

**Hanford Single-Shell Tank Sidewall Coring Project – 15548**

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**ABSTRACT**

As part of an enhanced Single-Shell Tank (SST) integrity project, Washington River Protection Solutions, the US DOE Hanford site Tank Operations Contractor, established an expert panel to provide recommendations for implementation of the project. In one of the main areas of interest, structural integrity, the panel recommended obtaining and testing a vertical core from the entire depth of the sidewall for SSTs that have leaked and have been operated at high temperatures for extended periods. Due to concerns over handling contaminated samples, the panel later recommended that the evaluation focus only on thermal degradation. SST 241-A-106 was selected as the best choice for sidewall coring based on heat exposure and other factors. During site preparation activities, nondestructive testing and evaluation of the exposed tank dome and sidewall was performed using impact echo, spectral analysis of surface waves, and sonic echo/impulse response acoustic wave test methods. Good results were observed in the tests performed on the dome, but results were inconclusive for the full wall height due to signal damping. Results indicated that no cracking was predicted in the upper wall. Sidewall coring of tank A-106 was completed over two weeks in May 2014. Over 38 feet of concrete core was successfully removed, to a depth approximately halfway through the tank footing. Nondestructive and destructive physical testing of the concrete core specimens was successfully performed and included visual examination and determination of transverse and longitudinal resonant frequency and dynamic modulus of elasticity; pulse velocity; static modulus of elasticity; Poisson's ratio; and compressive strength. The testing indicated favorable results with values generally greater, and in many cases significantly greater, than expected in comparison with the values originally specified and those used in the current structural analysis of record. Petrographic analysis was performed to assess the quality and condition of the concrete and the extent of any deterioration or deleterious reactions occurring within the concrete, and determined that the concrete within the examined core segments is in overall good condition, with a minor amount of microcracking and minor evidence of deleterious mechanisms that do not appear to have significantly affected the overall quality and integrity of the concrete. The results of the testing performed on the concrete core removed from the sidewall of SST 241-A-106 do not reveal any deficiencies with the structural integrity of the tank.

**INTRODUCTION**

The Hanford site Tank Operations Contractor, Washington River Protection Solutions (WRPS), initiated the Single-Shell Tank Integrity Project (SSTIP) to improve the understanding of the integrity of the SSTs until the waste can be retrieved from the tanks for treatment. The SSTIP Expert Panel was established by WRPS to provide recommendations for implementation of an enhanced SSTIP. The panel presented 33 recommendations with ten providing the basis for a robust plan to enhance the understanding of the SST integrity. WRPS has adopted 16 of the panel's recommendations. One of the four key elements from the panel is to improve the understanding of the SST structural integrity (designated as "SI"). In Recommendation SI-3, *Obtain and Test Sidewall Core*, the panel recommended obtaining and testing a vertical core from the entire depth of the sidewalls for two tanks that have leaked and had been operated at high temperatures for extended periods. Due to concerns over handling contaminated samples, the panel later recommended that the evaluation focus only on thermal degradation.

Over 38 feet of 3.3-inch nominal diameter concrete core was removed from SST 241-A-106 and shipped offsite for testing. The results from inspection, physical testing, and petrographic examination of the core specimens provide engineering mechanics properties that are compared to those used to perform the structural analysis of record (AOR) for the type of tanks in A-farm and the 28-day design compressive strength of 3,000 psi originally specified for the tanks in A-farm during their construction in the mid-1950s. The AOR is a detailed finite element modeling and analysis effort performed to understand the structural response of the SST during thermal and operating loads and during seismic events. Additional results are provided from the nondestructive testing and evaluation (NDE) of the exposed tank dome and sidewall performed using acoustic wave test methods prior to removal of the core.

### **ACTIVITIES PERFORMED PRIOR TO CORING**

The sidewall coring project involved obtaining concrete core from SST 241-A-106 that still contains waste. Consequently, there were potential risks to human health, the environment, and the structural integrity of the tank. However, as a result of systematic planning, structural analysis, technical expert and stakeholder review, and successful demonstration and mockups of the planned core drilling, the risks were identified and minimized to the extent practical. Sidewall coring was successfully completed on an SST before in 1981 with the coring of the concrete sidewall of 241-SX-115. Lessons learned from the 241-SX-115 coring activities were incorporated into the planning for the 241-A-106 sidewall coring project.

### **Planning**

The systematic planning process, data quality objectives (DQO), defined by the US EPA was used to determine whether a concrete core sample should be collected from a SST and if so, determine the tank to be cored. As a result of the DQO process, the decision was made to proceed with coring a single tank that was exposed to high heat and had not leaked. Tank 241-A-106 was selected as the best choice for sidewall coring based on heat exposure and risk factors such as accessibility to the tank, interferences from retrieval, remaining waste volume, and expected soil contamination around the tank. The waste temperatures in tank A-106 reached a high of 594°F (the highest of all SSTs), as shown in Figure 1.

From the DQO process, a sampling and analysis plan was developed to provide an overview of the process that would be used to collect sidewall core specimens and the quality assurance project plan elements that would be required to perform the work. The sidewall coring details were extensively documented in a drilling plan that described tank selection; site preparation; coring technique and control; demonstration of coring capabilities; concrete testing to be performed on the removed core; project, quality assurance, environmental, safety, and health requirements; and project deliverables. Specific risk mitigation addressed in the drilling plan included core hole deviation control, avoidance/limitation of cutting rebar, and the ability to discontinue core activities during advancement of a core hole and move to an alternate core hole. The 241-A-106 sidewall coring concept is illustrated in Figure 2.

### **Analysis**

A structural analysis evaluated a finite element model of the tank and surrounding soil for several scenarios, including a baseline pre-drilling case, a soil-offloading case with an excavated hole in the soil for the caisson installation, and a during-drilling case with a caisson hole in the soil and applied live load from drilling operations. The model used degraded concrete properties due to the high temperatures experienced by the tank over a long period. The demands from the three scenarios were compared to code calculated concrete capacities corresponding to the section being evaluated (i.e., wall, haunch, and dome). The during-drilling scenario included capacities with the 4-in. nominal core hole removed where the section rebar was left intact and also where tension or compression bars were cut. The analysis concluded that the drilling activities do not negatively impact the structural integrity of the tank.

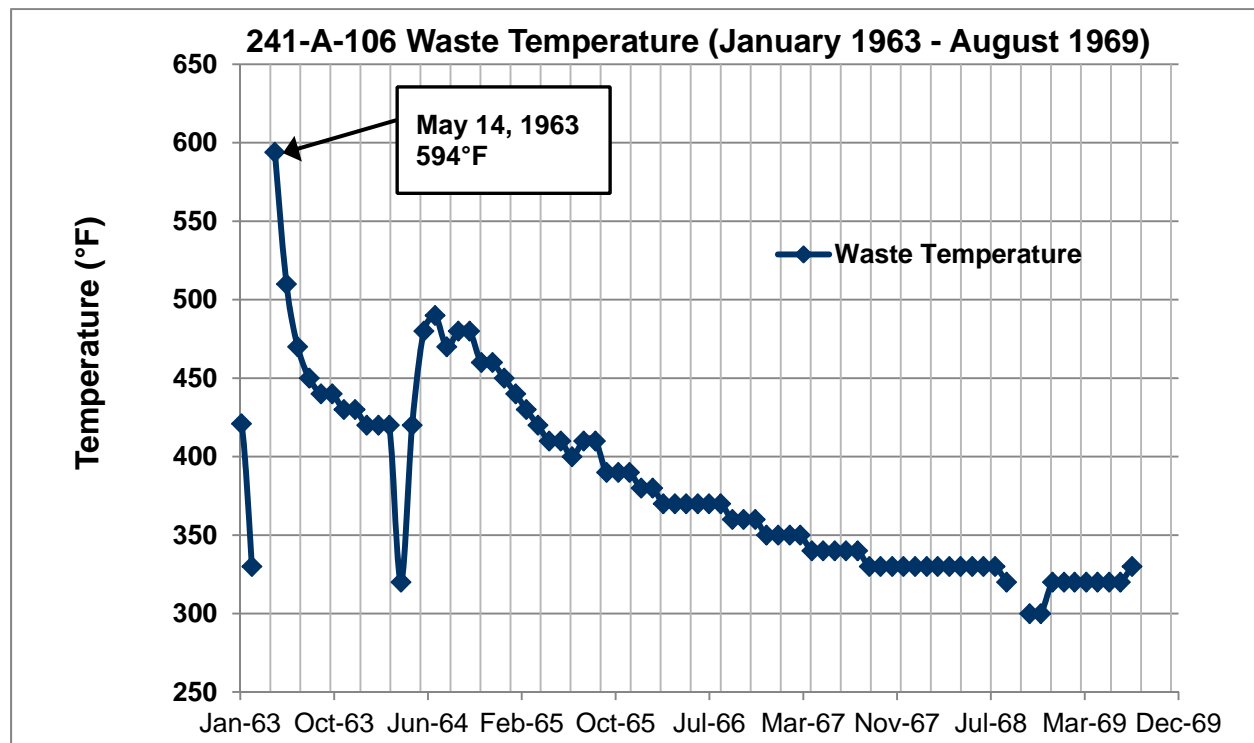


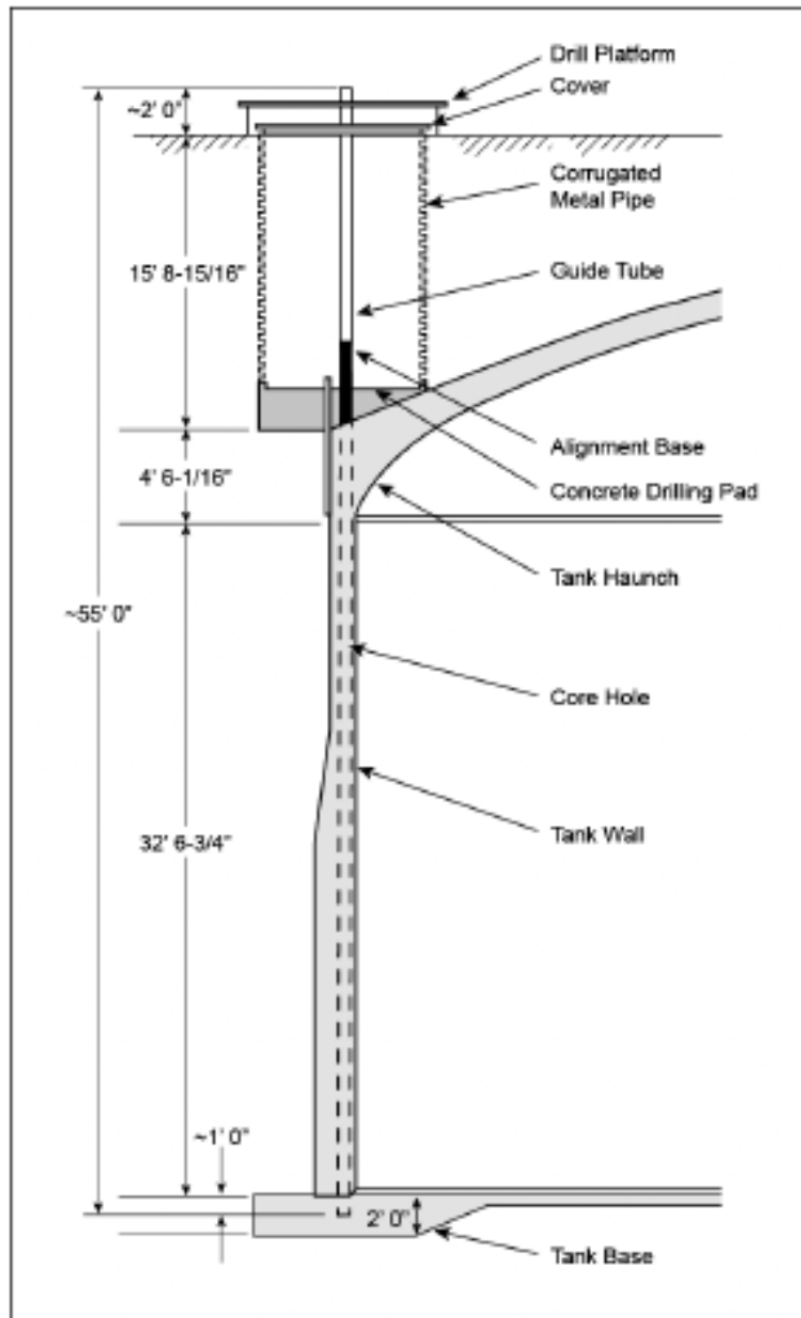
Fig. 1. Tank A-106 Waste Temperature

**Review**

The 241-A-106 sidewall coring project was extensively reviewed by WRPS technical experts, an Independent Qualified Registered Professional Engineer (IQRPE), and project stakeholders (US DOE and the State of Washington Department of Ecology). The IQRPE made several recommendations that were incorporated into the revised drilling plan, and concluded that the sidewall coring would not adversely affect the structural capacity of the tank provided the planned controls were met. Originally, Ecology was not convinced that the data obtained from coring into a tank that still contained waste was worth the potential risk to human health and the environment. However, as a result of the extensive planning conducted (i.e., the DQO process and development of the sampling and analysis plan) and observation of the successful demonstration, Ecology recommended proceeding with sidewall coring.

**Demonstration**

Demonstration testing was conducted on a subsurface reinforced concrete wall of a mothballed nuclear power plant containment building. The purpose of the testing was to demonstrate the capabilities of the proposed coring method, feasibility of the operations, and the ability to conduct activities safely. The objectives were established specifically to address concerns on the ability to control and measure vertical deviation, obtain intact core suitable for strength testing, and provide for control of the circulating fluid for waste minimization and contamination control. The demonstration report concluded that the demonstration was a success in meeting all objectives and supported the decision to move forward with the coring of the tank sidewall. Lessons learned and recommendations for improvement from the successful demonstration were incorporated into the revised drilling plan. Prior to coring, a series of mockups was conducted to familiarize personnel and train operators and to provide proof of principle of the design changes made subsequent to demonstration testing.



Not to scale.

Fig. 2. Tank A-106 Sidewall Coring Concept

## CONCRETE CORING ACTIVITIES

### Site Preparation

To facilitate excavation of the soil over the tank haunch, an 8-ft diameter caisson consisting of corrugated metal liner plates was installed as excavation advanced. The final excavation extended approximately six feet below the top edge of the tank haunch. Once excavation was completed, the asphaltic membrane

covering the concrete was removed and NDE testing was performed on the exposed tank dome and sidewall. The haunch and sidewall surfaces were scanned using concrete penetrating radar and the identified locations of rebar were marked to aid in positioning core hole entry points. With the entry points identified, vertical alignment assemblies were installed, a concrete pad covering the haunch and exposed wall was placed, and a lid was placed over the caisson. Mobilization and alignment of the core rig and equipment completed site setup.

### **Coring**

Coring of the tank sidewall was initiated on May 6, 2014 and retrieval of the final core run was completed on May 21, 2014. A total of 13 core runs were made, retrieving 38.3-ft of 3.3-in. nominal concrete core from the tank haunch, wall, and footing. The coring activities took a total of only eight hours of actual drilling time to cut the total core length, with no difficulties, equipment failures, or core hole problems occurring. Verticality surveys were conducted at the beginning of the coring and following completion of each core run. The final verticality survey showed a maximum core hole deviation of 0.070-ft (~7/8-in.) from horizontal, well within the maximum deviation of 2-in. allowed per the drilling plan.

### **Radiological Survey of the Core**

Radiological surveys were conducted on the retrieved core from the time the core barrel was pulled from the hole until the core was packaged for shipment. Fixed radiological contamination was detected on the core collected in core runs number 5 and 6 at core lengths of approximately 4.4 and 4.6-ft, respectively, into the haunch. No additional radiological contamination was detected in the retrieved core, core cuttings, or on core tooling during the remainder of the coring activities. Dose measurements performed in the core hole indicated a higher dose rate at a depth consistent with the location where the fixed radiological contamination was found on the retrieved core.

The depth of contamination on the retrieved core is at a location near the top of the tank steel liner. During A-farm SST construction, lead flashing was installed above the liner in a groove cast into the concrete haunch and filled with grout. As there is not any evidence that tank A-106 was overfilled during waste operations, it is speculated that boiling waste or contaminated condensate may have run down behind the flashing or seeped through the grout, resulting in the fixed contamination and higher dose observed at this location in the tank sidewall.

### **Cutting of Rebar**

Horizontal (hoop) rebar was cut in the haunch, but no rebar was cut in the wall or footing. Based on the structural analysis, the drilling plan limited the number of consecutive hoop rebar that can be cut to no more than four. Three horizontal rebar were cut within relative proximity to each other at depths of 1.13-ft, 1.52-ft, and 1.65-ft, but none of these rebar appeared to be cut completely through. The last rebar cut was at a depth of 4.8-ft and appeared to be a bent vertical (meridional) rebar extending up from the wall into the haunch. In no case was the established limit for cut rebar exceeded.

### **Examination of the Removed Core and Inspection of the Core Hole**

Visual examination of the core was performed as soon as it was removed from the core barrel. Each segment was examined for the presence of rebar, air pockets, fractures, size of aggregate, and any anomalies. After the core was examined and labeled, each segment was photographed. A representative close-up photo of the top of Core Run #6 showing (circled) the fixed area of contamination at 4.6-ft (4,000 disintegrations per minute beta/gamma) and the cut rebar at 4.8-ft is shown in Figure 3.



Fig. 3. Top of Core Run #6 Photo Record

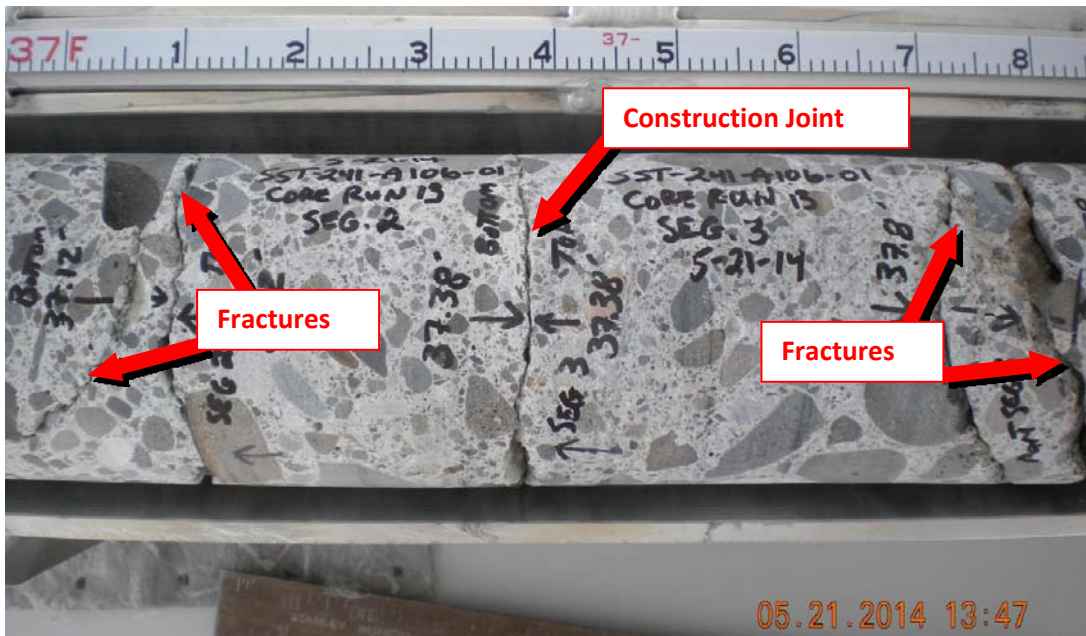
Overall the core was in good condition. The concrete in the haunch was observed to have a significant number of small air pockets measuring about a 1/16-in. in diameter. A few larger air pockets were observed in the core retrieved from the wall and footing. Several of the breaks in the core can be attributed to the coring method. A few of the breaks coincided with rebar or large aggregate. It is difficult to attribute any of the breaks to pre-existing fractures in the concrete; however, two breaks in the lower portion of the core retrieved above and below the wall/footing interface are clearly fractures.

The core was handled and packaged in accordance with ASTM C42/C42M [2], *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*. Once the core segments were packaged, the packages were removed from the tank farm and appropriately shipped offsite to the testing laboratory for concrete testing.

#### **Fractures Observed Above and Below the Wall/Footing Interface**

Above and below the transition (construction joint) from the wall to the footing, the core showed two fractures extending both upward and downward from each end of what appeared to be the water stop. The water stop is a 1/4-in. x 7-in. steel plate installed between the wall/footing interface. The fractures are shown in Figure 4. The water stop was observed on one side of the core hole in the downhole inspection video. The edge of the water stop appears to have been cut into, but not through, by the core bit.

The fractures are graphically depicted in Figure 5 to provide their approximate orientation with regards to the tank. The fractures propagate towards the inside of the tank. Although the direct cause of the fractures is unknown, it is speculated that with their orientation towards the inside of the tank, the fractures may be due to out-of-plane shear forces imposed at this intersection as a result of soil backfilling operations.



The construction joint is shown at a depth of 37.38-ft. Fractures are shown above and below the joint. The length between the fractures is approximately the height of the water stop.

Fig. 4. Fractures Observed in Core at Each End of Water Stop

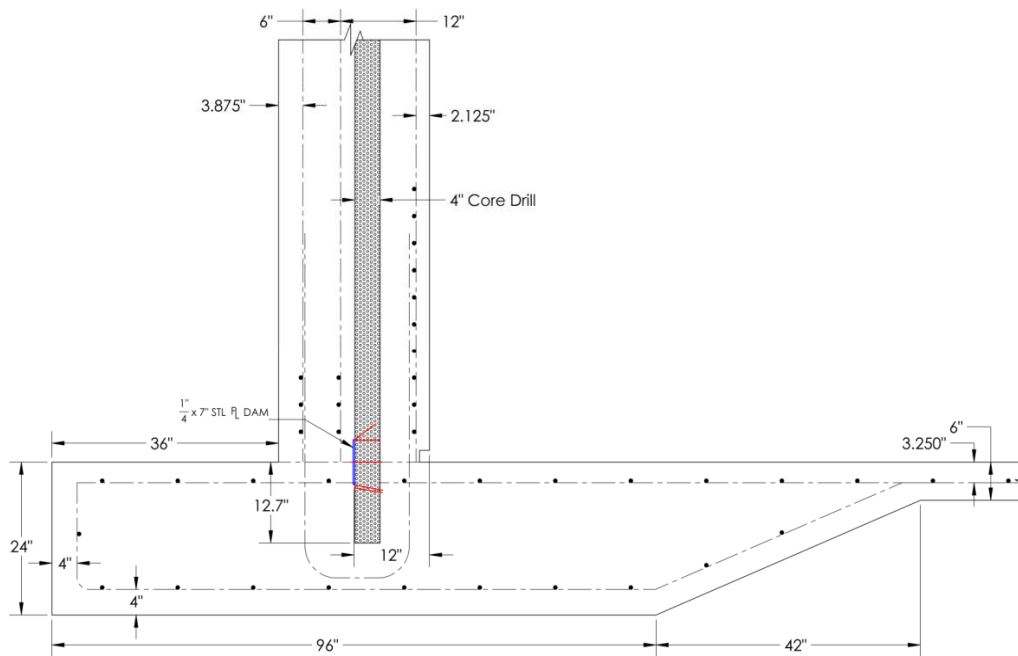


Fig. 5. Depiction of Fracture Orientation

As part of the AOR effort, the shear friction across a diagonal crack at the bottom of the tank wall was evaluated. The assumed crack is shown in Figure 6. While it is not known if the fracture seen at the top of the water stop propagates to each wall face, the crack analyzed provides a reasonable evaluation for comparison if it does. The largest demand to capacity (D/C) ratio for the assumed diagonal crack is 0.35, considerably less than the allowable of 1.0. As such, the fractures observed in the core above and below the wall/footing interface do not appear to impact the structural integrity of the tank.

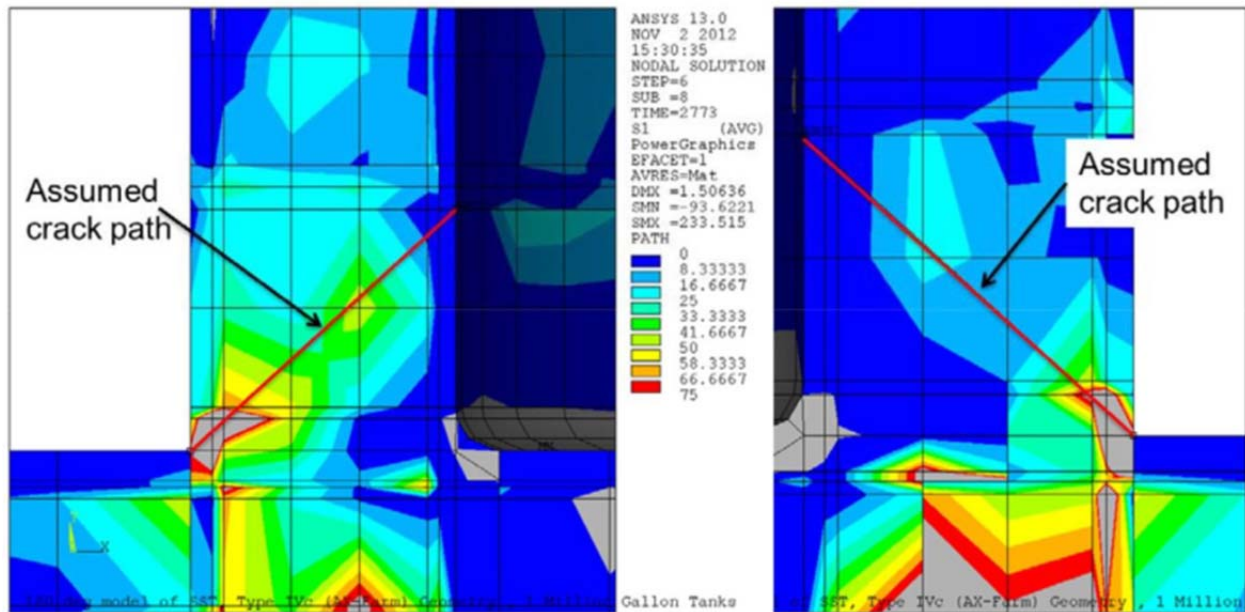


Fig. 6. Diagonal Shear Friction Crack Evaluated in Analysis of Record

### NDE OF THE EXPOSED TANK DOME AND SIDEWALL

NDE testing was performed on the exposed tank dome and sidewall prior to removal of the core. During site preparation, three acoustic wave NDE methods were used: Impact Echo (IE), Spectral Analysis of Surface Waves (SASW), and Sonic Echo/Impulse Response (SE/IR).

#### Impact Echo

The IE test method uses sound waves to measure the effective thickness of a concrete member and also to locate cracks, seams, or flaws that are parallel to the test surface. The exposed area of the dome was gridded out on 6-inch intervals. Tests with the IE method were conducted on 6-inch intervals at all accessible points by pressing the test head against the dome and impacting each test point with a hammer. At a few test locations, the exposed concrete surface was too rough for the collection of usable data. The IE test results indicated that the dome portion tested is in overall relatively good condition, with most points showing only the thickness echo from the dome bottom. There were several points near the wall that showed a minor reflection about 15-18 inches deep. These points may have been affected by the curvature of the dome bottom or other geometry effects.

#### Spectral Analysis of Surface Waves

The SASW test method uses surface waves to allow the measurement of the velocity versus depth profile through a member and can be used to measure the depth of surface-opening cracks, measure freeze-thaw damage, and look for effects of heat or other mechanisms on relative concrete strength. Tests with the



SASW method were conducted at 1-ft intervals on the gridded points of the exposed dome. At a few test locations, the exposed concrete surface was too rough for the collection of usable data. The SASW results showed that the overall average velocities of the concrete across the dome were consistently high. Most of the tested points showed a drop in velocity at 0.6-0.8 feet but no velocities that would be considered “low” after the drops (i.e., the velocities are all in a range that would be considered typical of “sound” concrete). The cause of the drops could not be determined, but they appear consistent with a possible change in concrete material, mix design, or strength. The smooth transition between velocities for most locations indicated that any interface was well-bonded.

### **Sonic Echo/Impulse Response**

The SE/IR method was used to examine wall concrete integrity and to look at the effectiveness of this method in assessing the condition of tank sidewall concrete below the excavation. Tests with the SE/IR method were conducted at three stations along the dome edge, with three receiver points centered above the wall on the dome top and three points with the receiver mounted on the wall side below the impact location on the dome top. The SE/IR tests done with the receiver mounted on the side of the wall all resulted in excessive ringing of the receiver, possibly due to mounting issues. The SE/IR test results showed only scattered weak echoes, with no echoes from the wall bottom evident. The signal mostly damped out with only a few very weak echoes seen, including one from about 23-24 feet where the wall thickness changes. There were no strong shallow echoes seen, indicating that there was not a significant crack parallel to the wall top and that there was not any debonding between the dome and the wall top expected.

### **NONDESTRUCTIVE CONCRETE CORE TESTING**

Concrete inspection and testing was performed by CTLGroup at their laboratory in Skokie, Illinois. Prior to arrival at CTLGroup, the core segments were received and surveyed by their subcontractor, Radiation Safety Services, Inc. Measurable activity was detected on core run numbers 5 and 6, corresponding to the fixed contamination on the core. The radionuclides in the other core runs were below minimum detectable activity. Upon delivery to CTLGroup, visual inspection was performed on all the core segments. Photographs were taken, noting any observed rebar, voids, and cracks. The core segments were prepared and subjected to nondestructive and destructive physical testing. Sections of core segments that contained rebar or measurable activity (hot spots) were not tested.

Length measurements of the core segments were taken. If the core segment length was greater than 12 inches, the sample was considered acceptable to be nondestructive tested. A total of 28 core segments were tested in accordance with ASTM C215 [3], *Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens*, and ASTM C597 [5], *Standard Test Method for Pulse Velocity Through Concrete*.

### **Resonant Frequency and Dynamic Modulus of Elasticity**

The resonant frequencies of the concrete segments were determined using ASTM C215. This test method covers measurement of the fundamental transverse, longitudinal, and torsional resonant frequencies of concrete prisms and cylinders. The accelerations of the concrete segment are recorded upon impact of the segment. The resonant frequencies are obtained from fast Fourier transform of the accelerations. Three reliable test results are used to calculate the average result. The dynamic modulus of elasticity, dynamic Poisson’s ratio, and dynamic modulus of rigidity (dynamic shear modulus) are then calculated from the formulas in ASTM C215.

The dynamic modulus of elasticity results indicated relatively good agreement between the transverse and longitudinal moduli, with an average of 6,256 ksi and 6,302 ksi, respectively.

### **Pulse Velocity**

The pulse velocities of the concrete segments were determined using ASTM C597. This test method covers determination of the propagation velocity of longitudinal stress wave pulses through concrete. The transit time of the pulse through the concrete segment between the transmitter and receiver are recorded. The pulse velocity is determined from the transit time using the formula in ASTM C597.

The testing for pulse velocity provides a benchmark against the compression wave velocities used in the NDE testing performed on the exposed tank dome and sidewall. The dome IE tests used a nominal velocity of 12,000 ft/s and the wall SE/IR tests used a velocity of 12,500 ft/s. Both velocities are typical of average strength (3,000 to 5,000 psi) mix designs. The measured pulse velocities of the 241-A-106 sidewall core segments are all significantly greater than these velocities, with an average of 17,365 ft/s. The higher velocities indicate higher compressive strength of the segments. The higher velocities do not significantly affect interpretation of the NDE results, other than the depths of the weak echoes seen in the SE/IR tests may be deeper than originally stated (e.g., the weak echo from about 23 ft may be from about 31 ft).

### **DESTRUCTIVE CONCRETE CORE TESTING**

A total of 34 core segments were tested in accordance with ASTM C469 [4], *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*. A total of 36 core segments were tested in accordance with ASTM C39 [1], *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. A total of 15 core segments were tested in accordance with ASTM C856 [6], *Standard Practice for Petrographic Examination of Hardened Concrete*. If the core segment length was less than 6 inches, the sample was not considered acceptable to be tested in accordance with ASTM C469. If the core segment length was greater than 24 inches, the segment was split into additional samples. After nondestructive testing was completed, the segments for ASTM C469 and ASTM C39 testing were cut to a nominal length of 6<sup>3</sup>/<sub>4</sub>-in. and capped. The capped length-to-diameter ratios of the samples generally fell within the preferred range of 1.9 to 2.1 stated in Section 7.2.1 of ASTM C42. The ratios were all greater than the minimum of 1.75, with the exception of sample #13-4 from the footing. Petrographic analysis was performed on core segments at approximately every three feet and on the two samples at the interface between the wall and the footing.

### **Static Modulus of Elasticity and Poisson's Ratio**

Modulus of elasticity and Poisson's ratio of the concrete segments were determined using ASTM C469. This test method covers determination of (1) chord modulus of elasticity (Young's), and (2) Poisson's ratio of molded concrete cylinders and diamond-drilled concrete cores when under longitudinal compressive stress. The sample is placed in a combined compressometer and extensometer frame that holds the strain dials which record the longitudinal and transverse strains at an assigned load interval. The sample in the test frame is subjected to compressive force in the axial (longitudinal) direction. The applied force is recorded along with the associated deformations in the longitudinal and transverse directions. The test is performed three times, with the first disregarded and the last two used to calculate an average result. The resulting stresses and strains are plotted and the modulus of elasticity and Poisson's ratio are calculated from the formulas in ASTM C469.

ASTM C469 tests were not performed on core segments #13-1 and #13-4. These segments correspond to the core just above and below the water stop, respectively. Segment #13-1 had a visible crack running diagonally along its length, and segment #13-4 had a relatively large void through its width. As there was uncertainty in estimating the initial ultimate load because of these anomalies, the decision was made to forego the ASTM C469 tests and proceed with compressive strength tests (ASTM C39).

The static modulus of elasticity and Poisson's ratio results are plotted in Figure 7 along with the thermally degraded moduli used in the current AOR. Upper bound, best estimate (mean), and lower bound values at 250°F and 350°F are shown, encompassing the peak temperature in the concrete wall of 280°F used in the AOR. The average modulus of elasticity of the core segments is 6,274 ksi. All of the core segments resulted in a modulus of elasticity greater than the upper bound modulus at 250°F. In general, the modulus of elasticity determined by nondestructive testing was a relatively good indicator of the modulus of elasticity determined by destructive testing.

The Poisson's ratio of the core segments is in the range from 0.18 to 0.37, with an average of 0.25. The range of Poisson's ratio varies throughout literature and other test data, but is generally in the range of 0.11 to 0.21 and more typically in the range of 0.15 to 0.20. All of the core segments but two resulted in Poisson's ratios greater than the typical maximum.

### **Compressive Strength**

Compressive strength of the concrete segments was determined using ASTM C39. This test method covers the determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. The sample is subjected to a compressive axial load at a rate within a prescribed range until failure occurs. The maximum load attained during the test is recorded and the compressive strength is calculated by dividing the load by the cross-sectional area of the specimen. The type of fracture pattern as defined in ASTM C39 is also recorded.

The compressive strength results and their average are plotted in Figure 8 along with the thermally degraded strengths used in the current AOR and the originally specified 28-day design strength of 3,000 psi. Upper bound, best estimate (mean), and lower bound values at 250°F and 350°F are shown, encompassing the peak temperature in the concrete wall of 280°F used in the AOR. The average compressive strength of the core segments is 10,132 psi. All of the core segments resulted in a compressive strength greater than the upper bound strength at 250°F.

Testing of segment #13-1 provided an indicator of the strength of the wall with a crack through it. The compressive strength of segment #13-1 was 6,420 psi, further indicating that the fractures observed in the core do not appear to impact the structural integrity of the tank. Testing of segment #13-4 provided an indicator of the strength of the footing. The only other sample from the footing (#13-3) was considered too short (just over 3-in.) to test. The capped length-to-diameter ratio of sample #13-4 was less than the minimum ratio of 1.75 in ASTM C42. This resulted in a correction factor being applied to the tested strength value as specified in ASTM C39 and ASTM C42. The corrected compressive strength of segment #13-4 was 6,167 psi, indicating that the void and fractures observed in the footing core segment do not appear to impact the structural integrity of the tank.

### **Petrographic Analysis**

Petrographic analysis was performed to ASTM C856. The petrography examination assessed the quality and condition of the concrete and the extent of any deterioration or deleterious reactions occurring within the concrete. The core segments were received by the petrographer and prepared for examination. The core segments were visually inspected and photographed as received. Each core segment was then cut in half longitudinally and one of the resulting halves was ground (lapped) to produce a smooth, flat, semi-polished surface. Lapped and freshly broken surfaces of the concrete were examined using a stereomicroscope at magnifications up to 45X. For thin-section study, a small rectangular block was cut from the top surface portion of core segments #1, #9-2, and #13-3, and one side of each block was lapped to produce a smooth, flat surface. The blocks were cleaned and dried, and the prepared surfaces were mounted on separate

ground glass microscope slides with epoxy. After the epoxy hardened, the thickness of the mounted blocks was reduced to approximately 20  $\mu\text{m}$  (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.

Based on the results of petrographic examination, the concrete represented by the core segments appeared to be in good condition overall. The concrete was composed of siliceous natural gravel coarse aggregate and natural sand fine aggregate uniformly distributed in a portland cement paste binder. The paste appeared to be of good quality, although some degree of paste alteration (leaching of calcium hydroxide from the paste) was observed. Only one crack and a very few microcracks were observed in the examined core segments. A very minor degree of alkali-silica reaction (ASR) had occurred in the concrete; however, no deterioration (no associated cracks or microcracks) was observed. The air content in the concrete was low, generally estimated at 1 to 3%.

Petrography was performed on core segments #13-2 and #13-3, corresponding to the segments on each side of the wall/footing construction joint. The concrete on both sides of the construction joint appeared similar to each other. The paste in segment #13-2 was moderately hard to locally moderate in some areas. The paste along the outer surface of segment #13-3 (i.e., the top of the footing) was carbonated to a depth of 1 to 4 mm. The paste-to-aggregate bond was moderately tight to moderate in segments #13-2 and #13-3. Two microcracks were present in segment #13-2, but they do not appear to be the result of deleterious reactions within the concrete. A crack was present in segment #13-3, corresponding to the fracture in the footing below the water stop. Petrography of this sample provided additional insight as to the condition of the concrete with a crack, further indicating that the fractures observed in the core do not appear to impact the structural integrity of the tank.

Microcracks were observed in three other core segments: two in segment #7-3, two in segment #10-4, and one in segment #12-3. Similar to segment #13-2, they do not appear to be the result of deleterious reactions within the concrete. Several isolated pockets of ASR gel were present in some of the cores, lining air voids but not filling them. The degree of ASR was considerably less than expected, considering the potential reactivity of the rock types. Given the age of the concrete and current degree of ASR, further reaction and associated expansion was deemed unlikely.

## **RESULTS**

NDE was successfully performed on the exposed tank dome and sidewall prior to sidewall coring using several acoustic wave test methods. Good results were observed in the tests performed on the dome, but results were inconclusive for the full wall height due to signal damping. Results indicated that no cracking was predicted in the upper wall, as confirmed by the removed concrete core.

Nondestructive and destructive physical testing of the concrete core specimens was successfully performed by CTLGroup in Skokie, IL. The testing included visual examination and determination of transverse and longitudinal resonant frequency and dynamic modulus of elasticity; pulse velocity; static modulus of elasticity; Poisson's ratio; and compressive strength. The averaged results are summarized in Table I. The results of the visual and microscopic inspection of the core segments indicate that the concrete removed from the sidewall is in overall good condition. The results of petrographic analysis indicated that the concrete within the examined core segments is in overall good condition, with a minor amount of microcracking and minor evidence of deleterious mechanisms that do not appear to have significantly affected the overall quality and integrity of the concrete.

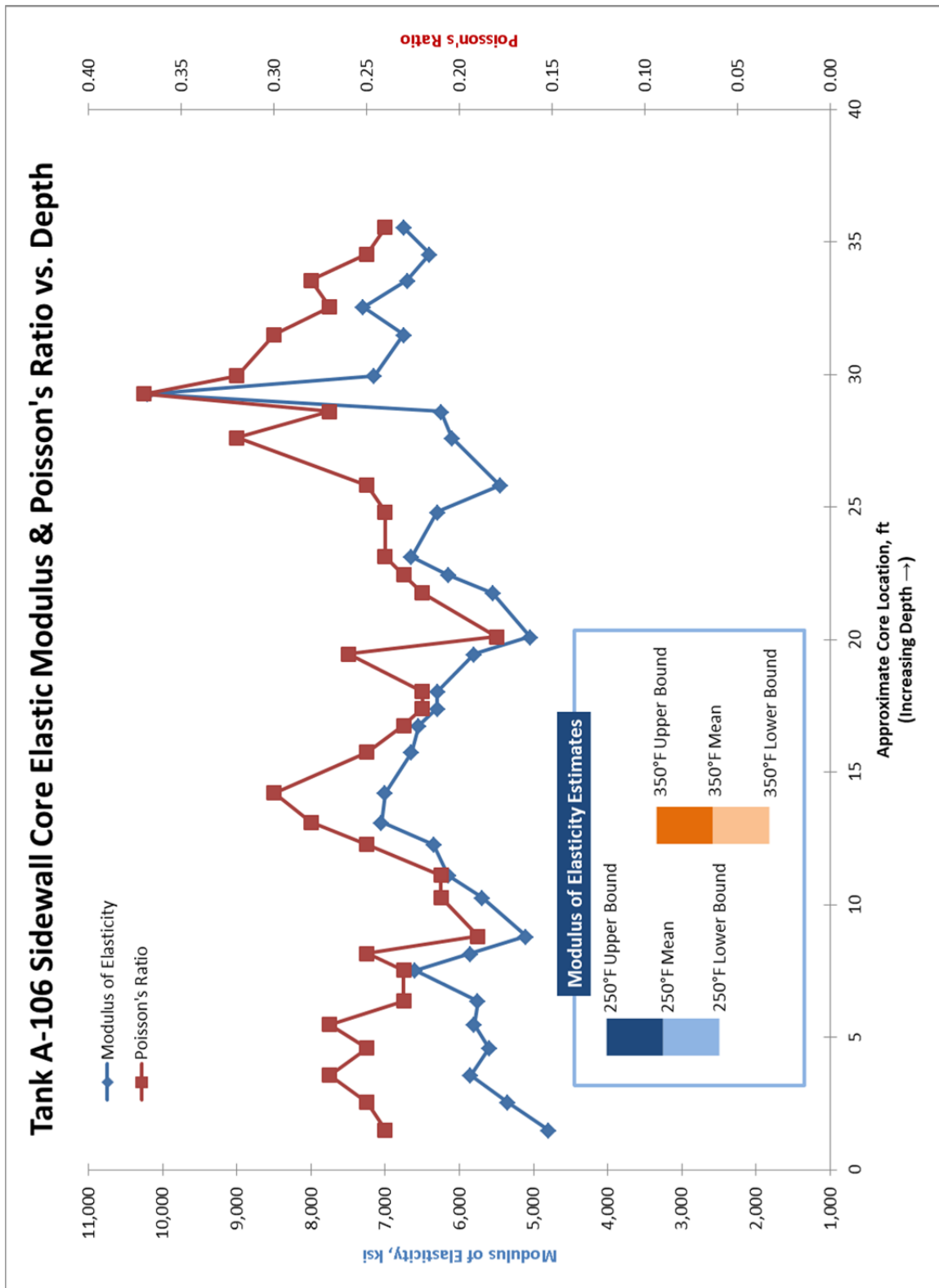


Fig. 7. Elastic Modulus and Poisson's Ratio Comparison

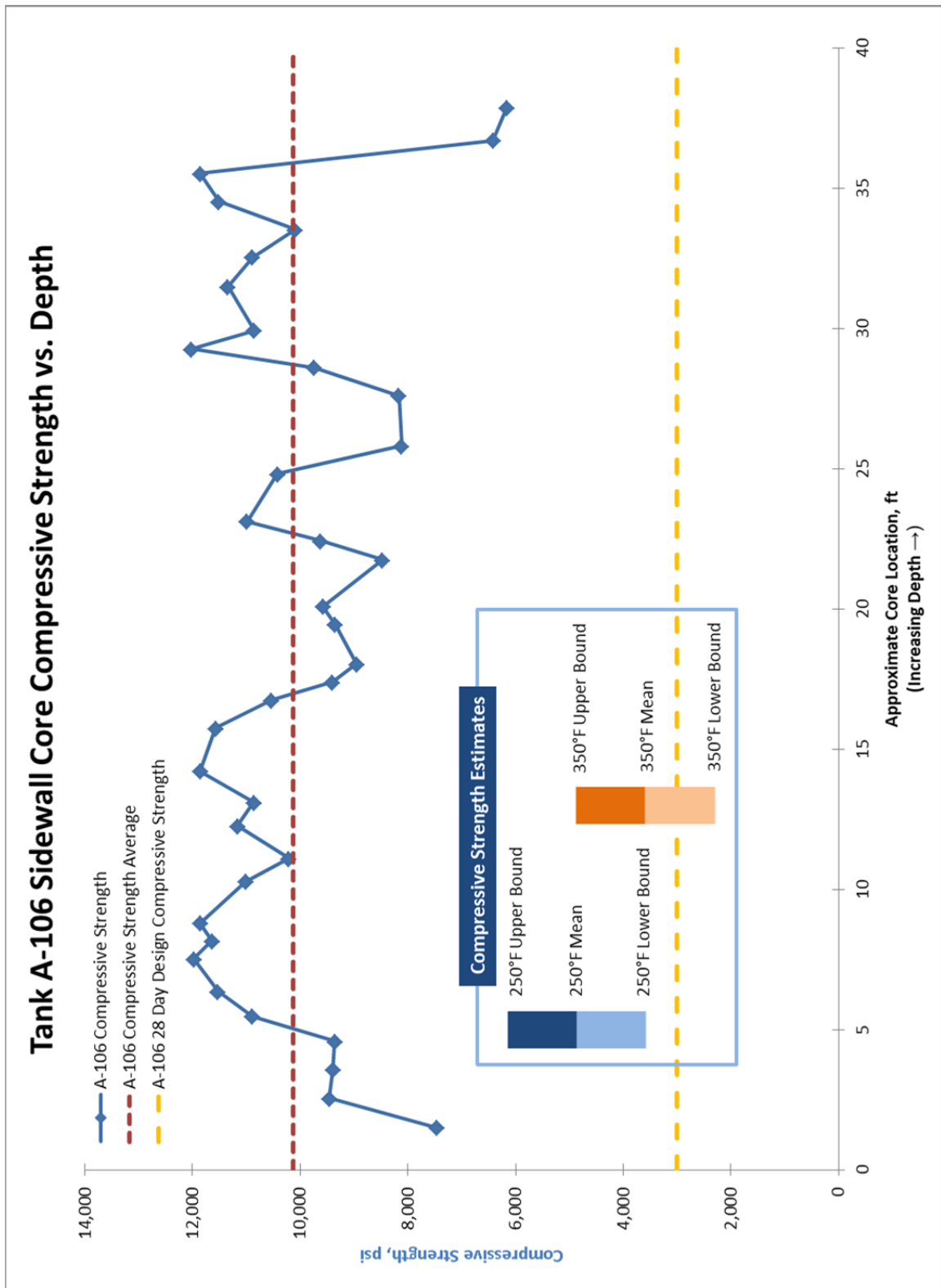


Fig. 8. Compressive Strength Comparison

TABLE I. Summary of Averaged Results

Property	Average Result
Transverse Resonant Frequency	3,477 Hz
Longitudinal Resonant Frequency	7,383 Hz
Dynamic Modulus of Elasticity	6,279 ksi
Pulse Velocity	17,365 ft/s
Static Modulus of Elasticity	6,274 ksi
Poisson's Ratio	0.25
Compressive Strength	10,132 psi

### CONCLUSIONS

The 241-A-106 sidewall coring project successfully removed over 38-ft of concrete core as a result of the extensive planning, demonstration and mockups, and vigilant field execution conducted. Inspection and testing of the concrete from the sidewall of tank A-106 was successfully performed. The physical testing indicated favorable results with values generally greater, and in many cases significantly greater, than expected in comparison with the values originally specified and those used in the current AOR for the type of tanks in A-farm. The effects of thermal degradation on the mechanical properties of the concrete for the SST with the highest thermal history appear to be negligible. The results of the testing performed on the concrete core removed from the sidewall of SST 241-A-106 do not reveal any deficiencies with the structural integrity of the tank.

### REFERENCES

1. ASTM C39-14a. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. American Society for Testing and Materials International. West Conshohocken, Pennsylvania.
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3. ASTM C215-08. *Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens*. American Society for Testing and Materials International. West Conshohocken, Pennsylvania.
4. ASTM C469-14. *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*. American Society for Testing and Materials International. West Conshohocken, Pennsylvania.
5. ASTM C597-09. *Standard Test Method for Pulse Velocity Through Concrete*. American Society for Testing and Materials International. West Conshohocken, Pennsylvania.
6. ASTM C856-14. *Standard Practice for Petrographic Examination of Hardened Concrete*. American Society for Testing and Materials International. West Conshohocken, Pennsylvania.