Sensor Network Demonstration for In Situ Decommissioning – 13332

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ABSTRACT

Florida International University's (FIU's) Applied Research Center is currently supporting the Department of Energy's (DOE) Environmental Management Office of D&D and Facility Engineering program. FIU is supporting DOE's initiative to improve safety, reduce technical risks, and limit uncertainty within D&D operations by identifying technologies suitable to meet specific facility D&D requirements, assessing the readiness of those technologies for field deployment, and conducting feasibility studies and large scale demonstrations of promising technologies. During FY11, FIU collaborated with Savannah River National Laboratory in the development of an experimental test site for the demonstration of multiple sensor systems for potential use in the in situ decommissioning process.

In situ decommissioning is a process in which the above ground portion of a facility is dismantled and removed, and the underground portion is filled with a cementious material such as grout. In such a scenario, the question remains on how to effectively monitor the structural health of the grout (cracking, flexing, and sinking), as well as track possible migration of contaminants within and out of the grouted monolith. The right types of sensors can aid personnel in better understanding the conditions within the entombed structure. Without sensors embedded in and around the monolith, it will be very difficult to estimate structural integrity and contaminant transport. Yet, to fully utilize the appropriate sensors and the provided data, their performance and reliability must be evaluated outside a laboratory setting. To this end, a large scale experimental setup and demonstration was conducted at FIU.

In order to evaluate a large suite of sensor systems, FIU personnel designed and purchased a pre-cast concrete open-top cube, which served as a mock-up of an in situ DOE decommissioned facility. The inside of the cube measures 10 ft x 10 ft x 8 ft. In order to ensure that the individual sensors would be immobilized during the grout pouring activities, a set of nine sensor racks were designed. The 270 sensors provided by Idaho National Laboratory (INL), Mississippi State University (MSU), University of Houston (UH), and University of South Carolina (USC) were secured to these racks based on predetermined locations. Once sensor racks were installed inside the test cube, connected and debugged, approximately 32 cubic yards of special grout material was used to entomb the sensors. MSU provided and demonstrated four types of fiber loop ringdown (FLR) sensors for detection of water, temperature, cracks, and movement of fluids. INL provided and demonstrated time differenced 3D electrical resistivity tomography (ERT), advanced tensiometers for moisture content, and thermocouples for temperature measurements. University of Houston provided smart aggregate (SA) sensors, which detect crack severity and water presence. An additional UH sensor system demonstrated was a Fiber Bragg Grating (FBG) fiber optic system measuring strain, presence of water, and temperature. USC provided a system which measured acoustic emissions during cracking, as well as temperature and pH sensors. All systems were connected to a Sensor Remote Access System (SRAS) data networking and collection system designed,

developed and provided by FIU. The purpose of SRAS was to collect and allow download of the raw sensor data from all the sensor system, as well as allow upload of the processed data and any analysis reports and graphs. All this information was made available to the research teams via the Deactivation and Decommissioning Knowledge Management and Information Tool (D&D KM-IT). As a current research effort, FIU is performing an energy analysis, and transferring several sensor systems to a Photovoltaic (PV) System to continuously monitor energy consumption parameters and overall power demands. Also, One final component of this research is focusing on developing an integrated data network to capture, log and analyze sensor system data in near real time from a single interface.

FIU personnel and DOE Fellows monitored the progress and condition of the sensors for a period of six months. During this time, the sensors recorded data pertaining to strain, compression, temperature, crack detection, moisture presence, fluid mobility, shock resistance, monolith movement, and electrical resistivity. In addition, FIU regularly observed the curing process of the grout and documented the cube condition via the nine racks of sensors. The sensors held up throughout the curing process, withstood the natural elements for six months, and monitored the integrity of the grout. The large scale experiment and demonstration conducted at FIU was the first of its kind to demonstrate the feasibility of state of the art sensors for in situ decommissioning applications. These efforts successfully measured the durability, performance, and precision of the sensors in question as well as monitored and recorded the curing process of the selected grout material under natural environmental conditions. The current energy analysis work is resulting in data on the constraints placed by some of the sensor systems on a power network that requires high reliability and low losses. In addition, a sensor system demonstration has determined that it is feasible to develop an integrated data network where data can be accessed in near real-time from all systems, thereby allowing for larger-scale integrated system testing to be performed. Information collected during the execution of this research project will aid decision makers in the identification of sensors to be used in nuclear facilities selected for in situ decommissioning.

INTRODUCTION

The U.S. Department of Energy has set a goal to reduce its footprint at various DOE sites, and has therefore identified many reactor buildings at Savannah River Site (SRS) for decommissioning. As an alternative to the traditional decontamination/disassembly/transport and disposal process, DOE is electing to utilize an *in-situ* Decommissioning (ISD) method as a way to safely trap contaminant and significantly reduce costs [1]. DOE has identified several reactor and process buildings that could be prime candidates for ISD. This process would permanently entomb a portion of a structure, or the entire structure, with its contaminants. These contaminants would be bound to the structure via a grout material that used to fill voids in the entombed structure. Several variations of the ISD exist that depend on the structure to decommission and the risks associated with the process and final form. One such approach involves removal of all above-ground portions of the structure, and the filling of all below grade areas with cementitious materials (i.e. grout). This specific approach was successfully implemented at INL with the Loss of Fluid Test Facility, and will be implemented at SRNL as part of several reactor decommissioning processes.

In order to ensure that such a entombed structure maintains the proper "health" to trap contaminants and mitigate water/fluid migration, a complex sensor network must be deployed that can survive the rigors of a grout filling operation, and continuously monitor the structure reliably for many years. Many of the sensors applicable to such a deployment have been developed, and exist at various technology readiness levels. Applicable technologies such as Electrical Resistance/Impedance Tomography (ERT) and Acoustic Emissions (AE) technology have been field-tested in large-scale environments, such as remediation sites [2] and aircrafts [3]. Other technologies, such as novel fiber-optic methods like FLR and FBG, are at varying stages of development; larger-scale testing of these technologies would assist in determining engineering challenges to address prior to full-scale deployment. The focus of this effort was to evaluate such promising sensor technology in an integrated operational scenario beyond the laboratory scale.

EXPERIMENTAL DESIGN

The main purpose of this effort was to evaluate performance and limitations of these sensor systems for their future use in monitoring as part of the ISD process. In order to evaluate a multitude of sensors in a single application environment, FIU worked on the design of a meso-scale testbed (MSTB) that could be embedded with various sensor technologies, and that would allow the sensor Principal Investigators (PI) to install and configure their systems prior to grouting. Based on the input from SRNL and the sensor PIs [4], FIU designed a MSTB that achieved those operational goals. The design and strategy for testing consisted of (1) a set of panels where the PIs would install and calibrate their sensor; (2) the panels would be transported to an open-top cube for placement and wiring; (3) the grout would be poured into the cube while the systems monitor the process; and (4) the sensors would monitor continuously for the next three months. The design, strategy and all the relevant aspects are described in detail below.

Sensor Systems

In order to maximize the knowledge gained from this test bed, a total of 270 sensors were located within the MSTB. This experiment utilized a range of sensors including Electrical Resistivity Tomography, Advanced Tensiometers, Piezoelectric Sensors, and Fiber Optic Sensors (ERT, AT, PES, FOS) to measure parameters such as strain, crack detention, corrosion, fluid mobility, moisture presence and temperature. These sensors were placed in coordinated locations within – and around- the volume of the MSTB in order to minimize interference between sensor systems. Several sensors that measured the same parameter, but utilized different approaches, were located near each other to compare datasets. Principal Investigators from Idaho National Laboratory (INL), Mississippi State University (MSU), University of Houston (UH), and University of South Carolina (USC) provided the sensors, installed them on FIU-developed sensor panels, and provided the necessary hardware/software for evaluating the performance of these sensors once embedded in the test bed.

Sensor Panels

FIU-ARC designed and constructed nine custom panels to support the 270 sensors that would be embedded in the MSTB. The panels were constructed from fiberglass reinforced plastic (FRP) rods and bars. The panels and associated dimensions are shown in Figure 1. A C3x4.1, 10.5-foot long steel C-channel was used at the top of the panel to support the combined weight of all the sensors, and was also used to provide structural support and bracing during grout pouring operations (Figure 2). Four of the panels had a 1-inch PVC water pipe attached to provide ports for future fluid injection and migration studies. The water pipe lengths varied from 2-foot to 6-

foot to allow for water injection near the location of appropriate sensors that could monitor such a condition. In addition, mobile panel racks were constructed of metal framing in order to house the sensor panels during sensor installation and subsequent storage prior to MSTB deployment.

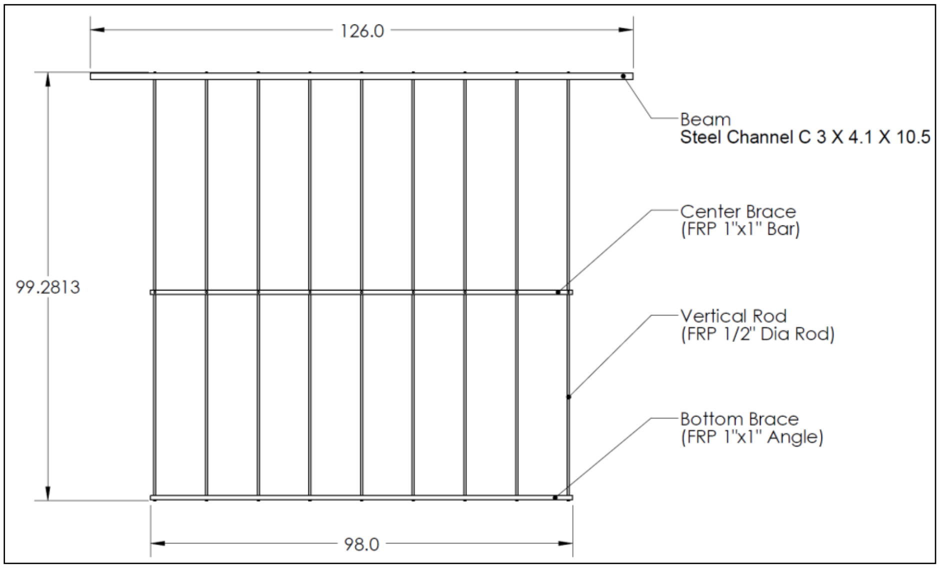


Figure 1. Typical Sensor Panel

Figure 2. Sensor Installed on Panels. As designed, many sensor PIs had to install sensors on multiple panels in order to have a sensing grid throughout the cube volume.

Test Area and Cube

The test area for the MSTB was located on the of FIU’s Engineering Center located in Miami, Florida. The test area is approximately 1,157 square feet and is covered with a 5-inch layer of gravel. The water table in the selected area averages between 4 to 10 feet below ground, thereby minimizing any flooding of the test cube during South Florida's rainy season. The test area is secured with a perimeter fence and several access gates for material delivery and egress. Utilities such as electricity, water, outdoor lighting, and internet, were also provided as part of the MSTB development and construction. Figure 3 shows the test area layout, which identified the test cube and portable container. These structures are described in the sections to follow.

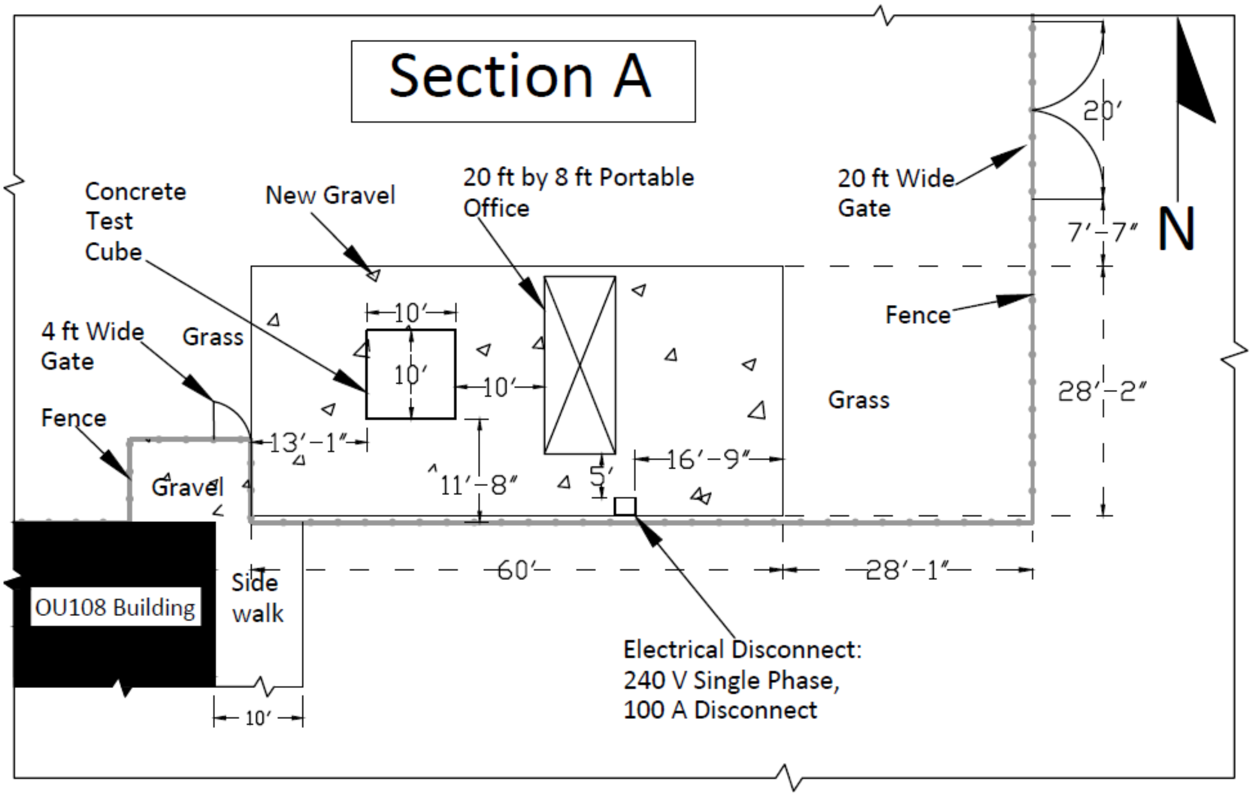


Figure 3. Section A – Details of Test Area Layout

The test cube is a custom-built, re-enforced open top concrete box with 10 ft x 10 ft x 8 ft interior dimensions, and with a wall/base thickness of 8 inches. The isometric and top views of the cube are shown in Figure 4 and Figure 5. The cube was designed to support the overall load of the grout material and the loaded sensor racks. In order to address possible health and safety hazards during the sensor panel installation and sensor system wiring, the cube was placed 4-feet into the ground. This allowed Sensor PIs and FIU to route and configure wiring at ground level. Figure 6 provide details of the installed cube including the inside and outside dimensions, rebar, mesh and concrete of the structure. Figure 7 provides images of the construction and installation process of the test bed.

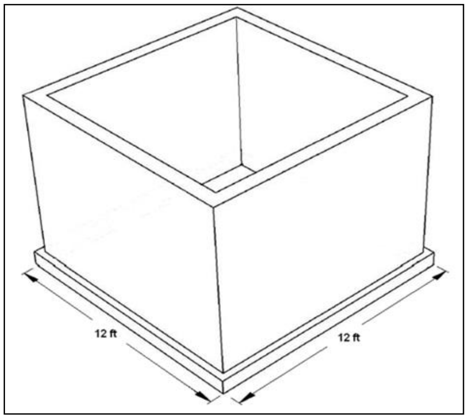


Figure 4. Test Cube Angle View

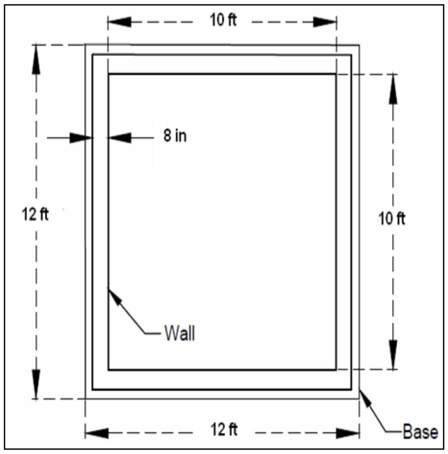
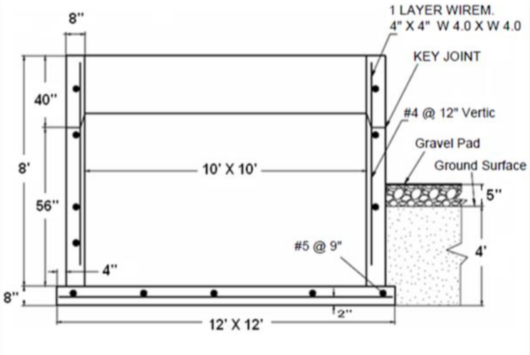


Figure 5. Test Cube Top View



REBAR: GRADE 60

W.W. MESH: 90KSI

CONCRETE: 4,000 PSI @ 28 DAYS

Figure 6. Test Cube Cross Section

Figure 7. Installation of Cube

Sensor System Stations

FIU-ARC utilized a portable office container to provide a temperature and humidity-controlled environment where the sensor systems' data acqusition and control modules could be housed during the grout pouring and monitoring phase. Figure 8 and Figure 9 show the exterior and interior of the office container. The portable office container is a modified 20-foot ISO container that was placed on the gravel pad, and wired for electrical and network service. The container interior provides an office layout with electrical ditribution, HVAC and workspaces. The container also includes a 36-inch access door, and four windows with security bars. Two of the windows were utilized to route all sensor system cabling into the container.

Figure 8. Office Container installed in Test Area.

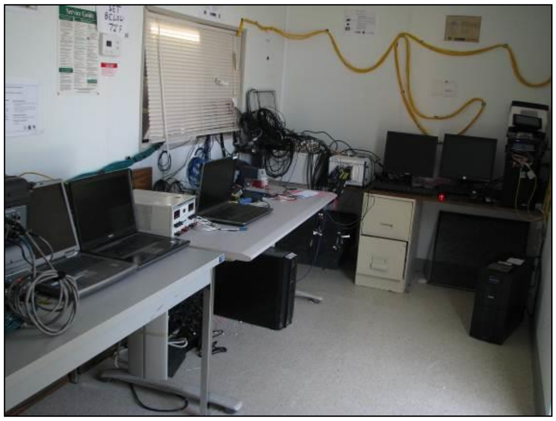


Figure 9. Interior space for office container with sensor systems equipment.

Cable Management

Several windows of the container were used as access ports to route sensor system cabling from the individual transducers to the acquisition & control modules. The cables from all the transducers located in the test cube were routed through 8, 3-inch PVC pipes that were mounted at a 4-foot elevation from ground (Figure 10). These pipes were secured on a unistrut structure located on the test cube, and on an additional unistrut assembly midway between the cube and the office container. The eight pipes were distributed in sets of 4 per each container window, which provided sufficient volume to feed all transducer cables into the container and near the individual sensor system stations.

Figure 10. Cable routing system installed between test cube structure and office container.

Ambient Conditions Monitoring

FIU installed and configured a weather station near the test cube (Figure 11). The weather station is located 3 meters above the ground level (i.e. total of 11 meters above sea level). The weather station is mounted on a 1-1/4 inch galvanized metal conduit, which is secured to the office container using two u-bolts attached to the container corners. Electrical grounding of the weather station is achieved by bonding it to the ISO container (through 10-AWG wire), which utilizes the FIU Operation & Utility Building grounding system.

Figure 11. Weather station installed on the office container.

The station uses several capacitive and piezoelectric sensors to collect air temperature, relative humidity, barometric pressure, solar radiation, rain, and wind vector. The weather station (WeatherHawk 510) collected hourly data on these environmental parameters. The data is retrieved by a Labview®-based application running on a PC located in the office container.

Utilities

Electrical service is provided via a 240-VAC, 100-amp distribution panel located on the container. This electrical service is provided by an OU building service panel. Electrical grounding of the container structure and all electrical loads is connected to the electrode-ring grounding system deployed at OU. The sensor network and associated systems will receive electrical energy from the local utility service. The wiring for all sensor systems will be distributed via two 20A circuits labeled as L1 and L2, from each leg of the 240 V service. L1 will feed power to Idaho National Laboratory's ERT system, Mississippi State University's FBRL, and FIU-ARC's PC and network support equipment. L2 is designated to provide power to South Carolina University's AE and University of Houston's sensors systems. These circuits are designed with the purpose of balancing the load powers to maintain both circuits operating well below their rated service capability. In order to address possible transient outages, or waveform disruptions, four uninterruptible power supplies (UPS) were utilized as short-term backup systems. The UPS were deployed to handle either several combined systems, or individual sensor systems. The distribution of the UPS are provided in the Table 1 below.

Table 1. Energy Consumption Required for Operation

	UPS #1	UPS #2	UPS #3	UPS #4
Sensor System #1	INL	UH	MSU	FIU
Sensor System #2		USC	-----	-----
Total Power (W)	1020	1200	100	386

Table 2 describes the power and energy requirements for the expected loads by each sensor system provided by the principal investigators. The total is the sum of each category, the actual power input is corrected to account for transmission system losses, and the safety factor is an additional precaution calculated by multiplying the value obtained in the actual power by a factor of 1.25 to account for possible load power variations during operation.

Table 2: Energy Consumption Required for Operation

	Power Input [W]	Energy 1 hour [Wh]
INL	1020	1020
MSU	100	100
USC	256.78	256.78
UH (approx)	1440	1440
Workstation	300	300
Switch / Router	10.50	10.50
Weather	75	75
Total	3202.28	3202.28
Actual Power	3443.31	3443.31
Safety Factor (25%)	4304.13	4304.13

GROUT AND MONITOR DEMONSTRATION

Sensor PIs, in collaboration with FIU-ARC and SRNL attached and wired their sensors to the rack and performed an operational check prior to placing each sensor panel inside the test cube. Figure 12 shows the installation sequence of the panels into the cube. A forklift was used to transport the instrumented panels to the test cube. Once the panels were inserted into the cube, they were bolted onto the metal channel on the top of the cube, and rechecked by sensor PIs (Figure 13).

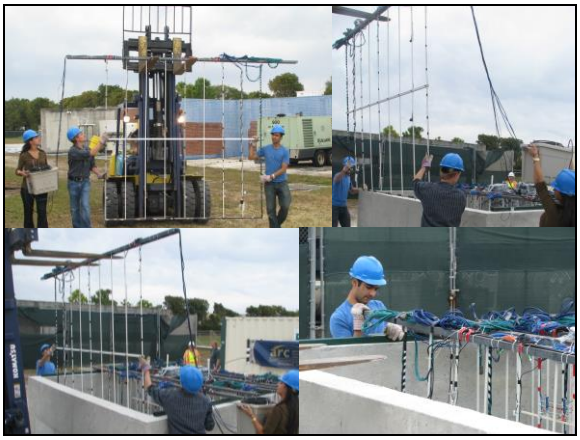


Figure 12. Panel installation

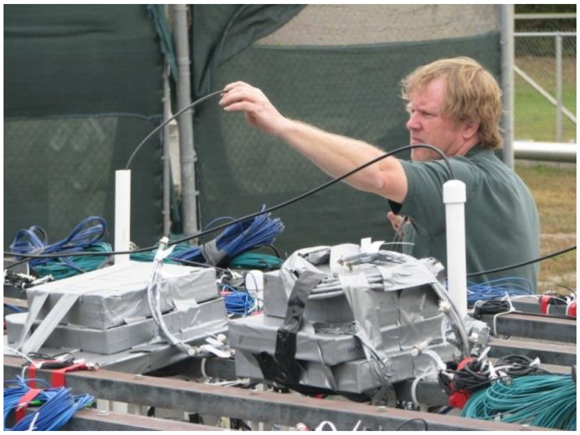


Figure 13. A PI from Idaho Nat. Lab Connecting/Testing Sensors

Once the sensor racks were installed inside the cube, the test cube was completely filled with a specially formulated grout on January 12th, 2012 (Table 3). Ambient weather conditions during placement were clear skies with no rain and limited humidity. The grout was pumped from bottom to top, and took about 4 hours to complete.

The grout was mixed and delivered by CEMEX and pumped by a local contractor, C&C Concrete Pumping, Inc. The average pumping pressure used to pump in the concrete was 1233 psig, the inside diameter of the pipe used was 5 inches. Grout installation took approximately 4 hours to complete. The grout installed was a special grout formulated by SRNL (Table 3). A total of 4 concrete trucks were delivered for the installation of the grout. Approximately 32 cubic yard of grout was delivered and pumped into the test cube. Excess water (Figure 21) from the cube was removed. Post inspections were completed daily; site conditions such as weather, surroundings, and any other irregularities are noted. There were 4 grout samples taken from each truck, filling 4 cylinders each, totaling 16 cylinders. A series of fresh quality assurance tests were done by FIU students on site at the time of pouring. These tests included flow cone and unit weight. These results are shown in Table 4.

Table 3: Grout Formulation

	Bulk Fill Grout With Gravel (lbs/cu yd)
Portland Cement	150
Fly Ash	500
Sand	1850
Pea Gravel (#8 stone)	800
Mix Water	415
Adva Cast 575 (oz/yd3)	39
VMAR 3 (oz/yd3)	275

Table 4: Grout Quality Analysis Test Results

Test	**Result**
Concrete Density	137.5 lbs/cft
Flow Test	17 inches
Air Content	1.10%

Figure 14 through Figure 16 depict the grout installation. A series of compressive strength tests (7, 14, and 28 day) were completed on the grout samples, as seen in Figure 17 below. The compressive strength of the grout steadily increased as expected, compressive streght values were not compare to any known values since this was a specially formulated grout developed by SRNL.

Figure 14. Grout Filling into Test Bed

Figure 15. Grout Pump

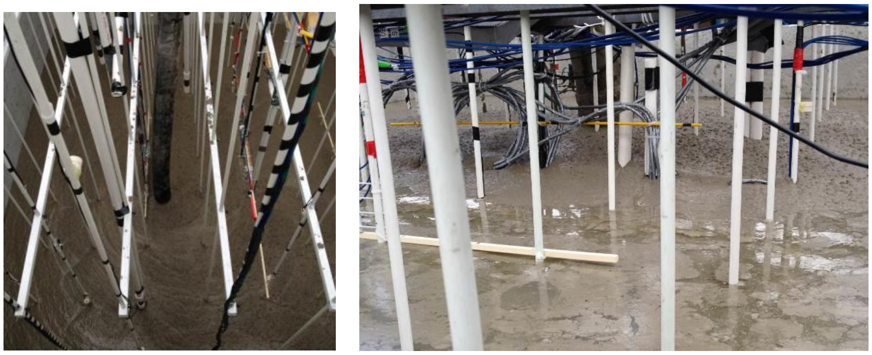


Figure 16. Grout Filling into Cube

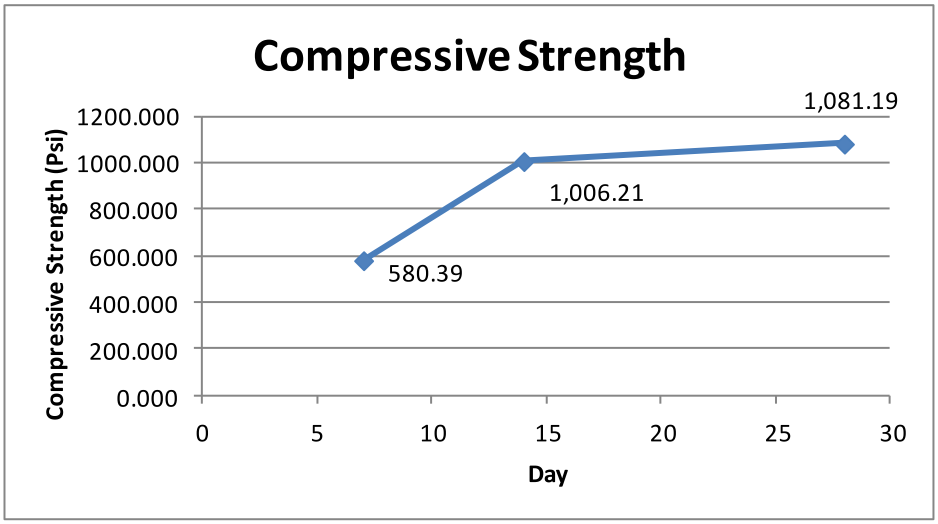
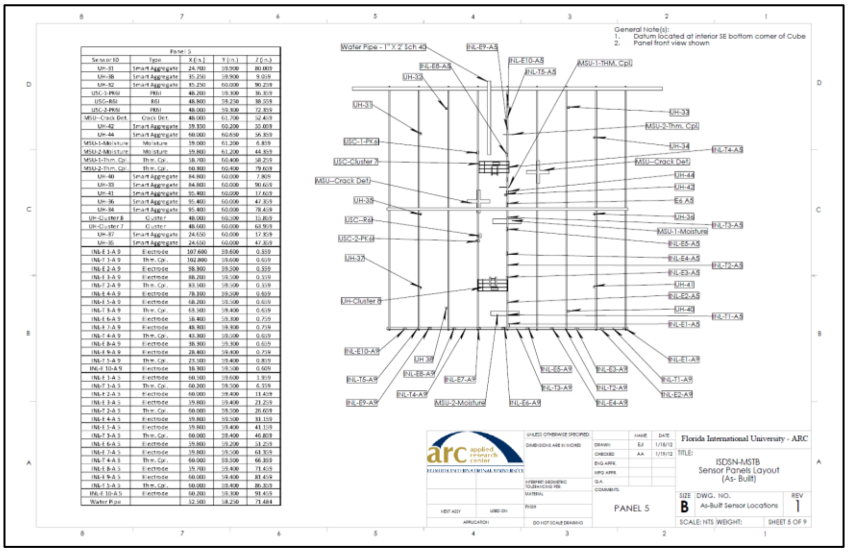


Figure 17. Compressive Strength

Sensor Installation and Operational Issues

Throughout the MSTB development and demonstration effort, several issues arose that could present deployment obstacles as such a monitoring system is attempted in a larger scale. One item that must be under consideration is the coordination of all technical and operational decisions between all involved parties. From sensor location selection to coordination of cable placement and routing, it is critical that all sensor systems are considered, and how system inadvertent interaction could influence overall performance. For example, the location of the ERT electrodes had to be coordinated with other sensor locations, due to the possible electromagnetic interference between systems during operation. In order to address this, sensor placement strategy was developed, and a meeting with all collaborators was dedicated to identify individual sensor locations. In addition, FIU developed a 3D CAD model of the entire cube structure with all relevant sensor locations (example shown in Figure 18) to ensure that any possible technical issues could be addressed prior to MSTB deployment and grouting.



Panel 5				
Sensor ID	Type	X (in.)	Y (in.)	Z (in.)
UH-31	Smart Aggregate	24.700	59.900	80.009
UH-38	Smart Aggregate	35.250	59.900	9.059
UH-32	Smart Aggregate	35.250	60.000	90.259
USC-1-PK6I	PK6I	48.200	59.300	36.359
USC--R6I	R6I	48.800	59.250	38.559
USC-2-PK6I	PK6I	48.000	59.300	72.359
MSU--Crack Det.	Crack Det.	48.000	61.700	52.459
UH-42	Smart Aggregate	59.350	60.200	55.059
UH-44	Smart Aggregate	60.000	60.650	56.359
MSU-1-Moisture	Moisture	59.000	61.200	6.859
MSU-2-Moisture	Moisture	59.800	61.200	44.359
MSU-1-Thm. Cpl.	Thm. Cpl.	58.700	60.400	58.259
MSU-2-Thm. Cpl.	Thm. Cpl.	60.900	60.400	79.659
UH-40	Smart Aggregate	84.800	60.000	7.809
UH-33	Smart Aggregate	84.800	60.000	90.659
UH-41	Smart Aggregate	95.400	60.000	17.659
UH-36	Smart Aggregate	95.400	60.000	47.359
UH-34	Smart Aggregate	95.400	60.000	78.459
UH-Cluster 8	Cluster	48.000	60.500	15.859
UH-Cluster 7	Cluster	48.600	60.000	63.959
UH-37	Smart Aggregate	24.650	60.000	17.359
UH-35	Smart Aggregate	24.650	60.000	47.359
INL-E 1-A 9	Electrode	107.600	59.600	0.559
INL-T 1-A 9	Thm. Cpl.	102.800	59.600	0.659
INL-E 2-A 9	Electrode	98.300	59.500	0.559
INL-E 3-A 9	Electrode	88.200	59.500	0.559
INL-T 2-A 9	Thm. Cpl.	83.500	59.500	0.559
INL-E 4-A 9	Electrode	78.100	59.500	0.659
INL-E 5-A 9	Electrode	68.200	59.500	0.659
INL-T 3-A 9	Thm. Cpl.	63.500	59.400	0.659
INL-E 6-A 9	Electrode	58.400	59.300	0.759
INL-E 7-A 9	Electrode	48.300	59.300	0.759
INL-T 4-A 9	Thm. Cpl.	43.300	59.500	0.659
INL-E 8-A 9	Electrode	38.300	59.300	0.659
INL-E 9-A 9	Electrode	28.400	59.400	0.759
INL-T 5-A 9	Thm. Cpl.	23.500	59.400	0.859
INL-E 10-A 9	Electrode	18.300	59.500	0.609
INL-E 1-A 5	Electrode	60.500	59.600	1.959
INL-T 1-A 5	Thm. Cpl.	60.200	59.500	6.559
INL-E 2-A 5	Electrode	60.000	59.400	11.459
INL-E 3-A 5	Electrode	59.800	59.400	21.259
INL-T 2-A 5	Thm. Cpl.	60.000	59.500	26.659
INL-E 4-A 5	Electrode	59.800	59.500	31.159
INL-E 5-A 5	Electrode	59.800	59.400	41.159
INL-T 3-A 5	Thm. Cpl.	60.000	59.400	46.859
INL-E 6-A 5	Electrode	59.800	59.200	51.259
INL-E 7-A 5	Electrode	59.800	59.500	61.359
INL-T 4-A 5	Thm. Cpl.	60.000	59.500	66.359
INL-E 8-A 5	Electrode	59.700	59.400	71.459
INL-E 9-A 5	Electrode	60.000	59.400	81.459
INL-T 5-A 5	Thm. Cpl.	60.000	59.400	86.359
INL-E 10-A 5	Electrode	60.200	59.300	91.459
Water Pipe		52.500	58.250	71.484

Figure 18. Front view of 3D CAD drawing identifying all sensor locations on Panel #5.

Another issue faced during sensor system installation was the sensor size and installation method utilized by the respective sensor PIs. Many different methods were used, and used items such as tape, epoxy and plastic ties, to bind the sensor on to the panel. These methods all exhibit varying levels of success, and will require careful consideration prior to selection of ultimate sensor locations within an ISD structure. Some of the sensor systems used in the MSTB required pre-deployment calibration, and required that power be continuously applied throughout the installation and deployment process. Depending on the number of sensors, as well as acquisition system size and energy demands, this can pose a technical challenge. For the MSTB sensor panel installation, this required that the system be transported to the test cube with all the necessary equipment connected, and with an uninterrupted power supply (UPS) to maintain the system energized.

One major issue during this demonstration was the management of the large number of cables that had to be routed, secured and fed into the respective sensor station for connection to acquisition systems. This required careful identification and labeling of all individual cables, as well as coordinated routing and wiring of sensor systems during deployment. One particular issue faced by cabling during grout pouring was the intrusion of water through several fiber-optic cable jackets. It was determined that the water was being forced through the jacket due to the hydrostatic pressure exerted by the grout on the cable, in conjunction with void spaces between the fiber and the jacket that allowed water to flow. This unexpected issue could have made a sensor system inoperable. There are several wireless sensor technologies that show promise to address such a challenge. For example, the Wireless Identification and Sensing Platform (WISP) was created by Intel Research Lab. It is a device that combines both RFID (wireless communication), computing (data transfer), and sensing. This WISP is a battery-less device, and a flexible platform that can add different sensors such as temperature, light, strain, and acceleration [5], but wireless sensors were not at a maturity level sufficient to test in this MSTB.

One final issue as part of this MSTB was the failure of several sensors upon the start of grout pouring. Although the sensors had been properly secured to the panels, and the sensor PIs attempted multiple methods to troubleshoot and repair the sensors, it was determined that the sensors had failed. This exemplifies the effects of the grouting process, and how the selected sensors must be sturdy and reliable enough to perform long-term monitoring, but must also survive the rigors of the grout pour and subsequent grout hydration process.

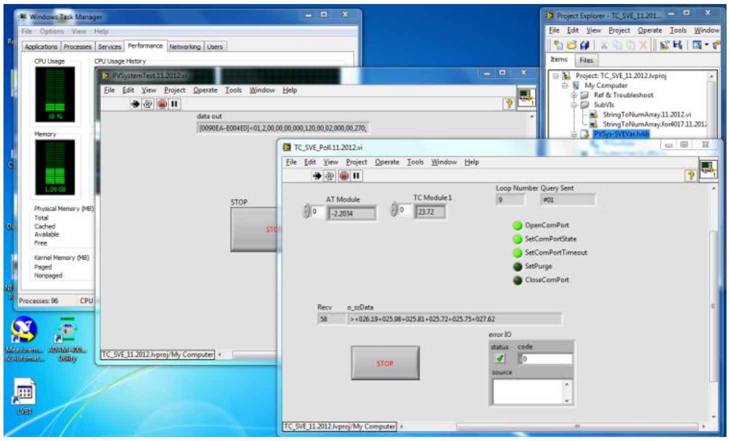
Continued Research

As part of FIU's continued support of this effort, two areas are currently under research relevant to lessons learned from this process. In particular, FIU is focusing on the power network required to final deployment of such a distributed system. Many of these sensor systems are combinations of various commercial components that have been integrated to complete the technical objective of the system, and have not been optimized for a possible full-scale deployment. This topic is focused on the current utilization of electrical energy by these systems, the type and quality of power required, and optimization strategies that can be used to minimize energy needs, especially when such ISD facilities that use this system transition into a long-term monitoring stage. One aspect of this effort is to power the sensors systems of renewable energy systems (Figure 19), which will allow for a better determination of future energy sources, as well as power management strategies for the sensor systems.

Figure 19. Photovoltaic System installed near the MSTB in order to power the sensor systems during energy analysis.

A real-time energy analysis of INL's ERT, TC and AT Systems was performed to estimate the minimum source size. A power monitor was installed on the systems, and allowed to log data during idle and injection mode for a period of days. It resulted in a mismatch on the load analysis performed theoretically versus the one measured with the power analyzer. Using this method, the energy consumption was determined to be 3.975 kWh. Based on the values collected, a PV system was designed. This system is now powering the INL's ERT, TC and AT Systems.

Another topic under review is the integration of these systems under a shared data network that can be used to monitor the composite sensor systems. Many of the sensor systems tested used proprietary software packages that required dedicated computers to acquire, log and analyze the data. FIU is focusing on bringing several of the sensor system data into one cube monitoring software package that can minimize computational resources for a final deployment, while allowing sensor PIs to access the data, and perform additional post-processing as needed. FIU has successfully demonstrated the capture of data in near real time from the Idaho National Lab thermocouple array (66 TC), active tensionmeter (2 AT), weatherstation, and PV power system, and made that data accessible for remote capture and processing. This is now being expanded to remove several of the large energy sources being used by the sensor systems (e.g. PC, laptops, etc) with a low-power microcontroller that can locally acquire the data, and make it accessible via a secure shared variable engine.



data out: [0090EA-E004E0]<01,2,00,00,00,000,120,00,02,000,00,270,
AT Module: 0 -2.2034
TC Module 1: 0 23.72
Loop Number: 9
Query Sent: #01
Recv: 58
o_szData: > +026.19+025.98+025.81+025.72+025.75+027.62
error IO
status: ✓
code: 0
source:

Figure 20. Demonstration VIs capturing data from the INL TC Array, Active Tensionmeters, Weatherstation and PV Power Station in near real time.

CONCLUSIONS

This MSTB demonstration was a first of its kind in developing a test bed at a scale large enough to integrate such a multitude of different sensor systems for simultaneous monitoring of a grouted structure. The demonstration involved collaboration among multiple parties that are leading advances in the ISD process, SHM, tomographic inspection and fiber optic sensor systems. The designs and data collected as part of the MSTB provided useful sensor deployment and monitoring data for DOE complex. The designs developed by FIU for this MSTB show potential for use in sensor deployment at structure undergoing ISD. As a path forward, a determination can be made on those sensors mature enough for deployment, as well as those sensors requiring additional development.

As a future effort, a determination of what sensor types will yield the data most indicative to monitor the grout pouring and long-term structural health processes. Also, a decision on what data types are required for specified areas in and ISD structures; will qualitative indicators be sufficient for monitoring the boundaries of the ISD structures, or is quantitative data required to assess severity of any potential contaminant migration. For the individual sensors, methods to assess the health of the sensor components (e.g. cables, sensing element(s), electrodes, housing, etc.) should be considered, especially when potential sensor failure or inconsistent data could adversely impact the monitoring strategy. As an alternative, potential accelerated aging tests with some of the selected sensor systems could provide useful data on potential failure modes of the sensor.

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