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U.S. Air Force Airfield Damage Repair (ADR) Modernization Program

Moisture Detection of Stored Rapid-Setting Cementitious Materials

Jameson D. Shannon, William D. Carruth, Gregory J. Norwood,
and Harold T. Carr

July 2018

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Final report

Prepared for Headquarters, Air Force Civil Engineer Center
Tyndall AFB, FL 32403-5319

Under Work Unit 2HGK76

Abstract

Storage of airfield damage repair (ADR) materials onsite is essential for rapid repair operations. However, ADR materials may have limited shelf lives and are prone to degradation in the presence of moisture. This study investigated methods of storage to reduce moisture damage and to monitor moisture present in ADR materials.

Various techniques were evaluated to reduce moisture in storage containers, and Super Sacks® of materials were installed with sensors to monitor moisture. Two common ADR materials, Rapid Set Concrete Mix® and Utility Fill 1-Step 750®, were included in the testing procedure. Two different sensors were tested for monitoring moisture: a standard soil moisture probe and an engineered Radio Frequency Identification Reader (RFID) moisture detector.

Absorpole desiccants were found to be the most beneficial of the techniques tested in reducing humidity and removing water from the storage container. The RFID moisture detector was found to be able to detect moisture events better than the soil moisture sensor, which was unable to detect moisture events even when stored outside. Recommendations for future storage conditions and monitoring are provided. This study demonstrates the capability of moisture monitoring in cementitious material Super Sacks and provides groundwork for further optimization of storage protocols.

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Preface

This project was conducted for Headquarters, Air Force Civil Engineer Center Tyndall AFB, FL 32403-5319, under the Airfield Damage Repair (ADR) Modernization Program. The technical monitor for this project was Dr. Craig Rutland, and the technical manager was Jeb S. Tingle.

This work was performed by the Airfields and Pavements Branch (APB) and the Concrete and Materials Branch (CMB), Engineering Systems and Materials Division (ESMD), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL), and the Sensor Integration Branch (SIB), Computational Science and Engineering Division (CSED), ERDC Information Technology Laboratory (ITL). At the time of publication, Dr. Timothy W. Rushing was Chief, APB; Mr. Christopher M. Moore was Chief, CMB; Mr. Quincy Alexander was Chief, SIB; Dr. Gordon W. McMahon was Chief, ESMD; Dr. Jerry Ballard was Chief, CSED; and Mr. R. Nicholas Boone was the Technical Director for Force Projection and Maneuver Support. The Acting Deputy Director of the ERDC-GSL was Dr. William P. Grogan, and the Director was Mr. Bartley P. Durst. The Deputy Director of ERDC-ITL was Ms. Patti Duett, and the Director was Dr. David Horner.

COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
yards	0.9144	meters

1 Introduction

1.1 Background

The U.S. Air Force Air Combat Command began the Airfield Damage Repair (ADR) Modernization Program to develop technologies to address operational limitations of current ADR equipment, materials, and tactics. The overall objective of the program is to modernize the Air Force's ADR capability through development of new ADR solutions that are suitable for fighter and cargo aircraft while scalable to the threat or damage. Since 2006, researchers at the U.S. Army Engineer Research and Development Center (ERDC) have been conducting research under the program to develop new, expedient pavement repair techniques in an effort to update repair guidance for military airfields. Damaged airfield pavements must be repaired quickly using suitable materials to reduce the total time that the airfield is removed from service, as well as reduce the need to conduct subsequent repairs to maintain an operable pavement surface, particularly during wartime scenarios. A more complete overview of the ADR Modernization Program from 2006 through 2015 is in Carruth et al. (2015).

Cementitious, rapid-setting concrete repair materials have been successfully demonstrated for repairing bomb-damaged concrete pavements as a part of the ADR Modernization Program. Based on results from numerous full-scale experiments, Rapid Set Concrete Mix® was identified as a versatile repair material and has been used to conduct many repairs capable of withstanding simulated and live aircraft maneuvers involving C-17 and F-15E aircraft (Priddy et al. 2011). As a result, Rapid Set Concrete Mix® is currently recommended as the surface capping material for a variety of repair types within the ADR scenario.

Rapid-setting flowable fill was first evaluated as a backfill material for crater repair in 2009 (Priddy et al. 2013). Utility Fill 1-Step 750® is a rapid-setting flowable fill material that was selected for use as a rapid backfill alternative because it can be easily placed with or without the use of external mixing. In cases where rapid-setting concrete supply is limited, it would be advantageous to use rapid-setting flowable fill as a capping material in place of rapid-setting concrete, particularly in lower traffic areas (Carruth and Howard 2016).

A proper way to store these cementitious materials and monitor their moisture level during storage is needed so that they can be deployed to various U.S. Air Force (USAF) facilities. If the materials are exposed to moisture, hydration of the cement can occur, which may render the materials unusable or make them more difficult to use. The testing described in this report was conducted to determine an optimal method for storage and moisture detection of these cementitious materials.

1.2 Objective and scope

The objective of the testing described in this report was to develop a storage method for rapid-setting cementitious materials used in the ADR crater repair process and a method for monitoring moisture of these materials. To achieve the objective, multiple experiments were performed including small-scale tests and testing of materials in storage that replicates the current storage scenario used by the USAF. Proper data were collected and analyzed in order to provide recommendations on material storage and monitoring.

Chapter 1 provides background information covering the history of the ADR program and the specific objectives and scope of the work covered in this report. Chapter 2 presents a description of the testing and describes all equipment and materials used during testing. Chapter 3 discusses and analyzes the test results obtained. Conclusions and recommendations are described in Chapter 4.

2 Experimental Program

2.1 Materials tested

The materials of interest in this study, Rapid Set Concrete Mix® (hereafter referred to as Rapid Set or RS) and Utility Fill 1-Step 750® (hereafter referred to as Flowable Fill or FF), are most commonly bought and delivered in Super Sacks®. These Super Sacks contain approximately 1 cu yd of material and may weigh up to 3,500 lb. Typical Super Sacks are manufactured of woven polypropylene and are not resistant to moisture. For current USAF storage applications of these products, the containers in which the Super Sacks are stored are lined with an aluminum barrier in an attempt to limit moisture intrusion as much as possible. Super Sacks of materials tested in this study were the same as those in current use.

2.2 Container storage environment

International Organization for Standardization (ISO) or conex containers can be useful for shipping and storage since they are relatively inexpensive and are easily shipped via sea or air freight. The current configuration for shipping Super Sacks of ADR materials utilizes a conex of dimensions 20 ft x 8 ft x 8.5 ft tall and has metal racks to securely ship up to 16 Super Sacks of material in each conex. However, due to weight limitations, only 12 Super Sacks are typically included for each conex. Figure 1 shows the conex with racks and Super Sacks. Schematics of the current USAF material containers, including detail callouts, are shown in Appendix A.

In order to assess the feasibility of long-term storage in a conex environment, a study was conducted to measure the internal temperature and humidity of the conex containers. Internal properties of four conex containers were measured over an approximate 3-month period. Of the four containers, three were fitted with moisture deterrent systems with a single container serving as a control. The four containers and moisture deterrents are listed in Table 1. Air temperature outside of the containers and rainfall data were also collected during the same time period. Illustrations of each of the moisture deterrents are shown in Figures 2 through 4.

Figure 1. Conex container with Super Sacks in racks.

Table 1. Conex containers listed with moisture deterrent type and data.

Conex	Moisture deterrent type	Moisture deterrent data
1	Spray coating	Kefa Airless 8125 -Paint-like spray coating
2	Liner	CorrPakBPS -Aluminum foil liner for conex
3	Desiccant	Absorpole -Hangable desiccant with ability to capture water
4	None	Control specimen

Kefa Airless 8125 is a water-based coating designed to store moisture during high humidity periods and release the moisture to be evaporated into the air during low humidity periods. This material can be applied by painting or spraying, is mold resistant, and was previously used by U.S. Army, Navy, and Coast Guard vessels.

The aluminum foil liner is a reflective barrier material designed to create a temperature- and humidity-controlled environment. The liner is attached to the interior of the conex and can be completely closed after the material is loaded. Absorpole is a calcium chloride desiccant that can absorb up to 2 liters of moisture and is designed for conex containers.

Figure 2. Kefa Airless 8125.

Figure 3. CorrPakBPS liner.

Figure 4. Absorpole.

2.3 Sensor testing for moisture detection inside conex

To investigate the actual effect of storage on the cementitious materials, sensors were used in an attempt to quantify the amount of moisture absorbed over a period of time. Sensors were installed in the Super Sacks at the shipping facility of both products. The Super Sacks were then filled and shipped to the ERDC facility in Vicksburg, MS, where they were loaded into a conex container and monitored. The conex container for this part of the study included Absorpole desiccants since they are currently used in deployed material containers. As in the container storage test procedure, rain, humidity, and air temperature outside of the conex were also monitored.

Two different types of sensors were used: a typical soil moisture sensor and an RFID moisture sensor. The typical soil moisture sensor (hereafter referred to as sensor 1) was an Onset soil moisture probe connected to a HOBO data logger. This type of sensor must be physically connected to a data collection device in order to function. To read the data, a computer must then be attached to the data collection device. Onset soil moisture probe sensors and the data logger are shown in Figure 5.

Figure 5. Sensor 1.

a. Sensor 1 embedded in Super Sacks.

b. Cabling attached to logger device at end of conex.

The second type of sensor (hereafter referred to as sensor 2) is an RFID-type sensor that does not need to be physically connected to a logger in order to collect data. These sensors feature a leak-sense cable that can detect moisture throughout the length of the cable and an RFID transmitter. Cables were manufactured by Phase IV Engineering. The RFID transmitter allows the sensor to remain in the Super Sack, which can be moved freely, and measurements can be obtained by using a handheld or permanent stationed receiver.

Due to the nature of sensor 2, measurements consist of a true/false output that indicates whether a certain moisture threshold has been crossed at the time of measurement. Sensor 2 does not actually measure the amount of moisture present. Since the sensor is not connected physically, it has an internal built-in battery, which on longer tested regimens would have to be replaced periodically. The number of measurements obtained in a given time period significantly affects battery life. A sensor 2 cable with an RFID transmitter installed in a Super Sack is shown in Figure 6.

Figure 6. Sensor 2 with RFID transmitter.

Twelve Super Sacks were stored in the conex container and monitored for approximately 6 months (September through January). The container was closed and reopened only in order to read measurements. Table 2 illustrates the 12 Super Sacks for this portion of the study. Super Sack identification (ID) was given based on four factors: inside conex or external (I or E), sensor type (1 or 2), material (RS or FF), and replicate number (1-3). Figure 7 shows the closed container with weather, temperature, and humidity monitoring devices attached.

Table 2. ID and descriptions of Super Sacks inside conex.

ID	Storage	Sensor	Material	Replicate
I-1-RS-1	inside conex	1	RS	1
I-1-RS-2	inside conex	1	RS	2
I-1-RS-3	inside conex	1	RS	3
I-1-FF-1	inside conex	1	FF	1
I-1-FF-2	inside conex	1	FF	2
I-1-FF-3	inside conex	1	FF	3
I-2-RS-1	inside conex	2	RS	1
I-2-RS-2	inside conex	2	RS	2
I-2-RS-3	inside conex	2	RS	3
I-2-FF-1	inside conex	2	FF	1
I-2-FF-2	inside conex	2	FF	2
I-2-FF-3	inside conex	2	FF	3

Figure 7. Conex closed with external weather monitoring devices attached.

2.4 Sensor testing for moisture detection outside conex

A group of instrumented Super Sacks was placed outside the conex with no protection from the environment in order to measure worst case scenarios for storage. Outside Super Sacks were monitored for 3 months (December through February). Table 3 illustrates the Super Sacks with identifiers used in this portion of the study.

Table 3. ID and descriptions of Super Sacks outside conex.

ID	Storage	Sensor	Material	Replicate
E-1-RS-1	external	1	RS	1
E-1-RS-2	external	1	RS	2
E-1-FF-1	external	1	FF	1
`E-1-FF-2	external	1	FF	2
E-2-RS-1	external	2	RS	1
E-2-RS-2	external	2	RS	2
E-2-FF-1	external	2	FF	1
E-2-FF-2	external	2	RR	2

3 Results

3.1 Container storage results

Temperature results from the four conex containers and the ambient air temperature are shown in Figure 8. Humidity and rainfall data during the same time period are shown in Figure 9. Day and night temperature cycles are clearly visible, with the temperature in all of the containers exhibiting higher peaks during the day than the ambient air temperature. During the approximately 3 months of data collection, the average ambient temperature and relative humidity were 75.4°F and 73.1 percent, respectively.

Figure 8. Temperature data from container storage.

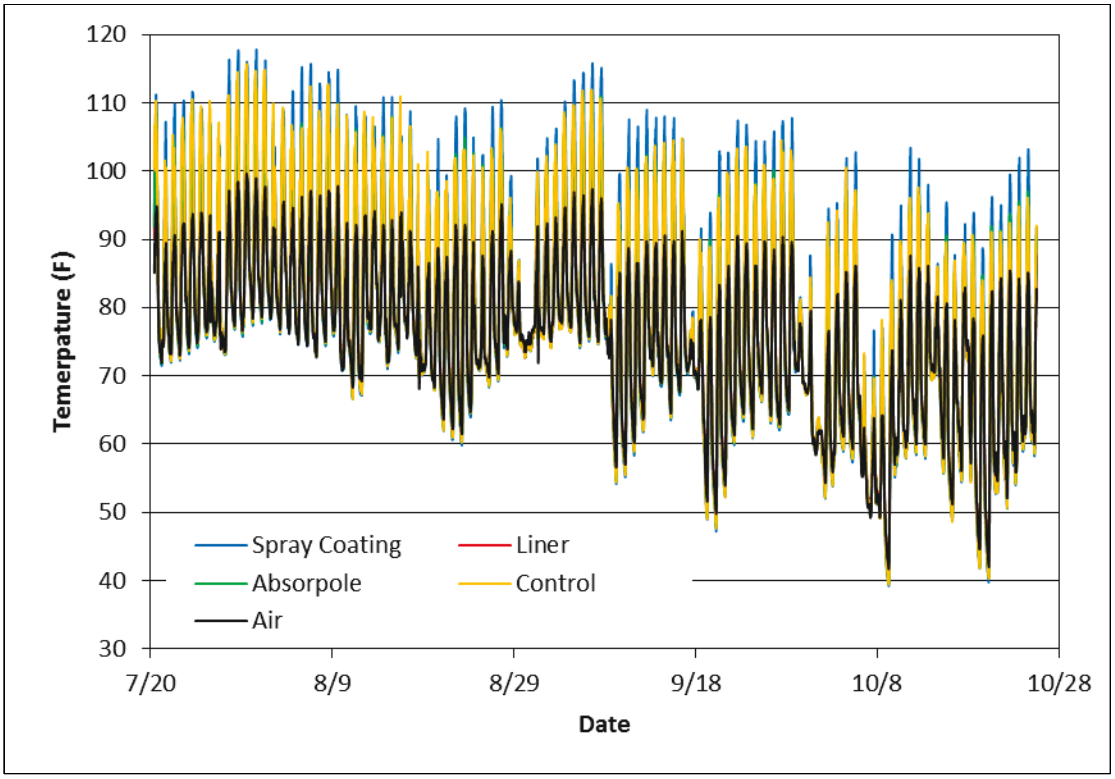
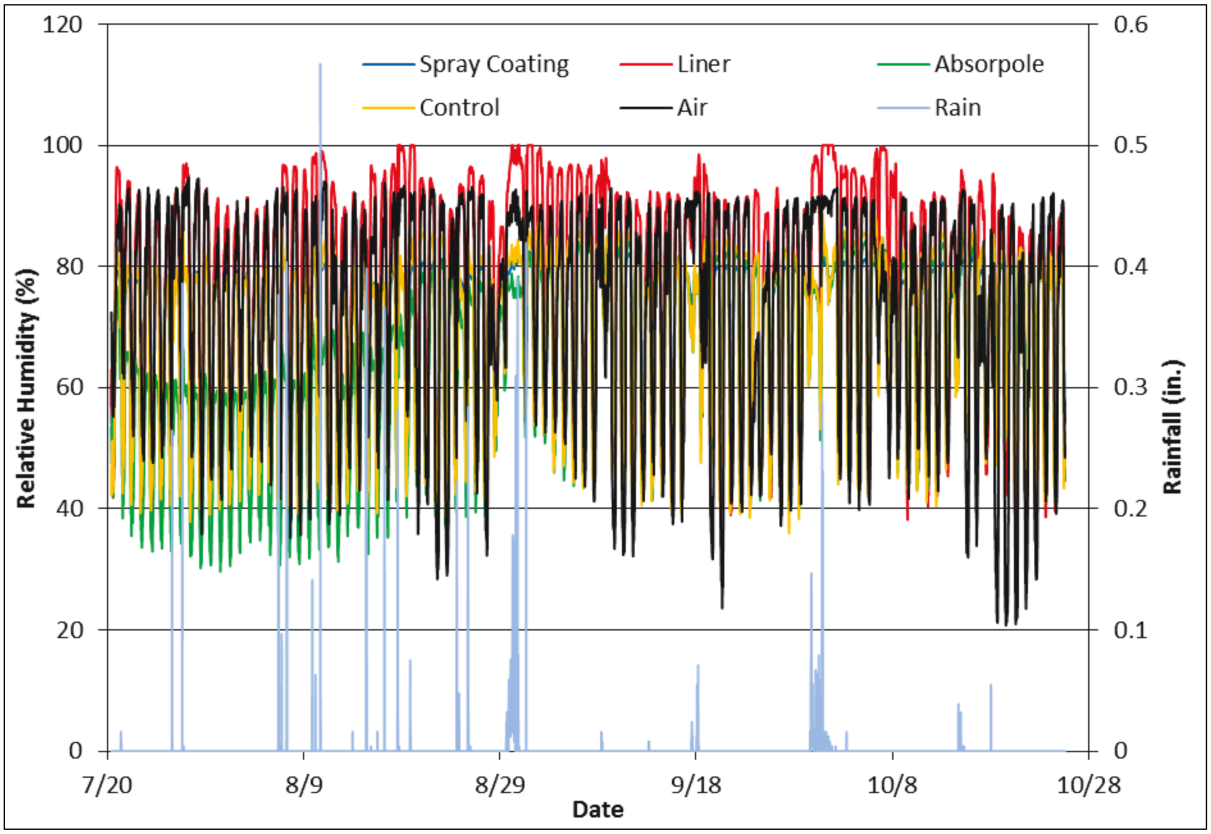


Figure 9. Humidity data for container storage.



The control conex had a 3.6°F higher average temperature than ambient, but 3.7 percent lower average humidity. All three containers with moisture deterrents recorded lower average temperatures than the control container by 0.6 to 1.5°F. This was not seen as a meaningful difference. Table 4 contains average temperature and humidity data with comparisons. The container with the aluminum foil liner exhibited an increased relative humidity compared to ambient, while the spray coating and Absorpole containers exhibited lower relative humidity by 1.3 percent and 8.4 percent, respectively. Only the container with the Absorpole had a lower average relative humidity than the control container. Neither the spray coating nor the liner were more effective at reducing humidity than the control container.

Table 4. Average temperature and humidity with comparisons.

	Control	Spray coating	Aluminum liner	Absorpole
Average temperature (°F)	79.0	78.4	77.5	77.8
Temperature difference from average control (°F)	---	-0.6	-1.5	-1.1
Temperature difference from average ambient (°F)	3.6	3.0	2.1	2.5
Average relative humidity (%)	69.3	71.7	77.7	64.7
Relative humidity difference from average control (%)	---	2.4	8.4	-4.7
Relative humidity difference from average ambient (%)	-3.7	-1.3	4.6	-8.4

3.2 Sensor testing results inside conex

Moisture detection results for sensor 1 inside of the conex are shown in Figure 10. Relevant statistics from the data set are shown in Table 5. The six instrumented supersacks in this portion of the study showed relatively consistent moisture measurements throughout the 6-month data collection period. The exception to this was specimen I-1-RS-2 that showed decreased readings during the last month. The specimen also recorded negative readings during the same time period. This was thought to be a sensor error, and the negative measurements were excluded from the results. Lower measurements during the same time period were not excluded from the results but are likely erroneous.

Means for the specimens ranged from 0.0896 to 0.1378. Standard deviations for each specimen were less than the difference between specimen means in almost all cases. Based on the statistics, it appears that differences in means between measured values were likely the results of small differences in the sensors themselves and not an indication of differences in moisture between supersacks. Rainfall events did not affect moisture content in any of the measured Super Sacks, and there were no noticeable differences in moisture detection between the two materials. Sensor 2 did not register any changes in moisture content for any of the six specimens during the testing period.

Figure 10. Sensor 1 (inside conex) moisture detection.

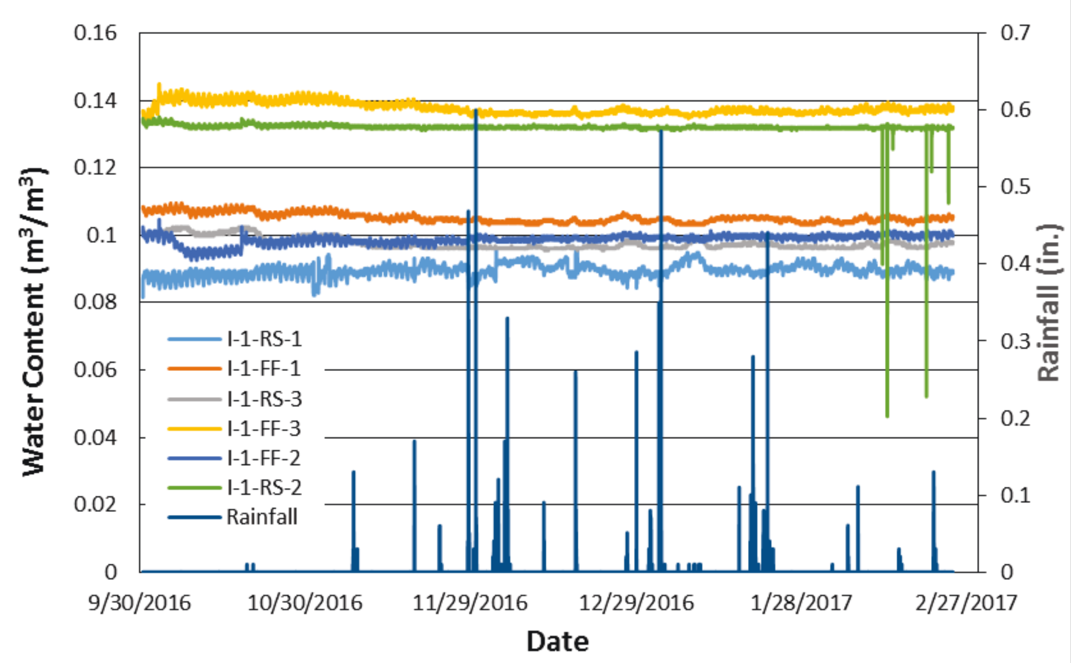


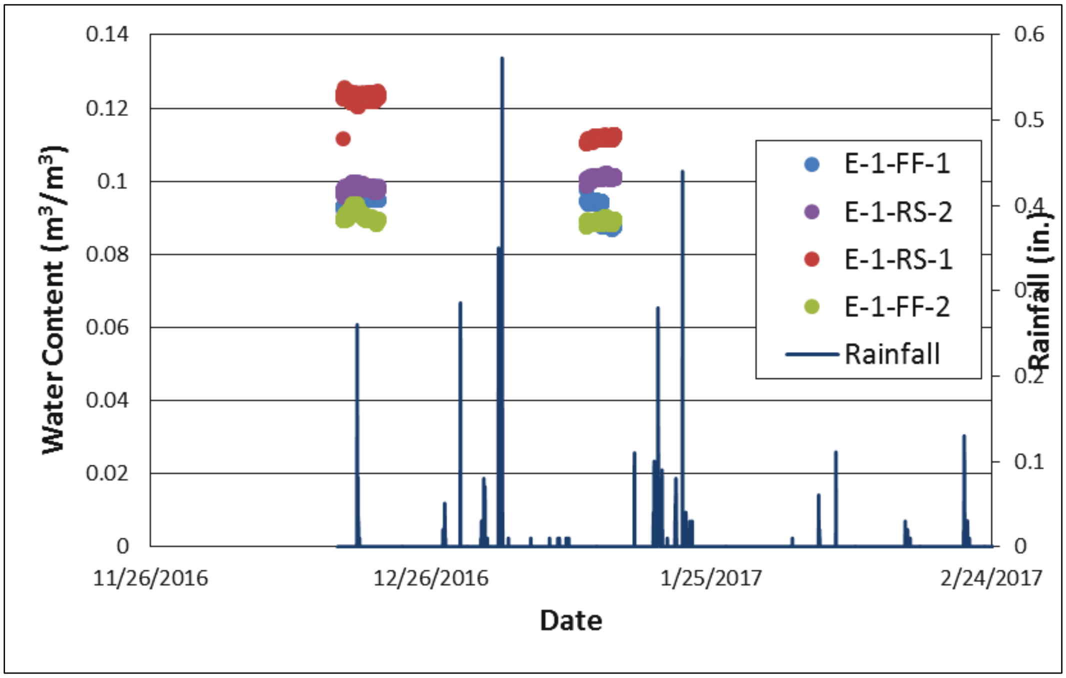
Table 5. Sensor 1 (inside conex) statistics.

	I-1-RS-1	I-1-FF-1	I-1-FF-2	I-1-RS-2	I-1-RS-3	I-1-FF-3
Mean	0.0896	0.1052	0.0988	0.1322	0.0977	0.1378
Standard error	1.50E-05	1.16E-05	1.17E-05	9.93E-06	1.47E-05	1.47E-05
Median	0.0896	0.1047	0.0992	0.1321	0.0969	0.1375
Standard deviation	0.0018	0.0014	0.0014	0.0012	0.0017	0.0017
Sample variance	3.18E-06	1.88E-06	1.94E-06	1.39E-06	3.03E-06	3.02E-06
Range	0.0147	0.0065	0.0121	0.089	0.007	0.0119
Minimum	0.0816	0.1031	0.0926	0.0462	0.0955	0.1331
Maximum	0.0963	0.1096	0.1047	0.1352	0.1025	0.145

3.3 Sensor testing results outside conex

Moisture detection results for sensor 1 outside of the conex are shown in Figure 11. Only two short periods of moisture collection data were able to be recorded. Sensor 1 had difficulty operating in normal outdoor conditions due to having to be physically connected to a logger in order to take measurements. After testing was started, the logger mechanism malfunctioned due to the elements in fewer than 7 days in multiple cases.

Figure 11. Sensor 1 outside conex.



A section of data deemed reliable in Figure 11 is highlighted in Figure 12. As seen in the figure, even when the sensors appeared to be functioning correctly, no moisture changes in the Super Sack were measured during the rainfall event. Based on physical appearance after rainfall events, it was apparent that moisture was entering the Super Sack; but in the limited amount of reliable data, no moisture increases in the Super Sacks were measured.

Sensor 2 data is shown in Figure 13. Because sensor 2 measures only changes in moisture, there are no values for the moisture measurement; instead, data points on the figure indicate whether there was a change in moisture present. Sensors in all four Super Sacks recorded a change in moisture content on major rainfall events. However, sensors also measured change in moisture content on nonrainfall events.

Figure 12. Sensor 1 outside conex (single rainfall event).

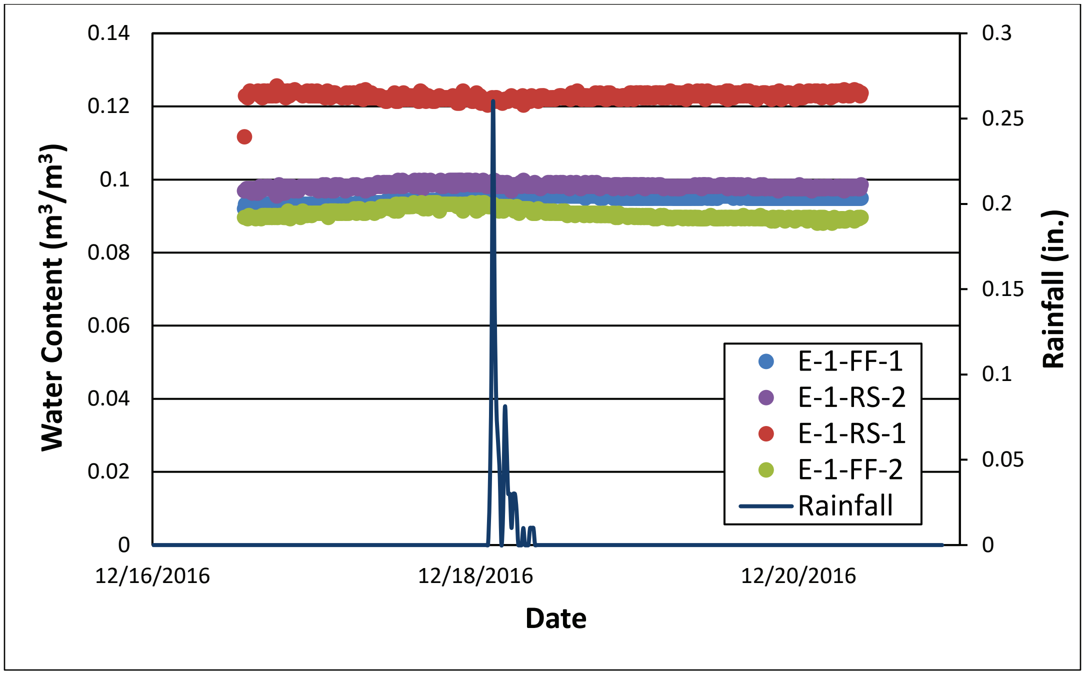
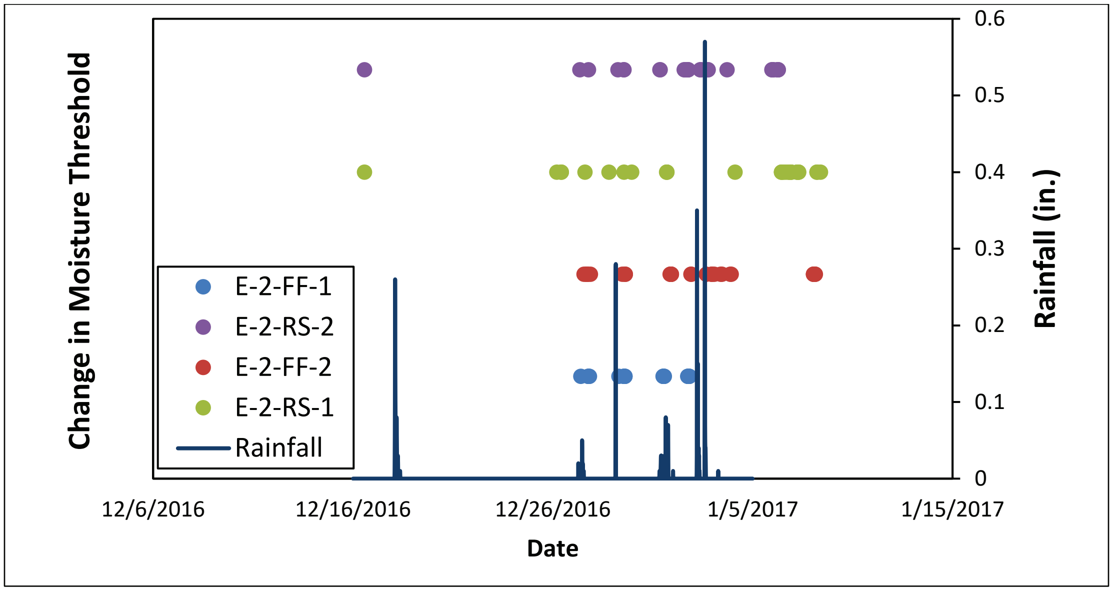


Figure 13. Sensor 2 outside conex.



Additional measurements not associated with rainfall events could be due to excessive dew or humidity, as the sensor is capable of picking up small moisture changes. This appears likely considering multiple sensors recorded a “wet” event not associated with rainfall. Sensor type 2 also registers a measurement when the sensor changes from a “wet” reading to a “dry” reading, and this may account for multiple readings from a single rainfall event.

4 Conclusions and Recommendations

4.1 Conclusions

Three moisture control mechanisms for the conex container were tested: Kefa Airless 8125 (spray-on liner), CorrpakBPS (aluminum liner), and Absorpole (desiccant based). All three exhibited lower average temperatures than the control conex, but only the Absorpole showed lower average humidity during the approximately 3-mo test period. Average humidity was lower by 4.6 percent compared to the control conex.

Super Sacks equipped with the soil moisture sensor for 6 mo inside the conex appeared to produce relatively precise readings in 5 of the 6 specimens. The exception was a small number of readings in a single month of a single specimen. No correlation between moisture readings and rainfall was perceived in this set of Super Sacks.

Outside Super Sacks with the soil moisture sensor exhibited testing issues stemming from the necessary data logger. These issues caused the data logger to malfunction in a few days after being placed outside. This issue occurred multiple times during the test procedure, and despite various attempts to protect the logger from the elements, outside data measurements with this sensor type could not be maintained reliably. Investigations into the few functioning measurements revealed no correction between measured moisture and rainfall events with this sensor type despite the Super Sack's being rained on directly.

The RFID sensors recorded no moisture changes during the 6-month period inside the conex in any of the six instrumented Super Sacks. Outside Super Sacks recorded moisture events that paired with rainfall events and additional moisture events that might have been due to other moisture sources, such as dew or humidity.

In general, Super Sacks left inside the conex appeared to be dry, and a visual inspection of the cementitious material indicated that the cement had not been exposed to water. A visual inspection of the cement stored outside indicated that water exposure had occurred, as signs of clumping and setting were observed in the Super Sacks. No differences in moisture prediction capabilities were observed between the cementitious material types.

Based on these findings, the storage of cementitious materials in Super Sacks inside a conex with Absorpoles installed was found to be beneficial to prolonging cementitious use life compared to the other methods investigated. The soil moisture sensor was unsuccessful at positively identifying a rainfall event inside and outside of the conex. It also exhibited malfunctions when outside of the conex. The RFID sensor indicated no moisture events when inside the conex but did measure moisture events corresponding to rainfall outside of the conex. There were also no RFID sensor malfunctions observed even when stored outside.

4.2 Recommendations for moisture monitoring

It is recommended that Super Sacks of cementitious material be stored in the presence of a desiccant for long-term storage, as it was shown to remove a substantial amount of moisture from the air. The soil moisture sensor is not recommended due to its inability to measure rainfall events and incompatibility with weather elements. The RFID sensor was able to correctly register rainfall events outside and registered zero rainfall events inside in all instrumented Super Sacks. Due to the self-contained nature of the RFID sensor, it was also easier to collect data readings through RFID. Therefore, it is recommended to use the RFID sensor over the soil moisture probe when monitoring moisture data.

Based on all four of the outside conex RFID sensors' exhibiting similar data, it is recommended that it be used in the following manner. The RFID sensor may be installed in a representative portion of the total cementitious material storage (e.g. 10 percent of the Super Sacks contain the sensors). The RFID measurements can then be read quickly at designated intervals (e.g., 1 month) to monitor the storage facility for excess moisture that may damage the materials. This would likely provide a strong level of moisture monitoring for a relatively small amount of time and low costs.

4.3 Recommendations for additional study

It is recommended that additional study be conducted on both sensor types. The soil moisture sensors exhibited a common issue with data loggers in that outside monitoring can be problematic. An additional study featuring how to use sensors of this type and how to correctly monitor data when exposed to weather elements may be beneficial. This would also allow for the additional collection of outside soil moisture sensor data, as only a small amount of this data type was found to be reliable.

Additional research is also needed concerning the RFID sensor. An extended study on expanding its use and improving its measurement quality and duration would be beneficial. Currently, these sensors are limited by battery life and number of measurements. Additional research could be undertaken to optimize the design and benefits with these considerations.

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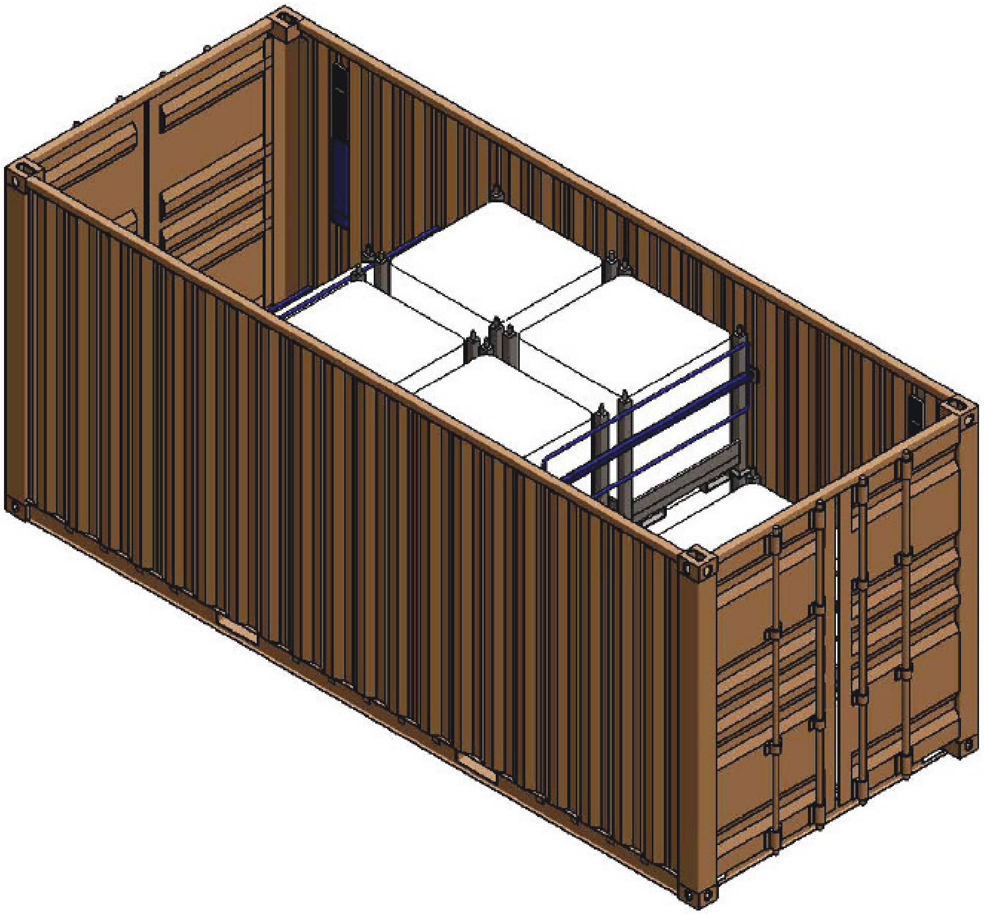
Appendix A: Material Container Drawings

Figure A1. Material container drawing isometric view.



REPAIR MATERIAL CONTAINER - ISOMETRIC VIEW

NTS

REPAIR MATERIAL CONTAINER CONTENTS:

TWELVE (12) METAL RACKS

TWELVE (12) SUPERSACKS OF CTS RAPID SET CONCRETE MIX

FOUR (4) CARGO BARS

FOUR (4) DESICCANT POLES

FOUR (4) BUCKETS (TWO (2) FILLED WITH 50 LBS OF CITRIC ACID, TWO (2) EMPTY)

Figure A2. Material container drawing plan view.

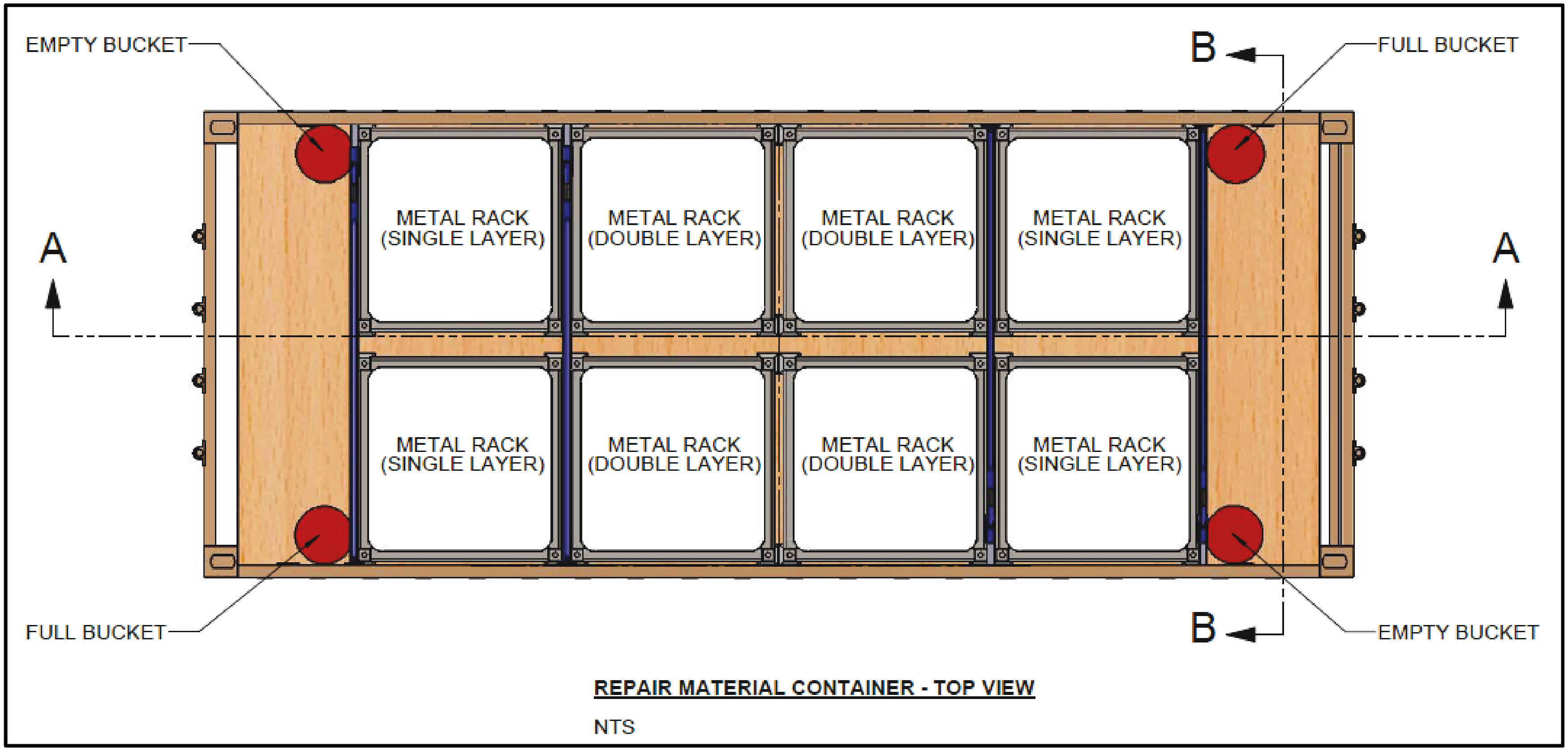
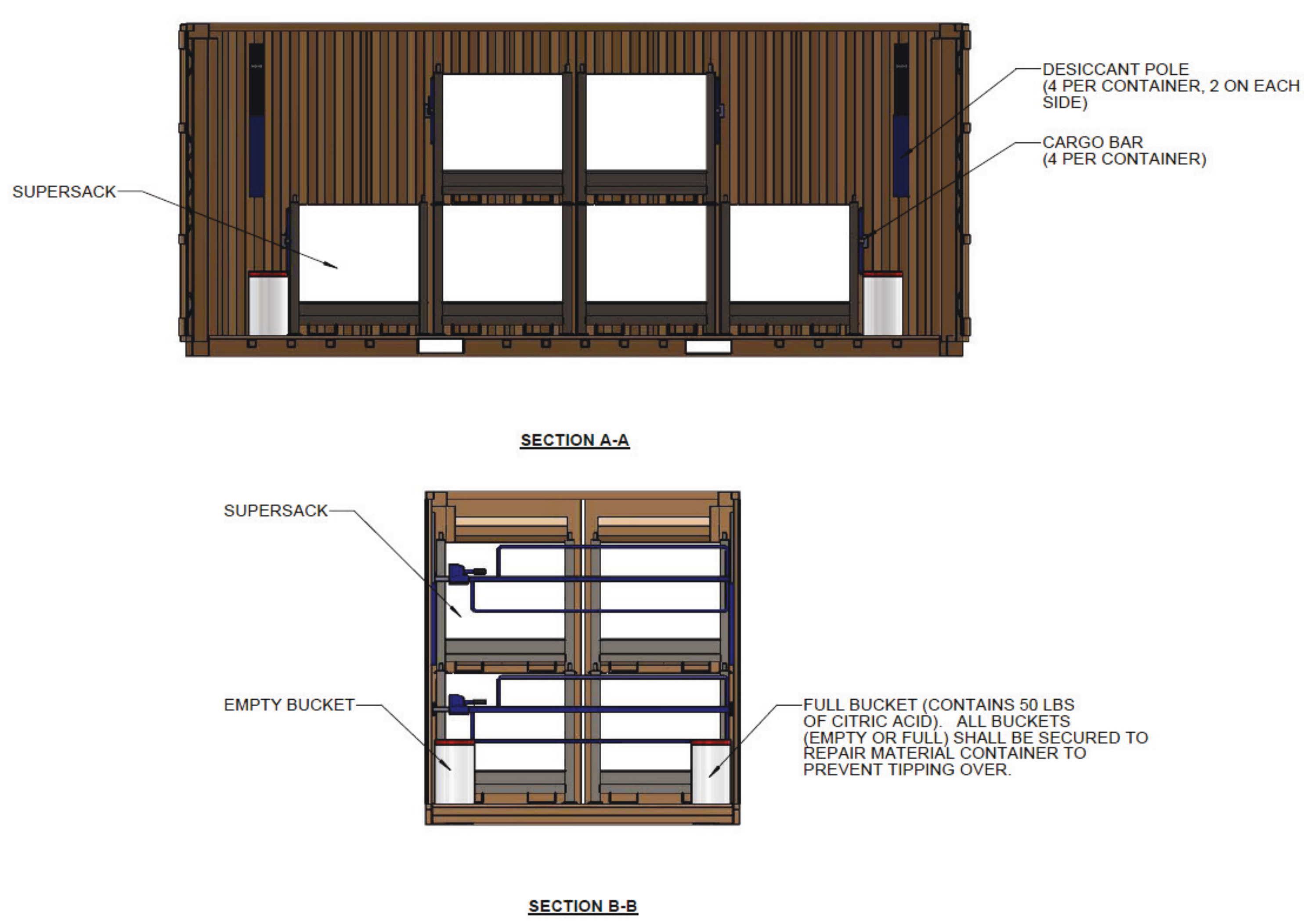


Figure A3. Material container drawing section view.



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
July 2018

2. REPORT TYPE
Final report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

Moisture Detection of Stored Rapid-Setting Cementitious Materials

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jameson D. Shannon, William D. Carruth, Gregory J. Norwood, and Harold T. Carr

5d. PROJECT NUMBER
445073

5e. TASK NUMBER

5f. WORK UNIT NUMBER
2HGK76

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
Geotechnical and Structures Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC TR-18-8

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, Air Force Civil Engineer Center
Tyndall AFB, FL 32403-5319

10. SPONSOR/MONITOR'S ACRONYM(S)
AFCEC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Storage of airfield damage repair (ADR) materials onsite is essential for rapid repair operations. However, ADR materials may have limited shelf lives and are prone to degradation in the presence of moisture. This study investigated methods of storage to reduce moisture damage and to monitor moisture present in ADR materials.

Various techniques were evaluated to reduce moisture in storage containers, and Super Sacks® of materials were installed with sensors to monitor moisture. Two common ADR materials, Rapid Set Concrete Mix® and Utility Fill 1-Step 750®, were included in the testing procedure. Two different sensors were tested for monitoring moisture: a standard soil moisture probe and an engineered Radio Frequency Identification Reader (RFID) moisture detector.

Absorpole desiccants were found to be the most beneficial of the techniques tested in reducing humidity and removing water from the storage container. The RFID moisture detector was found to be able to detect moisture events better than the soil moisture sensor, which was unable to detect moisture events even when stored outside. Recommendations for future storage conditions and monitoring are provided. This study demonstrates the capability of moisture monitoring in cementitious material Super Sacks and provides groundwork for further optimization of storage protocols.

15. SUBJECT TERMS

Airfield Damage Repair,
Rapid-setting materials
Moisture-Measurement
Pavement materials
Building materials-Moisture
Moisture detection
Storage
Cement composites-Storage
Building materials-Moisture
Cement composites-Moisture
Moisture meters

16. SECURITY CLASSIFICATION OF:

a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		31	**19b. TELEPHONE NUMBER** *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18