UNIVERSITY OF NORTH DAKOTA
Grand Forks

Performance Evaluation of Low Permeable Concrete Bridge Deck

Final Report

December 2004

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 — STATE: UND; YEAR: 03 - NUMBER: 01; SURF:	CONSTRUCTION PROJ NO 8: IM-NH-8-029(050)062 — LOCATION: Cass Counties
	EVALUATION FUNDING 48: 1 X HP&R; 2 CONSTRUCTION; 3 DEMONSTRATION; 4 IMPLEMENTATION	NEEP NO. 49 — PROPRIETARY FEATURE? 51: Yes; X No
SHORT TITLE	TITLE 52	Performance Evaluation of Low Permeable Concrete Bridge Deck
THIS FORM	DATE 140 — MO. 12 -- YR. 2004	REPORTING: 1 INITIAL; 2 ANNUAL; 3 **X** FINAL
KEY WORDS	KEY WORD 1: 145 High Performance Concrete	KEY WORD 2: 167 Fly Ash
	KEY WORD 3: 189 Portland Cement	KEY WORD 4: 211 Ground Granulated Blast Furnace Slag
	UNIQUE WORD 233	PROPRIETARY FEATURE NAME 255

CHRONOLOGY	Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
	277	2002 281	285	289	293

QUANTITY AND COST	QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS)	UNITS	UNIT COST (*Dollars, Cents*)
	297	1 LIN. FT; 2 SY; 3 SY-IN; 4 CY; 5 TON; 6 LBS; 7 EACH; 8 LUMP SUM 305	306

AVAILABLE EVALUATION REPORTS	CONSTRUCTION	PERFORMANCE	FINAL
	315		X

EVALUATION	CONSTRUCTION PROBLEMS	PERFORMANCE
	318: 1 X NONE; 2 SLIGHT; 3 MODERATE; 4 SIGNIFICANT; 5 SEVERE	319: 1 EXCELLENT; 2 X GOOD; 3 SATISFACTORY; 4 MARGINAL; 5 UNSATISFACTORY

APPLICATION	320: 1 ADOPTED AS PRIMARY STD.; 2 PERMITTED ALTERNATIVE; 3 ADOPTED CONDITIONALLY	4 X PENDING; 5 REJECTED; 6 NOT CONSTRUCTED	*(Explain in remarks if 3, 4, 5, or 6 is checked)*

REMARKS	321
	Based on the test results, the recommended fly ash replacement percentage for low permeable concrete is 38% and the recommended GGBFS replacement percentage is 35%. 700

University of North Dakota
Department of Civil Engineering

Performance Evaluation of Low Permeable Concrete Bridge Deck

Final Report

Submitted to:
North Dakota Department of Transportation

By:

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December 2004

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The contents of this report reflect the views of the author or authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not reflect the official views of the North Dakota Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Acknowledgement

The authors wish to thank the North Dakota Department of Transportation for the funding provided and other assistance with this project.

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1.0 - Introduction & Background

1.1 Introduction

Intrusion of water into the concrete matrix can act as a delivery mechanism for potentially harmful materials. These materials can accelerate corrosion of reinforcing steel in the concrete. Corrosion of the reinforcing steel occurs when chlorides, from deicing salts or cast-in-place chlorides, attack the steel. The corrosion reduces the cross-sectional area of the steel, which decreases the stiffness and strength of the structure. Corrosion of the steel also causes the concrete to crack because of increased volume due to rust. Another problem caused by water intrusion into the concrete matrix is expansion due to freezing. When water that has filled the air voids in the concrete is subjected to freezing temperatures, it turns to ice and expands. This increase in volume can cause the concrete to crack and lose strength.

Steps can be taken to prevent corrosion of the reinforcing steel in concrete bridge decks. The North Dakota Department of Transportation (NDDOT) requires the use of epoxy coated reinforcing steel throughout the structure. Coating the steel with a protective layer is an excellent means to prevent corrosion, but it does not prevent the absorption of water and the consequent freezing and cracking that may occur. To do this, researchers must find an acceptable concrete mix design that will lower the permeability of the concrete with no loss in strength.

This research project will investigate the use of fly ash and ground granulated blast furnace slag (GGBFS) as partial replacements for Portland cement in concretes designed for bridge deck applications in the State of North Dakota.

1.2 Mineral Admixtures

Finely divided mineral admixtures are powdered or pulverized materials used to improve or change some of the plastic and/or hardened properties of Portland cement concrete. Generally, mineral admixtures are naturally occurring materials or industrial byproduct materials. Based on their chemical and physical properties, certain finely divided mineral admixtures are classified as cementitious, pozzolanic, or pozzolanic and cementitious materials.

Cementitious materials are substances that alone have hydraulic cementing properties (i.e. the ability to set and harden in the presence of water). Pozzolanic materials are siliceous or aluminosiliceous materials that alone possess little or no cementitious value but will, in finely divided form and in the presence of water, chemically react with the calcium hydroxide released by the hydration of Portland cement to form compounds possessing cementitious properties. Materials may possess both pozzolanic and cementitious properties. Some types of fly ash and GGBFS exhibit both pozzolanic and cementitious properties. Since a goal of this project is to enhance concrete by replacing some of the Portland cement with mineral admixtures, it is desired that the admixtures possess both pozzolanic and cementitious properties.

Fly ash is the fine ash resulting from coal fired electric power generating stations. The inorganic or mineral constituents of coal, such as clay, quartz, feldspar, shale, fuse and chemically recombine during combustion to produce the various crystalline and glassy phases of fly ash. The fused material is carried away from the combustion chamber by exhaust gas. As the fused material cools, it solidifies into spherical particles. The fly ash particles are then collected from the exhaust gases by electrostatic precipitators or bag filters. Generally, no further processing of the fly ash is needed for use in blended cement or concrete. (1)

Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium. Other minor constituents are magnesium, sulfur, sodium, potassium, and carbon. The specific gravity of fly ash usually ranges between 2.2 and 2.8 and the color is usually tan or gray.

The American Society for Testing and Materials (ASTM) distinguishes between Class F fly ash and Class C fly ash in ASTM C 618. Class F fly ashes usually contain less than 10% calcium and less than 5% carbon; while Class C fly ashes usually contain 10 to 30% calcium and less than 2% carbon. Class F fly ashes have pozzolanic properties. Class C fly ashes usually possess both pozzolanic and cementitious properties.

GGBFS is a nonmetallic product consisting of silicates and aluminosilicates containing calcium and other elements developed in a molten condition simultaneously with iron in a blast furnace. The molten slag is rapidly chilled by quenching in water to form a glassy, sand-like granular material. The granulated material is then ground to less than 45 microns. The rough and angular-shaped ground slag in the presence of water and an activator such as sodium hydroxide or calcium hydroxide hydrates and sets in a manner similar to Portland cement. ASTM C 989 lists three classes of slag; Grade 80, Grade 100, and Grade 120.

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(1) Kosmatka, Steven H. and Panarese, William C., “Design and Control of Concrete Mixtures: Thirteenth Edition,” *Portland Cement Association*, Skokie, IL, 1994, pages 68-72.

Fly ash and GGBFS affect concrete both when freshly mixed and also when hardened. These admixtures affect freshly mixed concrete in a variety of ways. Positive effects of the admixtures relate to water requirements, workability, finishability, and pumpability.
Water requirements are generally lower in concrete mixes containing fly ash or GGBFS compared to concrete mixes containing only Portland cement. This is beneficial because typically strength will increase with a reduction in water. Workability, finishability, and pumpability are very important in the construction phase. Improved workability will decrease the amount of labor required to construct a concrete structure. Improved finishability improves the aesthetics of any concrete structure. Improved pumpability can also reduce the labor required because it may allow concrete to be pumped rather than placed by other more expensive means.

Fly ash and GGBFS can also have negative effects on freshly mixed concrete. The two major properties that are negatively affected by fly ash and GGBFS are air content and setting time. Air contents in concrete mixes containing fly ash or GGBFS are generally lower compared with the air content of the same mix containing only Portland cement. Thus the use of more air-entraining admixture is required to reach a specific air content in the concrete. In addition, the time of set of concrete mixes containing fly ash or GGBFS may be increased.

Hardened concrete is also affected when mineral admixtures like fly ash and GGBFS are used. The properties of hardened concrete that are positively affected by the addition of fly ash and GGBFS are permeability, alkali-aggregate reactivity, resistance to sulfate attack, and freeze-thaw durability. Permeability of concrete is generally reduced with the addition of fly ash and GGBFS. The alkali-silica reactivity between cement alkalies and reactive silica in aggregate can be controlled with the addition of mineral admixtures. The admixtures provide additional calcium silicate hydrate to chemically tie up the alkalies in the concrete. The resistance to sulfate attack can be improved with the addition of fly ash and GGBFS by reducing the amount of reactive elements needed for expansive sulfate reactions, primarily calcium.

Fly ash and GGBFS also have negative effects on hardened concrete. The major properties that are negatively affected are rate of strength gain, drying shrinkage and creep, resistance to deicer scaling, and carbonation. The strength of concrete can be increased by fly ash and GGBFS, but these admixtures reduce the rate of strength gain in the concrete. Drying shrinkage and creep tend to increase as the amount of fly ash or GGBFS is increased, which can lead to cracking in the concrete. The resistance of concrete to deicer scaling typically decreases as the amount of fly ash or GGBFS increases. It is recommended to use a minimum of 564 lbs of cementitious material and a maximum water/cementitious ratio (w/c ratio) of 0.45 to control the effects of deicer scaling. Carbonation tends to increase with the addition of fly ash and GGBFS. This tends to increase the shrinkage and reduces the alkalinity.

The improvements made on concrete properties due to the addition of fly ash and GGBFS generally outweigh the drawbacks that they impose on other properties. Additionally, these admixtures reduce the cost of the concrete and reduce the amount of waste requiring disposal. Both fly ash and GGBFS are waste products from other industries. The industries that produce fly ash and GGBFS sell these products for a very reasonable price in order to avoid the expense of disposing of them.

2.0 - Project Objectives

The purpose of this project was to develop concrete mix designs containing fly ash and GGBFS suitable for producing low permeability bridge decks at no or minimal increase in cost. The project had two major tasks:

- The objective of task one was to test various fly ash and GGBFS amended concrete mix designs and make recommendations for optimal Portland cement replacement levels for these two mineral admixtures.
- The objective of task two was to install instruments to monitor temperatures and corrosion rates in three concrete bridge decks being constructed on southbound I-29 in Fargo, North Dakota.

The mix design information generated from this research will be used by NDDOT to assist in construction of three concrete bridge decks. One deck will use only Portland cement as cementitious material. A second deck will use a mix design with fly ash and Portland cement. And a third deck will use a mix design with GGBFS and Portland cement. These decks will have instrumentation in them to measure the temperature at various depths in the concrete and also to determine corrosion rates in the reinforcing steel. Additionally, samples will be extracted to determine the chloride ion concentration at various depths in the concrete deck. This testing will allow the investigators to determine if the durability of the concrete is truly enhanced by the addition of the mineral admixtures.

3.0 - Concrete Mix Testing Program

3.1 Concrete Mix Test Plan

A goal of this project is to determine appropriate quantities of mineral admixtures to be used in the final concrete mix design for a highway bridge deck application. To accomplish this, ten different concrete mixes were prepared using fly ash and GGBFS as a replacement cementitious material for Portland cement. These mineral admixtures were used to replace the Portland cement on a 1:1 ratio by weight.

Five concrete mixes were prepared for each mineral admixture to determine the optimal replacement of Portland cement. The primary variable for each mix was the quantity of cementitious materials (including admixtures) used. Some small corrections had to be made with the air-entraining agent and the w/c ratio to meet the design parameters of the project. These corrections were made on a mix-to-mix basis based on the changes presented by the increase or decrease in mineral admixture used. The replacement percentages of fly ash and GGBFS for Portland cement were 20%, 25%, 30%, 35%, and 40% by weight. The base mix design that was used for the entire project conformed to the current NDDOT mix design requirements for bridge decks, which are based on *the NDDOT's Standard Specifications for Road and Bridge Construction, 1997, Volumes 1 and 2.* The requirements were that the mix designs must attain a 28-day compressive strength of at least 4,000 psi, have a slump of 2.5 to 3 inches and an air content of 6.0%.

The aggregate source for this study was Aggregate Industries, from the Rollag, North Dakota pit. The coarse aggregate met the NDDOT 816.02 Size No.3 specifications. The fine aggregate met the NDDOT 816.01 specifications. Moisture contents of the aggregates were determined before mixing operations on a day-to-day basis to adjust for the amount of free moisture on the aggregates. To attain the desired air content of the concrete, an air-entraining admixture was used. AEA-92 air –entraining admixture, supplied by Brett Admixtures of Minneapolis, Minnesota, conforming to AASHTO M 154-00 was added to reach the desired air content.

All of the cementitious materials such as the Portland cement, fly ash, and GGBFS were supplied by, Lafarge Dakota Inc. The cement used in this project was type I/II Portland cement meeting AASHTO M 85-00 specifications. This cement was produced at their Exshaw cement manufacturing plant in Alberta, Canada. The Class C fly ash meeting AASHTO M 295-00 specifications came from the Coal Creek Station source located in Underwood, North Dakota. The GGBFS slag was Holcim (Holnam) GranCem, meeting ASTM C 989 specifications.

3.2 Test Methods

For each concrete trial mix, four 4.5 cubic foot batches of concrete were prepared for a total volume of 18.0 cubic feet. Three of the batches were used to cast specimens for testing compressive strength, flexural strength, shrinkage control, and freeze thaw durability. The fourth batch was cast into a slab in order to take core samples for permeability testing.

Concrete mixing was preformed in accordance with AASHTO T 126-97. Mixing was done with the following steps:

1. Place all coarse aggregate in the mixer before starting rotation.
2. Rotate the mixer and add some of the mixing water.
3. After a few revolutions, add half of the fine aggregate and air-entraining admixture.
4. As the mixer is rotating, add the cement and fly ash or slag, then the remaining fine aggregate, and finally add the remaining mixing water.

5. Operate the mixer in the following manner: 1) mixer rotates for 3 minutes; 2) mixer is shut down to allow concrete mix to set for 3 minutes with a damp cloth covering the open end of the mixer during the rest period; and 3) mixer rotates for 2 minutes to complete mixing procedure.

After mixing, the plastic properties of the concrete were tested. Once the plastic properties had been tested, all of the necessary specimens were cast for the scheduled tests on the hardened concrete.

The following tests were performed on the various concrete mixes to determine the optimum replacement percentages of Portland cement with fly ash and GGBFS:

1. Slump Test (AASHTO T 119-99)
2. Unit Weight and Yield of Concrete Test (AASHTO T 121-97)
3. Air Content of Concrete by Pressure Method (AASHTO T 152-01)
4. Compressive Strength (AASHTO T 22-97)
5. Flexural Strength (AASHTO T 97-97)
6. Rapid Chloride Ion Permeability (AASHTO T 277-96)
7. Length Change of Hardened Concrete (AASHTO T 160-97)
8. Freeze Thaw Durability (AASHTO T 161-00)

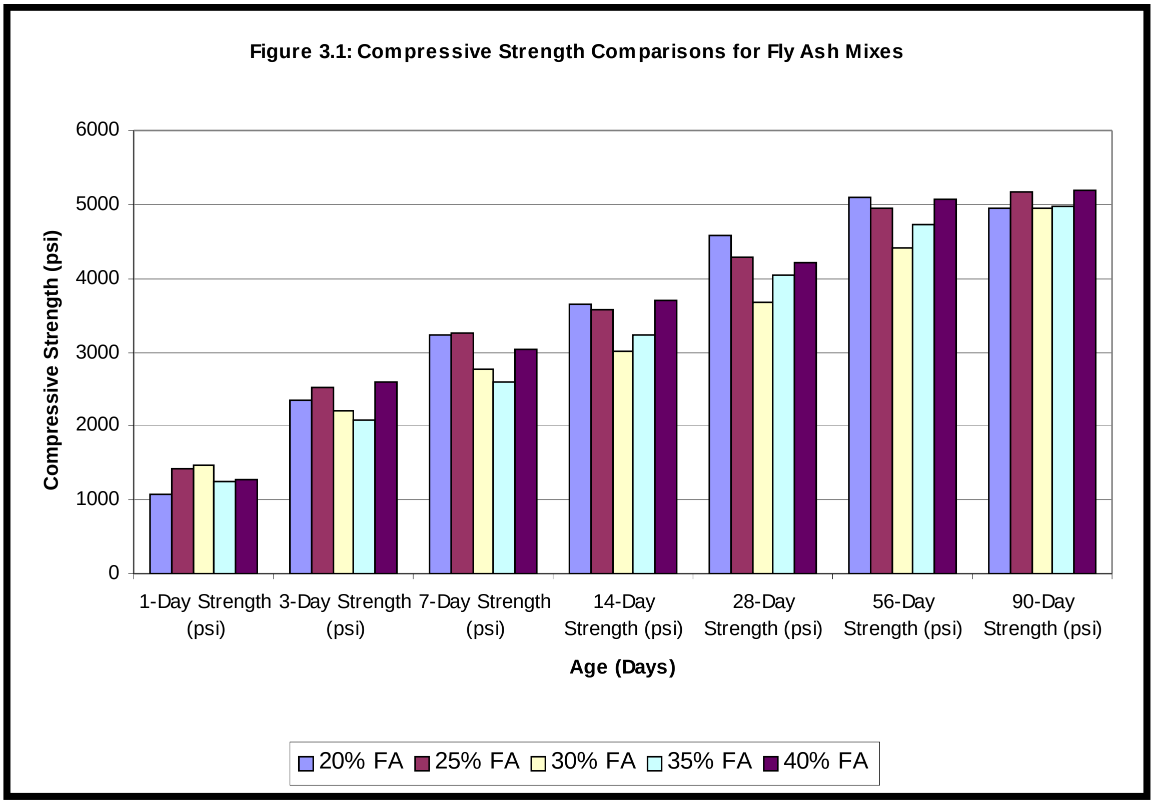
3.3 Mix Design Test Results

The tests performed for plastic properties included slump, air content, unit weight, concrete temperature, and relative yield of the mixes. These properties were measured and recorded after each batch of concrete was mixed. Two of these properties, the slump and the air content, were control parameters for the mixes. A slump of 2.5 - 3 inches and an air content of 6.0% were to be maintained in all of the mixes to be acceptable for the project.

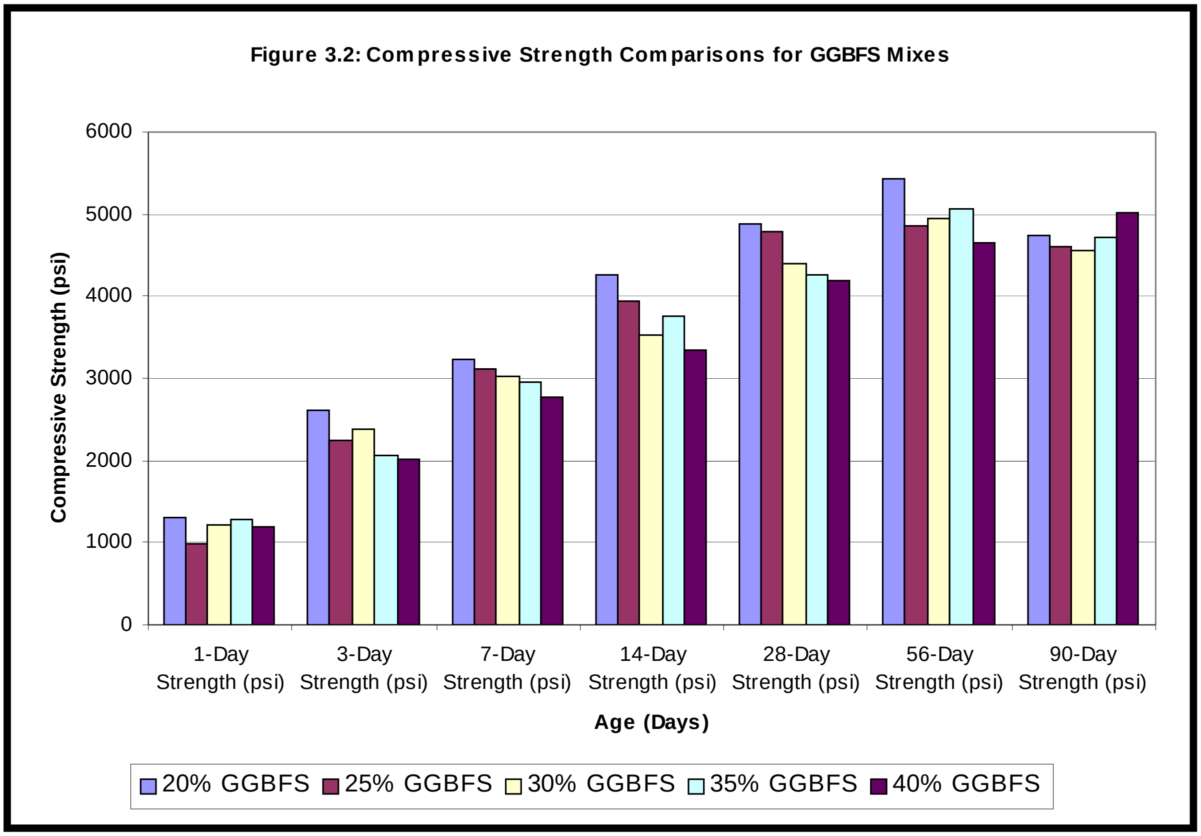
The plastic properties for the fly ash enhanced mixes are listed in Table C-1 of Appendix C and the plastic properties for all the GGBFS enhanced mixes are listed in Table D-1 of Appendix D. The slump and air content for both types of mixes were consistently within the control parameters of the project and the relative yields were consistently close to 1.0. The w/c ratio generally decreased with the increase in fly ash used, which was expected since fly ash effects workability and slump.

Six-inch by twelve-inch cylinders were cast for the compressive strength tests. These cylinders were tested at ages of 1, 3, 7, 14, 28, 56, and 90 days to develop strength relations for the concrete. Three cylinders were loaded to failure at each test date to get an average compressive strength for each mix. The 28-day compressive strength was a control parameter for this project. The design 28-day compressive strength parameter was 4,000 psi.

The compressive strength results for the fly ash mixes are listed in Table C-2 of Appendix C. A comparison of the results is shown in Figure 3.1. The results from the compressive strength tests show that at an age of 90 days, the concrete with the largest percentage of fly ash reached the highest compressive strength of the five mixes. The 30% fly ash replacement mix did not reach the required 4,000 psi strength at 28 days, but the other four mixes did meet the required 4,000 psi strength at 28 days.

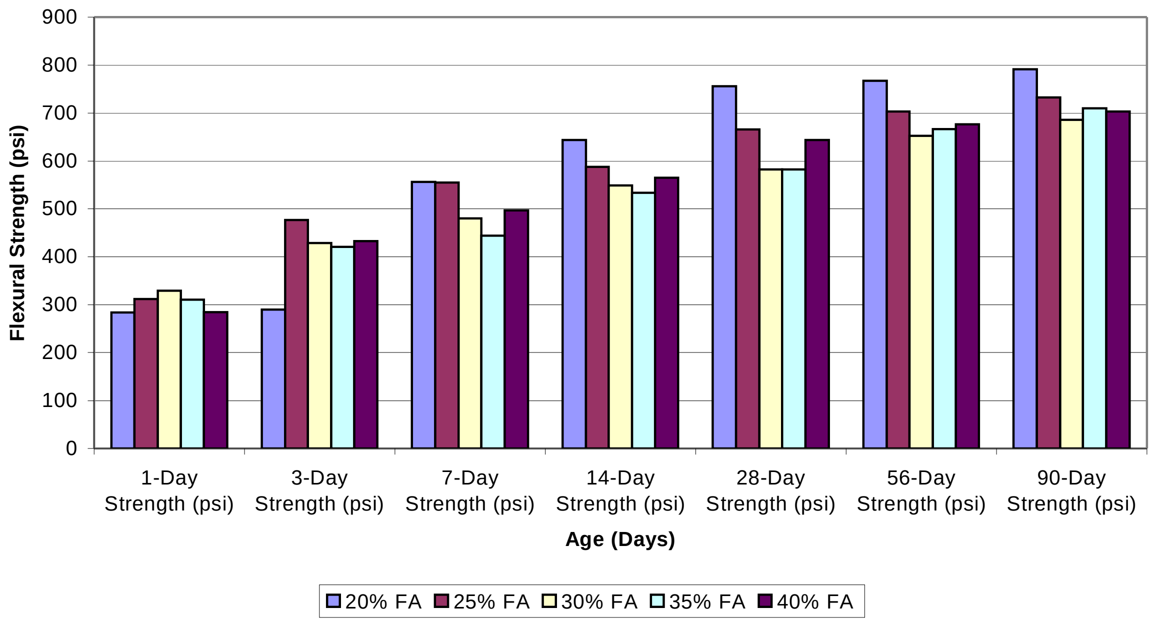


The compressive strength test results for the GGBFS mixes are listed in Table D-3 of Appendix D. A comparison of these results is shown Figure 3.2. One very interesting trend was observed with the GGBFS mixes. The trend shows that the 90-day strengths of four out of the five mixes were lower than the 56-day strengths. Apparently at some time between an age of 56 and 90 days, the GGBFS had a negative affect on the strength of the concrete. This trend should be further investigated to determine the effects of GGBFS on strength properties in concrete. All five of the mixes did meet the required 4,000 psi compressive strength at 28 days.



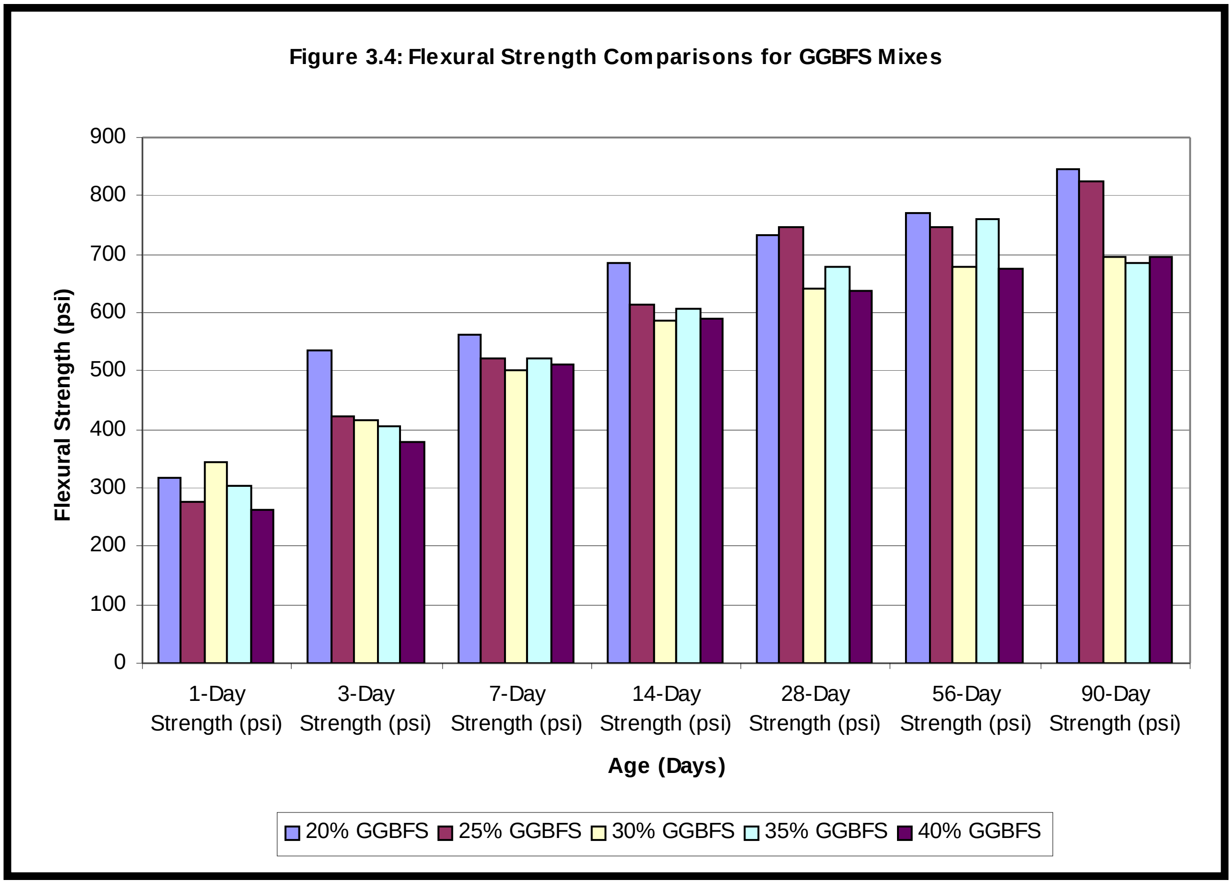
The flexural strength test specimens were cast as 6" x 6" x 21" concrete beams. For the test, third point loading was applied until the beam was broken. These beams were tested at ages of 1, 3, 7, 14, 28, 56, and 90 days to develop strength relations for the concrete. The modulus of rupture was calculated using the maximum load that was applied to the beam and the cross-sectional area at failure. Three beams were loaded to failure at each test date to obtain an average flexural strength for each mix. The flexural strength test results for the fly ash replacement mixes are listed in Table C-4 of Appendix C. A comparison of these results is shown in Figure 3.3.

Figure 3.3: Flexural Strength Comparisons for Fly Ash Mixes



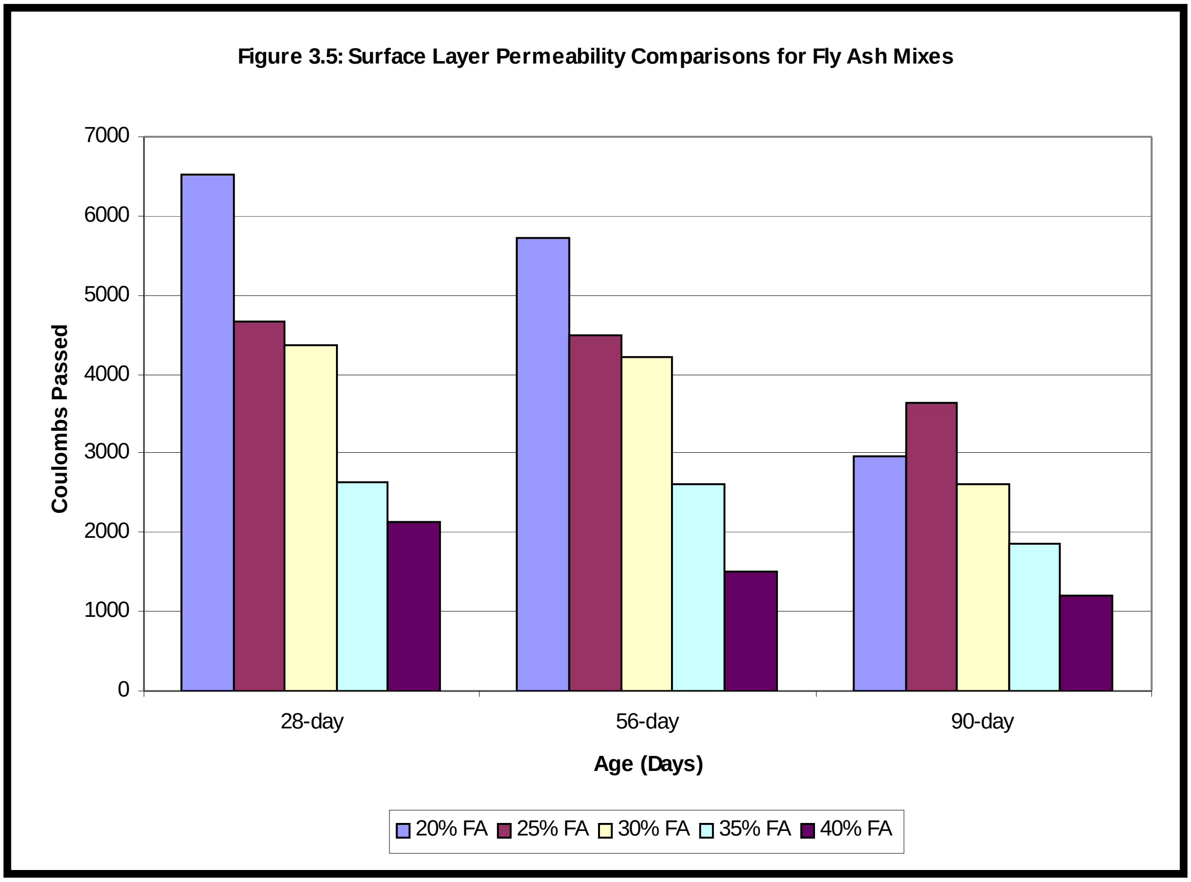
The flexural strength test results for the GGBFS mixes are listed in Table D-4 of Appendix D. A comparison of these results is shown in Figure 3.4. These results correlate with the compressive strength results to the extent that the 35% replacement mix shows a decrease in flexural strength from 56 to 90 days.

The rapid chloride ion permeability test was performed for each concrete mix at ages of 14, 28, 56, and 90 days. The results from this test are reported in terms of the charge passing, measured in coulombs, through a 2-inch thick core section from a concrete slab. Three cores were tested at each age to determine an average permeability for each mix. The permeability was tested at the surface of the slab, at a depth of two inches below the surface, at a depth of four inches below the surface, and at a depth of six inches below the surface. The surface layer of the

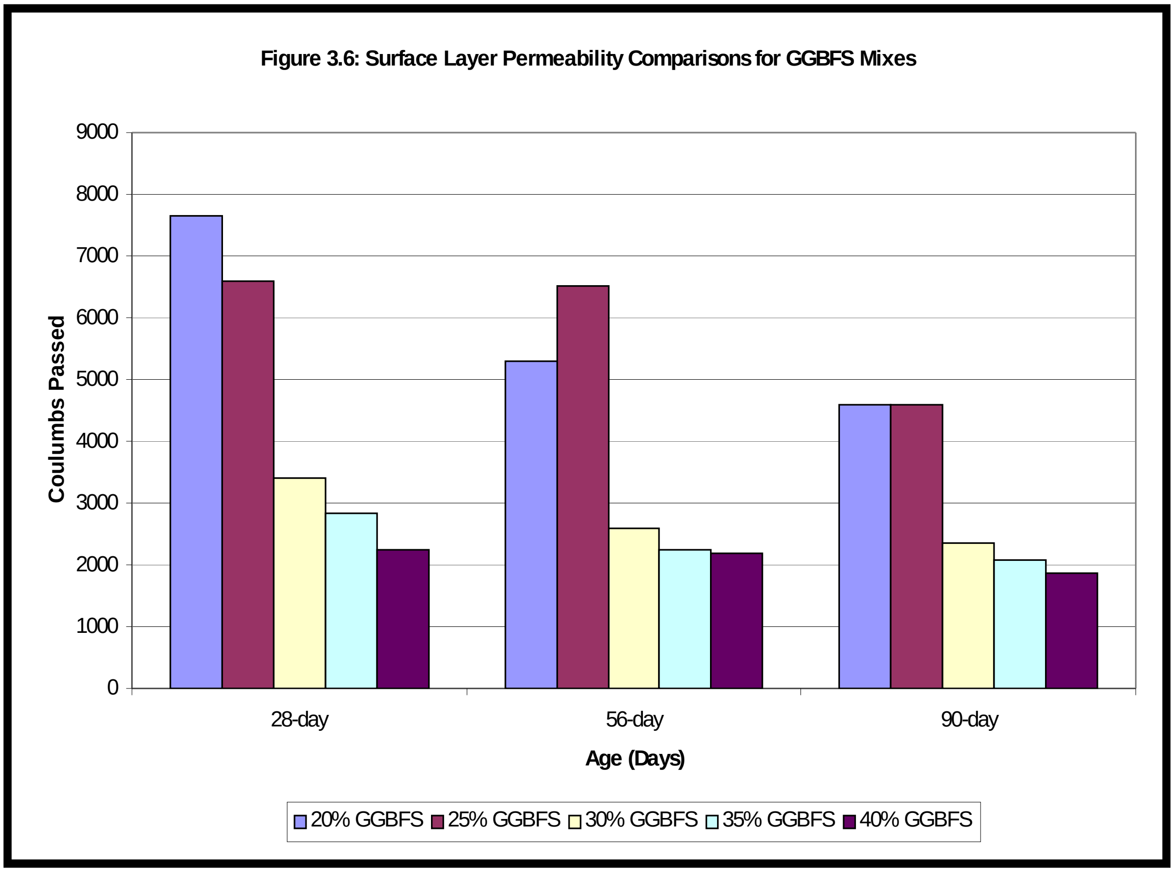


concrete is of primary interest in this test because it acts as a protective layer to limit the intrusion of water and other materials that could be harmful to the concrete matrix.

The rapid chloride ion permeability test results for the fly ash mixes are located in Table C-5 of Appendix C. Comparisons of the results for the surface layer of the test cores are shown in Figure 3.5. The results show that with an increase in fly ash replacement the permeability of the concrete decreases. It can also be seen that as the concrete ages the permeability decreases. None of the mixes met the criteria for low permeability (i.e., < 2000 coulombs passes) by an age of 28 days. The 40% fly ash replacement mix met the low permeability criteria at an age of 56 days and the 35% fly ash replacement mix met the low permeability criteria at 90 days.



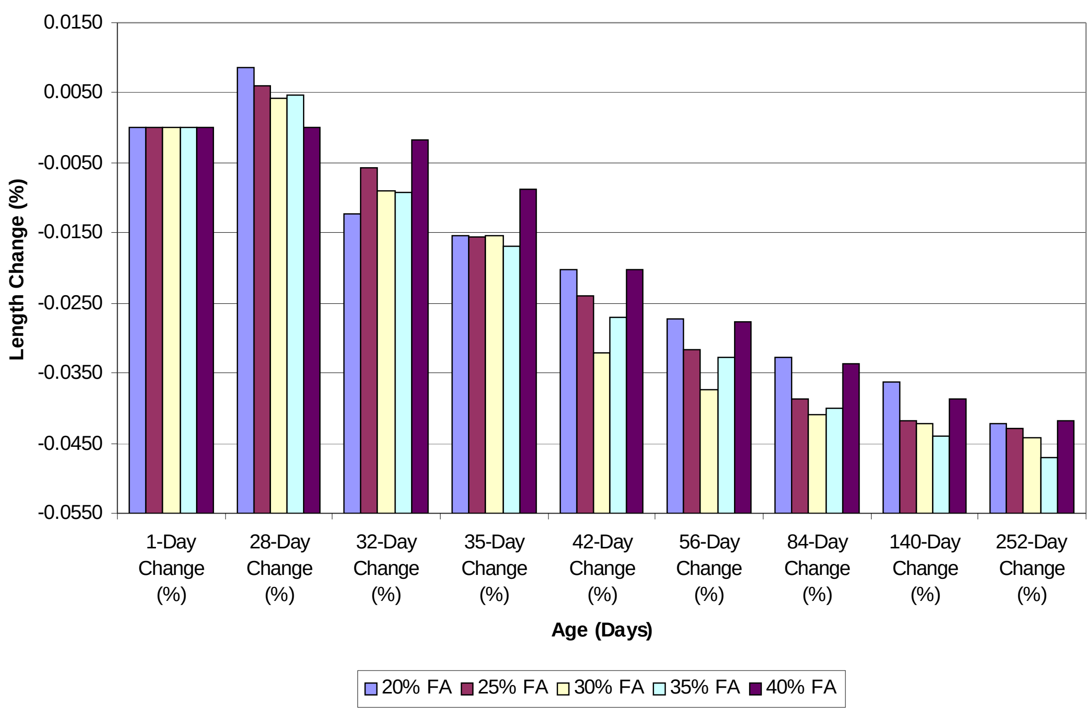
The rapid chloride ion permeability test results for the GGBFS mixes are located in Table D-5 of Appendix D. A comparison of the results for the surface layer of the test cores is shown in Figure 3.6. The results for this test show that when the percentage GGBFS increased the permeability of the concrete decreased; and when the curing time increased the permeability also decreased. None of the GGBFS mixes met the criteria for low permeability concrete at 28 or 56 days. The 40% GGBFS replacement mix met the low permeability criteria at 90 days; and both the 30% and 35% GGBFS replacement mixes were very close to the low permeability criteria at 90 days.

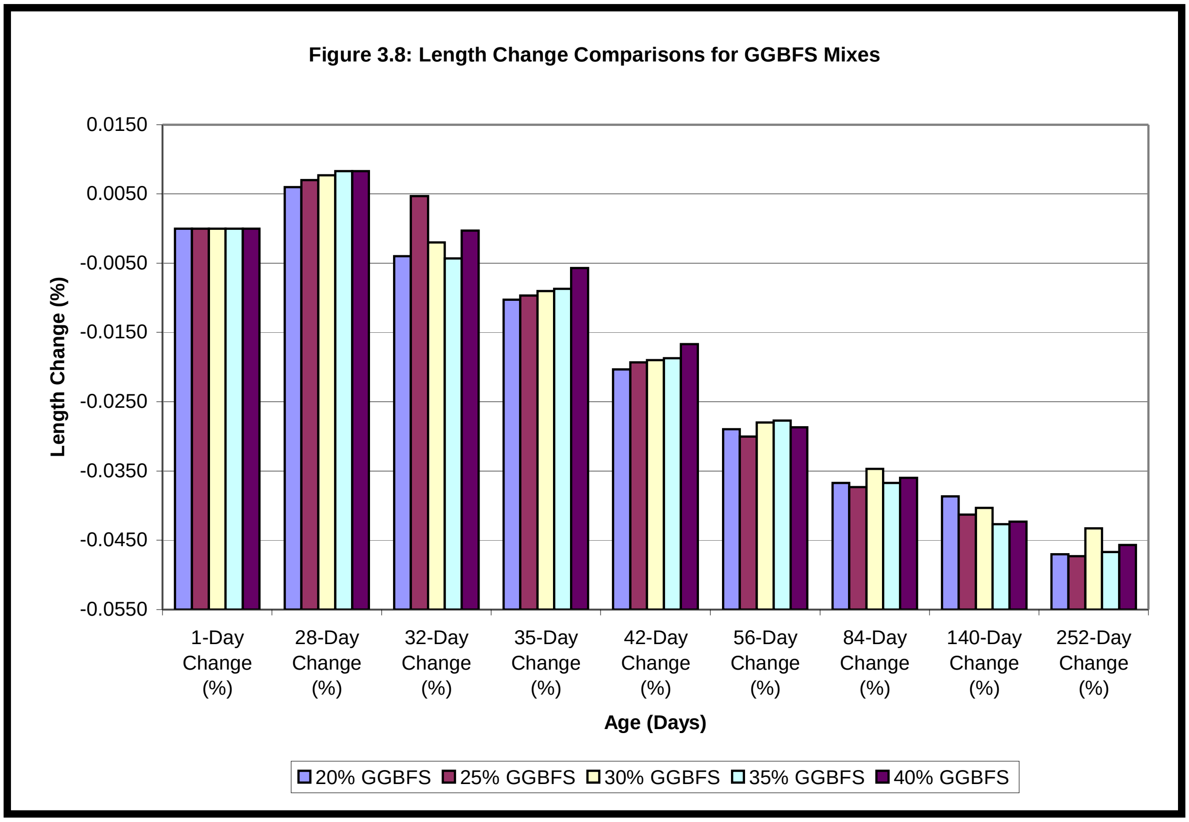


The shrinkage control tests (ASTM C 157) were performed at ages of 1, 28, 32, 35, 42, 56, 84, 140, and 252 days. The results are reported in terms of the percentage of length change of the specimen from the original length. Three test specimens were measured at each test date to represent an average for each mix. Since the use of fly ash and GGBFS admixtures generally increases the percentage of length change in concrete, this test was performed to ensure that any change in length due to the mineral admixtures was not enough to cause excessive cracking in the concrete.

The results from the shrinkage tests for the fly ash mixes are located in Table C-6 of Appendix C. A comparison of these test results is shown in Figure 3.7. The results indicate that all the fly ash replacement mixes were within 0.01% length change of one another. The results from the shrinkage control tests for the GGBFS mixes can be found in Table D-6 of Appendix D. The test results are shown in Figure 3.8. The results for the GGBFS amended mixes were similar to those obtained for the fly ash amended mixes. The results show that all the mixes were within 0.005% length change of one another.

Figure 3.7: Length Change Comparisons for Fly Ash Mixes





The freeze/thaw tests for this project were performed by the NDDOT in Bismarck, North Dakota. Freeze/thaw durability was a major consideration for this project because one of the goals was to find a low permeability concrete mix design that can be used by the NDDOT. North Dakota experiences severe temperature changes in the fall, spring, and winter months. In these months, it is common for a pavement to experience freezing and thawing conditions many times each week. Because of this fact, it is important to simulate what will happen when these concrete mixes experience numerous freezing and thawing cycles.

The results for the freeze/thaw durability tests are located in Table C-7 of Appendix C. A comparison of these results is shown in Figure 3.9. The results show that the durability factors increased along with the addition of fly ash until about 35% replacement and then the durability factor decreased with the addition of more fly ash. The results for the freeze/thaw durability tests for the GGBFS mixes are located in Table D-7 of Appendix D. A comparison of these results is shown in Figure 3.10. The results show a general increase in durability with an increase in GGBFS, although the 20% GGBFS mix did have a much higher durability factor than the other four mixes. The 30% 35%, and 40% GGBFS mixes reached durability factors very similar to that of the 30%, and 35% fly ash mixes.

Figure 3.9: Freeze/Thaw Durability Comparisons for Fly Ash Mixes

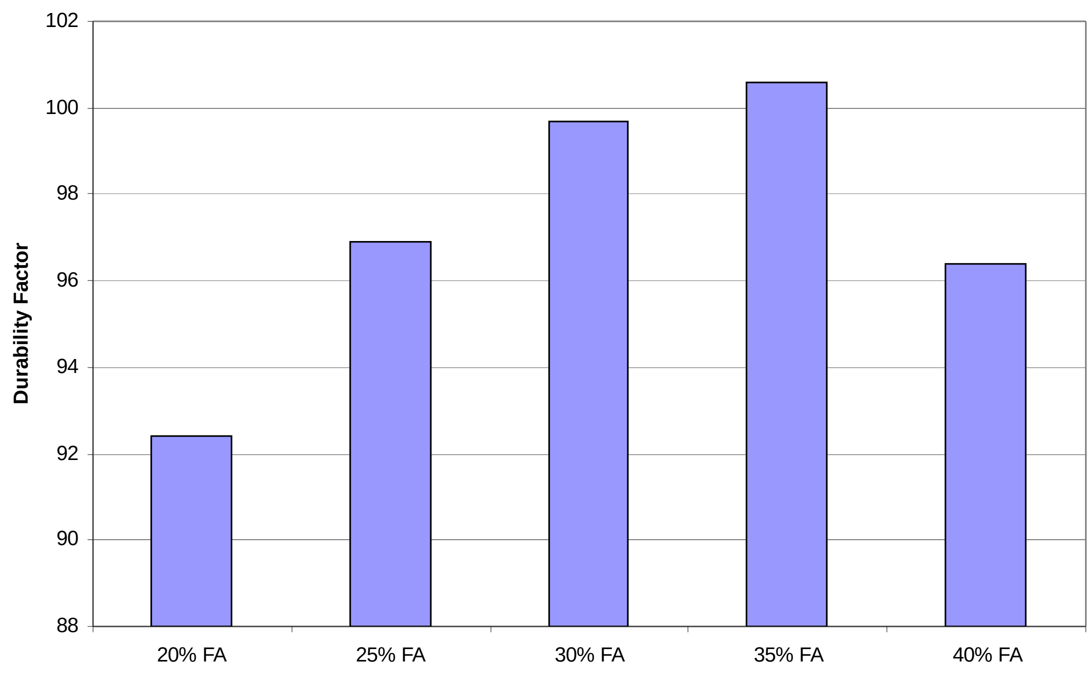
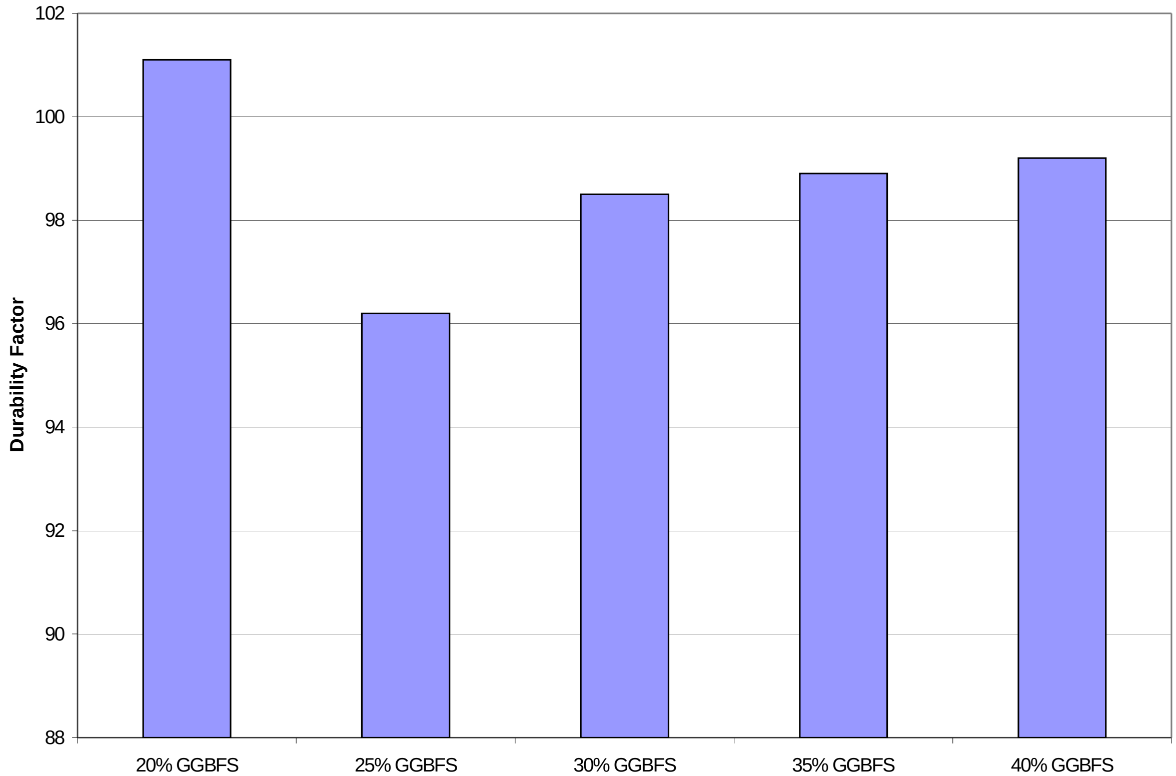


Figure 3.10: Freeze/Thaw Durability Comparisons for GGBFS Mixes



3.4 Mix Design Recommendations

When the laboratory-testing phase of the project was completed, Greg Johnson used the results to recommend three low permeable concrete mix designs for bridge decks to be constructed on I-29 in Fargo, North Dakota. (Greg summarized the recommendations in a report sent to the NDDOT dated May 21, 2002.) Each mix design specified a different combination of cementitious materials. Mix number one contained 611 lbs./yd^3 of Portland cement, mix number two contained a combination of 397 lbs./yd^3 of Portland cement and 214 lbs./yd^3 of GGBFS (i.e., 35% cement replacement), and mix number three contained a combination of 379 lbs./yd^3 of Portland cement and 232 lbs./yd^3 of fly ash (i.e., 38% cement replacement).

The various materials specified for the low permeable bridge decks are described in Table 3.1. The material proportions for the recommended concrete mixes are listed in Table 3.2. The plastic properties of the recommended mixes were determined by preparing representative batches in the laboratory, and the results are listed in Table 3.3. The compressive strengths of the recommended mixes were also tested, and the results are contained in Table 3.4.

Table 3.1 Descriptions of Materials Specified for Low Permeable Bridge Decks

Material	Material Description
Cement	Type I/II Portland meeting ASTM C 150, supplied by Lafarge Dakota, Plant:Exshaw, Alberta, Canada. Terminal:Grand Forks, North Dakota.
Fly Ash	Class C mineral admixture meeting ASTM C 618, supplied by Coal Creek Station, Underwood, North Dakota.
GGBFS	Ground Granulated Blast Furnace Slag - Holcim (Holnam) GranCem meeting ASTM C 989, Skyway Terminal, Chicago, Illinois.
Fine Aggregate	3/8" Down Sand meeting NDDOT 816.01 specifications, supplied by Ames S&G.
Coarse Aggregate	1"- #4 Gravel meeting NDDOT 816.02 Size No. 3 specifications, supplied by Ames Sand & Gravel.
Admixtures	1. AEA 92 air entraining admixture, conforming to ASTM C 260, supplied by Brett Admixtures, Minneapolis, Minnesota

Table 3.2 Material Proportions Specified for the Low Permeable Bridge Decks

Material*	Mix 1 (Portland Cement)	Mix 2 (GGBFS)	Mix 3 (Fly Ash)
Cement (lbs.)	611	397	379
GGBFS (lbs.)	0	214	0
Fly Ash (lbs.)	0	0	232
Fine Aggregate (lbs.)	1178	1136	1154
Coarse Aggregate (3/4"-#4) (lbs.)	1900	1858	1915
Admixtures: 1. AEA 92 (oz.)	5.1	6.1	4.3
Water (gallons)	30.5	31.5	26.3
Water (gallons/sack)	4.69	4.85	4.05
Water/Cementitious Ratio	0.42	0.43	0.36

* Note: The above batch weights are based on the aggregate being in a saturated-surface-dry condition. These batch weights were adjusted according to the amount of free moisture on the aggregate at the time of batching. Laboratory mixing was performed in general accordance with AASHTO T 126-93 on April 17 and 23, 2002

Table 3.3 Plastic Properties of Low Permeable Bridge Deck Mixes

Properties	Mix 1 (Portland Cement)	Mix 2 (GGBFS)	Mix 3 (Fly Ash)
Slump (inches)	3.25	3.25	3.5
Air Content (%)	6.1	6.0	5.5
Concrete Temperature (^oF)	75	74	75
Unit Weight (lbs/ft^3)	143.8	142.4	144.8
Relative Yield	1.015	1.008	0.999

Table 3.4 Compressive Strengths of Low Permeable Bridge Mixes

	Mix 1 (Portland Cement)	**Mix 2 (GGBFS)**	**Mix 3 (Fly Ash)**
1-Day Strength* (psi)	1958	1958	1220
3-Day Strength (psi)	2837	2837	2061
7-Day Strength (psi)	3390	3390	2607
14-Day Strength (psi)	4029	4029	3158
28-Day Strength (psi)	4471	4471	3832

*Note: Compressive strength tests were performed using 6" x 12" cylinders according to AASHTO T 22-97.

Maturity functions were also determined for each of the low permeable concrete deck mixes following the methods contained in ASTM C 1074-98. The maturity function for the Portland cement (only) mix is shown in Figure 3.11, the maturity function for the GGBFS mix is shown in Figure 3.12, and the maturity function for the fly ash mix is shown in Figure 3.13. The figures illustrate the relationship between strength development (y-axis) and the temperature-time factor (x-axis). On each figure, the data from the strength tests used to develop the maturity function is shown in red and the maturity index curve is shown as a dashed trend line. The equation for the maturity function developed for each mix is also included in the figure.

Figure 3.11: Temperature-Time Factor (Portland Cement Mix)

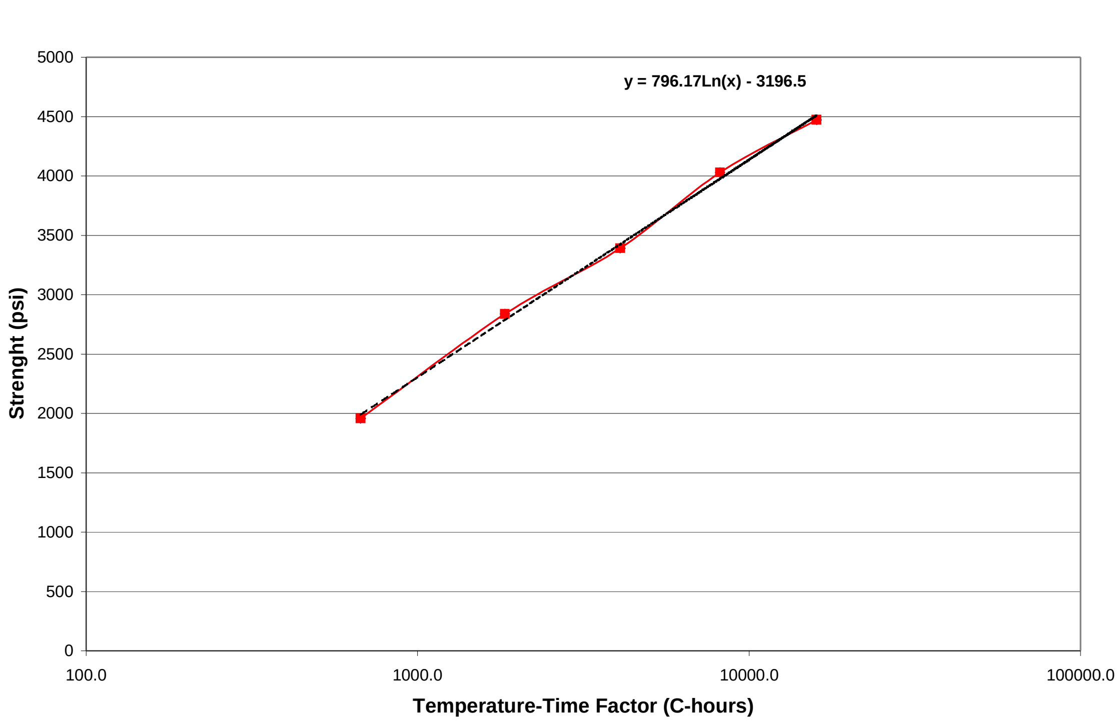
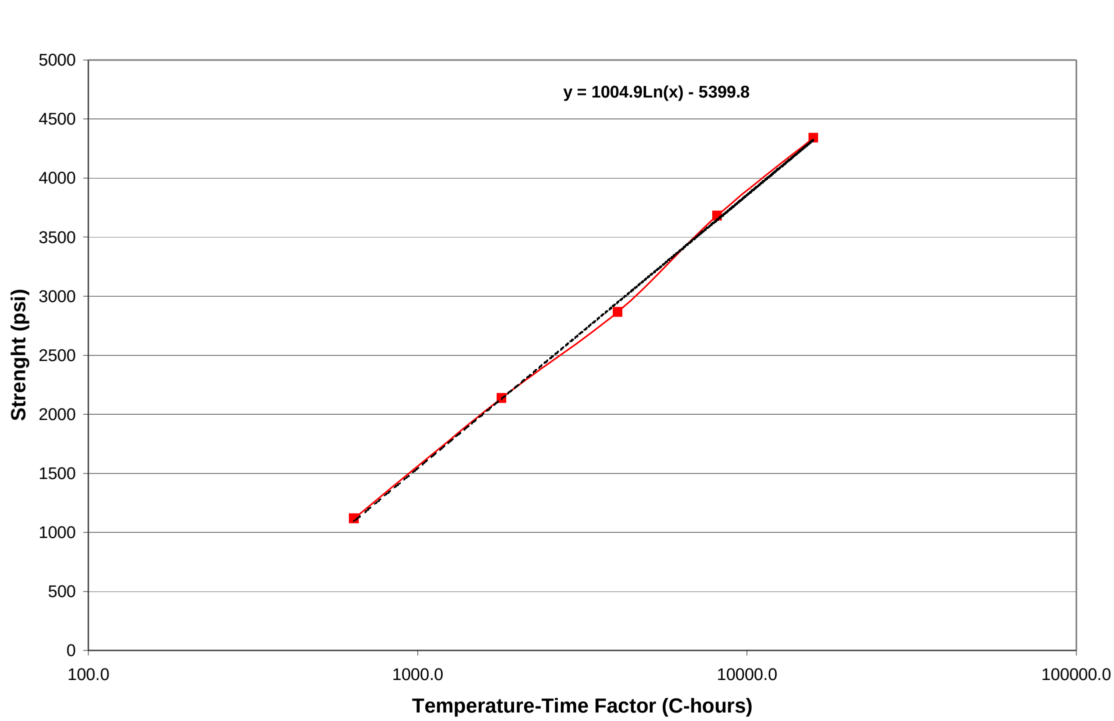


Figure 3.12: Temperature-Time Factor (GGBFS Mix)



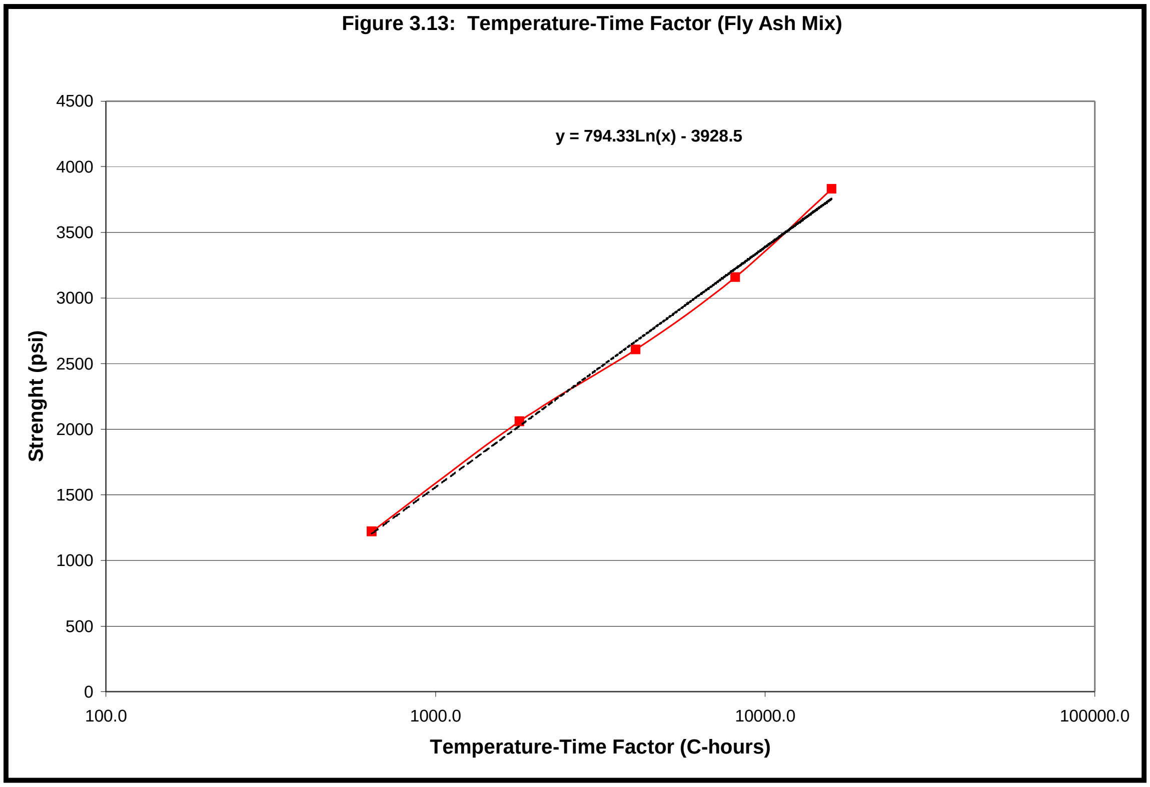


Figure 3.13: Temperature-Time Factor (Fly Ash Mix)
y = 794.33Ln(x) - 3928.5
Strenght (psi)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
100.0
1000.0
10000.0
100000.0
Temperature-Time Factor (C-hours)

4.0 – Bridge Deck Monitoring

4.1 Bridge Deck Locations

In July of 2002, Greg Johnson and Kyle Folland placed instruments in the decks of three bridges being constructed on southbound I-29 in Fargo, North Dakota. The instruments will be used to monitor corrosion rates in the reinforcing steel and temperature changes in the concrete bridge decks. The goal of the monitoring activities is to determine if partial replacement of Portland cement with an optimized quantity of locally available fly ash or GGBFS can extend the service life of bridge structures.

The three bridges are at the following locations:

	Name	**Cement Replacement**	**Location**
Site 1	17^{th} Ave. South	GGBFS (35% by wt.)	Station 3368 + 07.33
Site 2	Texas Turn	Fly Ash (38% by wt.)	Station 3386 + 60.15
Site 3	9^{th} Ave. South	None	Station 3408 + 52.06

The following cementitious materials were used for the bridge decks:

- The Portland cement was Lafarge Type I/II, supplied from Exshaw, Alberta Canada.
- The fly ash was Type C from the Coal Creek Station in Underwood, North Dakota.
- The GGBFS was Holcim GranCem 100, from the Skyway Terminal in Chicago, Illinois.

Material test data for the GGBFS is contained in Appendix G. The concrete mix design requirements for the three bridge decks as constructed are summarized in Table 4.1.

Table 4.1 Concrete Mix Design Requirements for the Bridge Decks

	17^{th} Ave S.	Texas Turn	9^{th} Ave. S.
Cementitious Mateial (lb./cy)	611	611	611
Portland Cement (lb./cy)	397	379	611
Fly Ash (lb./cy)	0.0	232	0.0
GGBFS (lb./cy)	214	0.0	0.0
Coarse Aggregate Size	No.3	No.3	No.3
Max. Water/Cement (gals./sack)	5.41	5.0	5.0
Max. w/c Ratio	0.48	0.443	0.443
Air Content (%)	5.0 – 8.0	5.0 – 8.0	5.0 – 8.0
Max. Slump (inches)	3	3	3
Design 28-Day Comp. Strength (psi)	4000	4000	4000

4.2 Bridge Deck Instrumentation

A Gecor 6 corrosion field test instrument will be used to monitor corrosion rates for the rebar in the bridge decks. In order to use the Gecor 6, an electrical contact must be attached directly to the rebar close to the point where the corrosion rate measurement is to be taken. To monitor corrosion in the bridges, fifteen contacts were attached to each bridge deck at approximately equidistant intervals along the east edge of the deck. Each contact consisted of a stainless steel rod attached to a 3-inch square stainless steel plate. The rod was attached directly to the rebar and the plate was set level with the deck surface so that it could be accessed as an electrical contact point for the Gecor 6. A picture of a contact attached to the deck rebar is shown in Figure 4.1.

Figure 4.1: Stainless Steel Contact Attached to Bridge Deck Rebar

The Gecor 6 measures the corrosion rate of steel by the “polarization resistance” technique. This is a non-destructive technique that works by applying a small current to the rebar and measuring the change in the half-cell potential. When a corrosion measurement is to be taken on a bridge, an electrical lead from the Gecor 6 will be attached to the contact plate on the bridge deck and another probe will be placed on the concrete over the rebar that is connected to the contact. All of the contacts are connected to rebar that run transverse to the length of the deck. To take a measurement, the Gecor 6 probe should be placed at least four inches away from the contact plate on a line with the plate perpendicular to the bridge sidewall barrier and on the side of the plate away from the sidewall barrier. When a measurement is taken with the Gecor 6, the diameter of the rebar must be specified for the corrosion rate calculation. The following rebar diameters are to be used for the corrosion calculations:

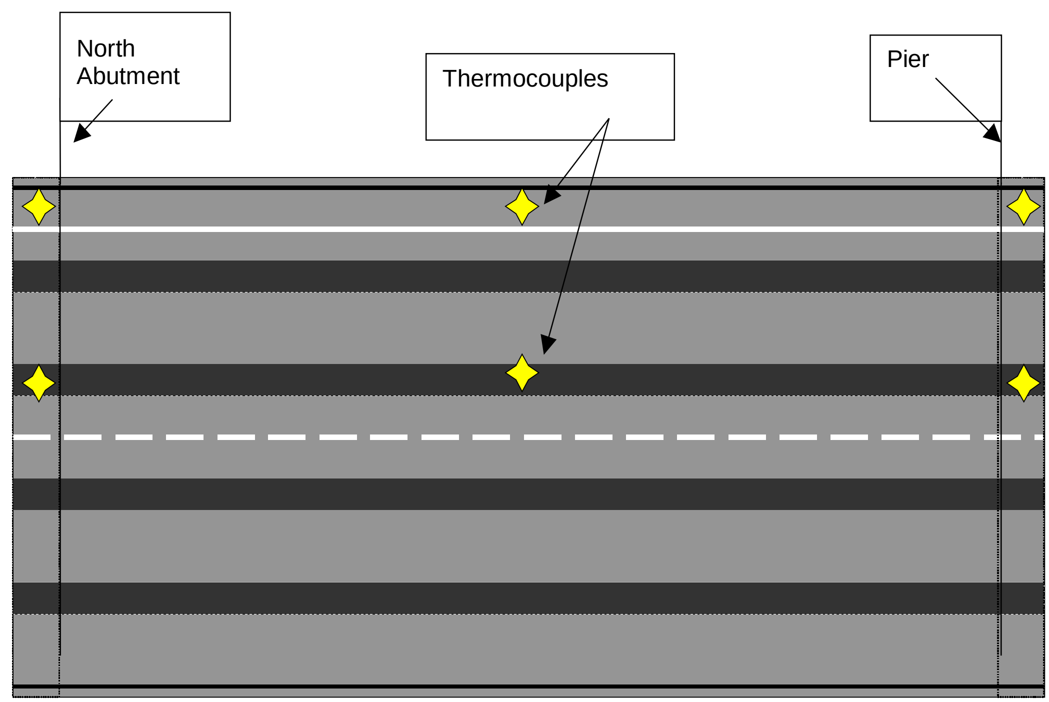
- 9th Ave. South - 5/8 inch rebar
- Texas Turn - 3/4 inch rebar
- 17th Ave. South - 5/8 inch rebar

Temperature monitoring equipment was also installed in the concrete bridge decks to record temperature changes in the concrete over time. Six sets of thermocouples were installed at various points on each of the three bridge decks. Two sets of thermocouples were installed over the abutment at the north end of the deck; one set was close to the sidewall barrier and the other set was close to the middle of the roadway. Two sets were installed at the midpoint of the span length, and two sets at the south end of the span over the pier. The general locations of the thermocouple sets are shown in Figure 4.2, and their exact locations on each bridge are listed in Table 4.2.

Each set consisted of three thermocouples placed at depths of 0.5 inch, 3 inches, and 5 inches below the surface of the concrete. Two redundant thermocouples were installed at all depths in case one was damaged during construction. A picture of the thermocouple arrangement is shown in Figure 4.3.

Each Teflon insulated thermocouple is attached to a wire that runs through a conduit to a data collection apparatus located below the bridge deck. The data logger is an Omega OM-320 microprocessor capable of storing > 32,000 data points. The data loggers are equipped with Omega OM-320-HLIM-1 analog interface modules. The data logging equipment is housed in a steel box attached to the bridge pier, and a 100- watt heater is installed in the storage box to protect the equipment from cold temperatures. A picture of the data collection setup is shown in Figure 4.4. All of the data logging equipment was purchased with an extended warranty.

Figure 4.2: General Location of Thermocouples on Bridge Deck



The data collection systems are programmed to take temperature readings in degrees Fahrenheit from the eighteen points where thermocouples are inserted in the concrete bridge decks. To maximize use of the computer memory in the data loggers, they have been programmed to collect more data as the temperature approaches freezing and as the rate of change of temperature increases.   When the temperature is well above freezing, data is collected every half hour from three thermocouples located at a single collection point at midspan on each bridge. For the rest of the thermocouples, when the temperature drops to within about five degrees of freezing the data logger will begin to collect data. If the temperature is close to freezing and the rate of temperature change is high, the data logger can collect temperature readings as often as one per minute.

Table 4.2 Exact Locations of Thermocouples on Bridge Decks

Bridge	Thermocouple Designation	Distance from North Edge of Deck	Distance from East Edge of Deck
9th Ave S.	A 1 to 3	8 ½”	14’-1½”
	A 4 to 6	9 ½”	1’-10”
	B 1 to 3	26’-7”	14’-0”
	B 4 to 6	26’-¼”	1’-10½”
	C 1 to 3	51’-6”	14’-4”
	C 4 to 6	51-0”	2’
Texas Turn	A 1 to 3	1’-11”	14’-4”
	A 4 to 6	1’-1”	1’-8”
	B 1 to 3	23’-2”	14’-2”
	B 4 to 6	23’-0”	1’-8”
	C 1 to 3	50’-6”	14’-4”
	C 4 to 6	50’-2”	1’-9”
17th Ave. S.	A 1 to 3	1’-4”	14’-4”
	A 4 to 6	1’-3½”	1’-9”
	B 1 to 3	25’-1½”	14’-3”
	B 4 to 6	25’-8½”	1’-9”
	C 1 to 3	50’-1½”	14’-4”
	C 4 to 6	49’-8½”	1’-9½”

Figure 4.3 Arrangement of Redundant Thermocouples at Each Temperature Recording Point

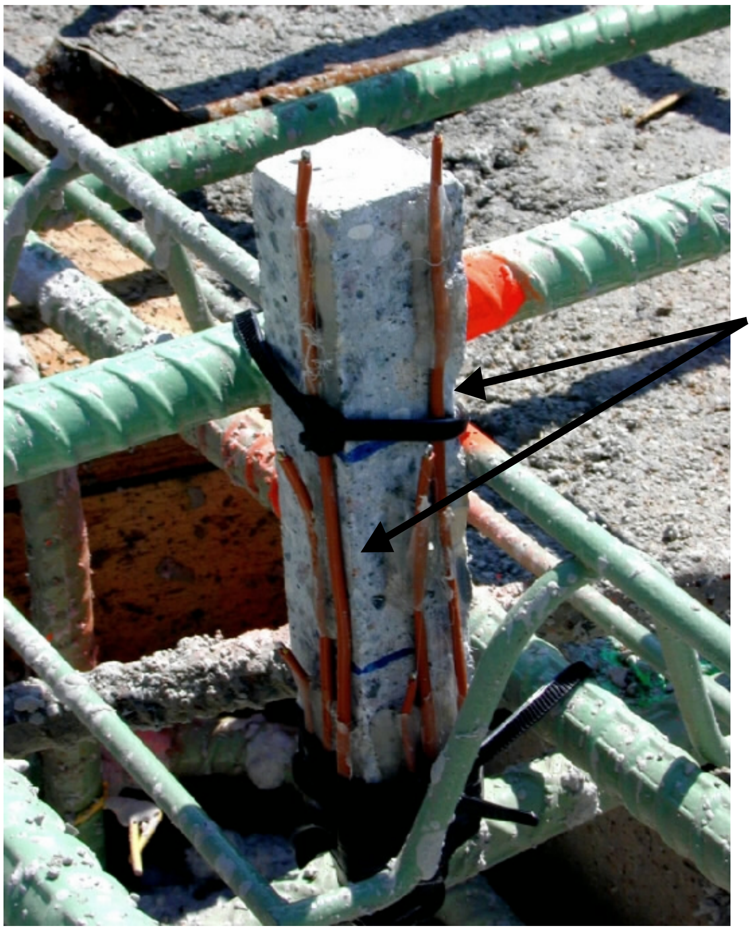
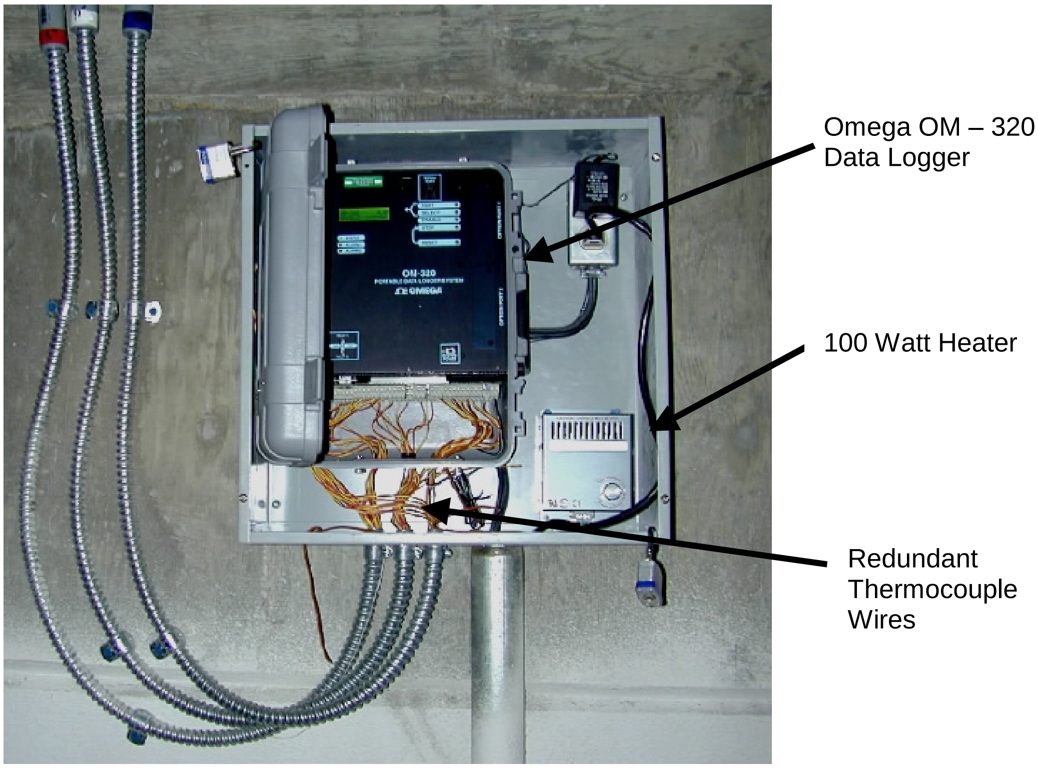


Figure 4.4   Equipment Used for Logging Temperature Data



4.3 Observation of Construction Activities

Greg Johnson and Kyle Folland observed the construction activities for the three bridge decks to verify that the corrosion rate test and temperature monitoring equipment were properly placed and not damaged during the construction process. One problem was discovered. The C1 thermocouple on the 9th Avenue Bridge was apparently damaged during construction and did not record temperatures during the initial curing of the concrete. However since redundant thermocouples were installed at all data collection points, it was possible to activate the duplicate thermocouple for future data collection.

The concrete used for construction of the bridge decks was tested in the field during the pours. The data collected for the 9th Ave. Bridge is summarized in Table 4.3; the data collected for the Texas Turn Bridge is summarized in Table 4.4; and the data collected for the 17th Ave. Bridge is summarized in Table 4.5. A complete set of results from the field tests is contained in Appendix G.

Table 4.3 – Concrete Data Collected in the Field for the 9th Avenue Bridge (No Cement Replacement)

Slump (inches)	Air Content (% Volume)	Concrete Temperature (deg. F)	Ave. 7-Day Compressive Strength (psi)	Ave. 28-Day Compressive Strength (psi)	Water Added (gal./sk.)
2.75	5.6	78	3865	4855	4.60
2.75	7.0	79	ND*	4130	4.57
2.5	6.0	79	3600	4335	4.56
3	7.0	80	ND	3955	4.70
3.75	7.0	80	3140	3945	4.73
2.75	6.0	78	3865	4655	4.80
2.75	7.0	79	ND	4130	4.57
2.5	8.0	79	3745	4335	4.56
3	7.0	80	ND	3955	4.70
3.75	7.0	80	3150	3945	4.73

*ND – No data collected

Table 4.4 – Concrete Data Collected in the Field for the Texas Turn Bridge (38% Cement Replacement with Fly Ash)

Slump (inches)	Air Content (% Volume)	Concrete Temperature (deg. F)	Ave. 7-Day Compressive Strength (psi)	Ave. 28-Day Compressive Strength (psi)	Water Added (gal./sk.)
2.5	6.6	72	3490	5105	3.59
3.25	6.1	76	ND*	5105	3.69
3	6.2	74	3360	5010	3.68
3.25	5.9	76	ND	5100	3.69
3	5.7	77	3360	5130	3.66
2.75	5.6	77	ND	5380	3.68

*ND – No data collected

Table 4.5 – Concrete Data Collected in the Field for the 17th Avenue Bridge (35% Cement Replacement with GGBFS)

Slump (in.)	Air Content (% Volume)	Concrete Temp. (deg. F)	Ave. 7-Day Compressive Strength (psi)	Ave. 28-Day Compressive Strength (psi)	Water Added (gal./sk.)
4	6.1	780	3850	5585	4.51
1.75	4.8	79	ND*	6220	4.24
2	4.6	79	4750	5945	4.24
3	4.8	78	ND	5690	4.33
3	6.2	79	3510	4595	4.33
2.5	5.1	81	ND	4975	4.33

*ND – No data collected

The thermocouples installed at each bridge were used to record concrete temperatures in the slab from the time the pours started until about 15 days afterwards. The objective was to monitor temperatures within the slabs during the initial concrete curing phase. Temperature profiles obtained for the first week after the pour at the three bridges are contained in Appendix H. All of the thermocouples appeared to be functioning properly except for the C1 probe on the 9th Avenue Bridge. No data was collected for this thermocouple during the initial curing phase.

From the figures in Appendix H, it appears that heat liberated due to cement hydration produced the highest internal temperatures during the first 24 hours of curing. The maximum temperatures recorded at all of the thermocouples in the three slabs during the first day of curing are listed in Table 4.6. The highest single temperature recorded for the 9th Avenue Bridge is indicated in Table 4.7; the highest single temperature recorded for the Texas Turn Bridge is indicated in Table 4.8; and the highest single temperature recorded for the 17th Avenue Bridge is indicated in Table 4.9.

Table 4.6 Maximum Temperatures Recorded at Each Thermocouple During First 24 Hours of Concrete Curing

Thermocouple Designation	9th Avenue Bridge (Max. Temperature, Degrees F)	Texas Turn Bridge (Max. Temperature, Degrees F)	17th Avenue Bridge (Max. Temperature, Degrees F)
A 1	116.4	86.9	109.2
A 2	120.8	92.0	111.1
A 3	121.8	95.2	113.4
A 4	115.4	82.4	110.2
A 5	114.4	89.2	110.2
A 6	114.3	91.6	109.0
B 1	114.7	86.3	110.1
B 2	117.9	89.7	112.1
B 3	119.8	92.7	113.2
B 4	115.1	87.2	107.9
B 5	118.7	90.5	109.6
B 6	119.1	91.3	109.9
C 1	ND*	88.0	112.3
C 2	121.9	92.8	115.1
C 3	123.0	94.9	116.1
C 4	115.0	86.9	110.3
C 5	119.9	91.1	113.7
C 6	118.9	92.7	112.3

Table 4.7 Maximum Concrete Temperature Recorded from All Thermocouples During Initial Curing of 9th Avenue Bridge

Thermocouple at which maximum concrete temperature was recorded	C3
Location of C3 probe	East edge, at pier, 5” deep
Maximum concrete temperature recorded	123.0 degrees F
Day and time that bridge pour started	6/27/02 at 5:15 AM
Time after start of pour when maximum concrete temperature occurred	11 hrs and 45 min
Maximum ambient temperature recorded on day of pour	90.0 degrees F
Time after start of pour when maximum ambient temperature occurred	11 hrs

Table 4.8 Maximum Concrete Temperature Recorded from All Thermocouples During Initial Curing of Texas Turn Bridge

Thermocouple at which maximum concrete temperature was recorded	C6.
Location of C6 probe	East edge, at pier, 5" deep
Maximum concrete temperature recorded	94.9 degrees F
Day and time that bridge pour started	8/1/02 at 8:00 AM
Time after start of pour when maximum concrete temperature occurred	12 hrs and 30 min
Maximum ambient temperature recorded on day of pour	71.5 degrees F
Time after start of pour when maximum ambient temperature occurred	11 hrs and 30 min

Table 4.9 Maximum Concrete Temperature Recorded from All Thermocouples During Initial Curing of 17th Avenue Bridge

Thermocouple at which maximum concrete temperature was recorded	C6.
Location of C6 probe	East edge, at pier, 5" deep
Maximum concrete temperature recorded	116.1 degrees F
Day and time that bridge pour started	6/27/02 at 5:15 AM
Time after start of pour when maximum concrete temperature occurred	13 hrs
Maximum ambient temperature recorded on day of pour	86.5 degrees F
Time after start of pour when maximum ambient temperature occurred	12 hrs and 30 min

5.0 – Summary and Conclusions

The purpose of this project was to develop concrete mix designs containing fly ash and GGBFS suitable for producing low permeability bridge decks at no or minimal increase in cost. The project had two major tasks:

- The objective of task one was to test various fly ash and GGBFS amended concrete mix designs and to make recommendations for optimal Portland cement replacement levels for these two mineral admixtures.
- The objective of task two was to install instruments to monitor temperatures and corrosion rates in three concrete bridge decks being constructed on southbound I-29 in Fargo, North Dakota.

The general concrete mix design used for this research is the current NDDOT mix design procedure, which is based on the NDDOT's *Standard Specifications for Road and Bridge Construction, 1997, Volumes 1 and 2.* The target requirements for the mix designs were a 28-day compressive strength of at least 4,000 psi, a slump of 2½ to 3 inches, and an air content of 6.0%. The variation of each mix design occurred in the fly ash-to-cement and GGBFS-to-cement replacements. The replacement of cement with the mineral admixtures was 20%, 25%, 30%, 35%, and 40% by weight. Tests were performed on the various concrete mixes to measure plastic properties and to determine performance characteristics of the hardened concrete.

Based on the test results, the recommended fly ash replacement percentage for low permeable concrete is 38% and the recommended GGBFS replacement percentage is 35%. The 38% fly ash replacement mix met the target design criteria for this project (i.e., slump, air content, and 28-day compressive strength). The two properties that had the greatest influence on the recommendation of optimal replacement percentage were freeze/thaw durability and rapid chloride ion permeability.

The 35% GGBFS replacement mix also met the target design criteria for this project. In this case, it was initially thought that the 40% GGBFS replacement might be recommended as the optimal replacement mix. However, the freeze/thaw durability and rapid chloride ion permeability results were very close for the 35% and 40% replacement mixes. It was then noted that the compressive strength of the 40% replacement mix was significantly lower than the 35% mix. This was the deciding factor for recommending 35% GGBFS replacement. When considering which GGBFS addition to recommend for an optimal mix design, it was noted that the 20% GGBFS mix had a much higher freeze/thaw durability factor than the other four mixes. However since this result did not seem to fit the overall trend of increasing durability with increasing GGBFS addition, these researchers decided not to recommend a 20% GGBFS replacement mix design. These investigators also recommend that the behavior of concrete containing GGBFS be researched further. The behavior of the strength properties after an age of 56 days is a point of concern because the data presented in this report shows a decrease in strength after an age of 56 days. This behavior could affect the durability of concrete that contains GGBFS.

In July of 2002, Greg Johnson and Kyle Folland placed instruments in the decks of three bridges being constructed on southbound I-29 in Fargo, North Dakota. The instruments will be used to monitor corrosion rates in the reinforcing steel and temperature changes in the concrete bridge decks. The goal of the monitoring is to determine if partial replacement of Portland cement with an optimized quantity of locally available fly ash or GGBFS can extend the service life of bridge structures.

A Gecor 6 corrosion field test instrument will be used to monitor corrosion rates for the rebar in the bridge decks. In order to use the Gecor 6, an electrical contact must be attached directly to the rebar close to the point where the corrosion rate measurement is to be taken. To monitor corrosion in the bridges, fifteen contacts were attached to each bridge deck at approximately equidistant intervals along the east edge of the deck. Each contact consisted of a stainless steel rod attached to a small square stainless steel plate. The rod was attached directly to the rebar and the plate was set level with the surface of the deck so that it could be accessed as an electrical contact point for the Gecor 6.

Temperature monitoring equipment was also installed in the concrete bridge decks to record temperature changes in the concrete over time. Six sets of thermocouples were installed at various points on each of the three bridge decks. Two sets of thermocouples were installed over the abutment at the north end of the deck; one set was close to the sidewall barrier and the other set was close to the middle of the roadway. Two sets were installed at the midpoint of the span length, and two sets at the south end of the span over the pier. Each set consisted of three thermocouples placed at depths of 0.5 inch, 3 inches, and 5 inches below the surface of the concrete. Two redundant thermocouples were installed at all depths in case one was damaged during construction.

Greg Johnson and Kyle Folland observed the construction activities for the three bridge decks to verify that the corrosion rate testing and temperature monitoring equipment were properly placed and that they were not damaged during the construction process. They determined that one thermocouple was damaged during construction. However since redundant thermocouples were used at each data collection point, this should not create a problem for future monitoring activities.

Appendix A

Trial Batch Weights for Fly Ash Mixes

Trial Batch Weights: 20% Fly Ash

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	112.8 lbs.	4.18 lbs.	18.80 lbs.
Cement	451.2 lbs.	16.71 lbs.	75.20 lbs.
Mineral Admixture	0.0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 1	1941 lbs.	71.91 lbs.	323.58 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1200 lbs.	44.46 lbs.	200.06 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	7.3 oz.	8.03 ml	36.1 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	1.7 gallons	0.53 lbs.	2.38 lbs.
Add Water	25.8 gallons	7.96 lbs.	35.81 lbs.
Total Batch Weight	3920.7 lbs.	145.2 lbs.	653.45 lbs.

Trial Batch Weights: 25% Fly Ash

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	141 lbs.	5.22 lbs.	23.50 lbs.
Cement	423 lbs.	15.67 lbs.	70.50 lbs.
Mineral Admixture	0.0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 1	1936 lbs.	71.72 lbs.	322.75 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1196 lbs.	44.30 lbs.	199.36 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	7.3 oz.	8.03 ml	36.1 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	1.2 gallons	0.36 lbs.	1.61 lbs.
Add Water	26.3 gallons	8.13 lbs.	36.58 lbs.
Total Batch Weight	3916.1 lbs.	145.0 lbs.	652.68 lbs.

Trial Batch Weights: 30% Fly Ash

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	169.2 lbs.	6.27 lbs.	28.20 lbs.
Cement	394.8 lbs.	14.62 lbs.	65.80 lbs.
Mineral Admixture	0.0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 1	1936 lbs.	71.72 lbs.	322.75 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1186 lbs.	43.93 lbs.	197.67 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	8.5 oz.	9.27 ml	41.7 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	1.3 gallons	0.39 lbs.	1.77 lbs.
Add Water	26.5 gallons	8.19 lbs.	36.84 lbs.
Total Batch Weight	3907.5 lbs.	144.7 lbs.	651.26 lbs.

Trial Batch Weights: 35% Fly Ash

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	197.4 lbs.	7.31 lbs.	32.90 lbs.
Cement	366.6 lbs.	13.58 lbs.	61.10 lbs.
Mineral Admixture	0.0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 1	1907 lbs.	70.62 lbs.	317.78 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1229 lbs.	45.50 lbs.	204.75 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	7.3 oz.	8.03 ml	36.1 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	2.0 gallons	0.61 lbs.	2.72 lbs.
Add Water	25.3 gallons	7.81 lbs.	35.12 lbs.
Total Batch Weight	3910.0 lbs.	144.8 lbs.	651.66 lbs.

Trial Batch Weights: 40% Fly Ash

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	225.6 lbs.	8.36 lbs.	37.60 lbs.
Cement	338.4 lbs.	12.53 lbs.	56.40 lbs.
Mineral Admixture	0.0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 1	1909 lbs.	70.69 lbs.	318.10 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1227 lbs.	45.46 lbs.	204.58 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	7.3 oz.	8.03 ml	36.1 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	2.6 gallons	0.80 lbs.	3.61 lbs.
Add Water	24.6 gallons	7.61 lbs.	34.23 lbs.
Total Batch Weight	3905.5 lbs.	144.6 lbs.	650.92 lbs.

Appendix B

Trial Batch Weights for Ground Granulated Blast-Furnace Slag Mixes

Trial Batch Weights: 20% GGBFS

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	0 lbs.	0.00 lbs.	0.00 lbs.
Cement	451.2 lbs.	16.71 lbs.	75.20 lbs.
Mineral Admixture	112.8 lbs.	4.18 lbs.	18.80 lbs.
Coarse Aggregate 1	1887 lbs.	69.88 lbs.	314.47 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1202 lbs.	44.51 lbs.	200.30 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	8.5 oz.	9.27 ml	41.7 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	1.2 gallons	0.38 lbs.	1.69 lbs.
Add Water	28.8 gallons	8.88 lbs.	39.98 lbs.
Total Batch Weight	3892.5 lbs.	144.2 lbs.	648.74 lbs.

Trial Batch Weights: 25% GGBFS

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	0 lbs.	0.00 lbs.	0.00 lbs.
Cement	423 lbs.	15.67 lbs.	70.50 lbs.
Mineral Admixture	141.0 lbs.	5.22 lbs.	23.50 lbs.
Coarse Aggregate 1	1887 lbs.	69.88 lbs.	314.47 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1187 lbs.	43.95 lbs.	197.78 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	8.5 oz.	9.27 ml	41.7 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	1.0 gallons	0.32 lbs.	1.45 lbs.
Add Water	29.5 gallons	9.09 lbs.	40.91 lbs.
Total Batch Weight	3883.0 lbs.	143.8 lbs.	647.16 lbs.

Trial Batch Weights: 30% GGBFS

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	0 lbs.	0.00 lbs.	0.00 lbs.
Cement	394.8 lbs.	14.62 lbs.	65.80 lbs.
Mineral Admixture	169.2 lbs.	6.27 lbs.	28.20 lbs.
Coarse Aggregate 1	1887 lbs.	69.88 lbs.	314.47 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1172 lbs.	43.39 lbs.	195.27 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	9.6 oz.	10.50 ml	47.3 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	0.9 gallons	0.27 lbs.	1.22 lbs.
Add Water	30.1 gallons	9.30 lbs.	41.83 lbs.
Total Batch Weight	3873.5 lbs.	143.5 lbs.	645.58 lbs.

Trial Batch Weights: 35% GGBFS

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	0 lbs.	0.00 lbs.	0.00 lbs.
Cement	366.6 lbs.	13.58 lbs.	61.10 lbs.
Mineral Admixture	197.4 lbs.	7.31 lbs.	32.90 lbs.
Coarse Aggregate 1	1887 lbs.	69.88 lbs.	314.47 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1175 lbs.	43.50 lbs.	195.76 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	7.3 oz.	8.03 ml	36.1 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	1.6 gallons	0.48 lbs.	2.16 lbs.
Add Water	29.4 gallons	9.09 lbs.	40.90 lbs.
Total Batch Weight	3870.8 lbs.	143.4 lbs.	645.13 lbs.

Trial Batch Weights: 40% GGBFS

Size	27.0 ft^3	1.0 ft^3	4.5 ft^3
Fly Ash	0 lbs.	0.00 lbs.	0.00 lbs.
Cement	338.4 lbs.	12.53 lbs.	56.40 lbs.
Mineral Admixture	225.6 lbs.	8.36 lbs.	37.60 lbs.
Coarse Aggregate 1	1887 lbs.	69.88 lbs.	314.47 lbs.
Coarse Aggregate 2	0 lbs.	0.00 lbs.	0.00 lbs.
Coarse Aggregate 3	0 lbs.	0.00 lbs.	0.00 lbs.
Fine Aggregate	1175 lbs.	43.53 lbs.	195.87 lbs.
Water Reducer	0.0 oz.	0.00 ml	0.0 ml
Air Entrainment	13.0 oz.	14.21 ml	63.9 ml
Other Admixture	0.0 oz.	0.00 ml	0.0 ml
Free Water	2.0 gallons	0.60 lbs.	2.72 lbs.
Add Water	29.0 gallons	8.96 lbs.	40.34 lbs.
Total Batch Weight	3868.1 lbs.	143.3 lbs.	644.69 lbs.

Appendix C

Summarized Test Results for Fly Ash Mixes

Table C-1: Plastic Properties for Fly Ash Mixes					
Mix No.	6	7	8	9	10
Mix Description	20% FA	25% FA	30% FA	35% FA	40% FA
Slump (in.)	3	3	3	2 1/4	3
Air (%)	6.2	6.1	6.2	5.8	5.6
Unit Weight (lbs/ft^3)	143.1	143.7	142.7	143.9	144.3
Temperature (^{o}F)	69	73	83	81	81
Relative Yield	1.012	1.009	1.014	1.006	1.001
W/C Ratio	0.42	0.41	0.41	0.40	0.40

Table C-2: Compressive Strength for Fly Ash Mixes					
Mix No.	6	7	8	9	10
Mix Description	20% FA	25% FA	30% FA	35% FA	40% FA
1-Day Strength (psi)	1070	1430	1470	1260	1280
3-Day Strength (psi)	2350	2520	2200	2090	2590
7-Day Strength (psi)	3240	3250	2770	2600	3050
14-Day Strength (psi)	3650	3570	3000	3230	3690
28-Day Strength (psi)	4570	4270	3680	4040	4200
56-Day Strength (psi)	5100	4960	4410	4720	5070
90-Day Strength (psi)	4950	5170	4940	4970	5180

Table C-3: Flexural Strength for Fly Ash Mixes					
Mix No.	6	7	8	9	10
Mix Description	20% FA	25% FA	30% FA	35% FA	40% FA
1-Day Strength (psi)	285	310	330	310	285
3-Day Strength (psi)	290	475	430	420	435
7-Day Strength (psi)	555	555	480	445	495
14-Day Strength (psi)	645	590	550	535	565
28-Day Strength (psi)	755	665	580	580	645
56-Day Strength (psi)	765	705	655	665	675
90-Day Strength (psi)	790	735	685	710	705

Table C-4: Permeability of Fly Ash Mixes						
Mix No.		6	7	8	9	10
Mix Description		20% FA	25% FA	30% FA	35% FA	40% FA
14-day	0"-2"			6958	3003	2999
	2"-4"			3668	2000	1998
	4"-6"			2949	1760	1765
	6"-8"			2537	1100	1614
28-day	0"-2"	6534	4660	4356	2635	2131
	2"-4"	2774	2299	2255	1233	1067
	4"-6"	2184	1892	1467	1042	954
	6"-8"	1958	1406	1454	853	816
56-day	0"-2"	5720	4497	4204	2612	1496
	2"-4"	1994	1529	1050	722	553
	4"-6"	4896	1413	754	581	498
	6"-8"	1475	980	533	418	390
90-day	0"-2"	2958	3632	2610	1860	1204
	2"-4"	1115	1127	826	520	364
	4"-6"	815	915	541	375	306
	6"-8"	880	807	510	358	306

Table C-5: Length Change for Fly Ash Mixes					
Mix No.	6	7	8	9	10
Mix Description	20% FA	25% FA	30% FA	35% FA	40% FA
1-Day Change (%)	0.0000	0.0000	0.0000	0.0000	0.0000
28-Day Change (%)	0.0087	0.0060	0.0043	0.0047	0.0000
32-Day Change (%)	-0.0123	-0.0057	-0.0090	-0.0093	-0.0017
35-Day Change (%)	-0.0153	-0.0157	-0.0153	-0.0170	-0.0087
42-Day Change (%)	-0.0203	-0.0240	-0.0320	-0.0270	-0.0203
56-Day Change (%)	-0.0273	-0.0317	-0.0373	-0.0327	-0.0277
84-Day Change (%)	-0.0327	-0.0387	-0.0410	-0.0400	-0.0337
140-Day Change (%)	-0.0363	-0.0417	-0.0423	-0.0440	-0.0387
252-Day Change (%)	-0.0423	-0.0430	-0.0443	-0.0470	-0.0417

Table C-6: Freeze Thaw Durability for Fly Ash Mixes					
	6	7	8	9	10
Mix Description	20% FA	25% FA	30% FA	35% FA	40% FA
Durability ctor	92.4	96.9	99.7	100.6	96.4

Appendix D

Summarized Test Results for Ground Granulated Blast-Furnace Slag Mixes

Table D-1: Plastic Properties for Ground Granulated Blast-Furnace Slag Mixes					
Mix No.	1	2	3	4	5
Mix Description	20% GGBFS	25% GGBFS	30% GGBFS	35% GGBFS	40% GGBFS
Slump (in.)	3	3 1/4	2 3/4	2 1/2	2 3/4
Air (%)	5.8	6.1	5.9	5.9	5.8
Unit Weight (lbs/ft^3)	143.16	142.6	142.6	143.3	142.8
Temperature (^{o}F)	66	69	79	79	81
Relative Yield	1.004	1.007	1.007	1.002	1.003
W/C Ratio	0.45	0.45	0.46	0.45	0.46

Table D-2: Compressive Strength for Ground Granulated Blast-Furnace Slag Mixes					
Mix No.	1	2	3	4	5
Mix Description	20% GGBFS	25% GGBFS	30% GGBFS	35% GGBFS	40% GGBFS
1-Day Strength (psi)	1310	980	1220	1280	1200
3-Day Strength (psi)	2610	2240	2380	2060	2030
7-Day Strength (psi)	3240	3120	3020	2940	2770
14-Day Strength (psi)	4250	3930	3520	3760	3340
28-Day Strength (psi)	4870	4780	4390	4250	4180
56-Day Strength (psi)	5430	4860	4940	5070	4650
90-Day Strength (psi)	4740	4600	4550	4720	5020

Table D-3: Flexural Strength for Ground Granulated Blast-Furnace Slag Mixes					
Mix No.	1	2	3	4	5
Mix Description	20% GGBFS	25% GGBFS	30% GGBFS	35% GGBFS	40% GGBFS
1-Day Strength (psi)	315	275	345	300	265
3-Day Strength (psi)	535	420	415	405	380
7-Day Strength (psi)	565	520	500	525	510
14-Day Strength (psi)	685	615	585	605	590
28-Day Strength (psi)	735	745	640	680	635
56-Day Strength (psi)	770	745	680	760	675
90-Day Strength (psi)	845	825	695	685	695

Table D-4: Permeability of Ground Granulated Blast-Furnace Slag Mixes						
Mix No.		1	2	3	4	5
Mix Description		20% GGBFS	25% GGBFS	30% GGBFS	35% GGBFS	40% GGBFS
14-day	0"-2"			5991	3806	2250
	2"-4"			3585	2304	1908
	4"-6"			2878	2191	1610
	6"-8"			2489	1656	1603
28-day	0"-2"	7638	6586	3407	2844	2253
	2"-4"	3729	2966	2001	1713	1493
	4"-6"	2568	1848	1724	1586	1149
	6"-8"	2256	1726	1402	1251	1164
56-day	0"-2"	5284	6505	2598	2230	2196
	2"-4"	2227	2248	1493	1105	1066
	4"-6"	1672	1463	1128	1023	797
	6"-8"	1584	1562	741	822	563
90-day	0"-2"	4602	4608	2338	2077	1878
	2"-4"	1424	1799	1111	876	836
	4"-6"	1366	1332	927	791	664
	6"-8"	1235	1171	859	701	413

Table D-5: Length Change for Ground Granulated Blast-Furnace Slag Mixes					
Mix No.	1	2	3	4	5
Mix Description	20% GGBFS	25% GGBFS	30% GGBFS	35% GGBFS	40% GGBFS
1-Day Change (%)	0.0000	0.0000	0.0000	0.0000	0.0000
28-Day Change (%)	0.0060	0.0070	0.0077	0.0083	0.0083
32-Day Change (%)	-0.0040	0.0047	-0.0020	-0.0043	-0.0003
35-Day Change (%)	-0.0103	-0.0097	-0.0090	-0.0087	-0.0057
42-Day Change (%)	-0.0203	-0.0193	-0.0190	-0.0187	-0.0167
56-Day Change (%)	-0.0290	-0.0300	-0.0280	-0.0277	-0.0287
84-Day Change (%)	-0.0367	-0.0373	-0.0347	-0.0367	-0.0360
140-Day Change (%)	-0.0387	-0.0413	-0.0403	-0.0427	-0.0423
252-Day Change (%)	-0.0470	-0.0473	-0.0433	-0.0467	-0.0457

Table D-6: Freeze Thaw Durability for Ground Granulated Blast-Furnace Slag Mixes					
Mix No.	1	2	3	4	5
Mix Description	20% GGBFS	25% GGBFS	30% GGBFS	35% GGBFS	40% GGBFS
Durability Factor	101.1	96.2	98.5	98.9	99.2

Appendix E

Batch Design Spreadsheet for Fly Ash Mixes

Project	Bridge	Date:	1/30/2002
Reported to:	ND/DOT		
Mix Number:	6		
Mix Description:	**20% Fly Ash**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	20 %
Mineral Admixture:	%		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.		Weights	Volume
Fly Ash:	2.65		112.8 lb/yd^3	0.682 ft^3
Cement:	3.15		451.2 lb/yd^3	2.295
Mineral Admixture:	2.83		0.0 lb/yd^3	0.000
Water:	27.5	gallons	229 lb/yd^3	3.673
Air:	6.0 %			1.62
			total voids:	8.270 ft^3

desired w/c ratio:		calculated w/c ratio:	0.41
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.56

Coarse aggregate 1:	62 %	=	1955 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1955 lb/yd^3	11.612 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1173 lb/yd^3	7.117 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.30 oz/100-wt.	7.3 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	10/4/2001
Reported to:	ND/DOT		
Mix Number:	7		
Mix Description:	**25% Fly Ash**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	25 %
Mineral Admixture:	%		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.		Weights	Volume
Fly Ash:	2.65		141 lb/yd^3	0.853 ft^3
Cement:	3.15		423.0 lb/yd^3	2.152
Mineral Admixture:	2.83		0.0 lb/yd^3	0.000
Water:	27.5	gallons	229 lb/yd^3	3.673
Air:	6.0 %			1.62
			total voids:	8.297 ft^3

desired w/c ratio:		calculated w/c ratio:	0.41
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.57

Coarse aggregate 1:	62 %	=	1952 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1950 lb/yd^3	11.583 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1173 lb/yd^3	7.120 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.30 oz/100-wt.	7.3 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	8/31/2001
Reported to:	ND/DOT		
Mix Number:	8		
Mix Description:	**30% Fly Ash**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	30 %
Mineral Admixture:	%		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.		Weights	Volume
Fly Ash:	2.65		169.2 lb/yd^3	1.023 ft^3
Cement:	3.15		394.8 lb/yd^3	2.009
Mineral Admixture:	2.83		0.0 lb/yd^3	0.000
Water:	27.8	gallons	232 lb/yd^3	3.713
Air:	6.0 %			1.62
			total voids:	8.364 ft^3

desired w/c ratio:		calculated w/c ratio:	0.41
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.57

Coarse aggregate 1:	62 %	=	1945 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1950 lb/yd^3	11.583 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1162 lb/yd^3	7.053 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.50 oz/100-wt.	8.5 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	8/27/2001
Reported to:	ND/DOT		
Mix Number:	9		
Mix Description:	**35% Fly Ash**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	35 %
Mineral Admixture:	%		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.	Weights	Volume
Fly Ash:	2.65	197.4 lb/yd^3	1.194 ft^3
Cement:	3.15	366.6 lb/yd^3	1.865
Mineral Admixture:	2.83	0.0 lb/yd^3	0.000
Water:	27.3 gallons	227 lb/yd^3	3.639
Air:	6.0 %		1.62
		total voids:	8.318 ft^3

desired w/c ratio:		calculated w/c ratio:	0.40
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.58

Coarse aggregate 1:	62 %	=	1950 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1920 lb/yd^3	11.404 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1199 lb/yd^3	7.278 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.30 oz/100-wt.	7.3 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	8/23/2001
Reported to:	ND/DOT		
Mix Number:	10		
Mix Description:	**40% Fly Ash**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	40 %
Mineral Admixture:	%		
Slump:	inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.	Weights	Volume
Fly Ash:	2.65	225.6 lb/yd^3	1.364 ft^3
Cement:	3.15	338.4 lb/yd^3	1.722
Mineral Admixture:	2.83	0.0 lb/yd^3	0.000
Water:	27.3 gallons	227 lb/yd^3	3.639
Air:	6.0 %		1.62
		total voids:	8.345 ft^3

desired w/c ratio:		calculated w/c ratio:	0.40
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.59

Coarse aggregate 1:	62 %	=	1947 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1920 lb/yd^3	11.404 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1194 lb/yd^3	7.250 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.30 oz/100-wt.	7.3 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Appendix F

Batch Design Spreadsheet for Ground Granulated Blast-Furnace Slag Mixes

Project	Bridge	Date:	2/11/2002
Reported to:	ND/DOT		
Mix Number:	1		
Mix Description:	**20% GGBFS**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	%
Mineral Admixture:	20 %		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.		Weights	Volume
Fly Ash:	2.65		0 lb/yd^3	0.000 ft^3
Cement:	3.15		451.2 lb/yd^3	2.295
Mineral Admixture:	2.83		112.8 lb/yd^3	0.639
Water:	30.0	gallons	250 lb/yd^3	4.006
Air:	6.0 %			1.62
			total voids:	8.561 ft^3

desired w/c ratio:		calculated w/c ratio:	0.44
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.41

Coarse aggregate 1:	62 %	=	1925 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1900 lb/yd^3	11.286 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1178 lb/yd^3	7.154 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.50 oz/100-wt.	8.5 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	1/16/2002
Reported to:	ND/DOT		
Mix Number:	2		
Mix Description:	**25% GGBFS**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	%
Mineral Admixture:	25 %		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.		Weights	Volume
Fly Ash:	2.65		0 lb/yd^3	0.000 ft^3
Cement:	3.15		423.0 lb/yd^3	2.152
Mineral Admixture:	2.83		141.0 lb/yd^3	0.798
Water:	30.5	gallons	254 lb/yd^3	4.073
Air:	6.0 %			1.62
			total voids:	8.644 ft^3

desired w/c ratio:		calculated w/c ratio:	0.45
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.38

Coarse aggregate 1:	62 %	=	1916 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1900 lb/yd^3	11.286 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1165 lb/yd^3	7.071 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.50 oz/100-wt.	8.5 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	9/6/2001
Reported to:	ND/DOT		
Mix Number:	3		
Mix Description:	**30% GGBFS**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	%
Mineral Admixture:	30 %		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.	Weights	Volume
Fly Ash:	2.65	0 lb/yd^3	0.000 ft^3
Cement:	3.15	394.8 lb/yd^3	2.009
Mineral Admixture:	2.83	169.2 lb/yd^3	0.958
Water:	31.0 gallons	258 lb/yd^3	4.140
Air:	6.0 %		1.62
		total voids:	8.727 ft^3

desired w/c ratio:		calculated w/c ratio:	0.46
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.35

Coarse aggregate 1:	62 %	=	1907 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1900 lb/yd^3	11.286 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1151 lb/yd^3	6.988 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.70 oz/100-wt.	9.6 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	8/29/2001
Reported to:	ND/DOT		
Mix Number:	4		
Mix Description:	**35% GGBFS**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	%
Mineral Admixture:	35 %		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.		Weights	Volume
Fly Ash:	2.65		0 lb/yd^3	0.000 ft^3
Cement:	3.15		366.6 lb/yd^3	1.865
Mineral Admixture:	2.83		197.4 lb/yd^3	1.118
Water:	31.0	gallons	258 lb/yd^3	4.140
Air:	6.0 %			1.62
			total voids:	8.743 ft^3

desired w/c ratio:		calculated w/c ratio:	0.46
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.32

Coarse aggregate 1:	62 %	=	1906 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1900 lb/yd^3	11.286 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1148 lb/yd^3	6.971 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	1.30 oz/100-wt.	7.3 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Project	Bridge	Date:	8/24/2001
Reported to:	ND/DOT		
Mix Number:	5		
Mix Description:	**40% GGBFS**		

Total Cementitious:	564 lb/yd^3	Percent Fly Ash:	%
Mineral Admixture:	40 %		
Slump:	3 inches	Air Content:	6.0 %

Batch Design Calculations:

	Sp. Gr.	Weights	Volume
Fly Ash:	2.65	0 lb/yd^3	0.000 ft^3
Cement:	3.15	338.4 lb/yd^3	1.722
Mineral Admixture:	2.83	225.6 lb/yd^3	1.278
Water:	31.0 gallons	258 lb/yd^3	4.140
Air:	6.0 %		1.62
		total voids:	8.759 ft^3

desired w/c ratio:		calculated w/c ratio:	0.46
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.30

Coarse aggregate 1:	62 %	=	1904 lbs.
Coarse aggregate 2:	0 %		0 lbs.
Coarse aggregate 3:	8 %		0 lbs.

	Sp. Gr.	Weights	
Coarse Aggregate1:	2.698	1900 lb/yd^3	11.286 ft^3
Coarse Aggregate2:		lb/yd^3	0.000 ft^3
Coarse Aggregate3:		lb/yd^3	0.000 ft^3
Fine Aggregate:	2.64	1146 lb/yd^3	6.955 ft^3

Water Reducer:	0.0 oz/100-wt.	0.0 oz/yd^3
Air Entrainment:	2.30 oz/100-wt.	13.0 oz/yd^3
Other Admixture:	oz/100-wt.	0.0 oz/yd^3

Appendix G

Field Test Data for Bridge Deck Pours

SLAG **SAMPLE WORKSHEET**

North Dakota Department of Transportation, Materials & Research

SFN 9994 (Rev. 02-2002)

Project Number IM-8-029(050)062	County Cass
Submitted by Willie Schacher	Date Sampled 7-18-2002
Brand Holcim	Date Received 7-22-2002
Type Grancem 100 Slag	Laboratory Number CE-39
Amount Represented 53.58 ton	Field Sample Number Prog C-86
Sample from Ames	

Quantitative Acid Test For Fly Ash				AASHTO T-105.5 Tested By:
Retained on .325 screen (Max. 20)			1.32%	AASHTO T-192 Tested By: TG
Fineness, Blaine Fineness Meter Specific Surface,			504 m2/kg	AASHTO T-153 Tested By: TG
Soundness, Autoclave Expansion			%	AASHTO T-107 Tested By:
Air Content of Mortar (Max. 12)			4.4 %	AASHTO T-137 Tested By: TG
Time of Setting - Gillmore Test				AASHTO T-154 Tested By:
		Initial Set	hr.	min.
		Final Set	hr.	min.
Compressive Strength - 50mm Cubes				AASHTO T-106 Tested By: TG
			39 Ref Cement	39A Cement/Slag PSI
		7 Day Break	4720	3850 (81.6%) PSI
		28 Day Break	5700	5735 (100.6%) PSI
Conformity to Specifications: Pass				

Remarks: 17th Ave Structure

* Attention Advised

[X] Fargo District

[X] Central Lab.

[x] Wanzek

[x] Seng Marohl

[ ]

[ ]

Testing Lab Supervisor

Date Report 9/9/2002

MISCELLANEOUS TEST SAMPLE REPORT

North Dakota Department of Transportation, Materials & Research
SFN 10080 (Rev. 09-2001)

Material Ground granulated Blast Furnace Slag	Project IM-8-29(050)062
Lab. No. CE-39	County Cass
Field Sample No. Prog. C-86	Sample From Ames - 53.58 ton shipment
Specification ASTM C 989-99	
Brand: GranCem/Holcim	Contractor: Wanzek

Date Received	Date Sampled	Submitted By
7/22/02	7/18/02	Schacher

Chemical Analysis	ND Lab Test	Certify %	Spec Limits
Sulfides	0.98	0.90	2.5 Max
Sulfur Trioxide	0.95	0.10	4.0 Max

Conformity to Specifications:

Date	Laboratory Supervisor
2-14-03	Dennis Blasl

Distribution:

Dist.

X Laboratory Research Section

REPORT OF TEST ON SAMPLE
Department of Transportation, Materials & Research
SFN 10080 (Rev. 6-92)

MATERIAL Ground Granulated Blast Furnace Slag	PROJECT IM-8-029(050)062(Used in Bridge Deck)
LAB. NO. CE-39 (Grade 100)	COUNTY Cass Co. - 17th Ave. Fargo Structure
FIELD SAMPLE NO. Prog. C-86	SAMPLE FROM Ames - 53.58 ton shipment.
SPECIFICATION ASTM C989-99 (Chem. C-114)	Contractor: Wanzek Constr.
Brand/Mfr: GranCem/Holcim, Chicago,Ill.	

DATE RECEIVED	DATE SAMPLED	SUBMITTED BY
7-22-02	7-18-02	W. Schacher

Chemical Analysis:	ND Lab Test(%)	Certify(%)	Spec. Limits(%)
Sulfide(S)	0.98	0.90	2.5 Max
Sulfur Trioxide(SO_3)	0.05	0.10	4.0 Max.

Distribution: (DJB)
~~1 Fargo~~ Dist.
~~1 Laboratory~~
~~1 Bridge Div.~~
1 Research Section

Art Schaffer - Chemist
1-15-03 AS

NDDOT Fax:7012398915 Jul 19 2002 10:05 P.02

07/19/02 FRI 07:54 FAX 612 590 2109 HOLNAM INC

TO: Willie
From: Ames

CE-39
7-22-02

Dennis Bl..l
Mat & Research

Certification on Slag

Holcim

Material Certification Report

Brand Name: GranCem
Material: GGBFS Cement
Type: 100 (ASTM C989)

Date Range: May 1-31, 2002
Lot Number: Multiple Lots

Certification

Holcim cement meets ASTM C989 specification for Grade GranCem 100 Ground Granulated Blast-Furnace Slag.
While permitted additions may result in differing compound calculations, the physical properties of the cement are virtually unchanged.

General Information

Supplier: Holcim (US) Inc.
Address: 3020 E 103rd Street
Chicago, IL 60617
Telephone: (773) 978-8280

Source Location: Chicago Skyway
3020 E 103rd Street
Chicago, IL 60617
Contact: Roberto Carrillo (773) 978-8280

The following information is based on average test data during the test period. The data is typical of cement shipped by Holcim. Individual shipments may vary.

Test Data on ASTM Standard Requirements

Chemical (C989, Table 2)		
Item	Limit	Result
Sulfide S (%)	2.5 max	0.3
Sulfur trioxide - SO_3 (%)	4.0 max	0.7

0.17%

Physical (C989, Table 1)		
Item	Limit	Result
45 µm (No. 325) Sieve (%)	20 max	1.07
Blaine Fineness (m2/kg)	-	579
Air Content (%)	12 max	5.04
Slag Activity Index (%)		
Average of Last 5 Samples:		
Avg 7 Day Index	75 min	[illegible]
Avg 28 Day Index	95 min	-
Current Sample:		
7 Day Index	70 min	89
28 Day Index	90 min	117
Compressive Strength Slag-Ref (psi):		
7 Day	-	26 (3770)
28 Day	-	48 (6970)

Test Data on Reference Cement

Chemical		
Item	Limit	Result
Total Alkalies as Na_2O (%)	0.60 - 0.90	0.76
C_3S	-	51
C_2S	-	21
C_3A	-	8
C_4AF	-	8.16

Physical		
Item	Limit	Result
Blaine Fineness (m2/kg)	-	379
Compressive Strength MPa (psi).		
7 Day	-	29 (4200)
28 Day	35 (5000) min	38 (5510)

Notes

Specific Gravity: 2.90

Progress C-86
17th Ave Structure
Wanzek
Sampled from Ames

Post-it® Fax Note 7671	Date 10/29	# of pages ▶ 1
To Bryon	From Sang	
Co./Dept. M & R	Co.	
Phone #	Phone #	
Fax # (701) 328-6913	Fax #	

PROJECT: IM-NH-8-029(050)062
Fargo, Cass County North Dakota

REPORTED TO: North Dakota
Department of

PROJECT NO.: 11128

MIX I.D.

Agg. Ind. 1. AE-3 Cement 6.0 sk 66, Fly Ash 33, FA 209, CA 314
Ames 1. AE-3 Cement 6.0 sack 66, Fly Ash 28, FA 212, CA 315
Ames 4, FA 28.5, Cement 65.3, F.A. 215.2 C.A. 316
NIC #1 Fly Ash 28, Cement 66, FA 209, CA 31
#2 Fly Ash 183.30; Cement 427.70; FA1216.60; CA 1824.90
NIC #3 Cement 94, FA 164, CA 246
NIC #6 Fly Ash 169.2, Cement 394.8, FA 1261.59, CA 1892.39

CAST BY: ND/DOT

Cyl. No.	Lab No.	Date Cast	Date Rec.	Conc. Temp.	Slump	Air Cont	Unit Weight	Location	Mix	3	3	Comp. Strength (psi) 7 (Days)	7	28	28	Water Added (gal/sk.)	Water Total
850	9713	6-27-02	6-28-02	78	2.75	5.6	—	9th Ave. Bridge Deck 93.5 yds	9 Ave Ames Sand & Gravel			3850	3880	4840	4870	4.60	4.60
851	9714	6-27-02	6-28-02	78	2.75	7.0	—	9th Ave. Bridge Deck 87.0 yds	9 Ave Ames Sand & Gravel					4160	4100	4.57	4.57
852	9715	6-27-02	6-28-02	79	2.5	6.0	148.6	9th Ave. Bridge Deck 152.25 yds	9 Ave Ames Sand & Gravel			3610	3590	4340	4330	4.56	4.56
853	9716	6-27-02	6-28-02	80	3	7.0	148.60	9th Ave. bridge Deck 249.25 yds	9 Ave Ames Sand & Gravel					4130	3780	4.70	4.70
854	9717	6-27-02	6-28-02	80	3.75	7.0	147.0	9th Ave. Bridge Deck 307.25 yds	9 Ave Ames Sand & Gravel			3120	3160	3850	3940	4.73	

PROJECT: IM-NH-8-029(050)062

REPORTED TO: Fargo, Cass County North Dakota
North Dakota
Department of

PROJECT NO.: 11128

MIX I.D.

Agg. Ind. 1. AE-3 Cement 6.0 sk 66, Fly Ash 33, FA 209, CA 314
Ames 1. AE-3 Cement 6.0 sack 64, Fly Ash 28, FA 212, CA 315
Ames 4. FA 28.5, Cement 63.3, F.A. 215.2 C.A. 316
HTC #1 Fly Ash 28, Cement 66, FA 209, CA 31
#2 Fly Ash 183.38; Cement 427.78; FA1216.60; CA 1824.98
HOC #3 Cement 94, FA 164, CA 246
HIC #4 Fly Ash 169.2, Cement 394.8, FA 1261.59, CA 1892.39

CAST BY: ND/DOT

Too small
refer to
previous sheet

Cyl. No.	Lab No.	Date Cast	Date Rec.	Conc. Temp.	Slump	Air Cont	Unit Weight	Location	Mix	3	3	7	7	28	28	Water Added	Water Total
												Comp. Strength (psi) (Days)				(gal/sk.)	
850	9713	6-27-02	6-28-02	78	2.75	6.0	—	9th Ave. Bridge Deck 93.5 yds	9 Ave Ames Sand & Gravel			3850	3580	4640	4670	4.80	4.80
851	9714	6-27-02	6-28-02	79	2.75	7.0	—	9th Ave. Bridge Deck 87.0 yds	9 Ave Ames Sand & Gravel					4160	4100	4.57	4.57
852	9715	6-27-02	6-28-02	79	2.5	8.0	148.8	9th Ave. Bridge Deck 152.25 yds	9 Ave Ames Sand & Gravel			3610	3690	4340	4330	4.58	4.58
853	9716	6-27-02	6-28-02	80	3	7.0	148.89	9th Ave. bridge Deck 248.25 yds	9 Ave Ames Sand & Gravel					4130	3780	4.70	4.70
854	9717	6-27-02	6-28-02	80	3.75	7.0	147.0	9th Ave. Bridge Deck 307.25 yds	9 Ave Ames Sand & Gravel			3120	3160	3950	3940	4.73	

PROJECT: IM-NH-8-029(050)062

MIX I.D.

REPORTED TO: Fargo, Cass County North Dakota
North Dakota
Department of

PROJECT NO.: 11128

T BY: ND/DOT

Agg. Ind. 1. AE-3 Cement 6.0 sk 66, Fly Ash 33, FA 209, CA 314
Ames 1. AE-3 Cement 6.0 sack 66, Fly Ash 28, FA 212, CA 315
Ames 4. FA 28.5, Cement 65.3, F.A. 215.2 C.A. 316
NIC #1 Fly Ash 28, Cement 66, FA 209, CA 31
#2 Fly Ash 183.30; Cement 427.70; FA1216.60; CA 1824.90
NIC #3 Cement 94, FA 164, CA 246
NIC #6 Fly Ash 169.2, Cement 394.8, FA 1261.59, CA 1892.39
CAS

Cyl. No.	Water Total	Lab No.	Date Cast	Date Rec.	Conc. Temp.	Slump	Air Cont.	Unit Weight	Location	Mix	3	3	7	7 (gal./sk.)	28	28	Water Added
											Comp. Strength (psi) (Days)						
672	4.51	9988	7-19-02	7-20-02	80	4	6.1	145.4	17th Ave. Bridge Deck Truck 6	17 Ave.	3090		3850		5450	5720	4.51
673	4.24	9987	7-19-02	7-20-02	79	1.76	4.6	149.79	17th Ave. Bridge Deck Truck 13	Ames Sand & Gravel 17 Ave.				SW¼-8-141-45	6240	6200	4.24
674	4.24	9988	7-19-02	7-20-02	79	2	4.6	148.99	17th Ave. Bridge Deck Truck 17	Ames Sand & Gravel 17 Ave.	3860		4750		5770	6120	4.24

									Ames Sand & Gravel		SW¼-8-141-45			
875 4.33	9989	7-19-02	7-20-02	78	3	4.8	148.99	17th Ave. Bridge Deck Truck 38	17 Ave.			5850	5530	4.33
									Ames Sand & Gravel		SW ¼ 8-141-45			
876 4.33	9990	7-19-02	7-20-02	79	3	6.2	148.60	17th Ave. Bridge Deck Truck 49	17 Ave, 2600	3510		4870	4520	4.33
									Ames Sand & Gravel		SW¼-8-141-45			
877 4.33	9991	7-19-02	7-20-02	81	2.5	5.1	148.59	17th Ave. Bridge Deck Truck 57	17 Ave.			4940	5010	4.33
									Ames Sand & Gravel		SW ¼ 8-141-45			

900	0192	6-1-02	8-2-02	76	3.25	5.9	147.39	Texas Turn Bridge Deck	EX			5160	5040	3.69
3.69														
									Ames Sand & Gravel					
901	0191	8-1-02	8-2-02	77	3	5.7	140.19	Texas Turn Bridge Deck	EX	3650	3070	5060	5200	3.66
3.77														
									Ames Sand & Gravel					
902	0190	8-1-02	8-2-02	77	2.75	5.8	140.19	Texas Turn Bridge Deck	EX			5250	5510	3.68
3.81														
									Ames Sand & Gravel					

Friday, August 30, 2002   Page 1 of 1

PROJECT: IM-NH-8-029(050)62

REPORTED TO: [illegible] North Dakota [illegible] Department

PROJECT NO.: 11129

MIX I.D.

Agg. Ind. 1. AE-3 Cement 6.0 sk 66, Fly Ash 33, FA 209, CA 314
Ames 1. AE-3 Cement 6.0 sack 66, Fly Ash 28, FA 212, CA 315
Ames 4. FA 28.5, Cement 65.3, F.A. 215.2 C.A. 316
NIC #1 Fly Ash 28, Cement 66, FA 209, CA 31
#2 Fly Ash 183.30; Cement 427.70; FA1216.60; CA 1824.90
NIC #3 Cement 94, FA 164, CA 246
NIC #6 Fly Ash 169.2, Cement 394.8, FA 1261.59, CA 1892.39
CAS

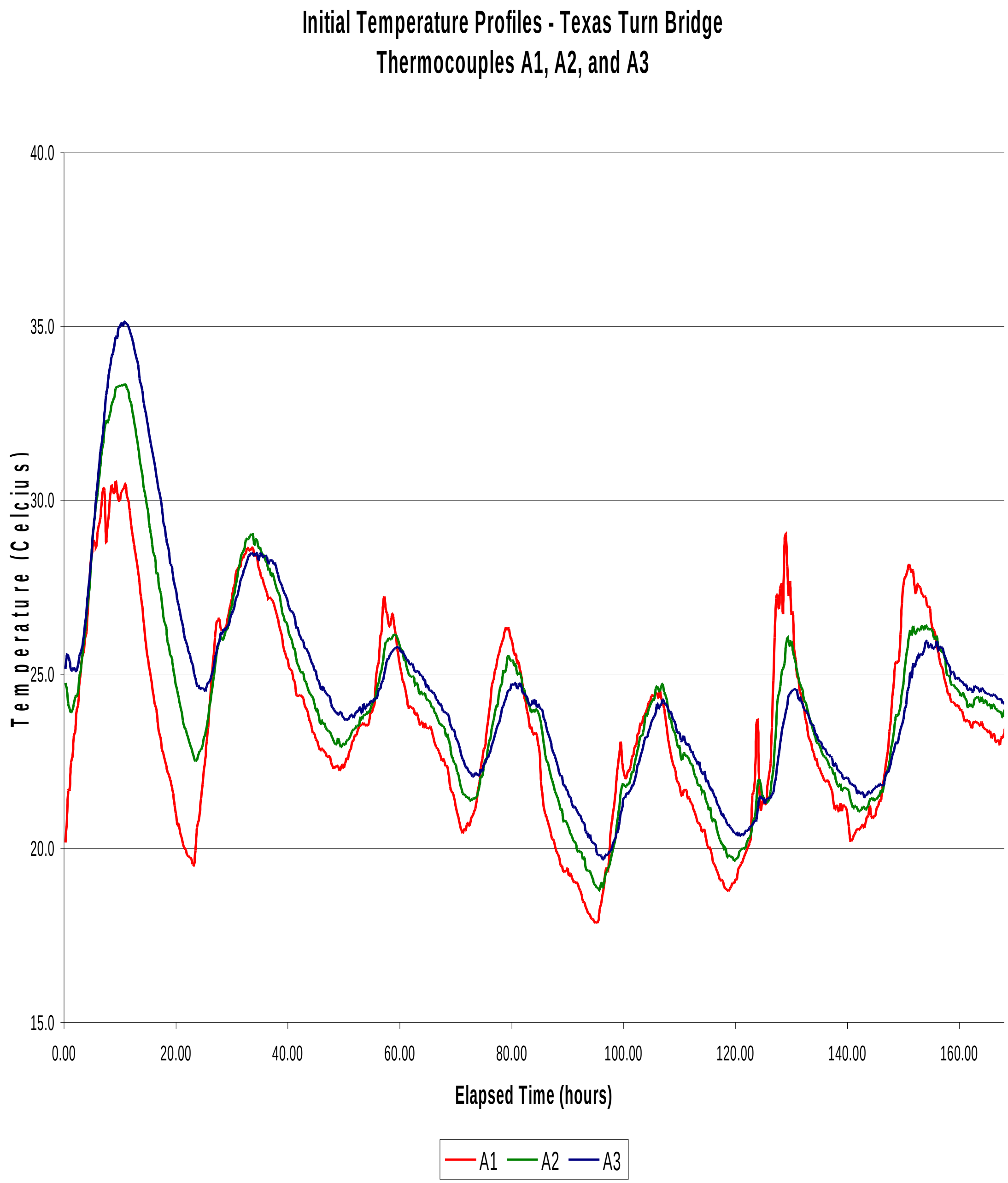
T BY: ND/DOT

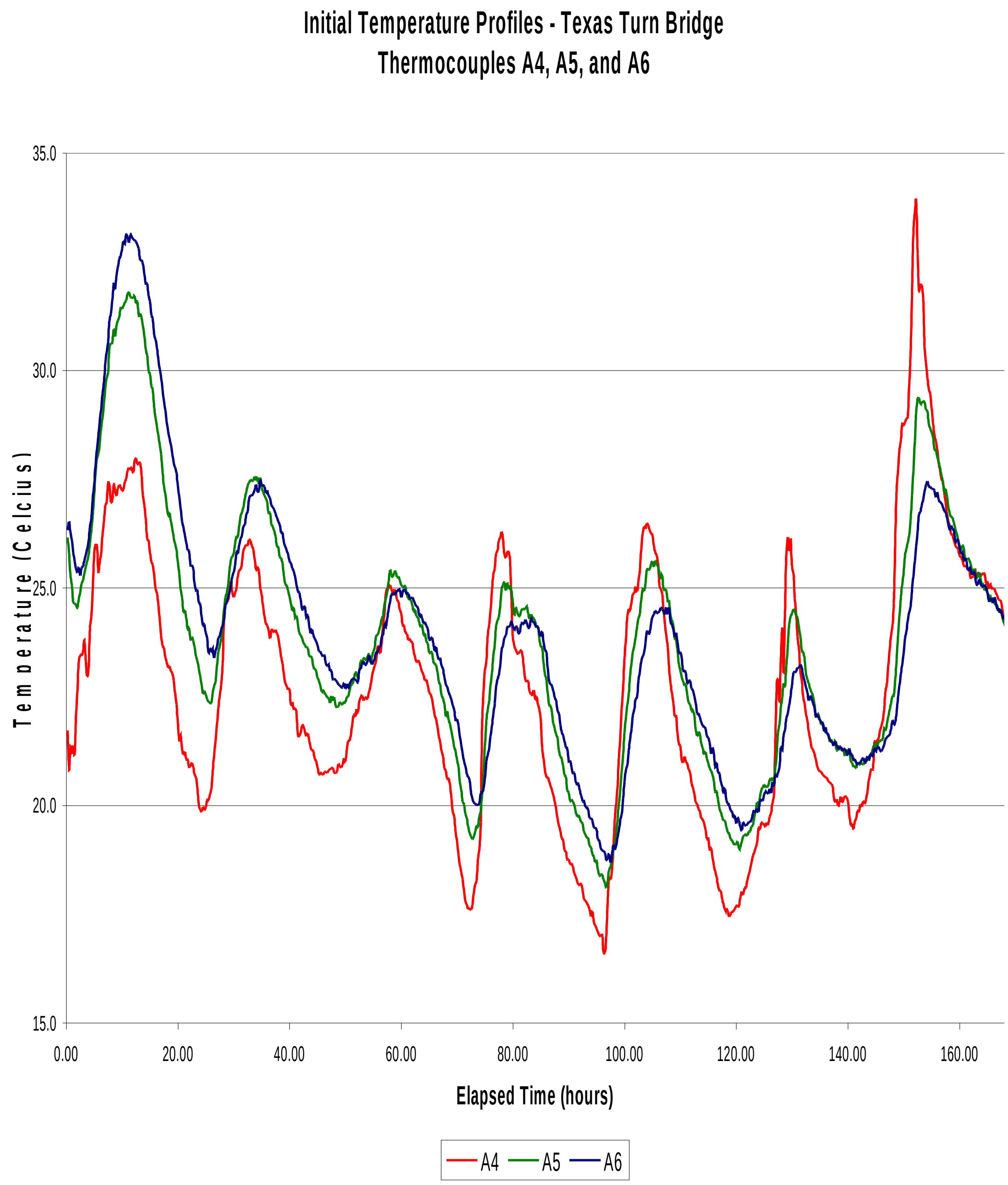
Cyl. No. / Water Total	Lab No.	Date Cast	Date Rec.	Conc. Temp.	Slump	Air Cont.	Unit Weight	Location	Mix	3	3	7	7	28	28	Water Added
										Comp. Strength (psi) (gal./sk.) (Days)						
887 / 3.59	0189	8-1-02	8-2-02	72	2.5	6.6	147.39	Texas Turn Bridge Deck	EX Ames Sand & Gravel			3470	3510	5190	5020	3.59
888 / 3.69	0189	8-1-02	8-2-02	79	3.25	6.1	14[illegible]	Texas Turn Bridge Deck	EX Ames Sand & Gravel					5120	5090	3.69
889 / 3.77	0189	8-1-02	8-2-02	74	3	6.2	147.79	Texas Turn Bridge Deck	EX Ames Sand & Gravel			3370	3300	5100	4920	3.68

02 10:17 NDDOT

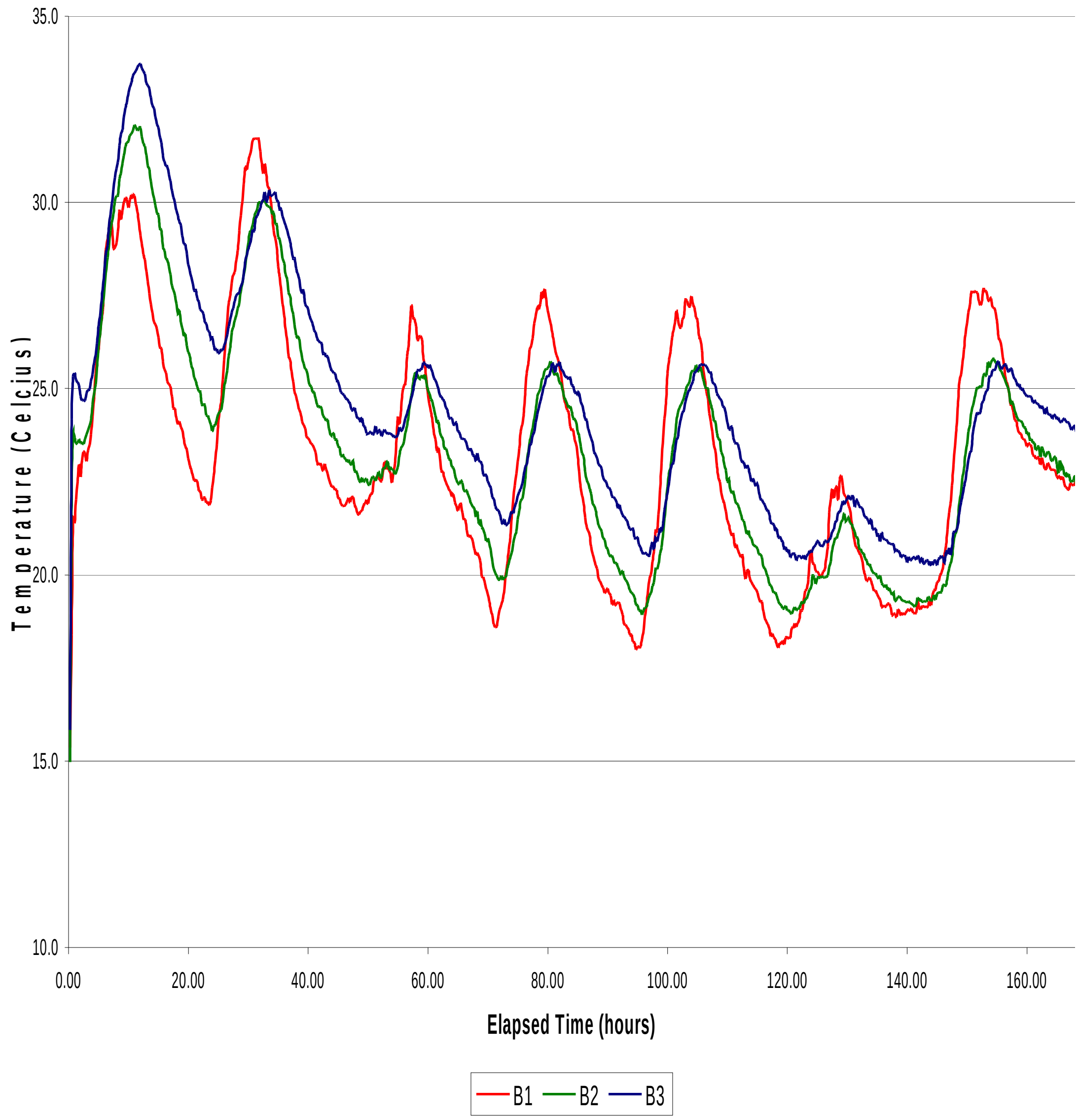
Appendix H

Temperature Profiles for Initial Curing Period for Concrete Bridge Decks

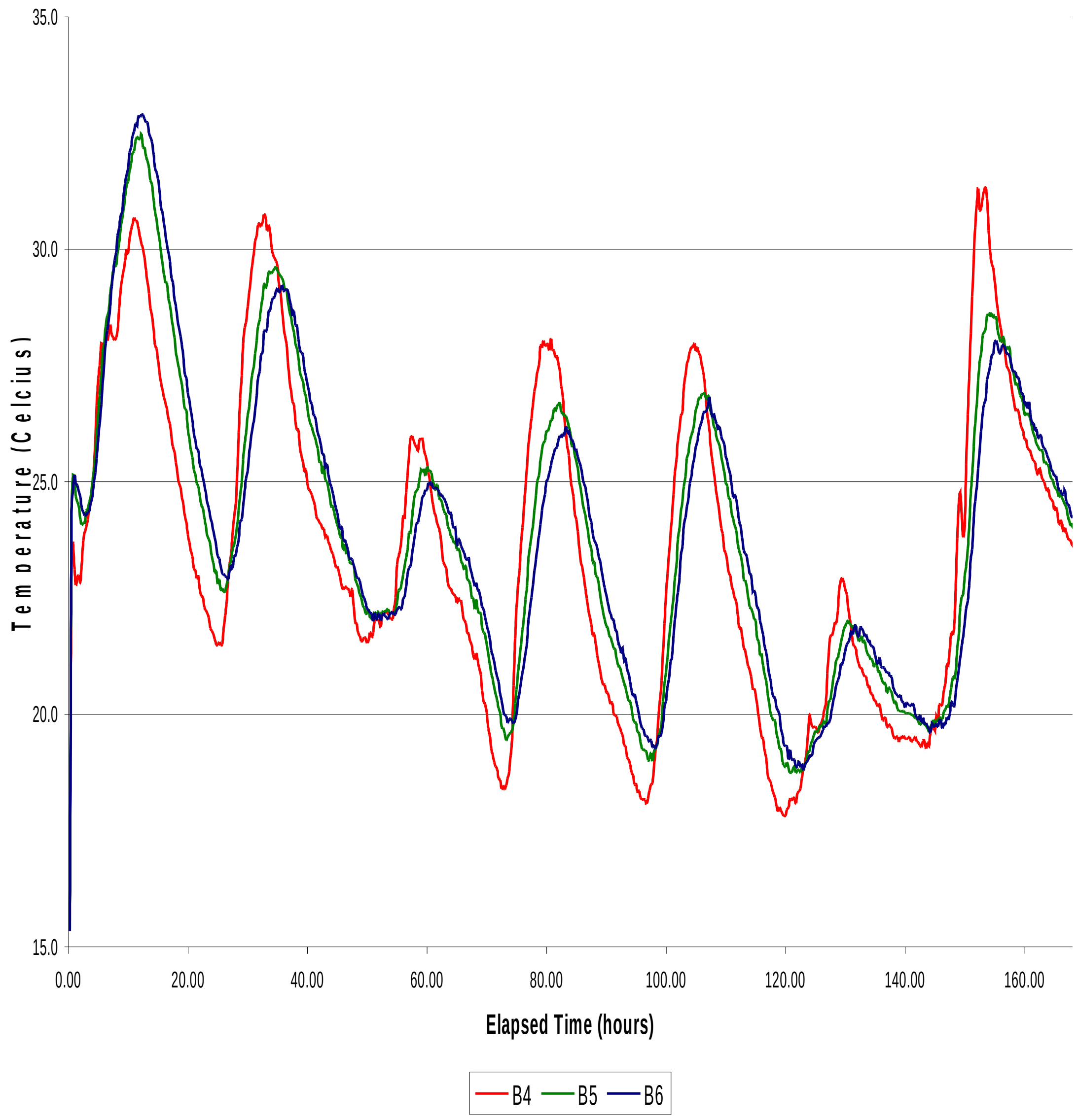

Initial Temperature Profiles - Texas Turn Bridge
Thermocouples A1, A2, and A3
Temperature (Celcius)
40.0
35.0
30.0
25.0
20.0
15.0
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
A1
A2
A3

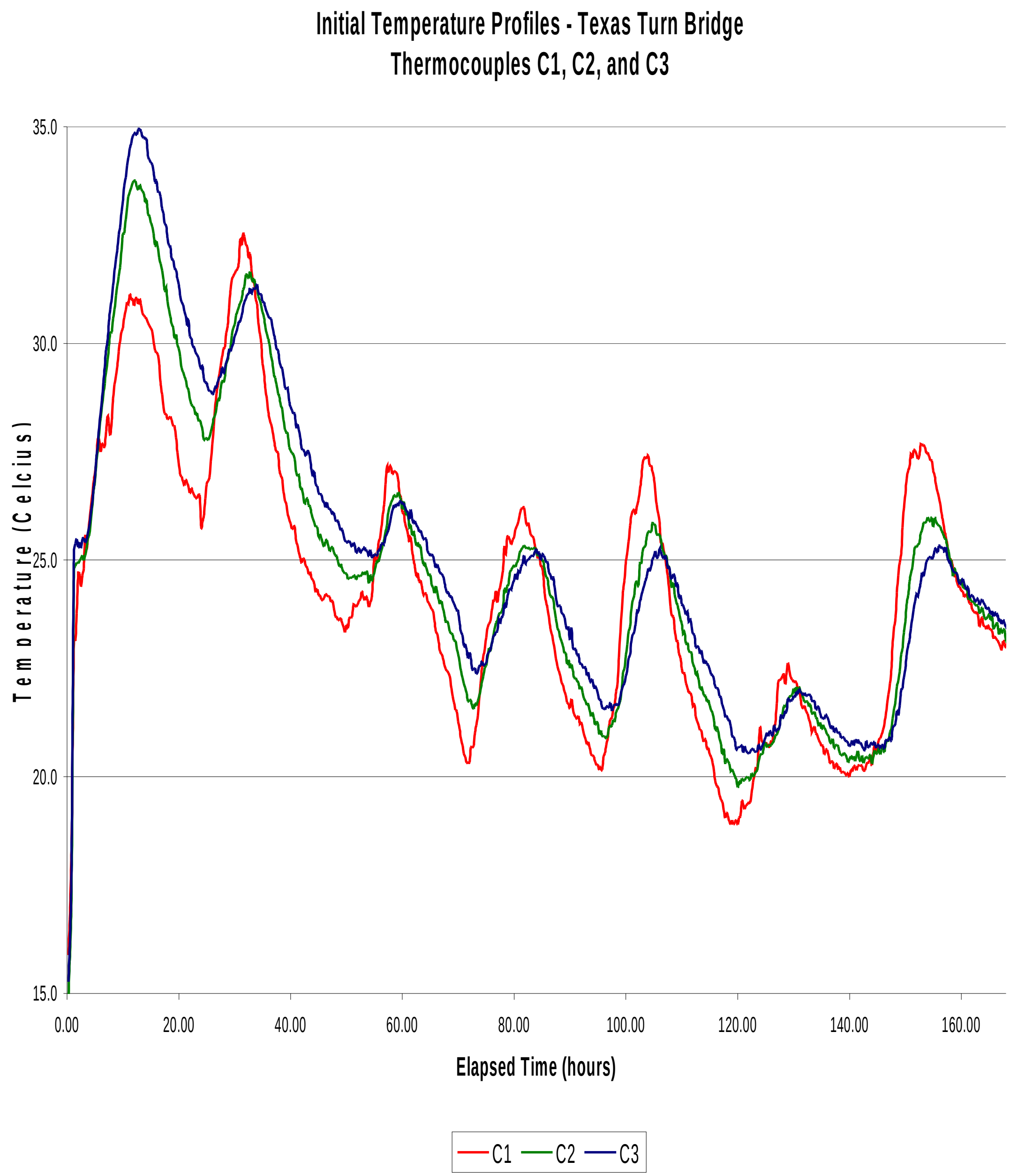

Initial Temperature Profiles - Texas Turn Bridge
Thermocouples A4, A5, and A6
35.0
30.0
25.0
20.0
15.0
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Temperature (Celcius)
Elapsed Time (hours)
A4
A5
A6

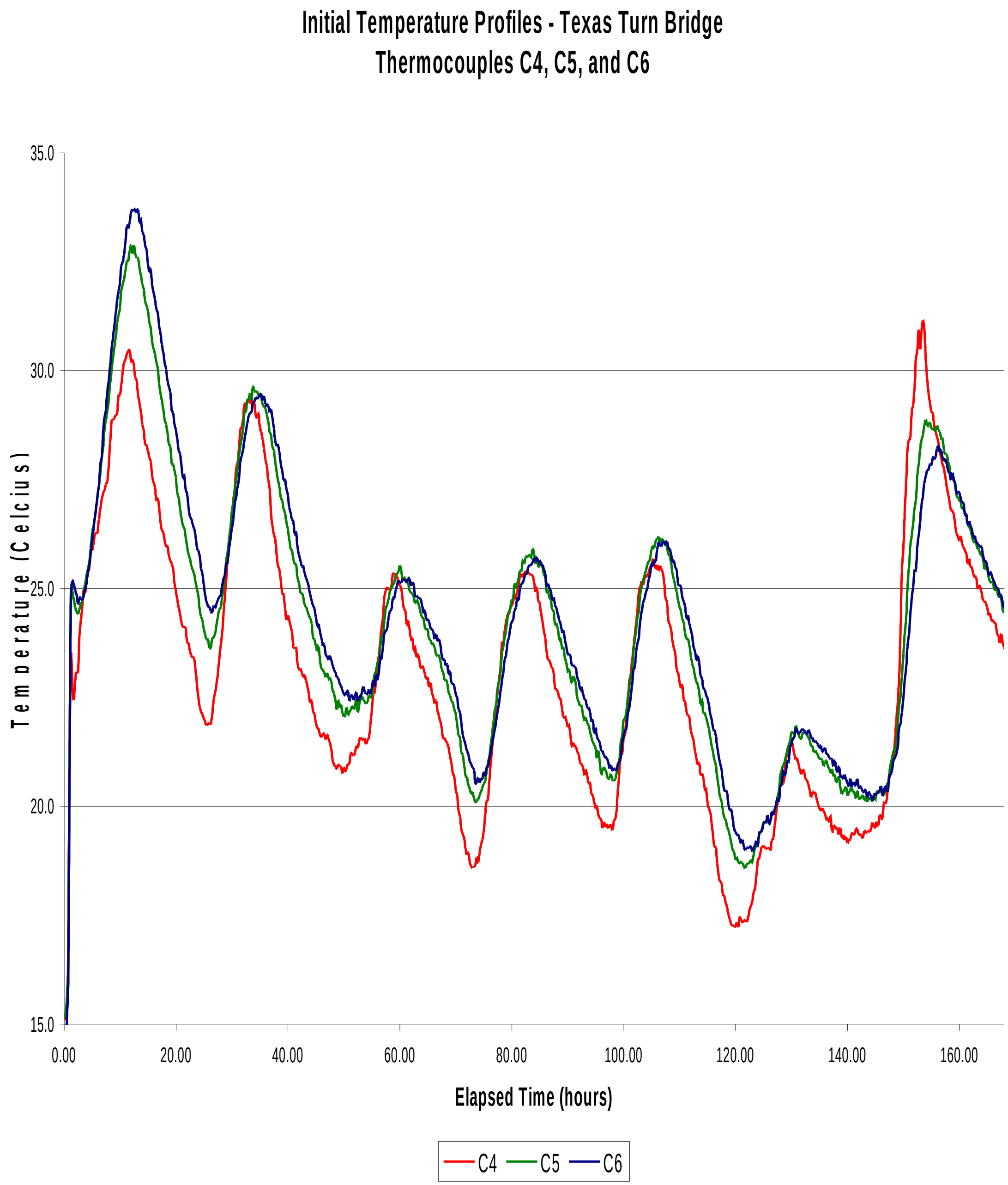
Initial Temperature Profiles - Texas Turn Bridge
Thermocouples B1, B2, and B3



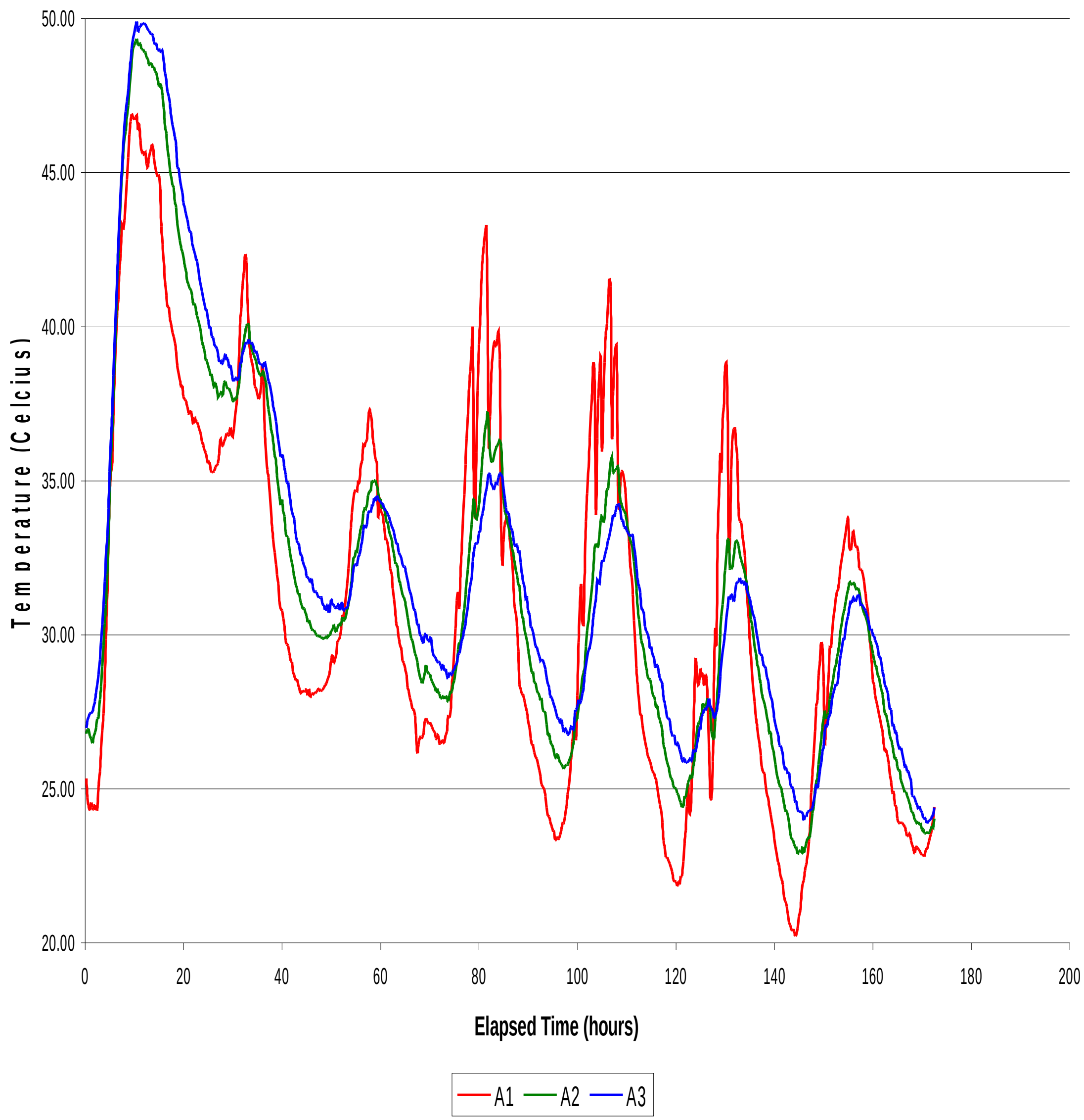
Initial Temperature Profiles - Texas Turn Bridge
Thermocouples B4, B5, and B6

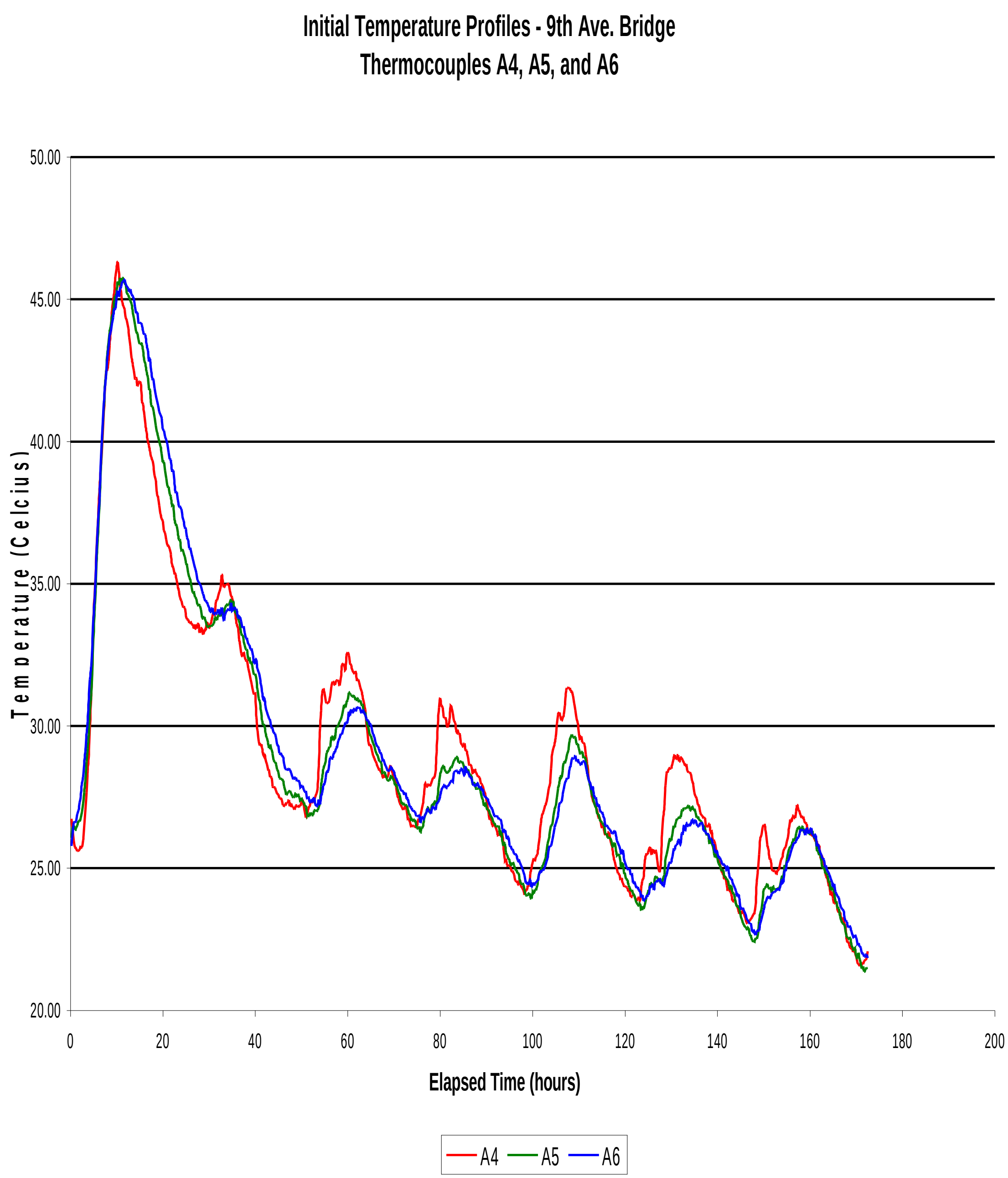



Initial Temperature Profiles - Texas Turn Bridge
Thermocouples C1, C2, and C3
T e m p e r a t u r e (C e l c i u s)
35.0
30.0
25.0
20.0
15.0
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
C1
C2
C3

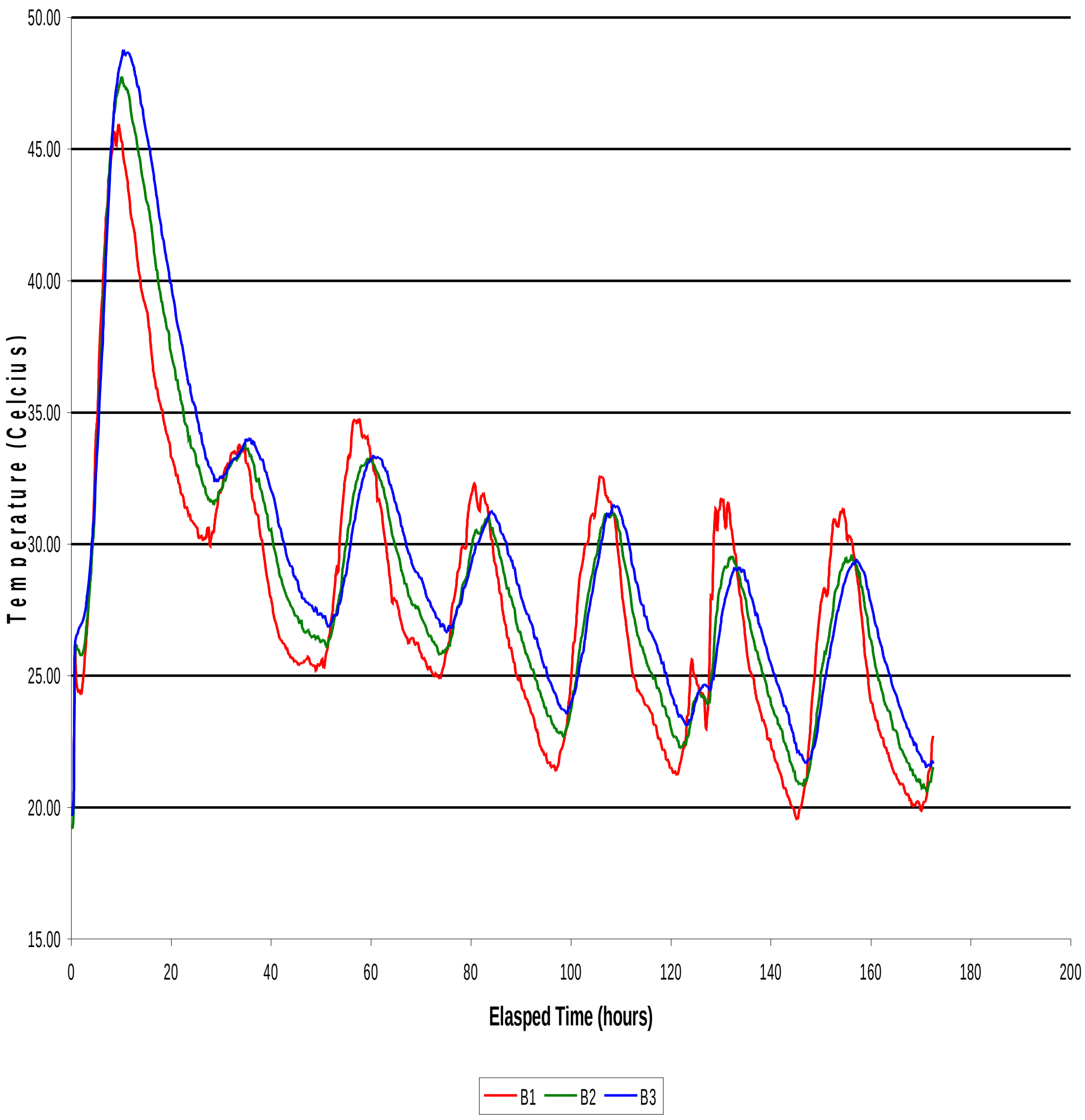

Initial Temperature Profiles - Texas Turn Bridge
Thermocouples C4, C5, and C6
Temperature (Celcius)
35.0
30.0
25.0
20.0
15.0
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
C4
C5
C6

Initial Temperature Profiles - 9th Ave. Bridge
Thermocouples A1, A2, and A3

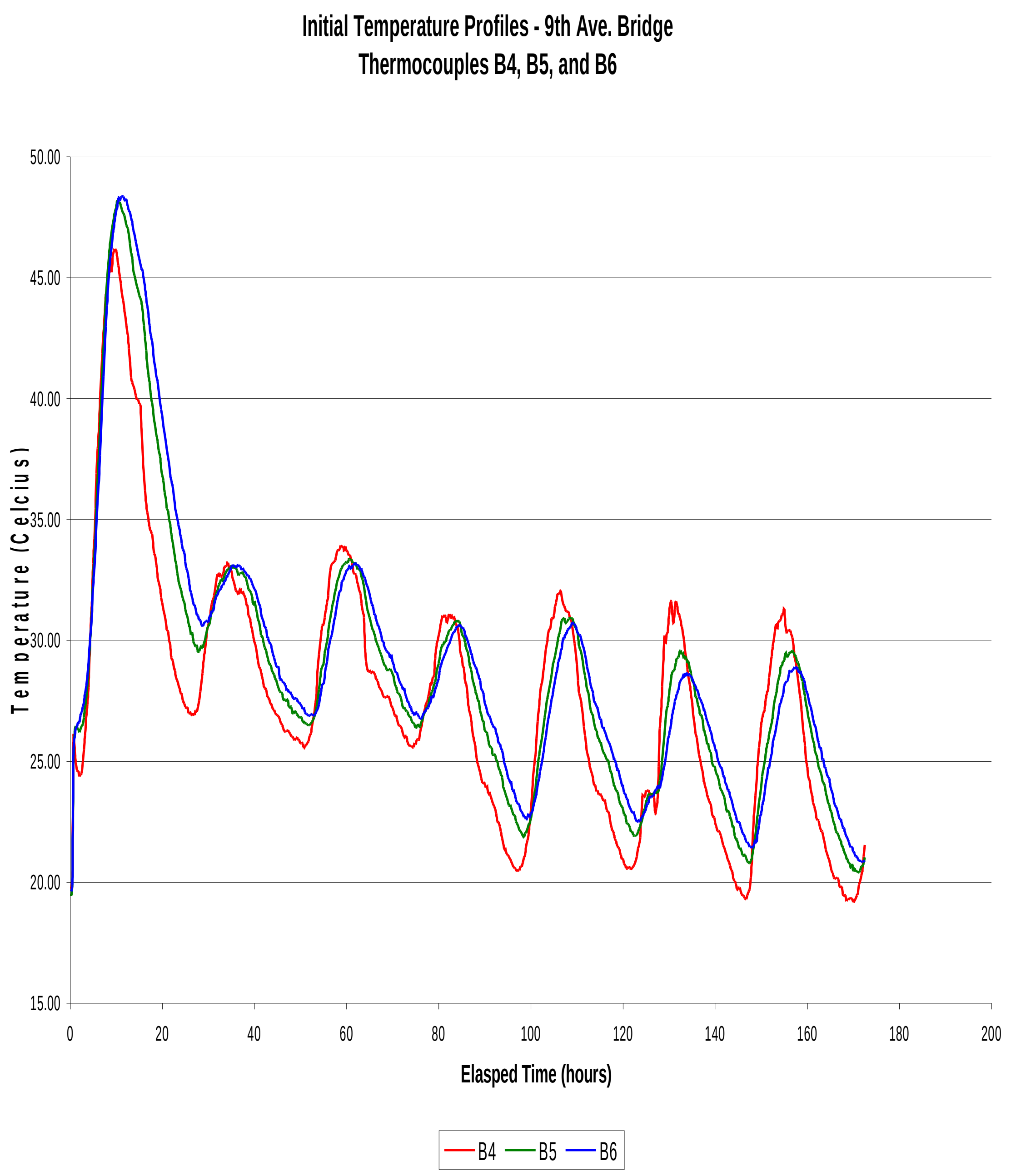


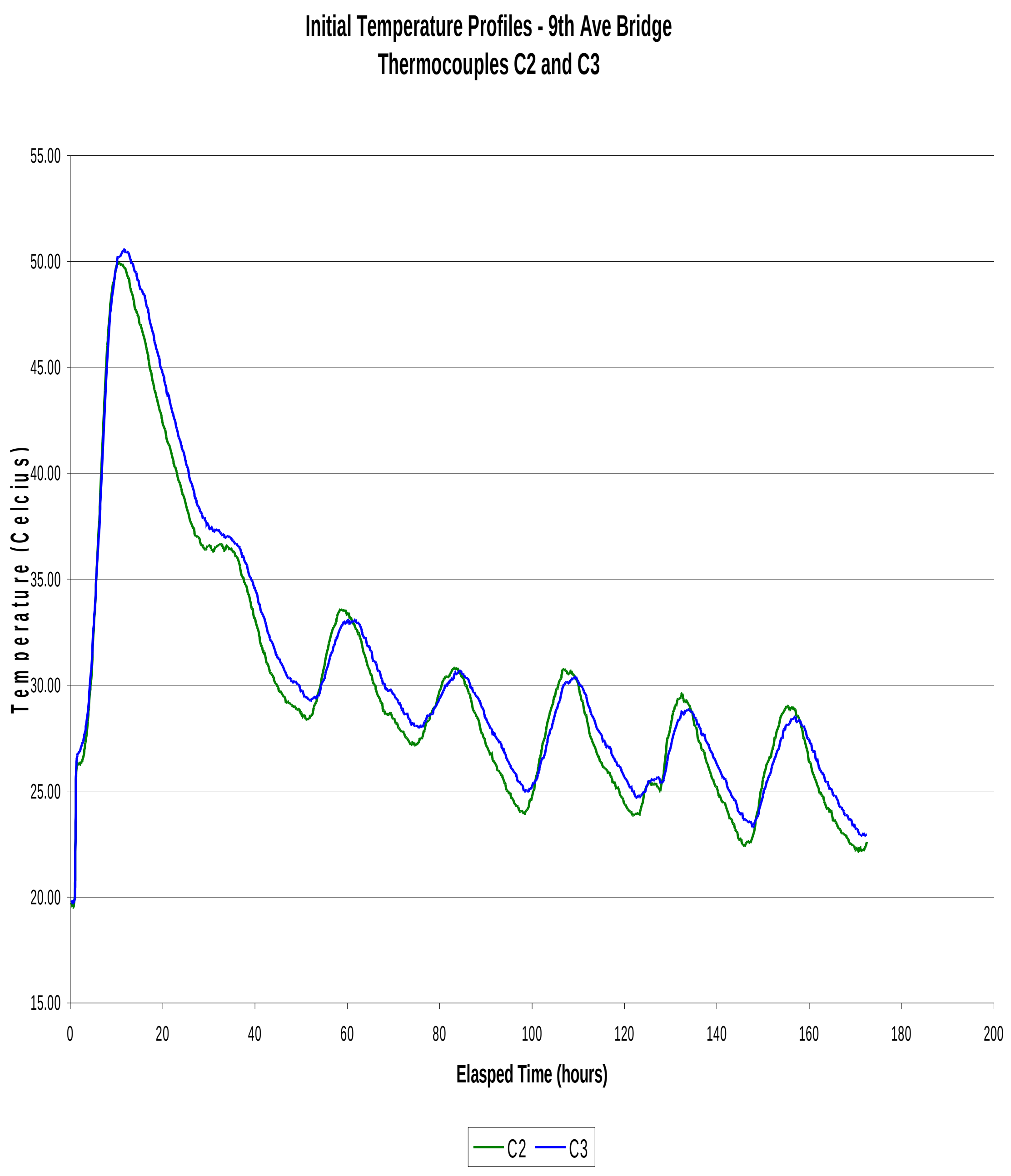

Initial Temperature Profiles - 9th Ave. Bridge
Thermocouples A4, A5, and A6
Temperature (Celcius)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
0
20
40
60
80
100
120
140
160
180
200
Elapsed Time (hours)
A4
A5
A6

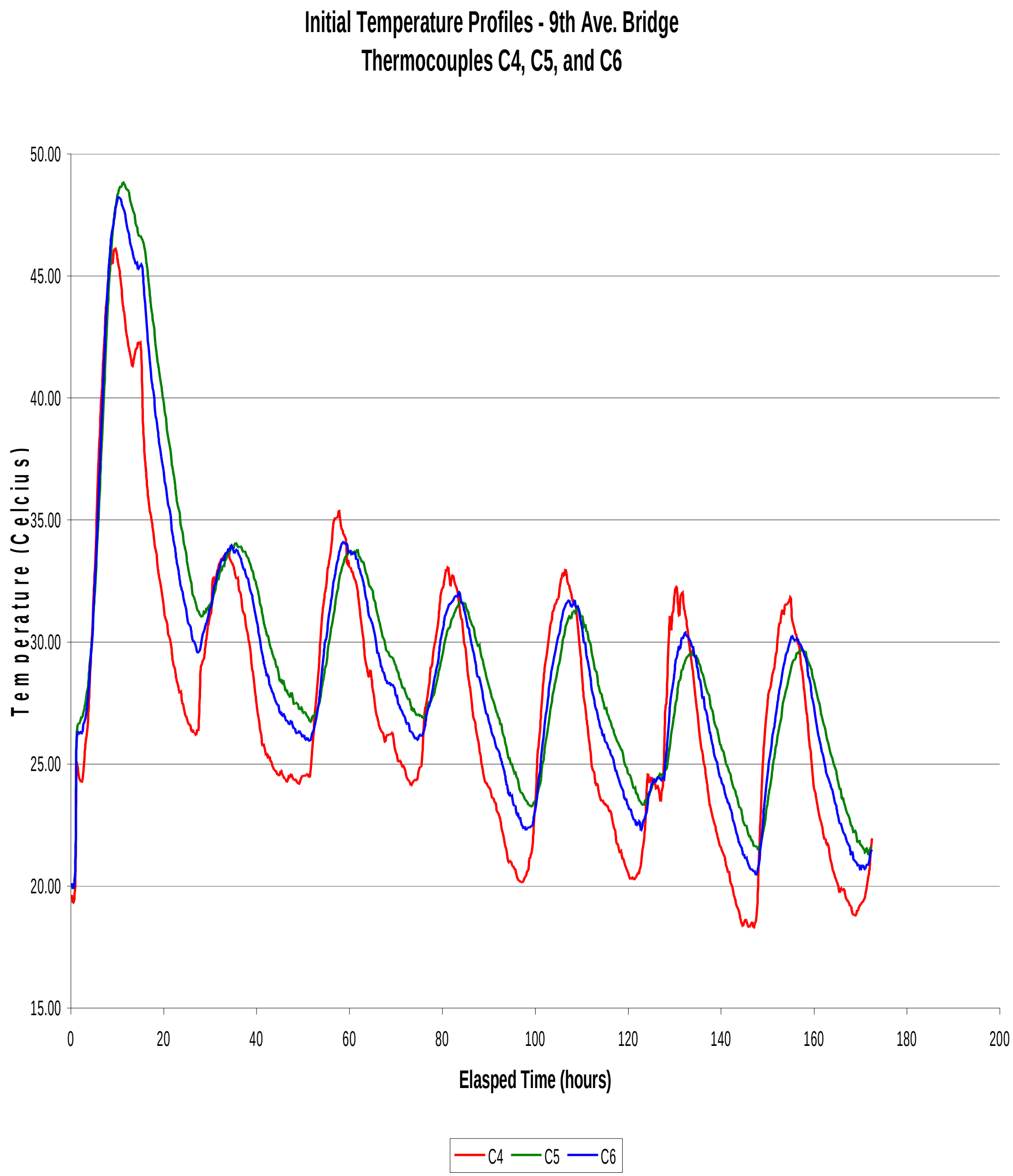
Initial Temperature Profiles - 9th Ave. Bridge
Thermocoucples B1, B2, and B3



H10

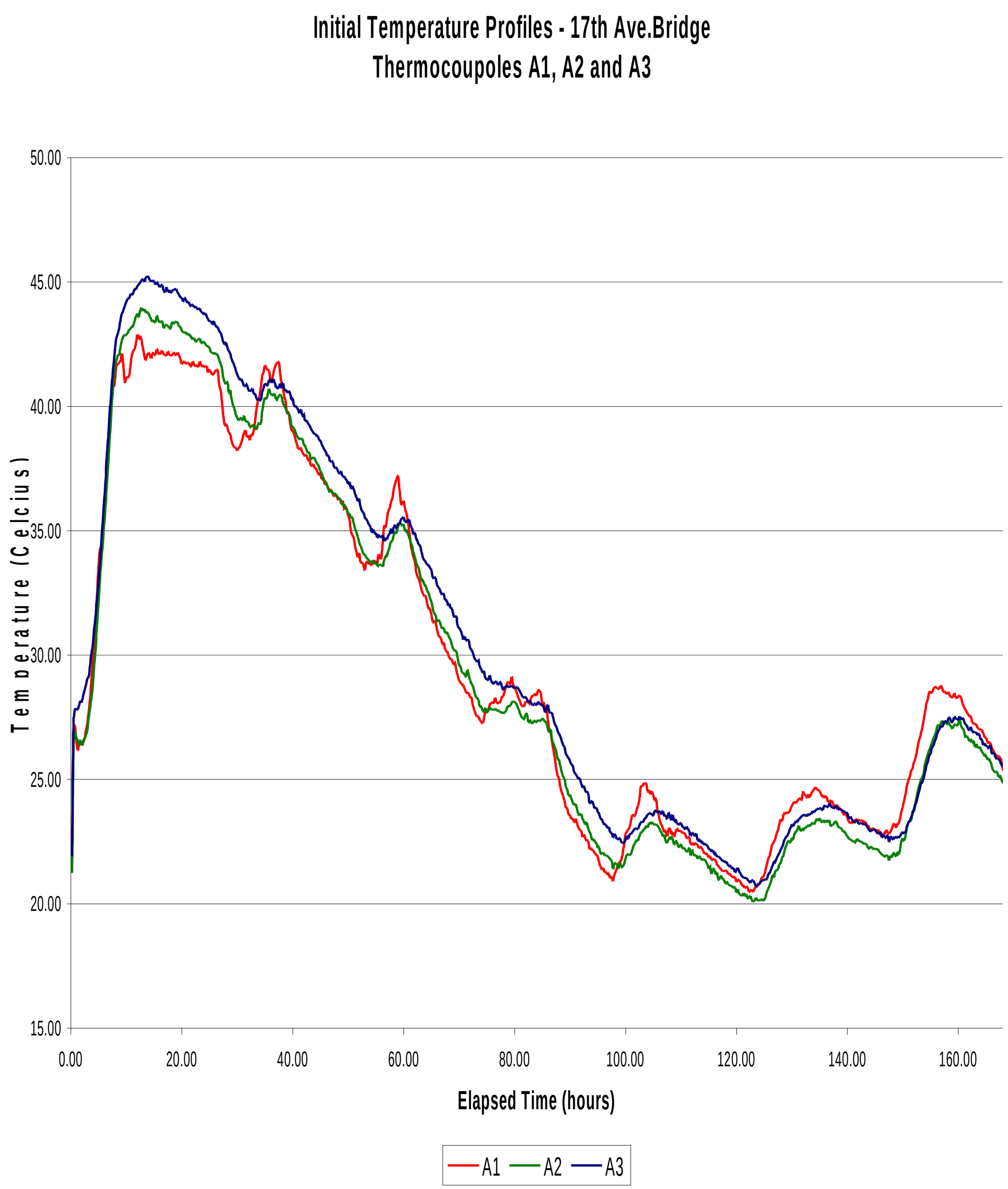

Initial Temperature Profiles - 9th Ave. Bridge
Thermocouples B4, B5, and B6
Temperature (Celcius)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
0
20
40
60
80
100
120
140
160
180
200
Elasped Time (hours)
B4
B5
B6


Initial Temperature Profiles - 9th Ave Bridge
Thermocouples C2 and C3
Temperature (Celcius)
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
0
20
40
60
80
100
120
140
160
180
200
Elasped Time (hours)
C2
C3

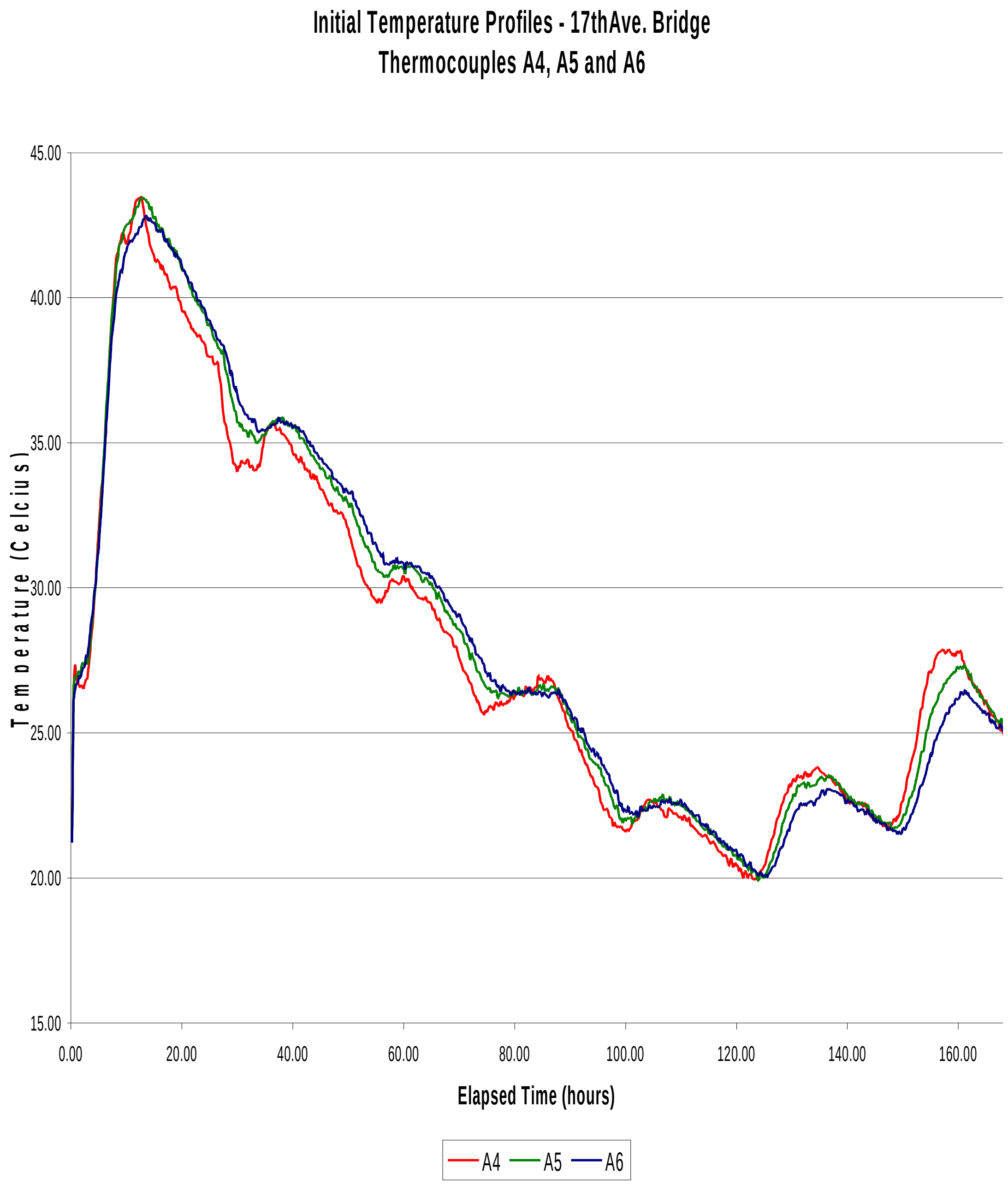


Initial Temperature Profiles - 9th Ave. Bridge
Thermocouples C4, C5, and C6
Temperature (Celcius)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
0
20
40
60
80
100
120
140
160
180
200
Elasped Time (hours)
C4
C5
C6

H13

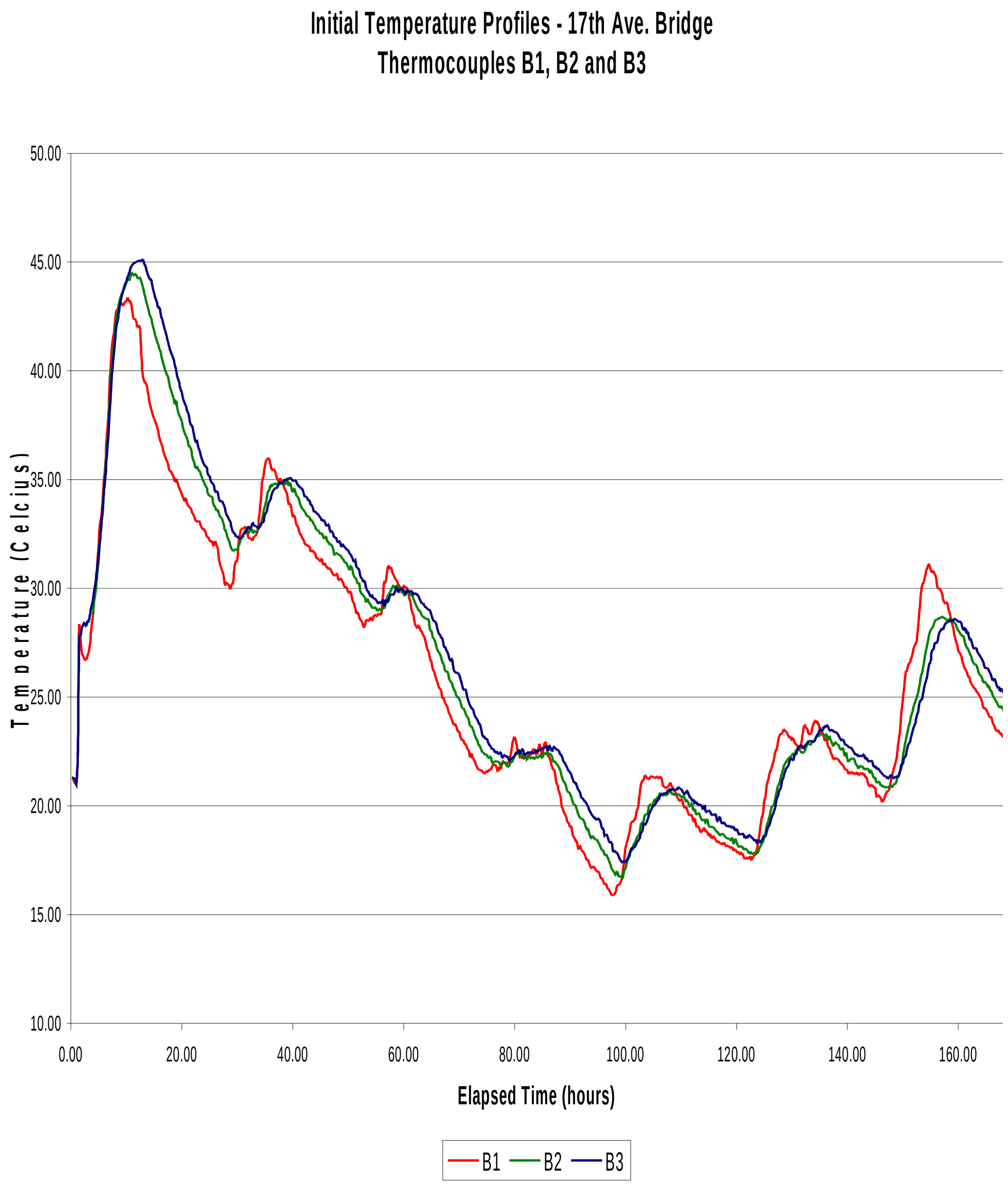


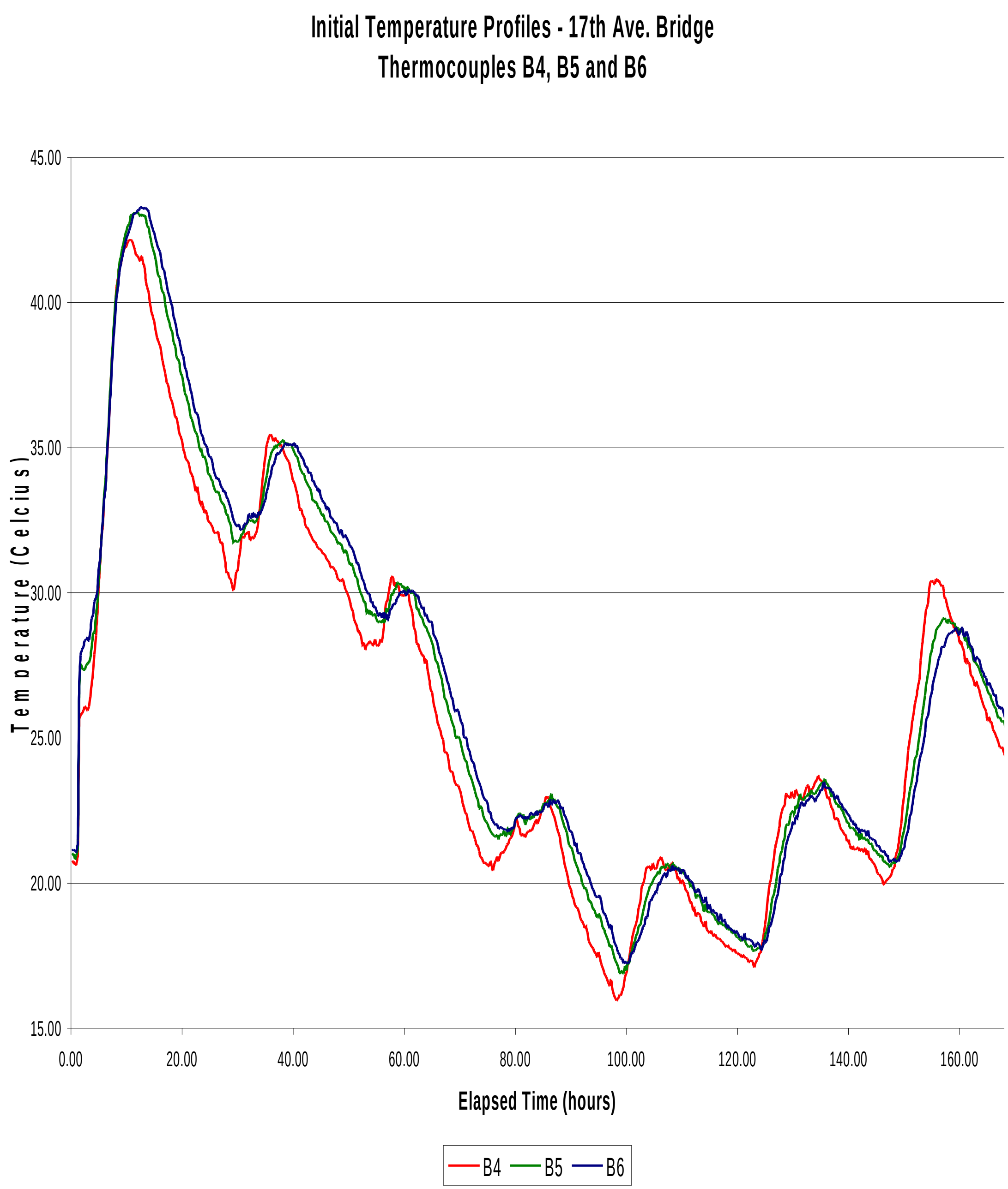
Initial Temperature Profiles - 17th Ave.Bridge
Thermocoupoles A1, A2 and A3
Temperature (Celcius)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
A1
A2
A3

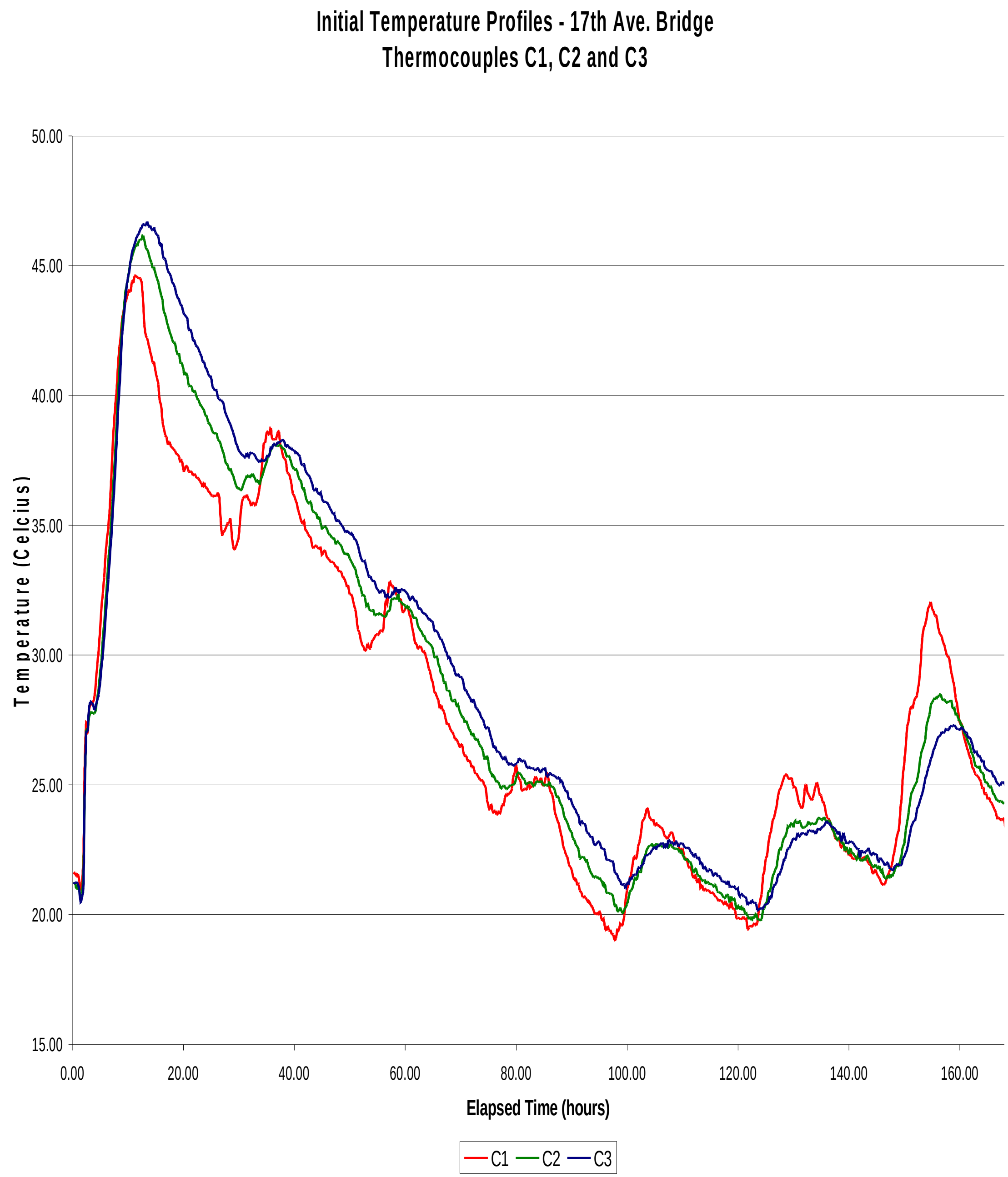


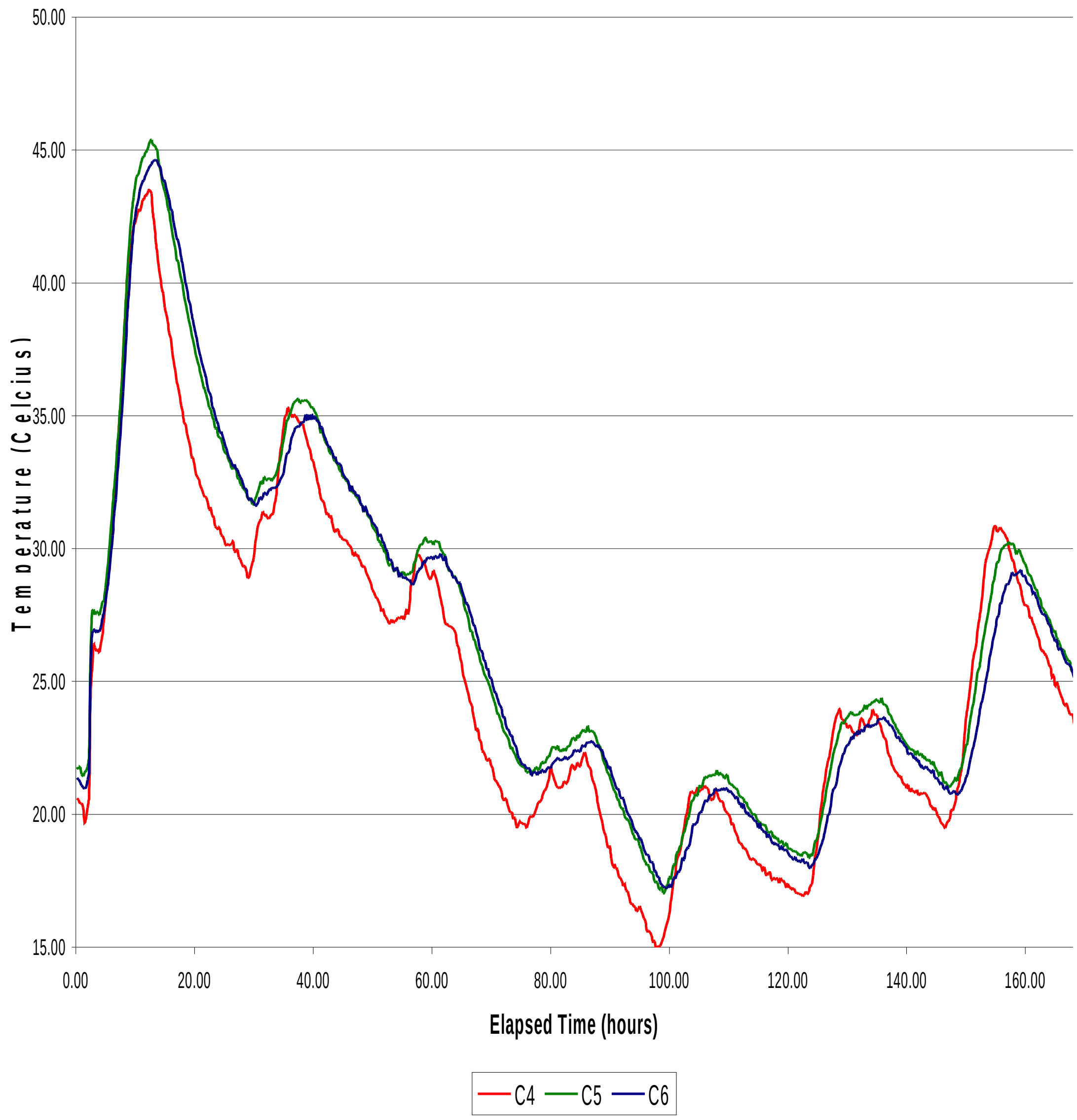
Initial Temperature Profiles - 17thAve. Bridge
Thermocouples A4, A5 and A6
Temperature (Celcius)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
A4
A5
A6

H15


Initial Temperature Profiles - 17th Ave. Bridge
Thermocouples B1, B2 and B3
Temperature (Celcius)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
B1
B2
B3


Initial Temperature Profiles - 17th Ave. Bridge
Thermocouples B4, B5 and B6
45.00
40.00
35.00
30.00
25.00
20.00
15.00
T e m p e r a t u r e (C e l c i u s)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
B4
B5
B6


Initial Temperature Profiles - 17th Ave. Bridge
Thermocouples C1, C2 and C3
Temperature (Celcius)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
Elapsed Time (hours)
C1
C2
C3



Initial Temperature Profiles - 17th Ave. Bridge
Themocouples C4, C5 and C6