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M3LW-16OR0403065 - COMPLETE REPORT DOCUMENTING THE CONSTRUCTION OF THE ENVIRONMENT ROOM FOR THE ALKALI-SILICA REACTION TEST ASSEMBLY

Identification of Mechanisms to Study Alkali-Silica Reaction Effects on Stressed-Confined Concrete Nuclear Thick Structures

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Table of Contents

Executive Summary

Three specimens, corresponding to 136" x 116" x 40" reinforced concrete blocks, have been cast for the purpose of this project and enclosed in an environmental chamber under specific temperature and relative humidity conditions to accelerate the ASR-induced expansion. Two specimens (Specimens 1 & 2) have been fabricated using highly reactive aggregates from North Carolina, according to a mix design study conducted by the University of Alabama. One of these two specimens was confined (Specimen 1) in a relatively rigid steel frame. The third specimen (Specimen 3), considered as a control specimen, was made with the same reactive aggregates, but the ASR has been mitigated, by incorporating lithium in the mix.

The concrete pouring day took place in the laboratory (High Bay) of the department of Civil and Environmental Engineering at the University of Tennessee, Knoxville. The operation started on Saturday, July 23rd, 2016, at 4:00 A.M. to avoid the impact of the summer high temperatures on the concrete. It ended at 5:00 P.M. the same day.

This report includes the description of the different tasks that the UTK research team has accomplished, with the participation of other research partners, before and during the fabrication of the specimens.

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Project Overview

Concrete structures, such as nuclear power plant (NPP) structures, are designed to withstand potential durability, service, and safety issues. Unfortunately, Alkali-Silica Reaction (ASR) is a major degradation mechanism of concrete that has often created a need for aging management and repair for many of these infrastructures. Several cases of ASR in NPP structures have been disclosed in Japan, Canada at Gentilly 2 NPP, and recently in the United States. Because of the deleterious effects of ASR in nuclear concrete structures, a need is present in identifying the degree at which ASR affects NPP structures which are commonly unreinforced in the thickness direction. With NPP concrete wall structures typically having a relatively large thickness, shear strength is achieved solely by the shear capacity of the concrete. As a result, these walls are typically designed unreinforced for shear stresses as allowed by ACI 318. Due to the existence of steel reinforcement within the concrete structure designed for flexural and axial loads, the lateral in-plane directions of the structure are typically confined against expansion. This confinement in the in-plane directions deters expansion due to ASR; however, the lack of reinforcement in the thickness direction of the structure allows for unconfined ASR expansion. The effects of these differences in confinement conditions in the development of ASR swelling and micro-cracking are important to understanding the effect of ASR expansion on the deterioration of mechanical properties of the concrete for these particular structures. At the macro-scale, the development of the ASR-induced concrete expansion is conditional to the possibility of free expansion: compression in one or two directions results in a redistribution of the expansion in the free direction. This research endeavor aims to extend the existing body of knowledge on the formation of ASR damage in stress-confined nuclear structures and its effect on the structural resistance of ASR affected reinforced concrete members.

Although the residual shear capacity of the ASR-affected stress-confined concrete is one of the research objectives, the deterioration of several mechanical properties of the concrete as a function of ASR expansion are also being investigated as a means to develop and improve reliable condition assessment methodologies including ASR models. The characterization of mechanical properties as a function of the stress-confined ASR expansion will be used to validate and improve models to more accurately predict the effects of confinement on the development of ASR damage in nuclear structures.

In order to achieve these objectives, three concrete specimens were cast and placed within a controlled environmental chamber. The concrete used for these specimens was designed to experience sufficient ASR expansion. Each of the three specimens is heavily instrumented with multiple types of sensors measuring deformation, strain, temperature and internal pressure. These specimens are being subjected to ASR for a period of a minimum of two years. After the period of allowed reaction, the specimens will be mechanically tested to observe the effects of ASR on their shear capacity.

Chapter 2: Construction of Rebar Cages

2.1 Design Concept

Three rebar cages were constructed. Each cage consisted of two layers of perpendicular intersecting #11 steel rebar. Each layer consisted of 10 long rebar and 12 short headed rebar (Figure 2.1). In order to separate the two layers, #11 rebar spacers were placed inside of a pipe sleeve connection. To ensure a rigid cage structure, the pipe sleeve connections were designed long enough to prevent any rotation and differential movement of the two layers of reinforcing bars.

2.2 Construction Process

Step 1: The top and bottom layers of rebar were laid out on the high-bay floor according to the dimensioned drawings in Appendix 1. The bars were welded together at corner intersections and selected intersections within the grid to ensure rigidity of the cage frame. After welding, the rebar was connected at each intersection with tie wire to ensure additional rigidity of the frame. Figure 2.1 shows the completed rebar layers.

Figure 2.1- Completed construction of rebar layers

Step 2: Steel tubing sleeves were welded to the top and bottom layers of reinforcement. The tubing was coped in order to achieve the maximum amount of weld-able area. #11 rebar spacers were placed in these sleeve connection in preparation for the placement of the top layer, as shown in Figure 2.2.

Figure 2.2- Installation of pipe sleeves and spacers

Step 3: The top layer of rebar was crane lifted on top of the spacers. Pipe sleeves were also welded to the top layer of rebar to finalize the connection, as shown in Figure 2.3.

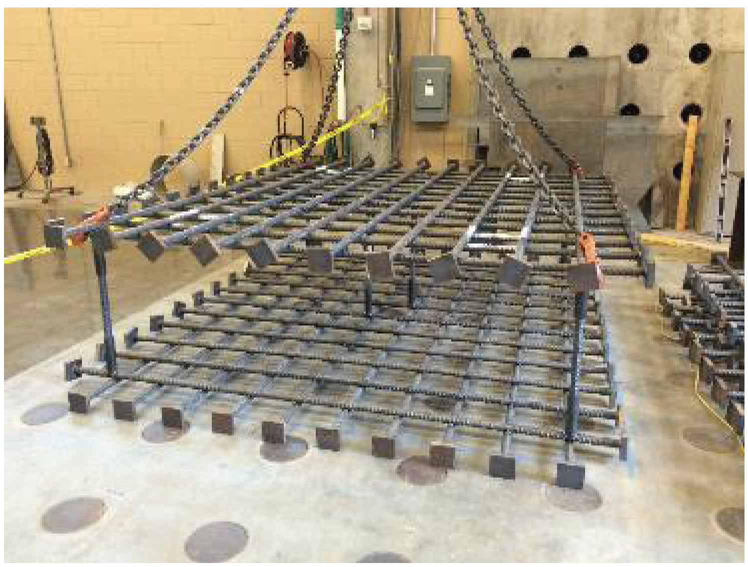


Figure 2.3- Completed construction of rebar cage

This process was completed an additional two times to manufacture the remaining cages for the specimens.

2.3 Discussion

In order to accurately represent a typical nuclear power plant structural systems, the concrete specimens would require #11 rebar spaced at 10 inches on center. Typical nuclear power plant wall structures do not have shear reinforcement. In order to accurately represent this type of structure, the spacers must not be capable of developing tensile resistance. To accomplish this, the pipe sleeve connection was designed to eliminate the development of tension within the bar. With this connection, the rebar is able to slide freely in the sleeves as the rebar layers separate due to expansion. The rebar was also de-bonded to ensure that the concrete was unreinforced through the depth.

Chapter 3: Design of Steel Supports

3.1 General Design

Steel supports, as shown in Figure 3.1, were designed and constructed to support both, the steel frame (related to the confined specimen) and concrete specimens. Besides, the bottom surface of each specimen needs to be accessible to install surface sensors. The current supports elevate the specimens 30 inches from the floor and hold the weight of the steel frame and concrete specimens separately while allowing for any movement due to expansion.

Figure 3.1- Unpainted steel support before welding

Because of the harsh environment (high temperature and relative humidity) in the environmental chamber for a significant period of time (around three years), the supports were painted to resist corrosion, as shown in Figure 3.2.

Figure 3.2- Painted steel supports in place

The dimensioned layout of supports is shown in Appendix 2.

Chapter 4: Installation of the Formworks

4.1 Bottom Formwork

The bottom formwork design consisted of three separate pieces. Each piece was made of a ¼" thick steel plate with several steel beams welded to the underside. The formwork was constructed in three separate pieces in order to be easily removed after concrete setting. Figure 4.1 shows the edge piece of the bottom formwork.

The primary design goal was to effectively eliminate any deflection due to the weight of the liquid concrete. For this reason, a stiff system of slab and beams supported by girders was designed. The steel plate would provide a smooth, water-tight surface to contain the fresh concrete. However, due to the significant weight of the liquid concrete, a system of supports was required to effectively eliminate any deflection under the weight. The plate was supported by steel junior I-beams spaced at 12 inches or less on center. These beams were stitch welded directly to the supporting steel plate in order to provide single solid pieces for ease of construction. After installation of the three bottom formwork pieces for a single concrete specimen, five steel girders were placed underneath the steel beams at a spacing of 3 feet and held in place by utility jacks, as shown in Figure 4.2. This design was used for each of the three specimens.

Figure 4.1- Edge pieces of bottom formwork being installed

Figure 4.2- Completed construction of bottom formwork with cage in place

4.2 Side Formwork

The formwork used to contain the fresh concrete against lateral movement was rented from ***MEVA formworks***. Their design experts recommended the use of their ***MevaLite*** product for the side formwork, after assessment of the project's needs.

Mevalite is a modular and lightweight hand-set clamp formwork system (Figure 4.3) allowing for fast, easy assembly and providing high quality concrete finishes as is necessary for this project. The panels are aluminum frame construction with all-plastic facing alkus on the finishing side. Unlike traditional wooden formwork, the alkus surface does not absorb moisture from the concrete, which was an important consideration for our research goals. Moreover, the panels were set up side-by-side and connected with multiple clamps at each joint. These clamps were then hammered tight, and steel threaded rods were placed under the bottom formwork to pull the sides together and resist lateral forces of concrete pouring. Threaded bars were also placed through PVC through the specimen to hold the panels together at the higher elevation. Figure 4.4 shows the completed side formwork.

Figure 4.3- Partially assembled side formwork system

Figure 4.4- Fully constructed side formwork system

4.3 Insulation of the Formworks

Thermal cracking of concrete is a significant issue that occurs when a large temperature differential exists between the internal core and the external sides of the concrete. Our goal was to slow the cooling process to minimize the temperature differential. In an attempt to eliminate all crack sources other than ASR, the formworks have been insulated by placing rigid foam sheathing insulation with an R-value of three around the side and on top of the specimens, shortly after pouring. The insulation was placed with edges overlapping and secured in place with tape and plastic wrap as shown in Figure 4.5.


Figure 4.5- Completed installation of insulation around formwork

4.4 Removal of the Formwork

All formwork were removed on August 4, 2016. Each specimen and concrete cylinder was covered with wet burlap to prevent moisture loss. The burlap was periodically moistened as required to keep the concrete surfaces wet.

Chapter 5: Design of Steel Confinement Frame

5.1 Design Concept

In order to understand the effects of alkali silica reaction (ASR) in confined concrete, a steel frame was designed to confine one of the concrete specimens. Due to the crane limitations in the structural lab, the frame was designed as four separate pieces. To reduce the impact of the stress concentration in the corners of the frame on the connection design, the connection was designed at approximately the quarter spans of the shorter sides as shown in Figure 5.1. The pieces were linked by a designed splice connection. The frame was designed to maximize rigidity in order to effectively minimize deflection of the frame due to the pressure of concrete ASR expansion. In order to accomplish this goal, a steel plate girder frame was designed. As opposed to standard hot rolled shapes, a steel plate girder could be fully customized in order to meet the needs of the research testing program.

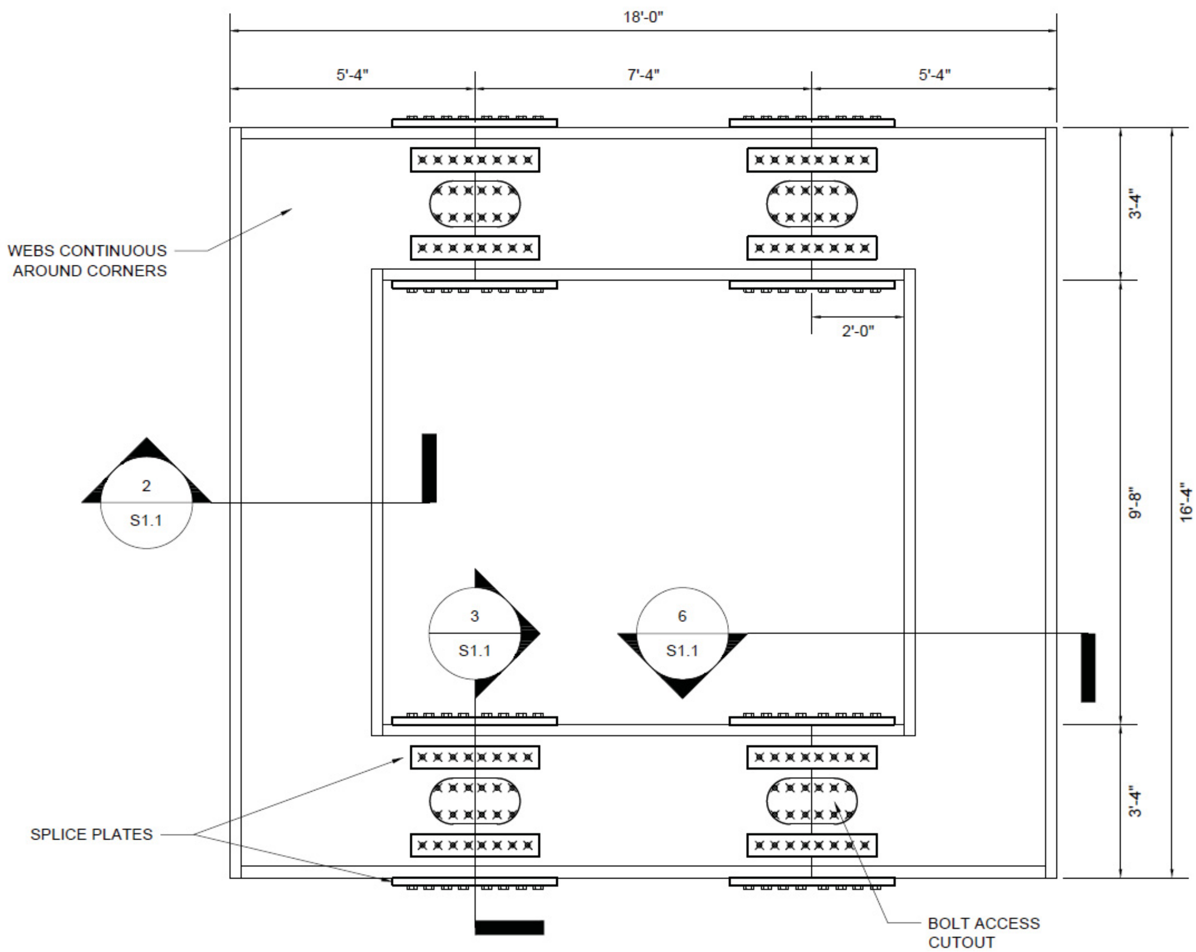


Figure 5.1- Plan view of steel confinement frame

It was also decided that lateral pressure will not exceed 1200 psi due to the possible maximum ASR expansion in real structures and redistribution of expansion in the unconfined direction. Therefore, the steel confinement frame and connection details were designed for a uniform pressure of 1200 psi on the interior flange.

5.2 Design of Cross-Section

The steel plate girder frame was designed with the primary goal of maximizing stiffness in bending. In order to achieve this goal, 3” thick plates were chosen as flanges to the plate girder. The interior flange also served as the side formwork for the confined concrete specimen. These flanges would be connected by three 2” thick web plates. All steel was manufactured from A572 Grade 50 steel plate. The cross-section is shown in Figure 5.2. The welds between the components were designed to fully transfer all member forces between the components. As a result, to maintain the constructability of the cross-section, the welds would be continuous on both sides of the inner-most web and continuous on the outside of the two outer webs. The three webs provide stiffness to the inside flange receiving the full development of internal pressure, effectively minimizing any local deflections of the flange.

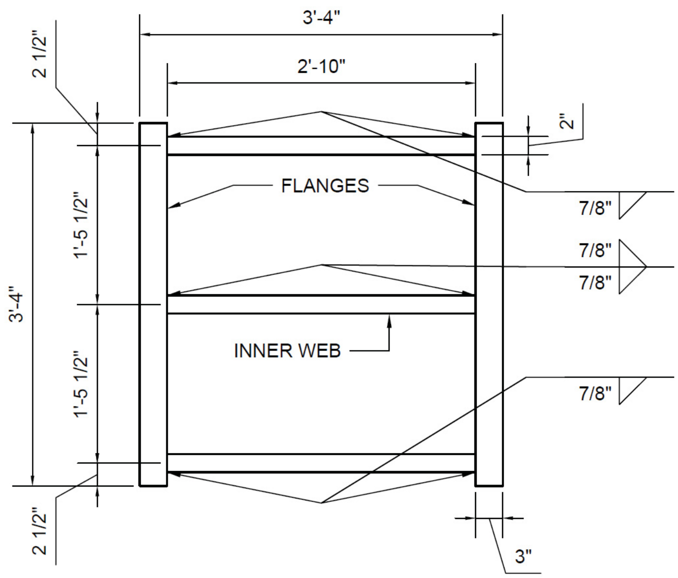


Figure 5.2- Design of steel confinement frame section

The use of 3” thick flanges provides the greatest moment of inertia for the cross section by pushing the cross-sectional area away from the neutral axis while also staying within the budget. Because the primary goal was to minimize deflection, the section was significantly overdesigned to the resist the bending forces induced by the concrete expansion. However, because the webs play a minor role in providing stiffness in bending, the webs were more efficiently designed to the resist of shear forces produced by the concrete expansion. Still, because of the expected expansion pressures, 2” thick webs were required to resist the relatively large shear forces.

In order to adequately transfer forces between the flanges and webs, relatively large fillet welds were required, but due to the accessibility of the interior of the cross-section during construction, only the center web could be welded on both sides. The remaining two webs were welded only on the outside planes of the webs. Fillet welds of this size are generally only seen in large-scale steel plate girders for bridge construction; however, because of the deflection limitation requirements, these large fillet welds were necessary to adequately involve all components of the cross-section in resisting applied forces.

5.3 Design of Splice Plate Connection

In order to connect the section of the steel frame, a complete bolted splice plate connection across each component of the cross-section was designed. In order to eliminate movement of the connection and minimize local deformation as a result of the connection, a slip-critical bolted connection was designed to transfer the forces between the segments of the frame. A slip-critical connection idealizes the failure condition as the relative movement between the two connected elements. Essentially, the bolts are torqued to a tension required to provide enough frictional resistance to prevent any relative movement between the connected elements and connector plates. The splice plates were designed to provide stiffness in excess of the typical cross-section at the connection. Maximizing the stiffness at the connection effectively minimizes the local deformations of the structural components at the connection. The bolted splice-plate connection cross-section is shown in Figure 5.3.

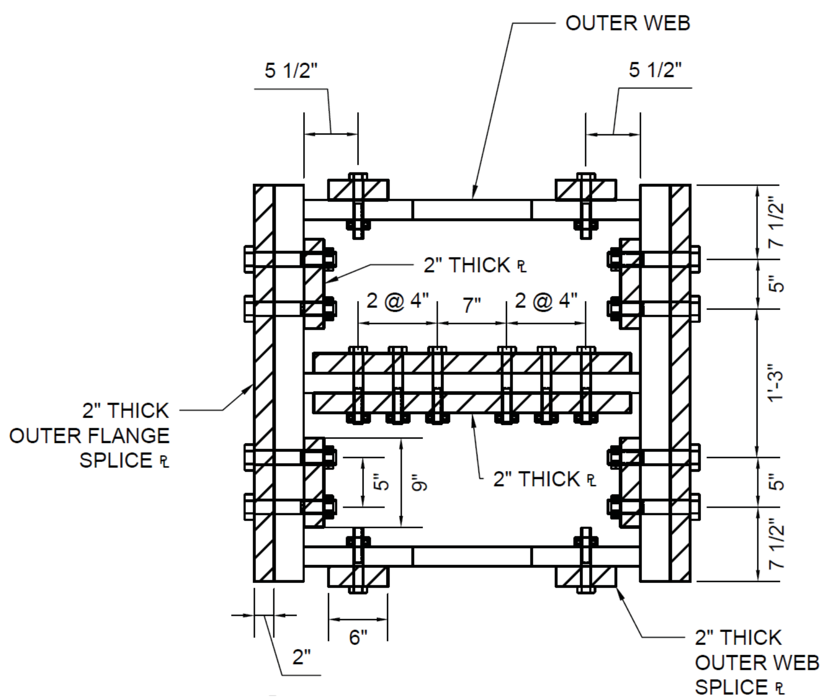


Figure 5.3- Design of splice plate connection

Due to the large internal forces caused by the concrete expansion, a total of 144 bolts were required for each splice plate connection. Sixty-four A490 bolts with 1.5" diameter were used to splice the flanges. Eighty A490 bolts with 1" diameter were used to splice the webs. The flange bolts were spaced at 4.5” to provide ample room for torqueing. The web bolts were spaced at a smaller 4” spacing due to their smaller size.

A small cutout was incorporated into the design of the frame at the connection in order to allow for easy access for bolting of the connection. The cut-out portion will also allow for the disassembly of the steel frame, after the experiment has ended, even with the structural hex nuts being inaccessible on the inside of the frame.

5.4 Design of Post-tensioned System

A post-tension system was designed to accompany the steel confinement frame in preventing any lateral movement of the confined concrete specimen. The Threadbar post-tension bar product manufactured by DYWIDAG-Systems International (DSI) was selected as the best option for use in our project due to its large cross-sectional area, ease of installation, and ease of connection to the steel frame. The design drawings are shown in Appendix 2-S1.2. Threaded bars of 2.5 inch diameter were placed at mid-span on each side of the steel frame as shown in Figure 5.4. The bars pass both over and underneath the confined concrete specimen as shown in Figure 5.5.

At first, these bars were hand tightened to provide additional stiffness to the system. However, as the expansion progress, the bars could possibly be stressed, providing up to 546 kips (546,000 pounds) of confining force at the mid-span of each side of the steel frame for each post-tension bar. The bars will be stressed by use of a stressing system as provided by DSI.

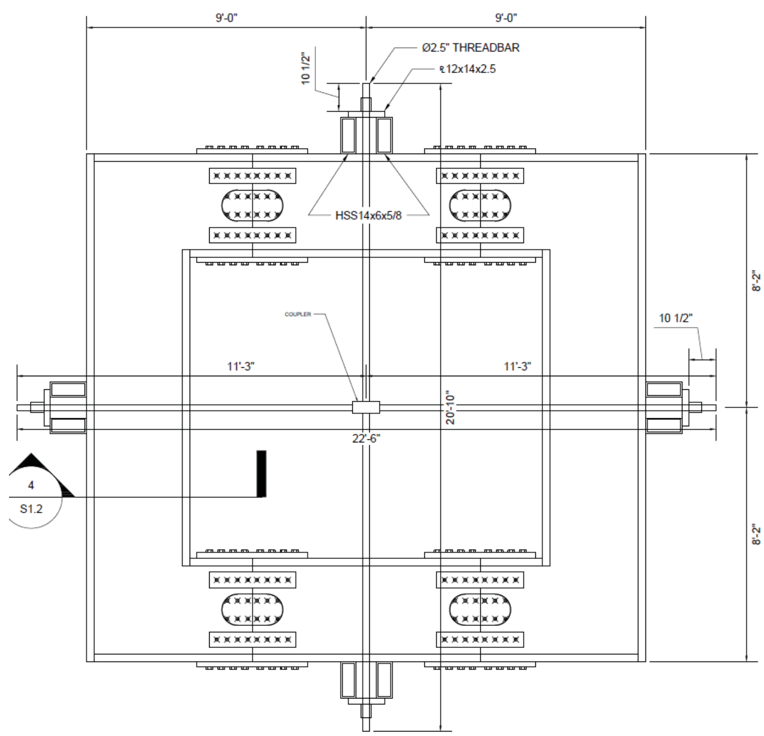


Figure 5.4- Plan view of post-tension design

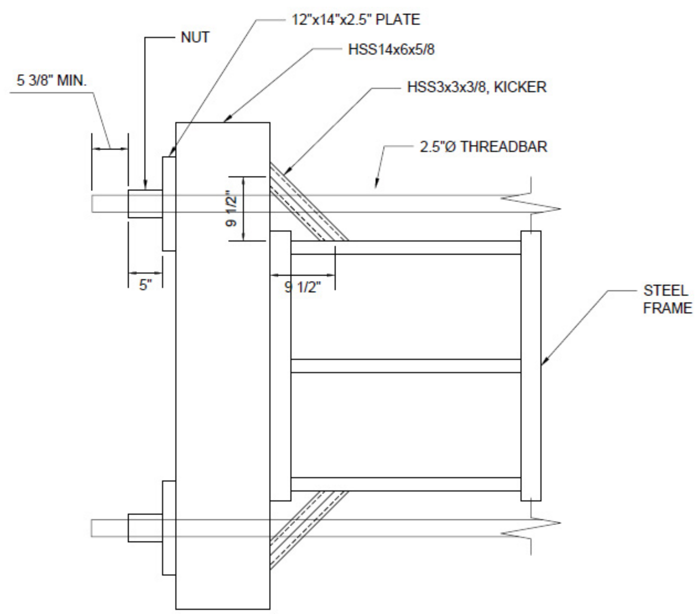


Figure 5.5- Elevation view of post-tension design

5.5 Estimation of Confinement Stress Distribution

The finite element (FE) method was used to estimate the stress distribution both at the interface between ASR concrete and the steel confinement frame and 24" away from the interface. As discussed earlier, the dimension of the ASR concrete is 136 inches (X) by 116 inches (Y) by 40 inches (Z). The material properties are presented in Table 5.1.

Table 5.1- Material Properties

Material	Elastic Modulus	Density	Poisson Ratio
	(ksi)	(lbs/ft^3)	
ASR Concrete	3824.0	150.0	0.2
Steel	29000.0	490.0	0.3

The ASR expansion was simulated with thermal expansion in the FE model where the thermal expansion coefficient (α) was modeled as 5.5E-6. Due to the symmetric geometry and loading positions of the mockup, only a quarter of it was modeled using commercial software ABAQUS. The boundary conditions of the model were determined according to the free expansion in thickness direction (Z) of ASR concrete, and other boundary conditions as shown in Figure 5.6.

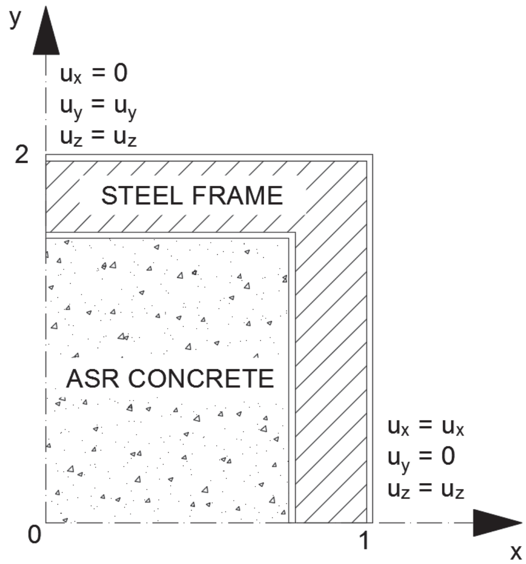


Figure 5.6- A Quarter of Mockup and Boundary Conditions in FE

Linear elastic material property was considered in the model. The maximum volume expansion rate of ASR concrete was taken as 0.5%. And the expansion of ASR was simulated by applying temperature increase. Solid elements were adopted in the model, the contact constraints between each part were modeled using "General Contact" provided by ABAQUS, which allows interaction of different meshes using penalty approach. Each node on the slave surface is forced to have the same motion as the point on the master surface, which means the translational and the rotational degrees of freedom are constrained. The friction coefficient was modeled as 0.28 between two sheets of high density polyethylene (HDPE) which was used at the interface between steel confinement frame and ASR concrete specimen. The model of a quarter of the experimental mockup is shown in Figure 5.7.

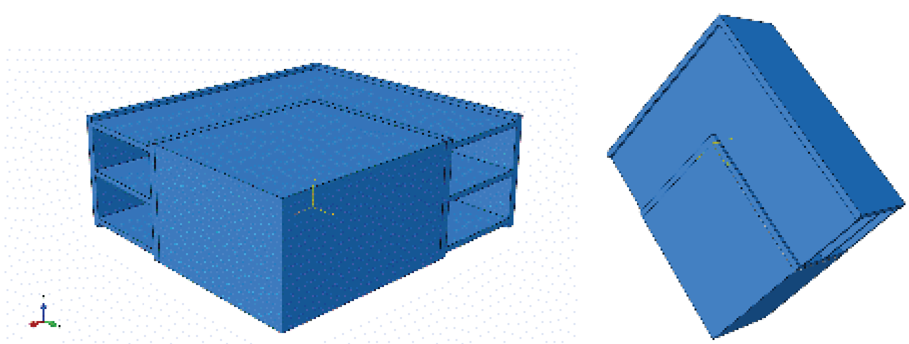


Figure 5.7- The modeled quarter of the mockup

A single load scenario was selected for the simulation: (1) Thermal expansion was achieved by applying temperature increase to ASR concrete in order to simulate the maximum projected expansion due to ASR.

The confinement pressure at the interface between ASR concrete and steel confinement frame is shown in Figure 5.8. As expected, the stress distributions are not uniform at the interface, especially at the corner locations.

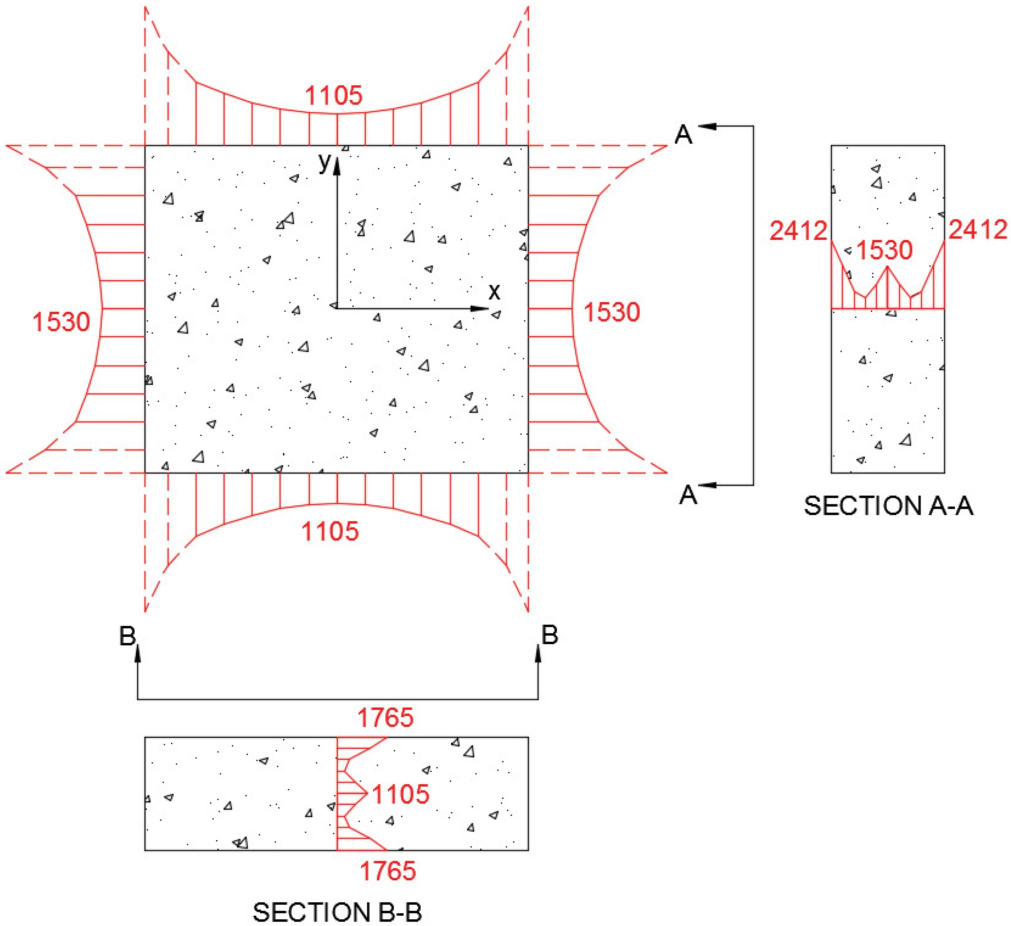


Figure 5.8- Confinement pressure (psi) at interfaces

However, the confinement pressure at 20” away from the interface is shown in Figure 5.9. Figure 5.9 shows that the stress distributions are fairly uniform. The minimum estimated stress is 1330 psi which exceeds the designed pressure of 1200 psi.

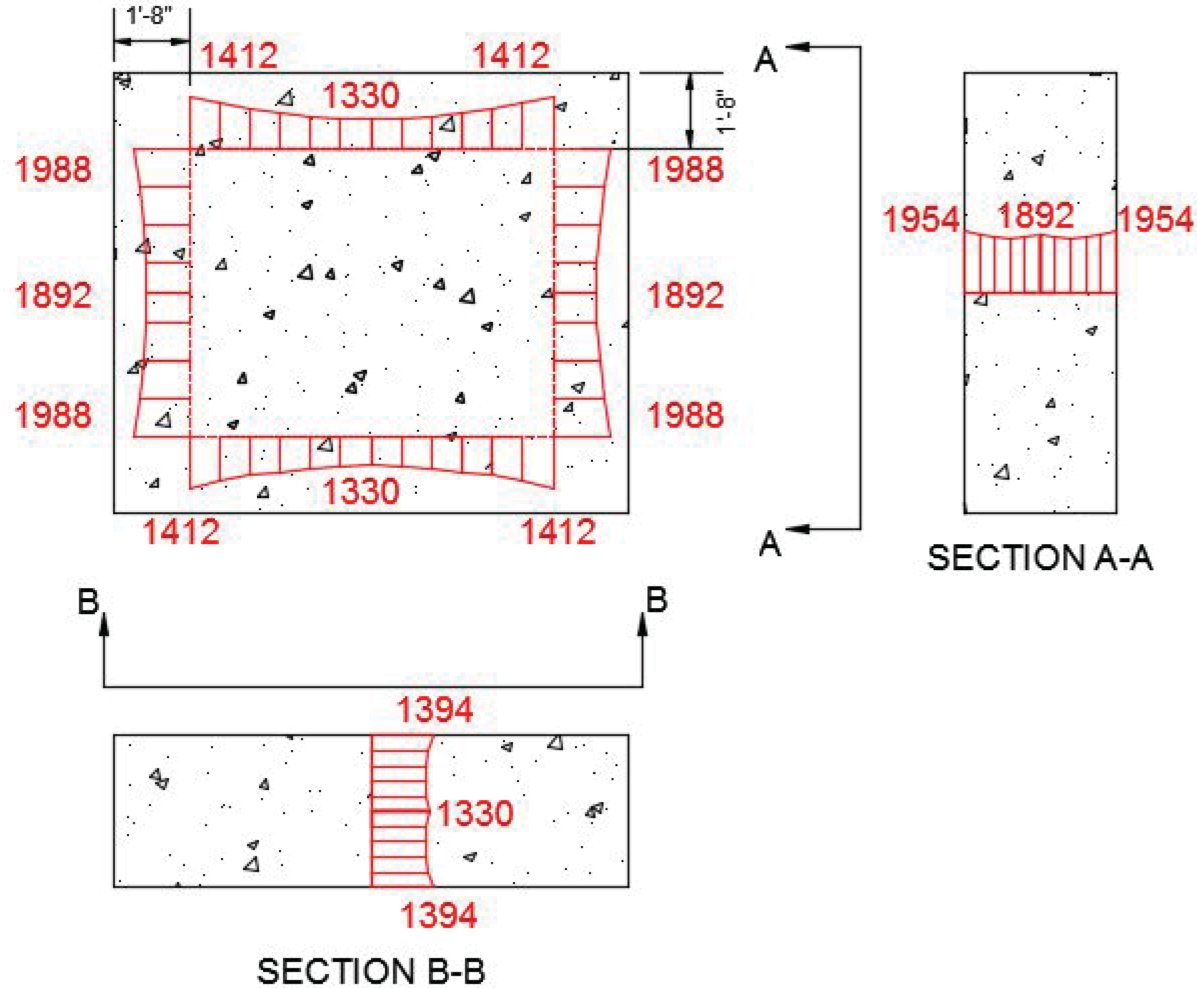


Figure 5.9- Stress (psi) distribution (20” away from the interface)

The displacements of ASR concrete at the interface are shown in Figure 5.10. The displacements in thickness direction are illustrated in Figure 5.11. Please note that these values were estimated without applying tension forces to those post-tensioned bars which are located as shown in Figure 5.4. When those post-tensioned bars are stressed in the future, based on the actual measured interface stresses, these displacements shown in Figure 5.10 will be reduced accordingly.

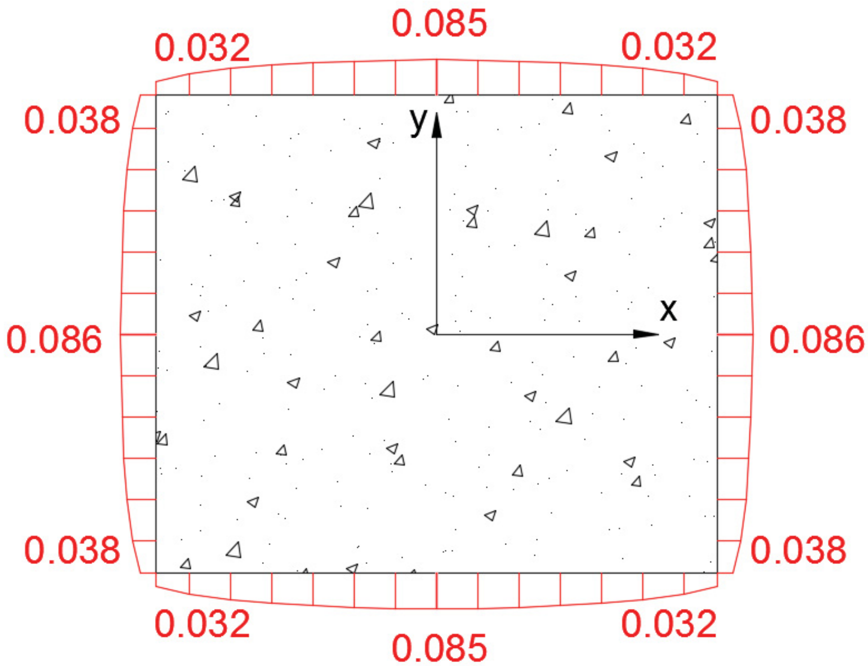


Figure 5.10- Displacement (inches) of ASR concrete at Interfaces

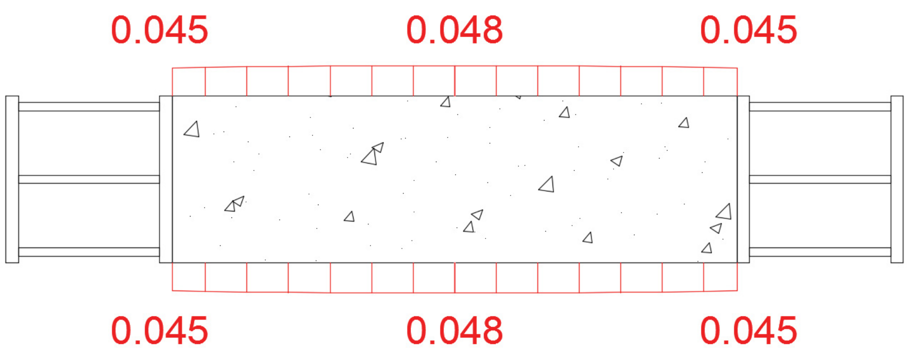


Figure 5.11- Displacement (inches) in thickness direction

Chapter 6: Manufacture, Delivery, and Assembly of the Steel Frame

6.1 Manufacturing of Frame

The steel confinement frame was manufactured by *Quality Machine and Welding of Knoxville*, TN. Fifteen personnel working 800 man-hours total were required to complete construction of the 56-ton frame in the allotted time. Prior to delivery, the manufacturing crew presented a demonstration of the assembly in their facility, as shown in Figure 6.1.

Figure 6.1- Demonstration of steel frame assembly

6.2 Delivery

The steel frame was delivered to the high bay by three separate trucks. The first delivered piece was placed on the supports and prepared for the additional connected sections. The splices plates were bolted in placed and spread to allow for the connection to be made to the other short sections. This process was repeated until the frame was completely connected.

6.3 Description of the Assembly Process Step By Step

Step 1: The first large U-shaped section was crane lifted onto the steel supports as shown in Figure 6.2.

Figure 6.2- Steel Frame Assembly

Step 2: The splice plates were crane lifted in place and secured with bolts to the U-shaped section as shown in Figure 6.3.

Figure 6.3- Steel Frame Assembly

Step 3: The short sections were slipped into the connection and secured with bolts as shown in Figure 6.4. The steel supports were then placed underneath to support the weight.

Figure 6.4- Steel Frame Assembly

Step 4: The splice plates were crane lifted in place and secured with bolts to the two short sections as shown in Figure 6.5.

Figure 6.5- Steel Frame Assembly

Step 5: The final U-shaped section was carefully crane-lifted and slid into the splice plate connection as shown in Figure 6.6. The steel supports were then placed underneath the section to support the weight.

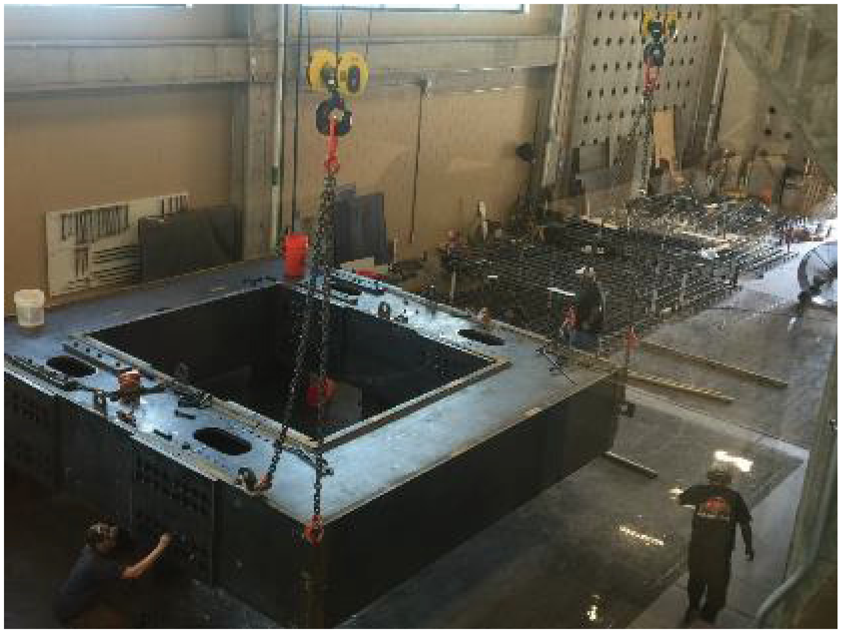


Figure 6.6- Steel Frame Assembly

Step 6: All bolts were set in place and hand tightened. The bolts were then torqued to design specifications as shown in Figure 6.7.

Figure 6.7- Steel Frame Assembly

Step 7: Spacers were welded in place in order to create a flat bearing surface over the exposed bolts for the concrete expansion on the inside of the frame. Besides, a plate was placed and welded in place against these spacers as shown in Figures 6.8 and 6.9. The plate ensures a solid surface for the concrete expansion. It also prevents concrete from setting around the exposed bolts, allowing for the disassembly of the frame at a later date.


Figure 6.8- Steel Frame Assembly


Figure 6.9- Steel Frame Assembly

Chapter 7: Installation of the Instrumentation

7.1 KM Strain Transducers

These KM strain transducers from Tokyo Sokki Kenkyujo Co., Ltd represented in the US by Texas Measurements, Inc. were used in the testing program.

A total of 76 KM transducers (including twelve with thermocouples) have been implemented in the three cages: A total of 32 KMs in each of the two reactive, confined and unconfined specimens, and 12 in the control specimen. The layout of these sensors and all sensors can be found in Appendix 3. These sensors were attached to the horizontal and vertical positioning bars, using Nylon cable ties, as shown in Figure 7.1.

Figure 7.1- Installation of KM Sensors in the cages

Besides, six KM sensors have been embedded in six prism cylinders (4 in. by 4 in. by 16 in.), designed to study the concrete creep phenomenon. Each KM was located in the center of the mold space before pouring and stabilized with wires, as shown in Figure 7.2.

Figure 7.2- Installation of KM strain gages in Creep Specimens

7.2 Electrical Strain Gauges

These strain gauges from Vishay Precision Group, Micro-Measurements were used.

A total of 32 electrical strain gages have been implemented in the three cages as follows: 24 gages attached to the rebar cage and the remaining eight gages attached to the confinement steel frame surface. The goal is to monitor the strain distribution inside and outside the steel plates under the ASR expansion condition.

In order to guarantee the performance of the strain gages, the method of attaching and coating was discussed and decided with the representatives from the strain gauge manufacturer. The installation of rebar strain gages conformed strictly to the *Tech Tip TT-611 (Strain Gage Installations for Concrete Structures)* and *Instruction Bulletin B-127-14 (Strain Gage Installations with M-Bond 200 Adhesive)* from Micro-Measurements.

A protective coating option, typically used for gauges submerged in salt-water for a long period of time, was selected. The coating procedure was in accordance with the *Instruction Bulletin B-147-6 (Application of M-Coat JA Protective Coating)* from Micro-Measurements.

The lead wires were protected by aluminum tape and soft plastic pipes to resist the potential impact of long-term erosion. The status of each gauge during installation was monitored by using a manual voltmeter. The installation and coating of the gauges started on June 14th 2016, and ended ten days later. Figure 7.3 shows a typical gauge on the rebar after costing.

Figure 7.3- Electrical Strain Gauge on the Rebar after Coating

7.3 SOFO Sensors

Five SOFO sensors from Smartec- Roctest, Inc were vertically embedded in the specimens to measure the expansion in the Z-direction. The installation procedure followed the *Installation and Handling Instructions* transmitted by the vendor. Each sensor was attached to a small-diameter steel bar with Nylon cable ties, as shown in Figure 7.4.

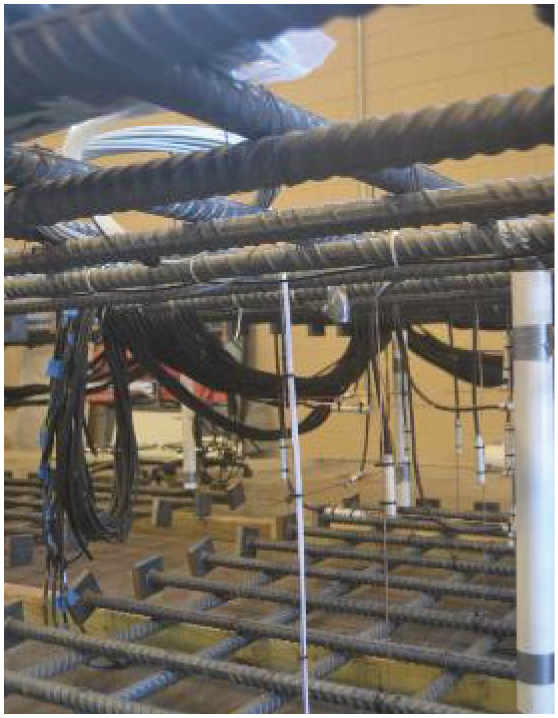


Figure 7.4- SOFO Sensors

7.4 Fiber Optics (FO)

The fiber optic sensors have been installed by ORNL. An adhesive grid sheet was used for attaching and protecting them in the measurement area. In the passive length, the fibers were protected by using soft plastic pipes. Refer to Figures 7.5 to 7.7.

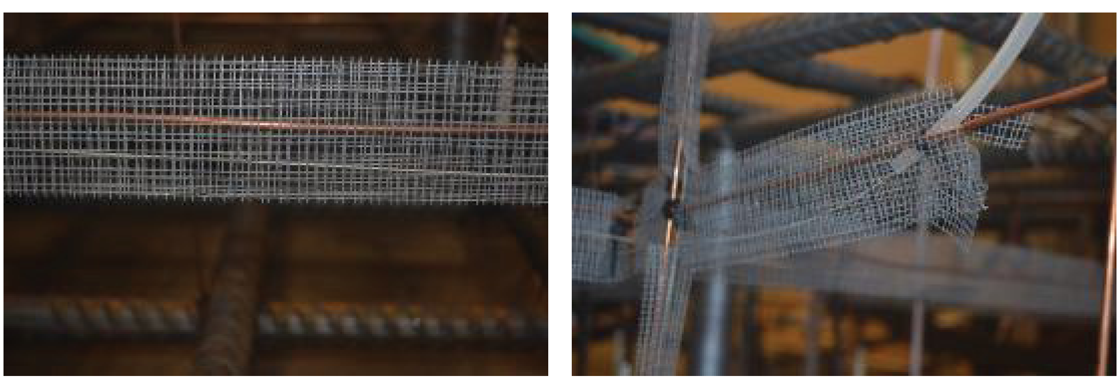


Figure 7.5- Installation of Fiber Optic Sensors in the measurement Area

Figure 7.6- Installation of Fiber Optic Sensors in the passive length

Figure 7.7- Installation of Fiber Optic Sensors

7.5 Acoustic Emission (AE) Sensors

A crew from the University of South Carolina, a research partner in this project, was in charge of installing the acoustic emission sensors. The sensors were attached to additional "positioning" bars and beneath the rebar by using epoxy glue and were protected by wrapping tape, as shown in Figures 7.8 and 7.9. The signal receiver part of the sensor was exposed in order to capture the acoustic vibration from cracking.

Figure 7.8- An acoustic emission sensor Attached to a positioning bar

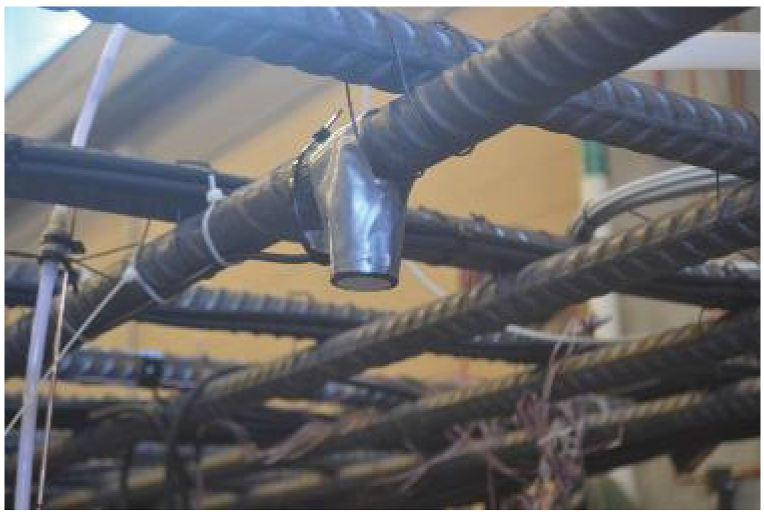


Figure 7.9- An acoustic emission sensor beneath the rebar

7.6 Data Acquisition Systems (DAQ):

Four different data acquisition systems are used in this project to continuously collect data from the three concrete specimens and some cylinders. The University of Tennessee, for the purpose of the current project, has recently acquired the two systems, detailed below. The other two systems have been stationed in the high-bay by ORNL and the University of South Carolina.

7.6.1 NI DAQ

The KM transducers and electrical strain gages were connected to the National Instruments (NI) DAQ. The corresponding acquisition software has been developed, using

Labview, then installed and calibrated, between end of June and mid-July, by Enable Education, an alliance partner of NI who also provided the UTK research team with the appropriate training.

7.6.2 SOFO DAQ

The SOFO sensors were connected to the SOFO DAQ on July 14th 2016. A training and system calibration have been assured by SMARTEC around mid-July. SMARTEC is planning to update their software soon. After which, the SOFO lite (Ethernet-based DAQ by SMARTEC) will be utilized for this project. Figure 7.10 shows the SOFO DAQ setup.

Figure 7.10- SOFO DAQ setup

7.6.3 LUNA DAQ

The LUNA DAQ (Figure 7.11) is used to collect data from the fiber optic sensors that were connected to this system a few days before the concrete pouring day.

Figure 7.11- LUNA DAQ setup

7.6.4 Mistras DAQ

The AE sensors were hooked up to this DAQ (Figure 7.12) on July 22nd 2016. These sensors were verified during the installation by following pencil-lead break test of *ASTM E569/E569M-13 (Standard Practice for Acoustic Emission Monitoring of Structures during Controlled Stimulation)*.

Figure 7.12- Mistras DAQ setup

7.7 Temperature/Humidity Sensors

During pouring concrete, three Temperature/Humidity sensors were installed to monitor the air temperature change within the environmental chamber. One was located in the material zone, one on the confinement steel frame, and the last one close to the large bay door. Data were collected hourly from 5:00 am to 4:00 pm on July 23rd 2016. Data were recorded as well around the moment of mixing ready to pour for each truck. Since July 23rd, the data has been recorded regularly with two or three intervals in daytime on weekdays.

7.8 Data Collection

The following sensors are continuously collecting data since July 23rd to date:

1. Concrete temperature from KM thermocouples;
2. Concrete strain from KM strain gages;
3. Rebar strain from electrical strain gages;
4. Air temperature and humidity inside and outside the chamber;

5. Deformation in the Z-direction from embedded SOFO sensors;
6. Expansion deformation from a digital micrometer;
7. Acoustic data from AE sensors;
8. DIC cameras (by the team partner from the University of Vanderbilt).

The following Instrumentation will be installed by September 9th:

1. DEMEC points;
2. SOFO surface sensors;
3. TPC pressure transducer;
4. FO surface sensors;
5. AE surface sensors.

So far, each DAQ has its own UPS battery backup. However, based on the power consumption, the batteries can only support 10 or 15 minutes. Consequently, a power backup system will be designed. Besides, to protect them from any eventual harm, the DAQs will be installed in specific enclosures for the entire duration of the project.

Chapter 8: Concrete Mix Design and Placement

8.1 Theoretical Concrete Mix Designs

The current project required the use of a concrete mix that allows a high expansion during the project duration. This implied the design of a specific mixture using high-reactive aggregates. This part of the project has been contracted to the University of Alabama. The high-reactive aggregates used in the mix were coarse aggregate from North Carolina. The used fine non-reactive aggregates were acquired from the Knoxville area; Midway Sand.

Two mixes were developed and used in this project: (1) a boosted/reactive mix with NaOH added to increase the alkali loading to 5.25 kg/m^3, (2) a mitigated mix with a lithium nitrate admixture used at 150% of the manufacturer's recommended dosage. The control and mitigated specimens had an alkali loading of 1.61 kg m^{-3}. The detailed mix design is summarized in Tables 8.1 and 8.2.

Table 8.1– The reactive mix design (Specimens 1 & 2)

Material	Weight (lb/yd^3)	Materials Properties				
		BSG*	AC**	Description	Alkali Content	Doped Content
Cement	590.0	3.15	NA	Cemex Knoxville Type II	0.41%	1.50%
Water	295.0	1.00	NA			
Rock	1988.8	2.74	0.40	NC 57		
Sand	1226.6	2.77	0.70	Midway Sand		
WR admixture	2.0 oz/cwt			ADVA 140		
Recover admixture	2.0 oz/cwt			Recover		
50/50 NaOH, lb.	16.6					
W/C	0.5					

*BSG = Bulk Specific Gravity
**AC = Absorption Capacity

Table 8.2- The control mix design (Specimen 3)

Material	Weight (lb/yd^3)	Materials Properties				
		BSG*	AC**	Description	Alkali Content	Doped Content
Cement	590.0	3.15	NA	Cemex Knoxville Type II	0.41%	1.50%
Water	295.0	1.00	NA			
Rock	1988.8	2.74	0.40	NC 57		
Sand	1226.6	2.77	0.70	Midway Sand		
WR admixture	2.0 oz/cwt			ADVA 140		
Recover admixture	2.0 oz/cwt			Recover		
LiNX, lb.	20.03					
W/C	0.5					

*BSG = Bulk Specific Gravity
**AC = Absorption Capacity

8.2 Chemicals Added to Concrete Mix

8.2.1 Safety Procedures

Two types of chemicals were cautiously used in this project, as shown in Table 8.3. Obtaining the authorization to use these products in the high bay has been a very long process, considering the risks related to the handling of such types of chemicals in such significant quantities, in a closed area.

- The chemicals have been, first, diluted then added to the concrete mix, while still in the truck. These two operations have been performed in compliance with the safety policies, required by the Environmental Health and Safety (EHS) office of the University of Tennessee at Knoxville and the OSHA standards, and under the close supervision of two UTK personnel from the civil engineering department and the EHS office. The PPE used during the dilution process and the batching, included goggles, long rubber gloves, face shields, and a poly-coated Tyvek, as shown in Figure 8.1.

Figure 8.1- PPE for handling of chemicals

Table 8.3- Description of used chemicals

Description	Quantity (lb)	Vendors' package size
Sodium Hydroxide (50%w/w) aqueous solution	560.0	(9) 20L Packages
30% lithium nitrate solution	350.0	55 gallons/drum

- Among the six concrete trucks supplied by Ready Mix USA, the first four were destined to the fabrication of Specimens 1 & 2 required the addition of sodium hydroxide. The two last trucks used for the fabrication of the control specimen required the addition of lithium nitrate solution to mitigate alkali-silica reaction.
- 50 % of the non-diluted sodium hydroxide solution is water.
- 70 % of the non-diluted lithium nitrate solution is water.

8.2.2 Dilution Process

The chemicals (sodium hydroxide and lithium nitrate) were diluted further (1:1) using tap water before batching. The amount of water added during this process was subtracted from the total mixing water for the concrete mix. During the dilution process, a specific amount of concentrated chemical solutions was added with stirring being done during the incremental addition to 5-gal bucket filled with water to one third of its volume. The solution was mixed using a chemically resistant paddle attached to a drill.

Knowing that the dilution of the sodium hydroxide in water will generate a significant amount of heat, this operation has been performed the day before the concrete pouring day to allow the solution to return to an ambient temperature. The diluted chemicals were eventually stored in 5-gal buckets with tight-fitting covers and stored as shown in Figure 8.2.

Figure 8.2- Diluted chemicals in buckets with tight-fitting covers

8.2.3 Chemical Addition Process

The diluted chemicals (NaOH or lithium) were cautiously added (batched) into each of the six concrete truck (using small buckets) upon their arrival to the high bay, as shown in Figure 8.3. The buckets were lifted to the concrete trucks' platform using the hand-operated forklift. The PPE had to be used during the batching as well.

Figure 8.3-. Adding chemicals to a concrete truck

8.3 Concrete Mixing Procedures

8.3.1 Procedure Overview

The concrete mixing operation was performed both at the plant, then at the high bay, once the required quantity of the specific chemical was added. At the plant, ice was first added manually to the truck, followed by the other materials: coarse aggregates, fine aggregates, and cement. In addition, about 10 gallons of water, with a minimum dosage of water reducer and recover admixture, were added at the plant to remove and wash the cement from truck's hopper into the drum. The water reducer and the recover admixtures were added to maintain an acceptable concrete slump value (6 to 8 inches).

Once the trucks were at the high bay, the diluted chemicals (Sodium hydroxide or lithium nitrate) were batched into the concrete trucks using 5-gal buckets. After the adding of chemicals to the concrete, the truck was allowed to rotate in the mixing mode for 3 to 5 minutes to perfectly mix the chemicals with concrete.

Tail water was held back at the trucks and added to achieve the target slump and workability. A detailed mix design is summarized in Table 8.4.

8.3.2 Ice Cubes Addition

The quantity of ice, manually added to each of the six concrete trucks in the plant, represented 70% of the mixing water. The goal of using ice was to avoid Delayed Ettringite Formation (DEF) by maintaining the concrete temperature below 70°F, which was challenging considering that the concrete pouring day was scheduled in July. About 10,000 pounds of ice were delivered to the Ready Mix USA plant, located less than 2 miles far from the high bay. Each bag was supposed to contain approximately 20 pounds of ice. Prior to adding ice into each truck, a representative sample of bags (about 15) has been weighed to verify the actual weigh and adjust the number of bags to add to each truck, avoiding the risk to negatively impact the concrete slump.

Table 8.4- Actual concrete mix details

Truck #	Concrete Quantity (cy)	Coarse Aggregate (Ib)	Fine Aggregate (Ib)	Cement (Ib)	Ice added (Ib)	Added water (Ib)	Water in SSD agg. (Ib)**	Water in diluted Chemicals (Ib)	Total water in mix (Ib)	Actual W/C
1	8.5	16890	10480	5160	1502.0	350.5	293.5	211.7	2357.7	0.46
2	8	15900	9860	4870	1393.7	500.7	276.1	199.3	2369.8	0.49
3	9	17850	11140	5485	1613.3	584.2	312.3	224.2	2734.0	0.50
4	7	13910	8620	4225	1505.3	292.1	241.3	174.0	2212.7	0.52
5	8	15890	9840	4815	1640.3	258.7	275.5	272.4	2446.9	0.51
6	8	15890	9840	4810	1654.8	208.6	275.5	272.4	2411.3	0.50

**Water is calculated based on 0.09% and 0.4% moisture content and absorption for the rock respectively, and 4% and 0.7% moisture content and absorption for the sand.

8.3.3 Concrete Quality Control

Several tests were performed prior to pouring concrete, for each truck, to make sure that the delivered concrete had the required fresh properties. Quality control testing is summarized in Table 8.5.

Table 8.5- Quality control tests

Test Method	**Design values**
Slump of Hydraulic Concrete (ASTM C143/C143M)	6 – 8 in
Unit Weight and Gravimetric Air Content (ASTM C138)	150 – 155 pcf
Air Content by Pressure Method (ASTM C231)	0 – 3%
Concrete Temperature	60 – 65^{0}F

The slump and concrete temperature were assessed twice for each truck: a first time at the beginning of the pouring, then at the middle portion of the concrete truck. The goal was to verify that the fresh concrete was still holding an acceptable slump and the concrete temperature was in the required range. The unit weight and air content sample were measured from the middle portion of the concrete truck to provide a representative measure. The results of the quality control testing are summarized in Table 8.6.

Table 8.6- Quality control results

Truck No.	Test results					
	Slump (in)		Temperature (F)		Air %	Unit weight (lb/ft3)
	Test 1	Test2	Test 1	Test2	Test 1	Test 1
1	6.00	8.00	69	72	1.9	152.6
2	8.50	8.50	66	-	1.5	153.1
3	8.50	9.00	65	66	1.2	152.5
4	7.50	7.50	62	61	1.2	155.6
5	7.25	8.00	65	-	1.6	153.9
6	6.50	7.50	66	69	1.5	152.5

8.4 Concrete Placement Procedure

8.4.1 Concrete Pouring Order

The six trucks delivered about 48.5 yd^3 (CY) of concrete for this project. Each truck contained 8.0 yd^3 of concrete except the first one contained 8.5 yd^3. The first two trucks were used to cast Specimen 1 and its companion cylinders and other small specimens, which will be discussed in the materials testing section. The third and fourth trucks were used to cast Specimen 2, and the last two trucks were used to cast Specimen 3 as well as their companion cylinders and other small specimens. Table 8.7 below summarizes the concrete quantities delivered.

Table 8.7- Concrete quantities by truck

Specimens	**Concrete quantity, CY**	**Description**
Specimen (1)	14.0	Reactive, confined, & contained NaOH
Specimen (2)	14.0	Reactive, unconfined, & contained NaOH
Specimen (3)	14.0	Control, unconfined, & contained $LiNO_3$
Materials Testing	3.5	Fresh concrete testing and small specimens
Others	3.0	Concrete for finishing

8.4.2 Concrete Placement Method

The concrete was placed in the formwork by a system of concrete hoppers. The concrete was transferred from the concrete truck to a large concrete hopper with a capacity of approximately two cubic yards. From the large concrete hopper, the concrete was discharged to a smaller concrete hopper with attached hose. The hose allowed the concrete to be precisely placed in selected locations in order to avoid the embedded sensors. The hopper system is shown in Figure 8.4.

Figure 8.4- System of hoppers for concrete placement

Throughout the placement of the concrete, professional concrete workers periodically and carefully vibrated the poured concrete to ensure consolidation. Care was taken to avoid all embedded sensors, as shown in Figures 8.5 and 8.6.

Figure 8.5- Filling concrete hopper from truck

Figure 8.6- Placement of concrete

8.4.3 Concrete Finishing Procedure

A team of professional concrete finishers prepared the finished for the three large concrete specimens. After full consolidation of the concrete specimen, the top surface of the three specimens were trowel finished to a flat surface (Figure 8.7). A few minutes after finishing, curing compound was sprayed onto the top surface. After which, wet burlap and then plastic sheeting was placed onto the concrete.

Figure 8.7- Finishing concrete surface

8.5 Concrete Material Testing

Table 8.8 summarizes the details of more than 150 cylinders fabricated in order to determine different mechanical properties as well as the fracture energy related to the concrete of each specimen (i.e. reactive confined, reactive unconfined, and control).

Table 8.8- List of total fabricated cylinders

<table>
<tr><th rowspan="3">Specimen Details</th><th colspan="6">Number of cylinders</th></tr>
<tr><th colspan="2">Reactive/ confined</th><th colspan="2">Reactive/unconfined</th><th colspan="2">Control</th></tr>
<tr><th>Truck 1</th><th>Truck 2</th><th>Truck 3</th><th>Truck 4</th><th>Truck 5</th><th>Truck 6</th></tr>
<tr><td>Steel cylinders (6" x 12")</td><td>25</td><td>25</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Plastic cylinders (6" x 12")</td><td>-</td><td>-</td><td>25</td><td>25</td><td>25</td><td>25</td></tr>
<tr><td>Fracture (8" x 8" x 4")</td><td>-</td><td>-</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>Fracture (16” x 26” Pipes)</td><td>2</td><td>1</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Fracture (8” x 26” Pipes)</td><td>2</td><td>4</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Creep (4" x 4" x 16")</td><td>-</td><td>-</td><td>2</td><td>1</td><td>2</td><td>1</td></tr>
<tr><td>Shrinkage (4" x 4" x 16")</td><td>-</td><td>-</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
</table>

The testing plan is summarized in Tables 8.9 to 8.11 for the mechanical properties and the fracture energy respectively.

Table 8.9- Mechanical properties of Mockup concrete

<table>
<tr><th>Test Methods</th><th colspan="2">Confined ASR samples</th><th colspan="2">Unconfined ASR samples</th><th>Unconfined Control samples</th><th>Total Number of Cylinders (per test time)</th></tr>
<tr><td>Compressive Strength (ASTM C39)</td><td colspan="2">3 cylinders per test time</td><td colspan="2">3 cylinders per test time</td><td>3 cylinders per test time</td><td rowspan="3">15 Cylinders:
- 5 steel cylinders.
- 10 plastic cylinders.</td></tr>
<tr><td>Static Modulus of Elasticity (ASTM C469)</td><td colspan="5">Compressive strength cylinders will also be used for measuring the modulus</td></tr>
<tr><td>Splitting Tensile Strength (ASTM C496)</td><td colspan="2">2 cylinders per test time</td><td colspan="2">2 cylinders per test time</td><td>2 cylinders per test time</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Test Method</td><td colspan="2">ASR Reactive samples</td><td colspan="3">Non-reactive samples</td><td>Total Number of samples</td></tr>
<tr><td>Creep of Concrete in Compression (ASTM C512/C512M)</td><td colspan="2">4" x 4" x 16"</td><td colspan="3">4" x 4" x 16"</td><td>6 Prisms</td></tr>
</table>

Table 8.10- Testing schedule for hardened properties

Test Methods	Test time (yrs)	Test Time (days)	# of Steel cylinders	# of Plastic cylinders
Creep of Concrete in Compression	0.16	60	0	6
Compressive Strength Static Modulus of Elasticity. Splitting Tensile Strength	0.02	7	5	10
	0.08	28	5	10
	0.25	91	5	10
	0.50	183	5	10
	0.75	274	5	10
	1.00	365	5	10
	1.50	548	5	10
	2.00	730	5	10
	2.50	913	5	10
	3.00	1095	5	10

Table 8.11- Summary of Wedge Splitting Test for Fracture Energy

Confinement Conditions	Crack orientation (/°)	Loading age (year)	Quantity	# Specimens
Confined (Reactive sample)	0	0.5	6	(3) Pipes (16” x26” Pipes)
		1.0	6	
		1.5	6	
	90	0.5	6	
		1.0	6	
		1.5	6	
	45	0.5	6	(6) Pipes (8” x26” Pipes)
		1.0	6	
		1.5	6	
Unconfined (Reactive sample)	/	0.5	6	(6) 3(8" x 8" x 4")
		1.0	6	
		1.5	6	
Unconfined (Non-Reactive sample)*	/	0.5	6	(6) 3(8" x 8" x 4")
		1.0	6	
		1.5	6	

Chapter 9: Environmental Chamber Construction

9.1 Design of Environmental Chamber

The environmental was designed by Norlake Scientific with the primary goals for temperature and humidity control being 100°F (+/- 2ºF) and 95% RH (+/- 2%). In order to maintain the temperature and relative humidity, a heating system consisting of both heating evaporators and heating units accommodated by air circulators was designed. The design drawings as produced by Norlake Scientific are shown in Appendix 4.

9.2 Delivery and Assembly

The environmental chamber was delivered as panels on multiple pallets. The panels consists of embossed steel filled with foam insulation. Each panel has a set of locks to secure adjacent panels to each other. The floor connection is sealed by a vinyl floor sealer placed underneath the wall panels.

The construction crew initially laid out the walls and verified the building dimension. Vinyl floor sealers were then placed in the locations of the walls. The construction crew began by assembling a corner section first. The remaining walls were built off of this corner until all wall panels had be erected and secured in place. Doors were installed according to the chamber design. Silicone caulk was used to seal the vinyl floor sealers to the concrete floor of the Highbay lab. A completed side of the chamber is shown in Figure 9.1.

Figure 9.1- Competed side of chamber wall

After all wall panels were secured in place. The steel post and beam system was installed to support the ceiling panels. Ceiling panels were installed and locked in place to adjacent wall panels and other ceiling panels. Each ceiling panel was attached to a steel beam supporting its span. The completed installation of ceiling panels is shown in Figure 9.2.

Figure 9.2- Completed ceiling before light installation

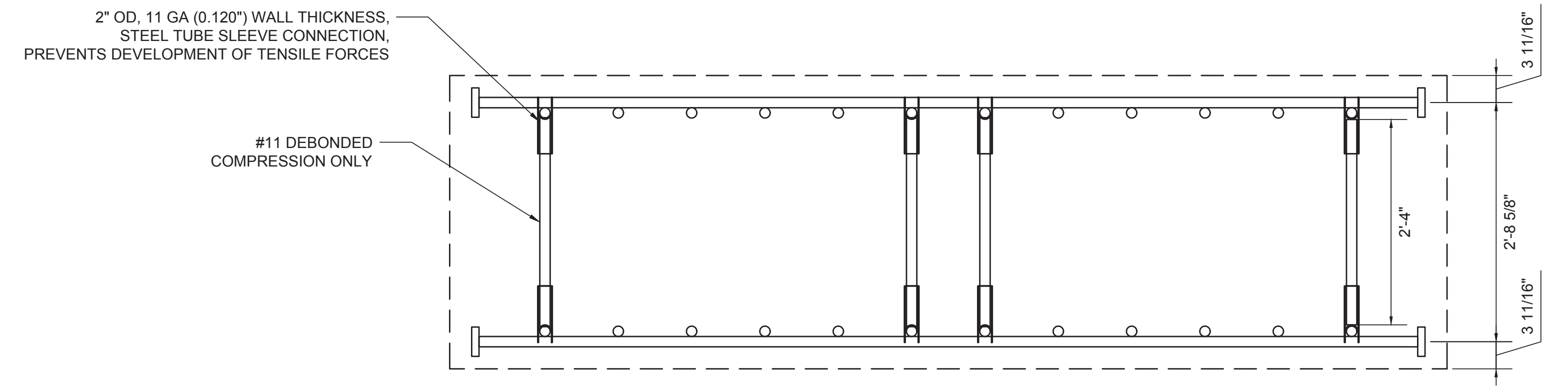
After installation of all panels, a second construction crew began the mechanical and electrical work. All misters and heating units were installed and connected to the electrical system. Afterwards, all lights were attached to the ceiling and connected to the electrical system. A full power up of the system was completed August 17, 2016 to test the operation of the heating and misting system as well as the lighting system. After confirmation of the system's working order, the system was powered down to finalize all connections and prepare the chamber for full-time operation. All concrete specimens were uncovered at this time.

Once completed, the chamber measured approximately 53 feet long and 24 feet wide. This area allows for all three samples and all concrete cylinders and other smaller specimens to be contained within the same environment.

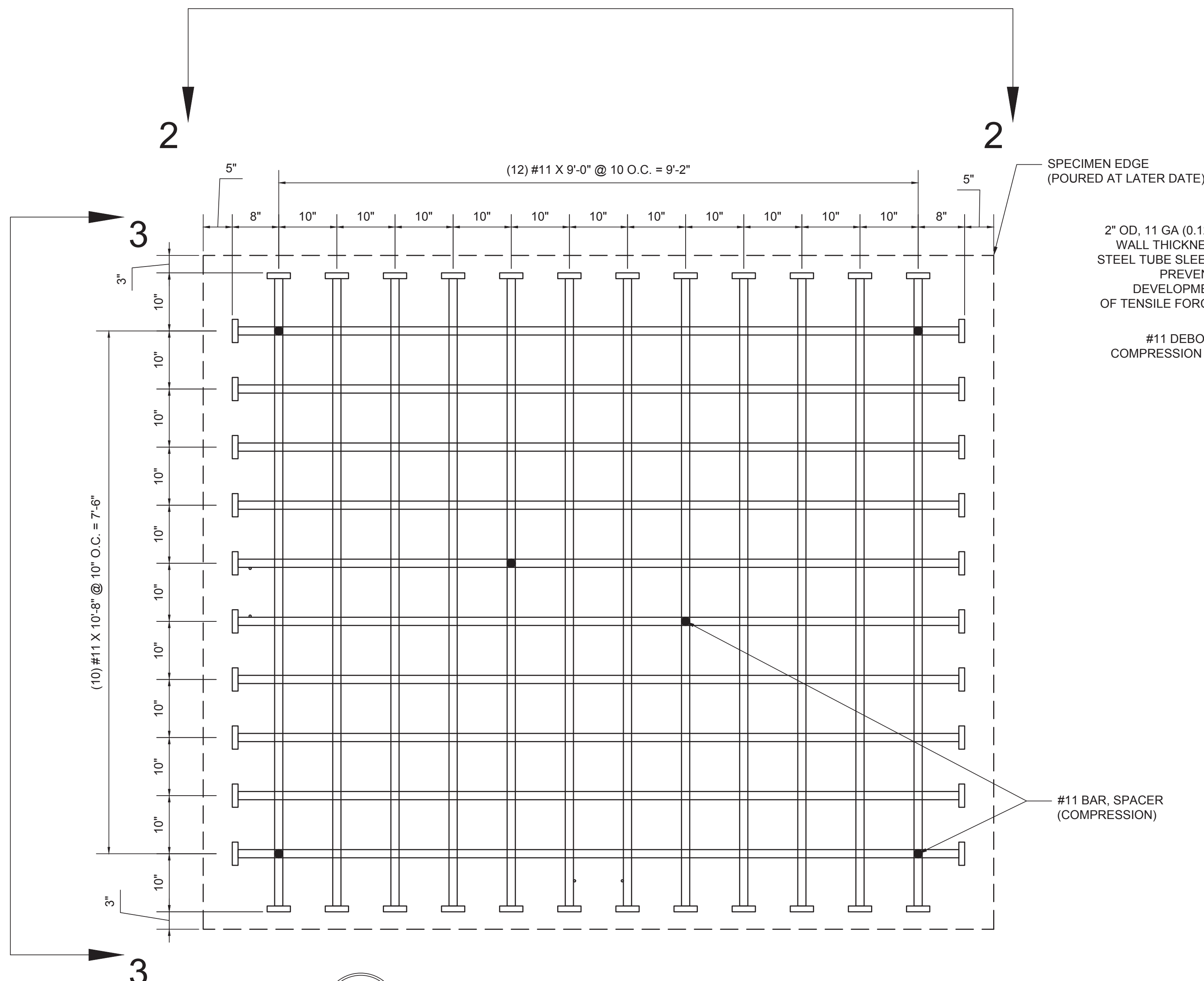
The chamber was initialized for full operation early morning August 19, 2016. The system was checked to meet specifications of 100°F/95% RH. All systems were working as intended and successfully maintained the required temperature and humidity. The chamber will operate uninterrupted until manual measurements will be taken. At which point, the chamber will be temporarily shut down for approximately 4 hours in order to achieve a workable environment.

Chapter 10: Conclusions

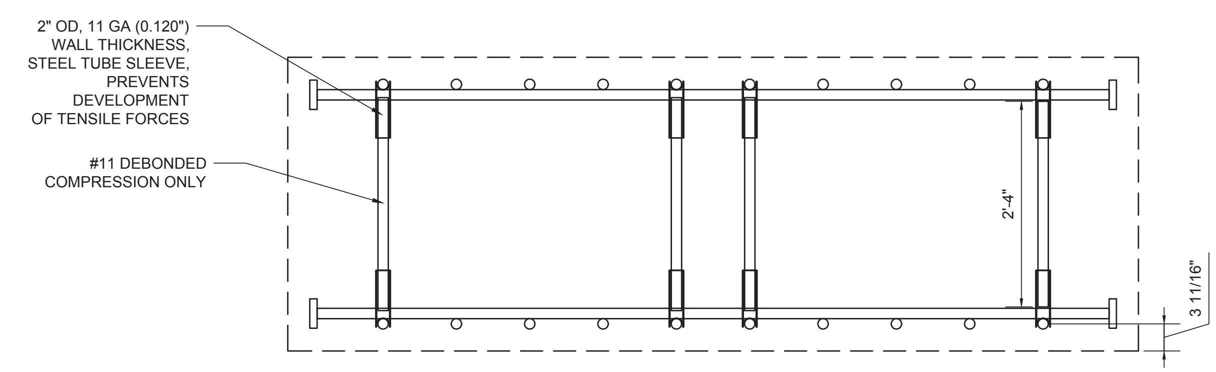
Three large-scale concrete specimens have been produced to test the development of ASR in stress confined concrete. Companion cylinders were also produced to determine the effects of ASR development on the mechanical properties of the concrete. Data is currently being collected and will be collected for the approximate two-to-three-year testing period. The data can serve as a means for identifying the distinctions between stress-confined ASR concrete and free ASR concrete expansion through a thorough analysis. The data will also serve as a means to calibrate existing models for development of ASR in stress-confined situations. After the three-year period of ASR expansion, the concrete specimens will be subjected to structural testing to assess the residual shear capacity.



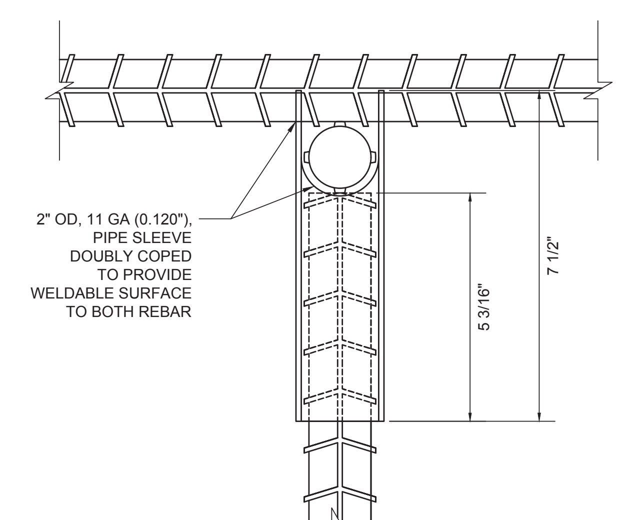
2 — ELEVATION VIEW OF REBAR CAGE LAYOUT
S1.1 — SCALE: 1" = 1'-0"



1 — PLAN VIEW OF REBAR CAGE LAYOUT - SPECIMEN 1
S1.1 — SCALE: 1" = 1'-0"



3 — ELEVATION VIEW OF REBAR CAGE LAYOUT
S1.1 — SCALE: 1" = 1'-0"



4 — PIPE SLEEVE CONNECTION DETAIL
S1.1 — SCALE: 6" = 1'-0"

DESIGNED BY: NWH
DRAWN BY: NWH
CHECKED BY:

ASR RESEARCH

REBAR CAGE LAYOUT

UNIVERSITY
OF
TENNESSEE
KNOXVILLE

CIVIL AND ENV.
ENGINEERING

851 NEYLAND DR.

KNOXVILLE, TN
37996-2313

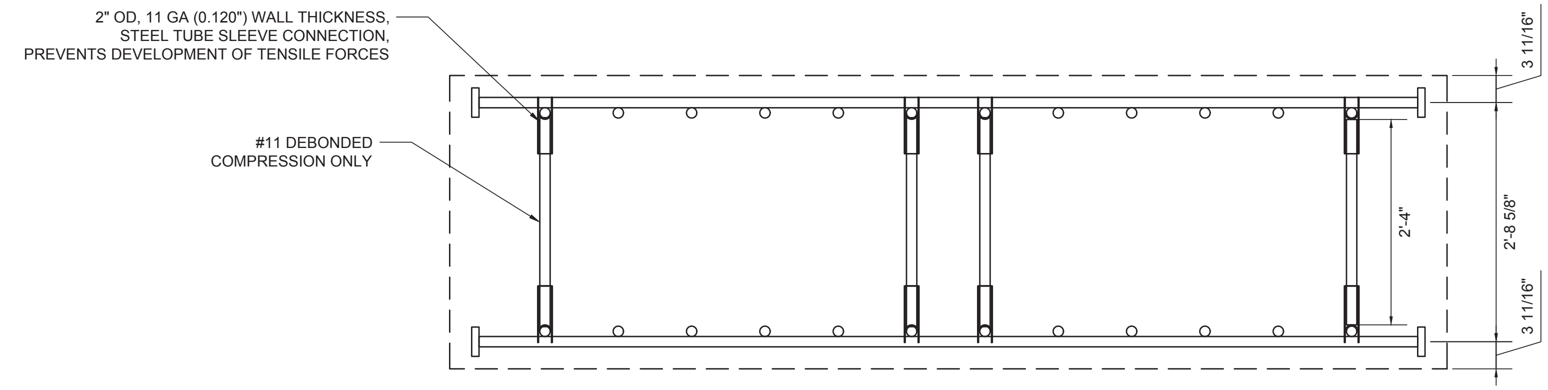
REVISIONS

DATE	DESCRIPTION

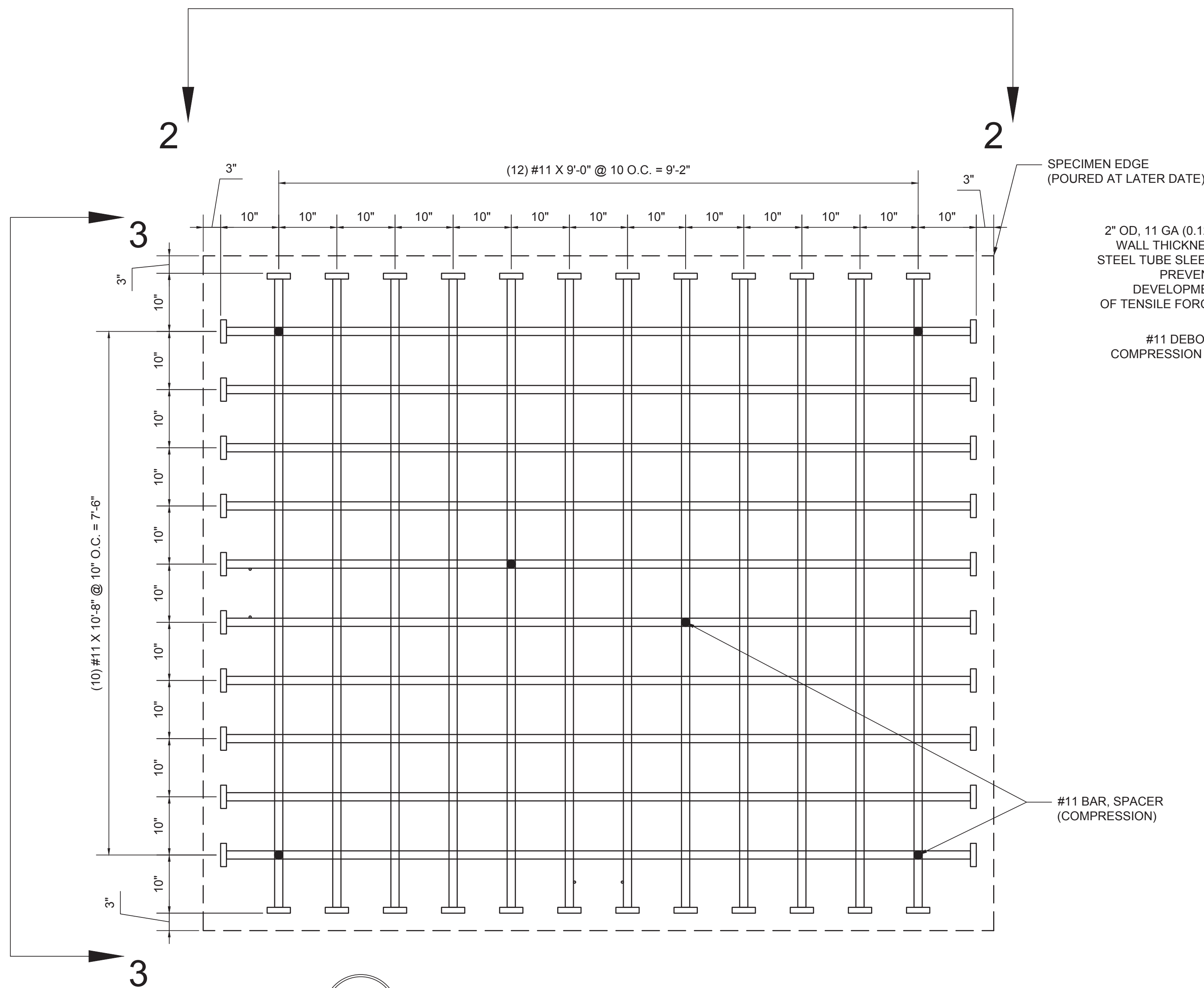
FILE NO.
0000

DRAWING NO.
0000

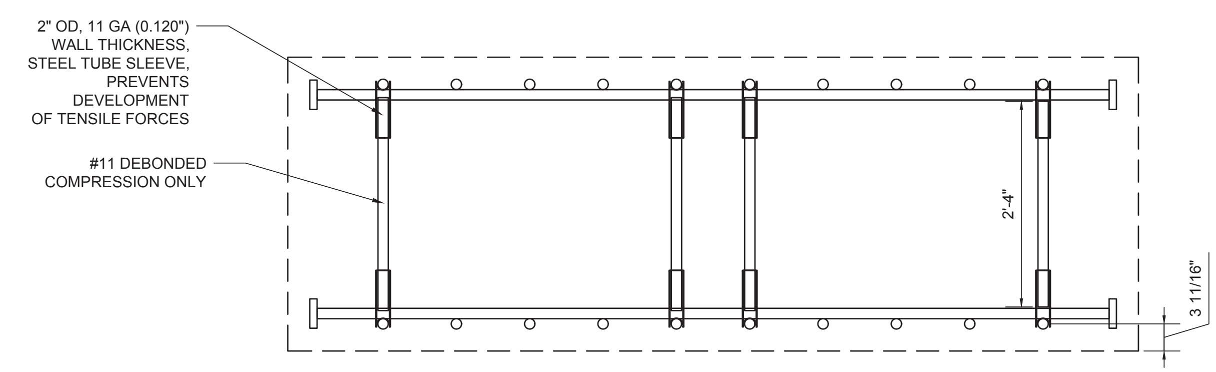
S1.1



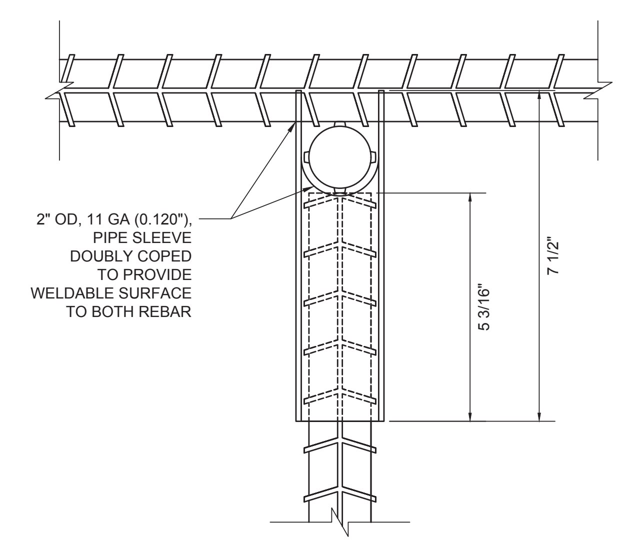
2 | S1.2 — ELEVATION VIEW OF REBAR CAGE LAYOUT
SCALE: 1" = 1'-0"



1 | S1.2 — PLAN VIEW OF REBAR CAGE LAYOUT - SPECIMENS 2 & 3
SCALE: 1" = 1'-0"



3 | S1.2 — ELEVATION VIEW OF REBAR CAGE LAYOUT
SCALE: 1" = 1'-0"



4 | S1.2 — PIPE SLEEVE CONNECTION DETAIL
SCALE: 6" = 1'-0"

DESIGNED BY: NWH
DRAWN BY: NWH
CHECKED BY:

ASR RESEARCH
REBAR CAGE LAYOUT

UNIVERSITY OF TENNESSEE KNOXVILLE
CIVIL AND ENV. ENGINEERING
851 NEYLAND DR.
KNOXVILLE, TN 37996-2313

REVISIONS

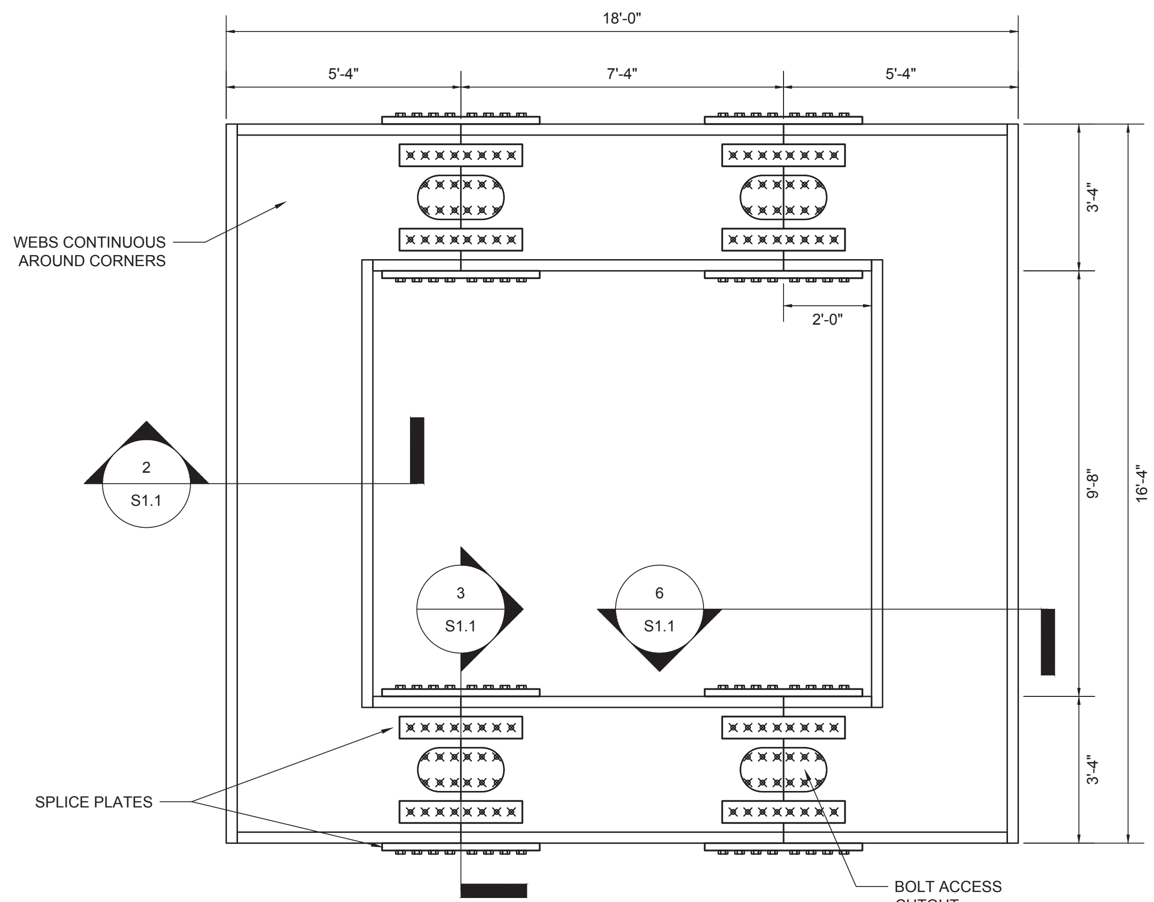
DATE	DESCRIPTION

FILE NO. 0000

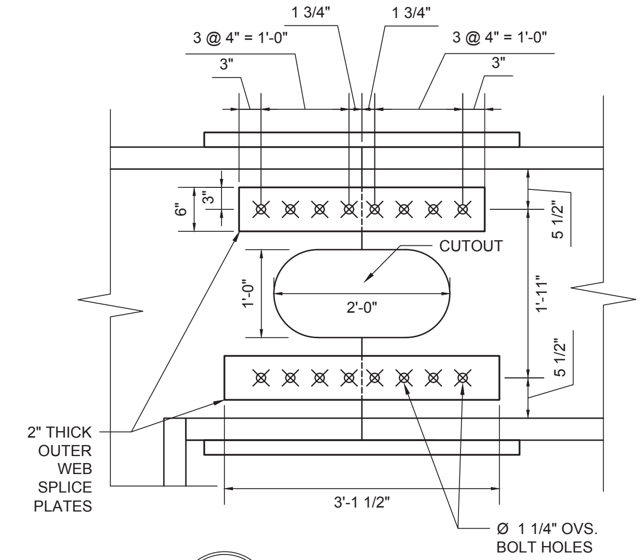
DRAWING NO. 0000

S1.2

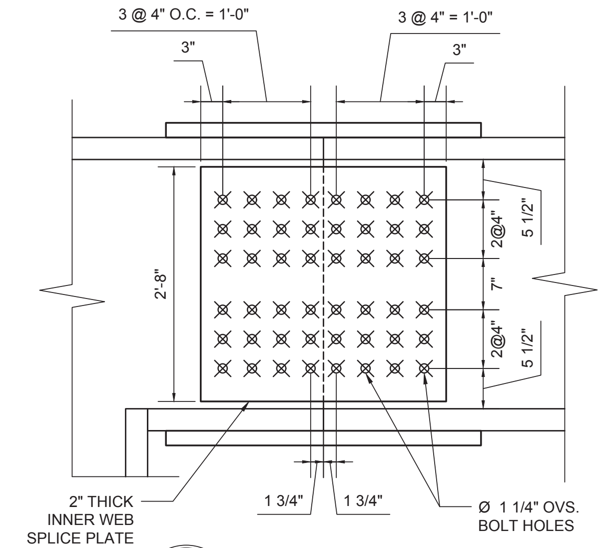
NOTES:
1. ALL STRUCTURAL STEEL SHALL BE A529 GR. 50 STEEL.
2. ALL WELDS SHALL BE E70 ELECTRODE STRENGTH.
3. ALL BOLTS THROUGH FLANGES SHALL BE Ø 1.5" A490.
4. ALL BOLTS THROUGH WEBS SHALL BE Ø 1" A490.
5. ALL BOLT HOLES SHALL BE OVERSIZED DIMENSION.
6. ALL SPLICE PLATES SHALL BE 2" THICK.



1 S1.1 PLAN VIEW: STEEL CONFINEMENT
SCALE: 1/2" = 1'-0"



4 S1.1 OUTER WEB SPLICE CONNECTION DETAIL
SCALE: 1" = 1'-0"



5 S1.1 INNER WEB SPLICE CONNECTION DETAIL
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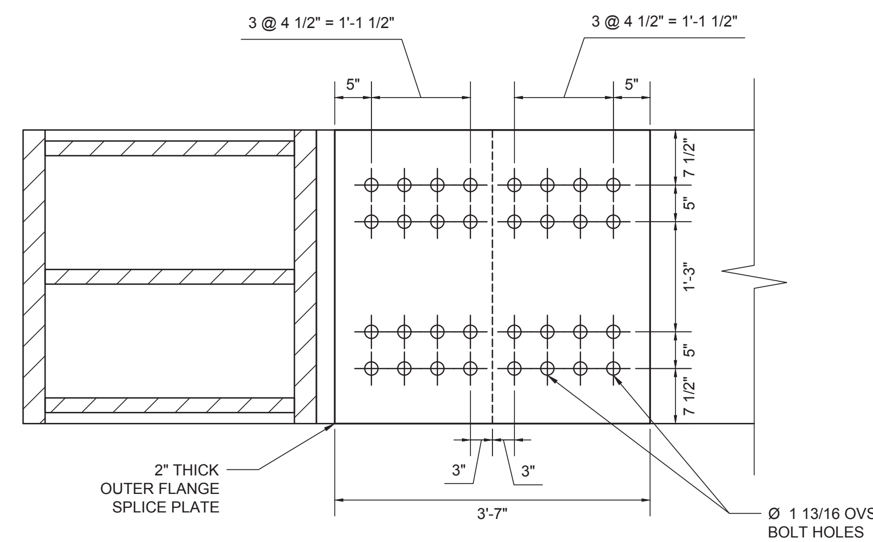
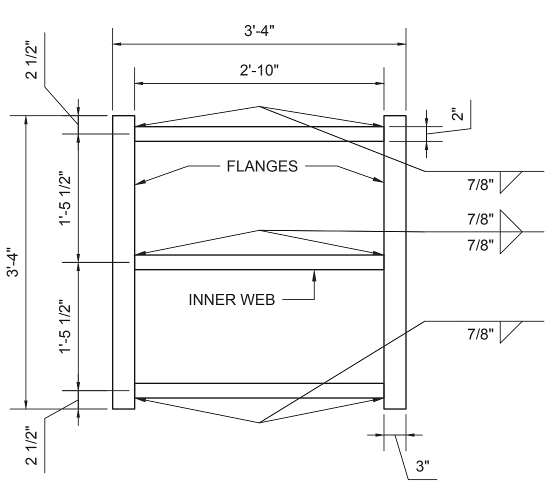
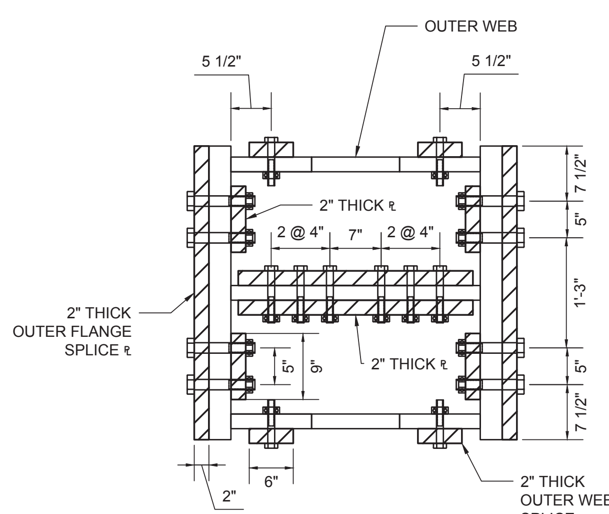


6 S1.1 FLANGE SPLICE CONNECTION DETAIL
SCALE: 1" = 1'-0"

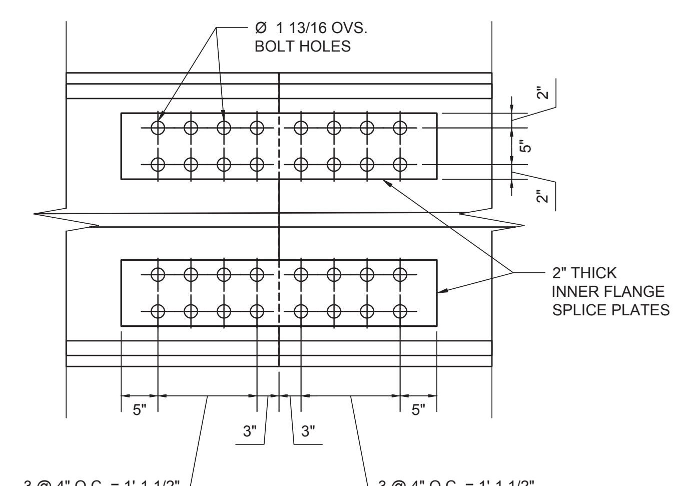
BOLT COUNT PER CONNECTION	
BOLT DIAMETER	QTY
Ø1"	80
Ø1.5"	64



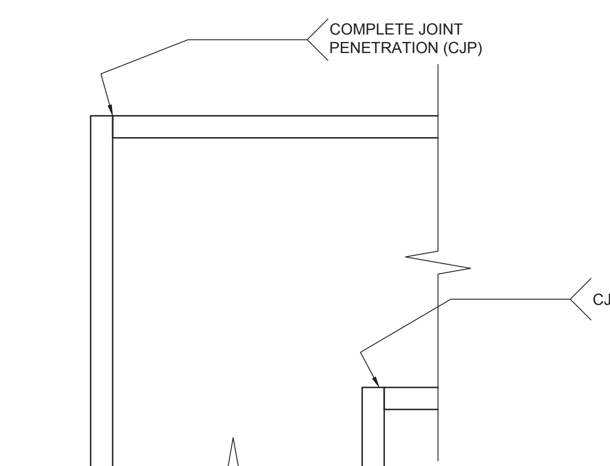
2 S1.1 BEAM CROSS SECTION
SCALE: 1" = 1'-0"



3 S1.1 SPLICE CONNECTION CROSS SECTION
SCALE: 1" = 1'-0"



7 S1.1 INNER FLANGE SPLICE CONNECTION DETAIL
SCALE: 1" = 1'-0"



8 S1.1 CORNER JOINT DETAIL
SCALE: 1" = 1'-0"

DESIGNED BY: LX, QG, NWH
DRAWN BY: NWH, LX
CHECKED BY: JZM

ASR RESEARCH

STEEL CONFINEMENT FRAME: DESIGN 1

UNIVERSITY OF TENNESSEE KNOXVILLE
CIVIL AND ENV. ENGINEERING
851 NEYLAND DR.
KNOXVILLE, TN 37996-2313

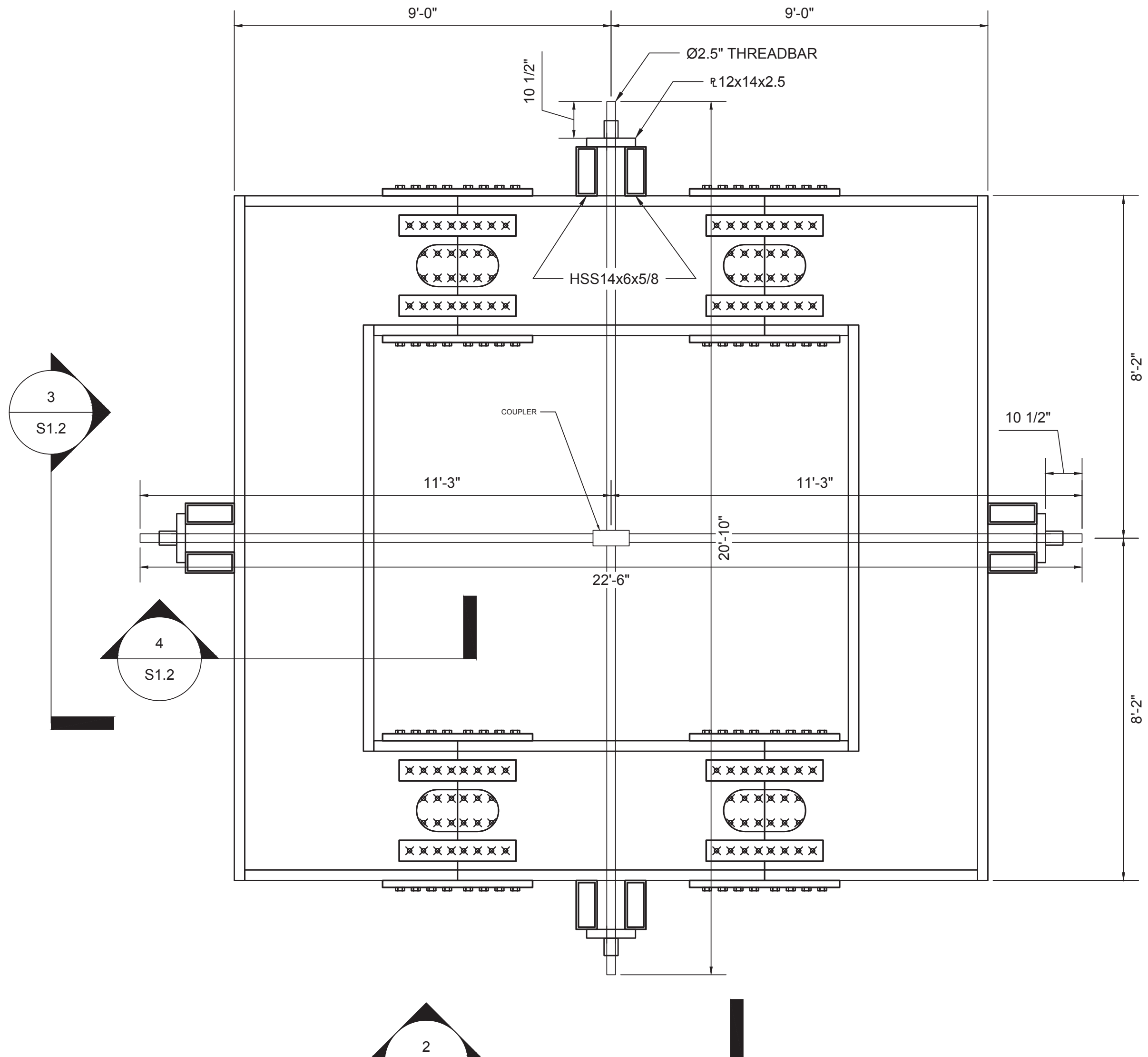
REVISIONS

DATE	DESCRIPTION

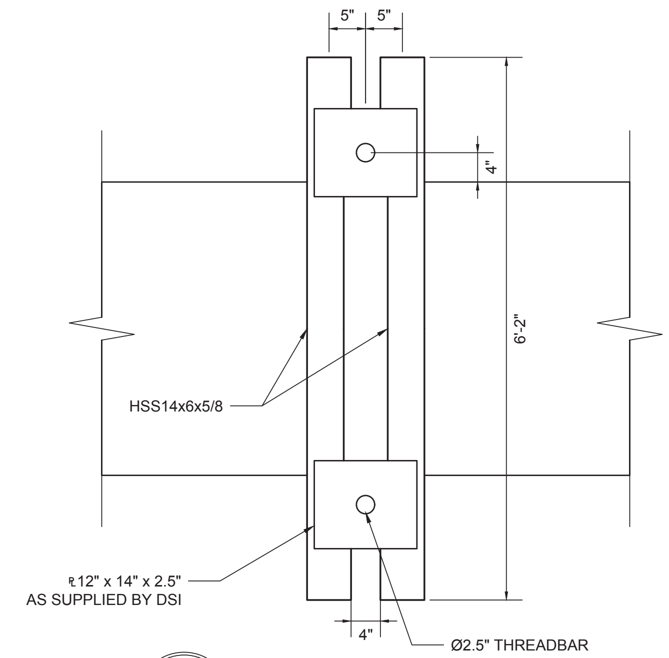
FILE NO. 0000

DRAWING NO. 0000

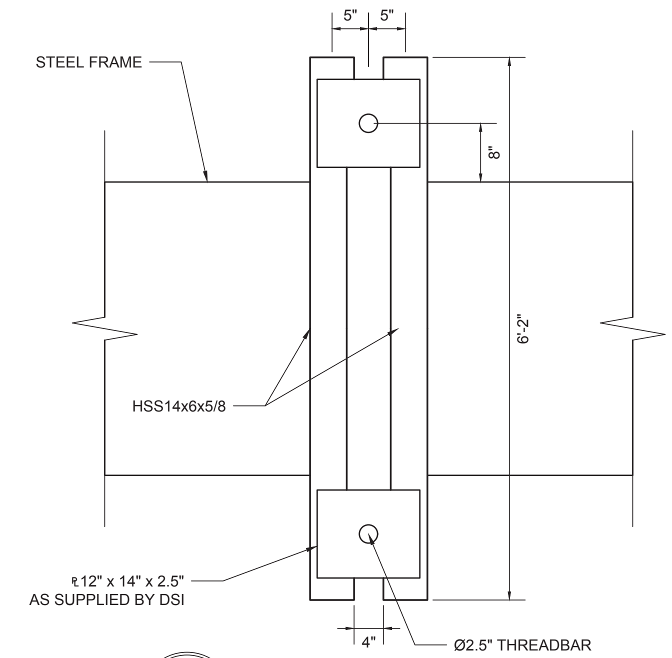
S1.1



1 / S1.2 — PLAN VIEW: STEEL CONFINEMENT
SCALE: 1/2" = 1'-0"



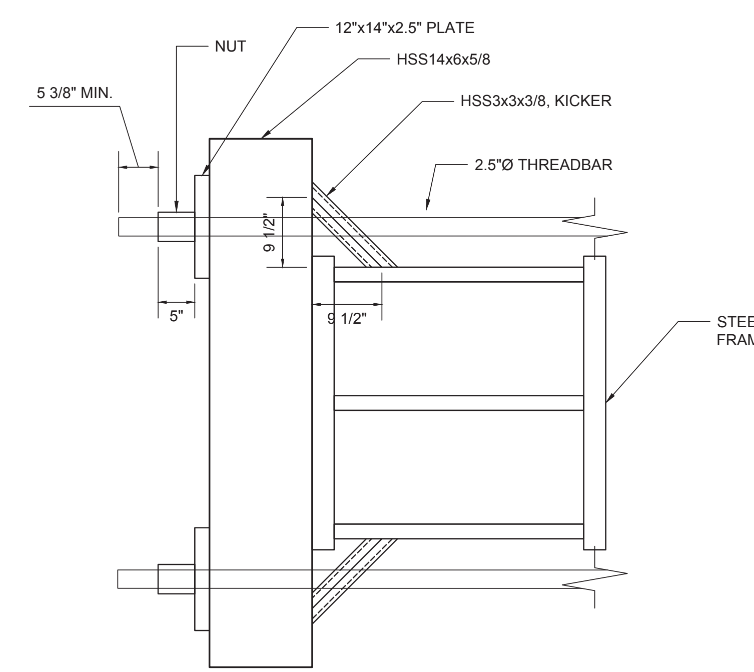
2 / S1.2 — ELEVATION VIEW - POST TENSION SUPPORT
SCALE: 1" = 1'-0"



3 / S1.2 — ELEVATION VIEW - POST TENSION SUPPORT
SCALE: 1" = 1'-0"

THREADBAR PROPERTIES		
NOMINAL BAR DIAMETER (INCHES)	ULTIMATE STRESS, fpu (KSI)	PRESTRESSING FORCE 0.7fpuAps (KIPS)
2.500000	150	546

NOTES:
1. HSS SECTIONS TO BE A500 GR. B STEEL.



4 / S1.2 — ELEVATION VIEW - POST TENSION SUPPORT
SCALE: 1" = 1'-0"

DESIGNED BY: LX, QG, NWH
DRAWN BY: NWH, LX
CHECKED BY: JZM

ASR RESEARCH
STEEL CONFINEMENT FRAME: POST-TENSION

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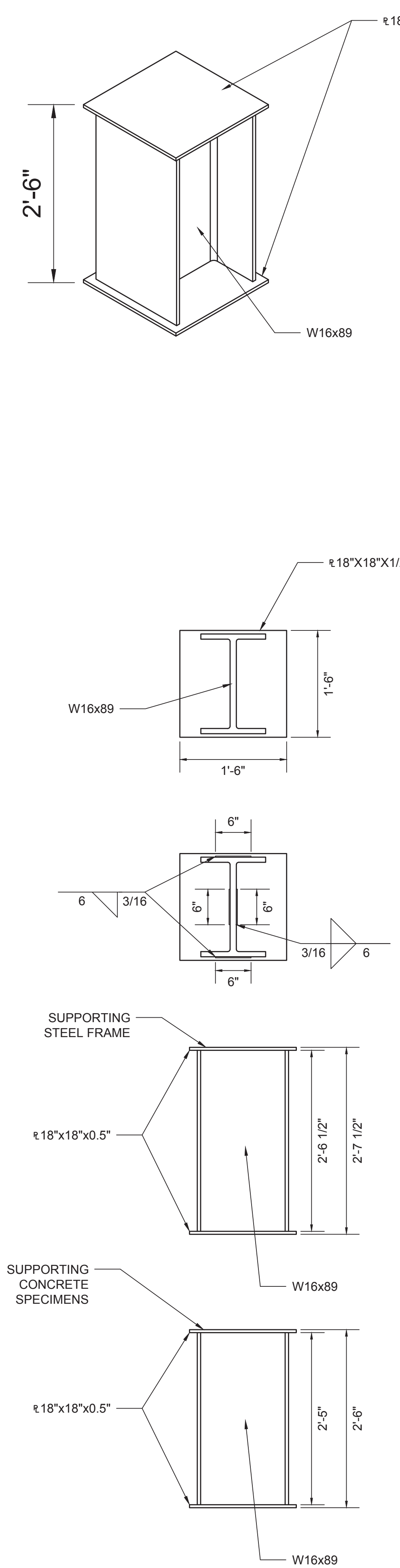
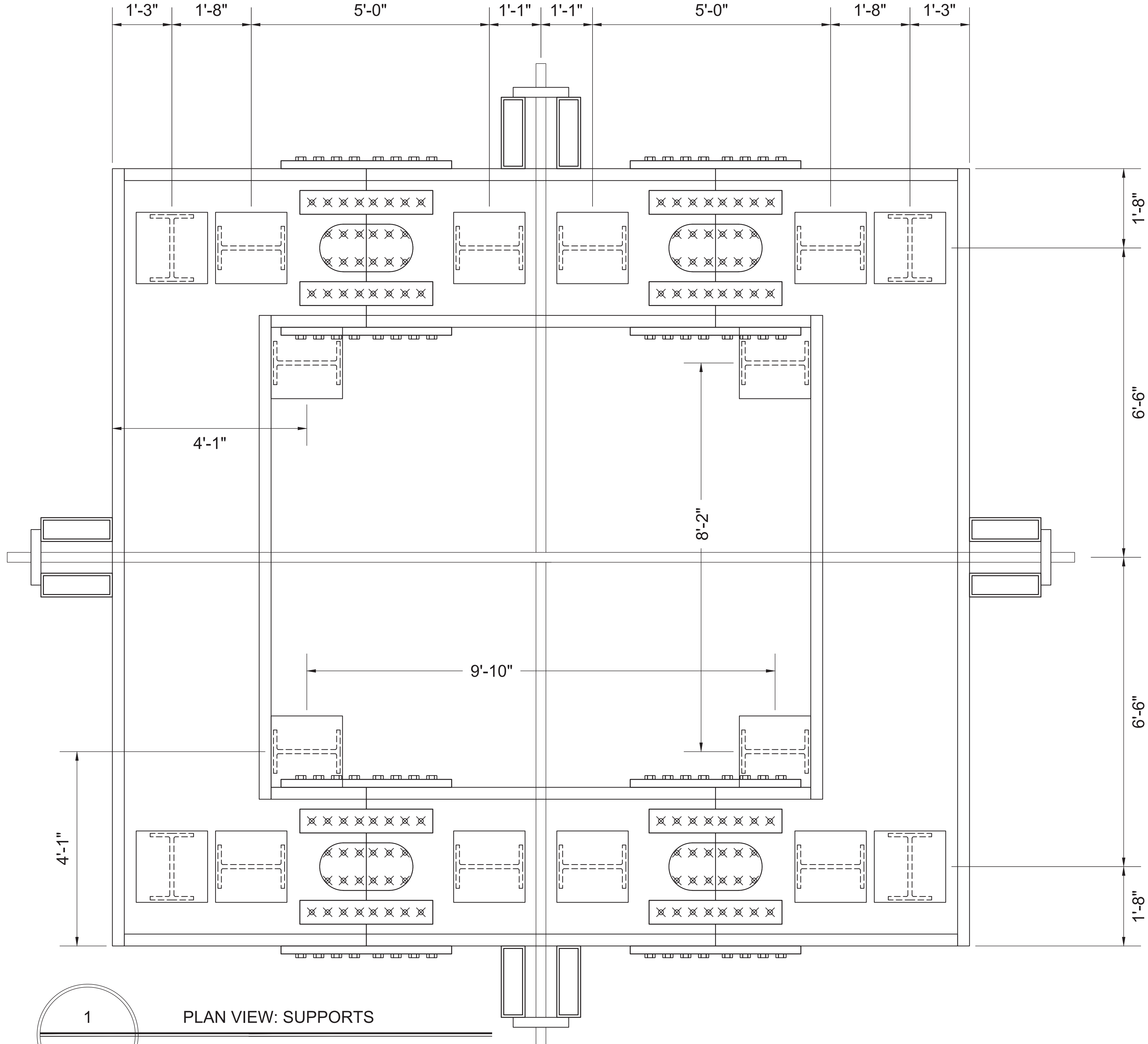
S1.2





1 PLAN VIEW: SUPPORTS

S1.3 SCALE: 1" = 1'-0"

DESIGNED BY: LX, QG, NWH

DRAWN BY: NWH, LX

CHECKED BY: JZM

ASR RESEARCH

STEEL CONFINEMENT FRAME: DESIGN 1

UNIVERSITY OF TENNESSEE KNOXVILLE

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S1.3

THE UNIVERSITY OF TENNESSEE, KNOXVILLE
ALKALI–SILICA REACTION (ASR) RESEARCH

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KNOXVILLE, TN
37996–2313

INDEX OF DRAWINGS

NOTES:

- SPECIMEN IDENTIFICATION:
  - SPECIMEN 1: CONFINED REACTIVE SPECIMEN, CONFINED BY STEEL FRAME
  - SPECIMEN 2: UNCONFINED REACTIVE SPECIMEN
  - SPECIMEN 3: UNREACTIVE CONTROL SPECIMEN

- SENSOR IDENTIFICATION:
  - KM: CONCRETE EMBEDDED STRAIN TRANSDUCER
  - SOFO: CONCRETE EMBEDDED OR SURFACE MOUNTED INTERFEROMETRIC FIBER OPTIC DEFORMATION SENSOR
  - AE: ACOUSTIC EMISSION SENSOR
  - TPC: CONCRETE EMBEDDED LOAD CELL

DESIGNED BY:
DRAWN BY:
CHECKED BY:

ASR RESEARCH
COVER SHEET

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DATE	DESCRIPTION

FILE NO.
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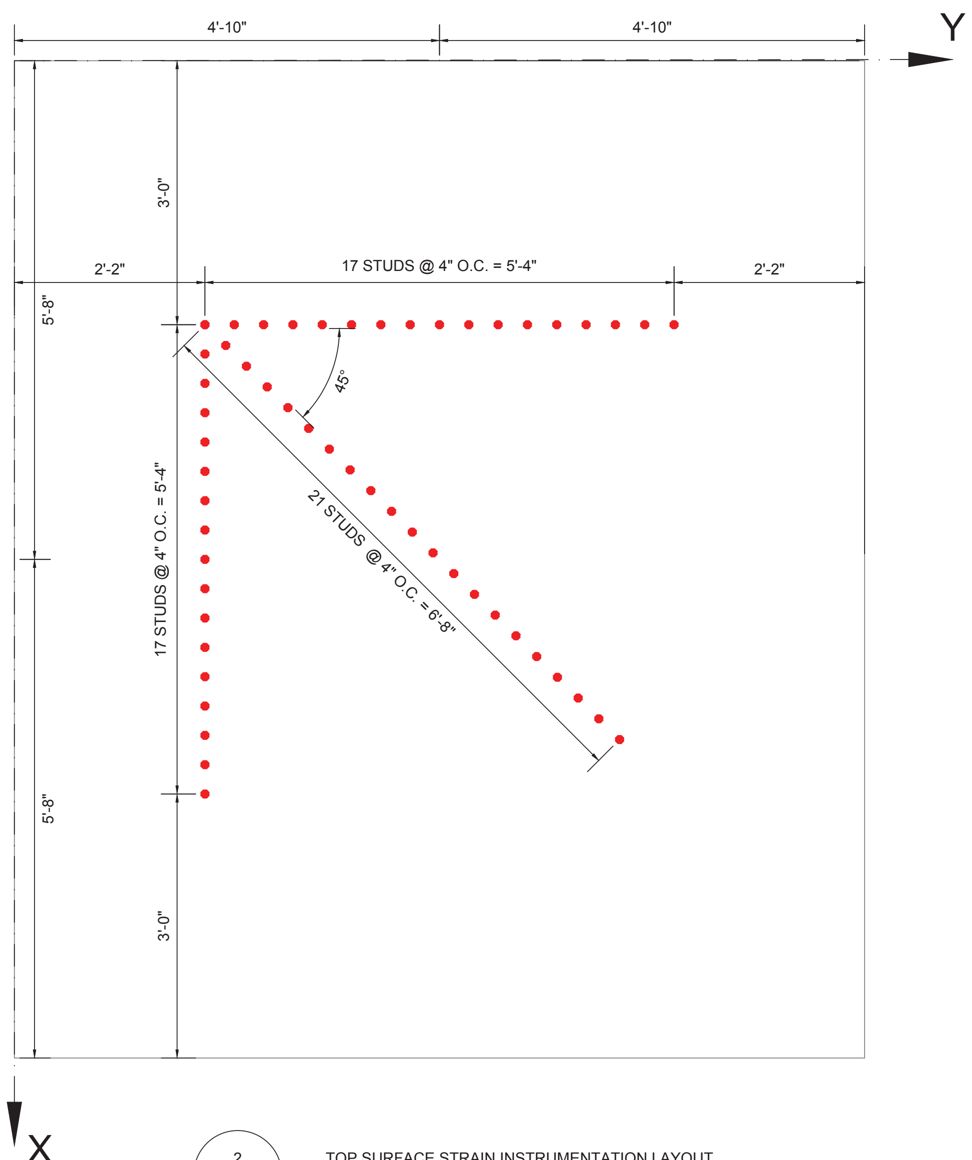
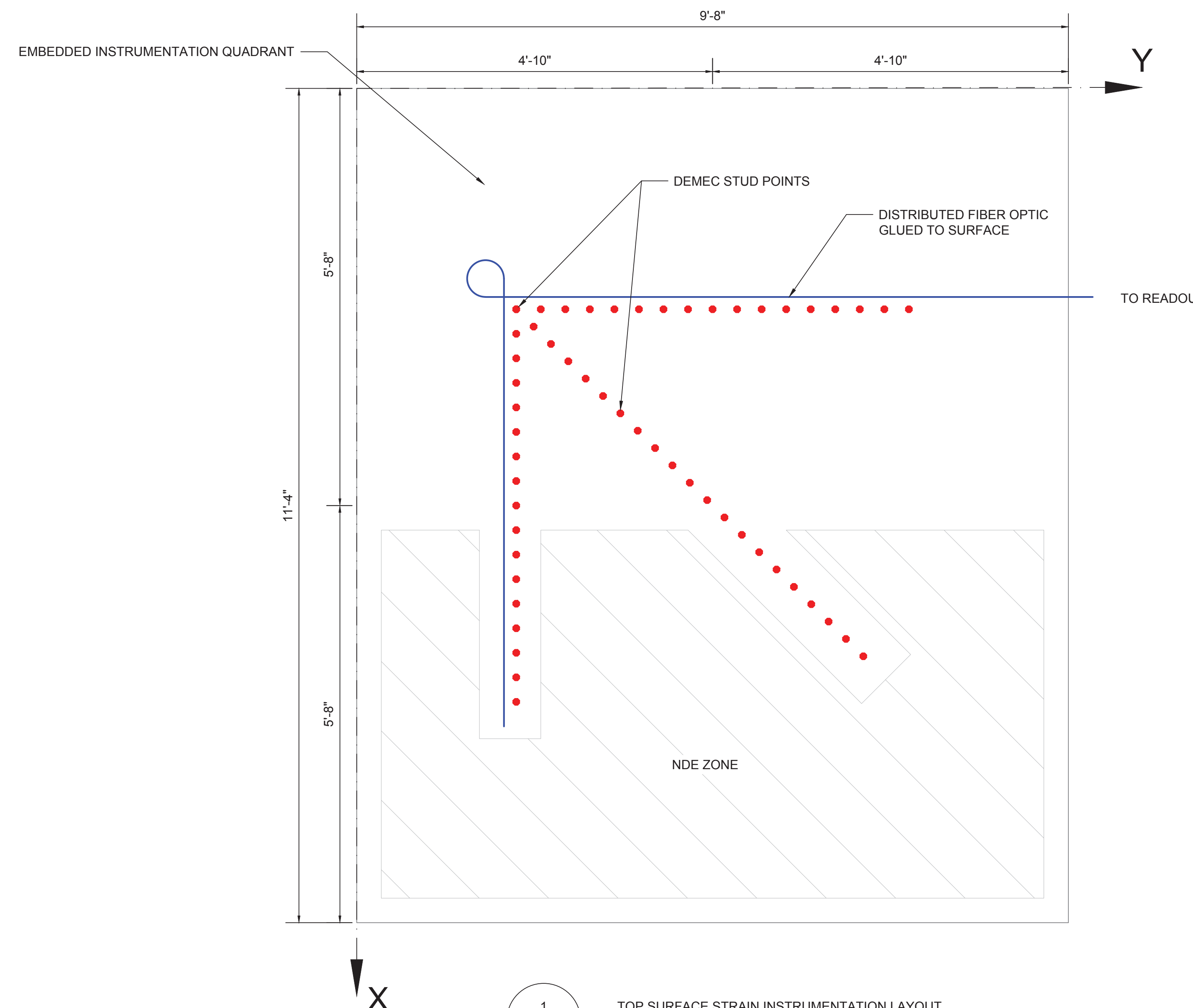
DRAWING NO.
0001

G1.1



2 / T1.1 — TOP SURFACE STRAIN INSTRUMENTATION LAYOUT

SCALE: 1" = 1'-0"



1 / T1.1 — TOP SURFACE STRAIN INSTRUMENTATION LAYOUT

SCALE: 1" = 1'-0"

NOTES:
- TOP SURFACE INSTRUMENTATION WILL BE THE SAME FOR ALL CONCRETE SPECIMENS.
- A GILSON HM-240 ADJUSTABLE READER WILL BE USED TO MEASURE THE DISPLACEMENT BETWEEN DEMEC STUDPOINTS.

DESIGNED BY:
DRAWN BY: NWH
CHECKED BY:

ASR RESEARCH

TOP SURFACE STRAIN INSTRUMENTATION

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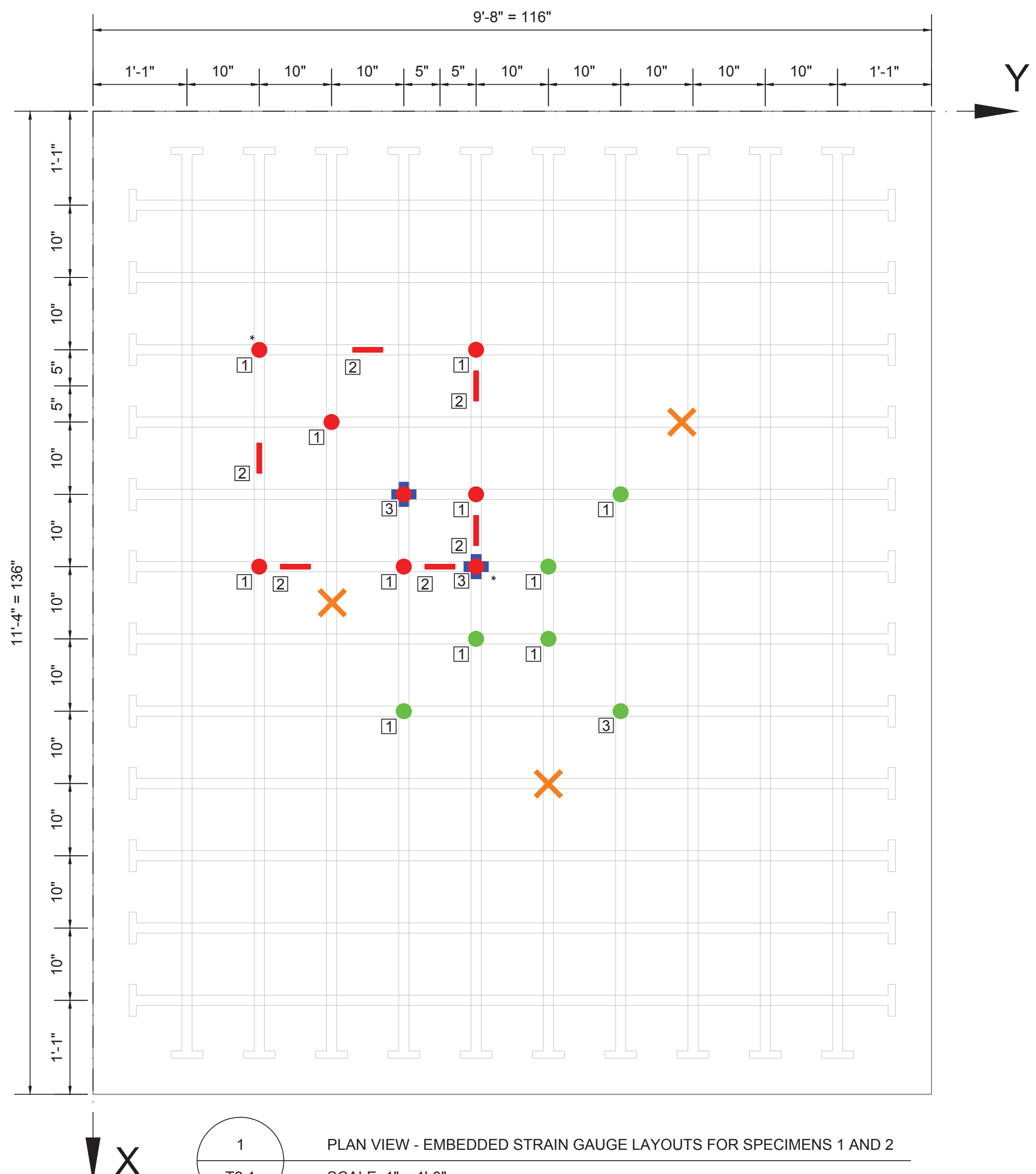
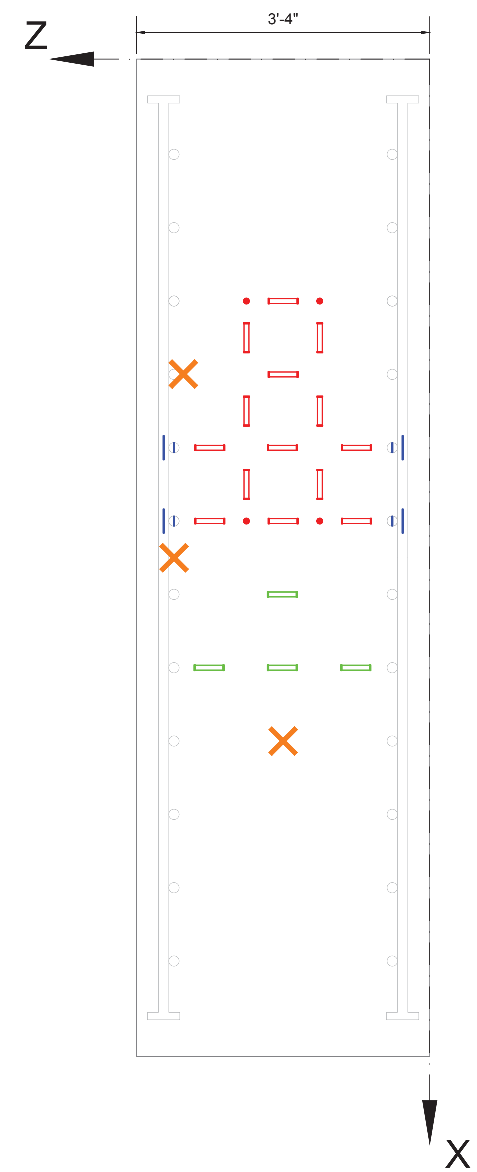
T1.1

- X-DIRECTION EMBEDDED SG
- Y-DIRECTION EMBEDDED SG
- Z-DIRECTION EMBEDDED SG
- X-DIRECTION REBAR SG
- Y-DIRECTION REBAR SG
- Z-DIRECTION EMBEDDED SG QUALITY CONTROL
- AE EMBEDDED SENSOR

NUMBER OF SG THROUGH DEPTH (Z-DIRECTION)
TYPE OF SG

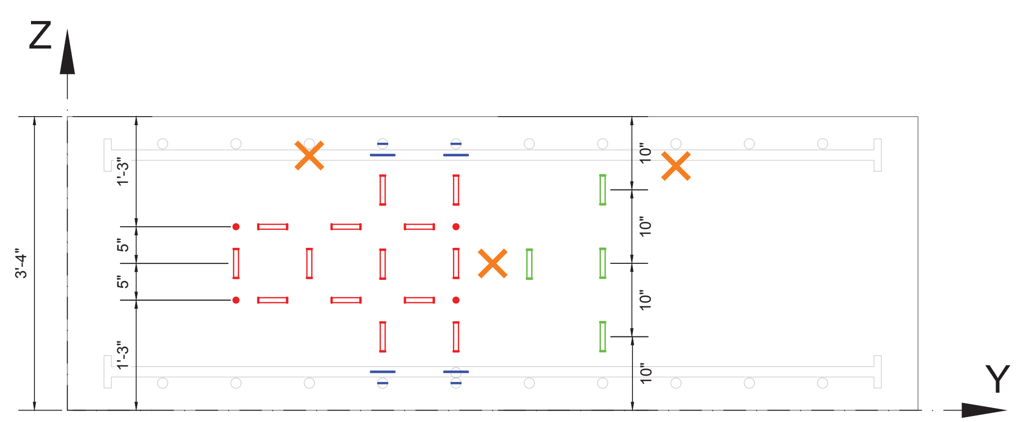


1
T2.1
PLAN VIEW - EMBEDDED STRAIN GAUGE LAYOUTS FOR SPECIMENS 1 AND 2
SCALE: 1" = 1'-0"



2
T2.1
ROTATED ELEVATION VIEW - EMBEDDED STRAIN GAUGE LAYOUTS FOR SPECIMENS 1 AND 2
SCALE: 1" = 1'-0"

EMBEDDED INSTRUMENTATION QUANTIITIES		
SPECIMEN	SENSOR	QUANTITY
1	KM-100B	28
	KM-100BT	4
	ELECTRICAL STRAIN GAUGE	8
2	KM-100B	28
	KM-100BT	4
	ELECTRICAL STRAIN GAUGE	8
3	KM-100B	8
	KM-100BT	4
	ELECTRICAL STRAIN GAUGE	8



3
T2.1
ELEVATION VIEW - EMBEDDED STRAIN GAUGE LAYOUTS FOR SPECIMENS 1 AND 2
SCALE: 1" = 1'-0"

DESIGNED BY:
DRAWN BY: NWH
CHECKED BY:

ASR RESEARCH
EMBEDDED STRAIN INSTRUMENTATION

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FILE NO. 0000

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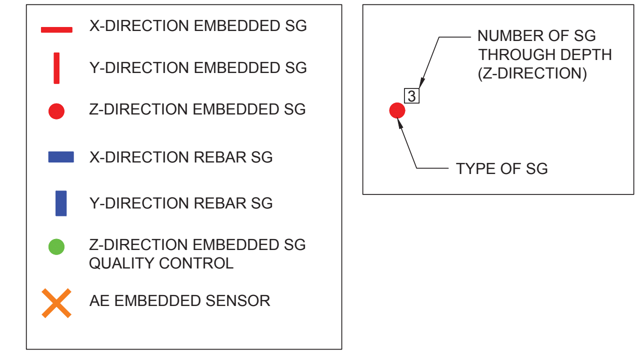
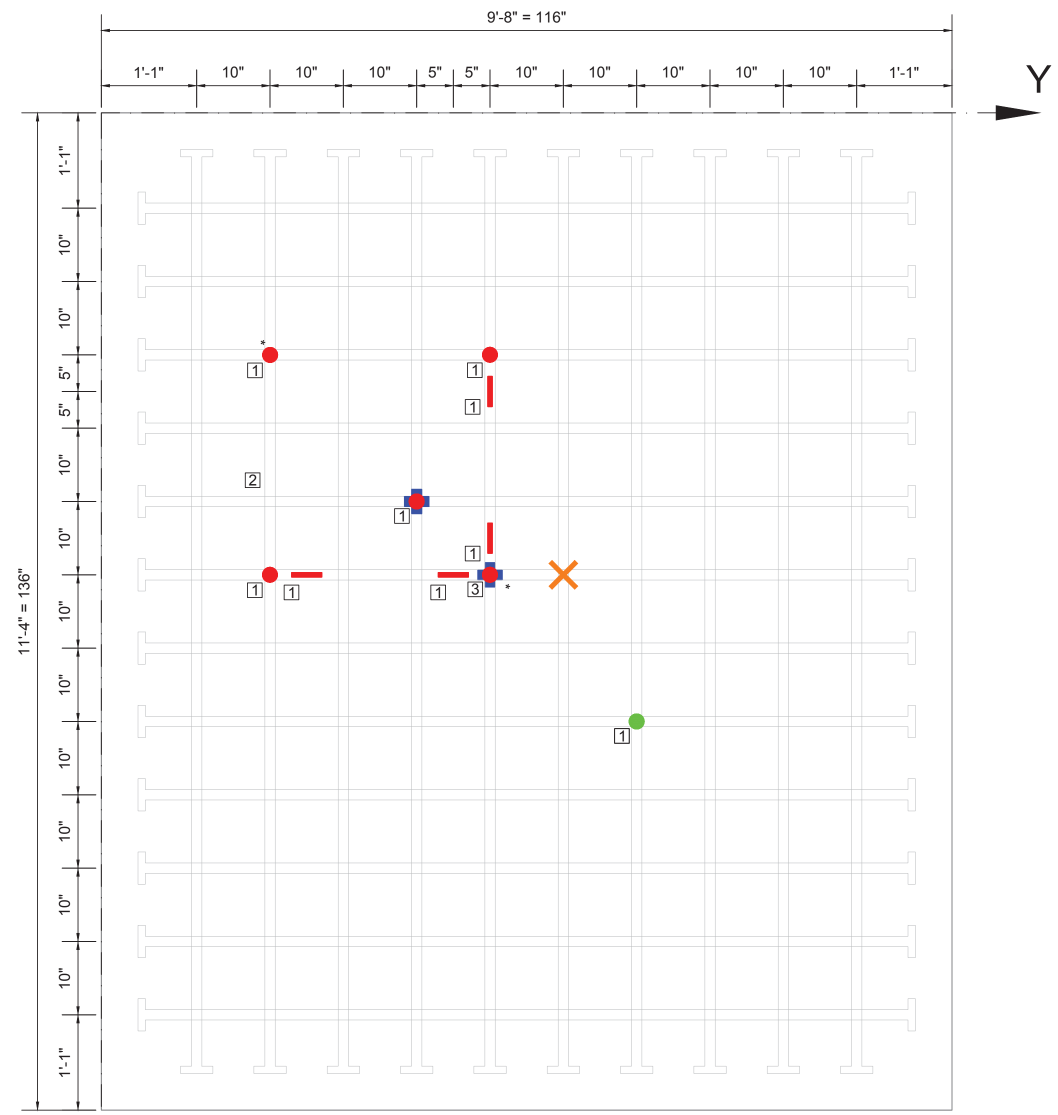
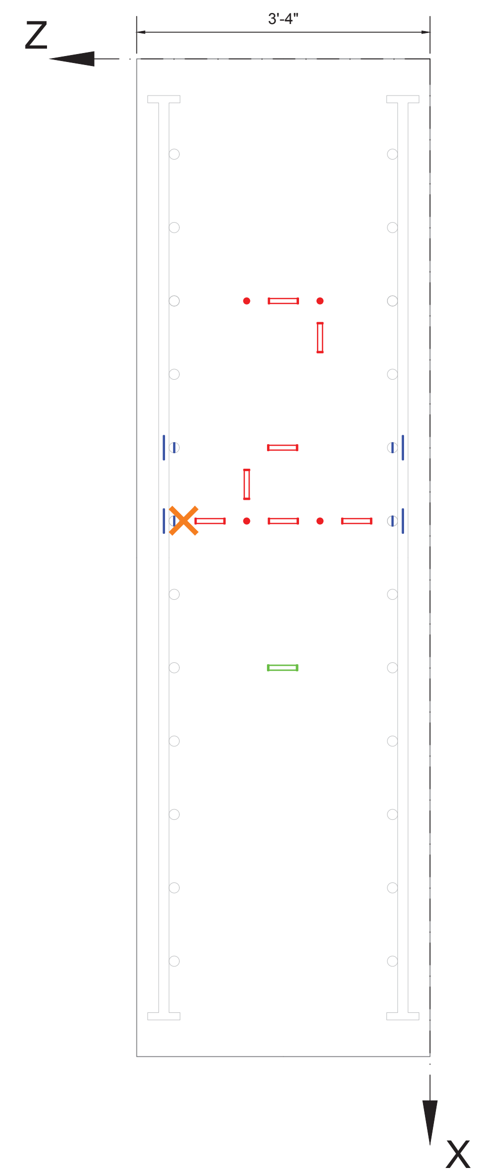
T2.1





1 / T2.2 PLAN VIEW - EMBEDDED STRAIN GAUGE LAYOUTS FOR SPECIMENS 3

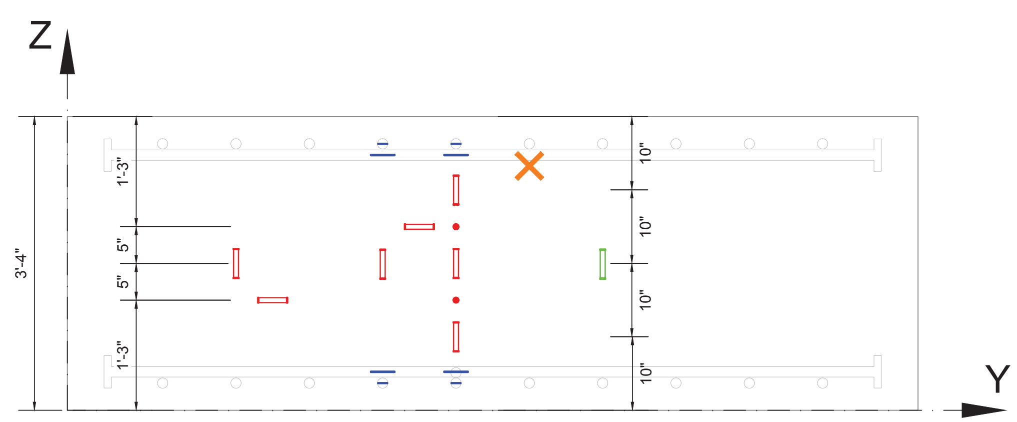
SCALE: 1" = 1'-0"



2 / T2.2 ROTATED ELEVATION VIEW - EMBEDDED STRAIN GAUGE LAYOUTS FOR SPECIMENS 3

SCALE: 1" = 1'-0"

EMBEDDED INSTRUMENTATION QUANTITIES		
SPECIMEN	SENSOR	QUANTITY
1	KM-100B	28
	KM-100BT	4
	ELECTRICAL STRAIN GAUGE	8
2	KM-100B	28
	KM-100BT	4
	ELECTRICAL STRAIN GAUGE	8
3	KM-100B	8
	KM-100BT	4
	ELECTRICAL STRAIN GAUGE	8



3 / T2.2 ELEVATION VIEW - EMBEDDED STRAIN GAUGE LAYOUTS FOR SPECIMENS 3

SCALE: 1" = 1'-0"

DESIGNED BY:

DRAWN BY: NWH

CHECKED BY:

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EMBEDDED STRAIN INSTRUMENTATION

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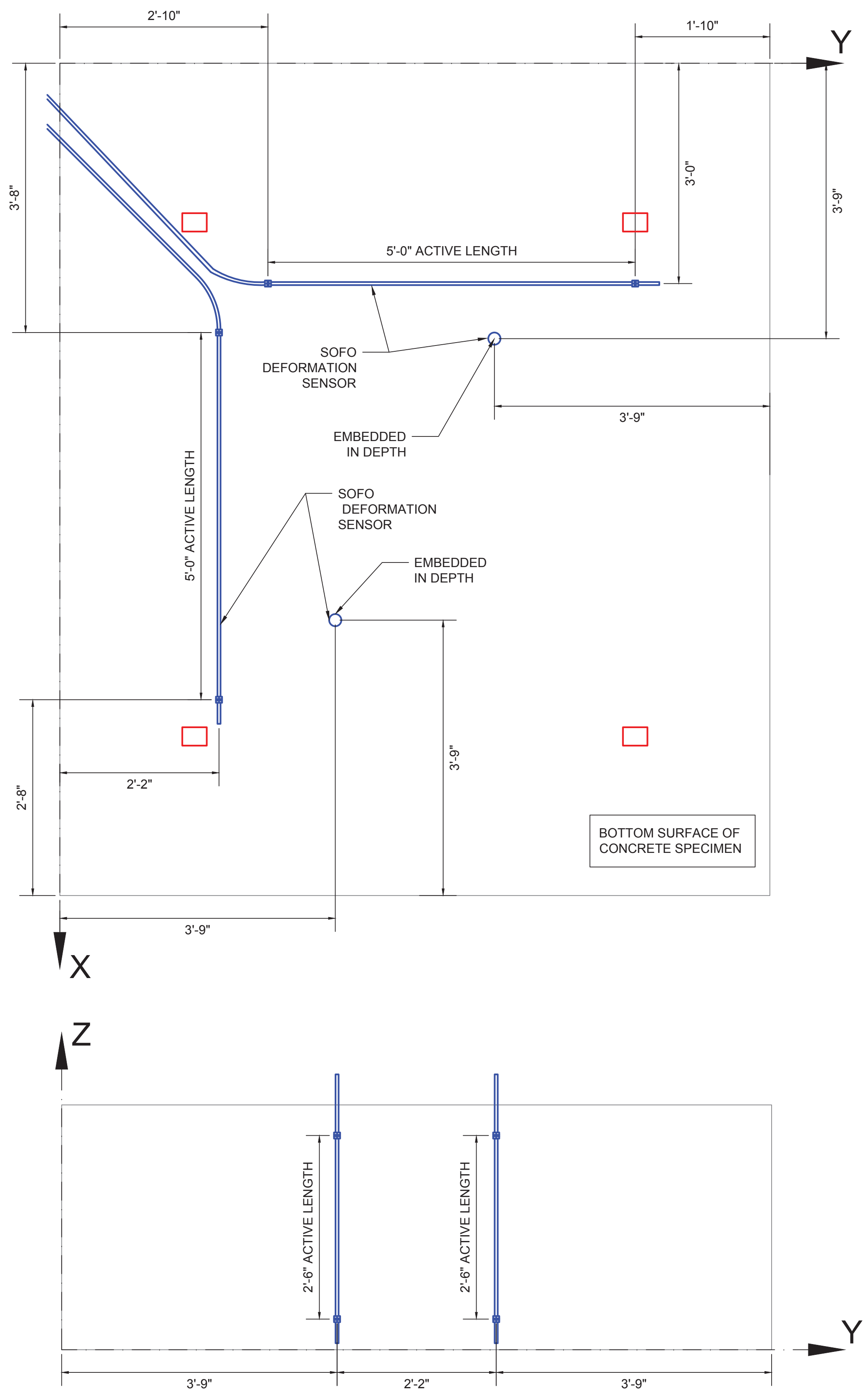
DATE	DESCRIPTION

FILE NO. 0000

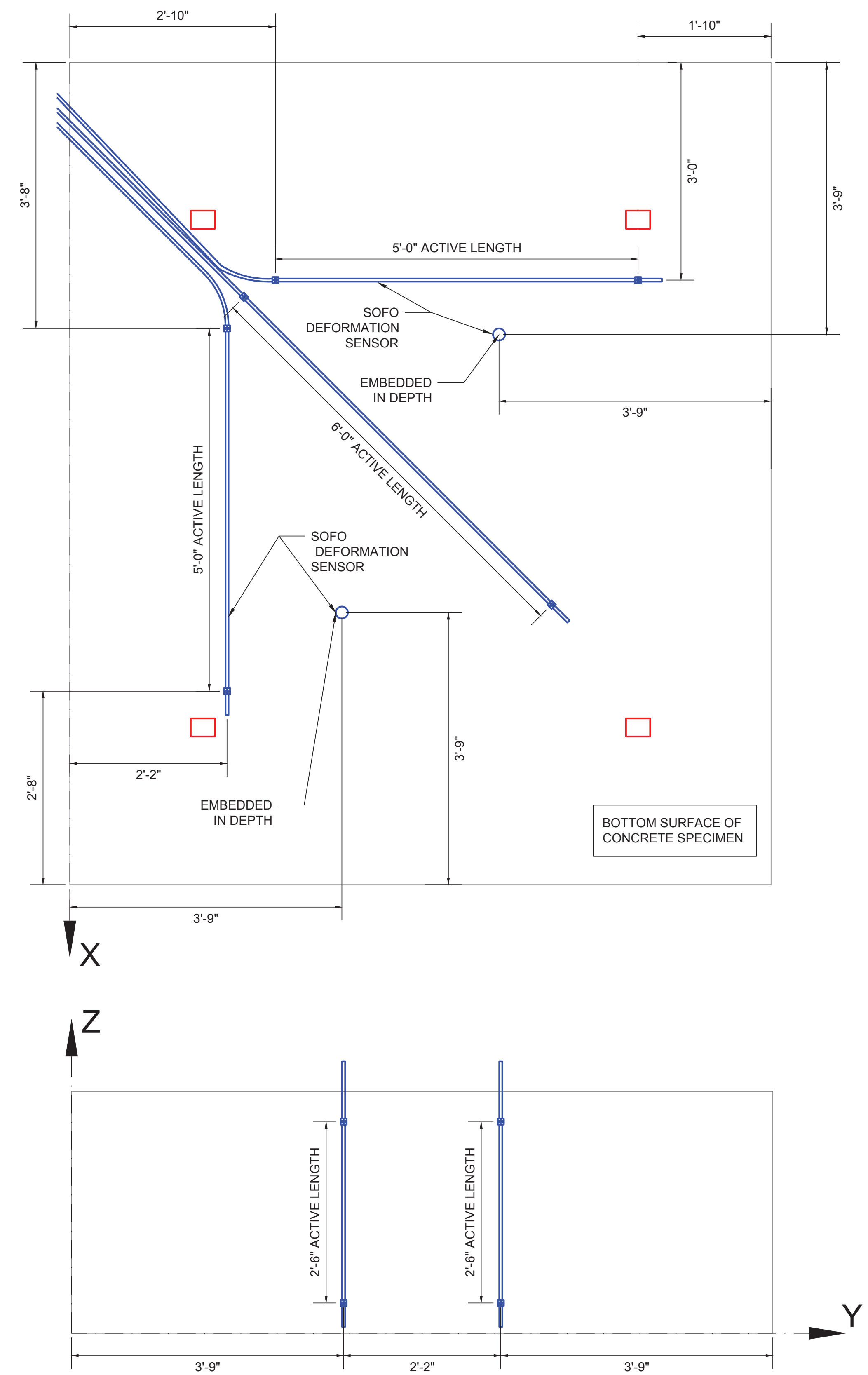
DRAWING NO. 0000

T2.2



1 | T3.1 — SOFO SENSORS - SPECIMEN 1

SCALE: 1" = 1'-0"



1 | T3.1 — SOFO SENSORS - SPECIMEN 2

SCALE: 1" = 1'-0"

DESIGNED BY:

DRAWN BY: NWH

CHECKED BY:

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BOTTOM SURFACE STRAIN INSTRUMENTATION

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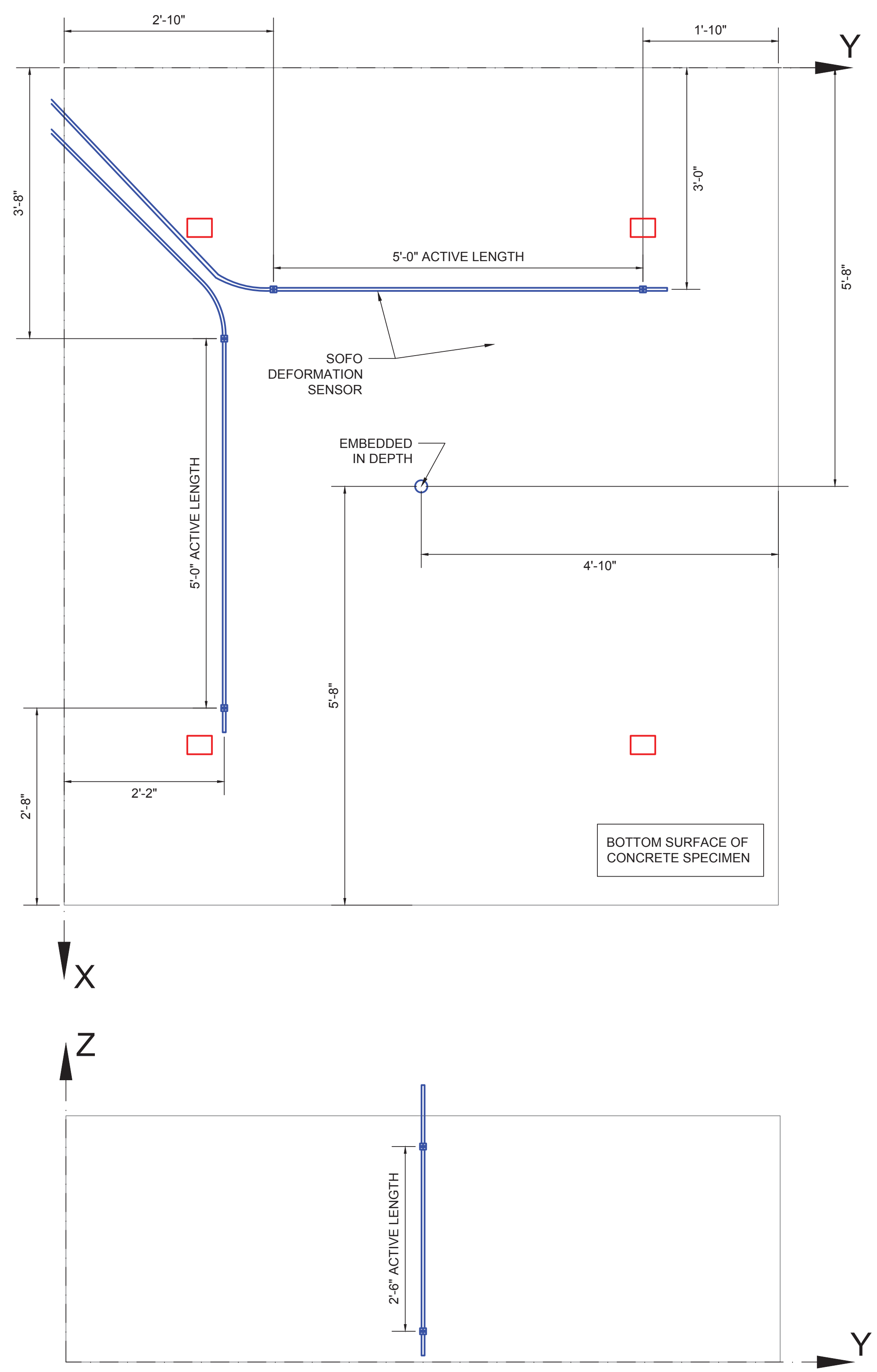
T3.1



1 / T3.2 — SOFO SENSORS - SPECIMEN 3

SCALE: 1" = 1'-0"

DESIGNED BY:
DRAWN BY: NWH
CHECKED BY:

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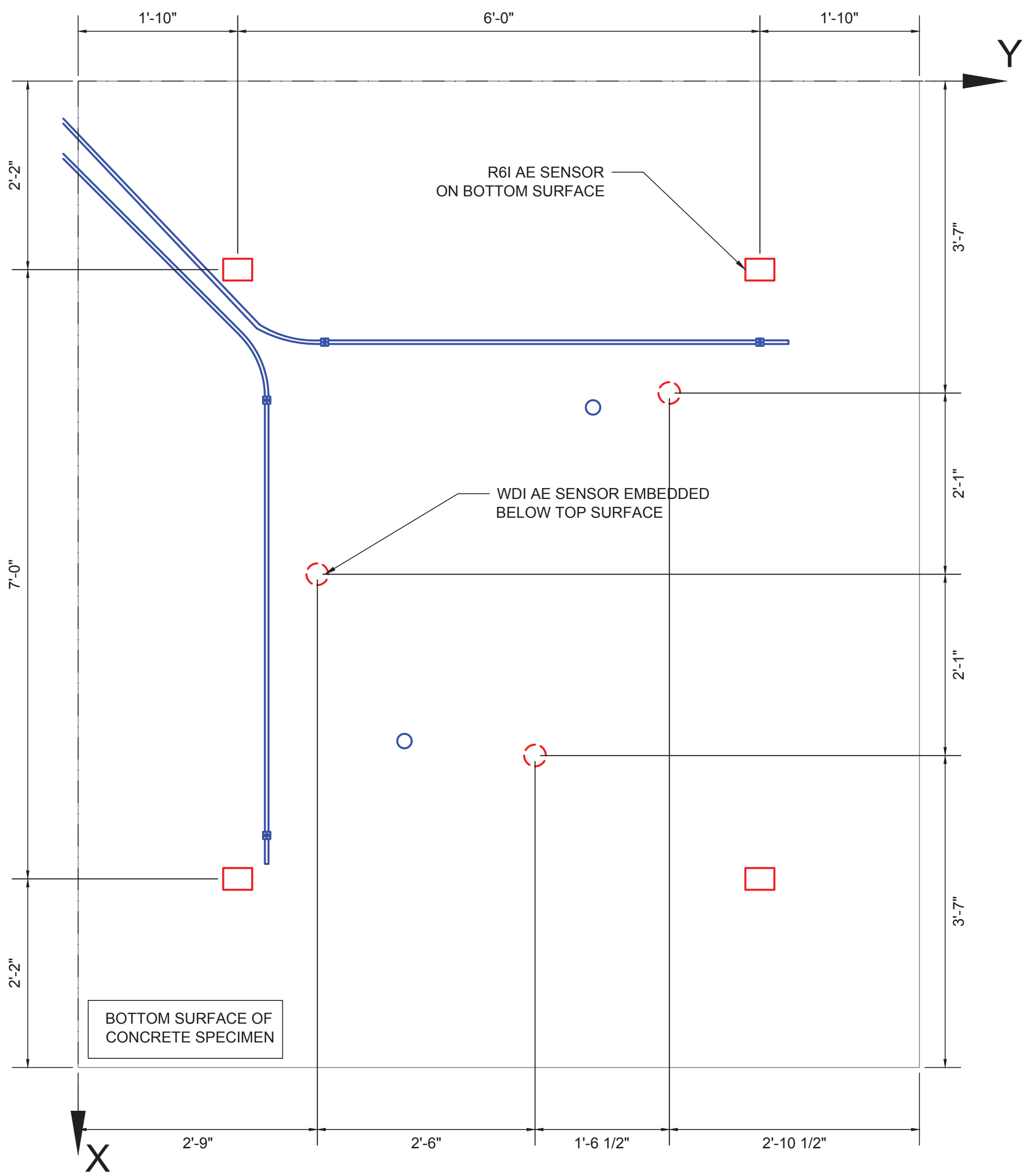
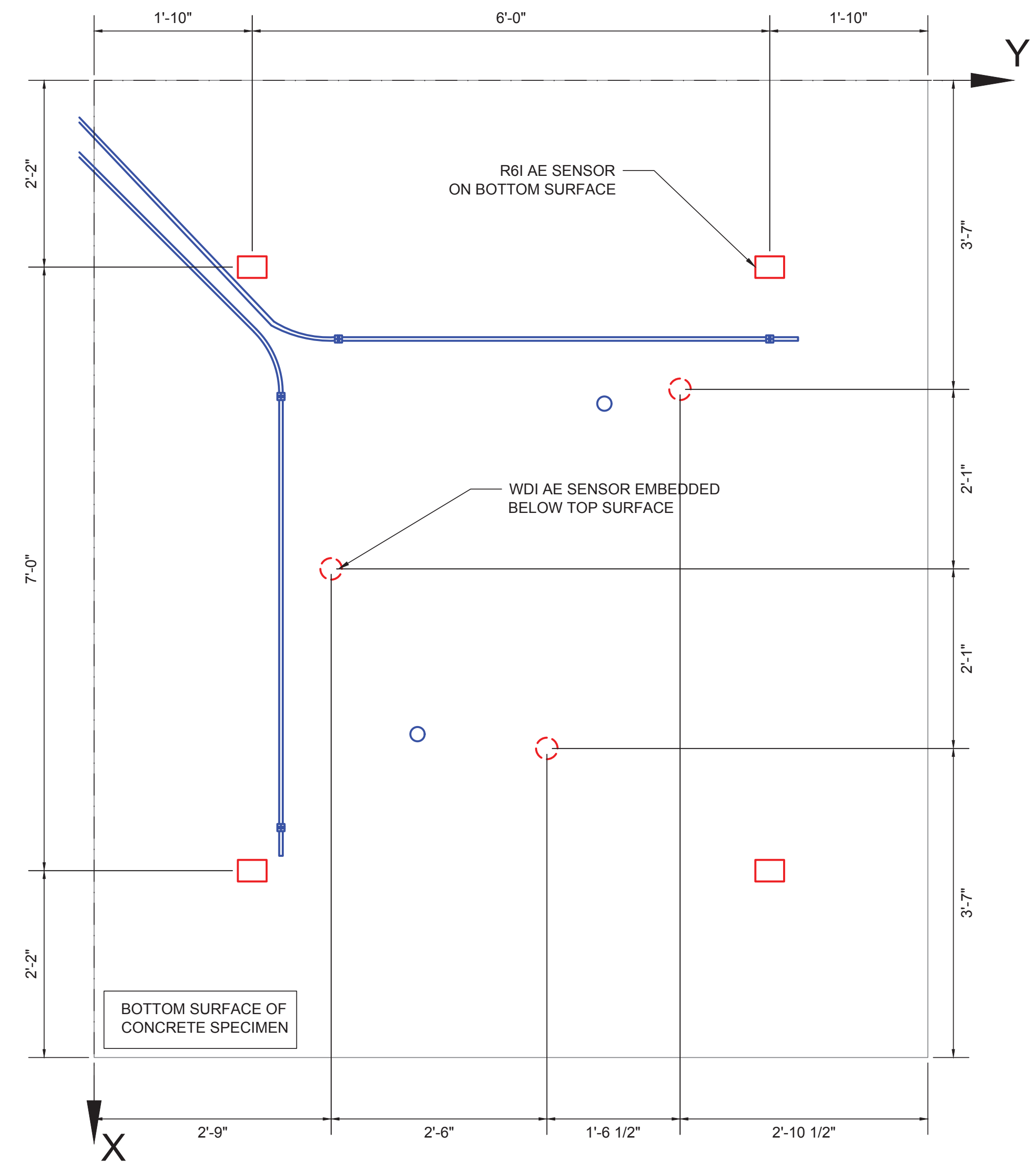
T3.2



1 / T3.3 — AE SENSORS - SPECIMEN 1

SCALE: 1" = 1'-0"



2 / T3.3 — AE SENSORS - SPECIMEN 2

SCALE: 1" = 1'-0"

DESIGNED BY:

DRAWN BY: NWH

CHECKED BY:

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BOTTOM SURFACE AE INSTRUMENTATION

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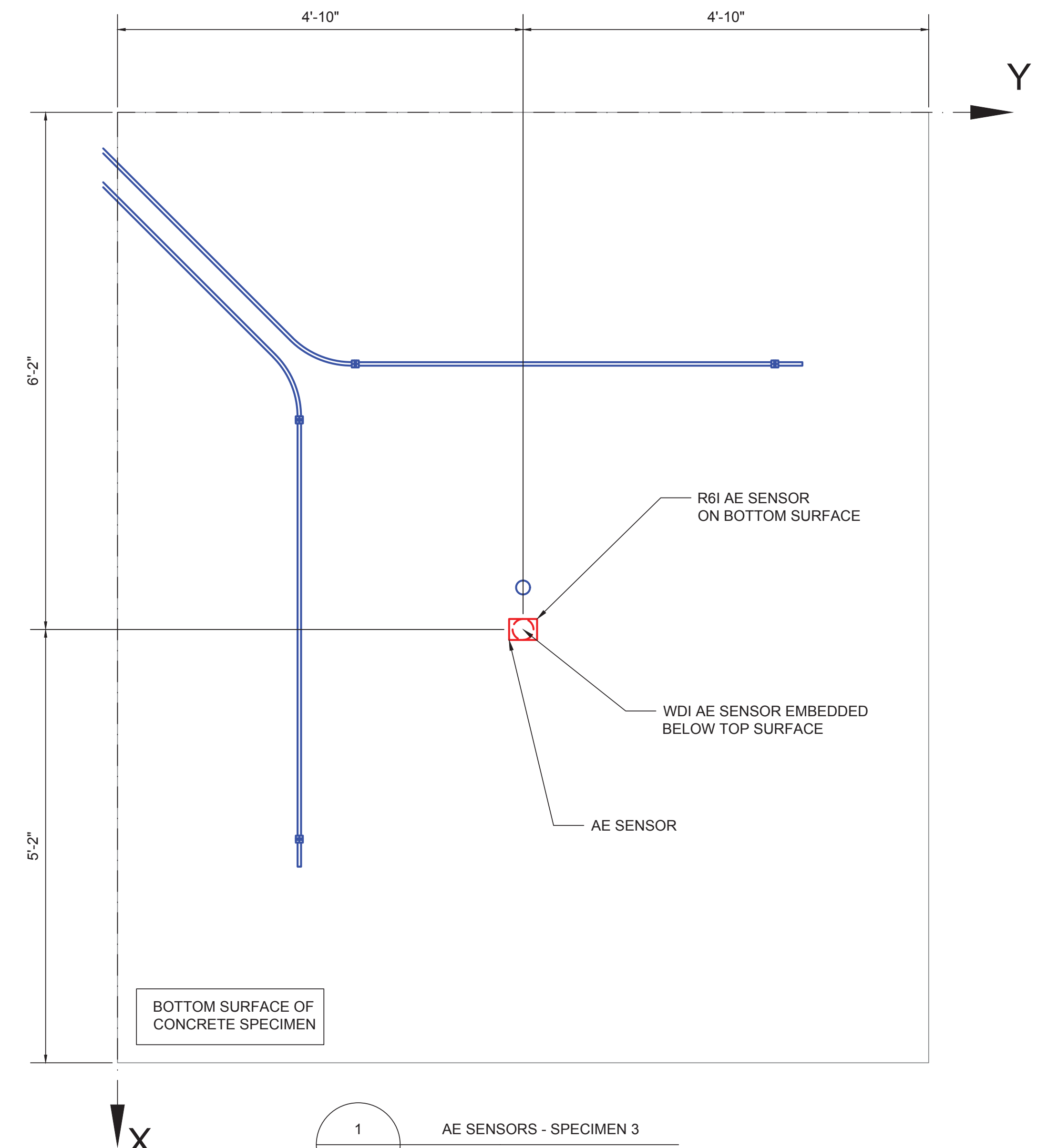
T3.3



1 / T3.4 AE SENSORS - SPECIMEN 3

SCALE: 1" = 1'-0"

DESIGNED BY:
DRAWN BY: NWH
CHECKED BY:

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BOTTOM SURFACE AE INSTRUMENTATION

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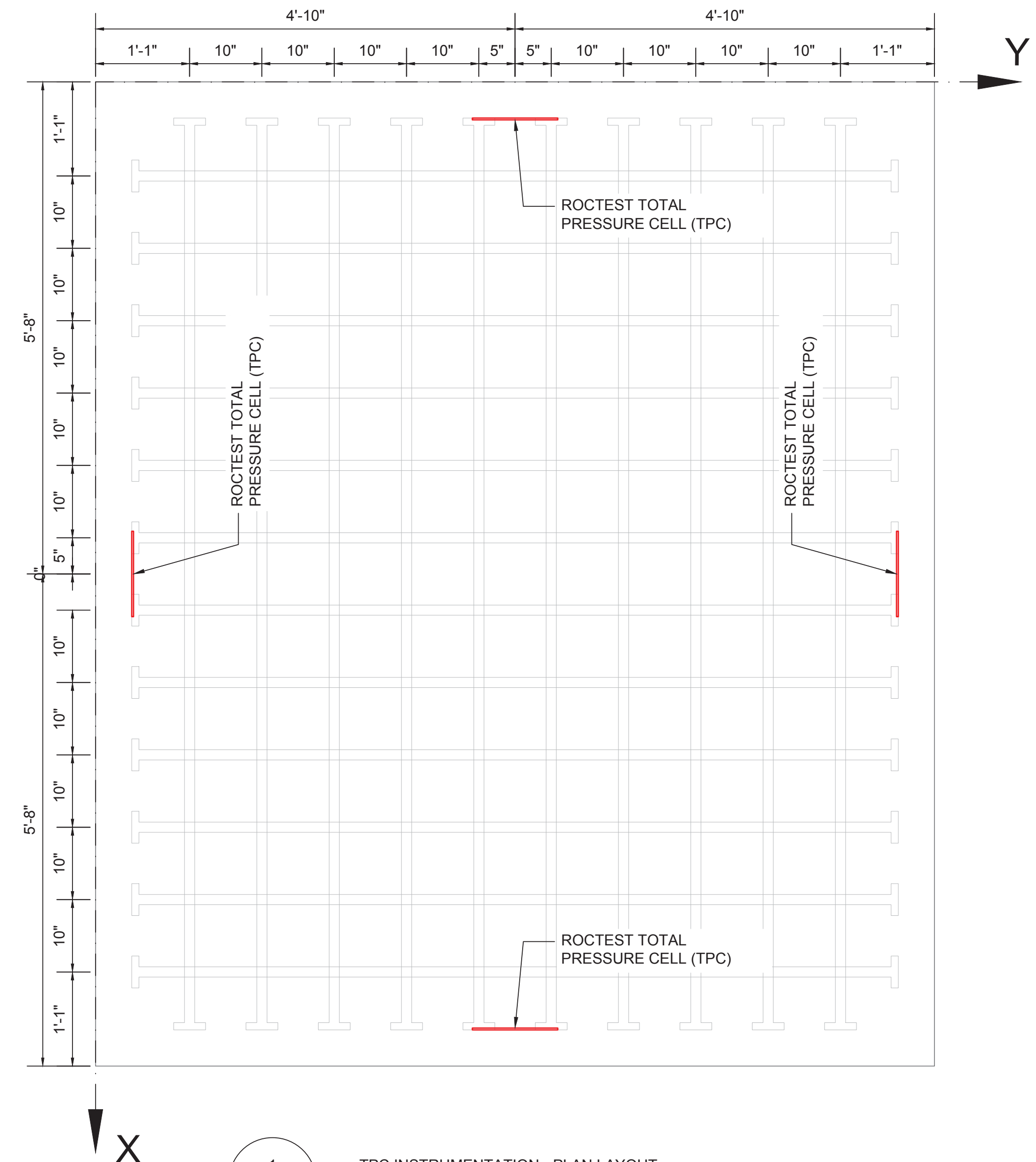
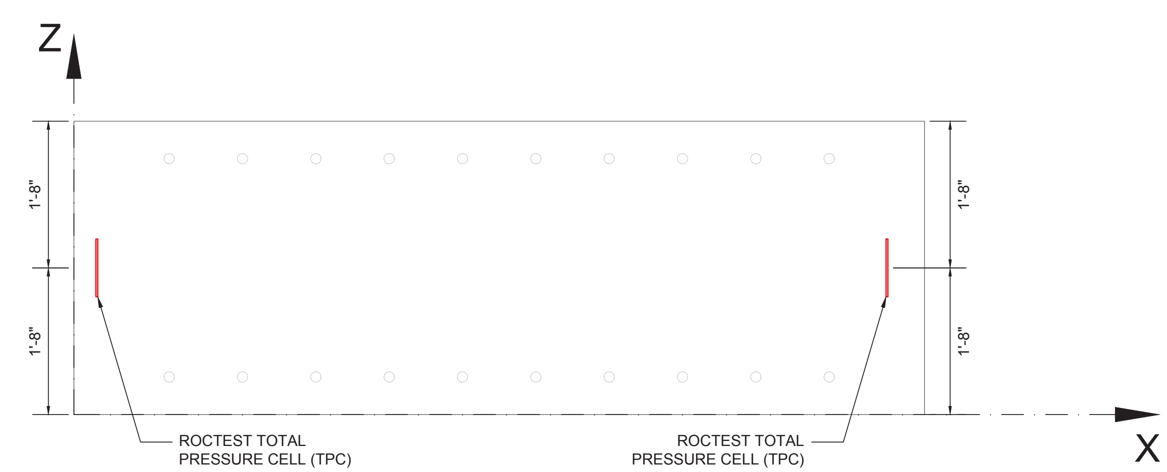
0000

T3.4



1 / T4.1 — TPC INSTRUMENTATION - PLAN LAYOUT

SCALE: 1" = 1'-0"



2 / T4.1 — TPC INSTRUMENTATION - ELEVATION LAYOUT

SCALE: 1" = 1'-0"

DESIGNED BY:

DRAWN BY: NWH

CHECKED BY:

ASR RESEARCH

TPC INSTRUMENTATION LAYOUT

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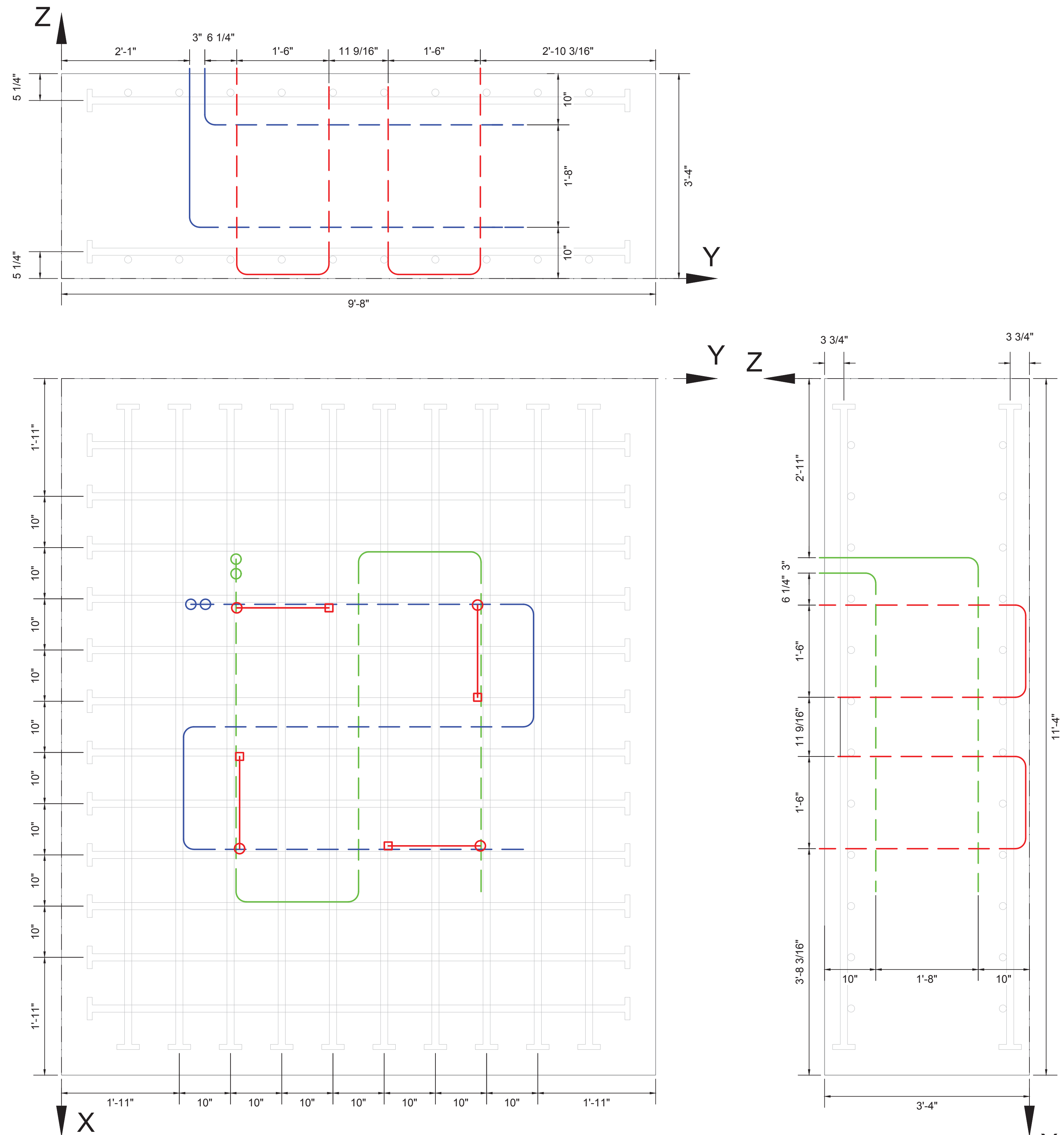
T4.1



1
T5.1

EMBEDDED DISTRIBUTED FIBER OPTIC LAYOUT
SCALE: 1" = 1'-0"

DESIGNED BY:
DRAWN BY: RL, NWH
CHECKED BY:

ASR RESEARCH
EMBEDDED DISTRIBUTED FIBER OPTIC

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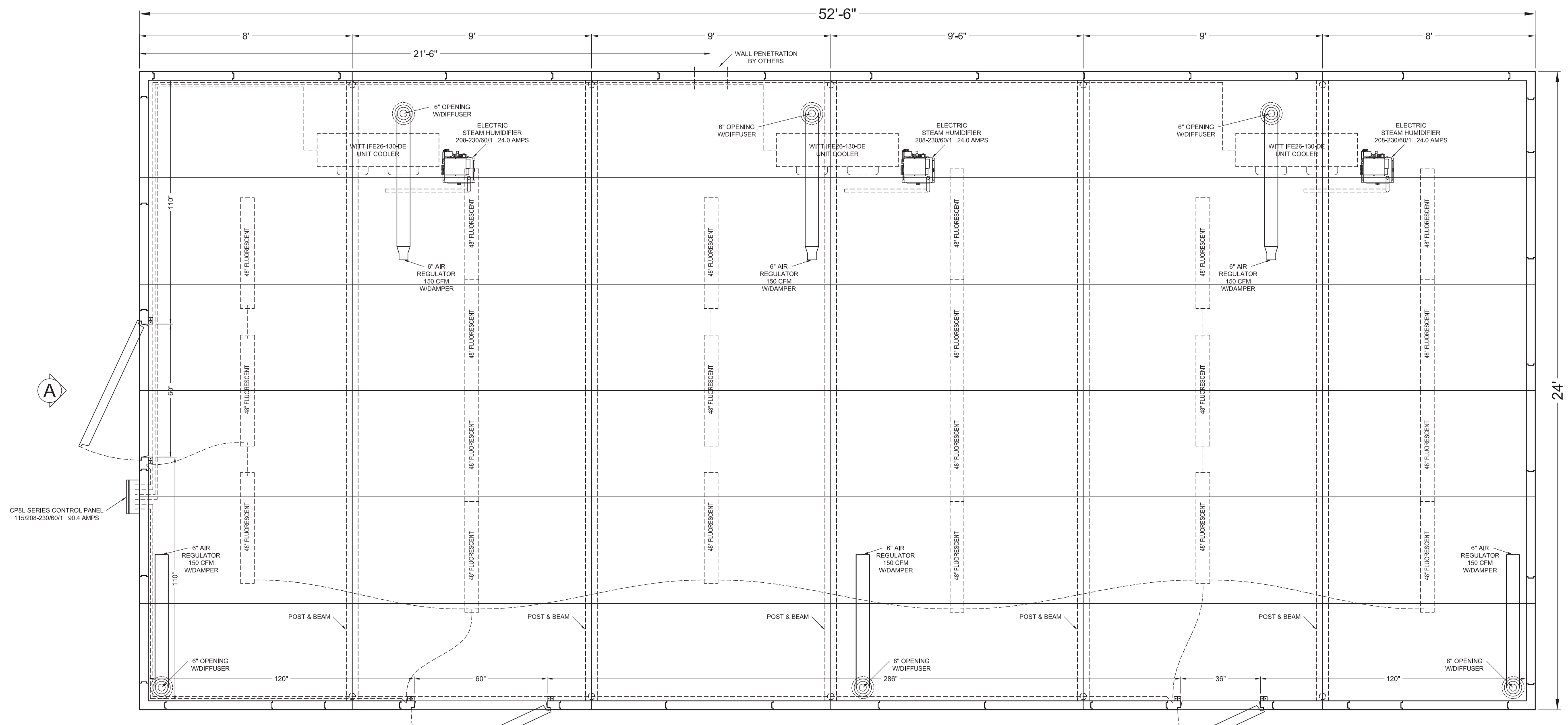
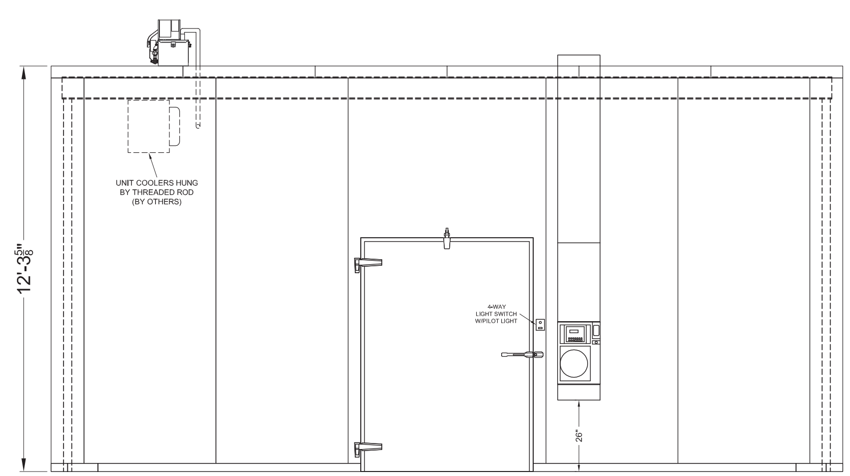
T5.1



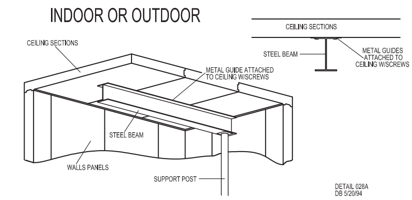
100°F/95% R.H. WARM ROOM

Less Floor
With Vinyl Floor Sealers

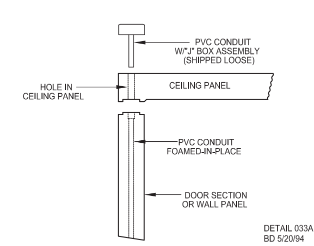


VIEW -A-

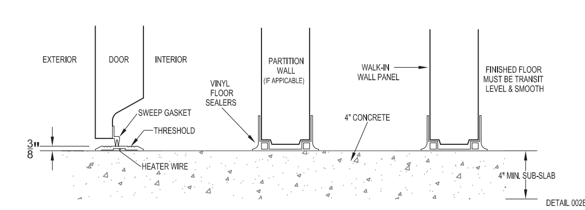
INDOOR OR OUTDOOR



INTERNAL STEEL BEAM



CONCEALED THROUGH PANEL ELECTRICAL DETAIL



VINYL FLOOR SEALERS ON TOP OF UNINSULATED FLOOR SLAB ON GRADE

SPECIFICATIONS (D27754A Quote Number NL1634888GA-B)

Nor-Lake is registered by UL to ISO 9001-2008. California State Contractor License #940932.
(1) Nor-Lake ENVIROLINE 4.0 Walk-In Cooler
Size: 52'6" long, 24'0" wide, 12'3 5/8" high
Finishes:
26 Gauge Corrosion Resistant Stucco Embossed Coated Steel - Interior wall, Exterior wall, Interior ceiling
26 Gauge Smooth Galvanized - Ceiling topside
1" Vinyl Floor Sealer for (1) Warm Room 100° F/95% R.H.

(1) 60" X 84" Walk-In Door left-hand swing
Includes door closer, cam lift hinges (one spring loaded), NL9800 deadbolt key/padlock handle with inside release, magnetic gasket, double sweep gasket & switch with pilot light.
(1) Four Way Light Switch With Pilot Light
(1) Door Through Panel Electrical; All Conduit Concealed Inside The Door Frame, Hole Pre-Drilled Through Ceiling And Field Installed Ceiling Mounted Junction Box With Conduit Provided

(1) 60" X 84" Walk-In Door right-hand swing
Includes door closer, cam lift hinges (one spring loaded), NL9800 deadbolt key/padlock handle with inside release, magnetic gasket, double sweep gasket & switch with pilot light.
(1) Three Way Light Switch With Pilot Light
(1) Door Through Panel Electrical; All Conduit Concealed Inside The Door Frame, Hole Pre-Drilled Through Ceiling And Field Installed Ceiling Mounted Junction Box With Conduit Provided

(1) 36" X 84" Walk-In Door right-hand swing
Includes door closer, cam lift hinges (one spring loaded), NL9800 deadbolt key/padlock handle with inside release, magnetic gasket, double sweep gasket & switch with pilot light.
(1) Three Way Light Switch With Pilot Light
(1) Door Through Panel Electrical; All Conduit Concealed Inside The Door Frame, Hole Pre-Drilled Through Ceiling And Field Installed Ceiling Mounted Junction Box With Conduit Provided

(21) 48" Fluorescent, Vapor-Proof, Warm Room Light Fixture With T5 Bulbs And Electronic Ballast (Shipped Loose) 149449
(3) 6" Diameter x 5' Insulated Supply Pipe For Vent And Duct Air System With Elbow, Diffuser And Ceiling Opening (one to be located behind each of the unit coolers for air circulation)
(3) 6" Diameter x 5' Insulated Exhaust Pipe For Vent And Duct Air System With Elbow, Diffuser And Ceiling Opening
(6) Motorized Damper 6" Diameter (to be wired to the cooling relay)
(6) 6" Air Regulator 150CFM On Exhaust/Supply End
(5) Beam W8x18 With (2) Posts For Indoor Use

(1) Model CP8L Series Control Panel, U.L. Approved. CP8L Microprocessor Based Programmable Temperature Controller, Liquid Crystal Alphanumeric Display with 4x20 Character, Humidity Display, Simultaneous Product and Air Temp. Display, System Mode Indicator, High/Low Audio/Visual Alarm with Dry Contacts, System Over/Under Temp Safety Shutdown, Power Failure Alarm, Service Prompts, Password Entry System and Expandable for Communication Ports and Light Control. Key Locked Door with Viewing Cover, Circuit Breakers and 10" Temperature/Humidity Chart Recorder.
(1) Dixell XR30C Controller for High Limit Safety Shut Down

(3) Electric Steam Humidifier (Unducted); 5 KW@ 208-230/60/1 (Note:"The humidifier requires a water source with low mineral content; i.e., resistance of 0.05 - 1.0 megohm and a pressure of 10–100 psi. Reverse osmosis treated water is Recommended.")

(3) IFE26-130DE Unit Coolers for Heat and Air Circulation
Calculated load for 100° F/95% R.H. is calculated from 50° F/50% R.H. ambient, 70° F floor temperature (uninsulated floor), (1) 36" x 84" walk-in door and (2) 60" x 84" walk in doors opening into 50° to 80° F ambient, no air vent, no people working in the room, and no additional electrical load. All calculations are based on data supplied by ASHRAE publications.

Refrigeration is "sized" for holding product only; that is, our calculation is based on product entering at the same temperature as the desired temperature of this walk-in. If you feel that this is insufficient, please advise.

Construction Approvals: cULus and CSA Electrical, UL Flame Spread-25 and ULC Flame Spread-50 in accordance with ASTME-84. NOTE: Indoor walk-in must be in an environmentally controlled space. Relative Humidity should be kept between 30%-60%, maintaining a Dew Point of 50° F or less.

Quotation is subject to change upon receipt of detailed specifications and/or refrigeration load information.

*** Clarifications ***
* Price does not include taxes, bonding, shelving, freight charges, or installation. Freight charges are included on an E-mail.
* The panel seams must be sealed with silicone during installation
* No refrigeration systems are included. Cooling is provided by ambient air around the room.
* Temperature uniformity is +/- 3° F at the control sensor in lieu of +/- 2° F
* Humidity accuracy is +/- 5% R.H. at the control sensor
* Nor-Lake insurance and warranties per the enclosed attachments
* Contractor is responsible for field verification
* The following warranties: 18 month parts and labor, 15 year walk-in panel
* Nor-Lake bid is based upon the E-mail received on 12/1/15 only. Other Documents will be reviewed and their cost implications evaluated when these documents are sent to Nor-Lake for review. No addenda have been received. Revision B is based on the E-mail received on 12/15/15.
* Due to possible discrepancies, errors or omissions in the plans and specifications, only the items, sizes, and parameters noted on the individual room quotations are included in the Nor-Lake bid. The Nor-Lake quotation supersedes all other documents.
* Nor Lake rooms offer a +/- 3° F temperature uniformity at the control sensor

NORLAKE, SCIENTIFIC
-SINCE 1947-
727 SECOND STREET, HUDSON, WI. 54016
(715) 386-2323 or (866)
A STANDEX COMPANY

N.S.F. FOAMED-IN-PLACE
ENVIROLINE WALK-IN
WARM ROOM LESS FLOOR
VINYL FLOOR SEALERS

52'6"x24'0"x12'3 5/8"

CUSTOMER:
UTK ENVIRONMENTAL CHAMBER

PROJECT:

A MINIMUM OF 2" CLEARANCE MUST BE ALLOWED AT ANY POINT WHERE THE WALK-IN IS ERECTED NEXT TO AN EXISTING BUILDING WALL.

ALL PANELS ARE FOAMED-IN-PLACE WITH HFC 245fa, CFC FREE POLYURETHANE INSULATION, ZERO OZONE-DEPLETION.

NOTE: INDOOR WALK-IN(S) MUST BE IN AN ENVIRONMENTALLY CONTROLLED SPACE. RELATIVE HUMIDITY SHOULD BE KEPT BETWEEN 30% - 60%, MAINTAINING A DEW POINT OF 50°F OR LESS.

PLEASE RETURN THE APPROVED DRAWINGS AS SOON AS POSSIBLE TO PREVENT ANY DELAY IN FABRICATION.

☐ **APPROVED**
☐ **APPROVED AS NOTED**
☐ **NOT APPROVED-RESUBMIT**

SIGNED ____________

DATE ____________

* * *

IMPORTANT:
CHANGES MADE AFTER THE PRINT APPROVAL MAY INVOLVE ADDITIONAL CHARGES AND THE POSSIBILITY OF A REVISED SHIPPING DATE

NO.	DATE	BY
A	5/11/16	B.R.D.

DATE: 4/1/16
SCALE: 3/8" = 1'
DRN. BY: B.R.D.
MSR APP
APP. BY:

D27754A