# Use of Cold-Weather Simulation to Analyze Concrete-Rock Interface Behavior

Joshua Barger [1*], Kenya Avina [1], Mitchell Geier [1]

[1] *Department of Civil Engineering, Construction Management and Environmental Engineering, Northern Arizona University, Flagstaff, AZ, USA,*

**Email:* chun-hsing.ho@nau.edu *(corresponding author)*

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The most common source of failure for tunnel lining occurs at the excavated surface. In turn, the following research was developed to confront the problems associated with cold weather climate's effect on concrete and the adhering connection between the concrete and the excavated rock surface. An analysis of the interface between concrete and three types of rock surfaces will be tested in respect to the bonding strength. Then the specimens will be subjected to freeze-thaw cycles in order to simulate one year of freezing and thawing and undergo bonding testing in order to determine the rate at which adhesion strength is lost when undergoing cold weather environment. The results of this project are to be determined based on the observations and data obtained to date.

Keywords: cold weather; freeze-thaw; interface; concrete rock; polymers; fibers

## 1.0 Introduction

This research project's purpose is to create an understanding of new concrete designs that are able to withstand the demands of high altitude tunnel construction. Results from the research are to help further the advancement of high altitude, cold climate, and reusable concrete design. The situation that creates the demand for this research is the Chinese government's proposition of a new national highway across the high mountains of the Himalayas into Tibet. This project will call for multiple tunnels for a roadway to travel through. The reinforcing inside of the tunnels must be able to be constructed at high altitude, in extreme cold, and be strong enough to support the tunnel structure. In collaboration with Dr. Shen and his Chinese research team, the team intends to analyze the interface between rock and concrete that has been subjected to a cold weather environment. To do so, the team will test several samples which include three different types of interfaces, different types of rock, and will subject the samples to a cold weather simulation using Freeze- Thaw testing. Three separate interfaces will be included throughout testing.

## 2.0 Project Background

### *2.1 Past Findings*

The project is conducted at Northern Arizona University Engineering Department by undergraduate students. The materials used in this project includes tools and materials for making concrete and testing specimen. The equipment that is utilized are the hydraulic compression press, the freeze-thaw cycle machine, stone saw, cement mixing drum, and lab oven. The conditions of the freeze-thaw machine are that the limit of number of samples is 32 that can fit in the machine at one time. This makes a strategic placement of samples in the machine to meet the cycle number required for each sample.

Past studies show how intermediate drying periods, moisture content and moisture affect freeze-thaw testing. Aging, along with freezing and thawing, cause deterioration in concrete at quicker rates [1]. Other research proved that cold weather concrete mixtures treated with non-chloride accelerators and certain polymer admixtures provide higher protection against freezing at ambient temperatures [2].

### *2.2 Project Constraints*

This project has constraints that project must meet to yield meaningful data. Due to the limited time in the school semester of this capstone class, all tasks must be completed before the end of the semester on December 8th. This time limit must include the maximum number of freeze-thaw cycles. Each sample is constrained to having at least fifty freeze-thaw cycles before testing. Lastly, the design concrete must have a compressive strength of 3,000 psi to be utilized in testing.

Through the creation of the cubic specimens, the concrete mix design will remain constant while the surface of the rock will be defined as the variable. In doing so, the results gained will not be dependent on the concrete design. Rather, the studies and findings will represent the differences from surface to surface, as well as the effects of the rapid freeze-thaw cycles has on the interface between the rock and concrete seam. The client requires that the team use an admixture in the mix by the name of AKKRO-7T, which is a liquid bonding admixture. In addition to this admixture, the client also recommends that the team use FIBERMESH 150, a multifilament synthetic fiber, which improves cohesion. In addition to the freeze-thaw testing, each specimen will undergo a modified split tension test in order to identify the load versus displacement for each. The specimens will be tested in varying increments of 50 freeze-thaw cycles.

## 3.0 Experimental Program

### *3.1 Specimen Design*

In order to create a representation of tunnel lining, 5”x5”x5” cubic specimens consisting of a 2.5” layer of concrete poured onto a 2.5” layer on sandstone. A model of the specimen can be seen in Figure 1. The sandstone was shaped into three types of rock surfaces: smooth, semi-rough, and rough defined by no saw cuts, cuts at ½ inch, and ¼ inch, respectively seen in Figure 2. A large plywood mold was created in which specimens of the selected rock surfaces were placed and poured with concrete.

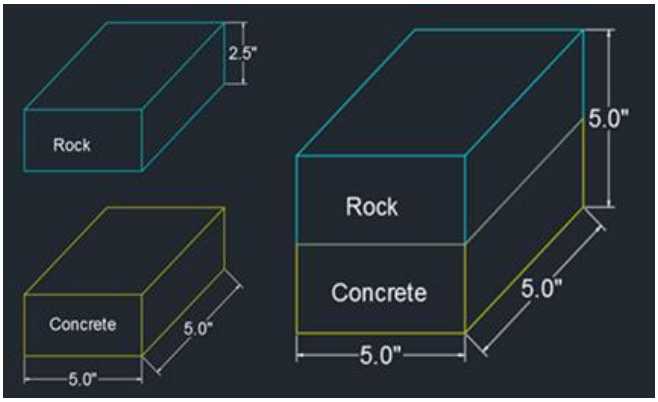


Figure 1: Model of Specimen Design

Figure 2: Flagstone surfaces: rough (left), semi-rough (middle), smooth (right)

The concrete mix was set to be used as conventional concrete with an addition of admixture and fiber. The concrete was composed of QUIKRETE 5000, a commercial grade blend for rapid high strength concrete composed of Portland cement, sand, aggregate or stone [3], AKKRO-7T a liquid bonding admixture [4], and FIBERMESH 150 for reinforcement [5].

*3.1.1 Preliminary Testing*

Preliminary testing was done in order to provide a concrete design mix that met a minimum strength requirement of 2500 psi. The portions were defined by the design mix specified in Table 1. As can be seen in the figure in Figure 3, the aggregate proportion was too high, and the mix was modified throughout a total of 6 trials. The concrete trial samples were mixed and left to curate for 7 days before undergoing a compression strength test based on the ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens [6]. Ingredient

Table 1: Original design mix proportions

| Design Mix per Specimen | | |
|---|---|---|
| **Ingredient** | **Quantity (lbs)** | **Proportion (%)** |
| Cement (QUIKRETE) | 1.123 | 14 |
| Water | 0.539 | 7 |
| Fine Aggregate | 2.178 | 26 |
| Coarse Aggregate | 4.396 | 53 |

Figure 3: Specimens for preliminary testing, original design mix (farthest left), modification improvements (left to right)

The proportions specified in Figure 4 demonstrate final design mix used for the specimens, and the quantities in pounds per specimen can be seen in Table 2. The largest portion of the mix was QUIKRETE which contained 20-30% of cement [3]; this information was used to modify the water portion to reach a water to cement ratio of 0.48. The addition of the fibers and admixture were very minimal and were used for the sole purpose of aiding the concrete under the freeze-thaw conditions.


Figure 4: Design mix proportions

Table 2: Original design mix proportions

| Design Mix per Specimen | | |
|---|---|---|
| **Ingredient** | **Quantity (lbs)** | **Proportion (%)** |
| QUIKRETE | 6.839 | 86.06 |
| Water | 1.0295 | 12.96 |
| AKKRO-7T | 0.075 | 0.94 |
| FIBERMESH 150 | 0.003 | 0.04 |

### *3.2.2 Cold-Weather Simulation*

In order to simulate a cold-weather environment, the specimens were subjected to a modified standard for ASTM C666 Resistance of Concrete to Rapid Freezing and Thawing after 7 days of curing. The freeze- thaw procedure would run for a total of 300 cycles at temperature ranges of 4 to $-18^{0}$ C [7]. The modification of the procedure derived from the dimensions of the specimens and the bins used to accommodate for the shape of the specimens.

Figures 5: Specimens undergoing freeze - thaw cycles

### *3.2.3 Interface Strength Testing*

The specimens were to be subjected to a splitting tensile test after intervals of 60 freeze-thaw cycles: 0, 60, 120, 180,240, and 300. A modification of the ASTM C496 Splitting tensile Strength of Cylindrical Concrete Specimens will be used with extensometers placed on both sides of the specimen [8]. The set up can be seen in Figure 6. Given that the specimens were not cylindrical in shape they were to be observed in their failure behavior. Based on the behavior of cylindrical specimens subjected to a load, the specimens were assumed to behave in a similar manner as can be seen in Figure 7; however, observations were made and recorded to verify predictions.

Figure 6: Specimen, before test, with placed extensometers on each side

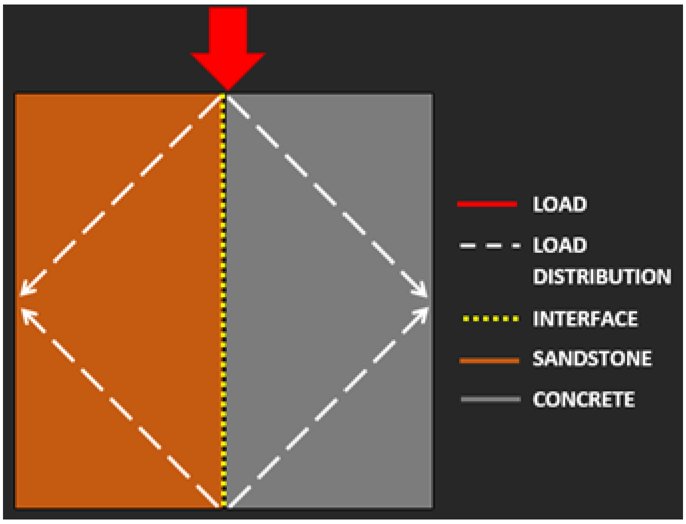


Figure 7: Illustration of the load distribution throughout the specimen

## 4.0 Findings and Analysis

### *4.1 Data Interpretation*

The concrete design mixture was tested in compression strength using the ASTM C39 test. The compressive test was conducted at both four days of curing and seven days of curing. The compressive failure stress of the purely concrete specimen in compression was 3.6 KSI at four days and 4.4 KSI at seven days of curing. The failure stress at seven days of curing is approximately 65% of the 28 day failure strength [9]. From this we can equate our 28 day strength to be approximately 5.94 KSI for our concrete design.

After the 5 inch cube specimen are created, control samples of no modified ASTM C666 test cycles are tested via the modified ASTM C496 test. The average results of the control test interface strengths are as follows; smooth surface stress of 296 psi, semi-rough surface stress of 362 psi, and rough surface stress of 253 psi. As seen if table 3, the spread of the failure stresses is approximately 30% for those tests with more than one result for a surface failure.

Table 3: Failure stress results of modified splitting test on the interface for 0 and 60

| Interface Failure Stress (Psi) | | | | |
|---|---|---|---|---|
| Date | Cycles | **Rough** | **Semi- Rough** | **Smooth** |
| 11/10/2017 | 0 | 232 | N/A | 236 |
| 11/28/2017 | 0 | 372 | 252 | 328 |
| 12/13/2017 | 0 | 154.8 | 472.4 | 324.8 |
| 12/13/2017 | 60 | 328.8 | 210 | 171.5 |
| 12/13/2017 | 60 | 292.8 | 574.8 | 118.4 |
| 12/13/2017 | 60 | 290.4 | 278 | 282.4 |

After undergoing the ASTM 666 freeze-thaw testing at 60 cycles, the interface failure stress appears to have trended downwards. The failure stress for the specimen interfaces that have 60 freeze-thaw cycles result in the rough interface failing at an average of 304 psi, semi-rough interface failing at an average of 244 psi, and smooth interface failing at an average of 191 psi as seen in table 3. These averages are taken to neglect outliers. From here, the results of the zero cycle and 60 cycle tests can be compared as shown in Figure 8. After undergoing the freeze-thaw testing, it appears that all the interface tension strengths are trending downwards at an average rate of 19% of the average initial interface strength per 60 of the freeze-thaw cycles.

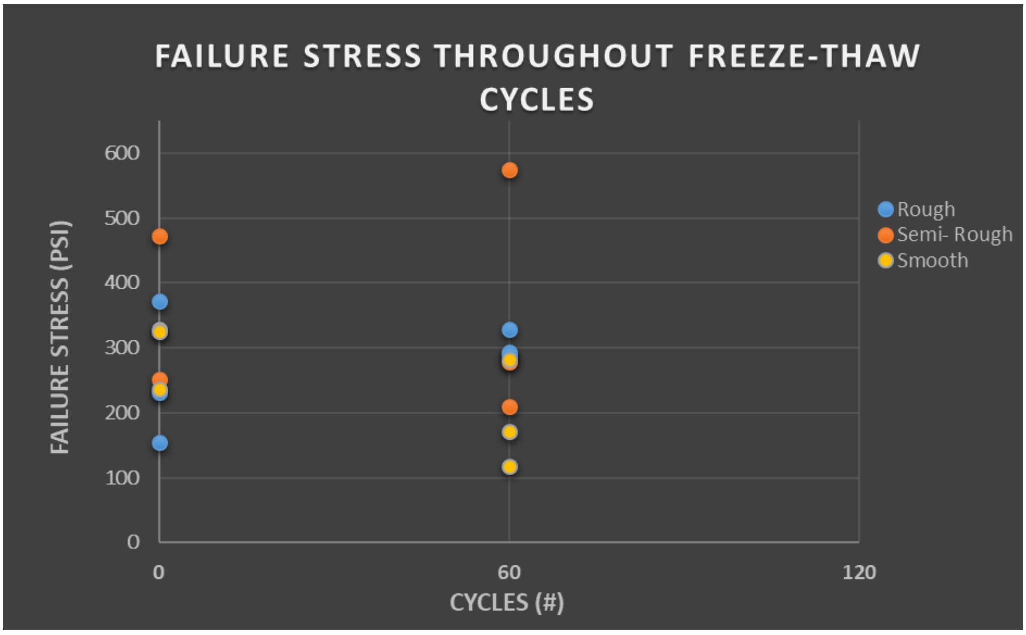


Figure 8: Failure stress trend of modified splitting test on the interface for 0 and 60

The data that has been collected so far is only of the control samples and of 60 freeze-thaw cycles, and therefore cannot be used to determine the long-term effect of the freeze-thaw testing on the interface of the specimen.

*4.2 Failure Behavior*

The failure of each of the specimen is recorded and shown to be similar amongst those with similar surface roughness. The tension failure of the specimen from the modified ASTM C496 test occurred at different locations in each type of specimen. Those specimen that have a smooth interface surface have failed at the interface of the stone and concrete as seen in Figure 9. Do note that the specimen shown in Figure 9 are representative of the majority of specimen tested. Those specimen that have a semi-rough interface have failed in a plane in the flagstone as seen in Figure 9. The specimen that have a rough interface have failed in a plane in the flagstone, also seen in Figure 9.

Figure 9: Representative control specimen failure planes of each type of surface roughness

actual

| | |
|---|---|
| | Critical Setbacks |
| | Future Work |

Each failure is at the weakest point of the specimen. For these specimen that do not have the smooth interface, the limiting factor of the interface tension strength is the weakest layer in the flagstone. Otherwise, those with a smooth interface find the weakest point of the specimen as the bond between the two materials.

## 4.0 Project Schedule

### *4.1 Project Progress Summary*

Based on the planned project schedule from the previous semester, seen in Appendix A, the project was predicted to complete a total of 250 cycles before the end of November. However, as seen in the updated project schedule in Appendix B, the project experienced delays and modifications that predicts the completion of 300 cycles by the end of January. Table 4 displays a schedule comparison; critical setbacks occurred at mixing stage of the project. Initially, the mixing was assumed to consist of one trial of the provided concrete design mix to obtain the design strength. However, various trials of the modified design delayed the overall progress of the project. The freeze-thaw cycles also contributed to the setbacks due to the increase of cycles and the inconsistencies within the recordings of that caused an overall shut down of the machine for two weeks. Setbacks were also encountered during the testing portion of the project due to the previous setback from the freeze-thaw machine as well as the having to alternative testing equipment from the 400K Tinnius Olsen to perform the splitting test and obtain the failure stress. The tasks presented in grey are those that have been started but are yet to finish, but will continue to proceed past the end of the term.

## 5.0 Cost Analysis

### *5.1 Material Costs*

Table 4: Project schedule comparison between predicted and updated to date

| Task ID | Task Name | Old Schedule Start | Old Schedule Finish | New Schedule Start | New Schedule Finish |
|---|---|---|---|---|---|
| **1.0** | **Project Start Up and Analysis** | **8/29/2017** | **11/16/2017** | **8/29/2017** | **11/16/2017** |
| 1.1 | Background Research | 8/29/2017 | 9/14/2017 | 8/29/2017 | 9/14/2017 |
| 1.2 | Material Consideration | 9/15/2017 | 9/22/2017 | 9/15/2017 | 9/22/2017 |
| 1.3 | Scheduling | 9/15/2017 | 10/4/2017 | 9/13/2017 | 11/20/2017 |
| 1.3.1 | Meeting 1 | 9/15/2017 | 9/15/2017 | 9/13/2017 | 9/13/2017 |
| 1.3.2 | Meeting 2 | 9/18/2017 | 9/18/2017 | 9/20/2017 | 9/20/2017 |
| 1.3.3 | Meeting 3 | 9/20/2017 | 9/20/2017 | 9/28/2017 | 9/28/2017 |
| 1.3.4 | Meeting 4 | 9/27/2017 | 9/27/2017 | 10/9/2017 | 10/9/2017 |
| 1.3.5 | Meeting 5 | 10/4/2017 | 10/4/2017 | 10/16/2017 | 10/16/2017 |
| 1.3.6 | Meeting 6 | - | - | 10/31/2017 | 10/31/2017 |
| 1.3.7 | Meeting 7 | - | - | 11/1/2017 | 11/1/2017 |
| 1.3.8 | Meeting 8 | - | - | 11/10/217 | 11/10/217 |
| 1.3.9 | Meeting 9 | - | - | 11/20/2017 | 11/20/2017 |
| 1.4 | Cost Estimating | 9/15/2017 | 10/4/2017 | 9/15/2017 | 10/4/2017 |
| 1.5 | Code and Standards Research | 9/5/2017 | 9/22/2017 | 9/5/2017 | 9/22/2017 |
| **2.0** | **Laboratory Work** | **9/8/2017** | **10/31/2017** | **9/8/2017** | **11/11/2017** |
| 2.1 | Laboratory Safety Training | 9/8/2017 | 9/8/2017 | 9/8/2017 | 9/8/2017 |
| 2.2 | Equipment Training | 9/11/2017 | 9/11/2017 | 9/11/2017 | 9/11/2017 |
| 2.3 | Mixing | 9/12/2017 | 9/13/2017 | 9/20/2017 | 11/10/2017 |
| 2.3.1 | Prelimenary Mixing and Testing | - | - | 9/20/2017 | 10/26/2017 |
| 2.3.2 | Specimen Mixing | - | - | 11/1/2017 | 11/1/2017 |
| 2.4 | Sample Molding | 9/14/2017 | 9/15/2017 | 10/20/2017 | 10/21/2017 |
| 2.5 | Curing | 9/18/2017 | 10/25/2017 | 11/1/2017 | 11/8/2017 |
| 2.6 | Laboratory Maintenance | 9/18/2017 | 9/18/2017 | 9/20/2017 | 11/11/2017 |
| **3.0** | **Data Collection** | **9/18/2017** | **11/16/2017** | **11/8/2017** | **1/27/2018** |
| 3.1 | Freeze-Thaw Cycles | 9/18/2017 | 11/9/2017 | 11/8/2017 | 1/26/2018 |
| 3.2 | Tensile and Compression Testing | 9/28/2017 | 10/30/2017 | 11/10/2017 | 2/8/2018 |
| 3.2.1 | ~~50 Cycles~~ 0 Cycles | 9/25/2017 | 9/25/2017 | 11/10/2017 | 11/15/2017 |
| 3.2.2 | ~~100 Cycles~~ 60 Cycles | 10/5/2017 | 10/5/2017 | 11/27/201 | 12/9/2017 |
| 3.2.3 | ~~150 Cycles~~ 120 Cycles | 10/16/2017 | 10/16/2017 | 12/10/2017 | 1/3/2018 |
| 3.2.4 | ~~200 Cycles~~ 180 Cycles | 10/25/2017 | 10/25/2017 | 1/3/2018 | 2/8/2018 |
| 3.2.5 | -- 240 Cycles | 11/6/2017 | 11/6/2017 | 11/27/2017 | 1/24/2018 |
| 3.2.6 | ~~250 Cycles~~ 300 Cycles | - | - | 11/27/2017 | 1/27/2018 |
| **4.0** | **Data Analysis** | **8/29/2017** | **11/16/2017** | **11/27/2017** | **2/15/2017** |
| 4.1 | Result Assessment | 11/7/2017 | 11/8/2017 | 11/27/2017 | 2/10/2018 |
| 4.2 | Statistical Analysis | 11/9/2017 | 11/13/2017 | 2/10/2018 | 2/15/2018 |
| **5.0** | **Project Management** | **8/29/2017** | **11/16/2017** | **8/29/2017** | **12/14/2017** |
| 5.1 | Supervising | 8/29/2017 | 11/10/2017 | 8/29/2017 | 12/14/2017 |
| **6.0** | **Presentation of Deliverables** | **11/14/2017** | **11/16/2017** | **11/28/2017** | **12/14/2017** |
| 6.1 | Assembly of Final Report | 11/14/2017 | 11/15/2017 | 12/8/2017 | 12/14/2017 |
| 6.2 | Assembly of Final Presentation | 11/16/2017 | 11/16/2017 | 11/28/2017 | 11/30/2017 |
| 6.3 | Website Development | 11/16/2017 | 11/16/2017 | 12/10/2017 | 12/14/2017 |

| | |
|---|---|
| (blue) | Major Tasks |
| (yellow) | Critical Setbacks |
| (grey) | Future Work |

Located below is a table summarizing the material costs throughout the duration of the project. The majority of the material costs derived from the machinery used throughout the testing process, which thankfully was already provided by the department laboratory. The remaining costs came from the basic materials used to mix and create our samples which include the QUIKRETE cement, the fiber-mesh and the AKKRO-7T polymer admixture.

Table 5: Material Costs

| Item | Quantity | Unit | Rate | Total |
|---|---|---|---|---|
| **Material** | **18** | **per item** | **$232.01** | **$417.26** |
| Cement Type III- Quikrete | 3 | bag | $23.09 | $69.27 |
| Fine Sand- Quikrete | 7 | bag | $3.72 | $26.04 |
| Aggregate | 1 | cyd | $15.00 | $15.00 |
| FiberMesh150 | 4 | bag | $12.25 | $49.00 |
| AKKRO-7T | 1 | bag | $97.95 | $97.95 |
| Tile Saw Rental | 2 | day | $80.00 | $160.00 |
| **Others** | **9** | | **$1,580.00** | **$2,880.00** |
| 400K Tinius Olsen | 4 | day | $300.00 | $1,200.00 |
| Hydrolic Press | 3 | day | $200.00 | $600.00 |
| Software | 1 | each | $1,000.00 | $1,000.00 |
| Resources | 1 | each | $80.00 | $80.00 |
| **Overall Project Cost** | | | | **$3,297.26** |

*5.2 Labor Costs*

Below is a similar table representing the labor costs for each task based on the respective prices of the project manager, research assistant and lab technician. Because the project manager is the most expensive, his work was limited compared to the research assistant and lab technician, however he was most involved with the project start up and analysis, in comparison. The majority of the team's time and therefore costs were designated to the laboratory work.

Table 6: Material Costs

| Task | Classification | | | Cummulative Labor | Labor Total |
|---|---|---|---|---|---|
| | PM | RS | LT | | |
| | $75/hr | $40/hr | $44/hr | (hrs) | ($) |
| Project Start Up and Analysis | 33 | 29 | 10 | 72 | $ 4,075.00 |
| Laboratory Work | 130 | 130 | 145 | 405 | $ 21,330.00 |
| Data Collection | 25 | 30 | 36 | 91 | $ 4,659.00 |
| Data Analysis | 6 | 23 | 28 | 57 | $ 2,602.00 |
| Presentation of Deliverables | 9 | 15 | 17 | 41 | $ 2,023.00 |
| **Total Service Distribution** | **192** | **213** | **217** | **622** | **$34,689.00** |

## 6.0 Project Impacts

The impacts of this project are far reaching. Socially, the value of the project conclusion is to realize the connection of communities with the utilization of a tunnel between those communities. Economically, the utilization of a tunnel will allow for increased trade between newly connected communities. Environmentally, the emissions from longer alternate routes will be saved due to the utilization of a tunnel. These impacts are what is expected from the conclusions of the rock-concrete interface design of this project.

## 7.0 Conclusion and Recommendations

### *7.1 Testing Conclusion*

The results of the testing that was done on the interfaces of the specimen are not complete to the desired 300 freeze-thaw cycles. Yet, conclusions from the control tests show that the highest tension stress achieved at the interface is 0.38 KSI with a roughly surfaced specimen. The failure location of this specimen is along one of the flagstone layers with traces of concrete filling the cuts of the rough surface. It is concluded that the added roughness of the surface increased the tensile strength of the stone-concrete bond.

### *7.2 Project Continuation*

As noted in the project schedule summary above, the team was not able to complete the initially planned requirements. Due to machinery malfunction, delays became present and the team was forced to leave the remainder of the project and the specimens included to a graduate team for completion. A continuing graduate student team will complete the remaining freeze-thaw cycles and continue to test them in the same manner at 60 cycle increments until the desired 300 cycles has be achieved. These results will then be tabulated similarly to the ones currently provided and will be submitted to the team’s technical advisor. From here, the project results of analysis for a full 300 cycles will be eligible for submission to an academic journal.

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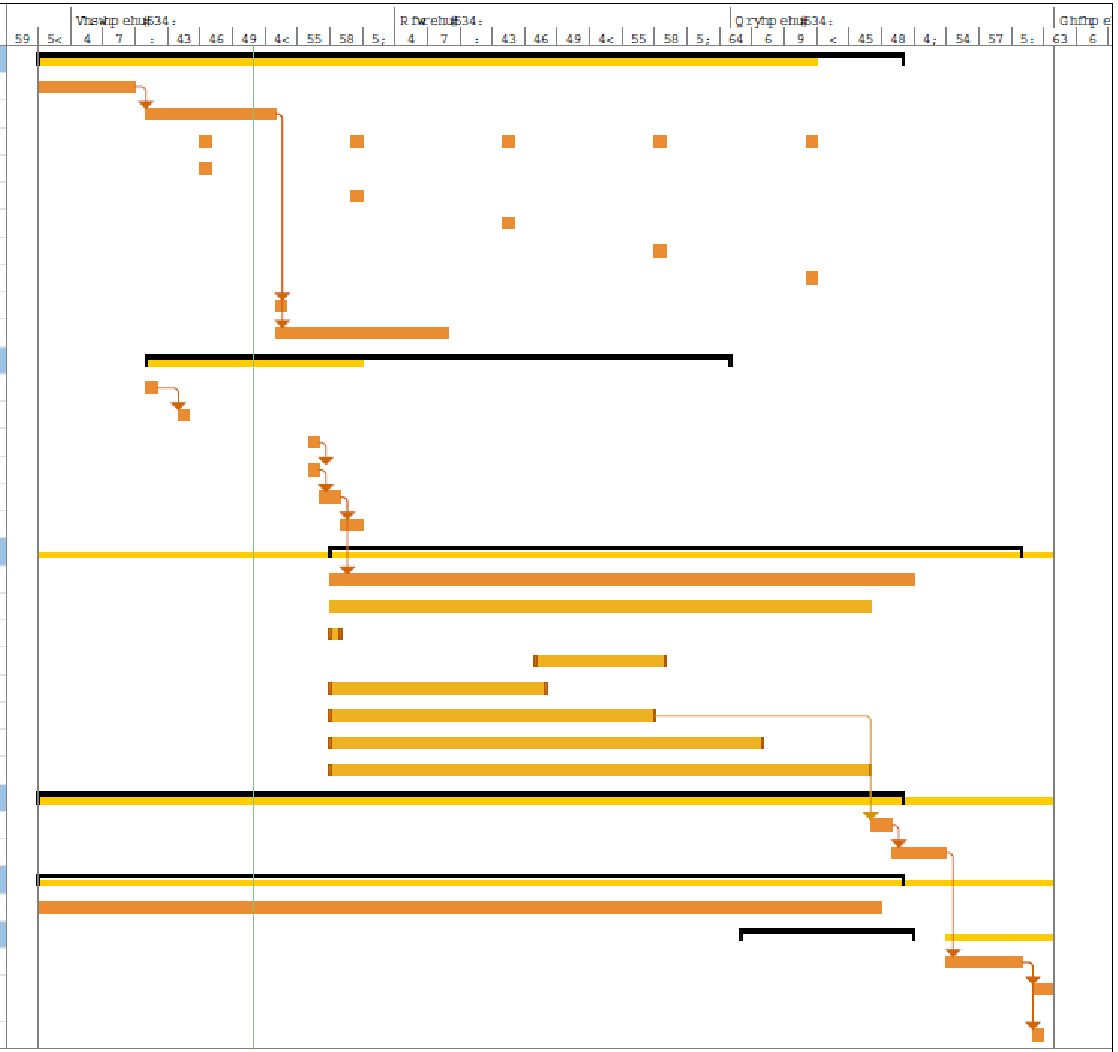
# Appendix A

| LG | Wdvn#LG | Wdvn#Qdph | Gxudwlrq | Vwduw | Ilqlvk |
|---|---|---|---|---|---|
| 4 | **1.0** | **Project Start Up and Analysis** | **60 days** | **Tue 8/29/17** | **Thu 11/16/17** |
| 5 | 1.1 | Background Research | 7 days | Tue 8/29/17 | Wed 9/6/17 |
| 6 | 1.2 | Material Consideration | 8 days | Fri 9/8/17 | Tue 9/19/17 |
| 7 | 1.3 | Scheduling | 43 days | Wed 9/13/17 | Wed 11/8/17 |
| 8 | | Meeting 1 | 1 day | Wed 9/13/17 | Wed 9/13/17 |
| 9 | | Meeting 2 | 1 day | Wed 9/27/17 | Wed 9/27/17 |
| : | | Meeting 3 | 1 day | Wed 10/11/17 | Wed 10/11/17 |
| ; | | Meeting 4 | 1 day | Wed 10/25/17 | Wed 10/25/17 |
| < | | Meeting 5 | 1 day | Wed 11/8/17 | Wed 11/8/17 |
| 43 | 1.4 | Cost Estimating | 1 day | Wed 9/20/17 | Wed 9/20/17 |
| 44 | 1.5 | Code and Standards Research | 14 days | Wed 9/20/17 | Thu 10/5/17 |
| 45 | **2.0** | **Laboratory Work** | **40 days** | **Fri 9/8/17** | **Tue 10/31/17** |
| 46 | 2.1 | Laboratory Safety Training | 1 day | Fri 9/8/17 | Fri 9/8/17 |
| 47 | 2.2 | Equipment Training | 1 day | Mon 9/11/17 | Mon 9/11/17 |
| 48 | 2.3 | Mixing | 1 day | Sat 9/23/17 | Sat 9/23/17 |
| 49 | 2.4 | Sample Molding | 1 day | Sat 9/23/17 | Sat 9/23/17 |
| 4: | 2.5 | Curing | 2 days | Sun 9/24/17 | Mon 9/25/17 |
| 4; | 2.6 | Laboratory Maintenance | 2 days | Tue 9/26/17 | Wed 9/27/17 |
| 4< | **3.0** | **Data Collection** | **46 days** | **Mon 9/25/17** | **Mon 11/27/17** |
| 53 | 3.1 | Freeze-Thaw Cycles | 40 days | Mon 9/25/17 | Fri 11/17/17 |
| 54 | 3.2 | Tensile and Compression Testing | 40 days | Mon 9/25/17 | Fri 11/17/17 |
| 55 | | 0 Cycles | 1 day | Mon 9/25/17 | Mon 9/25/17 |
| 56 | | 50 Cycles | 9 days | Sat 10/14/17 | Wed 10/25/17 |
| 57 | | 100 Cycles | 16 days | Mon 9/25/17 | Sat 10/14/17 |
| 58 | | 150 Cycles | 22 days | Mon 9/25/17 | Tue 10/24/17 |
| 59 | | 200 Cycles | 30 days | Mon 9/25/17 | Fri 11/3/17 |
| 5: | | 250 Cycles | 36 days | Mon 9/25/17 | Mon 11/13/17 |
| 5; | **4.0** | **Data Analysis** | **60 days** | **Tue 8/29/17** | **Thu 11/16/17** |
| 5< | 4.1 | Result Assessment | 2 days | Tue 11/14/17 | Wed 11/15/17 |
| 63 | 4.2 | Statistical Analysis | 3 days | Thu 11/16/17 | Mon 11/20/17 |
| 64 | **5.0** | **Project Management** | **60 days** | **Tue 8/29/17** | **Thu 11/16/17** |
| 65 | 5.1 | Supervising | 58 days | Tue 8/29/17 | Tue 11/14/17 |
| 66 | **6.0** | **Presentation of Deliverables** | **12 days** | **Thu 11/2/17** | **Fri 11/17/17** |
| 67 | 6.1 | Assembly of Final Report | 5 days | Tue 11/21/17 | Mon 11/27/17 |
| 68 | 6.2 | Assembly of Final Presentation | 2 days | Wed 11/29/17 | Thu 11/30/17 |
| 69 | 6.3 | Website Development | 1 day | Wed 11/29/17 | Wed 11/29/17 |



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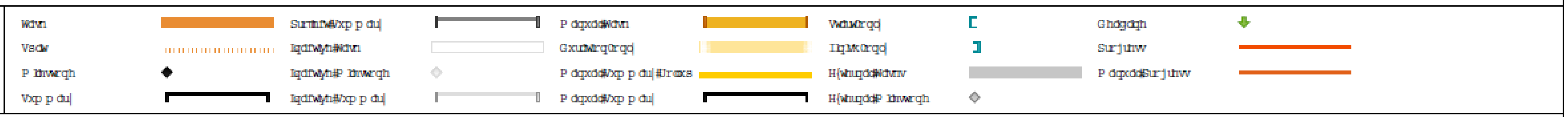
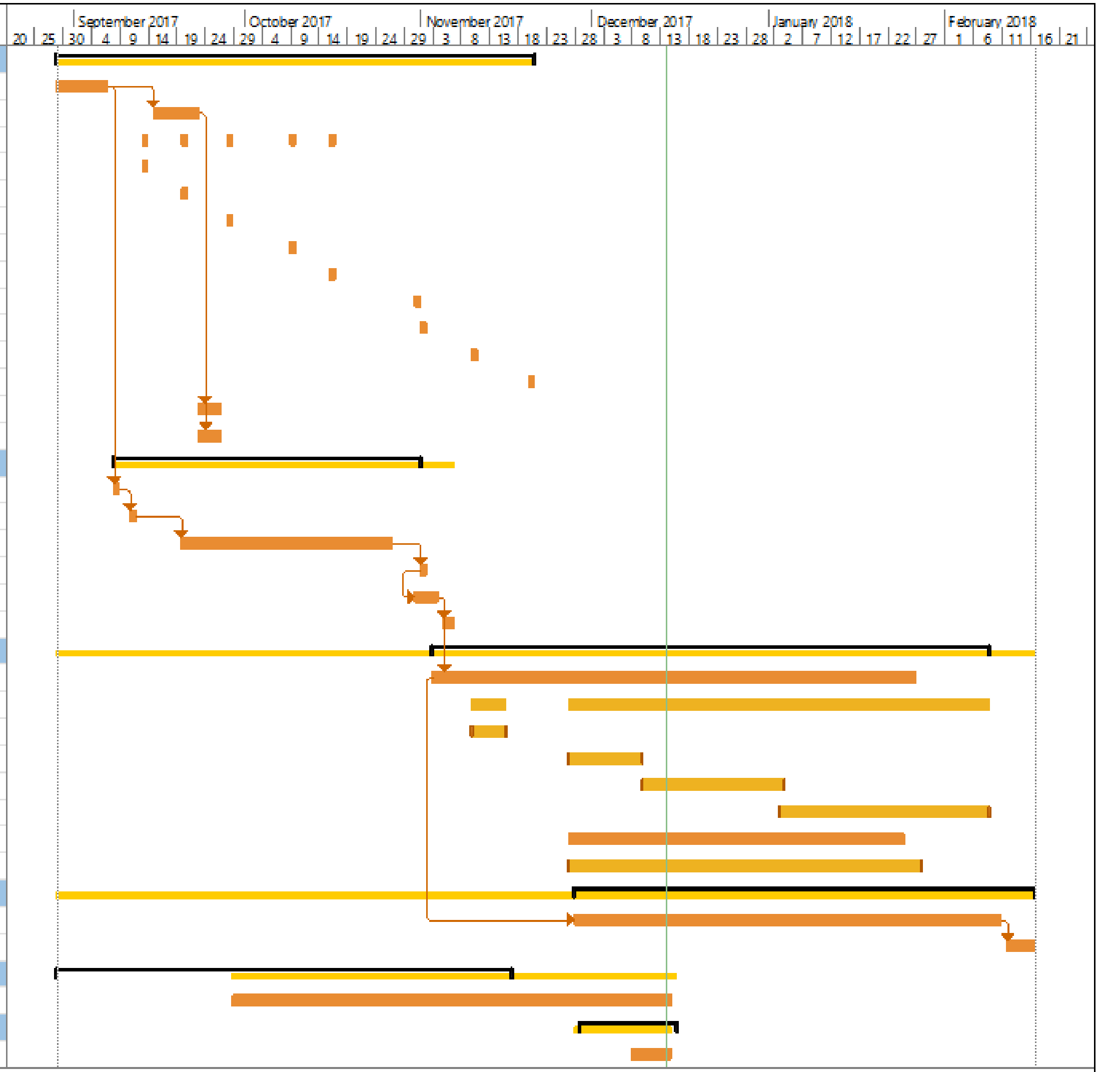


# Appendix B

| ID | Task ID | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 1 | **1.0** | **Project Start Up and Analysis** | **64 days** | **Tue 8/29/17** | **Mon 11/20/17** |
| 2 | 1.1 | Background Research | 7 days | Tue 8/29/17 | Wed 9/6/17 |
| 3 | 1.2 | Material Consideration | 6 days | Fri 9/15/17 | Fri 9/22/17 |
| 4 | 1.3 | Scheduling | 53 days | Wed 9/13/17 | Mon 11/20/17 |
| 5 | | Meeting 1 | 1 day | Wed 9/13/17 | Wed 9/13/17 |
| 6 | | Meeting 2 | 1 day | Wed 9/20/17 | Wed 9/20/17 |
| 7 | | Meeting 3 | 1 day | Thu 9/28/17 | Thu 9/28/17 |
| 8 | | Meeting 4 | 1 day | Mon 10/9/17 | Mon 10/9/17 |
| 9 | | Meeting 5 | 1 day | Mon 10/16/17 | Mon 10/16/17 |
| 10 | | Meeting 6 | 1 day | Tue 10/31/17 | Tue 10/31/17 |
| 11 | | Meeting 7 | 1 day | Wed 11/1/17 | Wed 11/1/17 |
| 12 | | Meeting 8 | 1 day | Fri 11/10/17 | Fri 11/10/17 |
| 13 | | Meeting 9 | 1 day | Mon 11/20/17 | Mon 11/20/17 |
| 14 | 1.4 | Cost Estimating | 4 days | Sat 9/23/17 | Tue 9/26/17 |
| 15 | 1.5 | Code and Standards Research | 4 days | Sat 9/23/17 | Tue 9/26/17 |
| 16 | **2.0** | **Laboratory Work** | **40 days** | **Fri 9/8/17** | **Tue 10/31/17** |
| 17 | 2.1 | Laboratory Safety Training | 1 day | Fri 9/8/17 | Fri 9/8/17 |
| 18 | 2.2 | Equipment Training | 1 day | Mon 9/11/17 | Mon 9/11/17 |
| 19 | 2.3 | Mixing | 29 days | Wed 9/20/17 | Thu 10/26/17 |
| 20 | 2.4 | Sample Molding | 1 day | Wed 11/1/17 | Wed 11/1/17 |
| 21 | 2.5 | Curing | 4 days | Tue 10/31/17 | Fri 11/3/17 |
| 22 | 2.6 | Laboratory Maintenance | 2 days | Sun 11/5/17 | Mon 11/6/17 |
| 23 | **3.0** | **Data Collection** | **73 days** | **Fri 11/3/17** | **Thu 2/8/18** |
| 24 | 3.1 | Freeze-Thaw Cycles | 64 days | Fri 11/3/17 | Fri 1/26/18 |
| 25 | 3.2 | Tensile and Compression Testing | 67 days | Fri 11/10/17 | Thu 2/8/18 |
| 26 | | 0 Cycles | 5 days | Fri 11/10/17 | Wed 11/15/17 |
| 27 | | 60 Cycles | 11 days | Mon 11/27/17 | Sat 12/9/17 |
| 28 | | 120 Cycles | 19 days | Sun 12/10/17 | Wed 1/3/18 |
| 29 | | 180 Cycles | 27 days | Wed 1/3/18 | Thu 2/8/18 |
| 30 | | 240 Cycles | 43 days | Mon 11/27/17 | Wed 1/24/18 |
| 31 | | 300 Cycles | 46 days | Mon 11/27/17 | Sat 1/27/18 |
| 32 | **4.0** | **Data Analysis** | **60 days** | **Tue 11/28/17** | **Fri 2/16/18** |
| 33 | 4.1 | Result Assessment | 55 days | Tue 11/28/17 | Sat 2/10/18 |
| 34 | 4.2 | Statistical Analysis | 5 days | Mon 2/12/18 | Fri 2/16/18 |
| 35 | **5.0** | **Project Management** | **62 days** | **Tue 8/29/17** | **Thu 11/16/17** |
| 36 | 5.1 | Supervising | 58 days | Fri 9/29/17 | Thu 12/14/17 |
| 37 | **6.0** | **Presentation of Deliverables** | **13 days** | **Wed 11/29/17** | **Fri 12/15/17** |
| 38 | 6.1 | Assembly of Final Report | 5 days | Fri 12/8/17 | Thu 12/14/17 |




Project: Simple Project Plan
Date: Thu 12/14/17

| | | | |
|---|---|---|---|
| Task | Project Summary | Manual Task | Start-only |
| Split | Inactive Task | Duration-only | Finish-only |
| Milestone | Inactive Milestone | Manual Summary Rollup | External Tasks |
| Summary | Inactive Summary | Manual Summary | External Milestone |
| Deadline | Progress | Manual Progress | |