MPC REPORT NO. 93-25

EXPANSIVE CONCRETE: AN OVERVIEW AND PERFORMANCE COMPARISON OF PROJECTS USING TYPE "K" SHRINKAGE COMPENSATING CEMENT

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November 1993

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`Technical Report Documentation Page

1. Report No. MPC 93-25	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Expansive Concrete: An Overview and Performance Comparison of Projects Using Type "K" Shrinkage Compensating Cement		5. Report Date November 1993 6. Performing Organization Code
7. Author(s) Kevin C. Womack		8. Performing Organization Report No.
9. Performing Organization Name and Address Utah State University Logan, UT		10. Work Unit No. (TRAIS) 1. Contract or Grant No.
12. Sponsoring Agency Name and Address Mountain-Plains Consortium North Dakota State University Fargo, ND		13. Type of Report and Period Covered Project Technical Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program

16. Abstract

This report presents a brief historical overview of the development of expansive (shrinkage compensating) concrete. Three Utah Department of Transportation projects using expansive concrete are discussed as to the performance of the expansive concrete. On-site inspections were performed on three projects.

17. Key Words	18. Distribution Statement		
concrete, expansive cement, Type "K"			
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 36	22. Price

Acknowledgements

The Utah Department of Transportation, Mountain Plains Consortium, and the Utah State University Vice President for Research provided funding to support this research project.

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EXECUTIVE SUMMARY

This report presents a brief historical overview of the development of expansive (shrinkage compensating) concrete. Three Utah Department of Transportation projects using expansive concrete are discussed as to the performance of the expansive concrete. On-site inspections were performed on three projects: (1) a bent repair at I-80 and Highland Drive, (2) a bridge deck rehabilitation at Starvation Reservoir, and (3) two overpasses where Utah 201 merges with I-80 near Black Rock. The inspecting engineers' diaries and contract documents were also reviewed to determine why there is a variance in the performance of the expansive concretes in these three projects. It appears that the poor performance of the expansive concrete in the Black Rock overpasses is due to insufficient water for the formation of the ettringite being provided to the concrete during curing. Placement of the same concrete in hot weather may have also contributed to the cracking in these bridge decks.

The recommendation is made that UDOT should have a new specification written that addresses directly the use of expansive concrete. The research that would be necessary to write this new specification is also discussed.

CHAPTER 1. INTRODUCTION

Within the state of Utah there is a large number of bridges, in both the Interstate and state highway systems, that use steel structural members in the bridge substructure. As the concrete bridge decks develop full depth cracks these steel members become subject to corrosion from water, which contains deicing salts, that seeps through these cracks. Corrosion of the steel structural members supporting bridge decks is a major concern for the Utah Department of Transportation (UDOT), the agency responsible for maintaining these bridges. Great expense is occurred by UDOT, and thereby the taxpayers of the state of Utah, in maintaining these steel structural members. Eventually, if not properly maintained, the structural integrity of these steel members will be compromised by the corrosion.

Cracking of concrete bridge decks is a natural phenomena that occurs due to the shrinkage of the concrete. Expansive concretes utilize either a special cement, known as Type "K" cement, or admixtures to either reduce or eliminate shrinkage cracking. In the past three years UDOT has used expansive concrete, made from Type "K" cement, in three different bridge projects. The performance of the expansive concrete used in these projects has varied greatly, from very satisfactory to totally unacceptable.

UDOT would like to continue employing expansive concrete for bridge decks in both new bridge construction and the rehabilitation of concrete decks in existing bridges. The potential for reduced maintenance costs makes the use of expansive concrete very attractive. However, engineers at UDOT have two concerns in the application of expansive concrete: Type "K" cement must be imported into Utah, significantly raising the cost of the concrete; and, second, why the variability in the performance of the expansive concrete utilized thus far?

The goal of this research is to address these issues. First, the potential for producing expansive concrete by using readily available admixtures, instead of making expansive concrete from Type "K" cement was examined. Second, an investigation was conducted to determine why the performance of the expansive concrete used in the three UDOT applications thus far has been so variable.

CHAPTER 2. OVERVIEW

France, the Soviet Union, and the United States are the countries that have focused on developing expansive concretes. Initially, the French used a clinker that contained a combination of dicalcium silicate, calcium sulfate, and other calcium aluminates and ferrites [1,2]. Termination of the expansion of the concrete was done by either introducing a blast furnace slag to the mixture or by the cessation of water curing. This last method of halting the expansion of the concrete has an impact on the types of curing that should be undertaken today in the use of expansive concretes.

The Soviets added calcium aluminate and gypsum or Plaster of Paris to portland cement to produce expansive concrete [3]. The Portland Cement Association also produced, and have researched, expansive concrete made in this way [4].

Researchers at the University of California at Berkeley originally used calcium aluminosulfate clinkers and blast furnace slag as admixtures placed in a concrete mix to produce expansive concrete [5]. Subsequently anhydrous calcium sulfoaluminate was added to portland cement, the combination of which produced an expansive cement [6]. This is the precursor of Type "K" cement that uses anhydrous calcium sulfoaluminate, calcium sulfate, and lime mixed into the portland cement. The anhydrous calcium sulfoaluminate comes from a separately burned clinker that is ground with the portland clinker or mixed with portland cement.

The expansion in the concrete is produced by the formation of ettringite during the hydration. This production of ettringite causes considerable expansion of the concrete which, if restrained, can result in large compressive forces within the concrete. The range of expansion for an expansive concrete can vary from no expansion up to ten or twelve percent expansion, depending on the type and amount of admixture used. Not enough expansion will result in cracking of the concrete as it cures and too much expansion can be just as bad especially if the expansion is restricted in some way, resulting in buckling of the concrete. The amount of blast furnace slag contained in the cement also effects the expansion of the concrete, the slag absorbs excess calcium sulfate thereby not allowing the creation of additional ettringite.

Expansive Cement vs. Admixtures

The one point of commonality between these approaches to producing expansive concrete is the use of calcium sulfates and aluminates to provide expansion. The University of California researchers created expansive concrete by either producing a cement that would result in an expansive concrete or by adding calcium aluminosulfate clinkers to a concrete mix. These two methods of producing expansive concrete show that using either an expansive cement or an admixture is an acceptable way of producing expansive concrete. Indeed, the key component of commercially available admixtures in use today to create expansive concrete is calcium sulfoaluminate, the same key component contained in Type "K" cement.

CHAPTER 3. PERFORMANCE COMPARISON

The three UDOT projects that have thus far utilized expansive concrete made from Type "K" cement are a bent cap repair on Interstate 80 where it passes over Highland Drive (done in 1990), a bridge deck rehabilitation on the U.S. Highway 40 bridge over Starvation Reservoir (also done in 1990), and two new overpasses crossing Interstate 80 at Black Rock (done in 1992). The performance of the expansive concrete has been acceptable in two cases: the Highland Drive and Starvation Reservoir projects. The use of expansive concrete in the overpass bridge decks at Black Rock has been completely unsatisfactory.

A study of the construction documents and inspecting engineers diaries was made to determine the cause for this variability of performance in the expansive concrete. It is recognized that these are three very different types of projects making any comparison more difficult, however, the focus was on the concrete and the variables that could effect the performance of the concrete.

Each project is discussed in detail and Table 1 contains a summary comparison of the variables that could have had an effect on the performance of the expansive concrete used in these three projects.

Starvation Reservoir (UDOT Project No. F-015(11))

This bridge deck rehabilitation, done in 1990, was the first UDOT project that used expansive concrete, made from Type "K" cement. The performance of the expansive concrete has been acceptable; small, random transverse cracks have developed in the bridge deck since the repair was completed. The major reason for the good performance of the expansive concrete in this project is that the use of a special material, the Type "K" cement, was noted within the specifications (see Appendix A) and these specifications were followed in the placement and curing of the expansive concrete [7].

The special section (Section 505S) written into the specifications, in addition to the standard section for concrete, added provisions to account for the use of Type "K" cement. The maximum water/cement ratio was increased to 5.6 gallons per bag from 5.0 gallons and, most importantly, provisions were written so that the expansive concrete would not be placed in ambient temperatures above 80° F and proper curing procedures would be followed. The key to curing expansive concrete is providing sufficient water so that the ettringite can form. Ponding or continuous sprinkling are the preferred methods of curing. Wet coverings can be used if enough water is provided, either under or through the coverings, to ensure the formation of the ettringite. The duration of curing expansive concrete should be at least seven days and must begin immediately after final finishing of the placed concrete [8]. The concrete on this project was placed between May and September, when daytime temperatures can reach 100° F, however, the placement of the concrete was done at night (most likely to cause the least disruption in traffic) when the ambient temperatures were cooler. Curing the placed concrete by wetting and then flooding for seven to ten days allowed the ettringite to form [7]. The result has been an acceptable performance of an expansive concrete in its first use by UDOT.

I-80 at Highland Drive (UDOT Project No. NI-80-3(29))

This project was a bent repair of the two eastern most piers supporting Interstate 80 as it crosses Highland Drive. Though not a bridge deck, where expansive concretes have been most commonly used, this project did utilize an expansive concrete made from Type "K" cement.

The performance of the expansive concrete in this case has been excellent, cracking has been kept to a minimum and the bents are in very good condition. The performance of the expansive concrete in this project is also a result of the use of an appropriate specification (modeled after the specification used in the Starvation Reservoir project, see Appendix B). It has also been aided, somewhat, by the fact that the bents are protected by the bridge that they support. The concrete for this project was placed during November of 1990, so the ambient temperature was not a problem, as proper cold weather concreting practices were followed and sufficient water was provided for the formation of the ettringite [9]. The result has been a fine performance of an expansive concrete.

Black Rock Overpasses (UDOT Project No. IR-F-BRF-9999(70))

This project encompassed two new overpasses where Utah State Highway 201 merges with Interstate 80, near Black Rock (see Figure 1). Two complete bridge decks utilized an expansive concrete made from Type "K" cement. Unfortunately, the performance of the expansive concrete in this project has been very poor. Soon after the placement of the bridge decks, which was done in March, May, and June of 1992, transverse cracks of the concrete appeared in both bridge decks. These cracks appear at regular four foot intervals and over the past year have transversed the entire width of, and gone full depth through, the deck in which they occur. Efflorescence can be seen on the underside of the bridge deck where water has seeped through the deck (see Figure 2).

The deck on the east bound overpass was placed in one day, on March 25 [10]. The placing of the concrete began early in the morning, between 3:00 and 4:00 a.m. [11], and ended about 10:00 a.m. Blankets and wet burlap were used to cure the concrete. The blankets were removed six days (March 31) after the placement of the concrete and the burlap was wet down. The following day (April 1) the burlap was removed [10].

The west bound overpass deck was placed between May 6 and June 26 [10]. Typically the placement of the concrete began at 7:00 a.m. and ended before noon, with the exception of one day when the placement of the concrete ended in the mid-afternoon [11]. During this time of the year this would result in some of the concrete for this deck being placed while the ambient temperature exceeded 80° F, particularly on the day when the placement of the concrete ended in the afternoon. The curing technique for the concrete in this deck was the same as that for the east bound deck, blankets and wet burlap were used with water being applied periodically. The duration of the cure was typically six to seven days [10,11].

A special provision, Section 505M, was also written into the specification for the expansive concrete to be used in this project (see Appendix C). This section is not as comprehensive as the special sections used in the Starvation Reservoir and Highland Drive projects, there is no mention of special curing procedures and the ambient temperature limitations are not mentioned (they are contained in the standard specification). Though the special specification should not be held wholly accountable for the cracks in the Black Rock bridge decks, a statement on special curing methods recommended for expansive concretes may have resulted in a better performing concrete.

The poor performance of the overpass bridge decks at Black Rock appears to be due to insufficient water being provided to the newly placed decks during the curing process. Ensuring that enough free water reaches the entire surface of a bridge deck when blankets and burlap are used would be very difficult, especially when additional water was only provided periodically and not constantly. This lack of necessary water impeded the formation of the ettringite in the concrete, the result being little or no expansion of the concrete and, therefore, cracks in the bridge deck.

Temperature may also have contributed to the cracking of the west bound overpass deck. Placement of expansive concrete in ambient temperatures above 80° F can result in extensive plastic shrinkage cracking if sufficient surface water is not provided to the curing concrete.

CHAPTER 4. CONCLUSIONS

Expansive concretes may be made from either Type "K" cement or by adding an admixture to the concrete mix. In both cases the key component that induces the expansion is calcium sulfoaluminate which, when combined with calcium sulfate and lime, forms ettringite which causes the concrete to expand. In the case of the Type "K" cement, the calcium sulfoaluminate comes from a separate clinker that is ground with the portland clinker. Or the calcium sulfoaluminate may be added to the concrete mix as a chemical admixture. Because the chemicals added is the same in both cases, the result is the same: an expansive concrete.

Expansive concretes are much more sensitive to placement conditions than standard concrete [8]. Though the actual placement of the concrete should require no special equipment, care must be taken to properly cure the expansive concrete. In cold weather, proper cold weather concreting practices must be followed. In all conditions it is essential that sufficient surface water is supplied to the concrete during curing in order for expansion of the concrete to occur and to avoid plastic shrinkage. Not allowing placement of the concrete in excessive heat, as written into the special specifications for the Highland Drive and Starvation Reservoir projects (see Appendix A), is another way of avoiding the possibility of plastic shrinkage cracking.

It appears that the full depth cracks in the Black Rock bridge decks are the result of insufficient water being supplied during curing for the formation of the ettringite. In addition, placement of some of the concrete in hot weather may have also contributed to the cracking of the concrete in the west bound bridge deck.

CHAPTER 5. RECOMMENDATIONS

Unfortunately, there is no existing on-site test to guarantee the performance of expansive concretes. Therefore, the key to successfully utilizing expansive concrete, produced either by the use of Type "K" cement or admixtures, is through a specification that addresses the use of this special concrete and engineers that see to it that the contractor follows these specifications. It is recommended that researchers at Utah State University write, for UDOT, an improved specification for the use of expansive concrete based on the specification that has been used successfully in the Highland Drive and Starvation Reservoir projects. An improved specification would be written to specify more completely satisfactory placement conditions, curing methods, and the desired expansion of the concrete mix.

Appropriate placement conditions and curing methods for expansive concrete are already well understood. American Concrete Institute papers [8] and construction documents from other users (the Ohio Department of Transportation and the Ohio Turnpike Authority have been large users of expansive concrete) can be used to expand on the portions of the UDOT specifications that address water/cement ratios, placement conditions, and curing methods.

The specification of a desired expansion of the concrete would also help to ensure proper performance of an expansive concrete. This expansion is a function of the type of cement and aggregate used to produce the concrete and the type and amount of the expansive admixture placed in the concrete mix. Environmental factors such as humidity may also influence the expansion. In order to write a specification, appropriate for use in Utah, on the desired percent expansion of this concrete further research will be necessary to determine the effect of the above variables, in particular local aggregates, on expansive concretes.

An additional element that should be contained in a new specification is the requirement that contractors submit to UDOT prior to the placing of any expansive concrete, batch specimens of their design mix to be tested for their expansive characteristics. Any mix design that does not meet the new UDOT specification for expansion would be rejected and new design mixes would be submitted to UDOT for testing. UDOT personnel could be trained in performing the standard ASTM test for expansion of concrete by Utah State University faculty as part of the development of this new specification.

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11. Phone Conversation with Dee Williams, UDOT Inspector. October 12, 1993.

TABLES

Table 1. Comparison Matrix for UDOT Applications of Type "K" Cement

	PROJECT NAME/LOCATION		
	I-80 at Highland Drive	**Starvation Bridge**	**Black Rock Interchange**
Type of Job	Bent Cap Repair	Bridge Deck Rehab	New Overpasses
Contractor	J.D. McNeil Construction	Gilbert-Western	Wadsworth Brothers and R. Wadsworth Construction
Concrete Supplier	Concrete Products Corp.	Tri-County Concrete and Uintah Basin Concrete	Bee Ready Mix
Aggregate Source	Concrete Products Pit	Fruitland Pit	Bauer Pit
Special Specifications: Cement	Type "K"	Type "K"	Type "K"
Special Specifications: Water	Increase from 5.0 to 5.6 gallons/sack	Increase from 5.0 to 5.6 gallons/sack	None
Special Specifications: Placement	Within 60 minutes-Air temp less than 80 °F	Within 60 minutes-Air temp less than 80°F	Air temp less than 80°F (in standard spec.)
Special Specifications: Curing	Water Cure-No Polyethylene Sheeting or plastic coated burlap	Water Cure-No Polyethylene Sheeting or plastic coated burlap	None
Air Entrainment	Airtite	Daravair	Amex 210
Water Reducer	400 N	WRDA-79	Cormix
Type of Concrete	Class AA (AE)	Class AA (AE)	Class AA (AE)
Bags of Cement per yd^3	7.5	7.0	6.5
% Air	4.9-7.4	5.4-7.5	5.0-7.5
Slump (inches)	5.25-7.25	4.0-6.0	2.75-6.0
Strength, 28 day (psi)	5,190-5,600	3,938-6,057	3,885-6,228
Placement Conditions: Air Temperature, °F	40-54	44-73 (placed at night)	54-90 (placed during day)
Placement Dates	11/1/90 to 11/19/90	5/31/90 to 9/7/90	3/25/92, 5/6/92 to 6/26/92
Method of Curing	Wrapped with wet burlap, insulated with heated blankets, removed after 7-10 days	Initially concrete was wet down, then flooded; water cure removed after 7-10 days	Initially concrete was wet down; blankets and damp burlap

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FIGURES

Figure 1. Overpass Bridges at Merger of Utah 201 and I-80

Figure 2. Full Depth Cracks and Efflorescence on Underside of Overpass Bridge Deck

APPENDIX A

Special Concrete Specification for I-80 at Highland Project

SPECIAL PROVISION

F-015(11)

SECTION 505S - BRIDGE DECK CONCRETE

505.1 DESCRIPTION: Furnish and place Portland cement concrete using shrinkage compensating cement for the new concrete deck wearing surface. The concrete shall be Class AA(AE) as defined by Section 505.04.

505.2 MATERIALS:

505.2.1 Cement: The cement shall be expansive hydraulic cement conforming to ASTM C-845, Type K.

505.2.2 Admixtures: The use of chemical admixtures shall be limited to ASTM C-494, Type D (Water-reducing and retarding admixtures).

505.2.3 Water/Cement Ratio: The maximum water/cement ratio given for Class AA(AE) concrete in Section 505.04 shall be revised from 5.0 gallons per sack to 5.6 gallons per sack.

505.2.4 Aggregate: 3/4" maximum.

505.3 CONSTRUCTION REQUIREMENTS:

505.3.1 Concrete Delivery: When supplying concrete using Type K shrinkage-compensating cement, ready-mix plants identified as "truck mix" shall proportion the concrete such that the volume placed into the truck is at least 2 cubic yards less than the rated maximum capacity of the mix truck.

505.3.1.1 All components of the concrete shall be introduced at the batch plant, which is to be located such that concrete can be delivered to the project site within 20 minutes after charging of the mixing drum.

505.3.2 Slump: Slump, at the time and place of concrete placement, shall be 5 plus or minus 1 inches.

505.3.3 Placing Concrete: The concrete shall be placed in the bridge deck within 60 minutes after mixing as specified in Section 505.08.

505.3.3.1 Maximum ambient temperature at the time of placement of concrete shall be 80 degrees Fahrenheit.

505.3.3.2 Immediately prior to placing new concrete adjacent to previously poured and hardened concrete at the centerline and other construction joints, the Contractor shall coat the vertical face of the existing concrete with a neat cement grout material. Such cement grout shall be applied by spraying the material on the vertical face with spraying equipment that will atomize the neat material and apply it to the indicated surfaces to a uniform width and thickness.

Liquid grout material, which drains off the vertical faces and does not adhere to the existing concrete surface, shall not be used.

505.3.4 Curing: Concrete shall be cured by the water curing method as per Section 506.19(a) except the use of polyethylene sheeting or plastic coated burlap blankets will not be permitted. If required by the Engineer, the surfaces of the concrete shall be given a fog spray of water prior to water curing if weather conditions so dictate. Spraying equipment shall be on hand.

505.3.5 Loading: Traffic will be permitted on the bridge deck after the 7 day curing period, or after the concrete has reached a compressive strength of 3,000 psi; whichever time period is greater.

505.4 METHOD OF MEASUREMENT: Per cubic yard of concrete placed in the bridge deck.

505.4.1 Batch tickets shall be used to establish the volume of concrete mixed and delivered to the job site. Yield tests will be randomly performed to verify batch volumes.

505.5 BASIS OF PAYMENT: Accepted quantities of this item shall be paid for as indicated below. Payment shall be compensation in full for all required labor, materials, tools, and equipment.

Pay Item	Unit
Bridge Deck Concrete	Cubic Yard

APPENDIX B

Special Concrete Specification for Starvation Reservoir Project

SPECIAL PROVISION

NI-80-3(29)

SECTION 505S - BRIDGE REPAIR CONCRETE

505.1 DESCRIPTION: Furnish and place Portland cement concrete using shrinkage compensating cement for the repair of existing bent columns and caps. The concrete shall be Class AA(AE) as defined by Section 505.04.

505.2 MATERIALS:

505.2.1 Cement: The cement shall be expansive hydraulic cement conforming to ASTM C-845, Type K.

505.2.2 Admixtures: Chemical admixtures shall be compatible with the concrete mix and limited to ASTM C-494, Type D (Water-reducing and retarding admixtures). Cement manufacturer must certify that admixtures have been sátisfactorily used.

505.2.3 Water/Cement Ratio: The maximum water/cement ratio given for Class AA(AE) concrete in Section 505.04 shall be revised from 5.0 gallons per sack to 5.6 gallons per sack.

505.2.4 Aggregate: 3/4 inch maximum.

505.3 CONSTRUCTION REQUIREMENTS:

505.3.1 Concrete Delivery: When supplying concrete using Type K shrinkage-compensating cement, ready-mix plants identified as "truck mix" shall proportion the concrete such that the volume placed into the truck is at least 2 cubic yards less than the rated maximum capacity of the mix truck.

505.3.1.1 All components of the concrete shall be introduced at the batch plant, which is to be located such that concrete can be delivered to the project site within 20 minutes after charging of the mixing drum.

505.3.2 Slump: Slump, at the time and place of concrete placement, shall be 5 plus or minus 1 inches.

505.3.3 Placing Concrete: The concrete shall be placed within 60 minutes after mixing as specified in Section 505.08.

505.3.3.1 Maximum ambient temperature at the time of placement of concrete shall be 80 degrees Fahrenheit.

505.3.3.2 Immediately prior to placing new concrete adjacent to previously poured and hardened concrete at construction joints, the Contractor shall wet the face of the existing concrete.

505.3.4 Curing: Concrete shall be cured by the water curing method as per Section 506.19(a) except the use of polyethylene sheeting or plastic coated burlap blankets will not be permitted.

505.4 METHOD OF MEASUREMENT: Not used.

505.5 BASIS OF PAYMENT: Accepted quantities of this item shall be paid for as indicated below.

Pay Item	Unit
Bridge Repair Concrete	Lump

APPENDIX C

Special Concrete Specification for Black Rock Overpass Project

SPECIAL PROVISION

IR-F-BRF-9999(70)

SECTION 505M - PORTLAND CEMENT CONCRETE

Section 505 shall be implemented with the following modifications:

505.02 MATERIALS: Add the following:

(I) Expansive Hydraulic Cement shall be Type K and conform to ASTM C 845-80.

(j) Pozzolan [fly ash] shall not be used.

(k) Water Reducing Admixtures shall be tested in trial mixtures with job materials and proportions. These tests shall evaluate the admixtures influence on expansion, water requirement, air content, rate of slump loss, strength, and drying shrinkage.

505.04 COMPOSITION OF CONCRETE: Add the following:

Class	Coarse Agg. Size	W/C Ratio	Minimum Bag Mix
Type K	1" to No. 4	.50	6.5
"	3/4" to No. 4	.50	6.5

Class Type K
Slump Inches 2.5" to 6.5"
Air Content 5.0% to 7.5%
Required Mix Design Strength 5210
28 Day Minimum Compressive Strength 3650

505.07 MIXING: Add the following:

(c) For Type K that is mixed on the job the revolutions shall be not less than 100 or more than 140.

(d) If the haul time from the batch plant is longer than 20 minutes, the coarse and fine aggregates shall be charged in the mixing drum. The mixing drum will be stopped. The cement will then be charged. The mixing drum will not be rotated until the water is added at the job site.

The water shall enter the mixing drum through an approved and calibrated water meter. A Manifold shall be placed between the water meter and the mixing drum. The residual water left in the hose between the Manifold and the end of the hose shall be determined and not be included as part of the allowed mix water. Admixtures shall be added at the job site through the Manifold at different intervals.

505.09 TRANSPORTING CONCRETE: Add the following:

If the haul time from the batch plant is longer than 20 minutes, the load size shall not exceed 6 cu. yd. The minimum load size shall not be less than 2 cu. yd. regardless of haul time.

505.13 METHOD OF MEASUREMENT AND BASIS OF PAYMENT

Delete this subsection in its entirety and substitute the following:

Accepted quantities of this item will be paid for as indicated below. Payment will be compensation in full for all required labor, materials, tools, and equipment.

Pay Item	Unit
Concrete Type K	Lump