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The Effects of Combined Supplementary Cementitious Materials on Physical Properties of Kansas Concrete Pavements

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All three ternary-blend concretes met specification requirements for the tests of alkali-silica reactivity. The 10% fly ash-27% slag combination was the most effective in preventing expansion. The 10% fly ash-27% slag concrete also had the highest strength and lowest permeability of the five concretes tested.

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Final Report

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Abstract

This study evaluated the effects of combining varying proportions of slag cement and Class C fly ash with Type I/II cement in concrete pavement. Three different ternary cementitious material combinations containing slag cement and Class C fly ash (10% fly ash with 27% slag, 15% fly ash with 25% slag and 20% fly ash with 24% slag) were combined with limestone coarse aggregate and a moderately-reactive fine aggregate. Two concretes used only Portland cement. Specimens of each concrete from the project were tested in the laboratory to evaluate physical properties. On-going pavement condition surveys will track pavement performance.

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Chapter 1: Introduction

The Kansas Department of Transportation (KDOT) has controlled harmful alkali-silica reactions (ASR) through testing and selective use of sand and gravel aggregates for more than 70 years. ASR can also be controlled through the addition of a non-reactive coarse aggregate "sweetener" and by the judicious use of selected supplementary cementitious materials. Current KDOT specifications allow the use of sands and gravels that may otherwise undergo ASR with the addition of a "sweetener" aggregate. Using one or more supplementary cementitious materials (SCMs) in a concrete may accelerate or hinder alkali-silica reactions, depending on the alkali and silica contents of the SCM and the aggregates used. Class C fly ash may aggravate ASR and until 2009 was not approved for use in Kansas pavements.

1.1 Research Purpose

The purpose of this project is to evaluate the effect of combining portland cement with Class C fly ash and slag cement on the physical properties, alkali-silica reactivity (ASR), and durability of concrete containing reactive fine aggregate and limestone coarse aggregate. Past KDOT research has looked at the effect of Class C fly ash on ASR in 100% siliceous sand-gravel concretes. One study evaluated a coarse-aggregate sweetener with fly ash and found that a substitution of up to 15% Class C fly ash will not adversely affect the ASR resistance or freeze-thaw durability of concrete mixtures containing 50% limestone (Abou-Zeid et al. 1995). Since the time of that study, changes have occurred in testing, availability of supplementary cementitious materials and the use of fly ash in precast concrete pipe. In 1999, KDOT began allowing the substitution of up to 25% Class C fly ash for Type II or I/II portland cement in precast concrete pipe. All the fly ash concretes that have been approved for concrete pipe have a minimum of 30% limestone sweetener. Slag cement and a portland cement blended with Class F fly ash are now readily available in Kansas. Previous research showed that both materials mitigate ASR in concrete.

Until recently, the alkali-silica reactivity of cementitious materials and aggregates was tested against standard aggregates and standard cements, respectively. A new standard test procedure evaluates the combined reactivity of cementitious materials and local aggregates. Test procedure ASTM C-1567: Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method) was introduced in 2004. The Accelerated Mortar-Bar Method evaluates the ASR potential of the combination of materials in a concrete in as little as 16 days.

Previous KDOT research evaluated fourteen combinations of cementitious materials, including Class C fly ash, Class F fly ash, Type I/II cement, and slag cement with reactive and nonreactive coarse aggregates and reactive fine aggregate from the Missouri and Kansas rivers. Concrete was mixed in the laboratory and tested for ASR using both the year-long KT-MR-23 Wetting and Drying Test of Sand and Sand-Gravel Aggregate for Concrete (Wetting and Drying Test) and the 16-day ASTM C-1567 Accelerated Mortar-Bar Method.

This study evaluated the effects of combining varying proportions of slag cement and Class C fly ash with Type I/II cement in concrete pavement. Three different ternary cementitious material combinations containing slag cement and Class C fly ash were combined with limestone coarse aggregate and a moderately-reactive fine aggregate. Specimens of concrete from the project were tested in the laboratory to evaluate physical properties. On-going pavement condition surveys will track pavement performance.

Chapter 2: Materials and Construction

2.1 Concrete Materials

The coarse aggregate used on this project was a CA-6 limestone produced in the APAC Louisburg Quarry in Miami County, Kansas (KDOT quarry number 4-061-10) with a specific gravity of 2.62. The fine aggregate was Kansas River FA-A sand produced in the Holliday #7 pit in Johnson County, Kansas (KDOT producer ID 815301) with a specific gravity of 2.61. This sand was considered moderately reactive and did not meet the requirements of KDOT Standard Specification 1102.2d (2) in testing with the KT-MR-23 Wetting and Drying Test. The 365-day modulus of rupture of 539 psi did not reach the 365-day minimum modulus of rupture of 550 psi. The 365-day expansion of 0.075% exceeded the 365-day maximum expansion (0.070%) requirement. Type I/II portland cement with a specific gravity of 3.15 produced by Lafarge North America (now Central Plains Materials) at the Sugar Creek, Missouri plant was used on the project. The ternary blends combined Lafarge MaxCem Type IS(30) cement and Iatan Class C fly ash. MaxCem is 70% Lafarge Sugar Creek Type I/II cement interground with 30% slag cement. The specific gravity of MaxCem was 3.09. The specific gravity of the fly ash was 2.67. Two existing KDOT requirements were waived to allow the experimental use of Iatan Class C fly ash for this project. Prequalification of the fly ash was not required, and KDOT allowed the use of more than 10% fly ash and the use of greater than 30% total supplementary cementitious materials. Admixtures used included air-entraining agent GRT Polychem AE and Type-A water reducer GRT Polychem 400NC.

2.2 Material Proportions

The five concretes studied varied in the proportion of cementitious materials and aggregates used. Two concretes used only Portland cement, one with an optimized aggregate gradation and one with a non-optimized gradation. Three concretes used ternary cementitious blends of cement, Class C fly ash and slag cement with an optimized aggregate gradation. The five concretes are listed below.

- 544 lbs/yd^3 plain cement, with optimized aggregate gradation,
- 602 lbs/yd^3 plain cement, with non-optimized aggregate gradation,

- 544 lbs/yd^3, 15% Class C fly ash and 85% MaxCem,
- 544 lbs/yd^3, 20% Class C fly ash and 80% MaxCem, and
- 544 lbs/yd^3, 10% Class C fly ash and 90% MaxCem.

The cementitious materials were proportioned by weight. The paste volume of these concretes varied as the water-cementitious ratio varied and lower specific gravity supplementary cementitious materials were substituted for cement.

The cement-only concretes were placed in 2007. The optimized-gradation concrete was the standard concrete for the project. The aggregate proportions were optimized for workability with 57% limestone and 43% sand. The optimized combined gradation had a workability of 36 and a target workability of 37, for a workability difference of 1. The individual and combined aggregate gradations are shown in Table 2.1. The water-cement ratios were 0.45 and 0.43. These concretes were designed with 6.0 ounces per cubic yard air-entraining agent and 15.0 ounces per cubic yard Type-A water reducer. A small area using a non-optimized gradation of 45% limestone and 55% sand was placed for this study. The non-optimized combined gradation had a workability of 46 and a target workability of 37, for a workability difference of 9.

TABLE 2.1
Aggregate Gradations by Cumulative Percent Retained

Sieve size, inches	APAC CA-6 limestone	Holliday FA-A sand	Optimized (57% LS, 43% sand)	Non-optimized (45% LS, 55% sand)
1	0	0	0	0
3/4	3	0	2	1
1/2	38	0	21	17
3/8	60	0	34	27
No. 4	94	2	55	43
No. 8	98	18	64	54
No. 16	98	43	75	68
No. 30	99	70	86	83
No. 50	99	90	95	94
No. 100	99	98	98	98
No. 200	99	99	99	99

Three ternary-blend concretes incorporating MaxCem Type IS(30) cement and Class C fly ash were placed in 2008. All three ternary-blend concretes used an optimized aggregate gradation with 56% limestone and 44% sand. The water-cement ratios were 0.41 and 0.43, and design unit weights varied accordingly. These concretes were designed with 5.4 ounces per cubic yard air-entraining agent and 35.4 ounces per cubic yard Type-A water reducer. The supplementary cementitious material proportions of the ternary blends are shown in Table 2.2. In this report the ternary-blend concretes are referenced by their fly ash and slag content; i.e., “10% fly ash, 27% slag”.

TABLE 2.2
Supplementary Cementitious Material Proportions in Ternary-Blend Concretes

Fly Ash	MaxCem Type IS(30)	Slag Cement Equivalent	Total SCM replacement
10%	90%	27%	37%
15%	85%	25%	40%
20%	80%	24%	44%

2.3 Construction

The concrete pavements in this study were constructed as part of the reconstruction of the intersection of US-24 and K-7 in Wyandotte County under KDOT project number 24-105 K-8248-01. See Figure 2.1 for a general overview of the project and location. Concrete paving occurred during the 2007 and 2008 construction seasons. APAC Kansas City Division was the concrete paving contractor. The pavement structure is 11 in. of plain dowel-jointed concrete pavement placed on 4 in. cement-treated base and 6 in. subgrade. Lime and cement were used to modify the subgrade soils on State Street east of the US-24/K-7 interchange in 2007. Fly ash was used to modify subgrade soils west, north and south of the interchange in 2008.

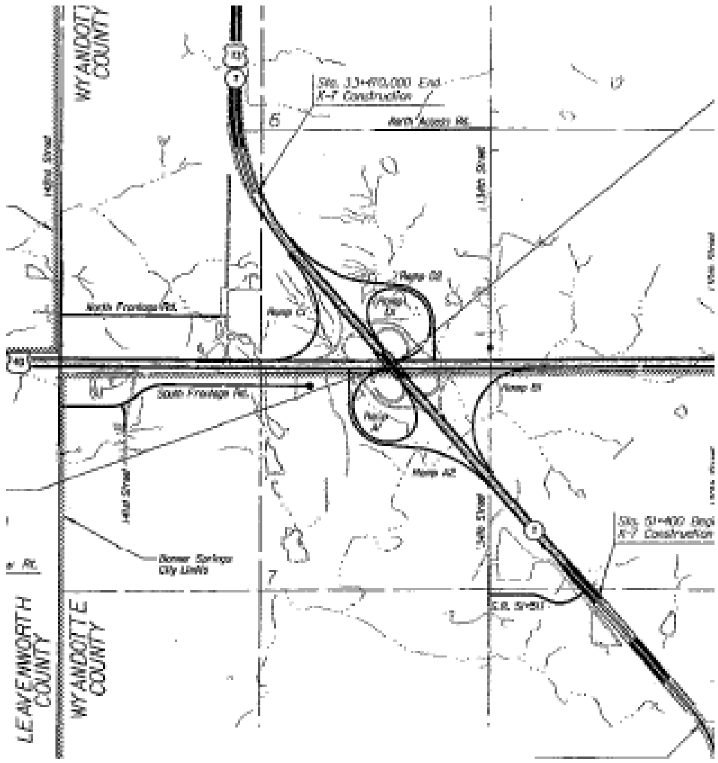


FIGURE 2.1
Detail of Plan Sheet Showing Location of Project No. 24-105-K-8248-01

State Street east of the US-24/K-7 interchange was paved from April to November of 2007 with an optimized-gradation paving concrete containing no supplementary cementitious materials. Standard KDOT construction methods were used. Concrete was batched and mixed in a central mix plant located on the job site and transported to the paving train in end-dump trucks. A belt-spreader distributed the concrete on the grade in front of the paver. Two lanes and the inside shoulder were placed together and the outside shoulder was placed later. A burlap drag attached to the paver provided light texturing. The paver was followed immediately by a ten-foot straight edge and bull floats. A longitudinal tining cart provided the final surface texture and curing compound was applied to the surface.

Paving with the ternary-blend concretes occurred from June to November 2008, using the same construction methods used for the cement-only concrete. The greatest construction challenge was finding the correct interval between the paver and the finishing operation. Fly ash and slag delay the onset of bleeding and increase amount of bleed water. When the finishers were too close to the paver, the surface was sealed before the bleed water could escape. Bleed water trapped under the finished surface of the pavement increased the water content in a layer just beneath the surface. This weakened layer can cause surface scaling or delamination. Bleed water rose after the completion of tining and the application of curing compound in some areas. The tining collapsed and closed and the surface had to be retextured. Figure 2.2 shows bleed water rising after finishing and tining.

FIGURE 2.2
Bleed Water Rising to Surface After Tining

The ternary-blend concretes were placed in 43 separate placements in 2008. There were also 79 cement-only concrete placements in 2008 that are not discussed in this construction report. The locations of the ternary-blend concrete placements are given in tables and plans in the Appendix. The ternary-blend concrete placements are numbered sequentially by date of placement.

Paving with a combination of 15% Iatan Class C fly ash and 85% MaxCem Type IS(30) cement began in June 2008 and continued until early October 2008. This concrete was placed on west-bound US-24 west of the US-24/K-7 interchange, on the southbound lanes of K-7 north of the US-24/K-7 interchange, and on ramps B1, C1 and D2. The 20% Iatan Class C fly ash and 80% MaxCem Type IS(30) cement concrete was placed in September, October and November 2008 on the southbound lanes of K-7 south of the US-24/K-7 interchange. Concrete with 10% Iatan Class C fly ash and 90% MaxCem Type IS(30) cement was placed in September, October and November 2008 on the east-bound lanes of US-24 west of the US-24/K-7 interchange.

Chapter 3: Concrete Testing and Results

Fresh and hardened concrete was tested to assess the quality and potential durability of the pavements constructed on this project. Prism, core or cylinder samples of each of the five types of concrete were cast in the field and cured under standard conditions. Sampling locations are shown on the plans in the Appendix.

3.1 Research Testing Program

The following tests were performed on specimens of all five types of concrete, except where noted in the test descriptions:

- KT-MR-23 Wetting and Drying Test of Sand and Sand-Gravel Aggregate for Concrete (Wetting and Drying Test)
- KT-MR-22 Resistance of Concrete to Rapid Freezing and Thawing (Freezing and Thawing Test)
- ASTM C457 Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete (Air Voids in Hardened Concrete)
- KT-71 Air Void Analyzer
- KT-18 Air Content of Freshly Mixed Concrete by the Pressure Method (Pressure Method)
- KT-73 Density, Absorption and Voids in Hardened Concrete (Boil Test)
- AASHTO T 277 Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration (Rapid Chloride Permeability Test)
- AASHTO T 22 Compressive Strength of Cylindrical Concrete Specimens (Compressive Strength Test)
- AASHTO T 24 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

The KT-MR-23 Wetting and Drying Test indicates the level of resistance of the concrete to degradation by alkali-silica reaction (ASR). KDOT specifications require that concrete complete the wetting and drying testing with a minimum modulus of rupture at 60 and 365 days of 550 psi. Specifications also require that the expansion measured at 180 days and 365 days not exceed the measured length by more than 0.050% and 0.070%, respectively.

Test specimens for KT-MR-23 Wetting and Drying Test Specimens were cast in the field for the three ternary-blend concretes placed in 2008. Samples were not cast in the field of the optimized-gradation cement-only concrete placed in 2007. Materials from the job site were used to cast laboratory specimens of the optimized-gradation cement-only concrete for comparison with the ternary-blend concretes sampled in the field. The optimized-gradation cement-only concretes used on the project were proportioned according to KDOT Standard Specification 1102.2a and were not expected to undergo deleterious ASR.

ASTM C1567 Accelerated Mortar-Bar Method measures the susceptibility of a combined of aggregates and cementitious materials to deleterious alkali-silica reactions. In this test method, the length of mortar bars are measured before and after fourteen days in 1N NaOH solution at 80° C. Material combinations that yield expansions of less than 0.10% have a low risk of deleterious expansion under field conditions. Lafarge North America, the supplier of the cementitious materials, performed ASTM C1567 Accelerated Mortar-Bar Method on laboratory specimens cast using the materials and mix proportions from this project.

The KT-MR-22 Freezing and Thawing Test indicates the level of resistance of the limestone coarse aggregate to degradation by freezing and thawing. This test method is a modification of ASTM C666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, Procedure B. KT-MR-22 specifies the types, gradations and proportions of materials to be used in casting test prisms. In KT-MR-22 the curing period is extended from 14 days as specified in C666 to 90 days. KDOT specifications require that concrete with Class I limestone coarse aggregate complete 300 cycles of freezing and thawing with a durability factor of 95. The specifications also require that concrete with Class I limestone coarse aggregate complete 300 cycles of freezing and thawing with a relative elongation, reported as expansion, of 0.025%.

ASTM C457 Air Voids in Hardened Concrete, KT-71 Air Void Analyzer, and KT-18 Pressure Method measure various parameters of the air-void system in concrete. A proper air-void system protects the concrete paste from freeze-thaw degradation. The parameter most closely correlated with the freeze-thaw durability of concrete paste is the spacing factor. The spacing factor is the average distance from any point in the concrete paste to the nearest air void. Industry standards require a spacing factor of no more than 0.200 mm in hardened concrete as measured by ASTM C457. KDOT specifies a maximum spacing factor of 0.250 mm as measured by KT-71 Air Void Analyzer. KT-71 Air Void Analyzer, KT-18 Pressure Method and ASTM C457 Air Voids in Hardened Concrete also measure the total air content of concrete. KDOT specifications require a total air content between 5% and 8% by volume as measured by KT-18.

KT-73 Boil Test and AASHTO T 277 Rapid Chloride Permeability Test indicate the resistance of the concrete paste to the intrusion of water. Water can cause freeze-thaw deterioration in both concrete paste and aggregates. Although these tests were not specified at the time of construction, current KDOT specifications require that concrete used in pavement have no more than 12.5% permeable voids as measured by KT-73 or transmit no more than 3500 C as measured by AASHTO 277.

AASHTO T 24 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete and AASHTO T 22 Compressive Strength Test measure the compressive strength of concrete. The lower specification limit in the KDOT Percent Within Limits specification for concrete strength is 3900 psi.

3.2 Concrete Test Results

Four concretes were tested using KT-MR-23 Wetting and Drying Test, including field-cast specimens of the three ternary-blend concretes and laboratory-cast specimens of the cement-only, optimized-gradation concrete. All specimens exceeded the minimum wetting and drying specification limits, indicating the pavements should not demonstrate deterioration due to ASR within the design life. The 20% fly ash-24% slag concrete was tested for modulus of rupture at 30 rather than 60 days of age. The results of KT-MR-23 are given in Table 3.1.

TABLE 3.1
Results of KT-MR-23 Wetting and Drying Test

Concrete	Date cast	Sample number	Modulus of rupture		Expansion	
			60 day	365 day	180 day	365 day
Cement-only Optimized	3/3/2011	11-0311	784	906	0.010%	0.014%
15% Fly Ash 25% Slag	7/15/2008	08-1721	880	860	0.017%	0.022%
20% Fly Ash 24% Slag	9/26/2008	08-2441	NA	877	0.013%	0.013%
10% Fly Ash 27% Slag	11/7/2008	08-3162	905	1014	0.006%	0.008%
	Specification limit		550 min	550 min	0.050% max	0.070% max

The results of the ASTM C1567 Accelerated Mortar-Bar Method testing are given in Table 3.2. All of the specimens expanded less than the recommended maximum of 0.10%, indicating that the concretes made from these material combinations have a low risk of deleterious expansion.

TABLE 3.2
Results of ASTM C1567
Accelerated Mortar-Bar Method

Concrete	ASTM C1567 Expansion
15% Fly Ash 25% Slag	0.03%
20% Fly Ash 24% Slag	0.03%
10% Fly Ash 27% Slag	0.04%
Recommended maximum	0.10%

Both the optimized and non-optimized cement-only concretes and the three ternary-blend concretes were tested using KT-MR-22 Freezing and Thawing Test. One of the five specimens failed to exceed the freezing and thawing durability specification limits, indicating that the limestone coarse aggregate at the sampling location may be susceptible to deterioration by freezing and thawing within the design life of the pavement. The specimens were disintegrating after 200 freeze-thaw cycles and were removed from testing. The expansion of the 10% fly ash-27% slag concrete was 0.126% at 200 cycles, five times the specified maximum allowable expansion of 0.025% at 300 cycles.

The 10% fly ash-27% slag concrete also failed to meet the specified durability factor (relative modulus at 300 cycles) of 95. The measured relative modulus of 53 at 200 cycles indicates a significantly elevated risk of deterioration of the concrete in this section due to freeze-thaw deterioration. The performance of the concrete in this test is governed by the resistance of the aggregates to degradation by freezing and thawing. A petrographic examination of these specimens after freeze-thaw testing found pervasive fracturing of the coarse aggregate particles.

The 10% fly ash-27% slag concrete received 60 rather than 90 days of curing prior to the beginning of freeze-thaw testing. Neither the reduced curing time nor the proportion of cementitious materials is believed to have been controlling factors in the freeze-thaw performance of the 10% fly ash-27% slag concrete. The reduction in the curing time of the freeze-thaw specimens may have resulted in lower paste strength or higher permeability. However, this concrete exhibited the highest strength at 28 days of age (7430 psi) and lowest permeability at 56 days of age (894 C) of the concretes tested in this study.

Lower durability aggregate was found at only one sampling location. In addition to the samples tested for this study, five standard production samples of the limestone coarse aggregate from this project were also tested with KT-MR-22 Freezing and Thawing Test. All five samples exceeded KDOT specifications for durability factor and expansion. The results of KT-MR-22 are given in Table 3.3.

TABLE 3.3
Results of KT-MR-22 Freezing and Thawing Test.

Concrete	Date sampled	Sample number	Durability factor	Expansion
Cement-only Non-optimized	7/31/2007	07-2760	95	0.013%
Cement-only Optimized	7/26/2007	07-3318	95	0.022%
15% Fly Ash 25% Slag	9/23/2008	08-2691	96	0.010%
20% Fly Ash 24% Slag	9/26/2008	08-2442	98	0.005%
10% Fly Ash 27% Slag	11/7/2008	08-3161	53*	0.126%*
Lab, cement-only	4/10/2008	08-0603	98	0.010
Lab, cement-only	6/9/2008	08-1293	98	0.014
Lab, cement-only	8/6/2008	08-1969	99	0.010
Lab, cement-only	9/30/2008	08-2715	97	0.015
Lab, cement-only	11/6/2008	08-3173	99	0.001
	Specification limit		95 min	0.025% max

*Value recorded at 200 freeze/thaw cycles when testing was terminated.

The air-void spacing factor as measured by ASTM C457 Air Voids in Hardened Concrete was below the recommended maximum of 0.200 mm for all but one concrete. Overall, this indicates the pavements should not demonstrate premature deterioration due to freeze-thaw damage to the concrete paste. The KT-71 Air-Void Analyzer spacing factor of the cement-only optimized gradation concrete was 0.306 mm. This spacing factor exceeds the specified KDOT maximum of 0.250 mm and may indicate an elevated risk of premature deterioration due to freeze-thaw damage to the concrete paste. The total air content as measured by KT-18 Pressure Method on fresh concrete was within the specified limits of 5% to 8% for all specimens. The total air content as determined by ASTM C457 on hardened concrete samples was within 1% of the KT-18 air content on fresh concrete from the same location on all but two samples. The 15% fly ash-25% slag concrete had a total ASTM C457 air content of 8.2% and a fresh concrete air content of 6.9%. The 10% fly ash-27% slag concrete had a measured air content of 13.4%, which was significantly higher than the fresh concrete air content of 6.4%. The results of ASTM C457, KT-71 and KT-18 are given in Table 3.4.

TABLE 3.4
Air Void Parameters

Concrete	Date cast	Sample number	Specimen type	C457 spacing factor, mm	AVA spacing factor, mm	C457 air content, %	KT-18 air content, %
Cement-only Non-optimized	7/31/2007		Fresh Concrete	-	0.219	-	5.0%
	7/31/2007	07-3391	Cores	0.216		5.7%	-
Cement-only Optimized	7/26/2007		Fresh Concrete	-	0.306	-	5.1%
	7/26/2007	07-3390	Cores	0.176	-	5.2%	-
15% Fly Ash 25% Slag	6/20/2008	08-1693	Cores	0.106	-	6.7%	6.5%
	7/15/2008	08-1910	Cores	0.092	-	8.2%	6.9%
	9/23/2008	08-2692	Cylinders	0.172	0.219	6.0%	5.9%
20% Fly Ash 24% Slag	9/26/2008	08-2443	Cylinders	0.187	-	5.7%	6.7%
10% Fly Ash 27% Slag	11/7/2008	08-3287	Cores	0.121	-	13.4%	6.4%
	11/7/2008	08-3208	Cylinders	0.141	-	7.0%	6.4%
Specification limit				0.200 max	0.250 max	-	5%-8%

Although no specification was in place in 2007, all of the specimens met the current specification requirements for both KT-73 Boil Test and AASHTO T 277 Rapid Chloride Permeability Test, indicating that the concrete sampled is likely to resist failure due to mechanisms related to water penetration into the concrete paste, such as freeze-thaw deterioration or ASR. The results of KT-73 and AAASHTO T 277 are given in Table 3.5.

TABLE 3.5
Results of Hardened Concrete Tests Performed on Core and Cylinder Specimens

Concrete	Date cast	Sample number	Specimen type	KT-73 Permeable voids	T 277 Rapid chloride permeability, C	T-22 Strength, psi
Cement-only Non-optimized	7/31/2007	07-3209	Cylinders	12.0%	2721	5600
	7/31/2007	07-3391	Cores	12.2%	2825	-
Cement-only Optimized	7/26/2007	07-3208	Cylinders	12.1%	2564	5710
	7/26/2007	07-3390	Cores	11.8%	3038	-
15% Fly Ash 25% Slag	6/20/2008	08-1665	Cores	10.9%	2094	5870
	7/15/2008	08-1910	Cores	11.1%	2607	5480
	9/23/2008	08-2692	Cylinders	11.1%	3372	5450
20% Fly Ash 24% Slag	9/26/2008	08-2443	Cylinders	10.7%	3223	6310
10% Fly Ash 27% Slag	11/7/2008	08-3287	Cores	10.5%	740	5880
	11/7/2008	08-3208	Cylinders	10.4%	894	7430
			Specification limit	12.5% max	3500 max	3900 min

All of the specimens exceeded the lower specification limit for compressive strength of 3900 psi, indicating that the concrete sampled is likely to adequately resist failure due to lack of strength during its design life. The results of AASHTO T 22 are given in Table 3.5.

Chapter 4: Discussion and Pavement Surveys

4.1 Discussion of Test Results

All three ternary-blend concretes met specification requirements for the tests of alkali-silica reactivity. The 10% fly ash-27% slag concrete had the lowest expansion in both the ASTM C1567 Accelerated Mortar Bar Method and KT-MR-23 Wetting and Drying Test. In KT-MR-23 Wetting and Drying Test, the 10% fly ash-27% slag concrete had the lowest expansion and the highest modulus of rupture at all ages. At 365 days, the modulus of rupture of the 10% fly ash-27% slag concrete was 12% higher than the modulus of rupture of the cement-only concrete. In comparison, at 365 days the modulus of rupture of the 15% fly ash-25% slag concrete and the 20% fly ash-24% slag concrete was 5% and 3% lower, respectively, than the modulus of rupture of the cement-only concrete.

The expansion of the 10% fly ash-27% slag concrete was 43% lower than the expansion of the cement-only concrete at 365 days. The expansion of the 20% fly ash-24% slag concrete was about the same as the cement-only concrete; 0.013% and 0.014%, respectively, at 365 days. The expansion of the 15% fly ash-25% slag concrete was 57% higher than the expansion of the cement-only concrete at 365 days.

The results of ASTM C1567 Accelerated Mortar-Bar Method also showed the 10% fly ash-27% slag combination was the most effective in preventing deleterious expansion. The expansion of the 10% fly ash-27% slag mortar was 15% and 19% less than the expansion of the 15% fly ash-25% slag mortar and 20% fly ash-24% slag mortars, respectively. An expansion difference of greater than 8.3% is statistically significant.

The 10% fly ash-27% slag concrete performed the best of all five concretes in the other tests, with the exception of KT-MR-22 Freezing and Thawing Test. This is a test of the freeze-thaw durability of saturated coarse aggregate, so these results depend on the durability of the coarse aggregate used and not on the composition of the cementitious materials. The 10% fly ash-27% slag concrete cylinders exceeded the strength of the cement-only optimized concrete cylinders by 30%. A strength difference that exceeds 14% is statistically significant. The strengths of the other concretes tested were not significantly different from the strength of the cement-only optimized concrete. The 10% fly ash-27% slag concrete was also the only concrete with significantly lower cylinder permeability than the cement-only optimized concrete as measured by the T-277 Rapid Chloride Permeability Test. The permeability of the 10% fly ash-27% slag concrete cylinders was 72% lower than the permeability of the cement-only optimized concrete cylinders. A permeability difference of 42% is statistically significant.

4.2 Pavement Condition Surveys

Pavement condition surveys will be performed on selected areas. Survey locations were selected to allow safe access to pavements during surveys and to interfere as little as possible with traffic in the interchange. Where possible, the concrete sampling locations were included in the survey sections. Pavements will be assessed for extent and types of cracking, extent of spalling along joints and surface condition. Signs of freeze-thaw distress, such as D-cracking or centerline spalling will be noted, as will signs of alkali-silica reactions. Complete surveys will be conducted when the pavements are five, ten, fifteen and twenty years of age. The pavements will be visited annually to visually assess the condition. If rapid deterioration is noted, more frequent surveys will be conducted. The locations selected for pavement condition surveys and the sampling locations are listed in Table 4.1 and shown on the plans in the Appendix.

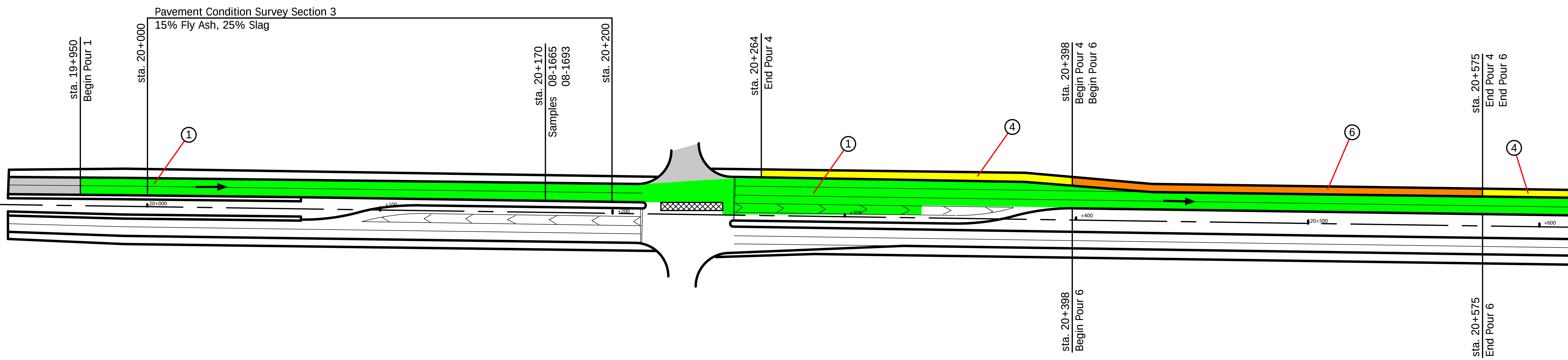
TABLE 4.1
Pavement Condition Survey Locations

Number	Description	Route	Location	Sheet
1	Cement-only, Optimized	East-bound State Street	Sta. 22+800 to Sta. 23+000	A7
2	Cement-only, Non-optimized	East-bound State Street	Sta. 24+600 to Sta. 24+800	A8
3	15% Fly Ash, 25% Slag	West-bound US-24	Sta. 20+000 to Sta. 20+200	A1
4	20% Fly Ash, 24% Slag	South-bound K-7	Sta. 31+600 to Sta. 31+800	A10
5	10% Fly Ash, 27% Slag	East-bound US-24	Sta. 20+500 to Sta. 20+700	A4, A5

Appendix A: Placement Locations

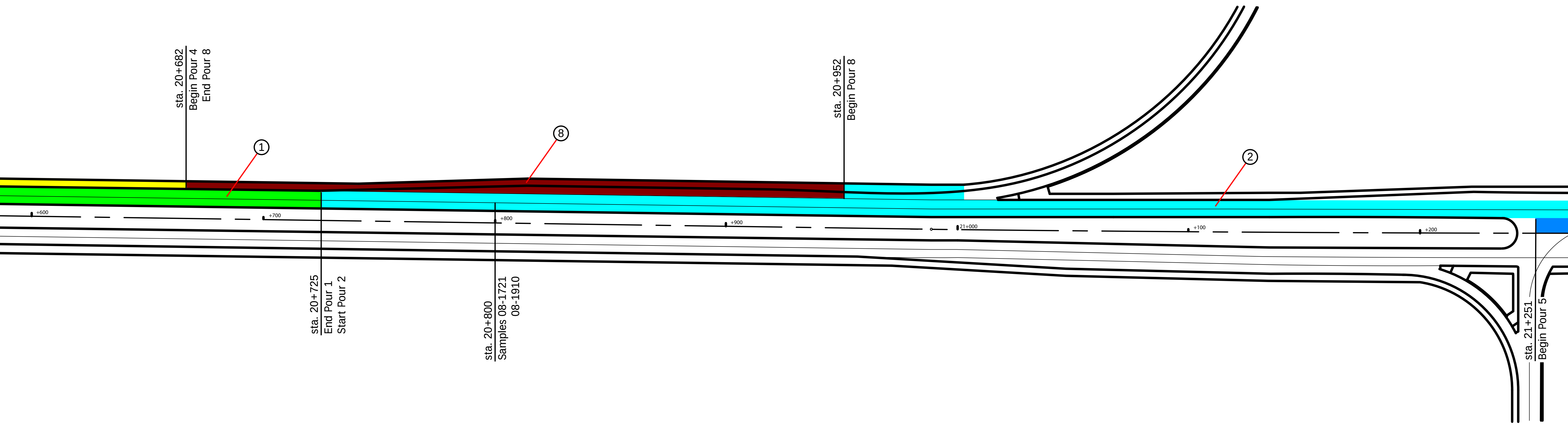
A1. West-bound US-24, stations 19+950 to 20+600; ternary blend with 15% fly ash, 25% slag.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
1	6/20/2008	1PM8204C	19+950	20+725	mainline	08-1665 08-1693
4	7/18/2008	1PM8204B	20+398	20+264	shoulder	
4	7/18/2008	1PM8204B	20+682	20+575	shoulder	
6	7/28/2008	1PM8204B	20+398	20+575	shoulder	



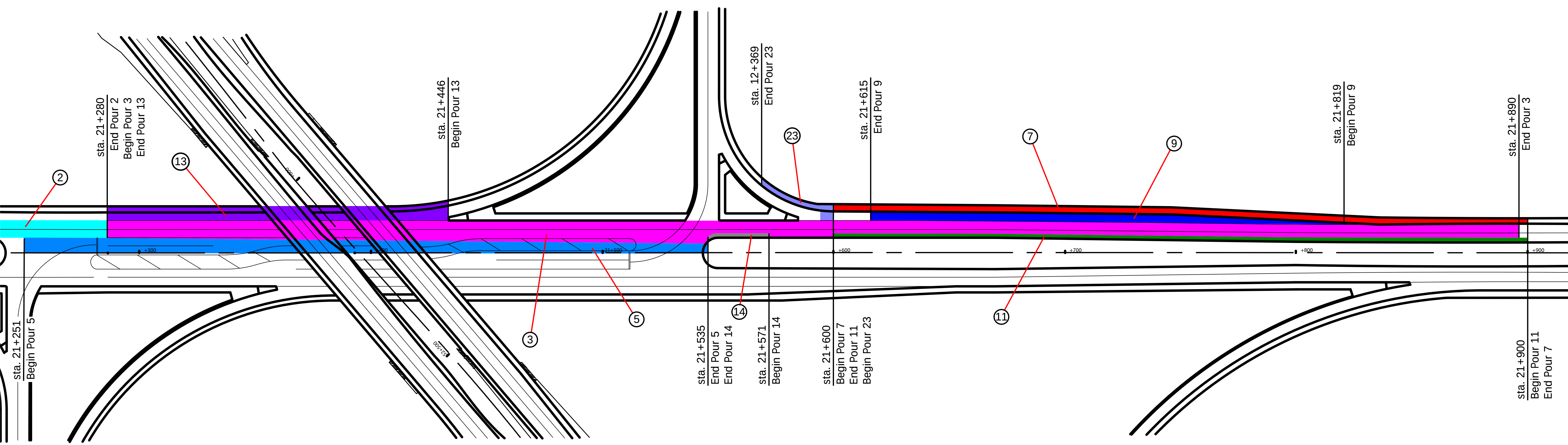
A2. West-bound US-24, stations 20+600 to 21+251; ternary blend with 15% fly ash, 25% slag.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
1	6/20/2008	1PM8204C	19+950	20+725	mainline	
2	7/15/2008	1PM8204B	20+725	21+280	mainline	08-1721 08-1910
4	7/18/2008	1PM8204B	20+682	20+575	shoulder	
5	7/19/2008	1PM8204B	21+251	21+535	mainline	
8	8/1/2008	1PM8204A	20+952	20+682	shoulder	



A3. West-bound US-24, stations 21+251 to 21+900; ternary blend with 15% fly ash, 25% slag.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
2	7/15/2008	1PM8204B	20+725	21+280	mainline	
3	7/16/2008	1PM8204B	21+280	21+890	mainline	
5	7/19/2008	1PM8204B	21+251	21+535	mainline	
7	7/31/2008	1PM8204B	21+600	21+900	shoulder	
9	8/1/2008	1PM8204B	21+819	21+615	right turn lane	
11	8/5/2008	1PM8204A	21+900	21+600	inside shoulder	
13	8/25/2008	1PM8204A	21+446	21+280	shoulder	
14	8/25/2008	1PM8204A	21+571	21+535	inside shoulder	
23	10/6/2008	1PM8204A	21+600	12+369	shoulder	



A4. East-bound US-24, stations 19+940 to 20+600; ternary blend with 10% fly ash, 27% slag..

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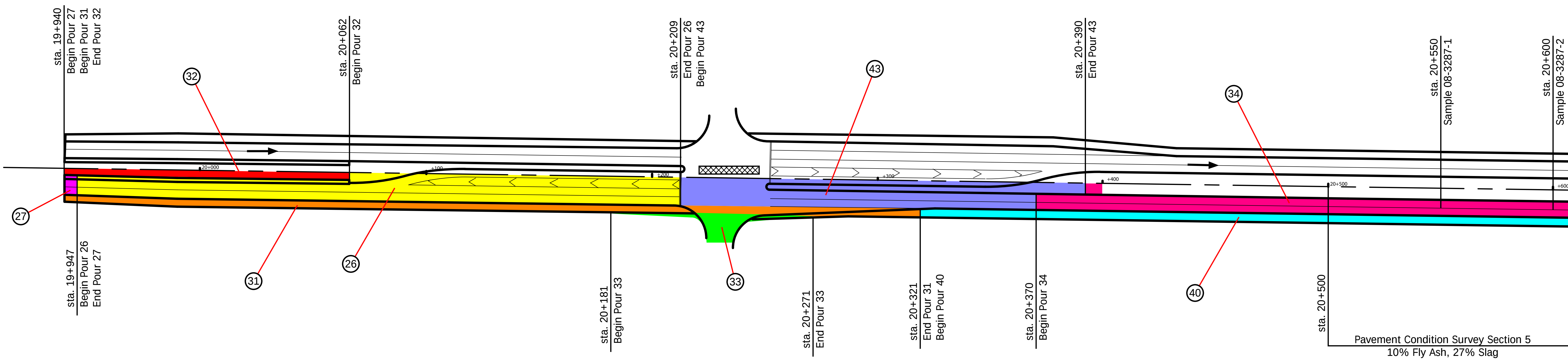
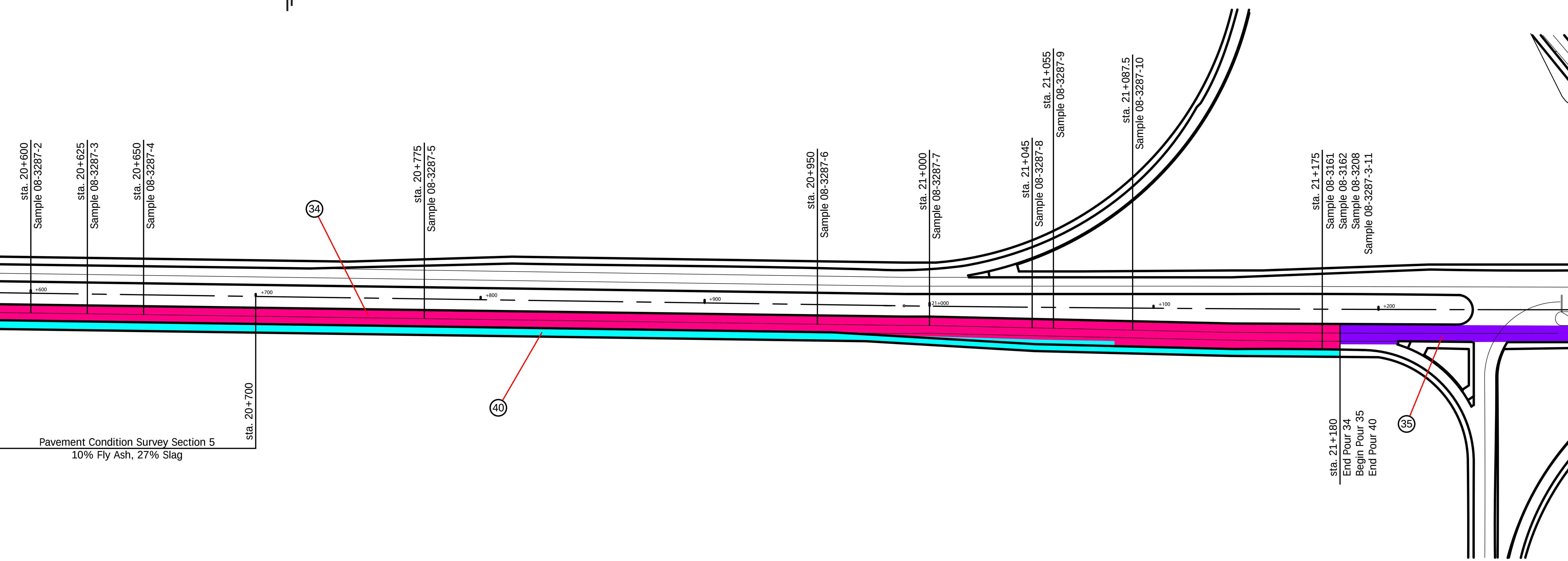
Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
26	10/11/2008	1PM8203A	19+947	20+209	mainline	
27	10/13/2008	1PM8203B	19+940	19+947	mainline	
31	10/23/2008	1PM8203A	19+940	20+321	lane 3 and shoulder	
32	10/24/2008	1PM8203A	20+062	19+940	shoulder	
33	10/27/2008	1PM8203A	20+181	20+272	142nd st intersection	
34	10/30/2008	1PM8203A	20+370	21+180	mainline	
40	11/7/2008	1PM8203A	20+321	21+180	lane 3	08-3287-1,2
43	11/14/2008	1PM8203A	20+209	20+390	left turn lane	



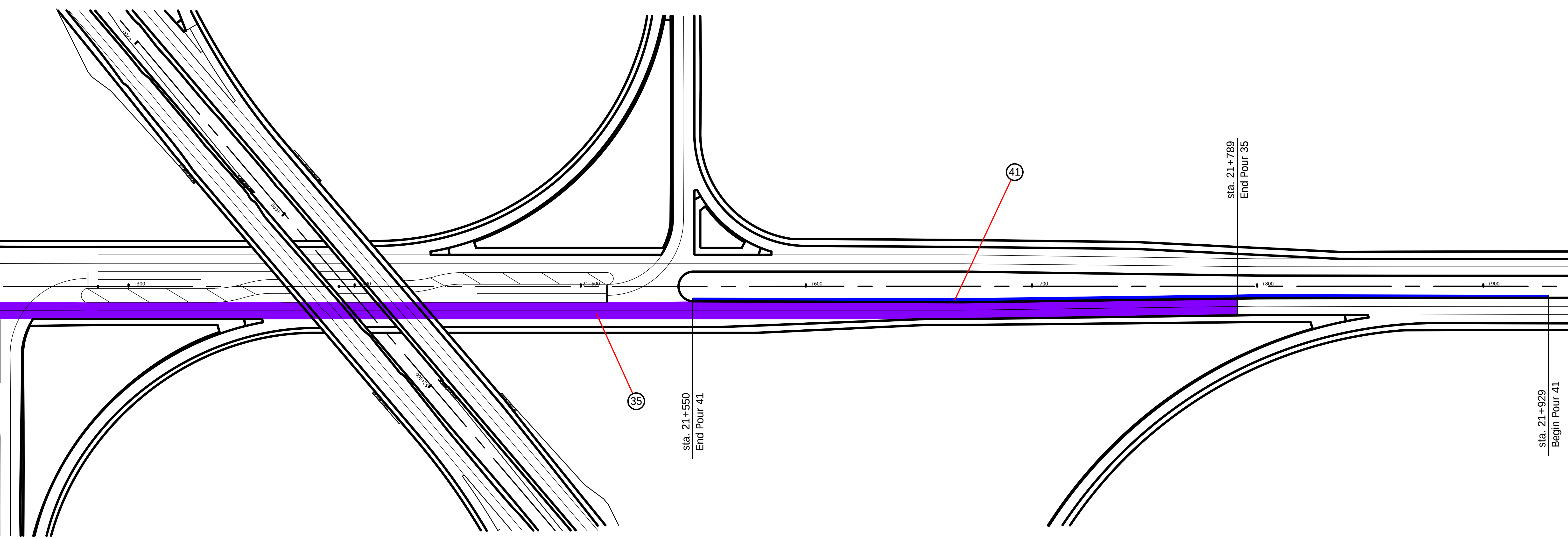
A5. East-bound US-24, stations 20+600 to 21+251; ternary blend with 10% fly ash, 27% slag.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
34	10/30/2008	1PM8203A	20+370	21+180	mainline	
35	10/31/2008	1PM8203A	21+180	21+789	mainline	
40	11/7/2008	1PM8203A	20+321	21+180	lane 3	08-3161 08-3162 08-3208 08-3287-3-11



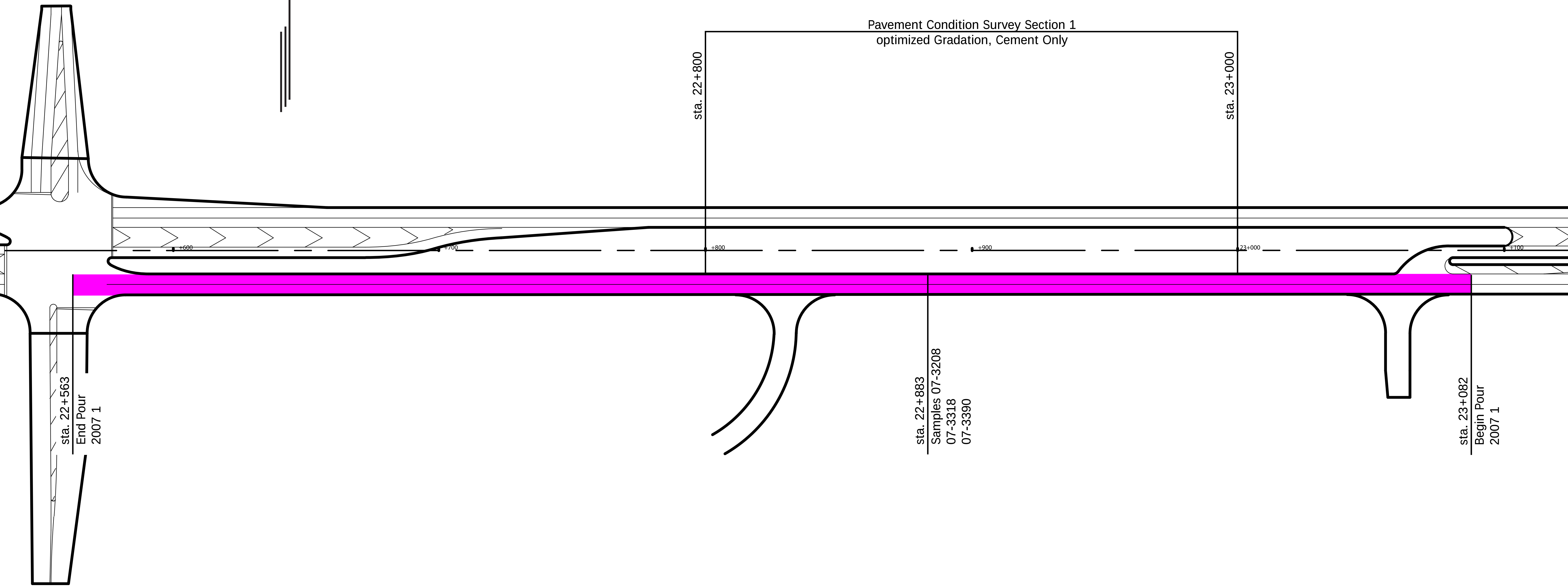
A6. East-bound US-24, stations 21+251 to 21+929; ternary blend with 10% fly ash, 27% slag.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
35	10/31/2008	1PM8203A	21+180	21+789	mainline	
41	11/9/2008	1PM8203A	21+929	21+550	inside shoulder	



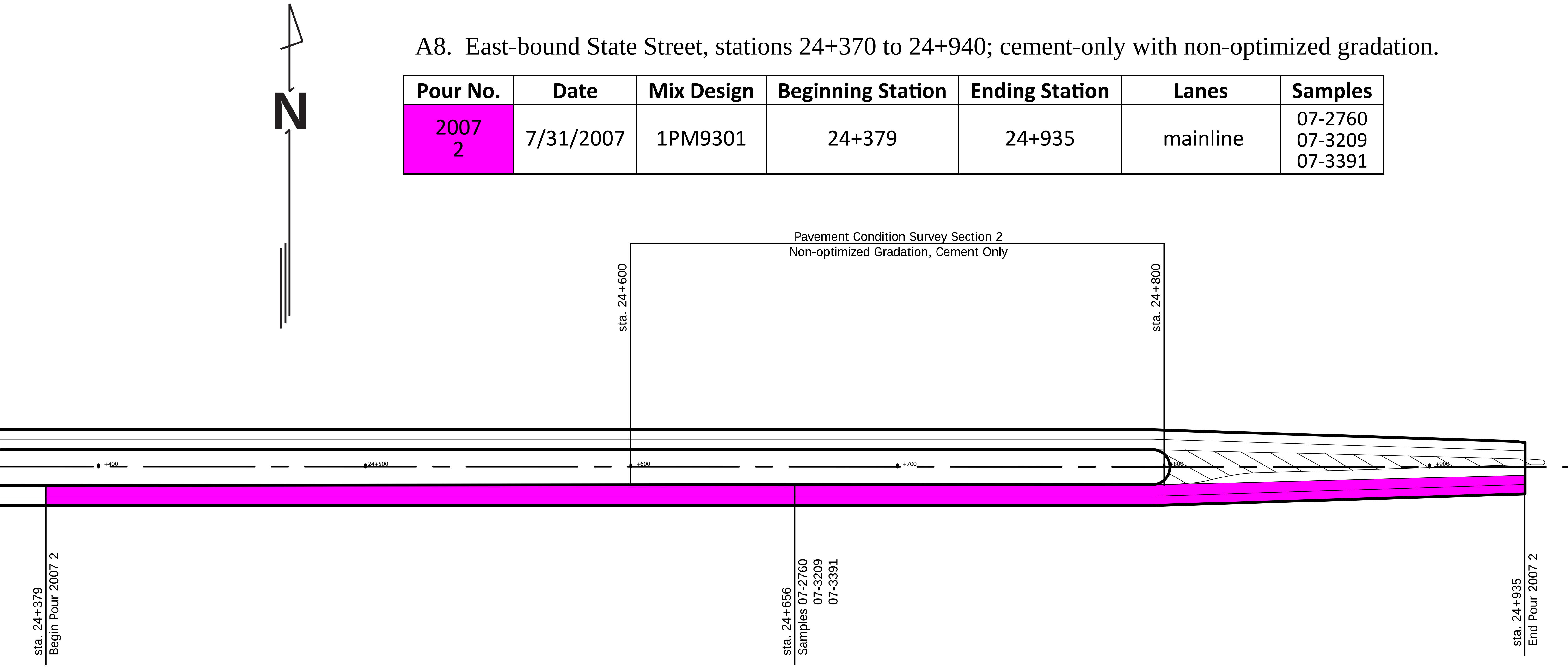
A7. East-bound State Street, stations 22+560 to 23+100; cement-only with optimized gradation.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
2007 1	7/26/2007	1PM9301	23+082	22+563	mainline	07-3208 07-3318 07-3390

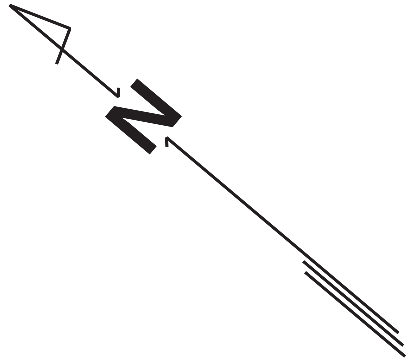


A8. East-bound State Street, stations 24+370 to 24+940; cement-only with non-optimized gradation.

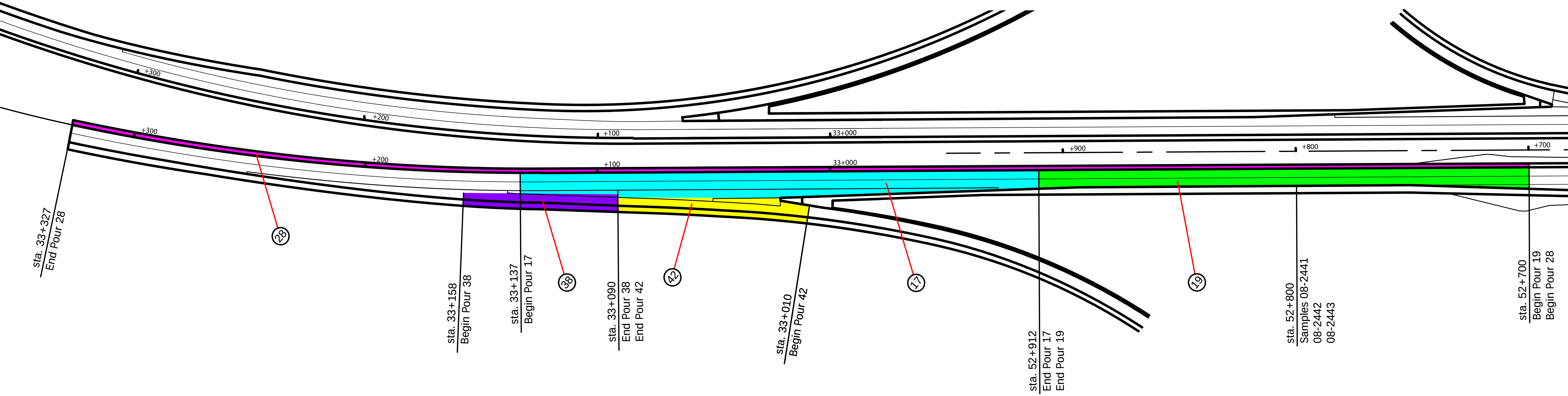
Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
2007 2	7/31/2007	1PM9301	24+379	24+935	mainline	07-2760 07-3209 07-3391



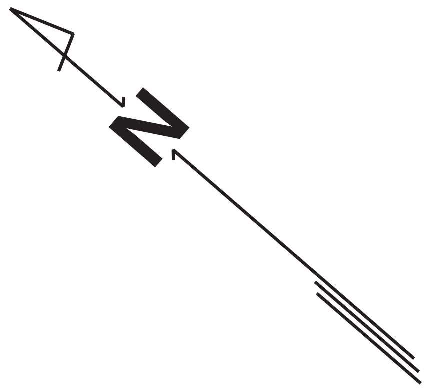
A9. K-7 South-bound, stations 33+330 to 52+700; ternary blends.



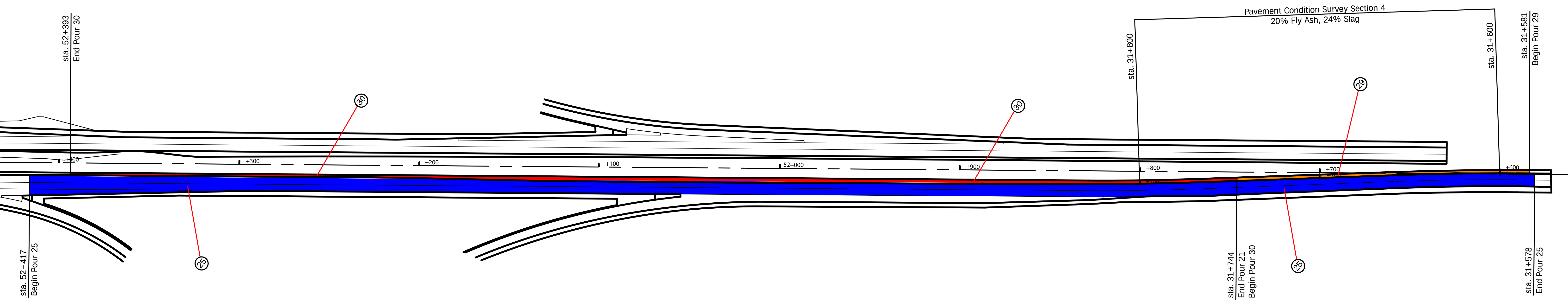
Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
17	9/23/2008	1PM8204A	33+137	52+912	mainline	
19	9/26/2008	1PM8205A	52+700	52+912	mainline	08-2441 08-2442 08-2443
28	10/16/2008	1PM8203A	52+700	33+327	inside shoulder	
38	11/5/2008	1PM8203A	33+158	33+090	gore at Ramp C1	
42	11/10/2008	1PM8203A	33+010	33+090	gore at Ramp C1	

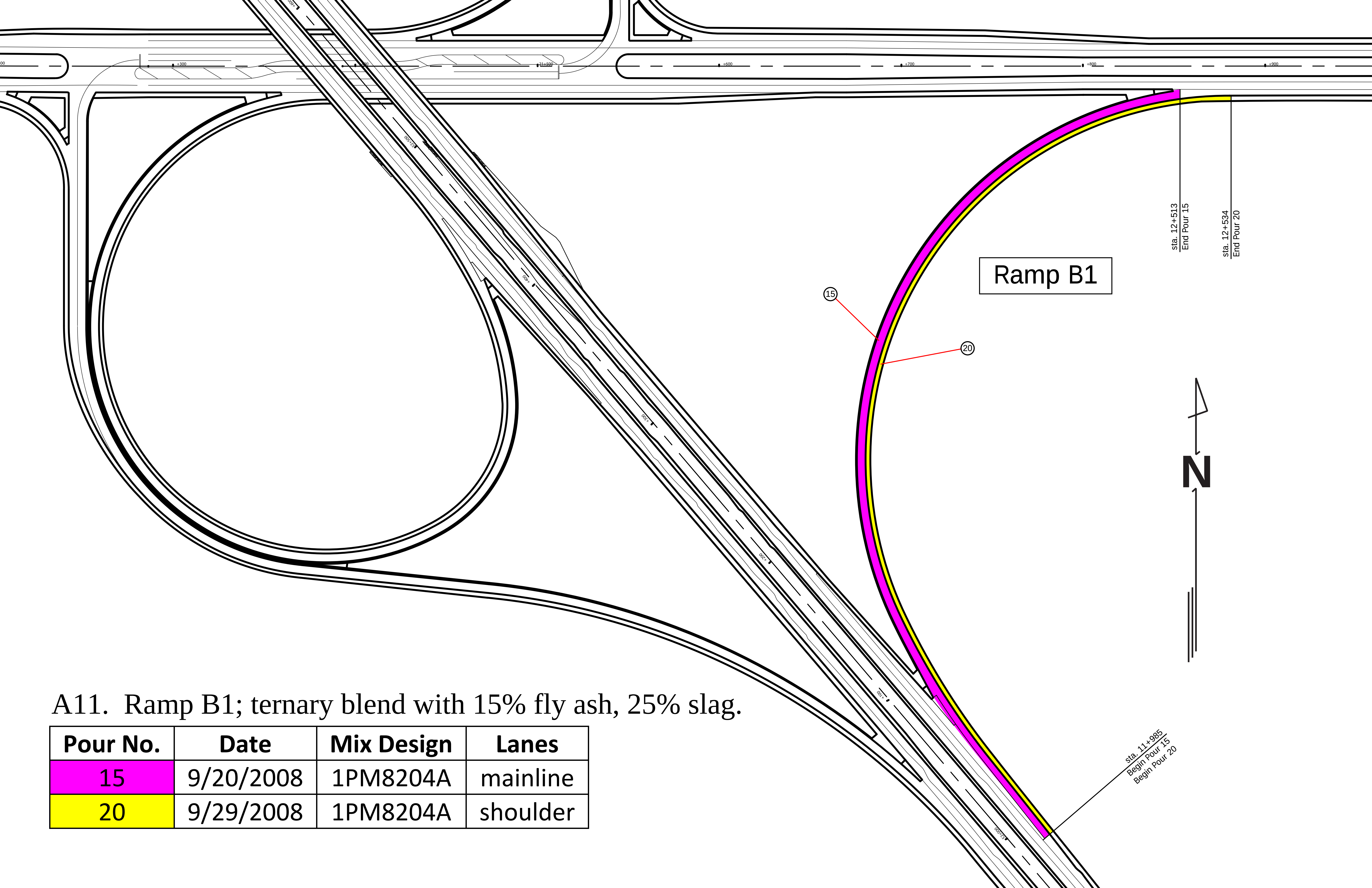


A10. South-bound K-7, stations 52+420 to 31+575; ternary blends.



Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes
25	10/9/2008	1PM8205A	52+417	31+578	mainline
29	10/17/2008	1PM8203A	31+581	31+744	shoulder
30	10/20/2008	1PM8203A	31+744	52+393	shoulder



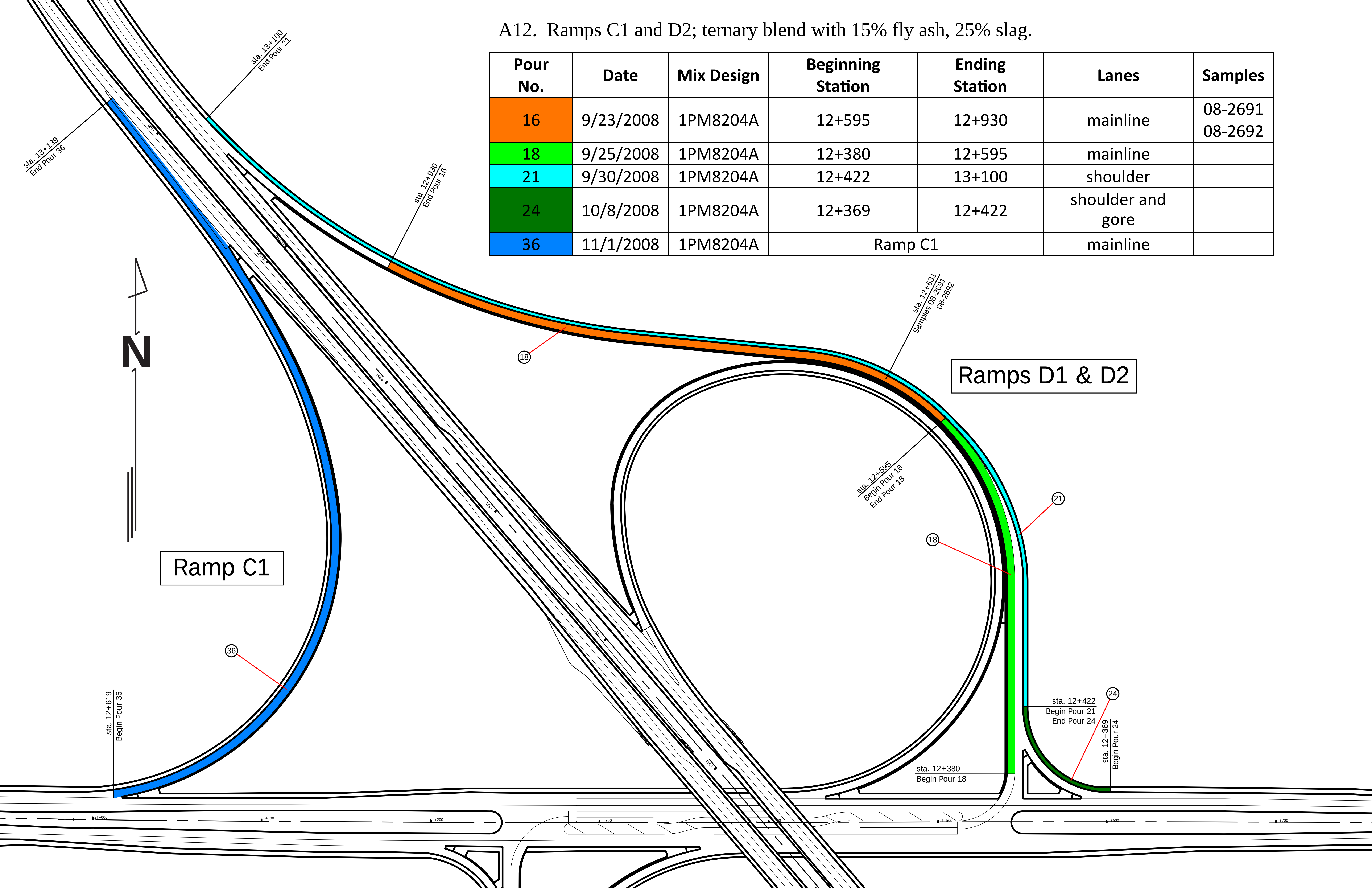


A11. Ramp B1; ternary blend with 15% fly ash, 25% slag.

Pour No.	Date	Mix Design	Lanes
15	9/20/2008	1PM8204A	mainline
20	9/29/2008	1PM8204A	shoulder

A12. Ramps C1 and D2; ternary blend with 15% fly ash, 25% slag.

Pour No.	Date	Mix Design	Beginning Station	Ending Station	Lanes	Samples
16	9/23/2008	1PM8204A	12+595	12+930	mainline	08-2691 08-2692
18	9/25/2008	1PM8204A	12+380	12+595	mainline	
21	9/30/2008	1PM8204A	12+422	13+100	shoulder	
24	10/8/2008	1PM8204A	12+369	12+422	shoulder and gore	
36	11/1/2008	1PM8204A	Ramp C1		mainline	



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