

Field Trial for Air Entrained Grout Enriched Roller Compacted Concrete

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ABSTRACT

Roller compacted concrete (RCC) is frequently used to armor earthen embankments for passing extreme floods and to construct gravity dams and stepped spillways. Early experience on RCC dam applications in the 1980s showed a tendency for seepage to develop along the lift lines. Therefore, RCC dam designers started including an upstream facing system as a watertight barrier. An alternative facing material that has been used extensively overseas and is starting to gain more widespread acceptance in the United States is Grout Enriched RCC (GERCC). The grout enriched method of face construction has been shown to be less expensive than other facing options, particularly on larger dam projects, and has also been used on exposed RCC embankment overtopping projects. However, in the United States, the use of GERCC technology has been fairly limited, primarily due to concern over the material's freeze-thaw resistance. The objective of this project is to develop a grout formulation and construction technique that allows the production of air entrained GERCC. The study includes four phases to systemically achieve this objective: (1) optimizing grout formulation, (2 and 3) evaluation of small scale laboratory samples of GERCC, and (4) conducting a field trial. This paper focuses on the final phase, a field trial conducted with ASI contractors at the Duck River Dam site located in Alabama. The results show that the adequate freeze thaw resistance can be attained by air entraining GERCC, but the results are very sensitive to the distribution of the grout through the RCC and adequate performance requires significant internal vibration.

Keywords: Roller Compacted Concrete, Overtopping Protection, Stepped Spillways, Freeze-Thaw Resistance

1. INTRODUCTION

Roller compacted concrete (RCC) is a no slump concrete which provides an economical method for armoring earthen embankments for passing extreme floods and constructing gravity dams and stepped spillways. RCC is typically constructed in lifts with conventional earthmoving equipment to deliver, spread and compact the material. Early experience with RCC dams in the 1980's showed a tendency for seepage to develop along the lift lines. Therefore, RCC dam designers started to include an upstream facing system as a watertight barrier. This facing system has traditionally been constructed using conventional concrete, an exposed geomembrane liner system, or geomembrane faced precast concrete panels.

An alternative facing material that has been used extensively overseas (in areas having limited freeze-thaw cycles) and is starting to gain more widespread acceptance in the United States is Grout Enriched RCC (GERCC). This innovative process includes the addition of a neat cement grout to the uncompacted RCC at each lift along the upstream and or downstream face. After the grout has soaked into the RCC, immersion vibrators are used to mix and to consolidate the grout and RCC to produce a seamless zone that is similar to conventional concrete. The grout enriched method of face construction has been shown to be less expensive than other facing options, particularly on larger dam projects (Fitzgerald, 2013). GERCC has also been used on the exposed RCC faces of embankment

overtopping projects. However, in the United States the use of GERCC technology has been fairly limited, primarily due to concern over the material's freeze-thaw resistance.

1.1. Background

Studies conducted by Cannon (1993) and Hazaree et al (2011) have shown that it is possible to entrain air in standard RCC, and achieve reasonable freeze thaw resistance. However, researchers and contractors attempting to integrate air entraining admixtures into GERCC to improve freeze-thaw resistance have not been successful to date. Forbes (1999) cited an early example at the Horseshoe Bend dam in New Zealand where a freeze-thaw resisting facing was desired. In order to achieve this, the grout was heavily dosed with an air entraining admixture to achieve 3-4% residual air in the GERCC facing. The initial trials using the air entrainer were unsuccessful since the grout became highly foamy and would not soak through the uncompacted RCC layer. McDonald (2002) described the most detailed studies in air entrained GERCC to date. The study consisted of laboratory tests which evaluated the grout formulation, dosage rate, and techniques to combine the grout with the RCC, as well as field trials. The laboratory tests showed that it is very difficult to produce a homogenous mixture by placing the grout on the top and/or bottom of the RCC. In addition, when internal vibrators are used to combine the grout and RCC, the air content of the mixture and therefore the freeze thaw resistance decreases substantially. Similar conclusions could also be drawn based upon their field trials, as well as field trials conducted in a separate study conducted by Tatro et al (2008). These two observations highlight the difficulty of using air entrained GERCC: current construction techniques require significant vibration energy to produce a homogenous mixture, but that vibration energy removes much of the entrained air from the grout, reducing the freeze-thaw resistance.

1.2. Summary of Previous Phases of This Study

The earlier phases of this study have focused on the evaluation of GERCC in the laboratory setting as described in an earlier paper (Musselman, 2016). The first phase of this project was to evaluate the effect of different chemical admixtures on the air content in the grout as well as the stability of the resulting air void system. The stability was assessed by allowing the grout to rest for 30 minutes after mixing and then placing the grout on a vibrating table for 1 minute and measuring the reduction in entrained air. Multiple air entraining admixtures (AEA) were evaluated at various dosages, and it was found that the synthetic AEA produced the most stable air void system. Other admixtures including water reducers and latex modifiers were also added to examine their effect. The second phase of the research was to combine the newly formulated grout mixtures with RCC under ideal conditions (in a concrete mixer) and examine the freeze-thaw resistance of the resulting GERCC. Six different grout formulations were evaluated following the procedure outlined in ASTM C666 and all showed acceptable freeze-thaw resistance. The final phase of laboratory testing was to simulate various construction techniques to incorporate grout into the RCC, including grout placed on the bottom of the RCC, grout placed on top, and grout injected into the RCC. The samples were saw cut to evaluate the distribution of the grout through the RCC. Specimens were also removed and subjected to freeze-thaw testing following ASTM C666. These tests showed that grout injection was the most promising method used in the lab, resulting in the best distribution of grout as well as the highest freeze thaw resistance. However, the freeze thaw resistance of these samples was lower than the freeze thaw resistance of the GERCC combined in a mixer.

1.3. Research Objectives

The objective of the final phase of research described in this paper is to validate the simulated construction process and material formulations developed in the laboratory under real world conditions. Additionally, the effect of various levels of vibration and grout dosage rates on the freeze-thaw resistance of GERCC are evaluated. The overall objective of the entire research project is to advance the use of GERCC and promote more cost effective and technically viable construction of armored earthen embankments, gravity dams, stepped spillways, and other hydraulic structures in climates subject to freeze-thaw cycles. Achieving cost-effective GERCC air entrainment and consolidation can significantly advance the competitiveness of RCC versus other alternatives. The research program

was collaboratively developed and executed by a team of individuals with academic, dam engineering, and dam construction backgrounds.

2. EXPERIMENTAL PROGRAM

Following the conclusion of the laboratory testing program described previously, the next phase in this research project was an attempt to repeat the air-entrained GERCC production and performance at full scale under real world conditions. This was done with the help of Schnabel Engineering (Schnabel) and ASI Constructors (ASI). ASI was in the process of constructing a new earthfill dam with a GERCC stepped spillway on the Duck River in Cullman County, Alabama. They generously offered to construct a test section at the dam site to test different air-entrained GERCC construction methods and grout dosages.

The test section consisted of a 3' high x 18' wide x 50' long form. The test section was large enough to simulate two lifts of RCC and use the equipment that is typical for RCC construction. The form can be seen in Figure 1.

2.1. Construction Procedure

The plan for the test section was to complete two 1' lifts over two nights. The RCC for these lifts was mixed on site in a mixing plant and then transported to the section via a large dump truck. The mix design for this RCC was the same mixture that ASI used for the Duck River project, which contained 319 lbs. of cementitious materials (cement and fly ash) per cubic yard. Four 6" x 12" test cylinders were made of the RCC on the first night for compressive strength testing. Before placing the RCC, a trained materials technician conducted a Vebe test in accordance with ASTM C1170/C1170M – 14. The RCC was then placed and spread with a bulldozer. This process can be seen in Figure 1.



Figure 1. Formwork and construction process for GERCC field trial

After the uncompacted RCC was in place, various GERCC construction methods were evaluated. These methods are summarized in Table 1. For the methods involving injection of the grout, an injector as seen in Figure 2 was used. This injector had twelve ¼" ports to better spread the grout through the RCC. Additionally, it had a foot pedal installed to help laborers push the device it into the stiff RCC. When placing the grout on the top or bottom of the RCC, it was placed in a ten to twelve inch wide strip along the face of the form. When the injector was used, an alternating pattern of injection locations was used, one approximately two inches from the face of the form, and another eight to ten inches from the face of the form. The grout used had a water to cement ratio of 0.95 with 6 fluid ounces of synthetic AEA and 6 fluid ounces of latex based water repelling admixture per 100 lbs. of cement. A red dye was added to observe how well the grout and RCC mixed. The same grout formulation that had been used in previous laboratory testing was used during the field trial. A grout plant and pump was used to transport the grout

via a hose to the injector at the test section. The operator of the grout pump relied on a volume gauge to control the amount of grout being dispensed. Before being placed, the grout was tested by a materials technician for air content and flow time in accordance with ASTM C231/C231M – 14 and ASTM D6910/D6910M – 09 respectively. Lastly, the grout temperature was recorded.

Table 1. GERCC Construction Methods

Designation	Lift	Construction Method	Dosage	Dosage Designation	Miscellaneous
GB	1	Grout on the Bottom	1.5 gal/ft	MD	Abandoned; vibration caused no mixing
GT	1	Grout on Top	1.5 gal/ft	MD	Heavy Vibration
HD-HV	1	Injection	2 gal/ft	HD	Heavy Vibration
MD-MVwP	1	Injection	1.5 gal/ft	MD	Loosened with a pitchfork; medium vibration
HD-NV	2	Injection	2 gal/ft	HD	No internal vibration; plate tamper only
HD-LV	2	Injection	2 gal/ft	HD	Low vibration
HD-MV	2	Injection	2 gal/ft	HD	Medium vibration
MD-MV	2	Injection	1.5 gal/ft	MD	Medium vibration
LD-MV	2	Injection	1 gal/ft	LD	Medium Vibration
Control	2	Injection	None		Control

The levels of internal vibration referenced in Table 1 correspond to the descriptions below:

- Heavy Vibration (HV) – Vibrator inserted every 5”-8” and held for 3-5 seconds
- Medium Vibration (MV) – Vibrator inserted every 5” and allowed to sink in and slowly pulled out but not held inside RCC
- Low Vibration (LV) – Same as “Medium Vibration” except inserted every 8”

The grout dosage designations referenced in Table 1 are defined as:

- Heavy Dosage (HD) – 2 gallons of grout per linear foot of RCC face
- Medium Dosage (MD) – 1.5 gallons of grout per linear foot of RCC face
- Low Dosage (LD) – 1 gallon of grout per linear foot of RCC face



Figure 2. Method for placing grout in RCC.

For all of the trials that included internal vibration, one 2” concrete vibrator was used. All of the trials included a plate compactor as seen in Figure 3a as well, which was used after the internal vibration was complete. After plate compaction took place, the remainder of the lift (plain RCC) was compacted using a vibratory roller as seen in

Figure 3b. Finally, the air content of the grout and RCC mixture was taken by a materials technician in accordance with ASTM C231/C231M – 14.



(a)



(b)

Figure 3. Compaction of GERCC and RCC

2.2. Sample Preparation

Approximately one week after construction was complete, cores were extracted to evaluate the grout distribution as well as the freeze thaw resistance of the GERCC. Cores were collected from areas representing each of the six different construction methods applied to the second lift. No cores were taken from the bottom lift because of the challenges in accessing this material to obtain cores, as well as the improved performance and variation of experimental parameters in the second lift. The cores were 4.25" in diameter, varied in length from 12" to 16", and included both horizontal and vertical cores. Horizontal cores were drilled 1" from the finished face of the GERCC. Four cores were taken from each location (3 vertical and one horizontal) for a total of 24 samples to be tested.

The 4.25" cores that were collected from the site were too large to fit in the freeze thaw chamber and had to be trimmed. An MK-2005G Pro Brick Saw as seen in Figure 4a was first used to cut the samples to 12" in length. Next, the same brick saw was used to cut the samples lengthwise. An example of a finished sample can be seen in Figure 4b. These samples are 12" long by 3" wide and 4.25" tall with rounded top and bottom.



(a)



(b)

Figure 4. Preparing the freeze-thaw samples

Prior to subjecting the samples to freeze thaw testing, the percent of grout coverage around the sample was estimated. This value was estimated at by having two individuals independently estimate how much of the surface area of the samples is covered in grout. The average of these two estimations was then taken as the percent covered.

2.3. Freeze-Thaw Testing

The next step was to subject these specimens to the freeze-thaw testing procedure outlined in ASTM C666. In order to gather data from these cycles of freezing and thawing, ASTM C215 – 14 “Standard Test Method for Fundamental Transverse, Longitudinal and Torsional Resonant Frequencies of Concrete Specimens” was used. This test measures both the weight of the specimen as well as the Dynamic Young’s Modulus after every 30 cycles of freeze thaw. The measurement of the weight records the amount of spalling, while the modulus of elasticity measures the amount of internal cracking and residual strength of the concrete. The dynamic modulus is determined by resting the specimen on rubber supports to allow free vibration to occur, placing an accelerometer on the end of the specimen and then striking it with a small hammer. The accelerometer detects the vibrations and records the frequency at which the specimen vibrates. With a known cross section geometry and weight, this can be used to determine the dynamic modulus of elasticity of the sample. The modulus and weight were recorded every 30 cycles for 300 cycles to capture each samples resistance to freeze thaw. A sample is considered failed if the dynamic modulus falls below 60% of its initial value.

3. RESULTS

3.1. Fresh Properties

For the grout, its air content, flow time through a Marsh Funnel and temperature were the primary fresh properties of concern. Air content was measured immediately after mixing and again 30 minutes after mixing for the grout used for lift one. An air reading was not taken after 30 minutes on the second lift because the results from the lab testing and lift 1 showed evidence that air stability was not a problem. For the RCC, the only fresh property measured was the Vebe time. Air content was also taken at two locations for the GERCC. The results for the fresh property tests are shown in Table 2.

Table 2. Fresh Properties

	Lift 1	Lift 2
RCC		
Vebe time (sec.)	19	13
Grout		
Temperature (°F)	79	86
Marsh Funnel flow time (sec.)	44	37
Initial air content (%)	35	19
Air content after 30 min. (sec.)	30	-
GERCC		
Air Content, Sample 1 (%)	2.5	2.8
Air Content, Sample 2 (%)	2.0	2.6

One major difference in the fresh properties when compared to the laboratory testing was the workability of the RCC. The RCC mixture used for the field trials was the same mixture being used to construct the spillway, which had a much lower Vebe time than the mixture used in the lab. This results in a more workable RCC, one that may require less energy to combine with the grout. This mixture design was not modified because it had been optimized for the local aggregate gradation, and the contractor was familiar with producing and placing this material.

The air content of the grout on the first lift was 35%. This was much higher than what had been observed in the lab. On the second lift, the air content was much more in line with expectations at 19%. Furthermore, the grout displayed excellent air stability; after sitting for 30 minutes, it stayed at an air content of 30% on lift 1. The reasons for the higher air content during the first batch of grout are unknown, as the formulation was not modified from Lift 1 to Lift 2. This could be because of the presence of foam within the test apparatus when measuring the air content, which had caused occasional problems during the laboratory testing. After mixing the grout with the RCC, air contents of the combined material were between 2.0% and 2.8%. These levels are not ideal for freeze thaw resistance but indicate at least some level of air entrainment.

3.2. Compressive Strength

Four cylinders were made on the first night of the test section at Duck River for compressive strength. All of these cylinders consisted of the plain RCC; no cylinders were made of the combined materials. These cylinders were cured on site and tested by the contractor’s testing agency. The average compressive strength of these four cylinders was 2160 psi, which is consistent with the strengths attained by the contractor throughout the project.

3.3. Grout Coverage

Grout coverage for specimens was evaluated by having two independent estimators evaluate the vertical cores taken from each section and estimate the percentage of surface area that is covered in grout. These two separate evaluations were then averaged at each location to yield the data in Figure 5.

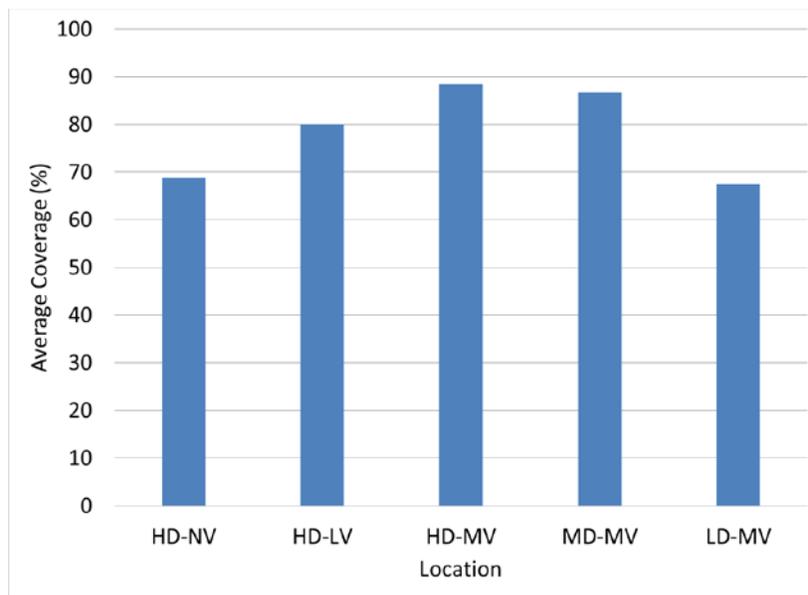


Figure 5. Grout Coverage

The locations with the highest estimated grout coverage underwent medium internal vibration, and had grout dosages of 2 gal/ft and 1.5 gal/ft respectively. The location with the lowest grout coverage also had medium internal vibration, but the grout dosage was low, with only 1 gal/ft. This data indicates that both grout dosage and vibration level affect the coverage, with more vibration and more grout both providing better grout coverage.

For the horizontal cores, instead of calculating the coverage, the depth of penetration from the face was recorded. The shallowest location of penetration was 8.5” while the deepest penetration was 12”, which is consistent with the width of the grout placement zone. This is encouraging data, showing that these construction methods can create a face with adequate grout depth to protect the dam under freeze-thaw conditions.

3.4. Freeze-Thaw Results

Figure 6 plots the dynamic modulus as measured by a Fundamental Transverse Frequency test vs. the number of freeze thaw cycles the specimens endured. A sample was considered failed when its measured modulus fell below 60% of its initial elastic modulus in accordance with ASTM C666/C666M – 15. The values are reported as a percentage of the initial modulus in order to compare all of the samples easily.

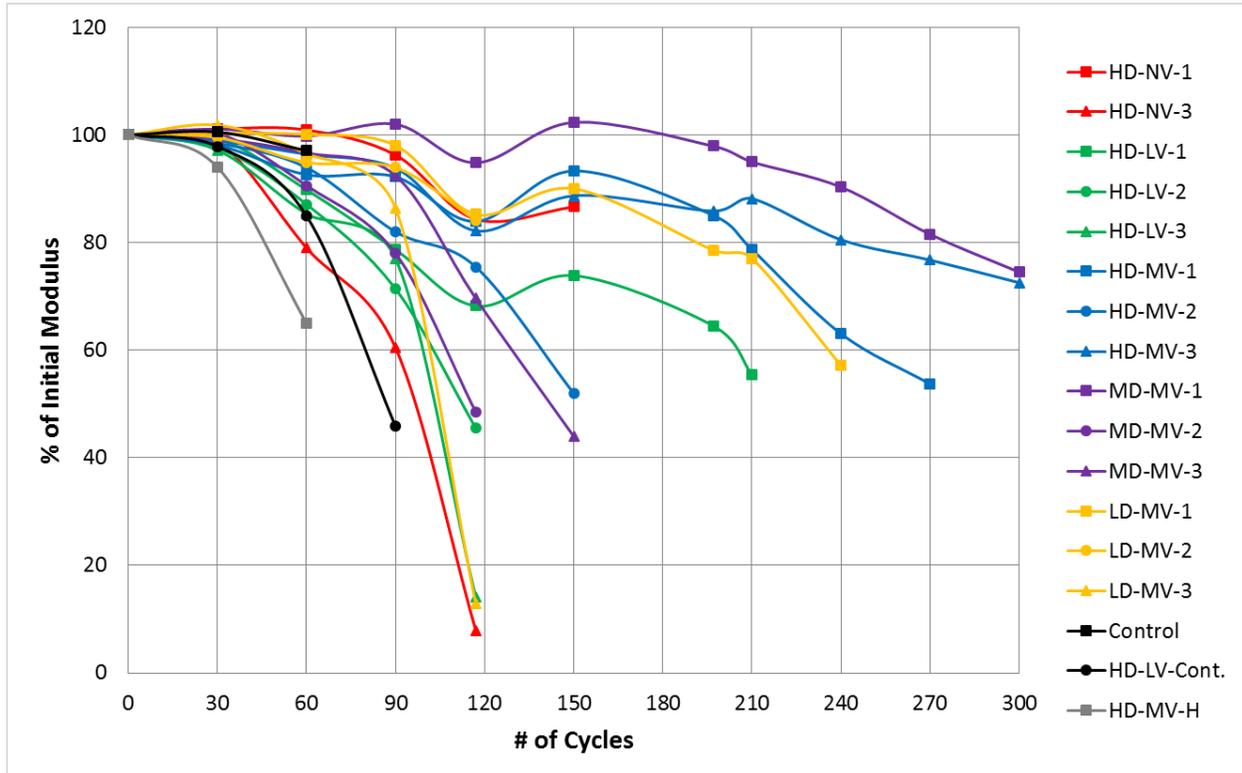


Figure 6. Percent of Initial Modulus vs. Freeze Thaw Cycles

Figure 6 shows that 2 samples retained over 60% of their initial elastic modulus after 300 cycles of freeze thaw. These samples were MD-MV-1 at a final elastic modulus of 75% and HD-MV-3 with a final elastic modulus of 73%. With one notable exception, the samples with no or little vibration performed similar or marginally better than the control specimens. The best performing location appears to be the HD-MV samples with two of the three samples making it to 270 cycles or more.

Figure 7 shows the average cycles to failure for each location. A key takeaway from Figure 7 is the confirmation that on average, HD-MV samples exhibited the greatest freeze thaw resistance. The next best in order were MD-MV and LD-MV. This shows a clear trend that with medium vibration the higher grout dosage the better the performance. Next, it is clear the no or little vibration performed the worst on average. Based on these observations, it appears that vibration is the most important factor for achieving freeze-thaw resistance, with grout dosage being secondary. This is likely a combination of how well the air entrained grout is mixed with the RCC as well as the compaction that occurs during vibration which helps to reduce permeability.

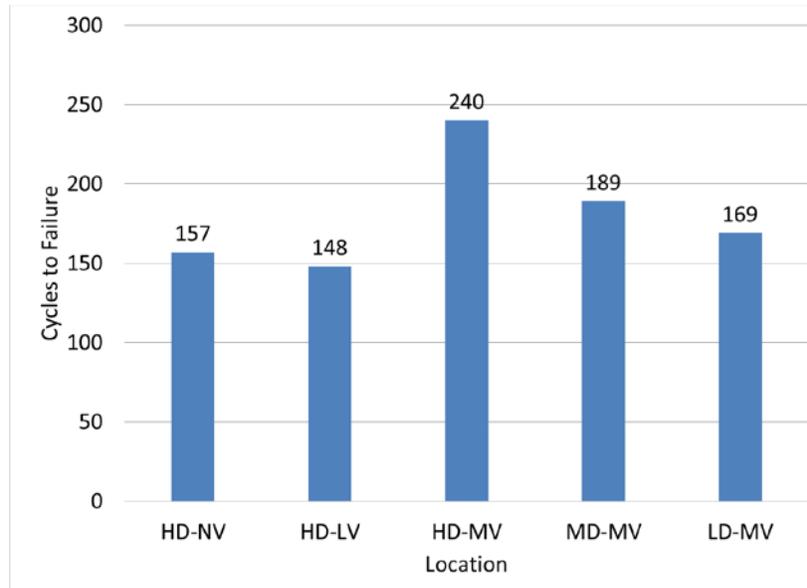


Figure 7. Average Cycles to Failure per Location

3.4.1. Specimen Weight Loss

Weight loss was monitored for all 17 samples during the freeze thaw testing. Results were encouraging, with 9 out of 14 “non-control” samples maintaining 60% or more of their mass. Table 3 includes the average weight retained per location. The highest average weight retained was HD-NV, in contrast to expectations. This location only had 2 samples, which could skew the data when compared to locations with 3 samples. Putting HD-NV aside, the best performing locations all had medium vibration at various levels of dosage. This supports the observations made during elastic modulus testing. When evaluating individual samples, the best performing was a HD-MV sample, which retained 93% of its initial mass. Additionally, the five samples that retained greater than 85% of their initial mass had either high grout dosages or medium vibration (2 HD-MV, 1 MD-MV, 1 LD-MV and 1 MD-LV). This further highlights the benefit of both increased vibration and increased grout dosage.

3.4.2. Grout Coverage vs. Freeze Thaw Performance

Table 3 also shows the average grout coverage compared to the average cycles to failure on the basis of location. The two locations with the highest coverage correlated to the highest freeze thaw durability. The remaining three locations show a loose correlation but do not have an exact coverage to location trend. This can be explained by the fact that one weak spot in a sample that has “90% coverage” can cause the entire sample to fail if that area of pure RCC deteriorates early in the testing while the remaining 90% still has little damage. Additionally, the compaction plays a role in the freeze thaw resistance as better compaction can reduce the permeability of the sample. This could lead to lower freeze thaw resistance for samples with insufficient compaction, even if the grout coverage is sufficient as is seen in the HD-LV samples.

Table 3: Percent of Weight Retained after 300 Cycles

Location	Avg. % Coverage	Avg. # Cycles to Failure	Avg. % Weight Retained
HD-NV	69	157	77.3
HD-LV	80	148	49.3
HD-MV	88	240	76.7
MD-MV	87	189	67.8
LD-MV	68	169	63.7
Control	0	90	38.1

4. CONCLUSIONS

The results from the research program described above support the following conclusions:

- Injection of grout into the RCC is an effective way to produce GERCC, particularly if air entrained grout is used
- The grout formation developed in this research program provides a stable air void system that is not degraded by reasonable internal vibration
- Freeze thaw resistance is increased with increased internal vibration. This is due to increased grout distribution as well increased compaction of the sample
- Freeze thaw resistance is increased with increasing grout dosage.

This study produced some of the first field produced GERCC samples that passed the freeze-thaw requirements of ASTM C666, but improvements can still be made. Some suggestions for future investigation include:

- Evaluating GERCC with AEA added to the RCC to evaluate the improvement in freeze thaw resistance
- Developing techniques that more thoroughly combines the grout and RCC to reduce or eliminate zones of RCC within the GERCC zone that do not get combined with grout
- Develop an automated process to produce GERCC that includes grout injection, mixing of RCC and grout, as well as compaction in order to further speed production and increase quality.

5. ACKNOWLEDGMENTS

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