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EVALUATION OF CONCRETE MIXES FOR FILLING THE STEEL ARCHES IN THE GALENA CREEK BRIDGE

June 2002

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16. Abstract

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To accomplish this objective, two mixes were developed utilizing a survey given to the surrounding states and input from local interviews. The two mixes were then tested for strength, shrinkage, segregation, bleeding and pumpability.

The results of the trial mixes show that both mixes performed adequately in their properties. They both were successfully pumped into the steel tubes and remained uniform throughout the entire length of the steel tubes. Both mixes had minimal bleeding, segregation, and shrinkage.

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Evaluation of Concrete Mixes for Filling the Steel Arches in the Galena Creek Bridge

Report No. CCEER 02-05

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Abstract

NDOT's design of the Galena Creek concrete arch bridge requires filling the four structural tubes that are part of the steel frame with a concrete or grout mix. This composite action between the steel and the concrete/grout will increase the strength of the structure by about forty percent. The main objective of this research project was to develop an adequate mix design and the most efficient way to pump it into the structural steel tubes.

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Chapter 1

Introduction

1.1 Introduction

This report covers the investigation of the concrete/grout mix that will be used for the four corner 16-inch x 16-inch x ½-inch structural steel tubes that are part of each arch span of the Galena Creek Bridge. Filling the tubes with a concrete or grout will increase the strength of the frame by about forty percent. Basic guidelines were given for this fill material. The fill material must have at least a 5000 psi (pounds per square inch) compression capacity. The material must be pumpable and the maximum aggregate should not exceed 3/8”. The maximum angle of inclination for the tubes is thirty-five degrees.

1.2 Objective

The objective of this project was to develop and test concrete/grout options for the filling of the structural tubes that are part of the NDOT alternative for the Galena Creek concrete arch bridge. The arch provides several challenges including the distance that the concrete/grout will need to travel, the method needed to pump the mix into the tubes, and the need for the concrete/grout to fill the entire tube.

1.3 Background

In the NDOT alternative for the concrete arch, a steel tube arch is constructed initially. Once the arch is constructed over Galena Creek, the hollow structural tubes of the arch, see cross-section of the arch frame Figure 1-1, will be filled with either a concrete or a grout mix to create composite action. After filling the tubes, concrete will be placed around the truss in order to form the concrete arch. The tubes will act as part of the primary reinforcement for the arch.

The structure as a whole will consist of two arch spans with sixty-two feet decks. The arch will span a length of 689-feet with the largest vertical clearance approximately 302-feet. The vertical distance of the arch itself is approximately 130-feet. It is necessary to pump the concrete/grout under pressure to be sure that all parts of the tube are filled. The arch will be constructed in 80-foot segments. The filling of the tubes could be done in segments, multiple segments or by filling half of the arch at a time. If each segment is done individually, access becomes an issue for the higher segments in the arch, since the concrete/grout must be delivered to each segment. NDOT has indicated a need for a 5000-psi compressive strength mix that is low to non-shrinkage.

1.4 Scope

The scope of this project was to develop and test several mix designs. A survey was conducted to provide a starting point for this project. The survey asked members of the surrounding state transportation departments about their experience and exposure to pumping concrete into tubes and their opinions concerning the tubes of the arch bridge. Interviews of Reno suppliers and contractors were also conducted. Based on the surveys and interviews, two mix designs were developed and tested for pumpability, bleeding, compressive strength, shrinkage and segregation.

Two sets of tests were conducted. The preliminary tests for each mix design consisted of: two 10-foot x 6-inch pipe systems to test for bleed water and later for compression strength, a cylindrical container to test for bleed water, cylinders molded to test for compression strength, and rectangular prisms molded to test for shrinkage. The field tests for each mix design consisted of: an 80-foot structural steel tube placed at an eighteen degree angle and filled with the mix design to test for pumpability and uniformity, a 5-foot tube filled with the mix design to test for axial strength, cylinders molded to test for compression strength, and rectangular prisms molded to test for shrinkage.

Chapter 2 of this report provides information on the selecting of the mix designs tested for this project. Chapter 2 also contains descriptions of the test methods used to determine the performance of the mix designs selected. Chapter 3 gives the results of the tests performed as well as some discussion of those results. Chapter 4 provides specific conclusions and recommendations on the mix designs based on the test results.

Experimental Program

2.1 Introduction

It is essential that an adequate mix design be found to fill the structural tubes of the arched bridge. In order for the composite action to occur, the tubes have to be completely filled with concrete and the shrinkage has to be minimal. The mix design developed will have to be pumpable, have to keep its uniformity (no segregation), have little or no shrinkage, and meet the 5000-psi stress requirement.

2.2 Surveys

To develop a mix design and procedure for pumping the mix into the tubes of the arch bridge a survey was sent to the transportation departments and Federal Highway Administration headquarters in Alaska, Arizona, California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, and Washington. The survey included a cover letter, short description of the project, a questionnaire, and pictures of the simulated bridge and cross-section of the frame with the steel tubes at the four corners, see Appendix A-1.

Thirty-two surveys were sent out. The survey provided questions on pumping experience in general and pumping through horizontal, vertical and inclined tubes. It also asked about experience with pumpable mixes and suggestions for the mix design needed and how to place it in the tubes. Nine surveys were returned expressing that they had no useful information. Seven surveys were returned with responses to the questions. The responding surveys came from the Departments of Transportation in Alaska, Arizona, Colorado, New Mexico, Oregon and Washington. The information received is summarized in Appendix A-2. Two specific responses are provided in the following paragraphs.

Ted Barber of New Mexico's Department of Transportation suggested a grout mix with high cement content and a superplasticizer to increase flowability. He suggested that the mix be pumped from the bottom up through the tube to prevent segregation.

Michael McMulley of Colorado's Department of Transportation sent some information on a smaller scale but similar project (7). In this project a composite pedestrian bridge was constructed using steel tubing 14 inches in diameter and approximately ½-inch thick. The arch is about 11.5-feet tall with a span of about 92-feet, see Figure 2-1. The arch is composed of four segments separated by transverse walls. Each segment had an opening at the lowest point designed to hook up to a pumping facility and a hole at the top for deairing. High strength concrete was pumped into the tube segments until it came out of the deairing openings then both ends were closed off. The mix used in the pedestrian bridge project was composed of a fine aggregate gradation, i.e. a grout mix. This arch was successfully constructed by pumping the tube in sections from the bottom up and using a grout mix.

2.3 Interviews

Nine concrete distributors and concrete pumping companies locally were interviewed, see Appendix A-3. Information gathered from these interviews presented mixed views on the pumping procedure needed to fill the structural tubes. Pumping from the top down would require vibrating the mix to ensure consolidation. Since vibrating the mix is not an option due to inability of access, pumping from the bottom up to prevent air voids and segregation provides for the better option.

Mark Baker of Reno Sparks Ready Mix created two specific mix designs to try. They were composed of fine aggregates, and a low water/cement ratio. They included fly ash for workability, superplasticizer for workability and prevention of segregation, and a shrinkage reducer.

CB Concrete company and American Ready-Mix also provided some mix designs from prior jobs. These mixes were not designed specifically for this project and they did not meet all desired criteria. The mix designs provided by CB Concrete were all composed of aggregate greater than 3/8" and did not include a shrinkage-compensating admixture. The mix designs provided by American Ready-Mix were designed for a 4000 psi compressive strength and did not include a shrinkage-compensating admixture.

2.4 Selection of Concrete/Grout Mix Design

Based on the surveys and interviews, the mix designs developed for testing are a type of grout mix (composed of fine aggregates) and tests were conducted by pumping the mix through the tubes from the bottom up to prevent air voids and segregation.

Of the three concrete mixing companies that provided mix designs, the two mixes designed by Mark Baker of Reno Sparks Ready-Mix were chosen as the best candidates for testing. These mixes were specifically designed to meet the criteria specified. Both mix designs contained a high cement content and low water/cement ratio to provide the required strength of 5000 psi. The maximum aggregate for both mixes was a #8 stone; this was well below the required 3/8-inch maximum aggregate. Fly ash and a superplasticizer were included to provide workability, pumpability, and uniformity (non-segregating). A shrinkage reducer was added to both mix designs to minimize the shrinkage.

The two mix designs are similar, but have the following variations. Mix design one, which will be referred to as the 8-sack mix, has 639 pounds per cubic yard (pcy) of cement, 113 pcy of fly ash, a water cement ratio of .34, and an aggregate ratio of 50/50 (#8 aggregate/sand), see Table 2-1. The second mix design, which will be referred to as the 8.5-sack mix, has 679 pcy of cement, 120 pcy of fly ash, a water cement ratio of .35, and an aggregate ratio of 40/60 (#8 aggregate/sand), see Table 2-2. Both mix designs contained the same admixtures.

2.5 Preliminary Testing

The mix design that will fill the tubes of the arch bridge will need to meet specific standards. The mixes were tested for the strength requirement of 5000 psi, minimal shrinkage, minimal bleeding, no indication of segregation, and the ability for the mix to be pumped successfully up the tubes. Two different bleed water tests, a compressive strength test, and a shrinkage test were performed.

2.5.1 Bleeding and Pumpability

Two vertical 10-foot PVC pipe systems with a 6-in diameter were constructed for each mix design, see Figure 2-2. The systems allowed for the grout to be pumped through the tubes from the bottom. The purpose of this test was to check the amount of bleed water and quality of the grout after pumping. After the curing process, 1-foot segments were cut from top, middle, and bottom of each tube. The PVC pipe was then removed. The specimens were given a visual inspection for uniformity, see Figure 2-3, and then are subjected to a compression strength test conforming to ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (6).

2.5.2 Compressive Strength Test for Cylindrical Concrete Specimens (ASTM C 39)

The purpose of this test was to determine the compressive strength of the grout specimens. This test was performed at 7-days, 14-days, 28-days, and 56-days after the casting of each mix design. For this test, cylindrical concrete specimens with a 6-in diameter and 12-in length were molded, see Figure 2-4, and moist cured for the designated time periods. Neoprene pads were placed at the ends of the specimens and then a testing machine was used to apply an axial load until failure, see Figure 2-5. The maximum load attained was recorded and divided by the cross-sectional area to obtain the compression strength (1).

2.5.3 Length Change Test of Hardened Hydraulic-Cement Concrete (ASTM C 157)

The purpose of this test was to determine the length change or shrinkage of the grout mixes due to factors other than externally applied forces and temperature changes. The grout mixes were placed in prisms that were 3-in x 3-in x 11.25-in with metal gage studs at the center of each end, see Figure 2-6. After a day, the molds were removed and an initial reading was taken using the length comparator, see Figure 2-7 (5). The prisms were placed into two different curing atmospheres to compare the difference in the shrinkage rates. Half of the specimens of each mix were moist cured, see Figure 2-8, and the other half were air cured, see Figure 2-9. Readings were taken at 7, 14, and 28 days, and 8 and 16 weeks. The length comparator readings at each test age were compared to the initial length comparator reading to calculate the shrinkage of the concrete, which was measured in microstrains (3).

2.5.4 Bleeding of Concrete Test (ASTM C 232)

The purpose of this test was to determine the relative quantity of mixing water that would bleed from the specimen. A metal bucket 11-in in height and 10-in in diameter was filled with the grout mixture and weighed. A cover was placed over the specimen to prevent evaporation of the bleed water, see Figure 2-10. Water was drawn off the surface with a pipet every ten minutes for the first forty minutes and then every thirty minutes thereafter until the bleeding finalized. The amount of water removed was recorded (4).

2.6 Field Test—Full Scale Structural Tubes

After the preliminary testing, a full scale test was conducted with two 80-foot structural tubes inclined and pumped from the bottom to the top. The pump used was a model 4045 trailer line pump with an 800-psi concrete pressure capacity, see Figure 2-11. Two smaller structural tubes, one-fourth scale of the original structural tubes, were also designed to be filled with the two different grout mixes. The smaller tubes were tested to obtain their compression strength capacity. A compressive strength test, a shrinkage test, and a slump flow were also performed.

2.6.1 The 80-Foot Structural Tubes

Two 80-foot tubes that were 16-inches x 16-inches x 5/16-inches were designed with plates at both ends. The 80-foot structural tubes were inclined at an eighteen-degree angle, see Figure 2-12. They were supported by the ground at one end and at a horizontal distance of 53 feet from the ground support a second support composed of a frame system, see Figure 2-13. The frame support was connected to the wall with four tensioned rods, see Figure 2-14. Figure 2-15 shows the actual steel frame mounted on the wall. A different grout mix was pumped into each tube from the lowest point, see Figure 2-16. The grout traveled up the pipes through two check valves, one every 25 feet, and then continued to be pumped until it came out of the top valve. Figure 2-17 shows the two 80-foot tubes resting on the framing system with the check valves seen pointing upward. After curing for twenty-one days the tubes were lifted to the ground and cut into five 5-foot sections, a 3-foot section and then at the very end of the tube, two 1-ft sections, see Figure 2-18. The tubes were cut to observe the uniformity of the grout mixture and to see if the pumping process successfully turned the system into one composite form i.e. no air voids or gaps.

2.6.2 The 60-Inch Structural Tubes

Two 4-inch x 4-inch x 1/8-inch structural tubes were designed with a plate and pin connection at both ends, see Figure 2-19. The distance from pin to pin was 60 inches. The tubes were both filled with the same mix. They contained the higher cement grout i.e. the 8.5-sack mix. After curing for 25 days, the tubes were placed in the vertical testing machine, see Figure 2-20, and axially loaded to failure.

2.6.3 Compressive Strength Test for Cylindrical Concrete Specimens (ASTM C 39)

This test was again repeated for the full-scale grout pour. The purpose of this test was to determine the compressive strength of the grout specimens. This test was performed at 7-days, 14-days, 25-days, and 28-days after the casting of each mix design. Unlike the first compressive strength tests, this time the cylinders were stored outside in their plastic molds simulating the curing process that will take place during the actual erection of the arch frame.

The molds were not removed until the day they were tested. The maximum load attained is recorded and divided by the cross-sectional area to obtain the compression strength.

2.6.4 Length Change Test of Hardened Hydraulic-Cement Concrete (ASTM C 157)

The purpose of this test was to determine the length change or shrinkage of the grout mixes due to factors other than externally applied forces and temperature changes. Half the specimens of each mix were moist cured and the other half were air cured. Readings were taken at 7, 14, and 28 days. The length comparator readings at each test age were compared to the initial length comparator reading to calculate the shrinkage of the concrete, which was measured in microstrains.

2.6.5 Slump Flow Test

The purpose of this test was to measure the unconfined flow of the grout mix. The grout was shoveled into the slump cone and then the cone was lifted away and the concrete was allowed to spread laterally, see Figure 2-21. The diameter was taken at two locations perpendicular to each other and then recorded (10).

Chapter 3

Experiment Results

3.1 Introduction

This section describes the results from the preliminary tests and the full-scale field tests. The two mix designs chosen for testing were evaluated through the series of tests described in Chapter 2. The two bleed water tests and the strengths for both mixes are discussed. The shrinkage of each grout mix from the length change test was calculated and is evaluated. A visual examination of the uniformity for the 10-foot pipe systems is presented. For the full-scale test the repeated compressive strength and shrinkage data is analyzed. The axial load and stress for the 60-inch tubes subjected to the vertical-testing machine were evaluated and are compared. And the full-scale 80-inch tubes were cut up after being pumped with each mix design and cured for the designated time period. The tubes were subjected to a visual inspection and this will be discussed.

3.2. Compressive Strength

To determine the resistance of the grout mixes to axial loading, the compressive strength test was very critical. The specified strength requirement for both of the trial mix designs was 5000 psi.

For the compression tests performed on the two different mix designs during the preliminary testing, the strengths for both mixes were above what was required as seen in Table 3-1. The strength requirement of 5000 psi was met by the 14-day mark for both mix designs. At the 28-day curing period (when the minimum strength requirement should be met) the specimens were tested to be 6590 psi and 6700 psi, for the 8-sack and the 8.5-sack mix respectively. The detailed compressive strength data for the 7, 14, 28, and 56-day curing periods are given in Tables 3-2 through 3-5. At the 7-day curing period the 8.5-sack mix was 290 psi higher in compressive strength than the 8-sack. At 14 days the 8.5-sack mix was still higher in compressive strength but the difference between the two mix designs decreased to 170 psi. At 28 days the 8.5-sack mix increased in strength, but dropped slightly below the 8-sack mix. Then at 56 days the 8.5-sack mix regained its higher strength with a 110 psi margin. The comparison between the two mix designs is shown in Figure 3-1.

For the field testing with the full-scale structural steel tubes, the compression test results are summarized in Table 3-6. The 28-day strengths were 6787 psi and 7128 psi, for the 8-sack and the 8.5-sack mix respectively. These strengths are well above the required 5000 psi strength that must be met. The early compression strengths were not as high in comparison to the preliminary compression strengths, but the later compression strengths were actually a little higher than the preliminary compression strengths. The detailed compressive strength data for the 7, 14, 25, and 28-day curing periods are given in Tables 3-7 through 3-10. After 7 days of curing the 8.5-sack mix was 624 psi greater in strength than the 8-sack mix. At 14 days the 8.5-sack mix was 677 psi above the 8-sack mix. At 25 days the 8.5-sack mix was 836 psi above the 8-sack mix. At 28 days the 8.5-sack mix was 341 psi above the 8-sack mix. The comparisons between the two mix designs are shown in Figure 3-2.

3.3 Bleeding

Bleeding is the migration of water to the top surface of freshly placed concrete or grout caused by the settlement of the solid materials (8). Bleeding can effect the durability of the mix and can also cause the mix to shrink. These two adverse effects are important in determining an adequate mix design for this project.

In attempting to perform both bleed water tests, data was unable to be collected due to the lack of water that bled up to the surface. According to the ASTM C 232 Bleeding of Concrete Test, a lack of rising water concluded that there was not enough bleed water to calculate the volume of bleed water per unit area of surface or the percent of water in the specimen that will bleed. This test ran a duration of two hours for each of the two mix designs and no water was able to be collected from either mix design.

The second attempt at measuring the bleed water in the mixes came from the pumping of the 10-foot PVC pipes. The pipes were left to cure for almost three months and during that duration the grout mixes contained within the tubes did not show any signs of bleeding or shrinkage indicated by the hole in the top of the apparatuses that were checked periodically.

The two tests provided positive results toward the insignificance of bleed water in the mix designs. There were no differences between the two mixes.

3.4 Compressive Strength for the Grout Pumped into the PVC Pipes

The compression test provided positive results. The average strengths were 7085 psi and 7715 psi, for the 8-sack and 8.5-sack mix respectively. These strengths were well above the required strength of 5000 psi. The detailed compressive strength data is given in Table 3-11.

In comparing the results from these cylinders cut from the PVC tubes with the cylinders made during the two concrete pours, the cylinders that were pumped tested as having a higher strength.

The visual inspection as seen in Figure 2-3 concluded that the mix remained uniform during the pumping and curing process. An issue was the concern of segregation. Figure 2-3 and other cross-sections show how well the mix stayed uniform. There were no differences between the two mixes.

3.5 Shrinkage

To obtain the increased strength in the arched structure from the grout filled tubes, it is essential for the steel and grout to form a composite system. Shrinkage can hinder this composite action. The goal was to obtain a mix design with minimal shrinkage. The Federal Highway Administration categorizes concrete into different performance grades depending on their amount of shrinkage, see Table 3-12.

The changes in length of the shrinkage specimens for both the preliminary testing and the field testing are summarized in Tables 3-13 and Table 3-14 respectively. The specimens numbered one through three were cured in the moisture room and the specimens numbered four through six were air cured. The negative numbers indicate expansion in the grout. The specimens that cured in the moisture room tend to display expansion due to the ability of the grout to constantly absorb water.

Both mix designs fell into Performance Grade Three, which is described as good, for shrinkage. The length changes in the preliminary tests indicated a larger shrinkage rate for the 8.5-sack mix design. The detailed length change data is given in Table 3-15. The length changes for the field testing set of tests were only continued through to the 28-day period due to lack of time, but according to the data collected up to this point, the rate of shrinkage for the two mix designs seemed to be fairly close in relation to each other. The detailed length change data is given in Table 3-16.

3.6 Slump Flow

The test result for both mix designs was a diameter of 13 inches see Table 3-17. According to the range of slump flow values in this test procedure the data collected was irrelevant to any type of evaluation concerning this test. The ranges specified in the testing procedure are all in the twenties; the data collected from the grout mixes were too low. Although too low for the specified test, the flow was sufficient for pumping.

3.7 The 80-Foot Structural Tubes

The cross-sections of the steel/grout system were very solid and uniform. Figure 3-3 through Figure 3-5 show cross-sections of the tube containing the mix design with the 8-sack of cement. Figure 3-6 through Figure 3-8 show cross-sections of the tube containing the 8.5 sack cement. The numbering is detailed in Figure 2-17. The damages done to the cross-sections as seen in the pictures were a result of the cutting process, due to the large size of the tubes the blades were unable to cut clean through the tube. The cutting process was a mixture of two different blades trying to cut through the tubes and some lifting and lowering of the tubes at the cuts to allow them to shear apart into the sections. Figures 3-9 and 3-10 show the machine and two different blades used in the cutting process. The 15-foot segments are seen in Figure 3-11.

The end plates were burned off to check the grout at the very top. This procedure concluded that the grout mix in each tube had successfully filled the entire tube and was still uniform in composition where the tube met the plate.

Due to the 5/16-inch walls of the steel tubes, deformation occurred on the lower portion of the tubes. The maximum deformations were 1 inch and 1½ inches for the tubes containing the 8-sack cement and the 8.5 sack cement respectively. The deformation in the actual structure will not be an issue because the wall thickness of the tubes are ½ inch.

3.8 The 60-inch Structural Tubes

Sixty-inch structural tubes were made to test the compressive capacity of the system. These 4-inch x 4-inch x 1/8-inch structural steel tubes had difficulty being pumped full of grout. They were designed with a 1-inch diameter opening for the grout. This diameter was determined so as not to initiate a decrease in the axial strength of the steel. The pump was unable to decrease the pressure low enough to allow the grout mix to sufficiently enter into the tube without jamming up the aggregate in the 1-inch diameter pipe.

The alternative was to burn off one end plate and hand pack the grout mix into the pipes with the aid of a vibrator, see Figure 3-11. This change in filling the tubes provided for some issues during the axial load test. These issues included: unequal bearing of the tube on the plate under compression, the field weld connection of the plate back on the tube, some generation of eccentricity, and an understanding that the mix was not pumped, simulating the actual proposed procedure.

The axial strength interpolated from the Composite Column Tables in the LRFD Manual for Steel Construction was 127.4 kips (9). This was based on an fy of 46 ksi and an f'c of 5 ksi. Hand calculations using actual concrete strength and a fy of 46 ksi determined a capacity of 159.4 kips. The actual fy is not known. The axial force vs. strain for the two tests are shown in

Figures 3-13 and 3-14. The maximum axial forces for the first and second tubes were 187 kips and 182 kips respectively.

The stress vs. strain curves for the two tests are displayed in Figure 3-15. The peak stresses for the first and second tubes were 11.75 ksi and 11.3 ksi respectively.

Both members failed in the same region. As seen in Figures 3-16 through 3-19 the buckling was accomplished in the lower region of the members near the plate that had been welded back on after filling the steel tubes with the grout mix. Buckling occurred on all four sides of both tubes. The buckling was uniform and therefore shows symmetric loading. The buckling at the field welded end may indicate a small gap existing between the end plate and the concrete. Therefore the steel was loaded more than the concrete. The concrete did crush inside the tube as seen in Figure 3-20.

Chapter 4

Summary, Conclusions, and Recommendations

4.1 Summary

To ensure a proper mix design that will successfully and completely fill the cross-sections of the arch in the Galena Creek bridge certain criteria must be considered. The criteria discussed in this report are: the minimum 5000 psi compressive strength, the need for a non-segregating uniform mix design, little or no shrinkage, the prevention of bleed water, and the ability for the mix to be pumped into the tubes.

Surveys taken from the surrounding states and local interviews provided information on the method in which the mix should be placed in the tubes. Pumping from the bottom up was found to be a very efficient way of accomplishing a composite system between the concrete and the steel. As seen in the cross-sections, the mixes remained uniform and filled the entire volume of the tubes.

Both mixes proved to be efficient in attaining the required compressive strength. The preliminary compression tests resulted in higher early strength and the field-testing compression tests resulted in higher later strength. The cylinders tested from the PVC pipes had the highest strength.

The shrinkage tests placed both mixes in performance grade three, which is described as good according to the Federal Highway Administration. The shrinkage was a lot greater in the specimens that were air cured verses the specimens that were moist cured. The specimens maintained in the moisture room were constantly exposed to water, which allowed them to absorb moisture and expand. The actual bridge will be between moist and air cured.

Since no bleed water was collected from any of the test specimens, a balanced mix design is indicated. This means the mix designs only contain enough water for the hydration process, which minimizes drying shrinkage.

The large-scale structural steel tubes were pumped successfully and formed a composite action with the grout mixes. The smaller structural steel tubes despite the complications getting the grout inside the tubes, provided good results under the axial loading. The values obtained were above the code capacity values.

4.2 Conclusions

1) The mix designs were successful in meeting the specified compressive strength. Both of the mixes tested met and exceeded the minimum requirement. Essentially three sets of tests were done to establish a strong confidence that the mix designs are able to reach the required strength.

2) Bleed water was not an issue with either of the mix designs tested. No free standing water could be seen at the top of either tube. Bleeding of concrete can indicate a non-uniform mix. This was one indication that the mixes tested were not prone to segregation. This result was a combination of the low water/cement ratio, the shrinkage compensating admixture, the addition of fly ash, and the large amount of fine aggregates. All these conditions aid in the elimination of bleed water.

3) Shrinkage of the grout mixes was still present, but was minimal. According to the Portland Cement Association, the average specimen will experience 34 percent of its shrinkage in the first month. And the amount of shrinkage can be relative to the size of the mass. Smaller masses

tend to have larger shrinkage amounts. Depending on NDOT's specific needs these mixes may need to be tested further. There has been no parameters set or tests done on grout or concrete within a confined environment, but according to current standard set by FHWA the mix designs tested are a grade three which was considered good. This comparison can be made with data given in Tables 3-14 and 3-15 and the standards set by FHWA given in Table 3-13.

4) The 80-ft structural steel tubes were pumped very successfully. Both mixes were able to fill the entire volume of the tubes. The cross-sections provided a clear picture in the ability of the grout mixes to keep their uniform composition through the pumping process and the curing process. Even the top end where the plate was burned off of the tube the grout remained uniform and composite.

5) The 60-inch structural tubes were a positive indication of the strength that can be obtained through the composite action of the grout encased in the steel tube. Both mixes achieved strengths higher than the design strength.

6) The pumping of the mix up through the bottom of the tubes has proven to be a successful method and one in which was probably the most feasible. Both mixes tested are sufficient in contending to be the fill in the Galena Creek Arch Bridge.

4.3 Recommendations

1) Based on the results, both mixes are very adequate to fill the structural steel tubes. No evidence has made one mix design dominate over the other mix design.

2) Pumping from the bottom up worked well. In filling the entire arch system the structure should be broken down into eighty-foot sections that are closed off from one another. The lowest end should have a hook-up for the hose of the pump. It may not be necessary to have three deairing holes per section, but maybe only one at the top allowing the grout mix to come up through. The top hole should be larger than 1 inch in diameter (preferably 2 inch) to prevent the aggregate from jamming in the 1-inch diameter pipe. This issue may be some of the cause in the deformation occurring in the bottom of the tubes.

3) The admixtures used in the two mixes proved to be adequate and the proper quantities for the desired results.

4) The two mixes have indicated a successful guideline for the slump and slump flow requirement needed in the mix design chosen for the fill of the structural tubes.

References

1. ASTM C 39-99 “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,” American Society for Testing and Materials. West Conshochocken, PA 1999.

2. ASTM C 143-99 “Standard Test Method for Slump of Hydraulic Cement Concrete,” American Society for Testing and Materials. West Conshochocken, PA 1999.

3. ASTM C 157-99 “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar Concrete,” American Society for Testing and Materials. West Conshochocken, PA 1999.

4. ASTM C 232-99 “Bleeding of Concrete Test,” American Society for Testing and Materials. West Conshochocken, PA 1999

5. ASTM C 490-99 “Standard Practice for Use of Apparatus for the Determination of Length Changes of Hardened Cement Paste, Mortar, and Concrete. American Society for Testing and Materials. West Conshochocken, PA 1999.

6. ASTM C 617-99 “Standard Practice for Capping Cylindrical Concrete Specimens. American Society for Testing and Materials. West Conshochocken, PA 1999.

7. Fischer, Michael and Konig, Gert. “Composite Pedestrian Bridge Constructed From Unbonded Prestress,” Lacer, No.5 2000.

8. Kosmatka, Steven H. and Panarese, William C., Design and Control of Concrete Mixtures. Portland Cement Association. Skokie, IL, 1994.

9. Load and Resistance Factor Design, Manual of Steel Construction. American Institute of Steel Construction, 1998.

10. MB-RDC-01 “Test Method for Measuring Slump Flow of Hydraulic Cement Concrete,” Master Builders. Cleveland, Oh, 2000.

Table 2-1: #8 Stone, 5000 psi, Non-Air Entrained 3/8” Concrete/Grout, 8-Sack Cementitious, Shrinkage Compensated

MATERIAL	BATCH WEIGHTS	VOLUME	S.G. (SSD)	% by Volume of Mortar (Ttl Mix)
N.C. Type II Cement	639	3.251	3.15	68.81
Chem Comp lll	120	0.652	2.95	
Pozzolanic Fly Ash	113	0.771	2.35	
Water	300	4.808	0	
Air (%)	1.8	0.878	0	**% by Volume of Aggregate (only)**
#8 Paiute	1371	8.421	2.61	50
Sand Paiute	1356	8.421	2.58	50
Total Weight	3911	27		
				Water/Cement Ratio
ADMIXTURES	**oz/100wt & per Yard**	**Oz/Yard**		0.34
Pozzolith 322-N	7	61.04		
Pozzolith 440-N	14	122.08		**Theoretical Unit Wt**
				144.85
				Slump/inch
				9

Table 2-2: #8 Stone, 5000 psi, Non-Air Entrained 3/8” Concrete/Grout, 8.5-Sack Cementitious, Shrinkage Compensated

MATERIAL	BATCH WEIGHTS	VOLUME	S.G. (SSD)	% by Volume of Mortar (Ttl Mix)
N.C. Type II Cement	679	3.454	3.15	75.91
Chem Comp lll	120	0.652	2.95	
Pozzolanic Fly Ash	120	0.818	2.35	
Water	320	5.128	0	
Air (%)	1.8	0.888	0	**% by Volume of Aggregate (only)**
#8 Paiute	1059	6.504	2.61	40
Sand Paiute	1571	9.756	2.58	60
Total Weight	3881	27		
				Water/Cement Ratio
ADMIXTURES	**oz/100wt & per Yard**	**Oz/Yard**		0.35
Pozzolith 322-N	7	64.33		
Pozzolith 440-N	14	128.66		**Theoretical Unit Wt**
				143.75
				Slump/inch
				9

Table 3-1: Compressive Strength (psi) at 7, 14, 28, and 56-Days from Preliminary Testing

Curing Time	8-Sack	8.5-Sack
7-day	4230	4520
14-day	5380	5550
28-day	6140	6100
56-day	6590	6700

Table 3-2: Compressive Strength Test Data for 7-Day Curing from Preliminary Testing

7-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	118750	6	28.3	4200	
	122250	6	28.3	4320	
	118250	6	28.3	4180	**4230**
8.5-Sack	127750	6	28.3	4510	
	128500	6	28.3	4540	
	128000	6	28.3	4520	**4520**

Table 3-3: Compressive Strength Test Data for 14-Day Curing from Preliminary Testing

14-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	146800	6	28.3	5190	
	156280	6	28.3	5520	
	153250	6	28.3	5420	**5380**
8.5-Sack	163710	6	28.3	5780	
	151020	6	28.3	5340	
	156890	6	28.3	5540	**5550**

Table 3-4: Compressive Strength Test Data for 28-Day Curing from Preliminary Testing

28-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	174500	6	28.3	6170	
	172000	6	28.3	6080	
	174500	6	28.3	6170	**6140**
8.5-Sack	172000	6	28.3	6080	
	174500	6	28.3	6170	
	171500	6	28.3	6060	**6100**

Table 3-5: Compressive Strength Test Data for 56-Day Curing from Preliminary Testing

56-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	192000	6	28.3	6780	
	183250	6	28.3	6480	
	184250	6	28.3	6510	**6590**
8.5-Sack	184500	6	28.3	6520	
	197000	6	28.3	6960	
	187500	6	28.3	6630	**6700**

Table 3-6: Compressive Strength (psi) at 7, 14, 25 and 28-Days from Field-Testing

Curing Time	**8-sack**	**8.5-sack**
7-day	2562	3186
14-day	3834	4511
25-day	5754	6590
28-day	6787	7128

Table 3-7: Compressive Strength Test Data for 7-Day Curing from Field-Testing

7-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	58000	6	28.3	2049.469965	
	78500	6	28.3	2773.85159	
	81000	6	28.3	2862.190813	**2562**
8.5-Sack	90750	6	28.3	3206.713781	
	87500	6	28.3	3091.872792	
	92250	6	28.3	3259.717314	**3186**

Table 3-8: Compressive Strength Test Data for 14-Day Curing from Field-Testing

14-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	103000	6	28.3	3639.575972	
	111000	6	28.3	3922.261484	
	111500	6	28.3	3939.929329	**3834**
8.5-Sack	125000	6	28.3	4416.961131	
	124500	6	28.3	4399.293286	
	133500	6	28.3	4717.314488	**4511**

Table 3-9: Compressive Strength Test Data for 25-Day Curing from Field-Testing

28-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	160000	6	28.3	5654	
	165000	6	28.3	5830	
	163500	6	28.3	5777	5754
8.5-Sack	177500	6	28.3	6272	
	190000	6	28.3	6714	
	192000	6	28.3	6784	6590

Table 3-10: Compressive Strength Test Data for 28-Day Curing from Field-Testing

28-day Compression Test					
	Compression Force (lbs)	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	189044	6	28.3	6680	
	200081	6	28.3	7070	
	187063	6	28.3	6610	6787
8.5-Sack	205175	6	28.3	7250	
	201250	6	28.3	7111	
	198750	6	28.3	7023	7128

Table 3-11: Compressive Strength for Cylinders Cut From 10-ft PVC Pumped Tubes

	Area Cut From	**Compression Force (lbs)**	**Diameter (in)**	**Cross-Sectional Area (in^2)**	**Compression Strength (psi)**	**Average Compression Strength (psi)**
8-Sack	Top	185,190	6	28.3	6540	
	Middle	210130	6	28.3	7430	
	Bottom	153350	6	28.3	5420	**6460**
	Top	219540	6	28.3	7760	
	Middle	218970	6	28.3	7740	
	Bottom	215980	6	28.3	7630	**7710**
8.5-Sack	Top	216960	6	28.3	7670	
	Middle	212180	6	28.3	7500	
	Bottom	215050	6	28.3	7600	**7590**
	Top	212960	6	28.3	7530	
	Middle	227040	6	28.3	8020	
	Bottom	225220	6	28.3	7960	**7840**

Table 3-12: Federal Highway Administration Performance Grades (16)

Shrinkage Grades		
FHWA HPC Performance Grade	**Description of Grade**	**Shrinkage (microstrains)**
3	good	<400
2	moderate	400-600
1	poor	600-800
0	very poor	>800

Table 3-13: Preliminary Testing Length Changes

Accumulative Length Changes							
8-Sack		**7-day**	**14-day**	**28-day**	**8-wks**	**12-wks**	**16-wks**
moist cured	1	35	49	39	50	37	39
	2	56	63	45	63	58	63
	3	-51	-38	-60	-41	-52	-46
air cured	4	33	64	78	124	127	132
	5	34	68	82	125	132	134
	6	22	64	82	120	128	133
8.5-Sack							
moist cured	1	49	60	48	65	38	62
	2	-43	-41	30	48	51	54
	3	58	51	3	-31	53	61
air cured	4	51	70	95	145	151	153
	5	52	77	98	163	251	255
	6	58	79	100	168	249	263

***The negative (-) indicates expansion.**

Table 3-14: Field-Testing Length Changes

Accumulative Length Change				
8-Sack		**7-day**	**14-day**	**28-day**
moist cured	1	-31	-28	-26
	2	-30	-25	-22
	3	-56	-53	-51
air cured	4	42	76	92
	5	47	83	109
	6	61	90	107
8.5-Sack				
moist cured	1	-15	-12	-10
	2	-6	-14	-7
	3	-12	-14	-7
air cured	4	59	89	104
	5	58	88	101
	6	55	84	103

***The negative (-) indicates expansion**

Table 3-15: Length Change Data from Preliminary Testing

Length Change Test Data								
8-sack		**1-day**	**7-day**	**14-day**	**28-day**	**8-wks**	**12-wks**	**16-wks**
moist cured	1	0.2065	0.203	0.2016	0.2026	0.2015	0.2028	0.2026
	2	0.1993	0.1937	0.193	0.1948	0.193	0.1935	0.193
	3	0.2014	0.2065	0.2052	0.2074	0.2055	0.2066	0.206
air cured	4	0.1987	0.1954	0.1923	0.1909	0.1863	0.186	0.1855
	5	0.2011	0.1977	0.1943	0.1929	0.1886	0.1879	0.1877
	6	0.205	0.2028	0.1986	0.1968	0.193	0.1922	0.1917
8.5-Sack								
moist cured	1	0.2062	0.2013	0.2002	0.2014	0.1997	0.2024	0.2
	2	0.2057	0.21	0.2098	0.2027	0.2009	0.2006	0.2003
	3	0.2183	0.2125	0.2132	0.218	0.2214	0.213	0.2122
air cured	4	0.2147	0.2096	0.2077	0.2052	0.2002	0.1996	0.1994
	5	0.1986	0.1934	0.1909	0.1888	0.1823	0.1735	0.1731
	6	0.2175	0.2117	0.2096	0.2075	0.2007	0.1926	0.1912

Table 3-16: Length Change Data from Field-Testing

Length Change Test Data					
8-sack		**1-day**	**7-day**	**14-day**	**28-day**
moist cured	1	0.2006	0.2037	0.2034	0.2032
	2	0.1957	0.1987	0.1982	0.1979
	3	0.1985	0.2041	0.2038	0.2036
air cured	4	0.3115	0.3073	0.3039	0.3023
	5	0.1572	0.1525	0.1489	0.1463
	6	0.2087	0.2026	0.1997	0.198
8.5-Sack					
moist cured	1	0.1951	0.1966	0.1963	0.1961
	2	0.1948	0.1954	0.1962	0.1955
	3	0.198	0.1992	0.1994	0.1987
air cured	4	0.2024	0.1965	0.1935	0.192
	5	0.2052	0.1994	0.1964	0.1951
	6	0.2075	0.202	0.1991	0.1972

Table 3-17: Slump Flow Data

Slump Flow Data	
	Diameter (in)
8-Sack	13
	13
8.5-Sack	13
	13

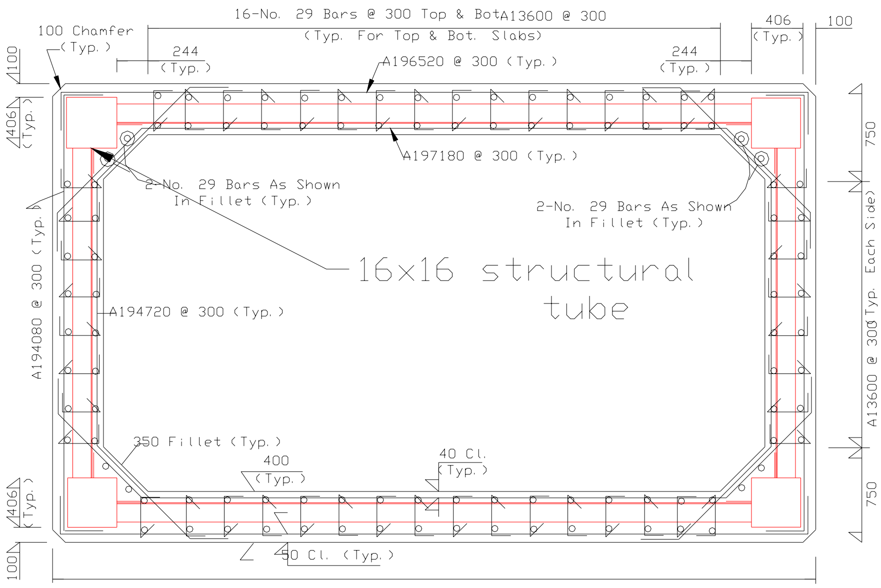

Figure 1-1: Cross-Section of Steel Arch's Structural Tubes at the Four Corners

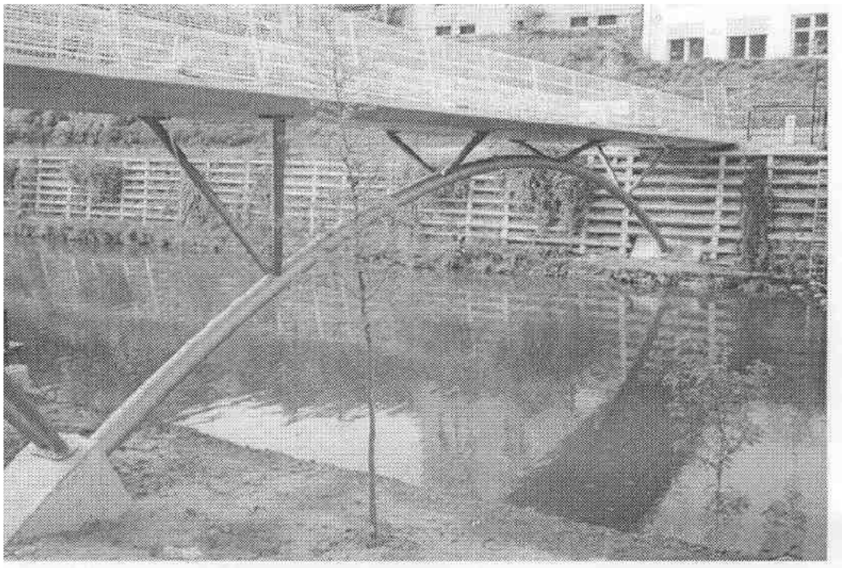

Figure 2-1: Pedestrian Bridge Supported by Steel Tube Filled with Concrete (9)

Figure 2-2: 10-ft x 6-in Diameter PVC Pipe Apparatuses

Figure 2-3: Cross-Section of Cut Cylinder from PVC Pipe Specimens

Figure 2-4: 12-in x 6-in Diameter Cylinder Grout Specimens

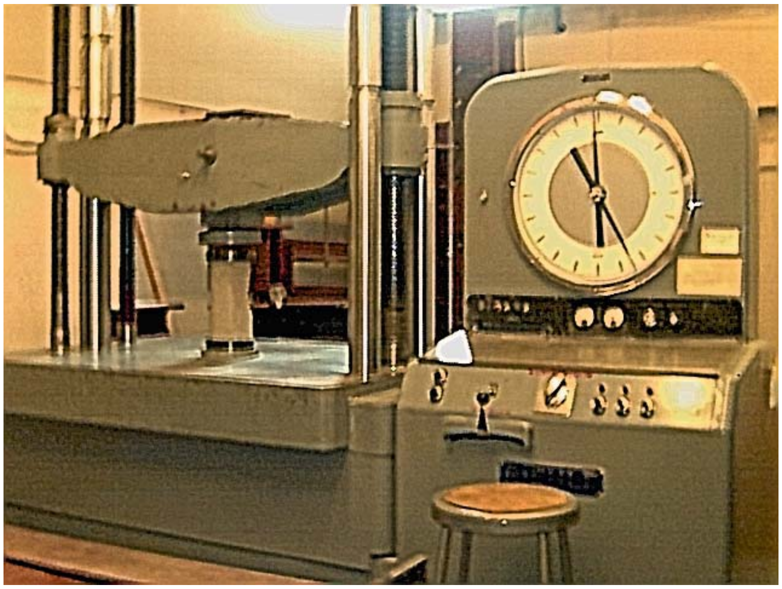

Figure 2-5: 12-in x 6-in Diameter Cylinder Being Tested in Compression

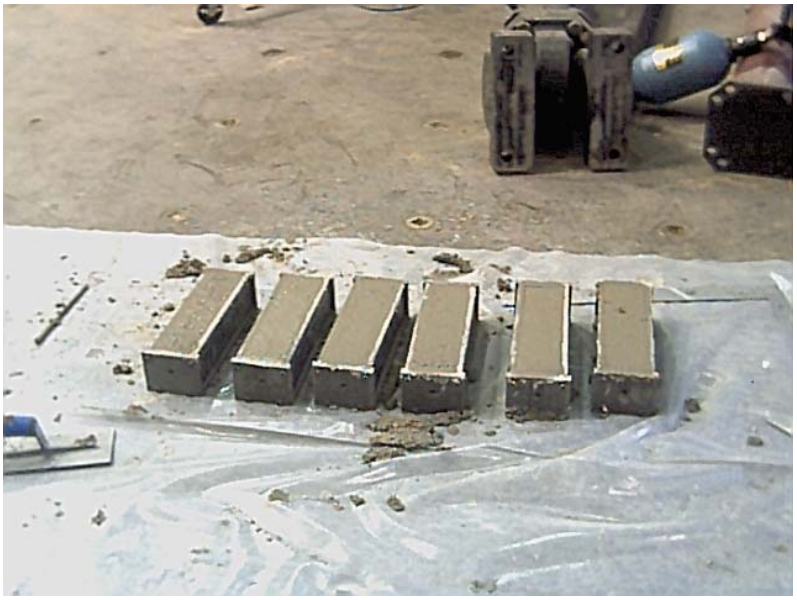

Figure 2-6: 3-in x 3-in x 11.25-in Prism Molds for the Length Change Test

Figure 2-7: Length Comparator with Shrinkage Specimen

Figure 2-8: Specimens Curing in Moisture Room

Figure 2-9: Specimens Air Curing

Figure 2-10: Metal Bucket and Cover for Bleed Water Test

Figure 2-11: Trailer Line Pump

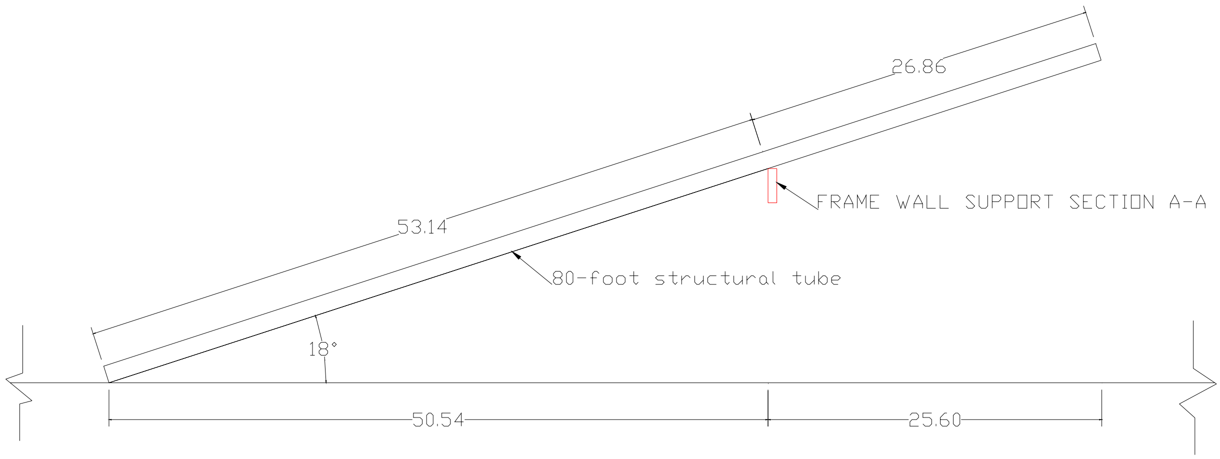

Figure 2-12: Structural Tubes Resting on Ground and Frame Support

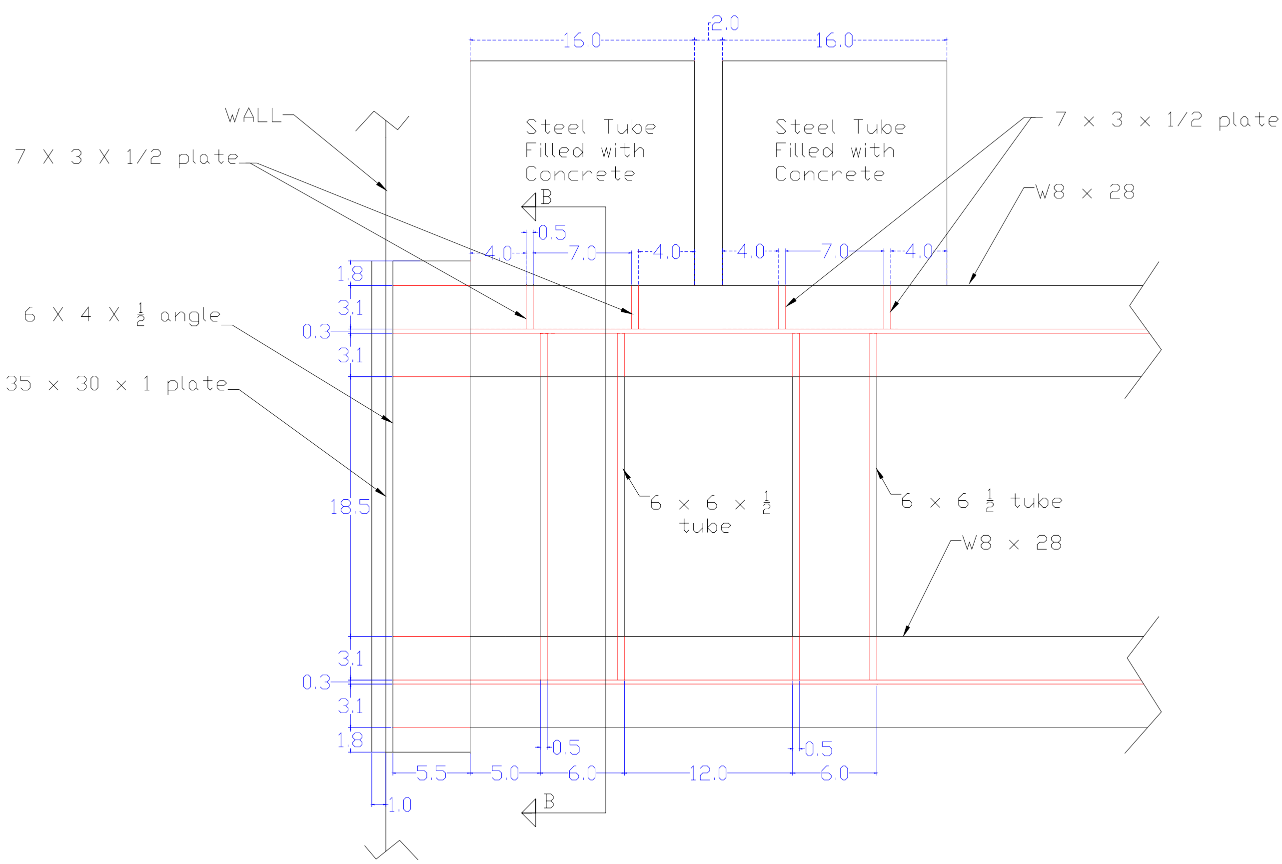

Figure 2-13: Frame System to Support Structural Tubes, Section A-A

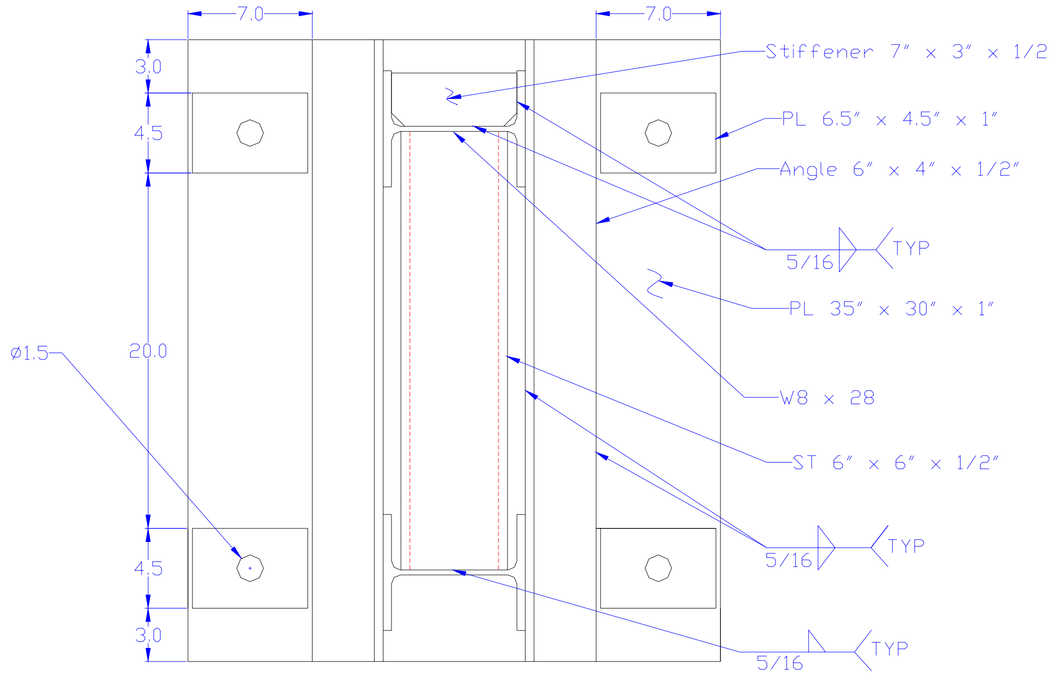

Figure 2-14: Frame System Attached to Wall, Section B-B

Figure 2-15: Actual Steel Frame Mounted to Wall

Figure 2-16: Pump attached at the bottom of the tube and pumping the grout mix up

Figure 2-17: The 80-ft Structural Steel Tubes Prior to Being Pumped Full with the Grout Mixes

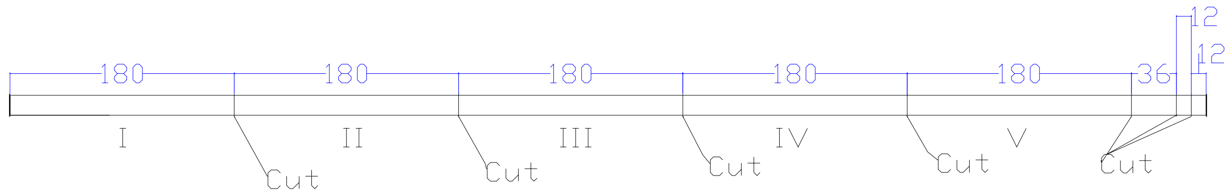

Figure 2-18: The cuts in the 80-ft Structural Tube

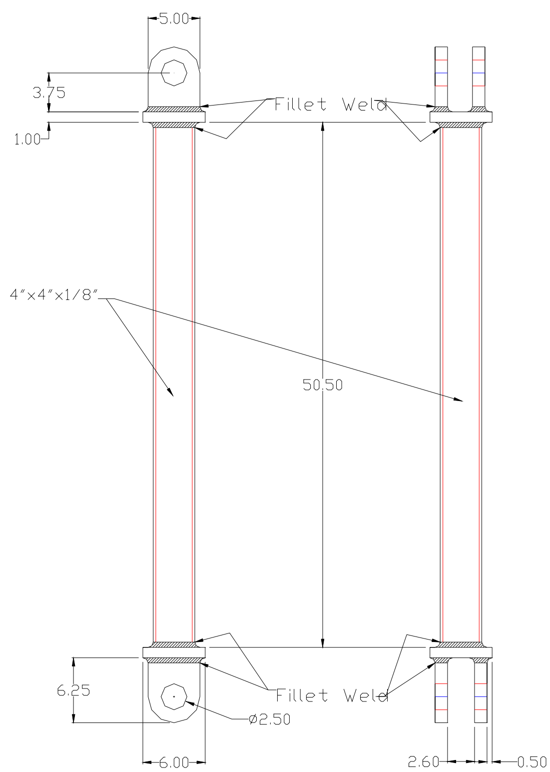

Figure 2-19: 4 x 4 x 1/8 Structural Tube Designed for the Vertical Testing Machine

Figure 2-20: Specimen in the Vertical Testing Machine

Figure 2-21: Slump Flow Test

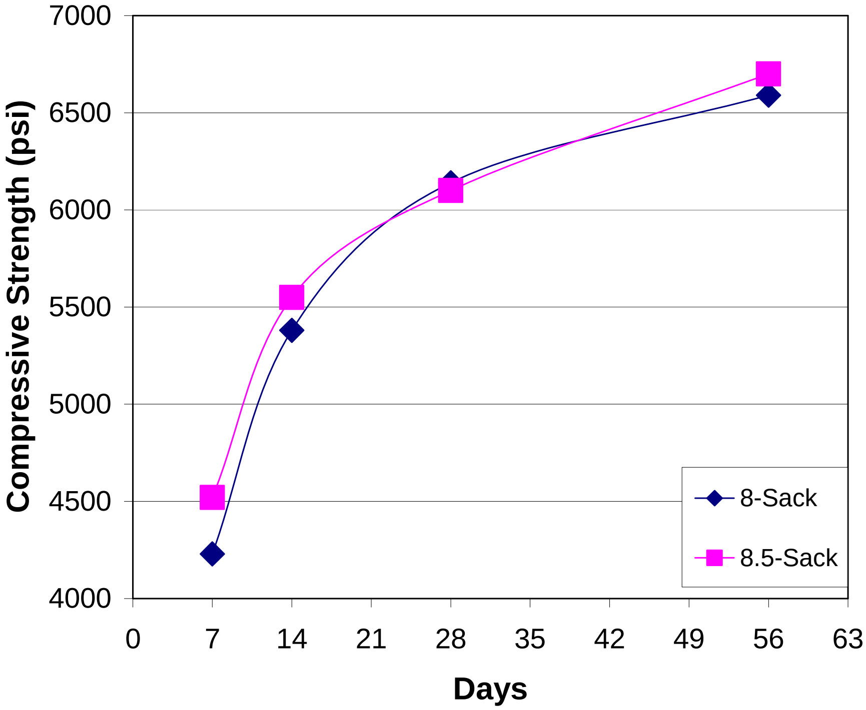

Figure 3-1: Compressive Strength Comparison for Preliminary Testing

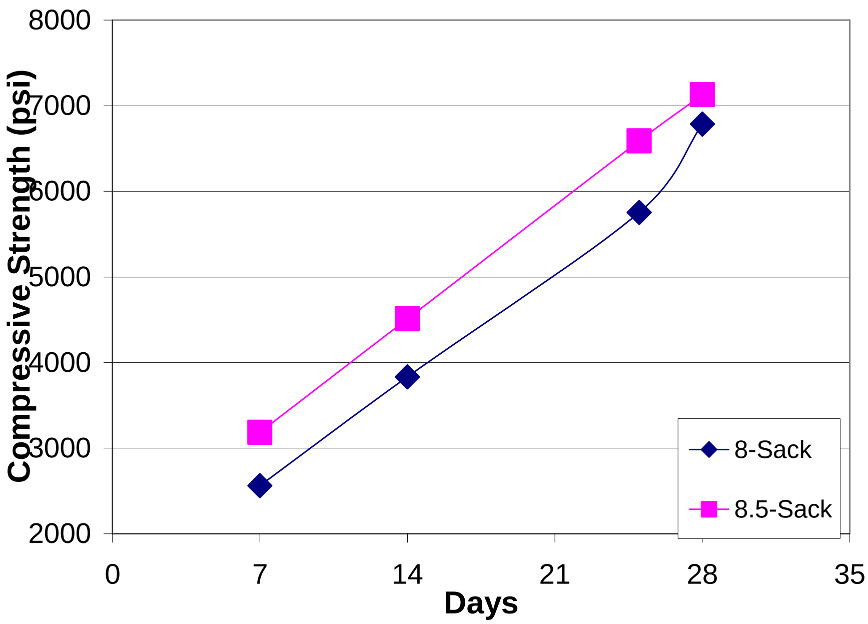

Figure 3-2: Compressive Strength Comparison for Field-Testing

Figure 3-3: Cross-section of Steel Tube with the Grout Mix Design containing 8-sack of Cement, Section III

Figure 3-4: Cross-section of Steel Tube with the Grout Mix Design containing 8-sack of Cement, Section IV

Figure 3-5: Cross-section of Steel Tube with the Grout Mix Design containing 8-sack of Cement, Section V

Figure 3-6: Cross-section of Steel Tube with the Grout Mix Design containing 8.5-sack of Cement, Section III

Figure 3-7: Cross-section of Steel Tube with the Grout Mix Design containing 8.5-sack of Cement, Section IV

Figure 3-8: Cross-section of Steel Tube with the Grout Mix Design containing 8.5-sack of Cement, Section V

Figure 3-9: The Structural Steel Tubes Starting to Get Cut

Figure 3-10: The Structural Steel Tubes Being Cut with the Larger Blade

Figure 3-11: The Structural Steel Tubes Cut in 15-foot Segments

Figure 3-12: 60-inch Tubes Curing After Ends Burned Off and Filled

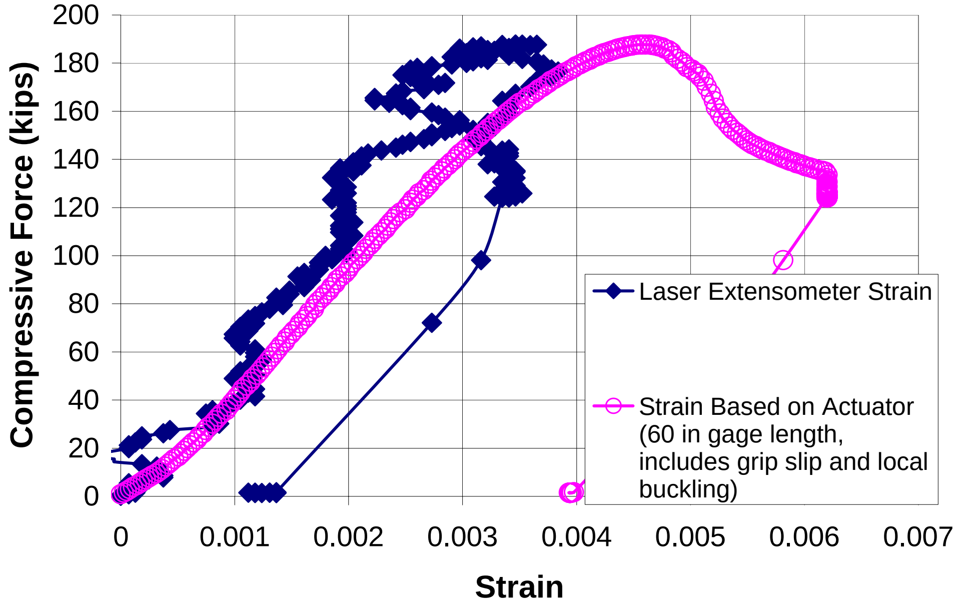

Figure 3-13: Test One-Axial Force vs. Strain

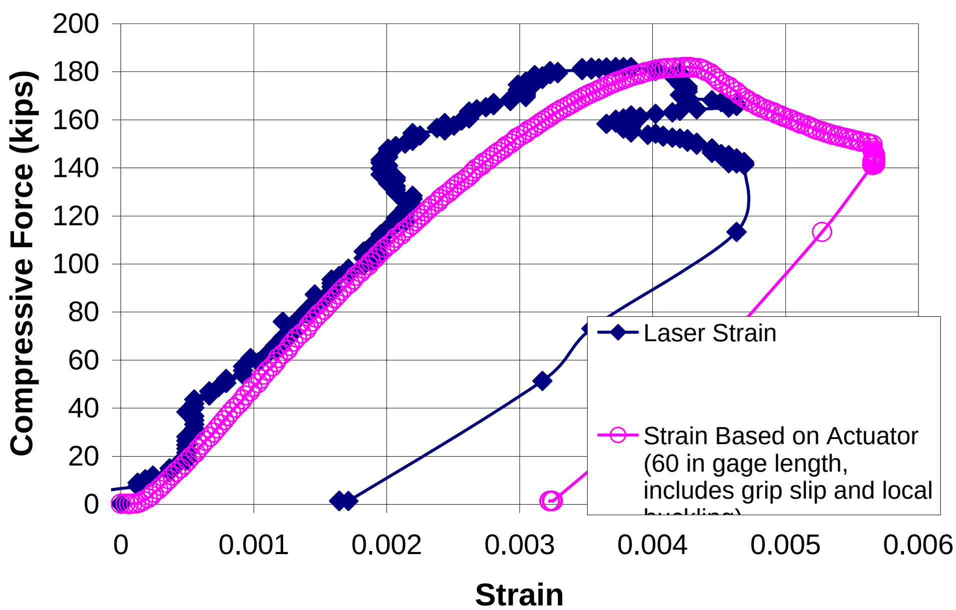

Figure 3-14: Test Two-Axial Force vs. Strain

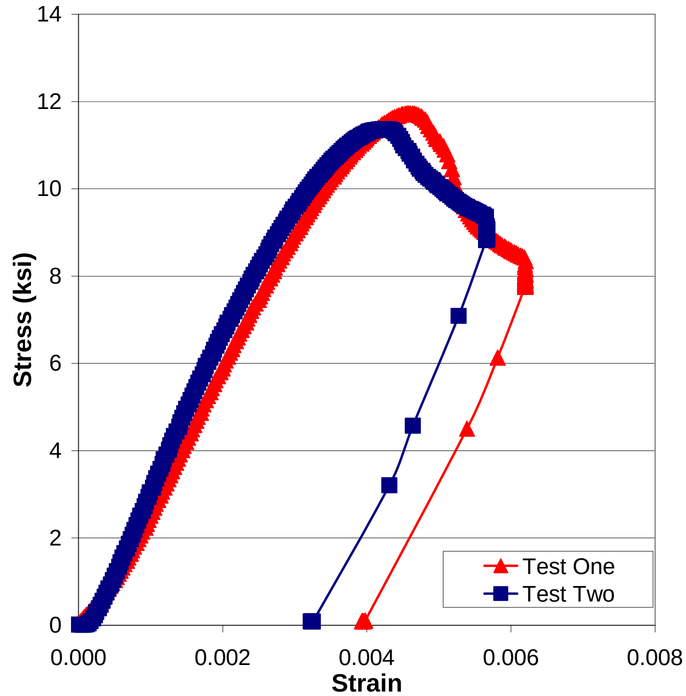

Figure 3-15: Comparison of the Stress vs. Strain Curves

Figure 3-16: First Test Local Buckling at Bottom

Figure 3-17: First Test Local Buckling Close-Up

Figure 3-18: Second Test Local Buckling at Bottom

Figure 3-19: Second Test Local Buckling All Four Sides

Figure 3-20: Concrete Exposed at Location of Buckling

Appendix

A-1: Sample Survey Prepared for Surrounding States

Department of Civil Engineering/258
College of Engineering
University of Nevada
Reno, NV 89557

(775) 784-4288 Fax (775) 784-1390

June 20, 2001

To Whom It May Concern:

Enclosed is a survey on the filling of structural tubes. The survey is designed to help us in our research here at the University of Nevada, Reno.

As part of a project granted to the University of Nevada, Reno; we have been asked to conduct a survey of the western states to determine if there are existing projects/methods for the filing of structural tubes. This project is part of the Nevada Department of Transportation alternative for the Galena Creek concrete arched bridge. The arch provides several challenges and we hope to find a little insight on techniques and design measures through these surveys taken by other DOT's.

The survey itself consists of two pages. A third page is given to show a superimposed image of what the arched bridge will look like when it is done and also a cross-section of the arch is provided showing the four structural tubes at the corners.

Thank you for your time and knowledge this will be very beneficial to our success in completing this project. Please return survey by July 15, 2001.

Sincerely,

Ambere Banghart
Civil engineering undergrad

Survey on the Filling of Structural Tubes

Summary

As part of a project granted to the University of Nevada, we have been asked to conduct a survey of the western states to determine if there are existing projects/methods for filling of structural tubes with grout or concrete. The purpose of this survey is to find the best mixture and method for placing either concrete or grout into structural steel tubes that are 16 x 16 inches. This project is part of the Nevada Department of Transportation alternative for the Galena Creek concrete arched bridge. The arch provides several challenges including the height that the arch is over the valley floor, the distance that the grout/concrete would need to travel, and the need for the grout to fill the entire tube. Initially a steel tube arch is constructed over Galena Creek. The hollow tubes of the arch will be filled to facilitate a composite action; concrete will then be placed around the truss to form a concrete arch. The tubes will act as part of the primary reinforcement for the arch. The top of the arch is 130 feet above the foundation. It is necessary to pump the grout/concrete under pressure to be sure that all parts of the tube are filled. The arch will be constructed in 80-foot segments. The filling of the tubes could be done in segments, multiple segments or by doing half of the arch at a time. The total length of the arch from foundation to foundation is 689 feet. NDOT has indicated a need for a 5000-psi compressive strength mix, which has expansive properties.

Survey

State_____________________________ Respondent__________________________

Phone Number____________________ E-mail______________________________

Mailing
Address____

____

1. Have you ever pumped concrete/grout a distance of a hundred feet or more?_______

   a) What was the maximum distance pumped?_________________________________

   b) What was the maximum lift?____

   c) What type of equipment was used?_______________________________________
   ____

   d) Was the mixture grout or concrete?_______________________________________
   ____

2. Have you had any experience constructing some type of structure that utilized pressure grouting/concrete?____

   a) What type of mixture have you found to work well with pressurized pumping? Was it concrete or grout?____
   ____

   b) Please elaborate on the successes and drawbacks______________________________
   ____
   ____

3. Have you ever filled large vertical structural tubes with concrete/grout?____________

   a) What were the dimensions?____

   b) Was the fill a concrete or a grout?____

   c) Did you have any problems with voids?___________________________________

   d) Did you pressure fill from the bottom or fill from the top?____________________
   ____

   e) Was an expansive admixture used?_______________________________________

4. Have you ever filled large horizontal structural tubes with concrete/grout?_________

   a) What were the dimensions?____

   b) Was the fill a concrete or a grout?____

   c) Did you have any problems with voids?___________________________________

   d) What was the method in which the tube was filled?_________________________
   ____

   e) Was an expansive admixture used?_______________________________________

5. Have you ever filled large inclined structural tubes with concrete/grout?____________

   a) What were the dimensions?____

   b) What was the angle of inclination?_______________________________________

   c) Was the fill a concrete or a grout?____

d) Did you have any problems with voids?_________________________________

e) Did you pressure fill from the bottom or fill from the top?____________________
____

f) Was an expansive admixture used?_______________________________________

6. Based on your experience can you suggest any type of mixture for the filling of large tubes in this project?____
____
____

7. What types of equipment would you use to facilitate such a project?_______________
____
____

10. Any other suggestions or comments?____
____
____

We would really appreciate it if you could return this survey by July 20, 2001. Thank you for your time and cooperation.

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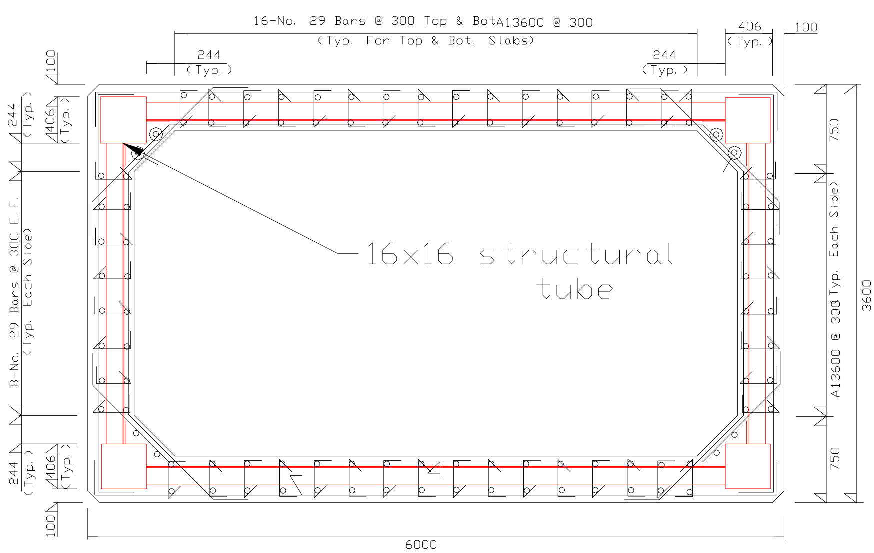
Galena Creek Arch Bridge over Galena Creek.



Cross-section of the arched section showing the four structural tubes at the corners

A-2: Information gathered from survey on surrounding states

Reference	Max pumped	Maximum lift	Type of Mix	Pressurized Pumping Mixture	Experience With Vertical Tubes	Experience with Horizontal Tubes
Alaska	150'	5'	concrete	Caltrans grout spec.for steel jacketed r/c column retrofit	Has filled 48" pipe piles with concrete from the top	Has pressure grouted 2' x 3' voided space 2" max
Arizona	280'-300'	5'	grout, type II portland cement and water	cement and water, grout *concerns-leaks when pressurized, concern w/ setting time during hot weather	no	Has filled pipes with a max 4" dia with grout from the lower elevation, problems with dams
Arizona						
Arizona						
California						
California						
California						
California						
California						
Colorado	400'	<100'	concrete		no	no
Colorado						
Colorado						
Idaho						
Idaho						
Idaho						
Montana						
Montana						
Montana						
New Mexico	900'	30'	concrete	A properly porportioned concrete mix	Has filled 10' dia pipes with concrete from the bottom	Has filled 10' dia pipes with concrete by pumping
New Mexico	105 '	50'	concrete	With post tensioning ducts-pure cement-water mixture w/o sand. Pressure grouting exterior of Jacked Casing-w/ z sack slurry *had to watch for over pressurization of soil exterior of jacked casing	no	no
New Mexico						
Oregon						
Oregon						
Oregon	150'	30'	Concrete w/ a Schweg 4" concrete pump	commercial concrete bag- shotconcrete, flowable concrete bridge repair	Has drilled shafts- 36" to 96" w/ concrete, used tremies from the bottom *had problems w/ voids	Has grouted around annular space between existing culvert and plastic insert, 24" to 72" w/ a low pressure grouting pump
Utah						
Utah						
UCSD						
Washington	3600'	50'	grout w/ grout pump into 4" dia p/t tube continuously	grout	no	no
Washington						
Washington						
Washington						
Washington						

Reference	Incline Experience	Suggestions for this Mix Design	Suggestions on Equipment	Other Comments
Alaska	no	Refer to grout manufacturer	Refer to grout manufacturer	Good Luck
Arizona	no	cement, fly ash and water	not sure	none
Arizona				NO INFORMATION
Arizona				NO RESPONSE
California				NO INFORMATION
California				NO RESPONSE
California				NO RESPONSE
California				NO RESPONSE
California				NO RESPONSE
Colorado	no			provided info on a simular project
Colorado				NO RESPONSE
Colorado				NO INFORMATION
Idaho				NO INFORMATION
Idaho				NO INFORMATION
Idaho				NO INFORMATION
Montana				NO INFORMATION
Montana				NO INFORMATION
Montana				NO RESPONSE
New Mexico	yes	A carefully and properly designed concrete mix w/ a din # of 18-24/lightweight easier if hard rock >=8" slump		Biggest emphasis on the mix that will make the whole project. Spend a lot of effort on the mix call if you need anything else
New Mexico	no	high cement content that is very flowable w/o segregation/ pressure grouting a sand cement mix from the bottom of the tube up		Concrete can't fall more than 5' w/o segregating (tremie is used to prevent this, but can't be used for 80'). Has personally specified a 5000 psi sand cement grout that was pumped through a 32m boom pump- mix was very flowable but noticed a slump change through a ten yard track. A super plasticizer may help flowablity
New Mexico				NO INFORMATION
Oregon				NO RESPONSE
Oregon				NO RESPONSE
Oregon	no		Place opening s on 6' centers and don't pump or fill tubes a distance longer than 6'	
Utah				NO RESPONSE
Utah				NO RESPONSE
UCSD				NO RESPONSE
Washington	no	may try grout mix used in 3600' horizontal run- 1 sack Portland (I or II) cement, max 4.5 gallons of water and water reducer	A grout pump may not be capable of the lift- try a concrete pump with a grout mix	
Washington				NO RESPONSE
Washington				NO RESPONSE
Washington				NO RESPONSE
Washington				NO RESPONSE

A-3: Information gathered from local interview

References	Maximum pumped	Maximum lift	Type of Mix	Pressurized Pumping Mixture	Experience With Vertical Tubes	Experience with Horizontal Tubes
Company A	350'		Concrete	Has used non shrink grout		
Company B						
Company C						
Company D	470'	171'	Concrete- 6 sack, 4000 psi w/ fibers pumped w/ 52-m Lucky Concrete boom pump		Has filled sonnet tubes w/ dia 2' to 6'- concrete w/ plasticizer poured in lifts from the top and vibrated to eliminate air voids	
Company E	300'		Concrete w/ a 56-m boom pump		Has filled 3' dia 30' long tubes from top and vibrated/ used a plasticizer	
Company F	300'-500'					
Company G	500'	30'	Concrete w/ a Schwinn Stationary Pump	3/4" max aggregate	Has filled w/ grout from the bottom up, used hydration stabilizer	
Company H	1000'	2'	Concrete w/ a Putzmeister		Has filled tubes w/ a 24" dia w/ concrete from the top using a plasticizer	
Company I	400'	170'	Used a 45-m Schwinn Pump	7 sack grout works well	Has filled tubes -earthquake proofing columns, filled from the top- rock pocketing due to bad vibrating methods, mix was 7 sack, 3/4" 6500 psi w/ plasticizer	Has filled 3x3 squares 24' long- used grout did not fill properly at the top

References	Suggestions for this Mix Design	Suggestions for Method	Suggestions on Equipment	Other Comments
Company A	With our mixture grout would be easier-flowability		A boom pump, 200 yd^3/hr 42-m and 52-m w/ 137'10" and 170' vertical reach respectively, Need a 50' x 50' space	
Company B	Grout or Concrete will work	Fill both sides from the bottom up with two check valves halfway up and a vent up top/or filling both sides in sections from the bottom up- *bottom up prevents air voids		
Company C	Approximately 8.5 sack grout w/ low w/c ratio(.4) superplasticizer for consolidation purposes, #8 or #7 stone, 15% fly ash- also gave three specific mix designs to try			Gave specific Mix Designs
Company D	Use lightweight concrete to keep weight down, 8 sack, grout will be a cleaner pour- *rock pocketing w/ concrete,use river rock fines- *local chipped rock tends to cause segregation	Fill continuously from top down to make structurally sound		
Company E	6-1/2 to 7 sack- *higher strength is prone to cracking			
Company F	Believes all mixes are pumpable- 5-6 sack, normal or light weight concrete will work, #67 stone- *no P gravel, use superplasticizer, slight amount of water reducer, *NO GROUT	Fill section by section	May consider temporary fill in the gap for easy acess	
Company G	Use stabilizer-superplasticizer to prevent segregation, fly ash for workability, shrinkage reducer (try eclipse will reduce by half), expansivecement bad news- hard to work with	Fill from bottom up to get rid of air voids	Use Line Pump from sides and Boom Pump from back	Brother Alex gave specific Mix Designs
Company H	9 sack grout 3/8" mix	Holes drilled in steel & pumped in sections- weld plates over holes/ or pressure pumping from bottom w/ vents	Pressure-grouting Pump	
Company I	Use 7 sack, 3/4"	Fill from the top down in segments	Use land fill	Will be getting a 58-m pump (174')

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