UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of NEXTERA ENERGY SEABROOK, LLC (Seabrook Station, Unit 1)	Docket No. 50-443-LA-2 ASLBP No. 17-953-02-LA-BD01

<u>Hearing Exhibit</u>

Exhibit Number: NER047

Exhibit Title: N. Ezell et al., "Experimental Collaboration for Thick Concrete Structures with Alkali-Silica Reaction" (2018)

Experimental Collaboration for Thick Concrete Structures with Alkali-Silica Reaction

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Abstract. Alkali-Silica Reaction (ASR) is a reaction that occurs over time in concrete between alkaline cement paste and reactive, non-crystalline silica in aggregates. An expansive gel is formed within the aggregates which results in micro-cracks in aggregates and adjacent cement paste. The reaction requires the presence of water and has been predominantly detected in groundwater-impacted portions of below grade structures, with limited impact to exterior surfaces in above grade structures. ASR can potentially affect concrete properties and performance characteristics such as compressive strength, modulus of elasticity, shear strength, and tensile strength. Since ASR degradation often takes significant amounts of time, developing ASR detection techniques is important to the sustainability and extended operation lifetimes of nuclear power plants (NPPs). The University of Tennessee, Knoxville (UTK) in collaboration with Oak Ridge National Laboratory (ORNL) designed and built an experiment representative of typical NPP structures to study ASR in thick concrete structures.

MOTIVATION, DESIGN, AND IMPLEMENTATION

The U.S. Department of Energy's Light Water Reactor Sustainability (LWRS) Program is interested in developing technologies and other solutions that can improve the reliability, sustain the safety, and extend the operating lifetimes of nuclear power plants (NPPs) beyond 60 years. Developing programs to study concrete structures is critical since many important safety structures in a NPP are constructed of concrete. The research presented here is motivated by the need to investigate deterioration of mechanical properties of concrete as a function of ASR expansion, investigate residual shear capacity of ASR-affected stressed-confined concrete structures, develop improved reliability condition assessment methodologies, and determine adequacy of nondestructive evaluation (NDE) in assessing the extent of

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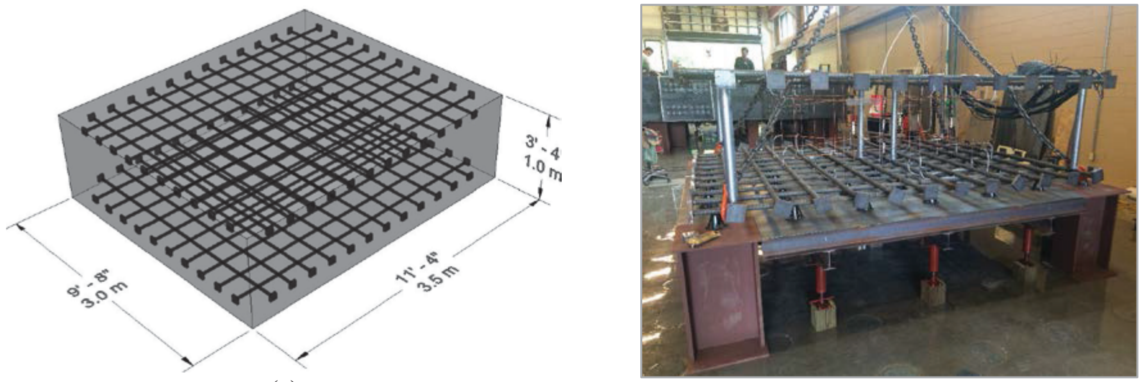
ASR in typical thick concrete structures. This paper describes the concrete specimen design, the collaborations between multiple universities and ORNL, and the instrumentation each collaborator installed on the specimens.

Three thick concrete specimens were constructed at the University of Tennessee [1]. The specimens are 3 m x 3 .5 m x 1 m, which is larger than a typical concrete test specimen, see Figure 1 and Figure 2. One specimen is confined in a steel frame, only allowing for expansion in one direction, see Figure 3.



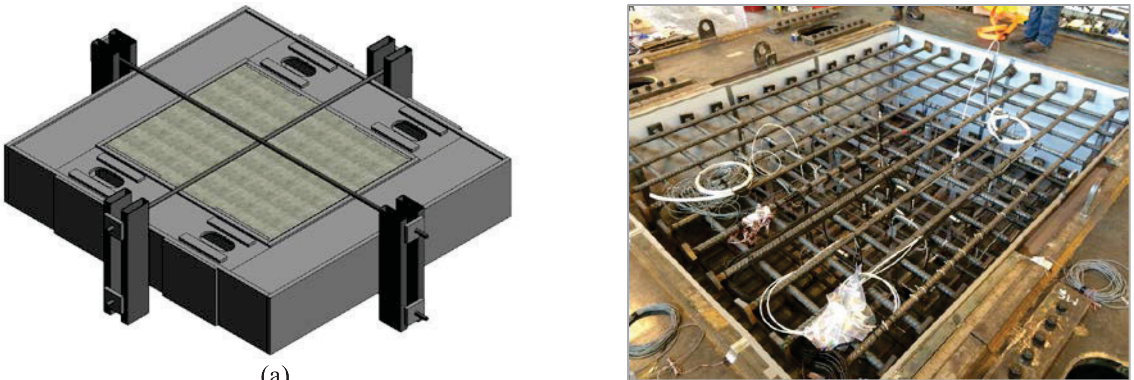
(a) (b)

FIGURE 1. (a) Unconfined thick concrete specimen design representative of a typical nuclear power plant structure. (b) Picture of rebar frame with the bottom framework for unconfined concrete specimen.

FIGURE 2. Picture of one of the unconfined concrete specimen inside the environmental chamber.

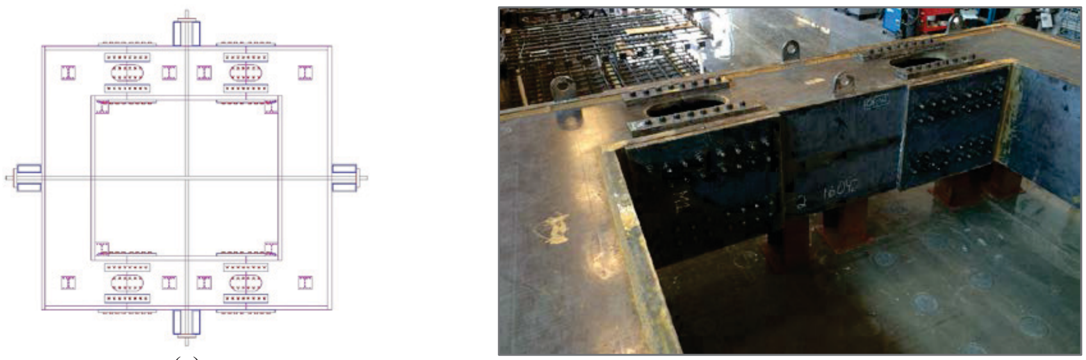
The two unconfined specimens have two mats of #11 rebar spaced at 25 cm (10 inches) on center, see Figure 1 and Figure 2. The one-meter thickness was selected in order to be representative of a NPP containment structure. The concrete mixture was designed in collaboration with the University of Alabama, Dr. Eric Giannini. Reactive mix was designed using reactive coarse aggregate and the addition of NaOH to expedite the reaction (accelerated expansion). This mix was used in two of the three specimens, the unconfined ASR (UASR) specimen and the confined ASR (CASR) specimen. The control mix was designed using the same aggregate with $LiNO_3$ to eliminate swelling of the ASR gel (no expansion). The control mix was used in the unconfined control specimen (CTRL).

The confined specimen also has two mats of #11 rebar spaced at 25 cm on center, see Figure 3. A rigid steel frame was used to simulate the passive restraint that could be present in an NPP structure due to the surrounding concrete or containment liner. The frame is a plate girder design that is composed with 56 tons of steel, see Figure 4. The steel frame was built in four sections, two C-shaped sections and two straight sections. These four sections were joined using bolted splice-plates, and the A490 bolts were tightened to a specific torque value. A post tension system was installed for additional confinement.



(a) (b)

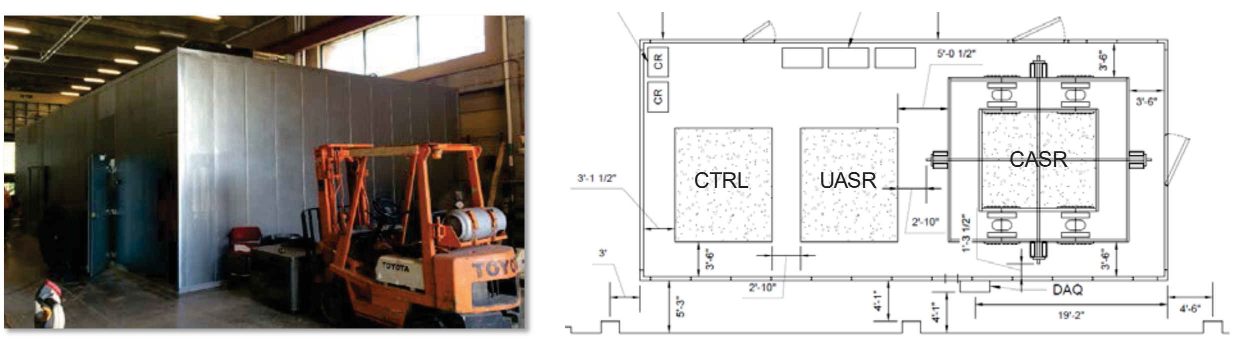
FIGURE 3. (a) Confined thick concrete specimen design. (b) Picture of rebar frame and steel frame for confined concrete specimen.



(a) (b)

FIGURE 4. (a) Confinement steel frame design. (b) Picture of steel frame used on confined specimen.

The experiment is designed to develop ASR (with 0.5% expansion) over a two-year period; however, ASR typically develops over decades. To accelerate the development of ASR, an environmental chamber was built surrounding the three specimens, see Figure 5. The chamber maintains a 100 °F (38 °C) temperature with 95% relative humidity.



(a) (b)

FIGURE 5. (a) Picture of the environmental chamber built around the concrete specimen. (b) Drawing of environmental chamber design.

INSTRUMENTATION

Instrumentation was installed to monitor ASR expansion by monitoring strain, structural deformation, and temperature within the concrete. An array of sensors was embedded and attached to the surface of the concrete. Table 1 has a complete list of the instruments and their purpose [2].

TABLE 1. Table of instruments installed on the UTK-ASR thick concrete specimens.

Instrument	Installation	Function
76 Transducers	Embedded	Point Strain
12 Thermocouples	Embedded	Temperature
21 Fiber Optic Sensors	Embedded / Surface	Strain and Temperature
32 Strain Gage	Embedded	Strain
4 Pressure Cell Sensors	Embedded	Pressure
12 SOFO Fiber Optic Extensometers	Embedded / Surface	Deformation
160 DEMEC strain gage	Surface	Deformation

The embedded sensor cabling was routed along the rebar and supported using zip-ties, see Figure 6.

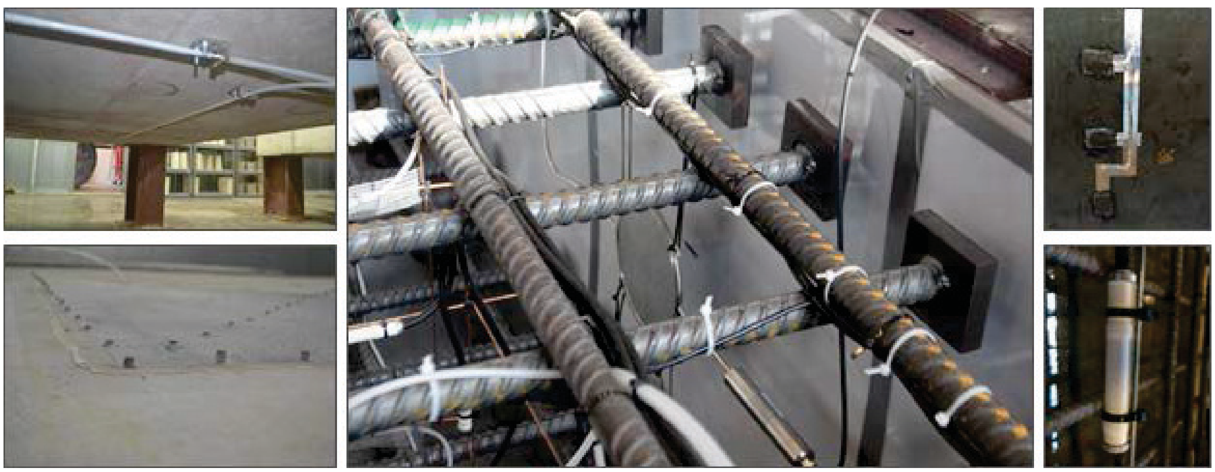


FIGURE 6. Images of instrumentation installed on and within specimens.

COLLABORATORS

There were many collaborators involved in this experiment. The University of Tennessee (UTK) designed and manufactured the test assembly. The assembly included the smaller test specimens, steel confinement frame, environmental chamber, installation of various sensor systems, and monitoring/data analysis from all of the collaborators. As previously stated, the University of Alabama designed the concrete mixture. Oak Ridge National Laboratory installed the embedded fiber optic sensors to monitor phase shift over time correlating to the expansion or compression of the concrete and development of micro-strains. ORNL is also heavily involved in studying the smaller test specimens. Vanderbilt University is using a digital image correlation (DIC) technique to capture the motion of a set of reference points and resolve three-dimensional displacement. Also, they are capturing strains over the deforming concrete surface by the use of a stereo-optical strain measurement system that utilizes two digital video cameras. The University of South Carolina is using an acoustic emission (AE) technique to evaluate (nondestructively) and monitor damage by detecting the sudden release of energy associated with crack formation or growth. The University of Nebraska has developed a diffuse ultrasonic wave (DUW) method to characterize micro-cracking damage by use of permanently attached piezoelectric sensors operating as ultrasonic transmitters and receivers. Georgia Institute of

Technology is assessing the nonlinear dynamic behavior of micro-cracks using surface wave evaluation (SWE) techniques by means of non-contact, air-coupled receivers to transmit and receive the nonlinear Ryleigh surface waves and obtain both the linear and nonlinear acoustic parameters.

Collaborators were invited to perform NDE measurements on the specimens. The participants were selected by the uniqueness of their NDE techniques. The goal of this is to evaluate the NDE techniques' ability to reliably identify and qualify ASR damage in NPP concrete structures. The University of Pittsburgh, in collaboration with the University of Minnesota, was invited to perform NDE measurements using the MIRA ultrasonic instrument on the concrete specimens. The ultrasonic system MIRA is a linear array system with dry point contact (DPC) transducers. The transducers can work as a transmitter or receiver. They are capable of emitting low frequency shear waves that can penetrate concrete. No contact liquid coupling is required for the transmission of shear waves to the tested medium [1].

CONCLUSIONS AND FUTURE WORK

After completion of the monitoring period, conclusions and analyzed data from the NDE methods will be compared to the monitoring data collected from installed instrumentation. Based on data comparisons, NDE methods may be recommended for suitability in testing thick concrete structures to assess the presence of ASR or determine the amount of damage due to ASR. Additionally, after the monitoring phase, the concrete specimens will be cut into smaller specimens and tested for residual strength. Specimens will be cut into beams and cylinders will be cored to test for residual shear capacity and compressive strengths.

ACKNOWLEDGMENTS

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