Number: 352A60

Serial Number: 106523

Description: ICP® Accelerometer Method: Back-to-Back Comparison (AT401-3)

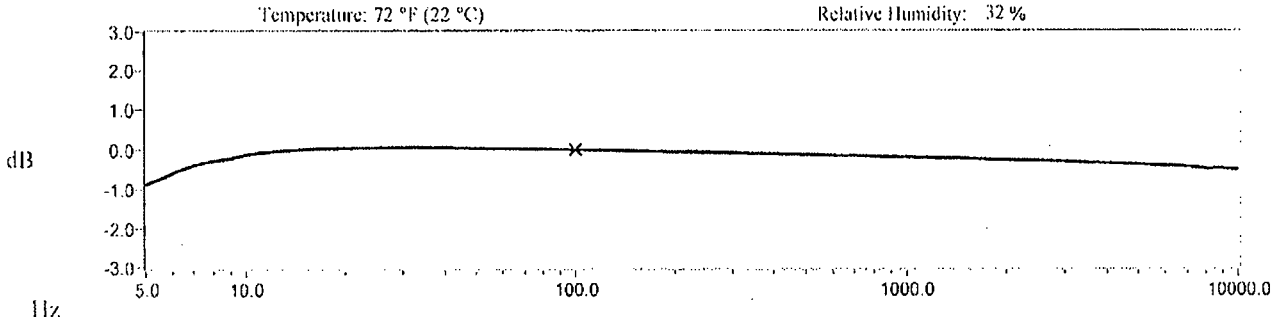
Manufacturer: PCB

Calibration Data

Sensitivity @ 100.0 Hz	**9.90**	**mV/g**	Output Bias	10.9	VDC
	(1.009	**mV/m/s²)**	Transverse Sensitivity	0.9	%

Sensitivity Plot

Temperature: 72 °F (22 °C) Relative Humidity: 32 %



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
5.0	-9.7	REF. FREQ.	0.0	5000.0	-4.3
10.0	-1.5	300.0	-1.1	7000.0	-5.0
15.0	-0.0	500.0	-1.6	10000.0	-5.8
30.0	0.7	1000.0	-2.3		
50.0	0.4	3000.0	-3.5		

Mounting Surface: Stainless Steel w/Silicone Grease Coating Fastener: Stud Mount Fixture Orientation: Vertical
Acceleration Level (rms)*: 10.0 g (98.1 m/s²)*

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.010 x (freq)².
*The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 822/277342 and PTB Traceable thru Project 1254.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI/NCSL Z540-1-1994 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz: +/- 2.0%, 10-99 Hz: +/- 1.5%, 100-1999 Hz: +/- 1.0%, 2-10 kHz: +/- 2.5%.

Technician: Mary Warren Date: 10/01/09

ACCREDITED
CALIBRATION CERT #1862.01

PCB PIEZOTRONICS
VIBRATION DIVISION
3425 Walden Avenue · Depew, NY 14043
TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

~ Calibration Certificate ~

Per ISO 16063-21

Model Number: WJ352A78/002C30

Serial Number: 69808

Description: ICP® Accelerometer

Method: Back-to-Back Comparison (AT401-3)

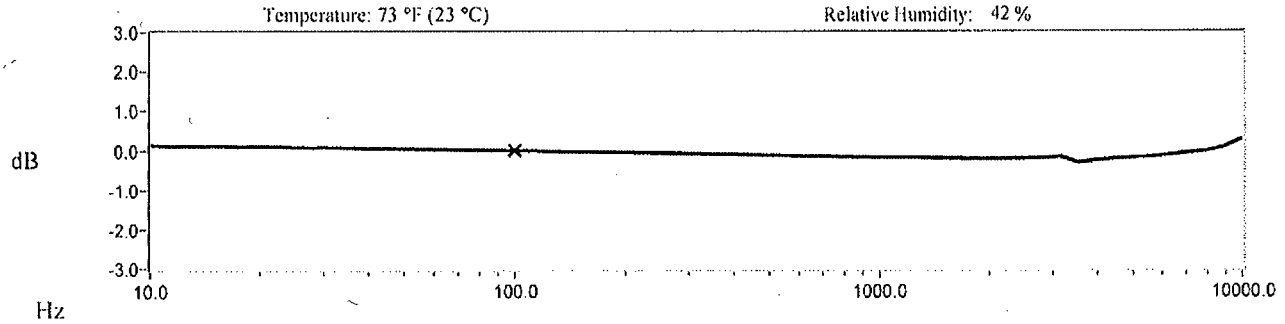
Manufacturer: PCB

Calibration Data

Sensitivity @ 100.0 Hz	**95.3**	**mV/g**	Output Bias	11.6	VDC
	(9.72	**mV/m/s²)**	Transverse Sensitivity	0.1	%
Resonant Frequency	45.1	kHz			

Sensitivity Plot

Temperature: 73 °F (23 °C) Relative Humidity: 42 %



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10.0	1.6	300.0	-1.0	7000.0	-0.7
15.0	1.5	500.0	-1.4	10000.0	3.4
30.0	1.0	1000.0	-2.0		
50.0	0.5	3000.0	-2.1		
REF. FREQ.	0.0	5000.0	-2.1		

Mounting Surface: Stainless Steel w/Silicone Grease Coating Fastener: Stud Mount Fixture Orientation: Vertical
Acceleration Level (ms)[1]: 10.0 g (98.1 m/s²)[2]
[1]The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.010 x (freq)[1]. [2]The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 822/277342 and PTB Traceable thru Project 1254.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
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Technician: Dave Grotke Date: 10/27/09

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CALIBRATION CERT #1862.01

PCB PIEZOTRONICS INC
VIBRATION DIVISION
3425 Walden Avenue · Depew, NY 14043
TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

cal4 - 3339518346.12

THIS IS PART OF DOCUMENT #107

Copy No. 1

Report for
Progress Energy

CTLGroup Project No. 059169

Petrographic Examination of Concrete Half Core from Delaminated Containment Wall, Crystal River, Florida

November 2, 2009

Submitted by:
Derek Brown

COA #4731

5400 Old Orchard Road
Skokie, Illinois 60077-1030
(847) 965-7500

9030 Red Branch Road, Suite 110
Columbia, Maryland 21045

www.CTLGroup.com

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For thin-section study, small rectangular blocks were cut from the core inner surface fracture region and within the body of the core. One side of each block was lapped to produce a smooth, flat surface. The blocks were cleaned and dried, and the prepared surfaces mounted on separate ground glass microscope slides with epoxy resin. After the epoxy hardened, the thickness of the mounted blocks was reduced to approximately 20 μm (0.0008 in.). The resulting thin sections were examined using a polarized-light (petrographic) microscope at magnifications up to 400X to study aggregate and paste mineralogy and microstructure.

Estimated water-cement ratio (w/c), when reported, is based on observed concrete and paste properties including, but not limited to: 1) relative amounts of residual (unhydrated and partially hydrated) portland cement clinker particles, 2) amount and size of calcium hydroxide crystals, 3) paste hardness, color, and luster, 4) paste-aggregate bond, and 5) relative absorbency of paste as indicated by the readiness of a freshly fractured surface to absorb applied water droplets. These techniques have been widely used by industry professionals to estimate w/c.

Depth and pattern of paste carbonation was initially determined by application of a pH indicator solution (phenolphthalein) to freshly cut and original fractured concrete surfaces. The solution imparts a deep magenta stain to high pH, non-carbonated paste. Carbonated paste does not change color. The extent of paste carbonation was confirmed in thin-section.

Derek Brown

Derek Brown
Senior Microscopist
Microscopy Group

DB/DB

Notes:
1. Results refer specifically to the sample submitted.
2. This report may not be reproduced except in its entirety.
3. The sample will be retained for 30 days, after which it will be discarded unless we hear otherwise from you.

to 0.4 in.). Somewhat uneven distribution of voids. Marginally air entrained based on the very low volume of moderate to small sized spherical air voids in the hardened cement paste.

Depth of Carbonation: 4 to 5 mm (0.16 to 0.20 in.) as measured from the outer surface. Negligible when measured from the inner fractured core surface.

Calcium Hydroxide*: Estimated 6 to 12% of small to medium sized crystals evenly distributed throughout the paste, and around aggregate to paste interfaces. Estimation of the volume is difficult due to the presence of calcite fines in the cement paste.

Residual Portland Cement Clinker Particles*: Estimated 4 to 8%. Some large cement particles, particularly belite clusters, of up to 0.15 mm in size suggest a portland cement as produced more than 30 years ago.

Supplementary Cementitious Materials*: None observed by the core supplied.

Secondary Deposits: None observed either in the body of the core and or near the fracture surface.

MICROCRACKING: A small number of medium length (5 to 10 mm), randomly orientated microcracks are evenly distributed throughout the body of the core. At the fractured end of the core there was no observed increase in microcracking relative to the body of the core.

ESTIMATED WATER-CEMENT RATIO: Moderate to moderately high (0.50 to 0.60) but estimation may be biased upwards due to the well advanced degree of hydration / apparent old age of the concrete.

MISCELLANEOUS:

1. Water droplets applied to freshly fractured surfaces were somewhat slowly absorbed by the hardened cement paste.

2. Some small areas of the inner fractured surface of the core, as received, exhibit a thin white haze of efflorescence-like substance suggesting leaching of lime in solution from within the core, or alternatively, moisture on or flowing past the fractured surface at the delamination position within the wall.

3. A moderate volume of fine calcite particles is present within the hardened cement paste, most likely from coarse aggregate crusher fines.

---

*percent by volume of paste

THIS IS PART OF DOCUMENT #107

Copy No. 1

Report for
Progress Energy

CTLGroup Project No. 059169

Petrographic Examination of Concrete Half Core from Delaminated Containment Wall, Crystal River, Florida

November 2, 2009

Submitted by:
Derek Brown

COA #4731

5400 Old Orchard Road
Skokie, Illinois 60077-1030
(847) 965-7500

9030 Red Branch Road, Suite 110
Columbia, Maryland 21045

www.CTLGroup.com

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Progress Energy
Crystal River
CTLGroup Project No. 059169

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Derek Brown

Derek Brown
Senior Microscopist
Microscopy Group

DB/DB

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---

*percent by volume of paste