Inspectioneering Journal

ASSET INTEGRITY INTELLIGENCE

Nondestructive Testing of Concrete Structures

Daniel Pearson, PE, *Structural Engineering Consultant at Wiss, Janney, Elstner Associates, Inc.*
Joshua White, PhD, PE, *Structural Engineering Consultant at Wiss, Janney, Elstner Associates, Inc.*
Ariel Suselo, PhD, PE, *Structural Engineering Consultant at Wiss, Janney, Elstner Associates, Inc.*

VOLUME 31, ISSUE 1
JANUARY | FEBRUARY 2025

Nondestructive Testing of Concrete Structures

Daniel Pearson, PE, *Structural Engineering Consultant at Wiss, Janney, Elstner Associates, Inc.*
Joshua White, PhD, PE, *Structural Engineering Consultant at Wiss, Janney, Elstner Associates, Inc.*
Ariel Suselo, PhD, PE, *Structural Engineering Consultant at Wiss, Janney, Elstner Associates, Inc.*

Introduction

Nondestructive testing (NDT) of metals is an integral part of the oil and gas, petrochemical, chemical, and process industries. There are well-established methods, codes, and standards within these industries that focus on the NDT of metals to ensure the integrity of piping, vessels, and other equipment. However, there is generally less familiarity in the industry with NDT methods used on concrete structures, despite the prevalence of concrete structures in these facilities. Concrete structures are commonly used for foundations, pipe racks, vaults, blast walls, tanks, spillways and pedestals. Because NDT methods for concrete are generally less known in these industries, they are less likely to be utilized in the inspection and evaluation of concrete structures.

This article will cover three concrete NDT methods and additional considerations will be presented for the use of these NDT methods within process facilities. Four brief case studies will also be presented that highlight the use of these NDT methods in the evaluation of concrete structures in process facilities. This article is geared toward inspectors, engineers, contractors, and others who desire to learn more about NDT tools available to aid in the evaluation of concrete structures in these facilities.

Figure 1. GPR survey being performed to locate reinforcing steel in a column as part of a structural evaluation in a refinery.

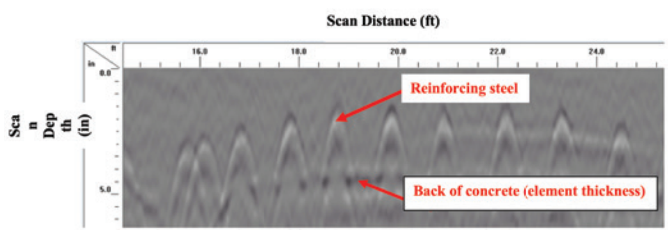

Figure 2. Example display of GPR line scan indicating reinforcing steel and back of concrete location.

Concrete NDT Technologies

Ground Penetrating Radar

Ground penetrating radar (GPR) is a geophysical technique commonly used to evaluate concrete and geological materials. The method uses electromagnetic waves to assess the internal characteristics of these materials. GPR surveys performed on concrete structures allow for the detection of embedded features such as steel elements (e.g., steel reinforcement, prestressing/post-tensioning stands, anchor rods, metal, and plastic conduit), verification of geometry (e.g., element thickness), and localization of internal defects (e.g., internal voids or poorly consolidated concrete) (**Figure 1**). The GPR method uses a radar antenna that transmits electromagnetic waves from scans collected at the testing surface. Electromagnetic signals are reflected from material interfaces with varying dielectric properties and collected by the antenna. These signals are then amplified and displayed for subsequent interpretation (**Figure 2**). Various GPR devices and antenna frequencies can be utilized depending on the specific application and scope of the inspection.

Ultrasonic Shear Wave Tomography

Ultrasonic shear wave tomography (UST), also known as ultrasonic pulse echo, is a low-frequency ultrasonic technique capable of generating 2-D and 3-D images of internal conditions within concrete elements. Typical UST systems utilize a transducer array that incorporates spring-loaded, dry point contact piezoelectric transducers (i.e., no coupling agent is required) (**Figure 3**). Each transducer emits ultrasonic shear waves (S-waves) and receives signals reflected from material boundaries or flaws. A processing algorithm (e.g., a synthetic aperture focusing technique) collects numerous signals from each scan and generates reconstructed images of the internal structure of the concrete (**Figure 4**). This technique is typically used to identify embedded elements in the concrete, assessment of geometry, and detection of internal conditions such as delamination, debonding, cracks, and voids in concrete.

Ultrasonic Pulse Velocity

Ultrasonic pulse velocity (UPV) is another low-frequency ultrasonic technique used to evaluate concrete materials. The method involves introducing pulsed longitudinal stress waves (P-waves) at the concrete surface and measuring received signals on opposing

Figure 3. UST survey being performed as part of a foundation assessment at a chemical plant.

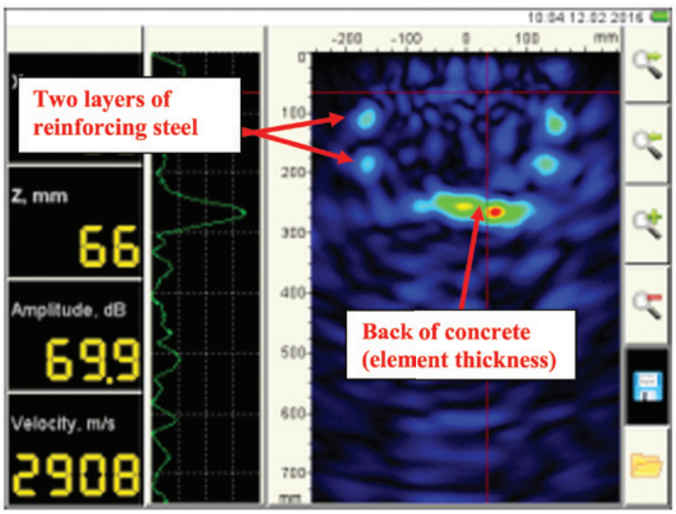

Figure 4. Example display of UST scan.

Figure 5. UPV testing on concrete cylinders which were used for a baseline velocity as part of an evaluation of columns on a compressor foundation.

or alternate faces of the test element (**Figure 5**). Stress pulses are transmitted and received using piezoelectric transducers that are acoustically coupled to the testing surfaces. Transit time and signal amplitude of a transmitted pulse are measured, and changes in arrival time, amplitude, and characteristics of the propagated waves are detected, which can indicate corresponding differences in the internal condition of the element.

UPV testing is commonly used to assess the concrete's uniformity and relative quality, relative strength, regions of internal cracking, and the extent of internal conditions such as poor consolidation. The testing technique is described in the ASTM C597, "Standard Test Method for Pulse Velocity through Concrete" [1]. UPV is most frequently utilized with transducers located on opposite faces of the tested element, also called direct measurements. Direct measurements require access on both sides of an element, which can be challenging in process facilities due to equipment, piping, or other obstructions. Testing locations and arrangements should be carefully considered prior to performing the evaluation.

Considerations for Concrete NDT in Process Facilities

Prior to performing NDT on concrete structures, careful planning is required regarding safety, site conditions, and evaluation objectives. Several of these considerations are discussed below.

Operation of NDT Equipment in Process Facilities

Safety is a critical part of any activity in a process facility. It is important to consider all aspects of the NDT equipment prior to its operation. For example, NDT equipment may not be certified as intrinsically safe, and specific areas of process facilities may require certified intrinsically safe equipment. Provided that normal operation of electronics is permitted, the use of non-intrinsically safe NDT equipment is generally not expected to adversely affect process facilities during normal operations.

The use of NDT equipment requires careful safety planning, which includes appropriate site-specific permits. For example, the Federal Communications Commission (FCC) sets output limits on GPR equipment. It requires GPR manufacturers to comply with these limits per the Code of Federal Regulations (CFR) Title 47, Part 15, Subpart F, "Ultra-Wideband Operation" [2]. Since the UST and UPV methods operate by transmitting sound waves in the acoustic and ultrasonic range rather than electromagnetic radiation, this equipment generally does not adversely affect equipment in process facilities; however, vibrating equipment can affect the test results.

Ambient Vibrations of Structures

Ambient vibration of structures due to process equipment can present challenges for UST and UPV testing. The vibrations in the structure will be measured by the UST and UPV sensors and may make some measurements difficult to discern by adding additional signal noise. Since GPR utilizes electromagnetic waves, it is not affected by structural vibrations. Expected vibration levels should be considered prior to performing the evaluation, and an appropriate NDT method should be selected and coordinated with facility operations.

Supplementing NDT Findings with Destructive Testing

An important consideration in an evaluation using NDT is performing destructive testing to confirm internal conditions. By extracting cores or creating exploratory openings (**Figure 6**), internal concrete conditions can be confirmed and correlated to NDT measurements. While the creation of cores or openings is technically destructive to the concrete, core and opening locations can typically be selected such that they have little-to-no consequence on the structural behavior of the element. Internal conditions that can be confirmed with destructive testing include, but are not limited to, reinforcing bar size, the presence of voiding or consolidation-related issues, and concrete strength. In general, destructive testing can help provide additional confidence in NDT measurements and valuable information to support the evaluation as a whole.

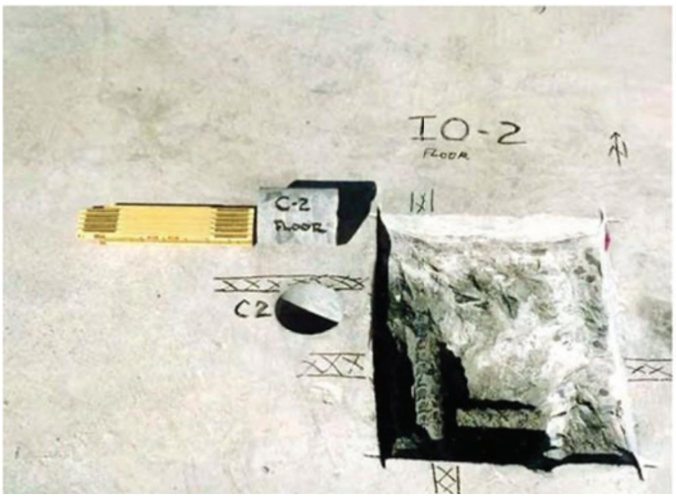

Figure 6. Exploratory opening verifying reinforcing size and cover. Concrete core extracted for additional laboratory testing.

Case Studies Involving Concrete NDT

Four brief case studies are presented below that involve the use of the concrete NDT methods discussed previously on concrete structures in process facilities.

Delayed Coker Unit Spillway

The delayed coker unit (DCU) at a refinery featured a spillway that directed released coke into a collection pit. The spillway was framed primarily with precast double tee (DT) beams. The top surface of the spillway was covered with ½-inch thick steel plates (i.e., wear plates). During inspection of the wear plates, it was observed that some of the wear plates had eroded, leaving the concrete surface of the DT beams exposed. Concerns were raised that without the wear plates, the concrete surface may be eroding and may reduce the structural capacity of the DT beams. The owner requested an evaluation be performed to characterize the severity of the erosion. Exploratory openings were not permitted, and all work was required to be performed on the underside of the spillway for safety reasons.

To investigate the potential of erosion of the top concrete surface of the DT beams, a multi-method NDT approach was utilized, which included GPR and UST testing. NDT was performed from the underside of the spillway at designated times when the coke drums were not cutting (**Figure 7**). GPR and UST testing were performed to measure the depth of erosion occurring on the top surface of the spillway DT beams. The GPR and UST results indicated that the maximum concrete erosion depth was between ¾ inch and 1 inch and varied depending on the location. Remaining clear cover from the top surface to the top layer of reinforcing steel was estimated to be between 1-3/4 inches and 2-1/2 inches, depending on the location. The maximum eroded depth was then utilized in structural calculations to verify that the DT beams had adequate structural capacity, even when considering the effects of erosion.

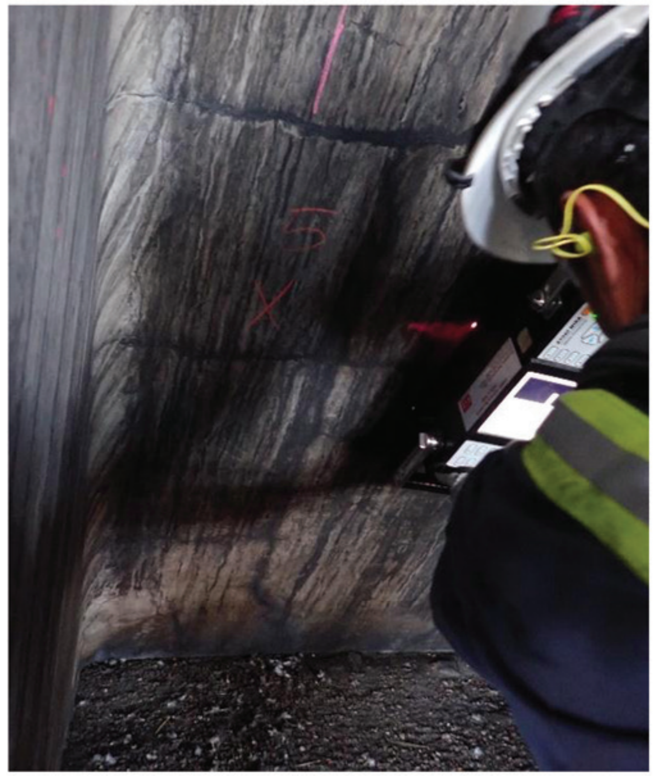

Figure 7. UST testing on underside of spillway DT beam flange.

The UST and GPR testing provided valuable measurements to evaluate the severity of the concrete erosion on the top surface of the spillway DT beams. Utilizing NDT provided an approach that did not require any exploratory openings or access to the top surface of the spillway. NDT provided a safe and effective way to evaluate the conditions and allowed the refinery to continue operating until the next turnaround to complete repairs.

Compressor Foundation Columns

The expansion of a chemical facility along the Gulf Coast involved the construction of two new reinforced concrete compressor foundations. During construction, following removal of the formwork, several of the columns exhibited consolidation-related surface defects, including honeycombing and voiding. Due to the surface defects, it was requested that the internal condition along the full height of all the columns be evaluated using NDT.

For this project, a multi-method NDT approach was utilized, which included UPV and GPR testing. Prior to UPV testing, GPR measurements were collected to determine the location of reinforcing steel in the column. During UPV testing, transducers were positioned on a grid, avoiding direct intersection with the

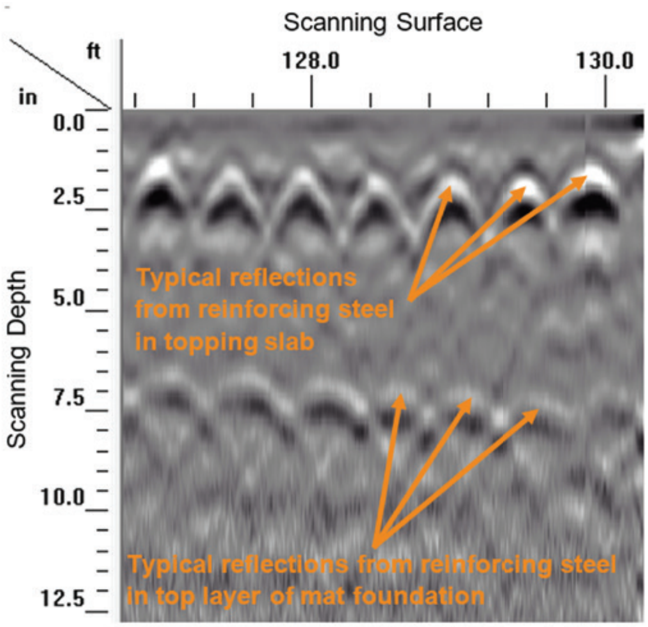

Figure 8. Typical GPR line scan indicating reinforcing steel within the topping slab and mat foundation.

Figure 9. Honeycombing on surface of blast wall (marked with arrow).

reinforcing steel. At each test location, the signal transit time, signal quality, and other signal features, as described above, were recorded and analyzed. Internal conditions, such as the presence of honeycombing, paste voids, or separations, affect the ability of an ultrasonic wave to propagate through a concrete member and can lengthen the actual transit time of transmitted waves and/or reduce the amplitude of the received wave. To determine a baseline concrete velocity to compare with the in-situ test results (**Figure 5**), the contractor provided four concrete cylinders from one of the concrete batches used during placement of the concrete columns. The average velocity values measured over the height of each column were in the expected range and had a relatively low standard deviation, indicating that the concrete tested was consistent with the well-consolidated baseline concrete.

Based on the UPV results, no detectable internal flaws or evidence of poor consolidation within the concrete columns were identified. Based on these results, the owner felt comfortable with the as-built condition of the columns and directed the contractor to proceed with construction. Utilizing NDT methods instead of removing and replacing the columns saved valuable time and money for the project.

Process Tower Foundation

As part of a capital improvement project at a chemical plant along the Texas coast, a new process tower was proposed to be installed on an existing mat foundation. While original structural drawings for the existing mat foundation were available, confirmation of the existing foundation conditions (i.e., in-situ concrete strength and reinforcing steel layout) was desired. The engineer of record (EOR) for the project requested an NDT assessment to be performed, in addition to material testing, to support the project.

For this project, GPR was utilized to determine the reinforcing steel configuration and overall depth of the mat foundation. The foundation featured a topping slab, which complicated the evaluation. The layout (i.e., spacing) of the reinforcing steel in the topping slab and top layer of steel in the mat foundation (**Figure 8**), along with the approximate depth of the foundation, were measured by GPR and consistent with the existing drawings. The EOR requested concrete cores in order to perform compressive strength testing. The concrete cores were accurately located using GPR to avoid reinforcing steel in the mat foundation.

The GPR results verifying the reinforcing layout, footing depth, and accurately locating the concrete cores were valuable to the project. Verifying as-built conditions and concrete materials testing gave the EOR confidence to proceed with the project. A new process tower was successfully constructed on the existing foundation. Utilizing the existing mat foundation saved critical time and money when compared to building a new foundation.

Central Control Building Blast Walls

The construction of a new central control building at a chemical plant included the construction of several perimeter concrete blast walls. During construction, following the removal of the formwork, the walls exhibited honeycombing and voiding in several locations (**Figure 9**). It was requested that the internal condition of the walls be investigated using an NDT approach to evaluate for the potential for consolidated-related deficiencies.

For this project, a multi-method NDT approach was utilized, which included UST and GPR testing. UST was utilized as the primary method to locate consolidation-related deficiencies. During UST testing, for a concrete element that does not contain consolidation-related deficiencies, a clear backwall reflection is typically present (i.e., signals from the opposite face of the test surface indicating wall thickness). For a concrete element that may contain

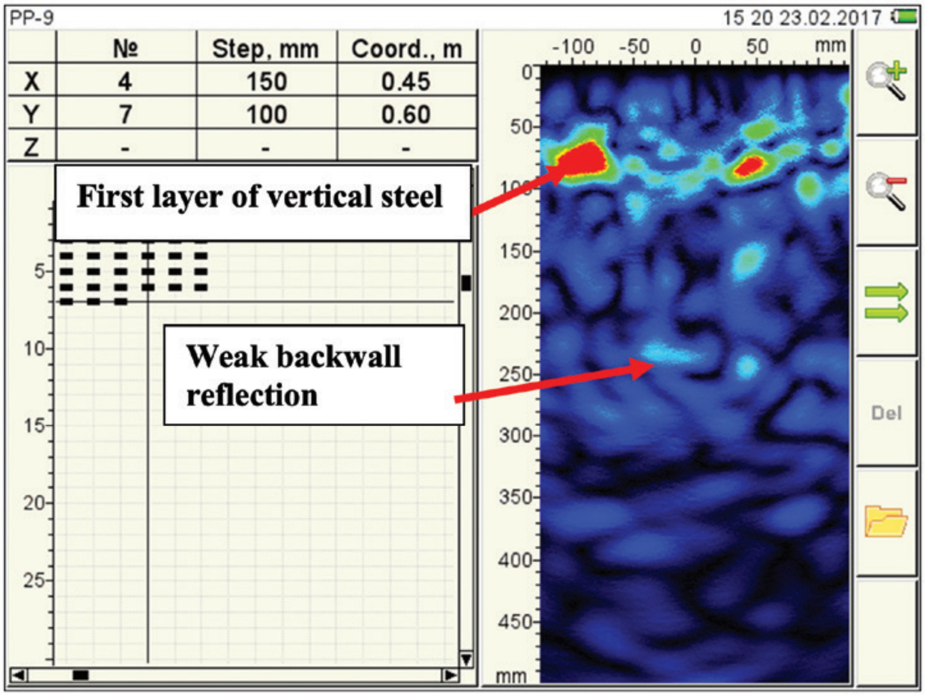

Figure 10. Example of weak backwall reflection on a UST scan.

consolidation-related deficiencies or internal cracks, a weak backwall signal or the lack of a clear backwall signal is typically present (**Figure 10**). During UST testing, several locations were identified where measurements indicated the potential for internal voiding. GPR was utilized as a secondary method to verify the results of the UST measurements. Voiding was confirmed at these locations using concrete core sampling. The areas of the walls with significant voiding were then repaired using either full-depth or partial-depth concrete repairs, depending on the location and extent of the voiding.

The UST and GPR testing allowed extents of the voiding to be accurately determined and further investigated. The concrete NDT helped accurately determine the extent of concrete repairs needed with minimum destructive openings and allowed the repair process to begin more quickly.

Conclusions

The concrete NDT methods discussed in this article can provide valuable information regarding internal conditions and inaccessible external conditions of concrete structures, often without the need for extensive destructive testing. Evaluation objectives, site conditions, and access constraints often influence which concrete NDT methods are most appropriate. As discussed, careful safety planning should occur before operating these tools in active process facilities, site conditions should be considered, and special consideration should be given to supplementary destructive testing to correlate NDT measurements with actual conditions. Additional information regarding the NDT methods discussed in this article can be found in ACI 228.2R-13, Report on Nondestructive Test Methods for Evaluation of Concrete in Structures [3]. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

REFERENCES

1. ASTM C597-22, 2023, "Standard Test Method for Pulse Velocity through Concrete," ASTM International.
2. Title 47 CFR Part 15, 2002, "Subpart F - Ultra-Wideband Operation," Code of Federal Regulations.
3. ACI 228.2R-13, 2013, "Report on Nondestructive Test Methods for Evaluation of Concrete in Structures", American Concrete Institute.

CONTRIBUTING AUTHORS

Daniel Pearson, PE

Daniel Pearson, PE, SE is a structural engineering consultant with Wiss, Janney, Elstner Associates, Inc. where he specializes in forensic investigations and evaluations of existing structures. He has experience in the investigation and evaluation of process plant structures, buildings, bridges, parking garages, and marine facilities. He received his Bachelor of Science and Master of Engineering in Civil Engineering from Texas A&M University. He is a licensed professional engineer and structural engineer in several states.

Ariel Suselo, PhD, PE

Ariel Suselo, PhD, PE, is a structural engineering consultant with Wiss, Janney, Elstner Associates, Inc., where he specializes in the forensic investigation and evaluation of existing structures. Dr. Suselo specializes in applying nondestructive evaluation (NDE) technologies, including mechanical waves and electromagnetic techniques utilizing multi-method approaches. He received a Ph.D. in Civil Engineering from the University of Texas at San Antonio and is a member of the American Concrete Institute and Structural Engineers Association of Texas.

Joshua White, PhD, PE

Joshua White, PhD, PE, is a structural engineering consultant with Wiss, Janney, Elstner Associates, Inc., where he specializes in the forensic investigation and evaluation of various concrete, steel, and timber structures. Dr. White's expertise includes the development, instrumentation, and application of both destructive and nondestructive evaluation multi-method approaches using mechanical waves, electromagnetic, and electrochemical test methods. He received a Ph.D. in Structural Engineering from the University of Texas at Austin and is a member of the American Concrete Institute and the International Concrete Repair Institute.