RESEARCH

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Sixty-Year Design Concrete Pavement-Performance Model Development: MnROAD Cell 53 Construction Report

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16. Abstract (Limit: 200 words)

The primary objective of this research study is to develop an improved service life prediction model for the Minnesota Department of Transportation's (Mn/DOT's) current 60-year concrete pavement designs. Secondary objectives include understanding the behavior of these pavements with regard to maturity, slab warp and curl, and thermal expansion. These objectives will be accomplished through extensive testing of materials during construction, and conducting seasonal load response testing under controlled loads of an instrumented concrete pavement test cell (Cell 53) built to Mn/DOT's current 60-year design standards. Load response testing of traditional designs constructed in MnROAD Phase I will be used in the development of the improved life prediction model. This construction report describes the construction and material testing done on MnROAD Low Volume Road test Cell 53. A summary of U.S. and international long-life concrete pavement designs is also included.

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Sixty-Year Design Concrete Pavement-Performance Model Development: MnROAD Cell 53 Construction Report

Final Report

Prepared by

Ryan J. Rohne

Minnesota Department of Transportation
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, Minnesota 55109

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Research Services Section
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EXECUTIVE SUMMARY

The primary objective of this research study is to develop an improved service life prediction model for the Minnesota Department of Transportation's (Mn/DOT's) current 60-year concrete pavement designs. Secondary objectives include understanding the behavior of these pavements with regard to maturity, slab warp and curl, and thermal expansion. These objectives will be accomplished through extensive testing of materials during construction, and conducting seasonal load response testing under controlled loads of an instrumented concrete pavement test cell (Cell 53) built to Mn/DOT's current 60-year design standards. Load response testing of traditional designs constructed in MnROAD Phase I will be used in the development of the improved life prediction model.

The adoption of changes in long-life concrete design based on MnROAD findings would not only benefit the state of Minnesota, but could also benefit other agencies (national and international) that accept the findings. Given the current backlog of needs for improving or maintaining the highway system, money saved on the optimization of long-life concrete pavements could be used to lengthen a project, or provide additional safety features.

The research objectives for this project include the following:

- Develop an improved service life prediction model for Mn/DOT's current 60-year concrete pavement designs.
- Understand the behavior of these pavements with regard to maturity, slab warp and curl, and thermal expansion.
- Understand the behavior of the thin concrete shoulder (4in.) to environmental loads.

New MnROAD Low Volume Road test Cell 53 was built with a large number of electronic sensors embedded in it to measure the pavement's response to load and environmental effects. Tables and figures describing the type, number, and layout of the sensors are included.

Samples of the subgrade soil, aggregate base material, and concrete mixes were taken during construction of the cell. Initial test results of these samples can be found in this report. In addition to material testing results, this report describes the design and techniques used to construct Cell 53. A review of U.S. and international long-life concrete pavement designs is also included.

INTRODUCTION

MnROAD Facility

MnROAD is a pavement research facility located along Interstate 94 in Albertville Minnesota, forty miles northwest of Minneapolis/St. Paul. Initially constructed by the Minnesota Department of Transportation (Mn/DOT) between 1990 and 1994 (Phase I), MnROAD consists of two primary roadway test segments, Mainline and Low Volume Road (LVR), containing several dozen distinct test cells, Appendix A. Subgrade, aggregate base, roadbed structure, drainage methods, and materials vary from cell to cell. Automated sensors are configured to record data continuously to the MnROAD database. All historical sensor, sampling, testing, and construction data can be found in the MnROAD database and in various publications [1].

The mainline test section consists of a 3.5 mile, two lane interstate roadway carrying "live" traffic diverted from Westbound I94. The Low Volume Road (LVR) is adjacent to Interstate 94 and the Mainline test sections. The LVR is a two lane, 2.5 mile closed loop that contains over 30 test cells. Controlled loading on the LVR is applied by an 80 kip, 18 wheel, five axle tractor/trailer. The tractor/trailer travels 80 laps daily on the inside lane of the LVR loop. The outside lane, monitored for environmental effects, remains unloaded except for lightweight test vehicles [2]. Additional isolated test sections have been installed and monitored at the MnROAD test site and throughout the state of Minnesota. Phase II reconstruction at MnROAD started in 2007 and is expected to be complete during the 2009 construction season. Phase II encompasses more than 20 research projects and reconstruction of 35 test cells.

Project Background

Due to increased traffic congestion and reduced highway construction budgets, emphasis is now being placed on designing and constructing longer life pavements. Using the current Mn/DOT design guide for concrete pavement design (based on 1981 AASHTO design guide), Mn/DOT is now constructing what is believed to be 60-year design concrete pavements. However, during the design process, both the traffic prediction and service life of the concrete pavement is being extrapolated far beyond the available charts in the current design method.

The primary objective of this research study is to develop an improved service life prediction model for Mn/DOT's current 60-year concrete pavement designs. Secondary objectives include understanding the behavior of these pavements with regards to maturity, slab warp and curl, and thermal expansion and also the behavior of the thin concrete shoulder to environmental loads. These objectives will be accomplished through extensive testing of materials during construction, and conducting seasonal load response testing under controlled loads of an instrumented concrete pavement test cell (MnROAD LVR Cell 53) built to Mn/DOT's current 60-year design standards. The work plan for Cell 53 is included in Appendix B. Load response testing of traditional designs constructed in MnROAD Phase I will be used in the development of the improved life prediction model.

Concrete pavement design standards in Minnesota may be altered if the Mn/DOT Pavement Engineering Section, through the findings from this study, believe that current 60-year concrete pavements designs are over or under designed. Alternatively, the life cycle costs of current Mn/DOT 60-year concrete pavement designs could be updated to more accurately reflect their potential performance. The data and results will also be available for organizations like FHWA and NCHRP, so they can improve their development of future concrete pavement design methods, e.i. MEPDG [3].

The research methods include:

- Construct and instrument a concrete pavement test cell based on Mn/DOT's current 60-year design standards.
- Collect and analyze sensor measurements including maturity, dynamic and environmental strain, displacement, slab warp and curl during and shortly after construction.
- On a monthly basis, collect and analyze dynamic and environmental strain, displacement, and slab warp and curl measurements.
- Frequently (at least seasonally) monitor surface distress and ride quality of the test cell for a 4-year period.
- After 2 years of traffic application, develop preliminary life prediction models based on available MnROAD data. Refine load response testing schemes if necessary.
- After 4 years of traffic has been applied, complete a life prediction model and prepare, publish, and present research papers and final reports based on the findings.

Research Objectives

The research objective for Cell 53 includes the following:

- Develop an improved service life prediction model for Mn/DOT's current 60-year concrete pavement designs.
- Understand the behavior of these pavements with regards to maturity, slab warp and curl, and thermal expansion.
- Understand the behavior of the thin concrete shoulder to environmental loads.

Report Organization

This chapter introduced the MnROAD test facility and the research objectives for this project. Chapter 2 describes Mn/DOT's long-life concrete pavement design. A summary of long-life concrete pavement designs from other states and countries is also included. Chapter 3 describes the construction of Cell 53. The geometric dimensions and construction techniques of the test cell are described along with tests done on the concrete and base layers. Chapter 4 describes the instrumentation installed in this test cell as well as initial warp and curl measurements and concrete maturity. Chapter 5 contains a summary and conclusions.

The appendices contain additional information. Appendix A summarizes the test cells on the MnROAD Mainline and Low Volume Road (LVR). Appendix B contains the work plan for this study and summarizes each project task. The concrete mix design used is included in Appendix

C and Appendix D includes the concrete tickets. Construction pictures are included in Appendix E and Appendix F includes sensor types and locations.

SYNTHESIS ON LONG-LIFE CONCRETE PAVEMENTS

Darter and Barenberg [4] conducted a study on "zero maintenance" JPCP characteristics. They determined that the use of dowel bars, short joint-spacing, good subdrainage, adequate sealing of joints, increased slab thickness, and increased foundation support are necessary to prevent joint faulting. Concrete shoulders should be of equal thickness to mainline pavement thickness and tie bars should be used. Transverse joints identical to the ones used in the traffic lanes should be used in the shoulders as well as the same subgrade which should have adequate drainage.

Cable and McDaniel [5] presented the common distress types in PCC pavement and their corresponding influencing factors. They found that deterioration of a concrete pavement is a continuous process where one form of distress can cause additional distresses. For example, cracking due to misaligned dowels can cause increased moisture absorption by the slab and freeze-thaw damage. Water plays an important role in pavement distress and should be removed to create well performing pavements. Drainage as well as grading of the subsurface is very important with good subbase drainage essential for long-term performance.

A reduction in permeability of high-performance concrete pavements over standard PCC mixes is considered to be an important factor of their potential longevity in extreme climates [4]. Many bridges are currently being designed for 100 year service lives. The same durability problems that affect concrete bridges affect concrete pavements. In 100 year bridge designs, the durability issues related to the concrete are controlled by increasing the strength and decreasing the permeability. Ion permeability test requirements of 2000 coulombs or less at 56 days was required in a 100 year design bridge in Louisiana [6].

Freeze-thaw damage and other durability problems in concrete are initiated by the presence of water. Substantial damage is only able to occur when water and ionic elements are free to migrate into and out of the concrete. Low w/cm ratio (below 0.40) as well as the inclusion of supplementary cementitious materials, decreases concretes permeability by forming a discontinuous capillary-void system [7].

Mn/DOT's 60-Year Concrete Pavement Design

The Minnesota Department of Transportation began building high-performance concrete pavements (HPCP) in 2000 under the FHWA TE-30 program. Since that time, the HPCP design has become the standard for most urban high-volume highways. The current design service life for Minnesota's HPCP is 60 years [8]. Minnesota's current long-life PCC pavement design is a Jointed Plain Concrete Pavement (JPCP) and is summarized in Table 1 below.

Corrosion of dowel bars is an important issue in a climate as severe as Minnesota's. Standard epoxy-coated steel dowel bars in Minnesota have had life spans as short as 15 years. In 2006, Mn/DOT approved of six types of dowel bars to be used in HPCP projects. Table 2 lists the types and properties of the approved dowel bars. All dowel bars are 15 in. long, mounted in a dowel basket, and are required to have a smooth surface [8].

Table 1. Typical design features for HPCP in Minnesota [8].

Design Feature	Material	Typical Dimensions
Slab thickness	HPCP mix	12 - 13 in.
Base course	Mn/DOT Class 5 material*	4 in.
Subbase	Mn/DOT select granular**	Minimum 36 in.
Transverse joints	Preformed Elastomeric Compression Seal	15 ft. spacing, perpendicular to direction of traffic
Dowel bars	Corrosion resistant	1.5 in. diameter, 15 in. long, spaced 12 in. apart on center
Texture	Astro-Turf or broom drag	1/25 in. average depth using ASTM E965

*Mn/DOT Class 5 is a dense graded granular material containing a minimum of 10% crushed particles
**See specification 3149 (Mn/DOT 2005) for information on the gradation of Mn/DOT select granular material

Table 2. Approved dowel bar types for HPCP projects in Minnesota [8].

Design Feature	Material(s)	Minimum Out -side Diameter	Additional Details
Stainless steel clad	316L stainless steel/carbon steel	1.5 in.	1.5 mm cladding thickness over Grade 60 (min) carbon steel
Stainless steel tube -Steel insert	316L stainless steel/carbon steel	1.5 in.	1.5 mm wall thickness, press-filled with Grade 60 (min) carbon steel
Stainless steel tube -Resin/Grout fill	316L stainless steel/resin or grout	1.5 in.	3.0 mm wall thickness, filled with resin or grout with minimum compressive strength 5000 psi
Stainless steel pipe -Schedule 40	316L stainless steel	1.25 in.	Pipe must conform to ASTM A312, have wall thickness of 3.5 mm, be filled or capped to prevent intrusion of concrete or other materials
Stainless Steel -Solid	316L stainless steel	1.5 in.	Solid stainless steel bar
Rolled zinc alloy -Clad	Zinc alloy (U.N.S. Z41121)/carbon steel	1.5 in.	1.0 mm cladding thickness over Grade 60 (min) carbon steel

The fine aggregates for HPCP are tested for ASR potential based on the accelerated mortar bar test method according to ASTM C 1260. Expansions greater than or equal to 0.15% require mitigation through the use of supplementary cementitious materials. If the expansion is greater than 0.30%, the aggregate is rejected [8]. Mn/DOT also uses a well graded combined aggregate gradation based on an 8-18 specification. The percent retained on all specified sieves should be

between 8% and 18% except for the coarsest sieve and sieves finer than No. 30, where the percent retained can be less than 18%. The acceptable gradation band for HPCP aggregates is shown in Figure 1 [8].

Mn/DOT uses supplementary cementitious materials to reduce the permeability and protect against durability issues such as ASR in HPCP mixes. A rapid chloride ion permeability value of 2,500 coulombs or less at 28 days is specified. Contractors typically meet this specification by using Class C fly ash. To protect against freeze-thaw damage, Mn/DOT specifies an air content of 7.0±1.5% for HPCP projects. The high air content is to protect against loss of air due to over-vibration and infilling of voids. Current projects provide incentives for w/cm ratios under 0.40.

Mn/DOT requires that new pavements be closed to traffic for 7 days or until a flexural strength of 350 psi is reached. A minimum cementitious content of 530 lb/yd^3 and a minimum cement content of 400 lb/yd^3 is required. The concrete is cured using poly-alpha-methylstyrene curing membranes. The supplementary cementitious content limits are 30% fly ash or 35% ground granulated blast furnace slag (GGBFS). SCM's are used to decrease permeability, improve durability, and mitigate ASR [8]. Aggregate quality is very important in long-life concrete. In Minnesota, the absorption content of aggregates is limited to 1.5% and the carbonate content is limited to less than or equal to 20% [7].

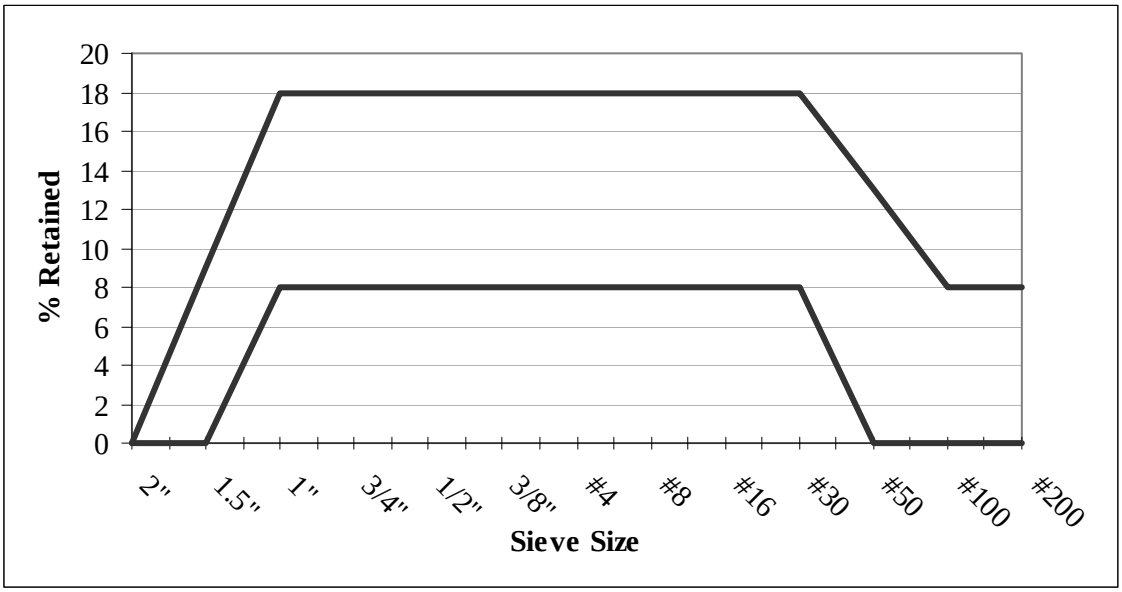

Figure 1. 8-18 Aggregate gradation acceptance band for Minnesota HPCP mixes [8].

Long-Life Concrete Pavements: Domestic Practices in the U.S.

The definition of long-life concrete pavements in others states vary but typically it refers to pavements with service lives of 30 to 40 years or more. While the climates and conditions vary tremendously throughout the United States, common to all the long-life PCC designs are well

graded aggregates, high strength concrete (approximately 650 psi flexure at 28 days), drainable bases, and in the case of JPCP, joint spacing near 15 ft. In every state investigated in this study, premature failures were attributed to saturated base layers even when high quality concrete was used.

Illinois

Illinois began investigating a long-life pavement program in the late 1990's. Illinois high volume pavements are typically Continuously Reinforced Concrete Pavement (CRCP) designs. The main changes that were made to the existing concrete pavement design in order to extend the service life was more rigorous concrete materials requirements in order to better resist freeze-thaw and ASR damage, and stricter construction tolerances [5]. The more rigorous material requirements include limiting the freeze-thaw expansion to 0.025 % elongation and if the ASTM C 1260 expansion test results in 0.10 % expansion, the equivalent alkalis in the cement are limited to 0.60 percent [9]. Table 3 summarizes Illinois long-life concrete mixture design.

Illinois uses a w/cm ratio less than 0.40 along with fly ash, or GGBFS, and entrained air. A hot mix asphalt stabilized base is also used. The subbase consists of a 12 in. aggregate layer. The maximum aggregate size of the top 3 in. of this layer is limited to 1.5 in. The maximum aggregate size of the bottom 9 in. of this layer is limited to 8 in. [9].

Table 3. Typical Illinois long-life concrete mix design [9].

Ingredient	Quantity
Coarse Aggregate	1840 - 1920 lbs
Fine Aggregate	1150 - 1250 lbs
Cement (Type I)	430 - 490 lbs
Fly Ash	135 - 145 lbs
Water	217 - 255 lbs
Admixtures	Air entrainment, water reducer

Texas

The Texas DOT (TxDOT) primarily uses CRCP for long-life pavements. In their experience, the primary failures in CRCP are punchouts, wide cracks, spalling, and construction joint failures. In almost all cases, punchout was preceded by pumping and erosion of the base. Absence of tied shoulders and insufficient slab thickness also contributed to punchout failure [10]. In order to improve pavement performance, TxDOT requires a stabilized base, tied shoulders, increased slab thickness, and the Coefficient of Thermal Expansion (CTE) is limited to decrease spalling [11].

Two types of stabilized bases are used in Texas. One consists of 6 in. of cement-stabilized base with a 1in. asphalt layer on top. The other is 4 in. of asphalt-stabilized base. TxDOT found that aggregate with high CTE creates issues with spalling. Based on this finding, the CTE of coarse aggregates is limited to 6.0E-6 in./in./˚F [10].

It was found that the use of tied concrete shoulders limited FWD deflection on the CRCP edge to 1/3 that of asphalt shoulders. The deflections measured were similar to those of an interior slab and it is expected that concrete shoulders will result in less erosion and pumping [10].

Washington

Washington typically uses jointed plain concrete designs for long-life PCC pavements. About 38% of the concrete pavements were older than 35 years as of 2006 in Washington. The three primary distresses found in these pavements are: joint faulting due to lack of dowels and poor underlying conditions, surface wear due to studded tires, and longitudinal cracking which is believed to have occurred early in the pavements life due to traffic loading. While the pavements are considered deficient in thickness (8-9 in.) and load transfer (no dowels at joints) for long-life, they have performed very well due to the use of high quality materials including large aggregate size with excellent characteristics [11].

The thickness of concrete pavements has increased to 13 in. in the high volume areas of Seattle, to accommodate diamond grinding around years 20-25 in order to remove wear due to studded tires. The bases typically consist of four inches of dense-graded HMA over 4 in. of crushed stone. This base was chosen based on the performance of three types of bases traditionally used in Washington [12]:

- Cement-treated base - Pavement had severe joint faulting, pumping, and cracking. Showed signs of erosion and voids and is no longer allowed in Washington.
- Asphalt-treated base - Pavements had minimal joint faulting. It was found that joint faulting occurred due to stripping because of the low asphalt content (2.5 to 4.5%).
- Crushed stone - Pavement faulted. Fines migrated from the base and subgrade to the top of the base course contributing to joint faulting. The height of the joint faulting was directly related to the height of the migrated fines.

Current concrete mix designs allow either gap or continuously graded aggregates with 0.8 in. max aggregate size. If used, fly ash is Class F and is limited to 35% replacement of the total cementitious content. Ground Granulated Blast Furnace Slag (GGBFS) or combinations of GGBFS and blended cements are permitted. Traffic opening is allowed when a compressive strength of 2,466 psi is reached as determined from compression tests or maturity measurements. Stainless steel dowels are used in all JPCP [12].

Iowa

Iowa typically uses JPCP design for long-life pavements. Ceylan, Cable, and Gopalakrishnan 2006 [13] conducted a survey on long-life concrete pavements in Iowa. Surveys were sent to the six Iowa DOT District Offices, 99 counties, and 40 cities. The survey asked to identify three pavements, 20 years old or older, that are performing well and three pavements that are under 20 years old which are not performing well. Twenty nine of the counties responded with 112 pavement sections and seven cities responded with 36 pavement sections. According to the Iowa DOT records, there are 30 pavement sections over 20 years old in the Interstate system and

according to the District Offices, there are 641 pavement sections over 20 years old that have not been resurfaced.

Limited data was available about the pavement subgrades. The well performing pavements had average w/cm ratio of 0.49 and the poor pavements had average w/cm ratios of 0.55. One of the most common distresses observed in the low and medium volume roads was longitudinal cracking. Longitudinal cracking can results from subgrade and concrete materials problems as well as heavy axle loads and subgrade failure.

Florida

Florida typically uses JPCP designs for long-life pavements. In Florida, pavements that range from 40 to 45 years old that are in good condition exist in the Interstate Highway System. These well performing long-life pavements typically have good subbase drainage, carefully constructed joints, and concrete materials and mixture designs that required longer curing times than typical pavements currently being used. The longer curing time allowed less restrained shrinkage and longer fatigue life [14].

The pavements that did not perform well typically had poor subbase drainage. Water was trapped between the subgrade and the pavement, causing pumping and corner cracks. Dowels were not used. Quality control was also an issue [14].

In a prematurely failed pavement, I-75, pumping was a problem. The base had low strength and the pavement had randomly spaced joints with some spaced more than 20 ft. Distress from thermal restraint also occurred because the longitudinal joints from all lanes and shoulders were tied [14]. As a result of the premature failures, Florida adopted new long-life concrete guidelines; all joints are doweled, no joint spacing greater than 15 ft, no randomly spaced joint patterns, no skewed joints, and all joints are sealed [14].

Two different drainable support designs are used in Florida. The first is 4 in. of asphalt- or cement-treated permeable base over a stabilized subgrade. An asphalt separation layer is used between the subgrade and base to prevent the migration of fines. The second support is a 5 ft. subgrade/embankment composed of special select material that meets AASHTO A-3 soil classification. The required permeability is $1.6x10^{-6}$ ft/s with less than 12% fines passing the No. 200 sieve. Since this layer lacks the fines to give adequate stiffness, 3 in. of AASHTO standard size 57 or 89 aggregate is placed on top of the subgrade (directly under the pavement) and blended with the top 6 in. of the special select material. An edge drain is also used in all concrete pavements in Florida [14].

California

California uses both CRCP and JPCP for long-life pavements. Rao, Darter, and Pyle 2006 [15], studied two CRCP in California; a stretch of I-80 between San Francisco and Sacramento, built in 1949 and the other, a section of I-5 in Tracy, built in 1971. Both pavements have served well beyond their design lives and capacity.

The I-80 project consisted of an 8 in. slab with two 12 ft. tied lanes using 0.63 in. diameter ties spaced at 30 in. A tongue and groove joint was used between the lanes with a 4 in. expansion joint at both ends of the one mile long CRCP lanes. The 360 day flexural strength of the concrete used was 810 psi. From 1949 to 2005 the lane carried about 40 million trucks. The remaining pavement in this section consisted of JPCP with 15 ft joint spacing. Cement treated 4 in. base (3.5%) was used over 8 in. of granular material under both sections. The concrete maximum aggregate size was 2.5 in. While the CRCP remains in good condition, the JPCP is not and has transverse cracking, corner breaks, and spalled joints [15].
The section of I-5 near Tracy, California was an 8.5 in. thick CRCP slab with 0.56% steel. The concrete used had a modulus of elasticity of 4.05E+06 psi and a 15 year flexural strength of 664 psi measured on cut beams. The CTE was measured to be 6.15E-6 in/in/˚F. The base layer was also cement treated (4%) and placed over an A-2-4 granular subbase. This pavement is also currently in very good condition [15].

Evaluation of the M-E Design Guide was also part of this study and both of these pavements performed as the MEPDG 2002 [3] predicted and were not outliers. It is believed that the low mix shrinkage as well as the long curing time during low to moderate temperatures played a significant role in the performance of these two pavements. Based on California's experience with long-life pavements, they recommend 28-day flexural strength of at least 675 psi, CTE below 6.0E-6 in/in/˚F, and using either a cement or asphalt treated base with good drainage properties [15].

Virginia

The typical high-performance pavement design in Virginia consists of a 9 in. doweled JPCP slab with 15 ft. joint spacing. Hossain and Elfino 2006 [16] investigated the premature failure of a JPCP in Virginia. They found that even though the concrete was of high quality and constructed with high quality materials, because drains were blocked, water was trapped under the pavement. Premature failure then occurred due to pumping of the trapped water. Pavement sections that did not have clogged drains remained in good condition.

The base consisted of 4 in. of AASHTO #57 aggregate mixed with 230 lb/yd^3. Under this layer was 6 in. of cement-treated soil using 10% cement by volume. The shoulder consisted of 6 to 9 in. of variable depth, undoweled tied shoulders with 4 in. of dense graded base material and a pavement edge drain.

Long-Life Concrete Pavements: International Practices

Germany and Austria typically use CRCP and a design catalog to select pavement thickness. The design thicknesses are based on previous laboratory research and field observations. In the Netherlands and the United Kingdom, mechanistic-empirical design software is used but very few miles of concrete pavements are constructed in these two countries. In Germany and Austria, maximum slab thickness is a common feature in the design catalogs with the maximum slab thicknesses being thinner than in the United States for similar traffic levels with often heavier trucks. Fatigue cracking has not been an issue with the thinner slabs [17].

Australia

Australia's experience with concrete pavement is mainly limited to the populous New South Wales area. While the rest of the country has had little experience with concrete pavements, they have borrowed the best practices of other countries and adapted them to their material and climate conditions. Australia has developed a catalog for long-life heavy-duty pavements. Concrete has a required minimum flexural strength of 653 psi and compressive strength of 5,076 psi at 28 days. The JPCP is also debonded from the base layer to allow for free curl and warping of the concrete [18].

A lean-mix concrete base is used with minimum compressive strength of 725 psi at 42 days. This layer has no induced joints and limited construction joints. Tied concrete shoulders are used with widths of 7 to 10 ft in the curb lane and 2 ft. in the median lane. All joints are sealed and a minimum of 12 in. of the subbase is select material with a CBR greater than 30% after a 4-day soak, a PI of less than12, and compressive strength of 145 psi. The top 6 in. is stabilized with 2% hydrated lime if the material has a soaked California bearing ratio less than 30% [18].

Austria

In Austria, the highest-volume pavements (18-40 million design axle loads) are typically 10 in. thick JPCP on 2 in. bituminous interlay and either 18 in. of unbound base or 8 in. of cement stabilized base with 18 to 20 ft pavement joint spacing. All concrete pavements are built in two lifts with recycled or inexpensive aggregates used in the bottom 8 in. and more wear resistant aggregate used in the upper 1.5 in. with an exposed aggregate surface. Dowels in the transverse joints are 1 in. diameter and 20 in. long. They are spaced more closely in the traffic wheel paths and farther apart between the wheel paths. Tie bars in the longitudinal joints are 0.55 in. in diameter, 27.5 in. long, and spaced 6.5 ft apart for three tie bars per slab. Sealant reservoirs are sawed 0.3 in. wide in both transverse and longitudinal joints. Preformed seals are used in transverse joints and liquid sealant is used in longitudinal joints [17].

Austria requires European standard type CEM II cement with an initial set time of no less than 2 hours at 68˚F, Blaine fineness no greater than 3,500 cm^2/g, and 28-day cube strength no less than 1,000 psi. In the lower concrete course of the two lift construction; the required 28-day flexural strength is 800 psi and 28-day compressive strength is 5,000 psi. The upper course is required to have a 28-day flexural strength of 1,000 psi and a 28-day compressive strength of 5,800 psi. Aggregate used for exposed aggregate concrete must have a polished stone value of at least 50. The lower course may consist of recycled concrete or asphalt aggregate (10% maximum for asphalt aggregate). Slag replacements of 20-25% are used. The minimum cement content in the lower course is 594 lb/yd^3 and 675 lb/yd^3 in the upper layer. The required air content is 4.0 – 6.0% [17].

Belgium

The E5 motorway from Brussels to Liege is a CRCP that is still in good condition after 34 years and with 112,000 vehicles per day as of 2000. This road has had minimal maintenance during the first 30 years and it is expected that it will have a life span of 40 to 50 years [19].

The E5 is a CRCP with slab thickness of 7.9 in. It has a 2.4 in. asphalt base above 7.9. in. of lean-mix concrete and finally a 7.9 to 31.5 in. sand subbase. The required average concrete strength was 10,443 psi at 56 days and apparent dry density of 143 lb/ft^3 [19]. The mix design used is shown in Table 4.

The E5 concrete was not air entrained because of the high strength and density. The w/cm ratio was 0.42. The required 56 day compressive strength of the lean concrete subbase was 1,450 psi and it had a cement content of 169 lb/yd^3. To prevent cracking, a slow curing blast furnace slag cement was used. Immediately after finishing, a bituminous emulsion was sprayed on then covered with sand. The asphalt base also prevents reflective cracking from the subbase. The performance of this road is attributed to the high-strength concrete base and asphalt base course and the high quality concrete. Other reasons are the excellent bond between the asphalt layer and upper and lower concrete layers. The good drainage due to side gutters, sufficient cross slope, thick layer of drainage sand, and drainage pipes on the edge of the shoulder also significantly contributed [19].

Table 4. Concrete mix for CRCP on E5 Motorway [19].

Ingredient	Quantity
Crushed stone 22/40	1261 lbs
Crushed stone 8/22	631 lbs
Crushed stone 2/8	589 lbs
River sand 0/2	681 lbs
Cement (CEM I or CEM III)	673 lbs
Water	286 lbs
Admixtures	HRWR

The Walloon Motorway is another successful long-life pavement in Belgium that has been in service for 35 years with hardly any maintenance and with average daily traffic of over 15,000 heavy vehicles. The road is located in a wet temperate area that experiences freeze-thaw cycles during 5 to 6 months of the year. It was built on clay loam that was stabilized by applying quick lime on successive layers 11.8 in. thick. The CRCP used was 7.9 in. thick, with 2.4 in. of dense macadam, then a lean-concrete 7.9 in. thick and finally a drainage layer of sand 9.8 in. thick above the specially compacted subgrade (colliery shale) which was 3.3 to 4.9 ft thick. The lean concrete layer had a cement content of 152 to 170 lb/yd^3. The largest aggregate used (22/40) was limestone with the other coarse aggregates being sandstone [20]. The concrete mix design is shown in Table 5. The w/c ratio varied from 0.40 to 0.42. The concrete used had 90 day compressive strengths ranging from 9,956 to 11,379 psi [19].

Table 5. Walloon Motorway mix design [19].

Ingredient	Quantity
Crushed stone 22/40	1269 lbs
Crushed stone 8/22	635 lbs
Crushed stone 2/8	592 lbs
Sand (FM 1.72 to 3.40)	719 - 731 lbs
Cement (HK40)	592 - 677 lbs
Water	254 - 271 lbs
Admixtures	HRWR

Canada

The standard concrete pavement used in Ontario is a doweled, JPCP with a 14 ft widened outside lane. Transverse joints are randomly spaced with an average spacing of 14 ft. Concrete thickness design is based on both the 1993 AASHTO Guide for the Design of Pavement Structures and the Canadian Portland Cement Association's mechanistic-empirical rigid design method with thicknesses ranging from 8 to 11 in. A 4 in. thick, asphalt-treated, open-graded drainage layer (0.75 in. maximum size aggregate, 1.8% asphalt cement) base layer is typically used. An open graded cement treated base is also an option [17].

Quebec has had problems with joint deterioration and frost heave in their concrete pavements in the past. In the mid 1990's, two standard concrete pavement designs were adopted by the Quebec Ministry of Transportation. The first was a JPCP with the slab thickness designed for truck traffic over a 30 year period with a thickness great enough to protect against frost heave (typically 10 to 13 in.). JPCP are dowelled, have sealed joints and a base of 6 in. of granular material with a granular subbase of varying thickness. These pavements have performed very well so far with the main distress types being joint and corner spalling. CRCP is the second standard pavement used in Quebec. A typical design uses an 11 in. CRCP slab on an open-graded cement-stabilized base [17].

A minimum concrete compressive strength of 4,350 psi is required in Ontario. An air content of 6.0±1.5% is used. Up to 25% GGBFS or up to 10% fly ash can be used or a mixture of both (up to 25%) where the amount of fly ash shall not exceed 10% of the total cementitious materials. In Quebec, ternary mixes are allowed (Portland cement, blast furnace slag, and fly ash) in CRCP but not in JPCP. Blended cements are also allowed. A minimum compressive strength of 5,100 psi is required for both CRCP and JPCP [17].

Germany

Germany uses a design catalog to select total pavement thickness with the standard design based on a 30 year service life. The total thickness includes the concrete slab, base layer, and frost protection layer with typical JPCP thicknesses of 8.6 to 13.8 in. Germany requires the use of a geotextile between concrete pavements and cement stabilized bases to unbond the two layers [17].

The German standard sets the maximum w/c ratio at 0.50, the minimum cement content at 540 lb/yd^3, and minimum air content at 4.0%. Beyond this standard, *Additional Guidelines for the Construction of Concrete Pavements* [17] sets the maximum w/c ratio at 0.45 and the minimum cement content for exposed aggregate layers at 702 lb/yd^3. Portland cement grade CEM I 32.5 (ASTM Type 1) is used and with the client's agreement, portland slag cement, portland burnt shale cement, portland limestone cement, or blast furnace cement may be used. Only cement with alkali contents less than 1.0% can be used. Pozzolans may be used but fly ash and silica fume cannot be used together. Supplementary cementitious materials are not taken into consideration in the calculation of the cementitious content or w/c ratio. In two-coarse construction, recycled or inexpensive aggregates may be used in the lower layer and different strength requirements exist for each layer. Requirements for aggregates include; high freeze-thaw resistance, high polishing resistance, and at least 35% must be crushed. Concrete in the high-volume strength class must have 60 day compressive strength of 4,350 psi and 650 psi flexural strength at 28 days [17].

CONSTRUCTION

Base and Pavement Design

MnROAD Low Volume Road (LVR) test Cell 53 is 125 ft long between stations 210+85 and 212+00. It consists of a 12 in. JPCP over 5 in. of Class 5 base and 36 in. of Modified Select Granular Subbase. Each lane of Cell 53 has the same panel sizes of 12 feet wide by 15 feet long in both the driving and passing lanes. Five No.13 epoxy coated tie bars were used per panel. Stainless steel 1.5 in. diameter dowel bars were spaced every 1.0 ft with 12 per panel. The shoulders consisted of 8 inches of Class 5 underneath 4 inches of concrete. Both shoulders were 8 ft wide with 7.5 ft. tooled joints. The shoulders were not tied to the pavement.

Concrete Mixture Proportions

The concrete mix design for both the lanes and shoulders of Cell 53 followed Mn/DOT's specifications for High Performance Concrete Pavements (HPCP's). The submitted mix design is included in Appendix C and summarized below in Table 6.

Table 6. Concrete mix design.

Material	Quantity	Units
Water	205	lb/yd^3
Cement	410	lb/yd^3
Fly Ash	175	lb/yd^3
w/cm ratio	0.35	
Fine Agg. (oven dry)	1123	lb/yd^3
CA #1 (size #4, oven dry)	627	lb/yd^3
CA #2 (size #67, oven dry)	1154	lb/yd^3
CA #3 (size #9, oven dry)	224	lb/yd^3
Air content	7±1.5	%
AEA (Sika AIR)	As needed	oz/cwt
WRA (Sikament 686)	0-8.0	oz/cwt

Placement of Concrete

Formed paving was used for both lanes and shoulders. The inside instrumented lane was poured on September 29, 2008 and the sensors were covered with concrete at 1:00 PM. The outside lane was poured on October 16, 2008 and both shoulders were poured on October 21, 2009. The concrete tickets from both lane pours are included in Appendix D. The forms were removed the next day in all cases. An L2KT keyed longitudinal joint was used between the inside and outside lanes. The shoulders were not tied to the lanes. All joints were tooled. A McCleary screed was

used to compact the concrete. Prior to paving, concrete was placed around the sensors and compacted with a pensile vibrator. Construction pictures are included in Appendix E.

Concrete Material Sampling and Testing

During construction, material samples were taken for testing by American Engineering Testing (AET). Table 7 summarizes the quantity and type of standard test performed on concrete material samples taken during the construction of test Cell 53.

The University of Pittsburgh Civil Engineering Laboratory tested the concrete samples for coefficient of thermal expansion and American Engineering Testing tested the concrete samples for freeze-thaw durability, flexural, and compressive strength. In addition Mn/DOT made and tested additional flexure beams on site.

Table 7. Material samples taken during construction.

Test (Standard)	Number of Samples	Test Age (Days)
Compressive Strength (ASTM C 39)	2	3
	2	7
	2	21
	2	28
Flexural Strength – Third Point (ASTM C 78)	1	1
	1	3
	5	7
	3	28
	2	47
Freeze-Thaw (ASTM C 666)	3	-
Coefficient of Thermal Expansion	2	-
Rapid Chloride Ion Permeability (ASTM C 1202)	3	28

Compressive Strength

Table 8 lists the results from compressive strength testing done on the concrete samples by AET. The cylinders listed in this table were cast on site then transported to AET's testing lab for curing. Mn/DOT requires 3000 psi to open a road to traffic. As shown in Table 8, the concrete used for this test cell had over 3000 psi at 3 days.

Flexural Strength

Table 9 lists the results from the flexural strength testing done by American Engineering Testing (AET) and Mn/DOT. The beams tested by AET were cured on site for the first 24 hours then transported and cured in a temperature controlled moist room. The Mn/DOT beams were cured

on site in a water bath. The difference in strengths between the AET and Mn/DOT beams reflects this difference in curing. A flexural strength of 350 psi is required by Mn/DOT to open a road to traffic. As shown in Table 9, the AET beams (lab cured) had more than 350 psi at 3 days and the Mn/DOT beams (field cured) had 525 psi at 7 days.

Table 8. Compressive strength testing results.

AET Inside Lane				
Age	**Date Cast**	**Date Tested**	**Strength (psi)**	**Type of Failure**
3	9/29/08	10/02/08	3270	Shear
3	9/29/08	10/02/08	3230	Cone & Shear
7	9/29/08	10/06/08	4470	Shear
7	9/29/08	10/06/08	4420	Cone & Split
21	9/29/08	10/20/08	5370	Side Fracture
21	9/29/08	10/20/08	5560	Cone & Split
28	9/29/08	10/27/08	5950	Cone & Split
28	9/29/08	10/27/08	5840	Cone

Table 9. Flexural strength testing results.

Age	**Date Cast**	**Date Tested**	**Strength (psi)**	**Air Content (%)**	**Slump (in)**	**Concrete Temp (°F)**
AET Inside Lane						
1	9/29/08	9/30/08	280	-	-	-
3	9/29/08	10/02/08	580	-	-	-
7	9/29/08	10/06/08	790	-	-	-
7	9/29/08	10/06/08	730	-	-	-
28	9/29/08	10/27/08	1080	-	-	-
28	9/29/08	10/27/08	1150	-	-	-
Mn/DOT Inside Lane						
7	9/29/08	10/06/08	590	-	-	-
7	9/29/08	10/06/08	460	-	-	-
28	9/29/08	10/27/08	505	-	-	-
AET Outside Lane						
7	10/16/08	10/23/08	710	6.2	2.25	62
47	10/16/08	12/02/08	840	6.2	2.25	62
47	10/16/08	12/02/08	930	6.2	2.25	62

Coefficient of Thermal Expansion

Tests to determine the coefficient of thermal expansion (CTE) were done at the University of Pittsburgh. The length change due to temperature changes was measured by a Geokon 4200A-2 Vibrating Wire Strain Gauge. This strain gauge was cast in the concrete cylinder are shown in

Figure 2. The cylinders were then tested according to the AASHTO procedure except that length change was measured using the imbedded strain gauge. Table 10 shows the coefficient of thermal expansion testing results.

Figure 2. Orientation of strain gauges in CTE cylinders.

Table 10. CTE testing results.

Specimen	1	2
Cast Date	9/29/08	9/29/08
Height (in)	12.125	12.125
Diameter (in)	6	6
CTE (10^{-6}/F)	5.3	5.3
Weight (lbs)	29.9	29.7
Description	Normal Concrete, Intact, no visible cracks	Normal Concrete, Intact, no visible cracks

Freeze-Thaw Testing

American Engineering Testing collected concrete samples and made freeze-thaw beams on site. The beams were then cured and tested at their laboratory according to ASTM C 666A. While there is no standard for mass loss after 300 cycles, generally less than 5% is considered acceptable. Length change is limited to 0.10% and failure for Reduction in Dynamic Modulus of Elasticity (RDME) is 60% after 300 cycles. As shown in Table 11, length change, mass loss, and reduction in dynamic modulus all show that this mix had very good freeze-thaw durability.

Table 11. Freeze-thaw test results.

Cycles Completed	Test Criteria	Beam No.			Average
		1	2	3	
30	Weight Loss (%)	.00	.01	.00	.00
	Length Exp. (%)	.00	.00	.00	.00
	RDME (%)	100	100	100	100
60	Weight Loss (%)	.00	.00	.01	.00
	Length Exp. (%)	.00	.00	.00	.00
	RDME (%)	100	100	100	100
92	Weight Loss (%)	.01	.02	.03	.02
	Length Exp. (%)	.01	.01	.01	.01
	RDME (%)	100	100	100	100
120	Weight Loss (%)	.04	.03	.04	.04
	Length Exp. (%)	.01	.01	.01	.01
	RDME (%)	100	100	100	100
153	Weight Loss (%)	.06	.05	.07	.06
	Length Exp. (%)	.01	.01	.01	.009
	RDME (%)	100	100	99	100
187	Weight Loss (%)	.1	.09	.16	.11
	Length Exp. (%)	.01	.01	.02	.01
	RDME (%)	98	99	98	98
213	Weight Loss (%)	.15	.18	.21	.18
	Length Exp. (%)	.02	.02	.02	.02
	RDME (%)	98	98	97	98
245	Weight Loss (%)	.20	.22	.27	.23
	Length Exp. (%)	.02	.02	.03	.02
	RDME (%)	97	97	95	98
276	Weight Loss (%)	.28	.26	.30	.28
	Length Exp. (%)	.03	.03	.04	.03
	RDME (%)	97	97	95	96
301	Weight Loss (%)	.31	.32	.33	.32
	Length Exp. (%)	.04	.04	.04	.04
	RDME (%)	96	96	94	95
Durability Factor		96	96	94	95

Rapid Chloride Ion Permeability

A concrete samples was not taken during the construction of this test cell but a sample was obtained from Cell 5 which used the same mix design. Three 2 in. thick pucks were cut from one 4x8 in. concrete cylinder. They were then tested according to ASTM C 1202. The test results are shown in Table 12. This mix had moderate to low ion permeability.

Table 12. Rapid chloride ion permeability test results.

	Coulombs	Milliamps (max)
Trial 1	2100	118.5
Trial 2	2080	121.4
Trial 3	1940	108.4
Average	2040	116.1

Base and Subgrade Testing

The base layers in Cell 53 consisted of a 5 in. thick Class 5 base on top of a 36 in. Modified Select Granular subbase on top of a clay subgrade. Samples of the clay subgrade and Modified Select Granular subbase were collected and proctor (Table 13) and gradation (Table 14) tests were performed. Material from the Class 5 base layer was not tested in Cell 53 but Class 5 was tested in other cells at MnROAD constructed at the same time as Cell 53. The average values from the Class 5 material tested in other MnROAD cells is shown in Tables 13 and 14. In addition Light Weight Deflectometer (LWD) tests were done on top of the Class 5 layer.

Table 13. Base and subgrade proctors.

Material	Opt. Moisture	Max Density (lb/ft^3)	Liquid Limit	Plastic Limit	Plasticity Index	Mn/DOT Class	Clay %	Silt %	Sand %	AASHTO Group	Group Index	R Value
Clay Subgrade	16.0	111.3	33.0	18.6	14.4	L	13.8	41.1	45.1	A-6	5	22.3
Clay Subgrade	14.8	111.4	31.2	19.0	12.2	L	13.0	39.2	47.9	A-6	4	27.7
Select Granular	9.8	124.1								A-2-6		
Select Granular	9.7	119.3								A-2-6		
Avg Class 5	9.3	128.1								A-1-b		

Table 14. Base and subgrade gradations.

Material	1”	3/4”	5/8”	1/2”	3/8”	#4	#8	#10	#16	#20	#30	#40	#50	#60	#100	#200
Clay Subgrade		100			98	93		88		83		77		71	64	54.9
Clay Subgrade		100			99	94		87		83		77		70	61	52.1
Select Granular	100	100	99	97	95	90	82	79	70		52	37	25		11	6.8
Select Granular	100	100	100	98	96	93	86	83	74		55	40	25		10	5.9
Avg Class 5	100	98	95	90	86	73	64	61	52	42	36	26	19	15	9	6.9

INSTRUMENTATION AND EARLY TESTING

Instrumentation

An important feature on the Mn/ROAD project is the extensive infrastructure available to support the instrumentation of pavement sections. Test Cell 53 was built with a large number of electronic sensors embedded in it to measure the pavement's response to load and environmental effects. Table 15 summarizes the type and number of sensors. Appendix F contains more information regarding the function and location of the sensors. Figure 3 shows the layout of the sensors in Cell 53. Installation photos can be found in Appendix E.

Table 15. Sensors used in Cell 53.

Sensor Code	Sensor Type	Measurement Type	Quantities
CE	Tokyo Sokki PML-60	Dynamic Strain	24
DT	Schaevitz HCD-500 Linear Variable Differential Transducer	Displacement	6
EC	Decagon ECH_2O-TE	Moisture	8
HC	Tokyo Sokki PI-5	Joint Opening	6
IK	Intellirock	Maturity	10
IV	Invar Reference Rod	Elevation	4
TC	Omega Thermocouple (Type-T)	Temperature	24
VG	Geokon 4202 Vibrating Wire	Environmental Strain	3
VW	Geokon 4200A-2 Vibrating Wire	Environmental Strain	16
WM	Watermark	Freeze-thaw Cycles	12
XG	Geokon 4202 Vibrating Wire	Temperature	3
XV	Geokon 4200A-2 Vibrating Wire	Temperature	16

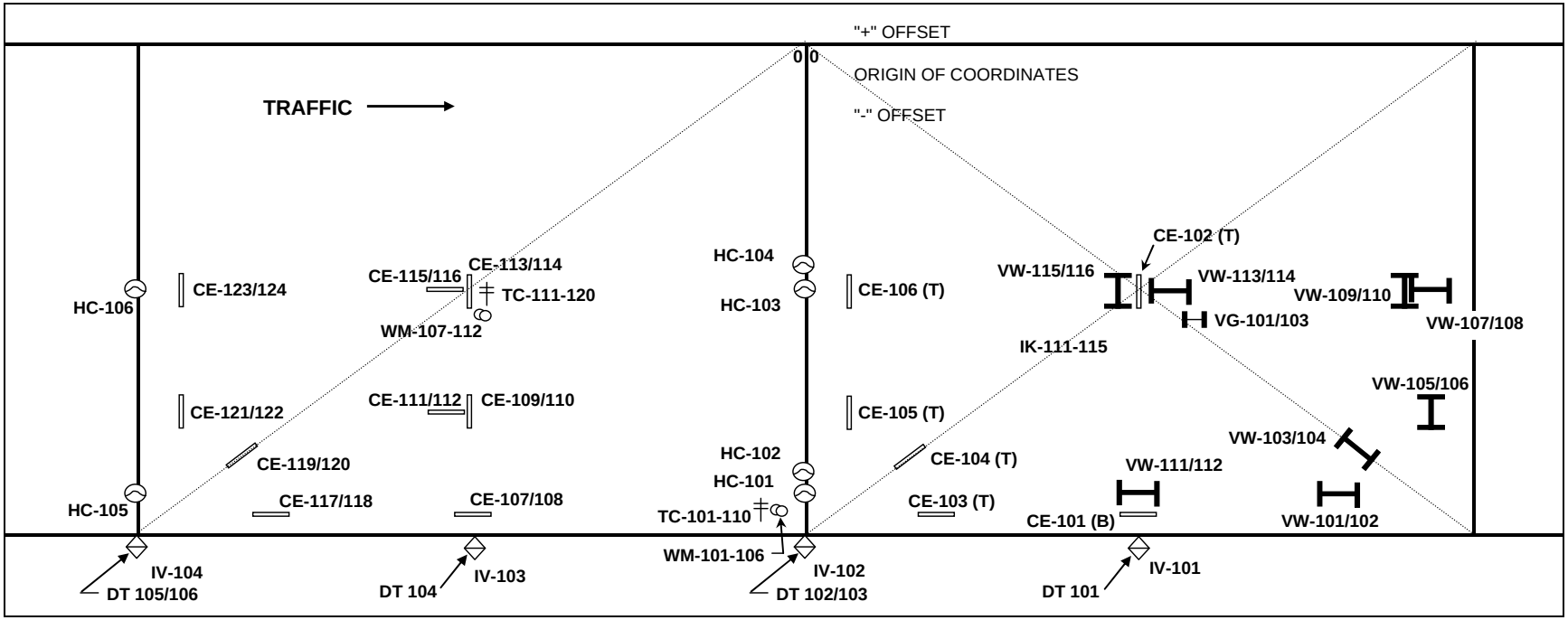

Figure 3. Sensor layout in Cell 53.

Early Testing

It is now realized that characterizing the early-age behavior of a concrete pavement can be paramount in understanding its long-term performance. The presence of "built-in curl and warp" can significantly affect how the slab response to dynamic vehicle loads. Another area of interest is in developing further understanding of how concrete maturity relates to stresses in the slabs, such that the timing of joint formation might be better predicted. To accomplish these objectives, intensive early age testing was carried out on Cell 53.

Warp and Curl Measurements

To characterize the built-in curl and warp of the new slabs, the a recently developed laser profiling device called the PALPS (Portable Automated Laser Profile System) was used over several of the panels in each test cell and shoulder to measure the slab profile during the first 72 hours of curing. The measurement locations are shown in Figure 4. The origin of all measurements was 6 in. from the pavement joint and 6 in. from the pavement edge as shown in the figure. Two longitudinal measurements and two diagonal measurements were then taken every 24 hours for the first four days after the pavement was poured.

The measured warp and curl for each measurement path is shown in Figures 5 through 8. At each measurement location, the measured warp and curl did not significantly change over the first four days. The built in warp and curl along measurement path G appears to be convex or "curled down." Along path H, the slab appears to be concave or "curled up." The initial drop in displacement at 1 ft in Figure 6 is from a surface sensor. Along path L, the slab is also "curled up." The drop in displacement at 9 ft is also from a surface sensor. The slab along path M is also "curled up" and also has a drop in displacement at 3 ft due to a surface sensor.

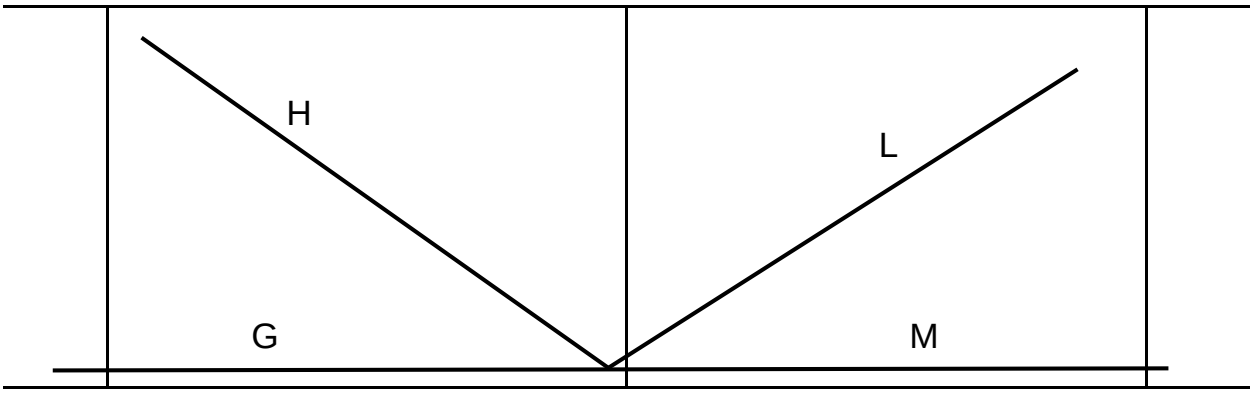

Figure 4. PALPS measurement paths.

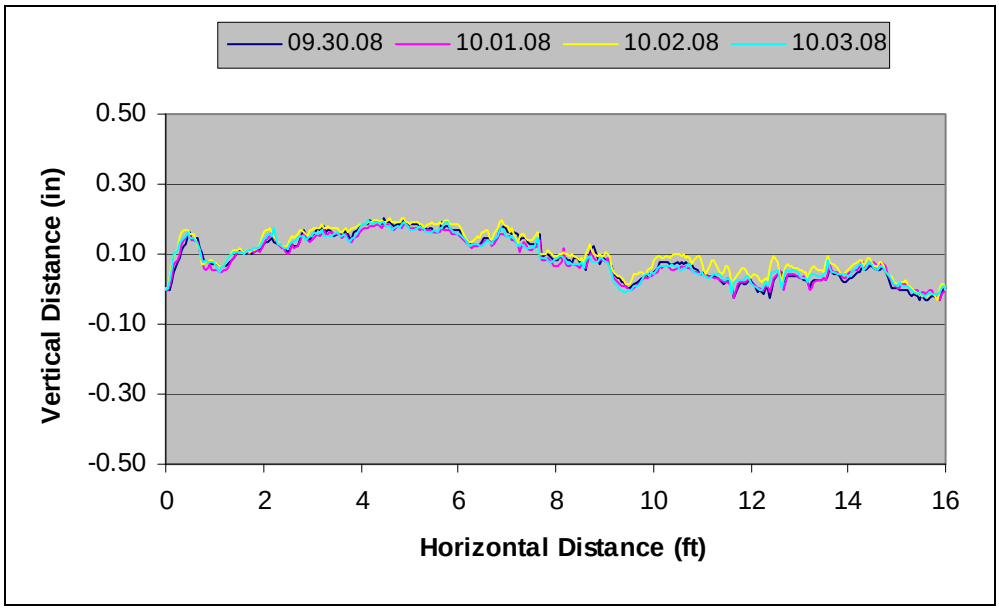

Figure 5. PALPS measurement along path G.

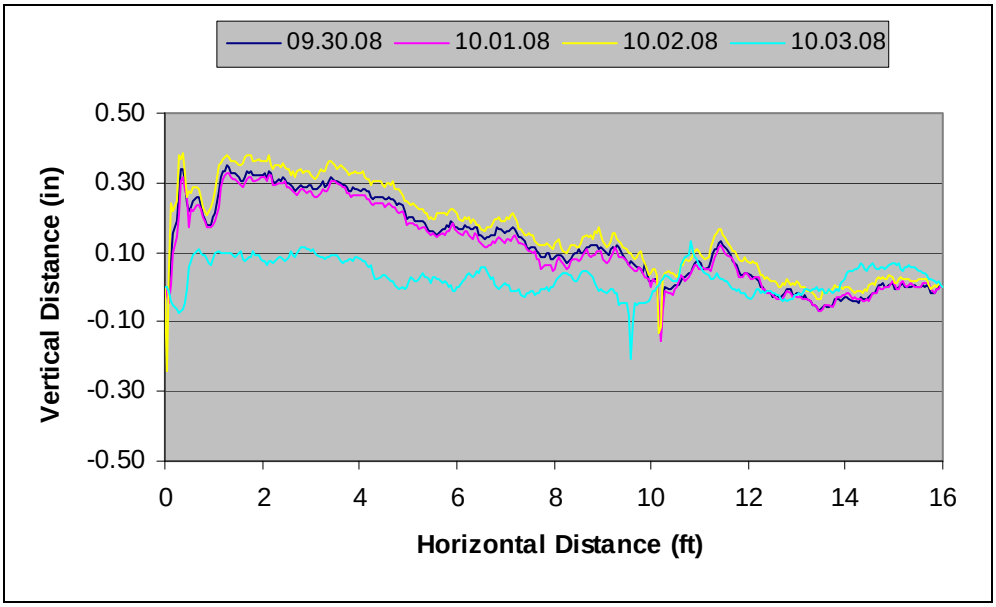

Figure 6. PALPS measurement along path H.

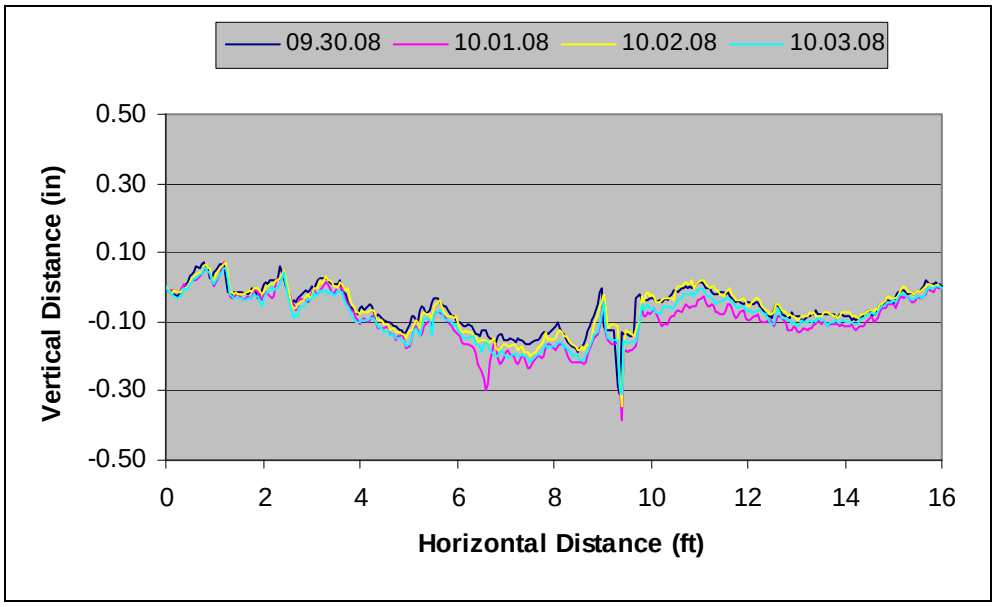

Figure 7. PALPS measurement along path L.

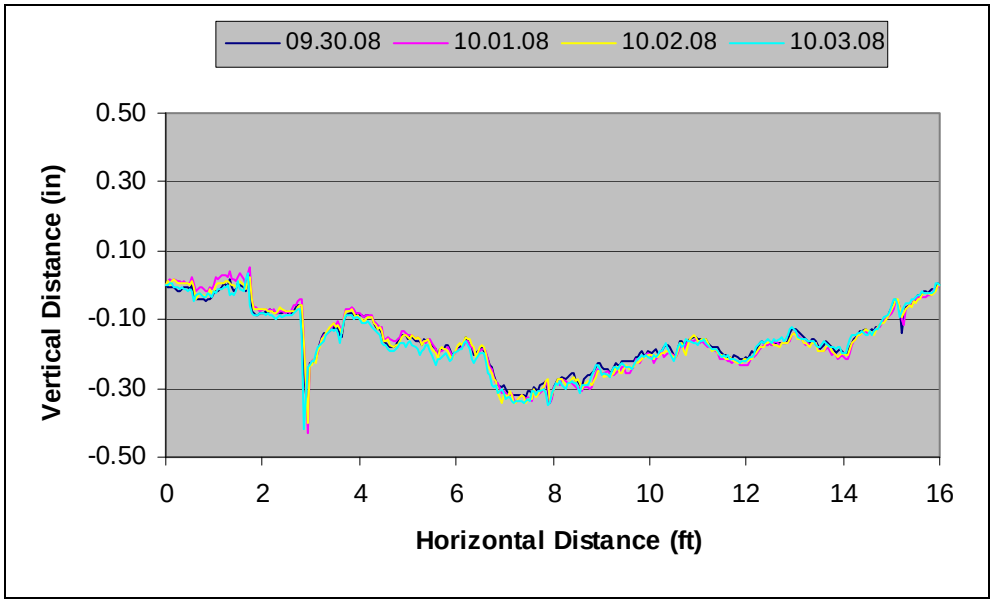

Figure 8. PALPS measurement along path M.

Concrete Maturity

Two maturity "trees" with sensors at 5 depths through the slab were installed in this test cell. Both "trees" were installed approximately at mid panel with one 6 in. (Edge) from the pavement edge and the other 36 in. (Mid) from the edge. Of the ten maturity sensors installed, only four survived construction. Figure 9 show the maturity at four different locations in the slab. As

shown in the figure, the maturity at 36 in. from the pavement edge was higher than at 6 in. and the maturity near the bottom of the pavement was higher than near the top.

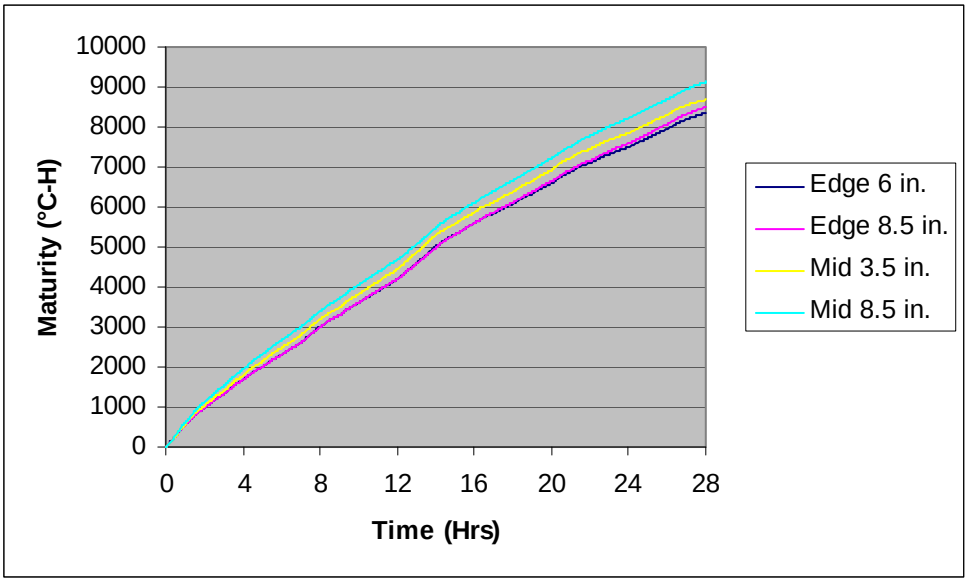

Figure 9. Maturity versus time data from maturity sensors.

SUMMARY AND CONCLUSIONS

MnROAD Low Volume Road test Cell 53 was built to represent Mn/DOT's current Long-Life or High Performance Concrete Pavement design. The primary objective of this research study is to develop an improved service life prediction model for Mn/DOT's current 60-year concrete pavement designs. Secondary objectives include understanding the behavior of these pavements with regards to maturity, slab warp and curl, and thermal expansion. These objectives will be accomplished through extensive testing of materials during construction, and conducting seasonal load response testing under controlled loads of an instrumented concrete pavement test cell (Cell 53) built to Mn/DOT's current 60-year design standards. Load response testing of traditional designs constructed in MnROAD Phase I will be used in the development of the improved life prediction model.

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Appendix A: MnROAD Test Cells

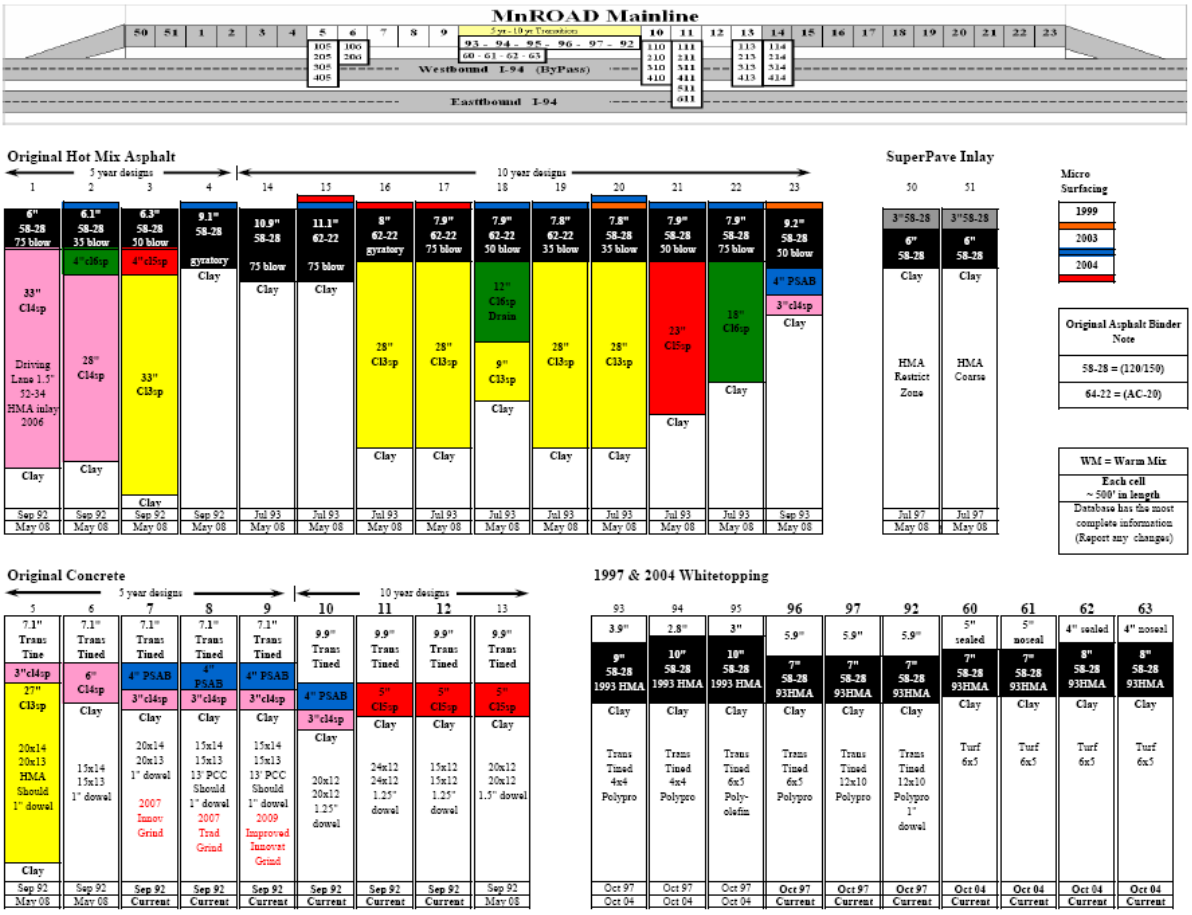


Figure A1. Phase I MnROAD Mainline test sections.

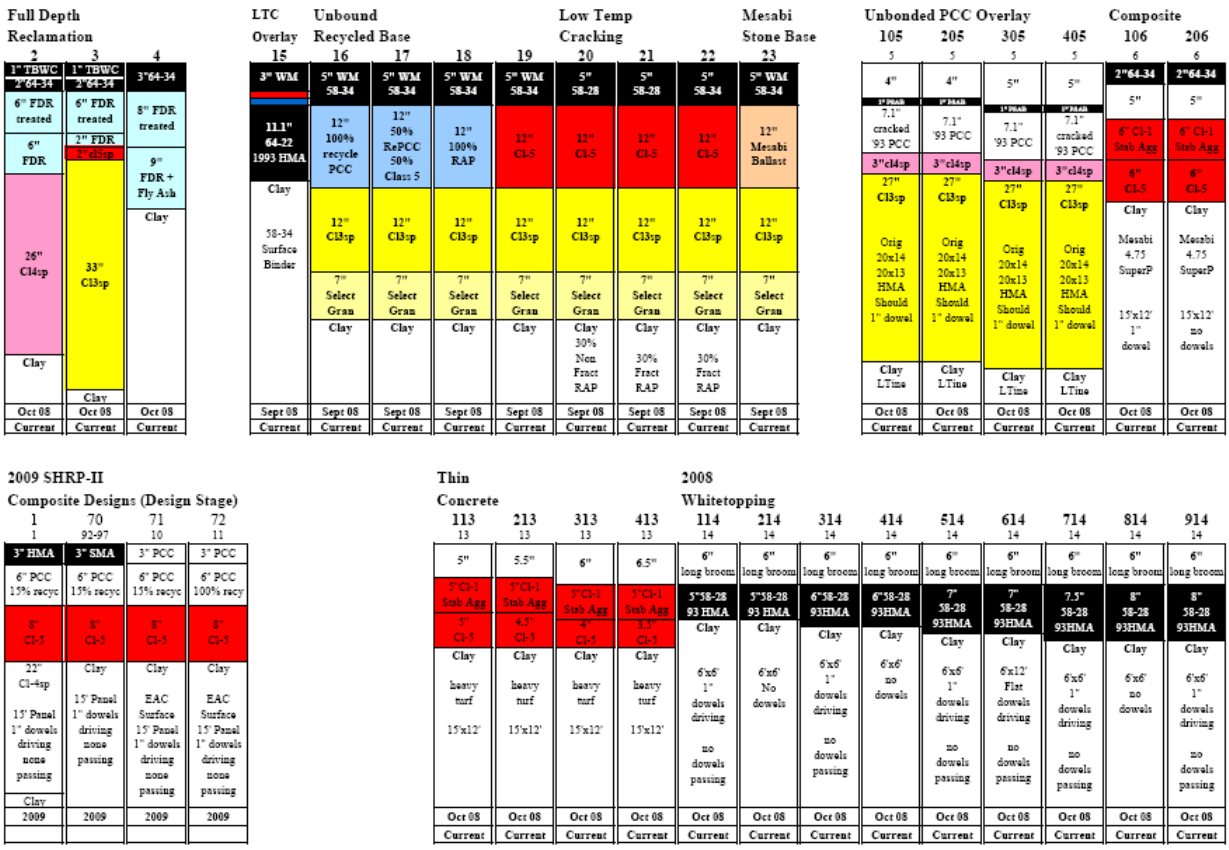


Figure A2. Phase II MnROAD Mainline test sections.

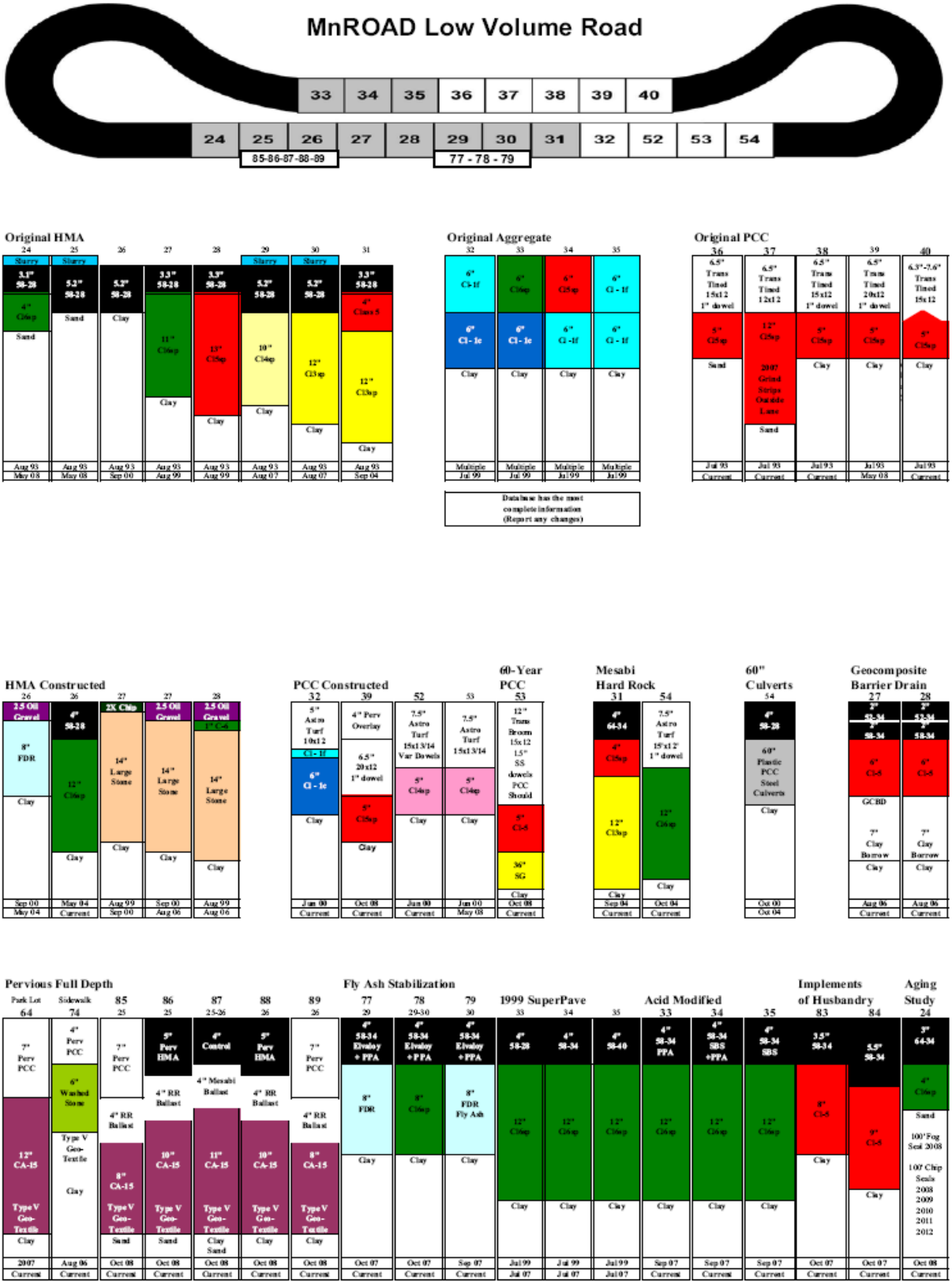


Figure A3. MnROAD Low Volume Road (LVR).

Appendix B: Work Plan

PROPOSED WORKPLAN FOR SIXTY-YEAR DESIGN CONCRETE PAVEMENT – PERFORMANCE MODEL DEVELOPMENT

Principal Investigator:

Name: Ryan Rohne, E.I.T
Department: Minnesota Department of Transportation
Office of Materials and Road Research
Title: Research Project Engineer
Address: 1400 Gervais Avenue, Maplewood, MN 55109
Phone : 651 366 5449
Fax: 651 366 5461
E-mail: Ryan.Rohne@dot.state.mn.us

Proposal Abstract

Due to increased traffic congestion and reduced highway construction budgets, emphasis is now being placed on designing and constructing longer life pavements. For concrete pavements, the new goal for urban high volume highways in Minnesota is toward a 60-year design life. Using the current Mn/DOT design guide for concrete pavement design (based on 1981 AASHTO design guide), Mn/DOT is now constructing what is believed to be 60-year design concrete pavements. However, during the design process, both the traffic prediction and service life of the concrete pavement is being extrapolated far beyond the available charts in the current design method.

The primary objective of this research study is to develop an improved service life prediction model for Mn/DOT's current 60-year concrete pavement designs. Secondary objectives include understanding the behavior of these pavements with regards to maturity, slab warp and curl, and thermal expansion. These objectives will be accomplished through extensive testing of materials during construction, and conducting seasonal load response testing under controlled loads of an instrumented concrete pavement test cell (MnROAD LVR Cell 53) built to Mn/DOT's current 60-year design standards. Load response testing of traditional designs constructed in MnROAD Phase I will be used in the development of the improved life prediction model.

Anticipated duration of research project: 54 Months

Total Budget Direct & Indirect Cost: $113300
Budget details (Direct & Indirect Costs):

Salaries: $106000
Supplies: Office Supplies & Instrumentation = $7300

Matching Funds: To facilitate the research process Mn/DOT will construct a Mn/DOT 60-year design concrete pavement test cell at MnROAD (on the low volume loop portion) for $43,113.

Research Matrix & Methods

- Construct and instrument a concrete pavement test cell based on Mn/DOT current 60-year design standards.
- Collect and analyze sensor measurements including maturity, dynamic and environmental strain, displacement, slab warp and curl during and shortly after construction.
- On a monthly basis, collect and analyze dynamic and environmental strain, displacement, and slab warp and curl measurements.
- Frequently (at least seasonally) monitor surface distress and ride quality of the test cell for a 4-year period.
- After 2 years of traffic application, develop preliminary life prediction models based on available MnROAD data. Refine load response testing schemes if necessary.
- After 4 years of traffic has been applied, complete a life prediction model and prepare, publish, and present research papers and final reports based on the findings.

Required Instrumentation

To perform the proposed measurements and monitoring, the following instrumentation would be required: dynamic and environmental strain sensors, thermocouples, slab moisture sensors, maturity dataloggers, invar elevation reference rods, and frost pins.

Work plan

1. **Task 1**

   Test cell layout, instrumentation, and data collection plan development

   This task involves includes determining the overall geometric layout and structural layers of the test cell, and the placement of the instrumentation to accomplish the research study objectives. Construction materials and specifications will also be developed.

   The geometric layout of the test cell will follow current Mn/DOT standards for 60-year design concrete pavements.

   The instrumentation plan will include detailed information on the geometric location of the sensors, and their function in achieving the study objectives. Data collection frequency will also be outlined and related to research objectives.

   The test cell load response data collection plan will be developed based on the research objectives and standard MnROAD facility operation practices. The plan will outline the suggested schedule of load response and non-destructive testing, distress survey, and ride quality measurement events.

   Deliverables for Task 1: Powerpoint presentation and a summary report detailing the following:

- Geometric layout and structural layers details for test Cell 53
- A copy of the construction plans and special provisions to the specifications
- Layout of instrumentation
- Performance monitoring plan

Duration of Task 1: September 2007 to March 2008

2. **Task 2**
   Literature review on long life concrete pavement life prediction models
   This includes an investigation of the current research initiatives and historical results related to the development of life prediction models for long life concrete pavements. Associated subject areas in the investigation will include maturity, dynamic and environmental strain, displacement, slab warp and curl, joint load transfer efficiency, joint faulting, and surface distress and ride quality of long life concrete pavements.

   Based on the findings of the investigation, final research objectives may be adjusted so as to not to repeat the study of well established parameters related to long life concrete pavements. A summary report of the investigation will be prepared and disseminated.

   Deliverables for Task 2: Powerpoint presentation and summary report of the literature review investigation, including recommendations for adjusting preliminary research objectives.

   Duration of Task 2: November 2007 to December 2007, November 2008 to February 2009.

3. **Task 3**
   Test section construction report
   This report will discuss the construction process and document the results from material tests performed during or shortly after the construction. The report will also include the results from maturity testing and early slab warp and curl measurements. As-built geometric and layer thickness data will also be included in the report and input into the MnROAD database.

   Deliverables for Task 3: Powerpoint presentation and construction report. Excel spreadsheets with updated cell and instrumentation data for input into the MnROAD database.

   Duration of Task 3: Beginning 12 weeks after the date of paving, and ending 12 weeks later.

4. **Task 4**
   Data Collection and Analysis
   Based on the data collection plan developed in Task 1, data will be collected, organized, and analyzed to characterize the load response of test Cell 53. Similar data will be collected from other MnROAD concrete pavement test cells in a effort to compare to the

results from Cell 53. Data organization (including insertion into the MnROAD database) and analysis will be done on a timely basis.

Deliverables for Task 4: Excel spreadsheets with data and analysis results from this task for input into the MnROAD database.

Duration of Task 4: Beginning 1 month after the date of traffic application on test Cell 53, and ending 36 months later.

5. **Task 5**
   Develop Preliminary Life Prediction Model
   Based on the analysis results from Task 4, a preliminary life prediction model for Mn/DOT's 60-year concrete pavement design will be developed. Based on the model developed, adjustments to the remaining data collection scheme will be invoked. An interim report will be written outlining the preliminary model that was developed.

   Deliverables for Task 5: Powerpoint presentation and interim research paper/report. A modified data collection scheme will be implemented (if necessary).

   Duration of Task 5: Beginning 2 years after the date of traffic application on test Cell 53 and ending 16 weeks later.

6. **Task 6**
   Develop Final Life Prediction Model and Summarize Other Performance Observations
   Using additional data collected since the completion of Task 5, a final life prediction model will be developed. Findings related to secondary research objectives will also be disseminated. This may include a forensic investigation and report of the performance or characteristics of test Cell 53.

   Deliverables for Task 6: Powerpoint presentations, a research paper/report describing the life prediction model developed, and paper(s) summarizing the findings of secondary research objectives.

   Duration of Task 6: Beginning 3 years after the date of traffic application on test Cell 53 and ending 6 months later.

7. **Task 7**
   Technical Brief, Implementation Strategies Report
   Based on recommendations of the Technical Advisory Panel, a four page technical brief, summarizing the findings of the study, will be prepared for general distribution. A brief report will also be prepared outlining suggested implementation strategies for the findings of the study.

   Deliverables for task 8: A technical brief and a brief report on implementation strategies.

Appendix C: Concrete Mix Design

JMF 08-033

REQUEST FOR CONCRETE MIX APPROVAL

Requested by: Tom Schmit — Phone: 651-319-2369
Firm Name: Aggregate Industries
Agency Enginner/Inspector: _____ — S.P.: 8680-157

Proposed Aggregate Sources

	CA #1		CA #2		CA #3		Sand	
Pit Number	171041		171041		119004		119004	
Pit Name	Agg. Ind.		Agg. Ind.		Agg. Ind.		Agg. Ind.	
Nearest Town	Elk River		Elk River		Lakeville		Lakeville	
Size	#4		#67		#9		C. Sand	
Sp. G. & Abs. (Provided by MN/DOT)	2.75	0.009	2.69	0.013	2.69	0.014	2.64	0.008

Proposed Cementitious Sources

	Cement	Fly Ash	Other
Manufacturer/Distributor	Lafarge	Head Waters Resources	
Mill/Power Plant	Davenport, IA	Coal Creek, ND	
Type/Class	I/II	C/F	
Specific Gravity	3.15	2.55	

Proposed Mix Designs

MN/DOT Mix Number	3A41HPC
Water (lbs/C.Y.)	205
Cement (lbs/C.Y.)	410
Flyash (lbs/C.Y.)	175
Other Cementitious (lbs/C.Y.)	0
W/CM Ratio	0.035
Sand (Oven Dry, lbs/C.Y.)	1123
CA #1 (Oven Dry, lbs/C.Y.)	627
CA #2 (Oven Dry, lbs/C.Y.)	1154
CA #3 (Oven Dry, lbs/C.Y.)	224
Maximum Slump	3"
% Air Content	7.00% ± 1.5%
Admix. # 1 (oz/100 # CM)	Sika AIR as needed
Admix. # 2 (oz/100 # CM)	Sikament 686 0-8.0 oz/cwt
Admix. # 3 (oz/100 # CM)	

The above mixes are approved for use, contingent upon satisfactoiry site perfromance and continuous acceptability of all materials sources, by:

JK Hart — Concrete Engineering Specialist — 5/21/08 — Date

Comments: Mix is designed for the materials at Agg. Ind. Rogers Plant (#2)

3A41HPC.xls
Job Mix Formula

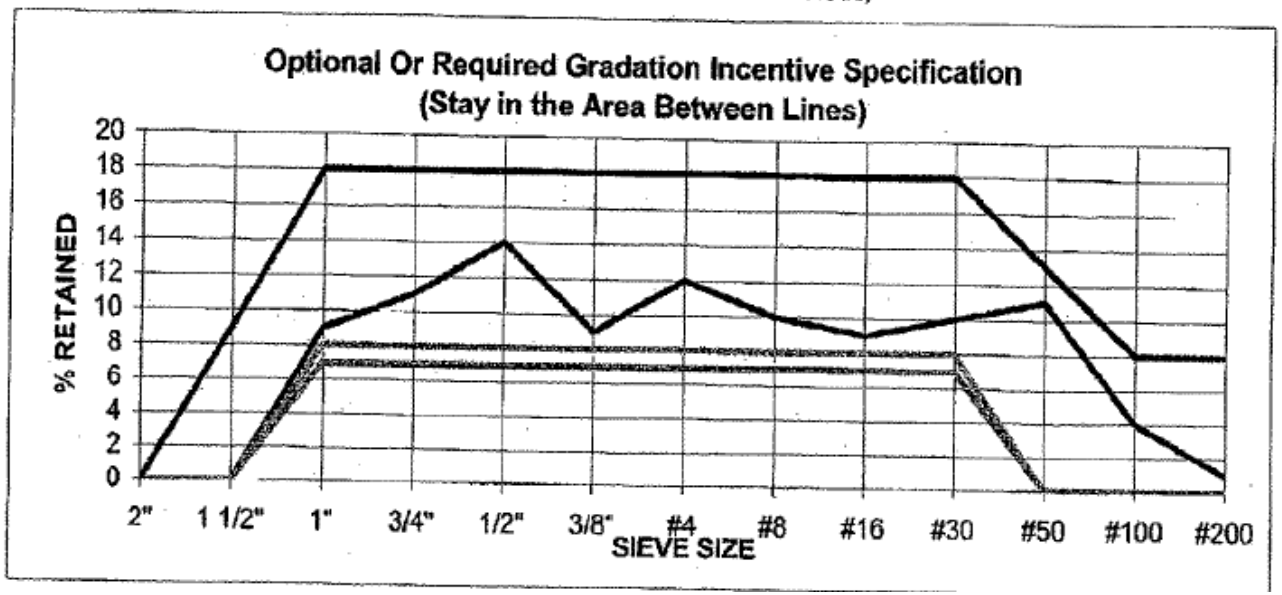
SP 8680-157
JMF08-033

	CA #1	CA #2	CA #3	CA #4	FA #1	FA #2
AGGREGATE SIZE	E.R. #4	E.R. #67	L.V. #9	L.V. Sand		
PROPORTION, %	20.00%	37.00%	7.00%	36.00%		
2"	100.0	100.0	100.0	100.0		
1 1/2"	100.0	100.0	100.0	100.0		
1"	53.9	100.0	100.0	100.0		
3/4"	6.7	97.1	100.0	100.0		
1/2"	0.1	61.3	100.0	100.0		
3/8"	0.1	38.5	100.0	100.0		
#4	0.0	6.5	96.0	100.0		
#8	0.0	0.0	27.9	92.0		
#16	0.0	0.0	2.6	72.0		
#30	0.0	0.0	0.5	44.0		
#50	0.0	0.0	0.5	14.0		
#100	0.0	0.0	0.0	2.0		
#200	0.0	0.0	0.0	0.0		

TOTAL % PASSING	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
100.00%				
100	± 5	95	100	0
100	± 5	95	100	0
91	± 5	86	96	9
80	± 5	75	85	11
66	± 5	61	71	14
57	± 5	52	62	9
45	± 5	40	50	12
35	± 4	31	39	10
26	± 4	22	30	9
16	± 4	12	20	10
5	± 3	2	8	11
1	± 2	0	3	4
0.0	1.6% max	0.0	1.6	1

Workability Factor 35
(% passing #8)

Coarseness Factor 66
(% retained above 3/8" / % retained above #8)



State of Minnesota Department of Transportation
Aggregates Test Report for Composite Materials

OCT 27 2008

Office of Materials
1400 Gervais Avenue
Maplewood, MN 55109

10/27/2008

Date Sampled: 10/16/2008 Usage: PAVEMENT Billing Agency: Project Number: 8680-157 Project Engineer: BOB RABINE
Date Received: 10/17/2008 Submitter: POSUSTA, K. Sampled From: BELT Plant Name: Agg Ind 2 Rogers

Test Procedures: AASHTO T-19, T-21, T-27(M), T-30(M), T-84(M), T-85(M), T-96(M), T-104(M), T-113(M), T-176(M), T-248(M), T-304 Method A, ASTM C123, ASTM C535, ASTM D3042, ASTM D4791(M), Litho(MP), Micro Deval(MP), Percent Crushing(MP), M = MN/DOT Modified, MP = MN/DOT Procedures

Composite ID: C08-CO-2819	ID: CO-CA08-1049 Field ID: 39A=6Q Propor: 7.00 Pit #: 19004 Pit Name: Agg Ind - La		ID: CO-CA08-1050 Field ID: 39A=6Q Propor: 36.00 Pit #: 19004 Pit Name: Agg Ind - La		ID: CO-CA08-1056 Field ID: 39A = 6Q Propor: 20.00 Pit #: 71041 Pit Name: Agg Ind - Elk		ID: CO-CA08-1057 Field ID: 39A = 6Q Propor: 37.00 Pit #: 71041 Pit Name: Agg Ind - Elk		ID: Field ID: Propor: Pit #: Pit Name:		ID: Field ID: Propor: Pit #: Pit Name:		Grad. Spec. : JMF08 Class. : JMF08-033 Quality Spec. :			
% Passing Sieve:	Lab Test	Field Test	Lab Test	Field Test	Lab Test	Field Test	Lab Test	Field Test	Lab Test	Field Test	Lab Test	Field Test	Lab Comp	Field Comp	Spec Limits Low	Spec Limits High
37.5mm (1 1/2")	100	100	100	100	100	100	100	100					100	100	95	100
31.5mm (1 1/4")	100	100	100	100	99	100	100	100					100	100		
25.0mm (1")	100	100	100	100	88	84	100	100					*98	*97	86	96
19.0mm (3/4")	100	100	100	100	23	25	98	97					84	84	75	85
16.0mm (5/8")	100	100	100	100	10	10	90	90					78	78		
12.5mm (1/2")	100	100	100	100	7	7	69	72					70	71	61	71
9.5mm (3/8")	100	100	100	100	5	6	46	49					61	62	52	62
4.75mm (#4)	97	97	100	100	2	3	7	9					46	47	40	50
2.36mm (#8)	21	23	94	94									35	35	31	39
2.00mm (#10)	11		90										33			
1.18mm (#16)	3	3	76	76									28	28	22	30
600um (#30)	1	1	48	47									17	17	12	20
425um (#40)	1		29										11			
300um (#50)	0	0	14	13									5	5	2	8
150um (#100)	0	0	2	2									1	1	0	3
75um (#200)	0.1	0.1	0.3	0.4									0.1	0.1	0.0	1.6

T-Clyne

Concrete Quality Analysis for C08-CO-2819

19004	CO-CA08-1049	CO-CA08-1050	Composite Value	Specification Value Low	High		
% Shale in Sand	***0.0	***0.0	0.0	0	2.5	Quality Specification:	3126.2C3

71041	CO-CA08-1056	CO-CA08-1057	Composite Value	Specification Value Low	High		
%Total Shale +1/2"	0.0	0.0	0.0		0.4	Quality Specification:	3137.2D3C
%Total Shale +4	***0.0	0.0	0.0		0.7		
% Sandstone	0.1	0.3	0.2				
% Carbonate	4.0	0.7	1.9		30		
% Iron Oxide	0.40	0.00	0.15				
% Unsound Chert	0.01	0.00	0.00				
% Soft Rock	0.3	0.2	0.2		2.5		
%Spall,SRock&Cball	0.7	0.2	0.4		3.5		
%Total Spall +1/2"	0.4	0.0	0.2		1.0		
%Total Spall +4	0.4	0.0	0.1		1.5		

a Assumed Value
* Value does not meet Spec
– Value out of Field Lab Tolerance
*** Trace (0.00 - 0.05) Detected

☐ Meets Requirements
☒ Does Not Meet Requirements
☐ For Info Only
☐ Incentive/Disincentive

Comments:

Copies To: Concrete Engineer
Metro Inspection
Metro Materials Engineer
Resident Engineer: DAN PENN
PROJ ENGR- T. CLYNE

Charge: 2 - 1012
2 - 1013
2 - 1014
2 - 1029

Report Approved By:

David B. Bahn

10/27/2008 8:03

Appendix D: Concrete Tickets

AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO [illegible] ITS STRENGTH. ANY WATER ADDED

EXPOSED CONCRETE TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT [illegible] ENTRAINING BE USED IN ALL EXPOSED CONCRETE PLUS PROPER CURING

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

BURN WARNING: Fresh mixed concrete, cement, mortar or grout may cause skin irritation or severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, wash thoroughly with water and see medical attention if irritation persists. KEEP OUT OF THE REACH OF CHILDREN.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
9/29/2008	68504	PCI	3570		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE — MAP PAGE

INSTRUCTIONS:
Prev Truck: Slump: 3
COME IN OFF 37 TO MN ROAD AT
MAIN GATE LOOK FOR PCI EMPLOYEE
TO DIRECT FROM THERE.

ORDERED BY — JOB 126

DRIVER NAME	ZONE	START JOB
BALKO, TODD	0	13:10

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	55	9.25	9.25	CY	0.00	0.00
SIF	STATE INSPECTION	1	9.25	9.25	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	1	LD	0.00	0.00

1:30 P.M.
7% Air
slump 2 3/4"

CERTIFICATE OF COMPLIANCE

PLANT #	CUSTOMER	JOB #
ROGERS PLANT 2	PCI	512153

DATE	SP / PO	REF / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.		
9/29/2008	SP 8680-157	001092	3A41HPC1	408	9.25	9.25	TOTAL	0.00

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.010	0.013	627	8	635	-1.9	633	5860	5940	1.4%
#9 Lkvl	119004 Lkvl	0.040	0.014	224	3	227	5.0	233	2160	2480	14.8%
C. Sand Lkvl	19004 Lkvl	0.038	0.008	1123	9	1132	33.7	1166	10780	10860	0.7%
CA50(#67)E.R.	171041 E.R.	0.019	0.013	1154	15	1169	6.9	1176	10880	10880	0.0%
Holcim I	HOLMC1A			410	0	0	0.0	410	3792	3785	-0.2%
Class C/F Ash	COCUNND			175	0	0	0.0	175	1619	1600	-1.2%
WATER	Water Totals:			205	-35	205	-44.6	160	1330	1316	-1.1%
Sika Air	SIAIR			4	0	0	0.0	4	37	37	0.0%
Sikament 686	SIKA686			6	0	0	0.0	6	324	324	0.0%

South bound
at 6c

Trim Water: -2 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.33
Batch Time: 12:58

Design Water: 1896 lbs
Total Water: 1728 lbs
Water Available to Add: 17 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

MN DOT - CERTIFICATE OF COMPLIANCE

596141

BATCH COPY

RECEIVED BY (legible signature)
X

AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER ADDITIONAL
ITS STRENGTH.

EXPOSED CONCRETE
ACTION OF FREEZING AND THAWING. WE RECOMMEND THAT
APPROPRIATE AIR

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

BURN WARNING
KEEP OUT OF THE REACH OF CHILDREN

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
9/29/2008	68506	PCI	3570		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE

INSTRUCTIONS:
Prev Truck: 408 Slump: 4
COME IN OFF 37 TO MN ROAD AT
MAIN GATE LOOK FOR PCI EMPLOYEE
TO DIRECT FROM THERE.

ORDERED BY:

DRIVER NAME		
MILLER, PAUL D.	0	13:31

1.45
1.50

DESCRIPTION		QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT		
3A41HPC1	MN ROAD HI PERFORMANCE P	55	9.25	18.5	CY	0.00	0.00
SIF	STATE INSPECTION	1	9.25	18.5	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	2	LD	0.00	0.00

CERTIFICATE OF COMPLIANCE

PLANT	SPEC NO.	CUSTOMER	PCI NO.
ROGERS PLANT	2	PCI	512153

DATE	SPEC NO.	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.		
9/29/2008	SP 8680-157	001090	3A41HPC1	403	9.25	18.5	TOTAL	0.00

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.010	0.012	627	8	635	-1.9	633	5860	5940	1.4%
#9 Lkvl	119004 Lkvl	0.040	0.014	224	3	227	5.8	233	2160	2300	6.5%
C. Sand Lkvl	19004 Lkvl	0.038	0.008	1123	9	1132	33.7	1166	10780	10840	0.6%
CRSB(#67)E.R.	171041 E.R.	0.019	0.013	1154	15	1169	6.9	1176	10880	10940	0.6%
Holcim I	HOLNCIA			410	0	0	0.0	410	3792	3785	-0.2%
Class C/F Ash	COCUNND			175	0	0	0.0	175	1619	1630	0.7%
WATER	Water Totals			205	-35	205	-44.6	160	1253	1242	-0.9%
Sika Air	SIAIR			4	0	0	0.0	4	37	37	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	216	219	1.4%

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 13:20

Design Water: 1896 lbs
Total Water: 1654 lbs
Water Available to Add: 27 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

MN DOT - CERTIFICATE OF COMPLIANCE

596143

BATCH COPY

RECEIVED BY (legible signature)
X

AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

EXPOSED CONCRETE TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT 6% ± 1½% AIR ENTRAINING BE USED IN ALL EXPOSED CONCRETE, PLUS PROPER CURING

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

BURN WARNING: Freshly mixed concrete, cement, mortar or grout may cause skin irritation, severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, flush thoroughly with water and see medical attention if irritation persists. KEEP OUT OF THE REACH OF CHILDREN.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
9/29/2008	68510	PCI	3570		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE

MAP PAGE:

INSTRUCTIONS:
Prev Truck: 403 Slump: 3
COME IN OFF 37 TO MN ROAD AT MAIN GATE LOOK FOR PCI EMPLOYEE TO DIRECT FROM THERE.

ORDERED BY:

ARRIVAL JOB: 150

START POUR: 215

FINISH POUR:

DRIVER NAME	ZONE	SCH. ARR.
PROELL, GARY	0	13:54

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	55	9.25	27.75 CY		0.00	0.00
SIF	STATE INSPECTION	1	9.25	27.75 CY		0.00	0.00
FUEL	FUEL SURCHARGE	1	1	3 LD		0.00	0.00

8.0% slump 3" 2:18 9 GAL ADD 1 2:24 Rich

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.
ROGERS PLANT	2	PCI	512153

TAX: 0
SUB TOTAL: 0
TRUCK TIME:
OTHER:
TOTAL: 0.00

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
9/29/2008	SP 8680-157	001092	3A41HPC1	178	9.25	27.75

Ingredient	Source	MCFAir	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.010	0.013	627	8	635	-1.9	633	5860	5960	1.7%
#9 Lkvl	119004 Lkvl	0.040	0.014	224	3	227	5.8	233	2160	2220	2.8%
C. Sand Lkvl	19004 Lkvl	0.038	0.008	1123	9	1132	33.7	1166	10780	11000	2.0%
CA50(#67)E.R.	171041 E.R.	0.019	0.013	1154	15	1169	6.9	1176	10880	10920	0.4%
Holcim I	HOLMCIA			410	0	0	0.0	410	3792	3790	-0.1%
Class C/F Ash	COCUNND			175	0	0	0.0	175	1619	1595	-1.5%
WATER	Water Totals			205	35	205	-44.6	160	1253	1236	-1.4%
Sika Air	SIAIR			4	0	0	0.0	4	37	37	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	216	216	0.0%

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 13:42

Design Water: 1896 lbs
Total Water: 1648 lbs
Water Available to Add: 27 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

MN DOT - CERTIFICATE OF COMPLIANCE

596146

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By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

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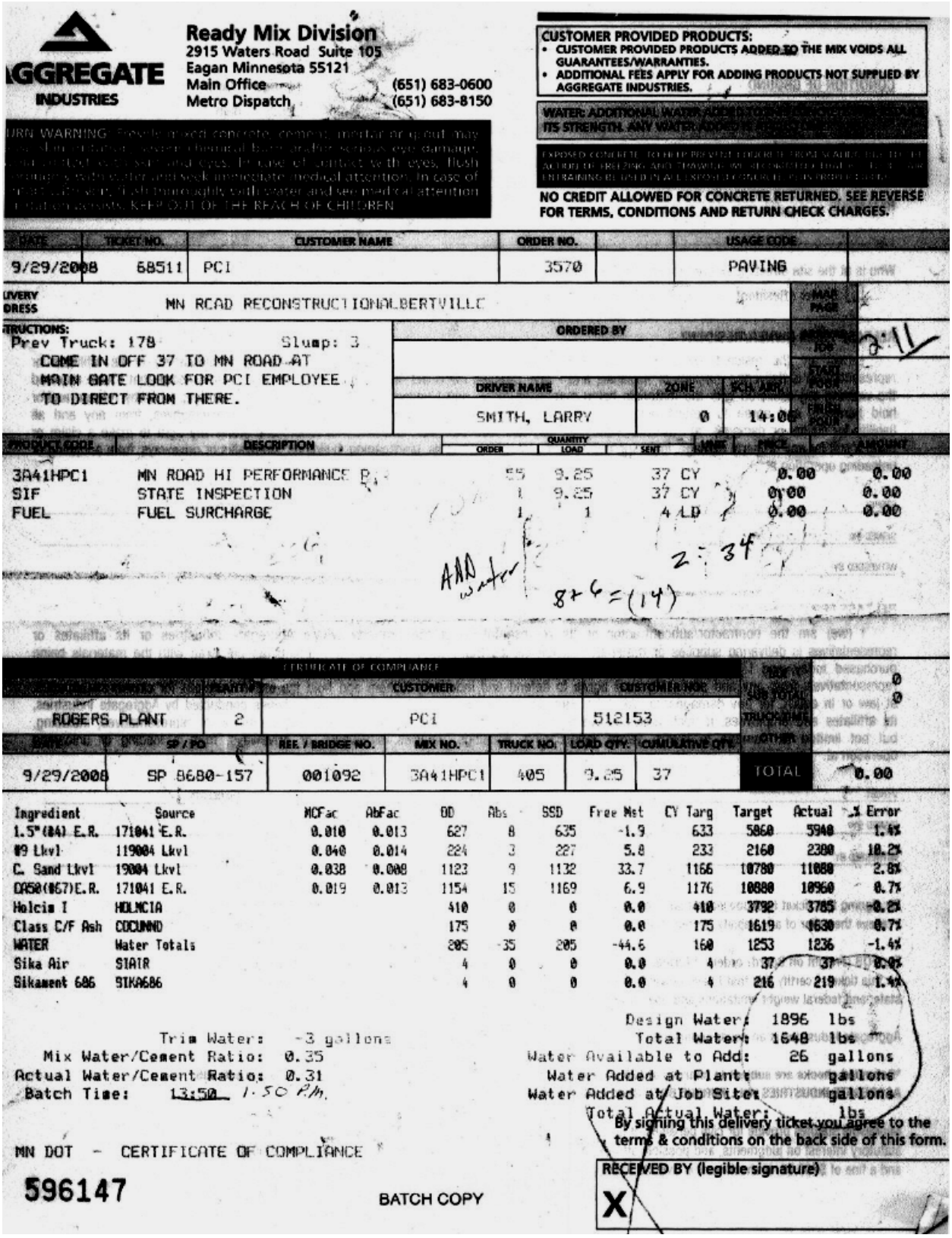

AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
9/29/2008	68511	PCI	3570		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE

MAP PAGE

INSTRUCTIONS:
Prev Truck: 178 Slump: 3
COME IN OFF 37 TO MN ROAD AT MAIN GATE LOOK FOR PCI EMPLOYEE TO DIRECT FROM THERE.

ORDERED BY

DRIVER NAME	ZONE	SCHEDULED
SMITH, LARRY	0	14:00

ARRIVED JOB 2:11
START POUR
FINISH POUR

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	55	9.25	37	CY	0.00	0.00
SIF	STATE INSPECTION	1	9.25	37	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	4	LD	0.00	0.00

Add water 2:34
8+6=(14)

CERTIFICATE OF COMPLIANCE

PLANT	CUSTOMER	CUSTOMER NO.
ROGERS PLANT 2	PCI	512153

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
9/29/2008	SP 8680-157	001092	3A41HPC1	405	9.25	37

TAX
TOTAL
TRUCK
OTHER
TOTAL 0.00

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(84) E.R.	171041 E.R.	0.010	0.013	627	8	635	-1.9	633	5860	5940	1.4%
#9 Lkvl	119004 Lkvl	0.040	0.014	224	3	227	5.8	233	2160	2380	10.2%
C. Sand Lkvl	19004 Lkvl	0.038	0.008	1123	9	1132	33.7	1166	10780	11088	2.8%
CR50(#67)E.R.	171041 E.R.	0.019	0.013	1154	15	1169	6.9	1176	10880	10960	0.7%
Holcim I	HOLNCIA			410	0	0	0.0	410	3792	3785	-0.2%
Class C/F Ash	COCUNND			175	0	0	0.0	175	1619	1630	0.7%
WATER	Water Totals			205	-35	205	-44.6	160	1253	1236	-1.4%
Sika Air	SIAIR			4	0	0	0.0	4	37	37	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	216	219	1.4%

Design Water: 1896 lbs
Total Water: 1648 lbs
Water Available to Add: 26 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 13:50 1:50 PM.

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596147

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

BURN WARNING: Fresh, mixed concrete, cement, mortar or grout may cause skin irritation, severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, flush thoroughly with water and see medical attention if irritation occurs. KEEP OUT OF THE REACH OF CHILDREN.

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO [illegible] REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S [illegible]

EXPOSED CONCRETE TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT [illegible] CONTAINING AT LEAST 6% AIR ENTRAINED CONCRETE FOR PROTECTION.

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
9/29/2008	68514	PCI	3570		PAVING	

DELIVERY ADDRESS MN ROAD RECONSTRUCTION ALBERTVILLE — **MAP PAGE**

INSTRUCTIONS:
Prev Truck: 405 Slump: 3
COME IN OFF 37 TO MN ROAD AT MAIN GATE LOOK FOR PCI EMPLOYEE TO DIRECT FROM THERE.

ORDERED BY — **ARRIVED JOB** — **START POUR** — **FINISH POUR**

DRIVER NAME	ZONE	SCH. ARR.
NICKENS, JELLY	0	14:20

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	55	9.25	46.25	CY	0.00	0.00
SIF	STATE INSPECTION	1	9.25	46.25	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	5	LD	0.00	0.00

2:56

CERTIFICATE OF COMPLIANCE

BATCHING PLANT	PLANT #	CUSTOMER	CUSTOMER NO.
ROGERS PLANT	2	PCI	512153

TAX 0
SUB TOTAL 0
TRUCK TIME
OTHER
TOTAL 0.00

DATE	SP / FO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
9/29/2008	SP 8680-157	00109X	3A41HPC1	177	9.25	46.25

Ingredient	Source	MCFac	AbFac	DD	Abs	SSD	Free Wet	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.010	0.013	627	8	635	1.9	633	5860	5980	2.0%
#9 Lkvl	119004 Lkvl	0.040	0.014	224	3	227	5.8	233	2160	2500	15.7%
C. Sand Lkvl	19004 Lkvl	0.038	0.008	1123	9	1132	33.7	1166	10780	10820	0.4%
CA50(#67)E.R.	171041 E.R.	0.013	0.013	1154	15	1169	6.9	1176	10880	11040	1.5%
Holcim I	HOLMCIA			410	0	0	0.0	410	3792	3785	-0.2%
Class C/F Ash	COCUNND			175	0	0	0.0	175	1619	1635	1.0%
WATER	Water Totals			205	35	205	-44.6	160	1291	1286	-0.4%
Sika Air	SIAIR			4	0	0	0.0	4	37	37	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	216	216	0.0%

Trim Water: -2.5 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.32
Batch Time: 14:08

Design Water: 1896 lbs
Total Water: 1698 lbs
Water Available to Add: 21 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

MN DOT - CERTIFICATE OF COMPLIANCE

596150

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

EXPOSED CONCRETE: TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT [illegible] TO BE AIR ENTRAINING BE USED IN ALL EXPOSED CONCRETE, PLUS PROPER CURING.

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

BURN WARNING: Freshly mixed concrete, cement, mortar or grout may cause skin irritation, severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, flush thoroughly with water and see medical attention if irritation persists. KEEP OUT OF THE REACH OF CHILDREN.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
9/29/2008	68516	PCI	3570		PAVING	

DELIVERY ADDRESS	MN ROAD RECONSTRUCTION/ALBERTVILLE	MAP - PAGE	
INSTRUCTIONS: Prev Truck: 177 Slump: 5 COME IN OFF 37 TO MN ROAD AT MAIN GATE LOOK FOR PCI EMPLOYEE TO DIRECT FROM THERE.	ORDERED BY	ARRIVAL JOB	254
	DRIVER NAME: PTONK, RON / ZONE: 0 / SCH. ARR.: 14:4	START POUR	
		FINISH POUR	

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	55	8.75	55 CY		0.00	0.00
SIF	STATE INSPECTION	1	0.75	55 CY		0.00	0.00
FUEL	FUEL SURCHARGE	1	1	6 LD		0.00	0.00

ADD 10 GAL

3.15

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.	TAX	0
ROGERS PLANT	2	PCI	512153	SUB TOTAL	0
				TRUCK TIME	
				OTHER	

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.	TOTAL	0.00
9/29/2008	SP 8680-157	001092	3A41HPC1	271	8.75	55		

Ingredient	Source	MDFac	ABFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.010	0.013	627	8	635	-1.9	633	5540	5680	2.5%
#9 Lkvl	119004 Lkvl	0.040	0.014	224	3	227	5.8	233	2040	2020	-1.0%
C. Sand Lkvl	19004 Lkvl	0.038	0.009	1123	9	1132	33.7	1166	10200	10180	-0.2%
CR50(#67)E.R.	171041 E.R.	0.019	0.013	1154	15	1169	6.9	1176	10290	10340	0.5%
Holcim I	HOLMCIA			410	0	0	0.0	410	3588	3595	0.2%
Class C/F Ash	COCUMND			175	0	0	0.0	175	1531	1525	-0.4%
WATER	Water Totals			305	75	380	44.6	160	1222	1208	-1.1%
Sika Air	SIAIR			4	0	0	0.0	4	35	35	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	204	210	2.9%

Trim Water: -2.5 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 14:27 2:27

Design Water: 1794 lbs
Total Water: 1598 lbs
Water Available to Add: 22 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

MN DOT - CERTIFICATE OF COMPLIANCE

596152

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

EXPOSED CONCRETE: TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT 6% TO 8% AIR ENTRAINING BE USED IN ALL EXPOSED CONCRETE, PLUS PROPER CURING.

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

BURN WARNING: Freshly mixed concrete, cement, mortar or grout may cause skin irritation, severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, flush thoroughly with water and see medical attention if irritation persists. KEEP OUT OF THE REACH OF CHILDREN.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2008	69171	PCI	6246		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE

MAP PAGE:

INSTRUCTIONS:
Prev Truck: Slump: 4
GO IN MAIN GATE AT MN ROAD,
TAKE LEFT ***READY

ORDERED BY:

ARRIVAL JOB:

START POUR:

FINISH POUR:

DRIVER NAME	ZONE	SCH. ARR.
DOCKHAM, DALE	0	13:17

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	57.01	9.5	9.5	CY	0.00	0.00
01F	STATE INSPECTION	1	9.5	9.5	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	1	LD	0.00	0.00
HOT H20	HOT WATER CHARGE	1	9.5	9.5	CY	0.00	0.00

Air Content 6.2
Slump 3"
Concrete Temp 68°
Air Temp 55°

CELL 53#
LEFT LANE

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.
ROGERS PLANT	2	PCI	512153

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
10/16/2008	SP 8680-157	001092	3A41HPC1	147	9.5	9.5

TAX		0
SUB TOTAL		0
TRUCK TIME		
OTHER		
TOTAL		0.00

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.008	0.013	627	8	635	-3.1	632	6090	6140	2.3%
#9 Lkvl	119004 Lkvl	0.027	0.014	224	3	227	2.9	230	2180	2160	-0.9%
C. Sand Lkvl	19004 Lkvl	0.036	0.008	1123	9	1132	31.4	1163	11050	11100	0.5%
CASO4@67%E.R.	171041 E.R.	0.027	0.013	1154	15	1169	16.2	1185	11260	11220	-0.4%
Holcim I	HOLNCIA			410	0	0	0.0	410	3895	3895	0.0%
Class C/F Ash	COLUMND			175	0	0	0.0	175	1662	1650	-0.7%
WATER	Water Totals			205	-35	205	-47.4	130	1221	1244	1.9%
Sika Air	SIAIR			4	0	0	0.0	4	33	33	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	222	222	0.0%

Scott Middaugh
OT QC

Trim Water: -3.5 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 12:56

1:15pm

Design Water: 1948 lbs
Total Water: 1694 lbs
Water Available to Add: 29 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

$88

MN DOT - CERTIFICATE OF COMPLIANCE

596796

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

BURN WARNING: Freshly mixed concrete, cement, mortar or grout may cause skin irritation, severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, flush thoroughly with water and see medical attention if irritation persists. KEEP OUT OF THE REACH OF CHILDREN.

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

EXPOSED CONCRETE: TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT 6% TO 8% AIR ENTRAINING BE USED IN ALL EXPOSED CONCRETE, PLUS PROPER CURING.

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2008	69172	PCI	6246		PAVING	

DELIVERY ADDRESS MN ROAD RECONSTRUCTIONALBERTVILLE

MAP PAGE

INSTRUCTIONS:
Prev Truck: 147 Slump: 4
GO IN MAIN GATE AT MN ROAD,
TAKE LEFT ***

ORDERED BY

ARRIVAL JOB 13:45

DRIVER NAME	ZONE	SCH. ARR.
UNGER, RON	0	13:3[illegible]

START POUR

FINISH POUR

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	57.01	9.5	19	CY	0.00	0.00
SIF	STATE INSPECTION	1	9.5	19	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	2	LD	0.00	0.00
HOT H20	HOT WATER CHARGE	1	9.5	19	CY	0.00	0.00

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.
ROGERS PLANT	2	PCI	512153

TAX	0
SUB TOTAL	0
TRUCK TIME	
OTHER	
TOTAL	0.00

DATE	SP / PO	REF / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
10/16/2008	SP 8680-157	001092	3A41HPC1	409	9.5	19

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.008	0.013	627	8	635	-3.1	632	6000	5990	-0.3%
#9 Lkvl	119004 Lkvl	0.027	0.014	224	3	227	2.9	230	2160	2140	-1.0%
C. Sand Lkvl	179004 Lkvl	0.036	0.008	1123	9	1132	31.4	1163	11050	11160	1.0%
CA50(#67)E.R.	171041 E.R.	0.027	0.013	1154	15	1169	16.2	1185	11260	11360	0.9%
Holcim I	HOLNCIA			410	0	0	0.0	410	3895	3895	0.0%
Class C/F Ash	COOLNWD			175	0	0	0.0	175	1662	1645	-1.0%
WATER	Water Totals			205	-35	205	-47.4	158	1261	1278	1.3%
Sika Air	SIAIR			4	0	0	0.0	4	33	33	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	222	225	1.4%

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.32
Batch Time: 13:11

Design Water: 1948 lbs
Total Water: 1728 lbs
Water Available to Add: 24 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

1:40pm SB

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MN DOT - CERTIFICATE OF COMPLIANCE

596797

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

BURN WARNING: Freshly mixed concrete, cement, mortar or grout may cause skin irritation, severe chemical burn and/or serious eye damage. Avoid contact with skin and eyes. In case of contact with eyes, flush thoroughly with water and seek immediate medical attention. In case of contact with skin, flush thoroughly with water and see medical attention if irritation persists. KEEP OUT OF THE REACH OF CHILDREN.

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

EXPOSED CONCRETE: TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT 6% TO 8% AIR ENTRAINING BE USED IN ALL EXPOSED CONCRETE. PLUS PROPER CURING.

NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2008	69174	PCI	6246		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONAL BERTHILLE — MAP PAGE:

INSTRUCTIONS:
Prev Truck: 409 Slump: 4
GO IN MAIN GATE AT MN ROAD, GO LEFT AROUND LOOP

ORDERED BY:

ARRIVAL JOB:

START POUR:

FINISH POUR:

DRIVER NAME	ZONE	SCH. ARR.
PETICKERT, ALAN	0	13:48

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	57.01	9.5	28.5 CY		0.00	0.00
SIF	STATE INSPECTION	1	9.5	28.5 CY		0.00	0.00
FUEL	FUEL SURCHARGE	1	1	3 LD		0.00	0.00
HOT H20	HOT WATER CHARGE	1	9.5	28.5 CY		0.00	0.00

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.	TAX	0
ROGERS PLANT	2	PCI	512153	SUB TOTAL	0
				TRUCK TIME	
				OTHER	

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.	TOTAL	0.00
10/16/2008	SP 0680-157	001092	3A41HPC1	402	9.5	28.5		

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Wat	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.008	0.013	627	8	635	-3.1	632	6000	5968	-0.7%
#9 Lkvl	119004 Lkvl	0.007	0.014	224	3	227	2.9	230	2180	2160	-0.9%
C. Sand Lkvl	19004 Lkvl	0.036	0.008	1123	9	1132	31.4	1153	11050	11120	0.6%
CR50(#67)E.R.	171041 E.R.	0.027	0.013	1154	15	1169	16.2	1185	11260	11360	0.9%
Holcim I	HOLMCIA			410	0	0	0.0	410	3895	3960	1.7%
Class C/F Ash	COCUR40			175	0	0	0.0	175	1662	1650	-0.7%
WATER	Water Totals			205	-35	205	-67.4	158	1261	1296	2.8%
Sika Air	SIAIR			4	0	0	0.0	4	33	33	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	222	222	0.0%

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 13:26

1:55pm SB

Design Water: 1948 lbs
Total Water: 1746 lbs
Water Available to Add: 22 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total

By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

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596799

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

Delivery Ticket

CUSTOMER PROVIDED PRODUCTS:
- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
- ADDITIONAL FEES APPLY FOR ADDING PRODUCTS NOT SUPPLIED BY AGGREGATE INDUSTRIES.

WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

EXPOSED CONCRETE: TO HELP PREVENT CONCRETE FROM SCALING DUE TO THE ACTION OF FREEZING AND THAWING WE RECOMMEND THAT 6% TO 8% AIR ENTRAINING BE USED IN ALL EXPOSED CONCRETE, PLUS PROPER CURING.

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DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2005	69176	PCI	6245		PAVING	

DELIVERY ADDRESS MN ROAD RECONSTRUCTIONALBERTVILLE

MAP PAGE

INSTRUCTIONS:
Prev Truck: 402 Slump: 4
GO IN MAIN GATE AT MN ROAD, GO LEFT AROUND LOOP

ORDERED BY

ARRIVAL JOB

START POUR

FINISH POUR

DRIVER NAME	ZONE	SCH. ARR.
KUCHERA, RANDY	0	14:05

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	57.01	9.5	38 CY		0.00	0.00
SIF	STATE INSPECTION	1	9.5	38 CY		0.00	0.00
FUEL	FUEL SURCHARGE	1	1	4 LD		0.00	0.00
HOT H20	HOT WATER CHARGE	1	9.5	38 CY		0.00	0.00

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.
ROGERS PLANT	2	PCI	512153

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
10/16/2005	SP 8600-157	001092	3A41HPC1	404	9.5	38

TAX		0
SUB TOTAL		0
TRUCK TIME		
OTHER		
TOTAL		0.00

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Wet	CY Targ	Target	Actual	% Error
1.5"(84) C.R.	171041 C.R.	0.909	0.013	627	8	635	-3.1	632	5000	5000	-0.3%
#9 Lkvl	119004 Lkvl	0.927	0.014	224	3	227	2.9	230	2180	2180	0.0%
C. Sand Lkvl	19004 Lkvl	0.936	0.008	1123	9	1132	31.4	1163	11050	11020	-0.3%
CR50(867)C.R.	171041 C.R.	0.927	0.013	1154	15	1169	16.2	1185	11260	11220	-0.4%
Holcim I	HOLNCEM			410	0	0	0.0	410	3895	3960	-0.4%
Class C/F Ash	CHOMMED			175	0	0	0.0	175	1662	1680	1.1%
WATER	Water Totals			205	-35	205	-47.4	158	1261	1276	1.2%
Sika Air	SIKAIR			4	0	0	0.0	4	33	33	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	222	225	1.4%

Trim Water: -2 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 13:43

2:05pm SB

Design Water: 1948 lbs
Total Water: 1726 lbs
Water Available to Add: 25 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

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Delivery Ticket

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- CUSTOMER PROVIDED PRODUCTS ADDED TO THE MIX VOIDS ALL GUARANTEES/WARRANTIES.
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WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

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NO CREDIT ALLOWED FOR CONCRETE RETURNED. SEE REVERSE FOR TERMS, CONDITIONS AND RETURN CHECK CHARGES.

DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2008	69178	PCI	6246		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE — MAP PAGE:

INSTRUCTIONS:
Prev Truck: 404 Slump: 4
GO IN MAIN GATE AT MN ROAD, GO LEFT AROUND LOOP

ORDERED BY:

ARRIVAL JOB: 226

START POUR:

FINISH POUR:

DRIVER NAME	ZONE	SCH. ARR.
BALKO, TODD	0	14:21

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3041HPCI	MN ROAD HI PERFORMANCE P	57.01	9.5	47.5	CY	0.00	0.00
SIF	STATE INSPECTION	1	9.5	47.5	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	5	LD	0.00	0.00
HOT H20	HOT WATER CHARGE	1	9.5	47.5	CY	0.00	0.00

Air Content 6.2
Slump 3½"
Concrete Temp 68°
Air Temp 59°

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.	TAX	0
ROGERS PLANT	2	PCI	512153	SUB TOTAL	0
				TRUCK TIME	
				OTHER	

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.	TOTAL	0.00
10/16/2008	SP 8680-157	001092	3041HPCI	108	9.5	47.5		

Ingredient	Source	MCFac	AbFac	OB	Abs	SSD	Free Wet	CY Targ	Target	Actual	% Error
1.5"(#4) C.R.	171041 C.R.	0.000	0.013	627	8	635	-3.1	632	6000	6000	1.2%
#9 Lkvl	119004 Lkvl	0.027	0.014	224	3	227	2.9	230	2180	2140	-1.8%
C. Sand Lkvl	19004 Lkvl	0.036	0.008	1123	9	1132	31.4	1163	11050	11060	0.1%
C050(367)C.R.	171041 C.R.	0.027	0.013	1154	15	1169	16.2	1185	11260	11220	-0.4%
Holcim I	HOLNCIA			410	0	0	0.0	410	3895	3895	0.0%
Class C/F Ash	CCOUWND			175	0	0	0.0	175	1662	1655	-0.4%
WATER	Water Totals			285	-35	285	-47.4	158	1251	1284	1.8%
Sika Air	SIAIR			4	0	0	0.0	4	33	33	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	222	222	0.0%

2:30 pm

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.31
Batch Time: 14:07

SB

Design Water: 1948 lbs
Total Water: 1734 lbs
Water Available to Add: 24 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Water Added: gallons

By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

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Delivery Ticket

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WATER: ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IS AT CUSTOMER'S RISK.

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DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2008	69180	PCI	6246		PAVING	

DELIVERY ADDRESS MN ROAD RECONSTRUCTIONALBERTVILLE — **MAP PAGE**

INSTRUCTIONS:
Prev Truck: 408 Slump: 4
GO IN MAIN GATE AT MN ROAD, GO LEFT AROUND LOOP

ORDERED BY — **ARRIVAL JOB** — **START POUR** — **FINISH POUR**

DRIVER NAME	ZONE	SCH. ARR.
JONES, DAVID	0	14:40

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SUM	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	57.01	9.5	57 CY		0.00	0.00
SIF	STATE INSPECTION	1	9.5	57 CY		0.00	0.00
FUEL	FUEL SURCHARGE	1	1	6 LD		0.00	0.00
HOT H20	HOT WATER CHARGE	1	9.5	57 CY		0.00	0.00

Thanks!
Dan

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.	TAX	
ROGERS PLANT	2	PCI -	512153	SUB TOTAL	0
				TRUCK TIME	0
				OTHER	

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.	TOTAL	
10/16/2008	SP 8680-157	001092	3A41HPC1	182	9.5	57	TOTAL	0.00

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Wat	CY Targ	Target	Actual	% Error
1.5"(#4) E.R.	171041 E.R.	0.008	0.013	627	8	635	-3.1	632	6080	6040	0.7%
#9 Lkvl	119004 Lkvl	0.007	0.014	224	3	227	2.9	230	2180	2140	-1.8%
C. Sand Lkvl	19004 Lkvl	0.036	0.008	1123	9	1132	31.4	1163	11050	11040	-0.1%
CA50(#67)E.R.	171041 E.R.	0.007	0.013	1154	15	1169	16.2	1185	11260	11280	0.2%
Holcim I	HOLNCIA			410	0	0	0.0	410	3895	3890	-0.1%
Class C/F Ash	COCLWND			175	0	0	0.0	175	1662	1655	-0.4%
WATER	Water Totals			205	-35	205	-47.4	158	1261	1292	2.5%
Sika Air	SIAIR			4	0	0	0.0	4	33	33	0.0%
Sikament 686	SIKA686			4	0	0	0.0	4	222	225	1.4%

2:43 pm

Trim Water: -3 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.32
Batch Time: 14:18

Design Water: 1948 lbs
Total Water: 1742 lbs
Water Available to Add: 23 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Actual Water: lbs

SB

By signing this delivery ticket you agree to the terms & conditions on the back side of this form.

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595205 2008 - 340 406

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AGGREGATE INDUSTRIES

Ready Mix Division
2915 Waters Road Suite 105
Eagan Minnesota 55121
Main Office (651) 683-0600
Metro Dispatch (651) 683-8150

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DATE	TICKET NO.	CUSTOMER NAME	ORDER NO.		USAGE CODE	
10/16/2000	69183	PCI	6246		PAVING	

DELIVERY ADDRESS: MN ROAD RECONSTRUCTIONALBERTVILLE — MAP PAGE:

INSTRUCTIONS:
Prev Truck: 182 Slump: 4
CO IN MAIN GATE AT MN ROAD, GO
LEFT AROUND LOOP

ORDERED BY:

ARRIVAL JOB:

START POUR:

DRIVER NAME	ZONE	SCH. ARR.
DOCKHAN, DALE	0	15:09

FINISH POUR:

PRODUCT CODE	DESCRIPTION	QUANTITY ORDER	QUANTITY LOAD	QUANTITY SENT	UNIT	PRICE	AMOUNT
3A41HPC1	MN ROAD HI PERFORMANCE P	59	2	59	CY	0.00	0.00
SIF	STATE INSPECTION	1	2	59	CY	0.00	0.00
FUEL	FUEL SURCHARGE	1	1	7	LD	0.00	0.00
HOT H20	HOT WATER CHARGE	1	2	59	CY	0.00	0.00

CERTIFICATE OF COMPLIANCE

READY MIX PLANT	PLANT #	CUSTOMER	CUSTOMER NO.
ROGERS PLANT	2	PCI	512153

TAX 0
SUB TOTAL 0
TRUCK TIME
OTHER
TOTAL 0.00

DATE	SP / PO	REF. / BRIDGE NO.	MIX NO.	TRUCK NO.	LOAD QTY.	CUMULATIVE QTY.
10/16/2000	SP 8680-157	0W1092	3A41HPC1	147	2	59

Ingredient	Source	MCFac	AbFac	OD	Abs	SSD	Free Mst	CY Targ	Target	Actual	% Error
1.5"(#4) C.A.	171041 C.A.	0.006	0.013	627	8	635	-3.1	632	1260	1240	-1.6%
#9 Lkvl	119004 Lkvl	0.027	0.014	224	3	227	2.9	230	460	540	17.4%
C. Sand Lkvl	19004 Lkvl	0.036	0.008	1123	9	1132	31.4	1163	2330	2340	0.4%
CA50(#67)C.A.	171041 C.A.	0.027	0.013	1154	15	1169	16.2	1185	2370	2360	-0.4%
Holcim I	HOLNC1A			410	0	0	0.0	410	820	875	6.7%
Class C/F Ash	COCRND			175	0	0	0.0	175	350	420	20.0%
WATER	Water Totals			205	-35	205	-47.4	158	257	284	10.5%
Sika Air	SIAIR			4	0	0	0.0	4	7	7	0.0%
Sikament 686	SIKA686			4	9	0	0.0	4	48	51	6.3%

Trim Water: -3.5 gallons
Mix Water/Cement Ratio: 0.35
Actual Water/Cement Ratio: 0.3
Batch Time: 14:46

3:15pm
SB

Design Water: 410 lbs
Total Water: 379 lbs
Water Available to Add: 3 gallons
Water Added at Plant: gallons
Water Added at Job Site: gallons
Total Added Water: lbs

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Appendix E: Construction Pictures

Figure E1. Placement of concrete around sensors.

Figure E2. McCleary screed used to compact the concrete.

Figure E3. Tooled joint and concrete finishing methods.

Figure E4. Instrumentation used in Cell 53.

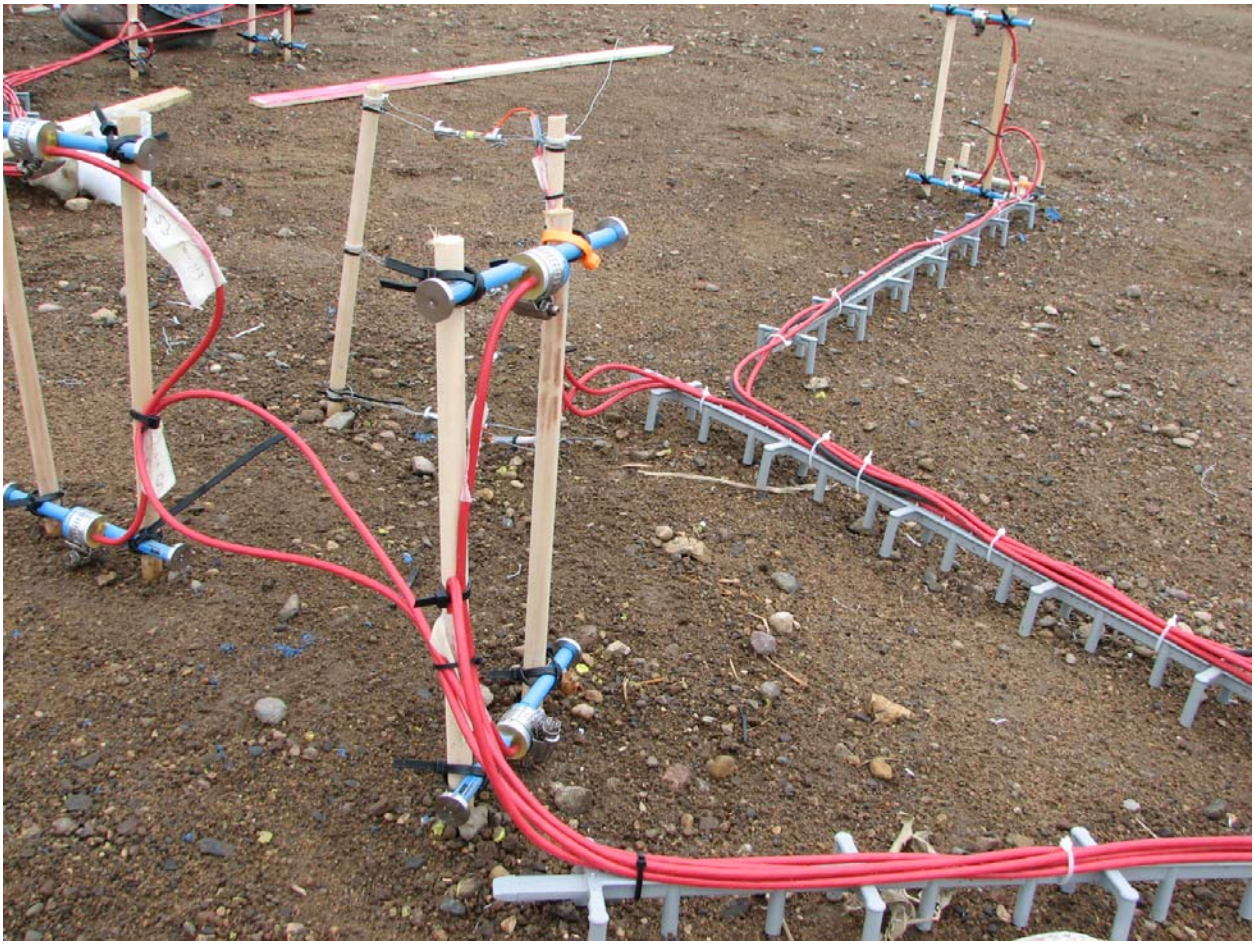

Figure E5. Vibrating wire strain gauges.

Appendix F: Cell 53 Instrumentation

Table F1. Cell 53 sensor locations.

CELL	MODEL	SEQ	ORIENTATION	STATION (FT)	OFFSET (FT)	DEPTH (IN)
53	CE	101	LONGITUDINAL	-7.5	-11.5	11.748
53	CE	102	TRANSVERSE	-7.5	-6	0.252
53	CE	103	LONGITUDINAL	-3	-11.5	0.252
53	CE	104	39°	-2.5	-10	0.252
53	CE	105	TRANSVERSE	-1	-9	0.252
53	CE	106	TRANSVERSE	-1	-6	0.252
53	CE	107	LONGITUDINAL	7.5	-11.5	0.252
53	CE	108	LONGITUDINAL	7.5	-11.5	11.748
53	CE	109	TRANSVERSE	7.5	-9	0.252
53	CE	110	TRANSVERSE	7.5	-9	11.748
53	CE	111	LONGITUDINAL	7.6	-9	0.252
53	CE	112	LONGITUDINAL	7.6	-9	11.748
53	CE	113	TRANSVERSE	7.5	-6	0.252
53	CE	114	TRANSVERSE	7.5	-6	11.748
53	CE	115	LONGITUDINAL	7.6	-6	0.252
53	CE	116	LONGITUDINAL	7.6	-6	11.748
53	CE	117	LONGITUDINAL	12	-11.5	0.252
53	CE	118	LONGITUDINAL	12	-11.5	11.748
53	CE	119	39°	12.5	-10	0.252
53	CE	120	39°	12.5	-10	11.748
53	CE	121	TRANSVERSE	14	-9	0.252
53	CE	122	TRANSVERSE	14	-9	11.748
53	CE	123	TRANSVERSE	14	-6	0.252
53	CE	124	TRANSVERSE	14	-6	11.748
53	DT	101		-7.5	-12.2	0.75
53	DT	102		0	-12.2	0.75
53	DT	103		0	-12.2	0.75
53	DT	104		7.5	-12.2	0.75
53	DT	105		15	-12.2	0.75
53	DT	106		15	-12.2	0.75
53	EC	101		16	-11.2	15
53	EC	102		17	-10.2	18
53	EC	103		18	-9.2	24
53	EC	104		19	-8.2	30
53	EC	105		20	-7.2	36
53	EC	106		21	-6.2	48
53	EC	107		22	-5.2	60
53	EC	108		23	-4.2	72
53	HC	101		0	-11	0.996
53	HC	102		0	-11	11.004
53	HC	103		0	-6	0.996
53	HC	104		0	-6	11.004
53	HC	105		15	-11	6
53	HC	106		15	-6	6
53	IK	101		-7.6	-7	0.996

Table F1. Sensor locations (cont).

CELL	MODEL	SEQ	ORIENTATION	STATION (FT)	OFFSET (FT)	DEPTH (IN)
53	IK	102		-7.6	-7	3.504
53	IK	103		-7.6	-7	6
53	IK	104		-7.6	-7	8.496
53	IK	105		-7.6	-7	11.004
53	IK	106		-7.6	-7	0.996
53	IK	107		-6.6	-6	3.5
53	IK	108		-5.6	-5	6
53	IK	109		-4.6	-4	8.5
53	IK	110		-3.6	-3	11
53	IV	101		-7.5	-12.2	6
53	IV	102		0	-12.2	6
53	IV	103		7.5	-12.2	6
53	IV	104		15	-12.2	6
53	TC	101		1	-11.5	0.5
53	TC	102		1	-11.5	1
53	TC	103		1	-11.5	2
53	TC	104		1	-11.5	3
53	TC	105		2	-10.5	4
53	TC	106		1	-11.5	5
53	TC	107		1	-11.5	8
53	TC	108		1	-11.5	11
53	TC	109		7	-6	0.5
53	TC	110		7	-6	1
53	TC	111		7	-6	1.5
53	TC	112		7	-6	3
53	TC	113		7	-6	5
53	TC	114		7	-6	8
53	TC	115		7	-6	11
53	TC	116		7	-6	15
53	TC	117		7	-6	18
53	TC	118		7	-6	24
53	TC	119		7	-6	30
53	TC	120		7	-6	36
53	TC	121		7	-6	48
54	TC	122		7	-6	54
55	TC	123		7	-6	60
56	TC	124		7	-6	72
53	VG	101	LONGITUDINAL	-6	-6.5	0.996
53	VG	102	LONGITUDINAL	-6	-6.5	6
53	VG	103	LONGITUDINAL	-6	-6.5	11.004
53	VW	101	LONGITUDINAL	-12	-11	0.996
53	VW	102	LONGITUDINAL	-12	-11	11.004
53	VW	103	39°	-12.5	-10	0.996
53	VW	104	39°	-12.5	-10	11.004
53	VW	105	TRANSVERSE	-14	-9	0.996
53	VW	106	TRANSVERSE	-14	-9	11.004

Table F1. Sensor locations (cont).

CELL	MODEL	SEQ	ORIENTATION	STATION (FT)	OFFSET (FT)	DEPTH (IN)
53	VW	107	LONGITUDINAL	-14	-6	0.996
53	VW	108	LONGITUDINAL	-14	-6	11.004
53	VW	109	TRANSVERSE	-13.5	-6	0.996
53	VW	110	TRANSVERSE	-13.5	-6	11.004
53	VW	111	LONGITUDINAL	-7.5	-11	0.996
53	VW	112	LONGITUDINAL	-7.5	-11	11.004
53	VW	113	LONGITUDINAL	-8	-6	0.996
53	VW	114	LONGITUDINAL	-8	-6	11.004
53	VW	115	TRANSVERSE	-7	-6	0.996
53	VW	116	TRANSVERSE	-7	-6	11.004
53	WM	101		7	-6.5	14.496
53	WM	102		7	-6.5	18
53	WM	103		7	-6.5	30
53	WM	104		7	-6.5	42
53	WM	105		7	-6.5	51.96
53	WM	106		7	-6.5	56.04
53	WM	107		0.5	-11.5	14.496
53	WM	108		0.5	-11.5	18
53	WM	109		0.5	-11.5	30
53	WM	110		0.5	-11.5	42
53	WM	111		0.5	-11.5	51.96
53	WM	112		0.5	-11.5	56.04
53	XG	101	LONGITUDINAL	-6	-6.5	0.996
53	XG	102	LONGITUDINAL	-6	-6.5	6
53	XG	103	LONGITUDINAL	-6	-6.5	11.004
53	XV	101	LONGITUDINAL	-12	-11	0.996
53	XV	102	LONGITUDINAL	-12	-11	11.004
53	XV	103	39°	-12.5	-10	0.996
53	XV	104	39°	-12.5	-10	11.004
53	XV	105	TRANSVERSE	-14	-9	0.996
53	XV	106	TRANSVERSE	-14	-9	11.004
53	XV	107	LONGITUDINAL	-14	-6	0.996
53	XV	108	LONGITUDINAL	-14	-6	11.004
53	XV	109	TRANSVERSE	-13.5	-6	0.996
53	XV	110	TRANSVERSE	-13.5	-6	11.004
53	XV	111	LONGITUDINAL	-7.5	-11	0.996
53	XV	112	LONGITUDINAL	-7.5	-11	11.004
53	XV	113	LONGITUDINAL	-8	-6	0.996
53	XV	114	LONGITUDINAL	-8	-6	11.004
53	XV	115	TRANSVERSE	-7	-6	0.996
53	XV	116	TRANSVERSE	-7	-6	11.004